ICIMOD Manual 2017/5

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FOR MOUNTAINS AND PEOPLE

Planning Management for Ecosystem Services

An Operations Manual

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About ICIMOD

The International Centre for Integrated Mountain Development, ICIMOD, is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush Himalaya – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalisation and climate change have an increasing influence on the stability of fragile mountain ecosystems and the livelihoods of mountain people. ICIMOD aims to assist mountain people to understand these changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues. We support regional transboundary programmes through partnership with regional partner institutions, facilitate the exchange of experience, and serve as a regional knowledge hub. We strengthen networking among regional and global centres of excellence. Overall, we are working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream – now, and for the future.

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Cover photo: A typical mosaic of ecosystems in Western Himalayas, Nepal with terraced agriculture, agroforestry and forests

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ICIMOD Manual 2017/5

Planning Management for Ecosystem Services

An Operations Manual

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Foreword

Over the last twenty years it has become increasingly established in policies and management for the environment to use the term 'ecosystem', to promote viewing and working with the environment as ecological systems, and to recognise that people are part of ecosystems. In 2005 the Millennium Ecosystem Assessment successfully established the concept of ecosystem services as the benefits for people from ecosystems, as well as showing that degradation of the environment is causing declines in the well-being of human society worldwide, including in the HKH. Management of the environment for ecosystem services is now central to global policies, such as the CBD Strategic Plan for Biodiversity 2011-2020, which has a Mission to 'take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services'[1]. Similarly, the UN global development agenda now defines the natural environment as an ecosystem, with the UN Sustainable Development Goal 15 being to protect, restore, and promote sustainable use of terrestrial ecosystems.

However, whilst work on the importance of ecosystem services for people is rapidly growing, such as through the IPBES[2], there is still a need to fully integrate the concepts of an ecosystem and ecosystem services with the actual management of the environment by rural communities, local and sectoral government agencies, and other development practitioners. One advantage of the ecosystem services concept for environmental management is that it encourages working for multiple benefits, such as water flow, climate regulation, and cultural values, as well as the production of goods such as food and timber. It also encourages management not only for local people but also with wider landscape and societal considerations. If we can understand and see the environment as an ecosystem in a practical way this will help us to better design activities and practice adaptive management, including adaptation to climate change, to achieve our goals.

Currently, there is a lack of operations guidance for development practitioners, natural resources managers, and conservation professionals to put 'managing for ecosystem services' into practice. As a result, many natural resources management activities that are intended to work with ecosystem services are still 'old wine in new bottles'. This publication aims to reduce the gap in understanding, planning, and managing the environment for ecosystem goods and services, thereby strengthening existing development and livelihood activities.

This Operations Manual has been developed primarily to support ICIMOD's regional partners working in transboundary landscapes (especially the Kailash Sacred Landscape Conservation and Development Initiative). It has been produced by ICIMOD, in collaboration with UN Environment World Conservation Monitoring Centre (UNEP-WCMC) and ICIMOD's partners in the region. Using established knowledge on ecology and ecosystem sciences, the Manual presents six steps for planning management for ecosystem services. Each step is explained in detail with easy-to-understand language so that the practitioners are guided towards the development of a management plan. This Manual enables natural resources managers to go beyond conventional empirical and *ad hoc* approaches to management, to a more systematic and practical understanding and use of ecosystem functioning to manage multiple ecosystem services. A case study on the use of this Manual has also been introduced.

This Manual is the first of such attempts in the region, and I am fully confident that, although it was developed first for ICIMOD and its transboundary landscape initiative partners, it will prove useful to a much wider audience in the HKH and beyond. I also believe that this is an ongoing process and that the Manual can be improved as more experiences and lessons are accumulated through the practical use of this approach in the field.

The Operations Manual is also developed with the specific purpose of supporting ICIMOD's partners in their use of the Framework for Integrated Ecosystem Management (FIEM), which has been developed by ICIMOD for its regional programme of transboundary landscapes. I believe that these two documents will contribute significantly

1 Convention on Biological Diversity
2 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

to successful ecosystem management in the HKH region, where diverse ecosystems such as forests, rangelands, wetlands, and farming lands are the basis for the survival and development of over 215 million people living in the region, and benefit directly or indirectly over one billion people in the downstream areas and beyond.

On behalf of ICIMOD, I would like to thank all the partners, stakeholders, and authors who have contributed to and supported the development of this Manual.

David Molden, PhD
Director General
ICIMOD

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Three workshops have been organized by ICIMOD and its partners to get inputs and feedbacks to the Manual: *Training Workshop on Piloting Ecosystem Management Framework in Transboundary Landscape* at Kathmandu in September 2014, the *Workshop on Management for Ecosystem Services-Planning for Bans-Maitoli Micro Watershed of KSL* in Pithoragarh, Uttarakhand, India in March 2015, and *Training of Trainers on Planning Management for Ecosystem Services-Using the Framework for Integrated Ecosystem Management and the Operations Manual* in Kathmandu from 8-11 August 2016.

We would like to extend our thanks to all the national partner institutions of the KSLCDI in China, India, and Nepal for their support by sending their participants to these workshops. They are: Wildlife Institute of India (WII), Central Himalayan Environment Association (CHEA), Govind Ballabh Pant National Institute of Himalayan Environment & Sustainable Development (GBPNIHESD), Uttarakhand Forest Department (India), Institute of Geographic Sciences and Natural Resources Research (IGSNRR), Sichuan University, Chengdu Institute of Biology (CIB), Kunming Institute of Botany (KIB), Research Centre for Applied Science and Technology (RECAST), Department of National Parks and Wildlife Conservation (DNPWC), and Api Nampa Conservation Area (ANCA).

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Acronyms and Abbreviations

ADA	Austrian Development Agency
ANCA	Api Nampa Conservation Area
ANSAB	Asia Network for Sustainable Agriculture and Bioresources
BES	British Ecological Society
BMZ	German Federal Ministry for Economic Cooperation and Development
CBD	Convention on Biological Diversity
CHEA	Central Himalayan Environment Association
CIB	Chengdu Institute of Biology
DFID	Department for International Development
DNPWC	Department for National Parks and Wildlife Conservation
EbA	Ecosystem-based Adaptation
ES	Ecosystem Service
FAO	Food and Agriculture Organization
FIEM	Framework for Integrated Ecosystem Management
GIZ	German Agency for International Cooperation
GBPNIHESD	Govind Ballabh Pant National Institute of Himalayan Environment & Sustainable Development
HILIFE	Landscape Initiative for Far-Eastern Himalayas
HKH	Hindu Kush Himalaya
HKPLCDI	Hindu Kush Karakoram Pamir Landscape Conservation and Development Initiative
IAS	Invasive Alien Species
ICIMOD	International Centre for Integrated Mountain Development
IGSNRR	Institute of Geographic Sciences and Natural Resources Research
KIB	Kunming Institute of Botany
KLCDI	Kangchenjunga Landscape Conservation and Development Initiative
KSLCDI	Kailash Sacred Landscape Conservation and Development Initiative
LTESM	Long-term Environmental and Socio-Ecological Monitoring
MEA	Millennium Ecosystem Assessment
UNEP-WCMC	United Nations Environment World Conservation Monitoring Centre
RECAST	Research Centre for Applied Science and Technology
RTLP	Regional Transboundary Landscape Programme
SALT	Sloping Agricultural Land Technology
SU	Sichuan University
USAC	Uttarakhand Space Application Centre
WII	Wildlife Institute of India
WRI	World Resources Institute

1. Purpose and Use of this Manual

1.1 Supporting ecosystem management and development

This Operations Manual provides a practical method for including ecosystem management in sustainable development planning and implementation at the site and landscape levels. It is primarily designed to support the work of ICIMOD and its partners in the Hindu Kush Himalaya (HKH), but is of use in most terrestrial environments of the world.

The Manual is one of a series of documents that support the Framework for Integrated Ecosystem Management (FIEM) in the HKH that has been developed by ICIMOD (Yi et al., 2017). This work is part of ICIMOD's Regional Transboundary Landscape Programme (RTLP)[3], which promotes cooperation across national boundaries to address the conservation and sustainable use of natural resources (biodiversity, rangelands, farming systems, forests, wetlands, and watersheds) in landscapes defined by ecosystems rather than administrative boundaries.

The FIEM of ICIMOD is summarised in Figure 1, and aims to support programme and project interventions in rural areas and landscapes to conserve and restore ecosystems as one of the most important pillars for sustainable development of mountainous regions. The Framework starts with the initiation of a development programme, and then moves to the step of characterisation of the biophysical and socioeconomic contexts for the development initiative. This Manual particularly supports describing the environment and people's relationship with it in terms of the ecosystem services, or benefits, that the environment provides. It gives guidance on how to determine the demand and supply of ecosystem services, and how to describe the environment in terms of ecosystem functioning to supply these services. This information is then used in defining goals and objectives for development, based on a shared vision of local people and other stakeholders, and includes determining impact indicators. The goals for ecosystem services and ecosystem functioning are then used to design strategies and plans for ecosystem management, including governance capacity. Implementation and adaptation of the plans are guided by information and learning on ecosystem functioning and the results of development interventions.

To complement this Manual other guidance materials are being developed by ICIMOD on subjects that support Integrated Ecosystem Management, such as gender and equity considerations, participatory approaches (Aryal et al. 2017), and watershed management. The book *Sharing Power* (Borrini-Feyerabend et al. 2004) is a recommended guide on the sociocultural aspects of promoting community-based governance and management of natural resources.

1.2 Intended users and uses of this Manual

This Manual has been produced to support the staff of ICIMOD and its partners, who work to improve the living standards of mountain people and to sustain vital ecosystem services, including those flowing from upstream to downstream. It is also of wider use in supporting terrestrial natural resource management in other mountain and lowland regions.

As this is a technical Manual, its language and approach assume a basic knowledge of scientific and development terms. Section 5 addresses communicating and building capacity using the approach in the Manual with people who do not have such an extensive background. A picture series has been developed to help those using this Manual to work with the local communities.

The geographical scale for ecosystem management covered by the Manual is principally the site or local scale and for landscapes such as water catchments, but the concepts and steps can be used on a wider regional scale.

The Manual presents six steps in planning management for ecosystem services as part of development. This approach is not intended to be a new and additional activity in development planning, but to be incorporated into

3 http://www.icimod.org/?q=9121

Figure 1: Suggested framework for the management of ecosystems in the HKH socioeconomic contexts

existing management planning, as explained below. The Manual aims to provide sufficient understanding of key concepts and knowledge for this approach, with a framework of steps and guidance for its use. The application of the six steps in this Manual will need to be adapted in each specific ecosystem management case, so that the steps build on, and are integrated with, existing planning and management methods and institutions.

The development of the concepts, steps, and guidance in this Manual has been led by UNEP-WCMC in support of the ICIMOD FIEM. The example of its application in Annex 4 has been developed in the Indian region of the Kailash Sacred Landscape Conservation and Development Initiative (KSLCDI), supported by ICIMOD and led by the Wildlife Institute of India (WII). The approach and content of this Manual are still in the development and testing phase, and feedback and suggestions for its improvement are invited.

1.3 Management for ecosystem services as part of rural development

1.3.1 Definition and benefits of management for ecosystem services

This Manual defines management for ecosystem services as,

> *'making plans and carrying out actions to manage the natural environment for a range of services for people, working with the functioning of the environment as an ecosystem.'*

The Manual aims to support the integration of the concepts of ecosystem services, and of ecosystem functioning to supply these services, into rural development, providing a practical and science-based approach.

Management for ecosystem services is not intended to be a new or separate activity for rural development, but rather to be an approach that strengthens existing development and livelihood activities involving the environment, such as farming, forestry, land use planning, water resource management, and biodiversity conservation. These activities tend to focus on a few objectives, such as timber, water, rare species, or providing food. One advantage of including the concept of ecosystem services in management is that it encourages a wider consideration of the benefits and beneficiaries involved in an area. Ecosystem services are usually categorised into supporting, provisioning, regulating, and cultural services, which includes all types of physical goods and non-extractive benefits from the environment (Millenium Ecosystem Assessment, 2005). Consideration of this range of services, and of who benefits from them locally and in other areas, helps to build sustainability and wider societal support for management decisions. For example, land managed for the provisioning ecosystem service of crop production may also have positive or negative effects on water quantity and quality elsewhere in the catchment through the regulating ecosystem service of the influence of vegetation and soil structure on water flows. The steps in this Manual enable managers to have a practical description of current and desired ecosystem functioning for a suite of ecosystem services.

In addition to managing for multiple benefits and with wider landscape-scale and societal considerations, management for ecosystem services also strengthens land management through understanding and working with the environment as an ecosystem. If we view the environment as an ecological system, it helps us to identify the key issues and places to focus on in order to achieve our goals, working in harmony with nature and natural processes. Having a practical understanding of the environment in terms of ecosystem functioning enables us to better design activities and to practice adaptive management.

Management for specific ecosystem services involves working to achieve a desired ecosystem functioning for these services. Different types of ecosystems, such as forests, grasslands, and agricultural lands, have particular aspects of ecosystem structure that can be managed to achieve desired aims. This way of working also helps the manager and planner to maintain a holistic approach to people and the environment whilst focusing on management needs. The key concepts of ecosystem services and ecosystem functioning for management are explained in Section 2 of this Manual.

1.3.2 Integration of management for ecosystem services with other development approaches

Ecosystem management and the approach in this Manual require some form of planning as a basic part of management. As outlined in Section 1.1, planning involves understanding the current situation and then setting goals and designing actions to achieve the goals. Most rural development initiatives that are promoted by outside agencies involve some form of situation appraisal and planning. Regulations and mechanisms by national and local governments for the use of natural resources also usually require a planning and management mechanism, such as village forest committees. This Manual provides a framework for strengthening village-to-landscape scale planning processes through the inclusion of ecosystem services in their objectives, and by understanding how to work with the environment in terms of ecosystem functioning to supply these services.

Since the concept of ecosystem services includes all material and non-material benefits to people from the environment, any activity and initiative involving the environment can potentially have its management goals written in terms of ecosystem services and desired ecosystem functioning. Annex 1 provides a list of ecosystem service types, which can be used as a guide to identify the services that are relevant in each situation. Section 4 of the Manual provides guidance on management of forests, grasslands, and agricultural lands for ecosystem services.

This Manual focuses on the biophysical aspects of ecosystem management, addressing how to understand and work with the environment as an ecosystem, but it does not address the equally necessary sociocultural and economic aspects of ecosystem management which are recognised in Figure 1. Other ICIMOD guidance materials will be developed to support these aspects, such as gender considerations and participatory approaches, which are essential to successful development practice.

An expanding area of concern and practice for ecosystem management is ecosystem-based adaptation to climate change (EbA), which was defined by the Convention on Biological Diversity as 'the use of biodiversity and ecosystem services to help people adapt to the adverse effects of climate change'. The approach in this Manual directly supports the planning of EbA activities through Step 5, 'Consider ecosystem resilience to drivers of change'.

1.4 How to use this Manual

Section 3 of this Manual presents six steps in planning management for ecosystem services as part of development. The steps guide the user in producing a management plan for an area, and Annex 2 includes a template management plan for adaptation, as required. A workbook to guide the user in recording the results of each step is included in Annex 3.

The six steps are presented as a stand-alone process so that they can be explained. However, we recommend that managers consider whether the steps can be integrated with existing planning and management processes for their area.

Before the six steps can be understood and implemented, it is necessary to read Section 2, 'Key concepts and knowledge for describing and working with ecosystem functioning'. The main text and figures in Section 2 offer guidance on how to describe the natural environment and ecosystem services. The tables in Section 2 note the possible indicators of ecosystem functioning and describe how they relate to ecosystem services and management. Section 2 also includes key questions to guide analysis of ecosystem functioning, as well as spatial considerations in management of ecosystem services.

Section 4 provides guidance on management of grasslands, forests, and agricultural lands for ecosystem services. It identifies the major services and key components of each type of ecosystem functioning that management should consider. Section 4 also discusses common management problems and practices in ecosystem functioning.

Section 5 offers a brief consideration of communicating with different types of stakeholders and building capacity for management of ecosystem services.

Section 6 is the bibliography of literature references cited in the Manual.

Annex 1 is a list of ecosystem service types, which can be used to help identify an area's ecosystem services.

Annex 2 is an example of a management plan for ecosystem services, which can be used as a template.

Annex 3 is a workbook which can be completed during the process of management planning for ecosystem services, to guide documenting the results of each of the steps.

Annex 4 is an example description of ecosystem condition and objectives for a mountain village in Uttarakhand, India, near the border with Nepal. This can be used to help understand how to apply the approach in the Manual.

2. Key Concepts and Knowledge for Describing and Working with Ecosystem Functioning for Ecosystem Services

2.1 Overview of concepts in management for ecosystem services

This section of the Manual presents some conceptual frameworks for working with ecosystem functioning to supply ecosystem services. The diagrams represent the main ideas or subjects in management for ecosystem services and how these relate to each other. They will help managers understand the key ideas and logic in management for ecosystem services, but they are not a sequence of actions to be followed, which is presented in Section 3.

The basis of this approach to management for ecosystem services is that ecosystem functioning can be easily understood in terms of core *ecosystem processes*, *ecosystem structure*, and *ecological interactions*. Whilst there may be a common perception that ‘ecosystems are too complex to understand’, it is possible to describe and work with a practical understanding of ecosystem functioning in relation to all types of ecosystem services. Figure 2 summarises this framework.

This section (2.1) of the Manual gives an overview of *ecosystem functioning* (Figure 3) and a detailed conceptual framework to guide management for *ecosystem services* (Figure 4). Section 2.2 provides key questions for working with ecosystem functioning, and the following sections explain the key concepts and how they are used in management for ecosystem services.

Figure 2: Basic conceptual framework of the key aspects of ecosystem functioning in relation to management for ecosystem services

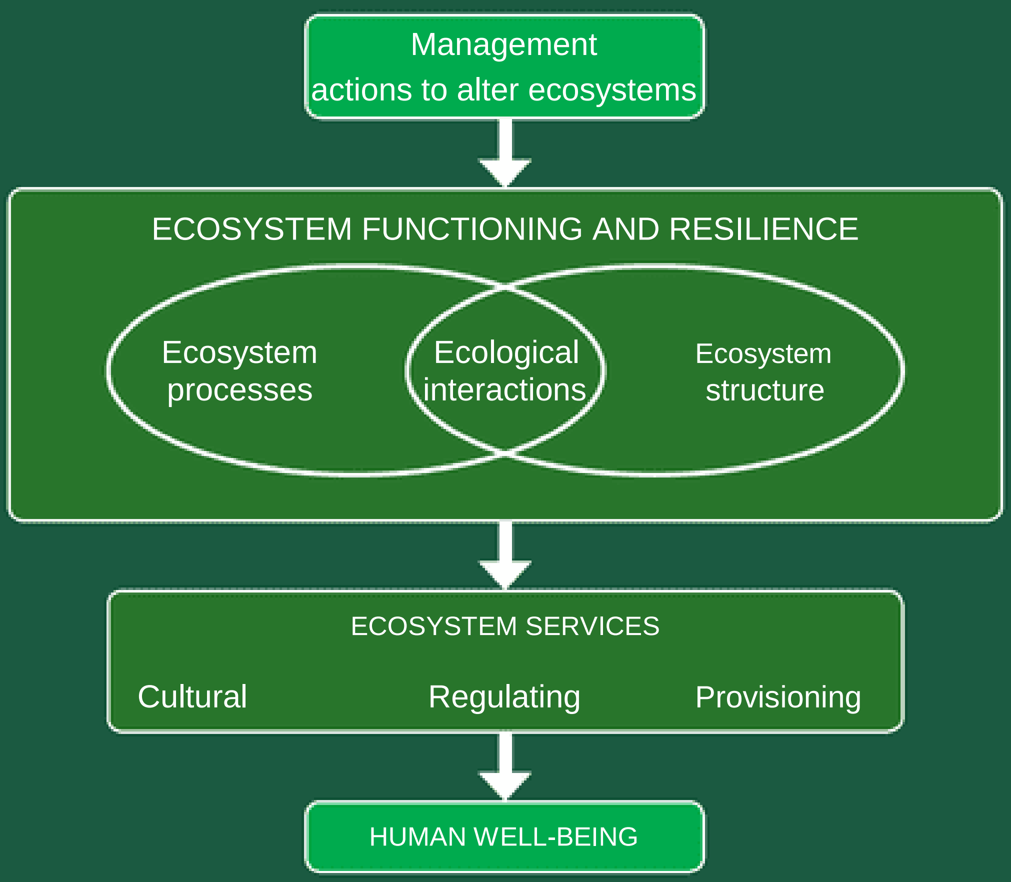
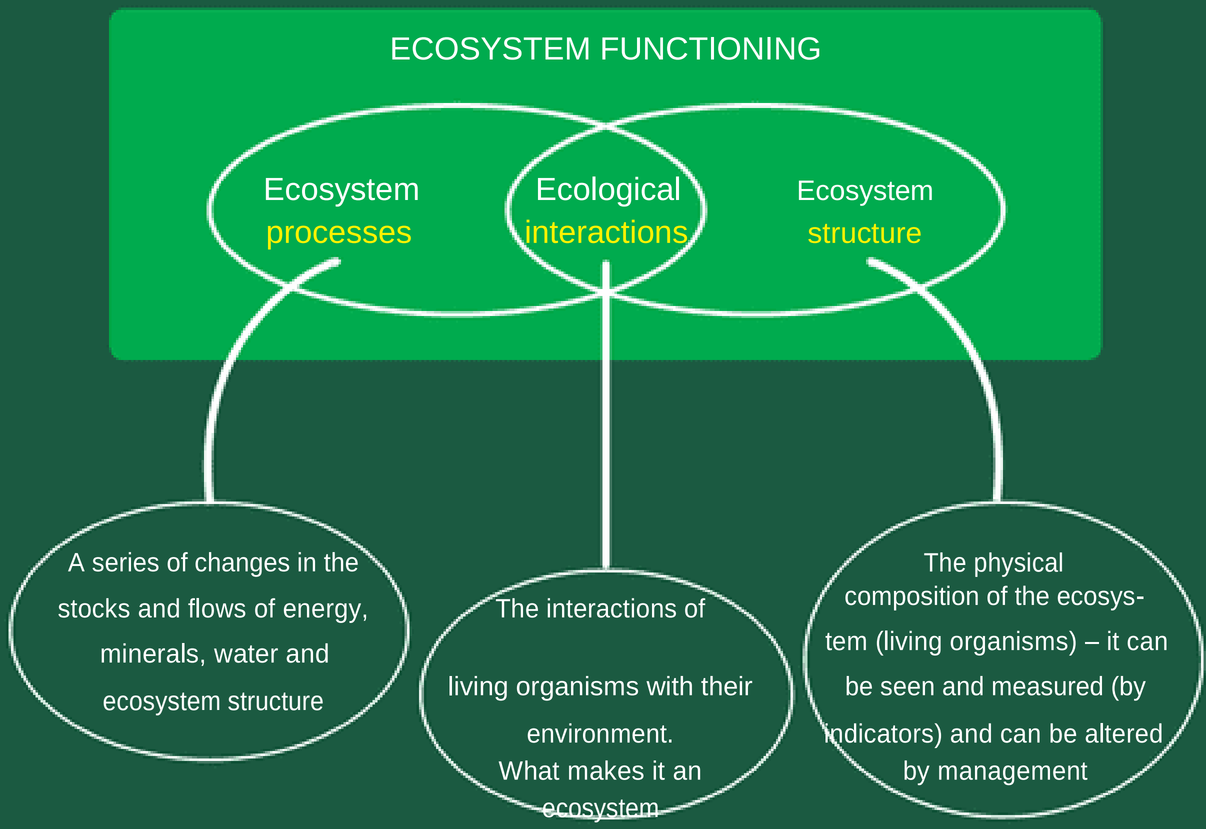


Figure 3: Definitions of aspects of the functioning of an ecosystem



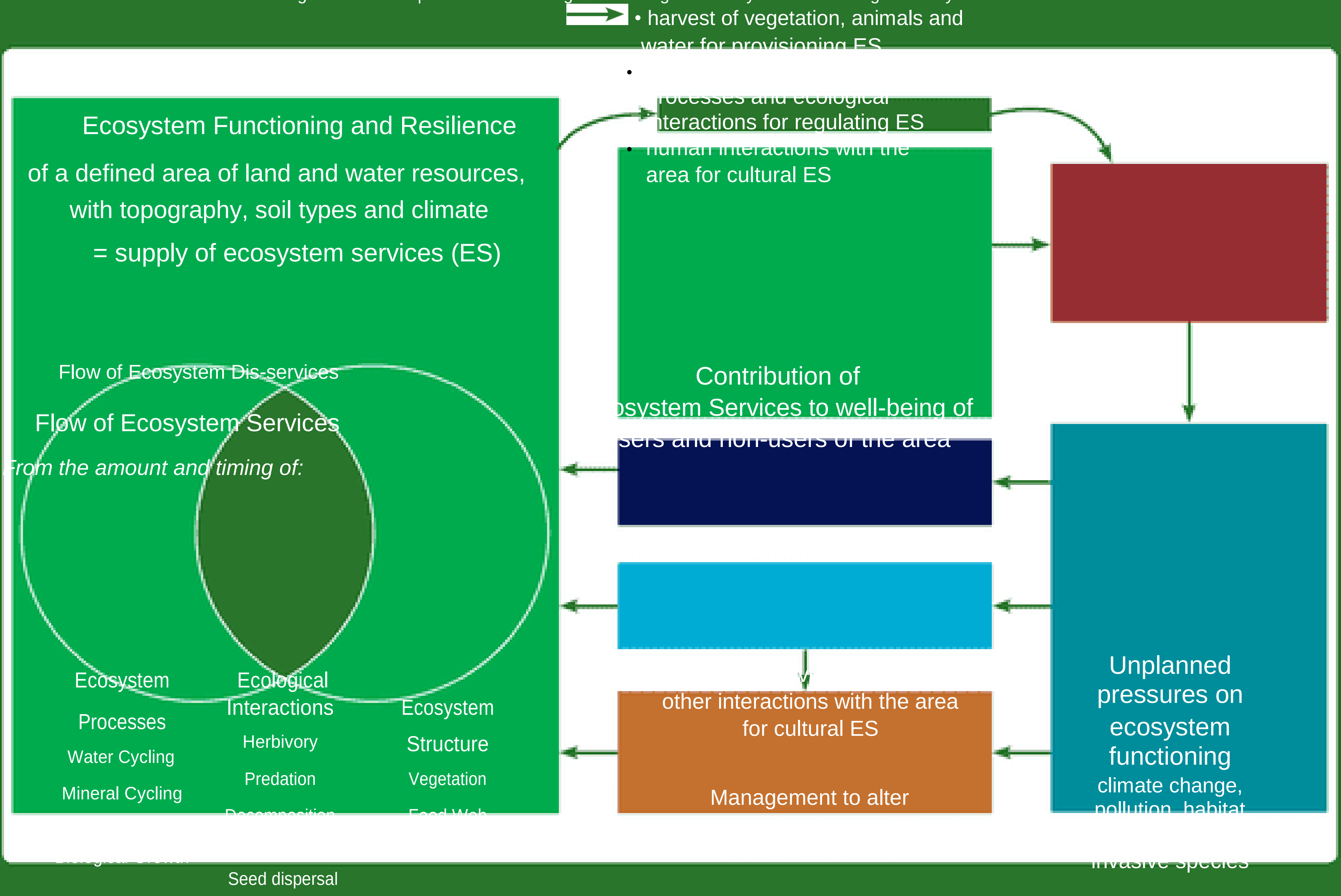
Fundamental to working with the environment as an ecosystem is to think of it in terms of the basic features of a system, which are the processes or changes that occur in the system, its structure or composition, and the interactions between its components (Figure 3).

In planning management for ecosystem services, the *ecosystem processes* are described first because understanding their functioning is a way to understand the forces for change which we can work with to supply ecosystem services. The *ecosystem structure*, such as vegetation and food webs, determines the functioning of the ecosystem processes and is the aspect of the ecosystem that can be physically seen and altered by management. Key *ecological interactions*, such as herbivory, pollination, and decomposition, are the interface between the concepts of ecosystem processes and structure. Identification and management for these interactions highlights the key aspects of ecosystem functioning for ecosystem services. Management for ecosystem services involves having a holistic perspective, recognising that change in one aspect of the ecosystem can mean change in the whole ecosystem.

A more detailed conceptual framework to support management for ecosystem services of a defined area is presented in Figure 4. This framework represents the ecosystem functioning of an area of land and water resources in terms of four core *ecosystem processes*, three types of *ecosystem structures*, and *ecological interactions*. Any terrestrial area, and the supply of any ecosystem service, can be described in terms of these aspects of ecosystem functioning. Management for ecosystem services can then be conducted by influencing the most relevant aspects of ecosystem functioning for the desired services.

To begin, the amount of *provisioning* ecosystem services obtained from an area comes from the harvesting of vegetation and animals, which are part of ecosystem structure. Next, the amount of *regulating* ecosystem services is determined by the functioning of the ecosystem processes and ecological interactions. Finally, *cultural* ecosystem services arise from all forms of human interaction with an area, including management actions and harvesting of provisioning ecosystem services.

Figure 4: A conceptual framework to guide working with ecosystem functioning for ecosystem services



Decision-for Describing and Working with Ecosystem Functioning [7]

Water is a subject that is uniquely cross-cutting in the conceptual framework. The movement of water through vegetation is the water cycling ecosystem process, harvesting of clean water can be a *provisioning* ecosystem service, regulation of water flows and quality is a *regulating* ecosystem process, and recreational and other interactions with water are *cultural* ecosystem services.

The amount of ecosystem services supplied by an area is obviously dependent on the physical environment of topography, soils, and climate, as well as the structure and functioning of the ecosystem. Although these factors are not so easily affected by management, some actions such as terracing of slopes can significantly alter topography, soils, and water flows.

Management for ecosystem services also recognises that the natural environment can generate harmful products and interactions with people, such as crop pests and poisonous plants and animals. These can be called ecosystem dis-services and the extent of their occurrence also depends on ecosystem functioning.

The extent to which ecosystem services and dis-services contribute to the well-being of people depends on many factors. Step 1 of this Manual offers guidance on the identification of ecosystem service beneficiaries such as direct users and non-users of an area. Step 2 addresses identification of the demand for ecosystem services, so that management of an area meets this demand.

Figure 4 identifies the main factors that can influence decision-making in planning the management of an area for ecosystem services. This Manual supports development of the goals, information, and skills for working with ecosystem functioning.

The physical management of an area for ecosystem services (and reduced dis-services) involves the alteration of various components of ecosystem structure, such as the cutting down or planting of trees, or the reduction of large predatory mammal populations, or grazing by domestic livestock. Planned management for ecosystem services requires defining the actions intended to alter ecosystem structure in order to produce the desired ecosystem functioning, as well as working with ecosystem processes and ecological interactions.

The harvesting of provisioning ecosystem services physically alters the ecosystem structure and functioning, so its consequences should be considered in management planning. Similarly, all human interactions with an area can be considered a type of cultural ecosystem service. If they physically alter the functioning of the ecosystem, they need to be included in management planning as well.

There are many unplanned direct pressures on ecosystem functioning. Step 5 of this Manual explains how to use descriptions of ecosystem functioning to analyse their resilience to drivers of change.

2.2 Key questions for working with ecosystem functioning

Initially, it may seem complicated to integrate management for ecosystem services based on ecosystem functioning into existing planning and management. However, the aim is to strengthen existing management goals with a practical understanding of how the environment 'works' as an ecosystem. The key skill for this understanding is to learn to 'see and read' the environment in terms of ecosystem functioning. The starting point is to ask how each of the four core ecosystem processes are functioning in each situation. Understanding the ecosystem processes naturally leads to describing the ecosystem structure and key ecological interactions, and seeing how these aspects of the ecosystem interact to supply ecosystem services. Figure 5 presents the four foundation key questions on ecosystem processes, which are 'doors' into understanding and working with ecosystem functioning.

The following key questions further assist the development of a practical understanding and description of the environment as an ecosystem:

Water Cycling

Figure 5: Foundation key questions for describing and

What happens to the water from rainfall? Is the water being cycled or leaving the ecosystem?

How long is water available in the soil for plant growth?

How is the vegetation influencing water cycling?

Mineral Cycling

How are the minerals cycling? Is the cycling open or closed, fast or slow, high or low volume?

How is the Sun's energy flowing?

How are the minerals cycling?

How is the biological growth?

Where are minerals being stored or lost in parts of the food web and soil?

How are the vegetation, herbivores and decomposers influencing mineral cycling?

How is the flow of solar energy to herbivores, predators and decomposers?

How is the water cycling?

Solar Energy Flow

How much capture of the sun's energy is there by plants (photosynthesis)?

Biological Growth

What is limiting the biological growth at each level of the food web?

2.3 What is an ecosystem?

There are several definitions of an ecosystem, so it is imperative in management for ecosystem services to have a suitable definition and understanding of the concept. This is a Manual on management for ecosystem services. What is managed, i.e. altered, is ecosystem functioning. So the logic is management of ecosystem functioning for ecosystem services (Figure 2).

Key messages

- The term ecosystem has two overlapping uses. One use is to refer to an area of the environment, for example a forest, as an ecosystem. In this spatial use of 'ecosystem' a defined area is often referred to in ways that imply it is an object or unit with particular properties, such as 'supplying water regulation services' or having 'integrity' or 'health'. The other use of the term 'ecosystem' is to view and describe the natural world in terms of ecological interactions and behaviours as a system. This use of 'ecosystem' is similar to the concept of 'an economy'; as it does not refer to a discrete physical object but instead to the interactions, stocks, and flows of the ecosystem.
- This guidance recommends working with both uses of the term ecosystem, as they overlap and are widely used, and to state which use is being employed.

Ecosystems as objects or units

Often the term ecosystem is used in phrases such as 'the ecosystems of a country', 'a forest ecosystem', the 'services from our ecosystems', or 'ecosystem health'. All of these uses imply that there is an object which is 'an ecosystem', and that this object is a physical unit with boundaries and properties which can be identified and described. This view logically leads to the spatial definition and mapping of areas as 'ecosystems'. Areas are usually categorised as different ecosystem types according to their dominant vegetation or environmental features, for example, as an oak forest, grassland, lake, or mountain ecosystem. Consistent with this view of ecosystems as objects, one of the most widely used definitions of an ecosystem is that adopted by the Convention on Biological Diversity (CBD) and the Millennium Ecosystem Assessment (MEA) (2005):

> *A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit*[4]*.*

However, other definitions do not describe an ecosystem as a 'functional unit', such as the definition given by the British Ecological Society (BES):

> *All the organisms and the abiotic environment found in a defined spatial area*[5]*.*

The BES concept means that an area defined as an ecosystem has spatial boundaries and scale that are defined by the observer or user of the concept. In this view, an ecosystem is not a physical object or unit with inherent boundaries and properties that exists 'in nature' and which can be physically 'discovered' as such. Its defining features and boundaries are determined by the interests of the person concerned.

Ecosystems as systems

The CBD and BES definitions of ecosystem do not explicitly include the system properties of the concept. For working with ecosystem functioning for ecosystem services, we suggest a definition of an ecosystem as:

> *A way of viewing the natural environment as having system properties that result from the ecological interactions between living organisms and their environment.*

From this definition, an ecosystem can be defined at any scale that is relevant, from a farmer's field to an extensive forest or grassland. The emphasis is on viewing the system properties that result from ecological interactions, such as the processes of change and flow of energy and matter, the structure of the system, and other emergent properties such as resilience to pressures. The environmental composition and properties of an area, in terms of the living organisms, soils, topography, and climate, determine the ecological interactions and ecosystem properties that occur, but there is not a whole object or unit that exists as a discrete ecosystem. In management of the environment for ecosystem services, focusing on the ecological system properties of an area is more useful than concern about the classification or naming of areas as ecosystems.

Whist using the term ecosystem as both a way of understanding the environment and as a type of physical unit may appear to be problematic, in practice this is very similar to the use of the term economy. Ecology and economy have the same root in the Greek word *oikos*, meaning 'house'. Economy originally meant 'household management' and has subsequently come to refer to an economic system and its interactions. Economies are defined, analysed, and managed at multiple scales, from households to countries to the entire planet, with attention given to economic interactions, stocks, flows, and benefits for people. However, an economy is not thought of as a physical object. Similarly, when we define a physical area as an ecosystem, considering its features as an 'ecological system', with stocks, flows, and system properties, is beneficial. This is also important to remember when concepts such as 'health', 'resilience', or supplying 'services' are ascribed to an 'ecosystem'.

2.4 Ecosystem services – linking ecosystems and people

Ecosystem service definitions

The simplest and most widespread definition of ecosystem services is 'the *benefits people obtain from ecosystems*', as defined by the MEA (Millennium Ecosystem Assessment, 2005). Examples of ecosystem services include products such as food, fuel, and water); regulation of floods, soil erosion, and disease outbreaks; and non-material benefits such as the recreational and spiritual benefits of natural areas.

4 https://www.cbd.int/convention/articles/default.shtml?a=cbd-02

5 http://www.britishecologicalsociety.org/about-ecology/key-concepts-in-ecology/

The MEA grouped ecosystem services into four broad categories:

- *Provisioning services: physical products obtained from ecosystems*, including food, fibre, fuel, genetic resources, ornamental resources, fresh water, biochemical, natural medicines, and pharmaceuticals.
- *Regulating services: benefits obtained from the regulation of ecosystem processes*, including regulation of air quality, climate, water, erosion, disease, pests, pollination, and natural hazards, as well as water purification and waste treatment.
- *Cultural services: non-material benefits people obtain from ecosystems*, including reflection, recreation, ecotourism, spiritual enrichment, cognitive development, social relations, sense of place, and cultural heritage values.
- *Supporting services are ecosystem processes necessary for sustaining the production of all other ecosystem services*. Examples are primary production (plant growth) and nutrient cycling for soil formation and water quality regulation.

A more complete list by the World Resources Institute of ecosystem services categorised according to the MEA categories is provided in Annex 1.

In the framework used in this Manual, the MEA category of supporting ecosystem services is replaced by the concept of ecosystem functioning. This includes the ecosystem processes that the MEA defines as supporting services. Accordingly, the supply of provisioning, regulating, and cultural ecosystem services depends on ecosystem functioning.

Since ecosystem services are defined in terms of benefits for people, it is important to recognise that the value or importance assigned to any ecosystem service is dependent on the people concerned. This means that the same feature can be considered a valuable ecosystem service by one group of people but not by another. An ecosystem service only exists when someone is benefitting from it! These assessments can differ even within the same group, such as the gender-specific needs and values of women and men.

For *provisioning* ecosystem services, a physical ecosystem component, such as a tree or an animal, only becomes an ecosystem service when someone harvests it or receives a direct benefit when it is sold or used. For example, when medicinal plants or timber from a forest are sold, it benefits the harvester, merchants, and consumers.

For *regulating* ecosystem services, people in the ecosystem area or downstream may benefit from the services without any harvesting or management of the ecosystem taking place. An example of this would be the benefits of a forest regulating the climate and water flows. People may benefit from regulating ecosystem services without even knowing that they do so. Management of an area may seek to increase the supply of regulating ecosystem services that benefit particular groups, such as farmers or urban residents.

Whether something is a *cultural* ecosystem service is entirely dependent on the values of the people who interact with the ecosystem. A natural area or a farmed area may be considered attractive and valuable by some local groups and individuals but not so by others.

One benefit of the ecosystem services concept for improving management of the environment is the attention it draws to regulating and cultural ecosystem services, as well as to the provisioning ecosystem services that management typically focuses on. This increased attention promotes management for regulating and cultural ecosystem services, which depend on the effective functioning of ecosystems.

2.5 Ecosystem functioning and society – keeping a holistic perspective

Classifications and frameworks to guide management for ecosystem services necessarily encourage describing the natural world and society's relationships with it in terms of categories, such as different types of ecosystem services. However, there is a risk of developing an overly compartmentalised and incorrect 'linear cause-effect' view of the relationships between ecosystems and people. Thus, it is important to have a holistic perspective in management for ecosystem services.

A basic holistic perspective means ensuring that all, and not just a few, of the issues of concern are considered in turn. A more fundamental holistic perspective views all the issues as different aspects of one 'whole'. An example of this would be considering the natural environment (ecosystems) and the people of an area as a single whole entity. Such a view means recognising that change in any one aspect of the whole results in change in all the aspects. It also recognises that the whole has emergent properties or behaviour; in other words, it is more than the sum of its 'parts'.

The approach of management for ecosystem services in this Manual is centred on having a holistic perspective of ecosystem functioning. The various aspects of ecosystem functioning, such as ecosystem processes, structure, and interactions, are all part of the same whole ecosystem. Viewing the environment with this holistic perspective is a paradigm that enables management to work more effectively and sustainably with nature.

A holistic perspective also leads to seeing an issue or subject in terms of nested 'wholes within wholes'. For example, one can view an individual person as one whole within the wider wholes of a family, an organisation, a town or village, and a country.

Figure 6 is one representation of a holistic perspective when using the ecosystem services concept. In terms of physical space and society's life-support systems, we can view people and society as part of ecosystems and embedded within them. Promoting human well-being is one aspect or purpose of society, towards which ecosystem services and economies contribute. Our economies are embedded within ecosystems, as well as within the activities and concerns of people and society. Changes in ecosystems and economies affect people and society, and vice versa.

2.6 Ecosystem function has two meanings

This Manual distinguishes two different uses of the term 'function' in relation to ecosystems:

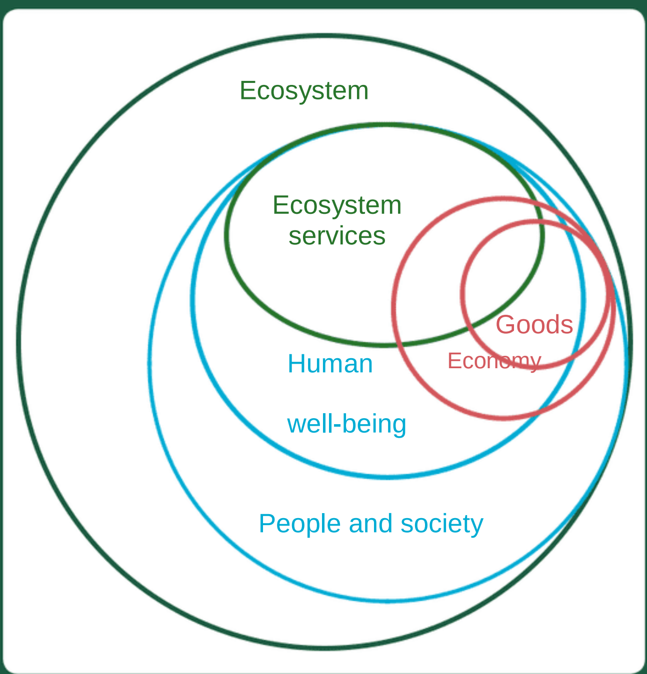
Processes use of 'ecosystem function' – referring to the processes or 'working' of an ecosystem.

Capability use of 'ecosystem function' – referring to the capability or role of an ecosystem to be useful to people, such as to supply ecosystem services.

It is important to be clear about which meaning is intended when the term 'ecosystem function' is used. The phrase 'measuring ecosystem function' could mean simply describing certain ecosystem processes, such as the cycling of minerals, without any concern for or reference to a particular desirable state or functioning of processes. This is a *processes use of ecosystem function*.

Alternatively, 'measuring ecosystem function' could mean the function of an ecosystem to provide a capability or property for people. For example, if it was said that there is an ecosystem function of regulation of soil erosion on farmland. This is a *capability use of 'ecosystem function'*, because it refers to an implicitly or explicitly de sirable state of ecosystem function for human benefit. The *capability use of 'ecosystem function'* is the meaning often used in work on the valuation of ecosystem services.

Figure 6: A representation of how people, society, and economies are embedded within ecosystems



Note that the relative sizes and overlaps of the circles in the diagram do not represent any quantitative relationships.

Using the form 'functioning' instead of 'function' helps to reduce the ambiguity about which meaning is intended. For example, compare 'The functioning of an ecosystem includes the flow of energy from plants to herbivores, carnivores, and decomposers' to 'A function of the forest ecosystem is to provide timber and regulation of water flows'. If the 'operation' or 'working' of an ecosystem is intended, then inclusion of the word 'processes' also helps to make this clear, such as 'the functioning of ecosystem processes'. The work of Jax (2010) is recommended for those seeking more explanation on the different meanings of ecosystem functioning.

Ecosystem functioning is sometimes defined as if it is the same as the functioning of ecosystem *processes*. However, the operation of the processes is determined by the structure of the ecosystem. Conversely, the structure depends on the functioning of the processes, as well as the ecological interactions between living organisms, as they are all aspects of the same ecosystem. This Manual, therefore, defines ecosystem functioning as the combination of ecosystem structure, ecosystem processes, and ecological interactions.

2.7 Biodiversity and ecosystem functioning

There are several ways to consider the concept of biodiversity in relation to management for ecosystem services and ecosystem functioning. One definition of biodiversity refers to all the living organisms in an environment, which is very similar to the definition of an ecosystem. Another concept of biodiversity focuses on the importance of the diversity and variability of living organisms. Scientists generally agree that the diversity of species and functional groups (such as herbivores and carnivores) has effects on many ecosystem processes and consequently on ecosystem services (Naeem et al., 2009). A third use of the term biodiversity is as a summary or shorthand term for important or valued species, such as attractive or endangered animals, or even just as another term for wildlife.

As noted in Section 2.6, this Manual suggests that in management for ecosystem services based on ecosystem functioning, the concepts of ecosystem structure, ecosystem processes, and ecological interactions are sufficient to guide management. The concept of biodiversity as all living organisms is already included in the concept of an ecosystem. Consideration of the diversity and variability of organisms in ecosystem functioning can be expressed in terms of ecosystem structure and ecological interactions. If the term biodiversity is used to mean important species, then such species can be recognised in terms of provisioning or cultural ecosystem services, with management objectives included for them.

2.8 Ecosystem processes

This section of the Manual gives key knowledge on how to understand and describe for ecosystem management the four core ecosystem processes: water cycling, mineral cycling, solar energy flow, and biological growth.

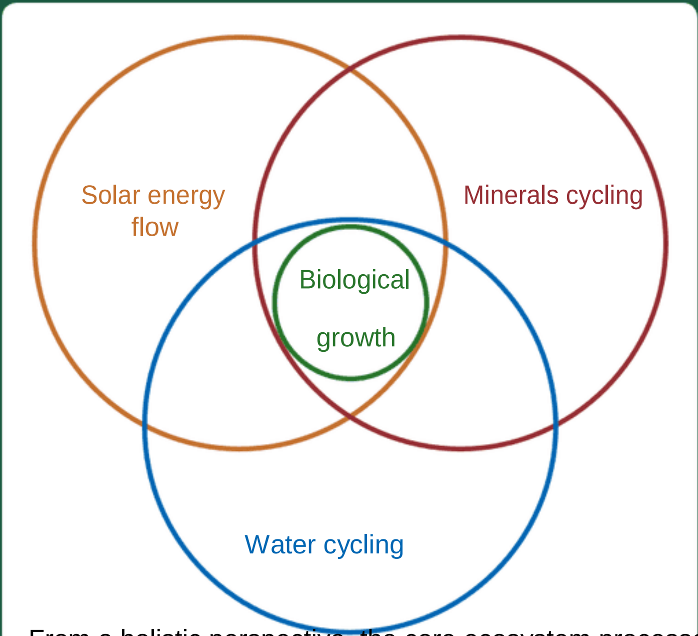
These can be called core ecosystem processes because they operate at all scales, from a single living organism to the entire planet. The existence of every plant, animal, and microbe depends on water and minerals and on energy derived from the Sun[6]. The activities of living organisms growing and reproducing can be summarised as biological growth.

Whilst each of the four core ecosystem processes can be considered individually, they are completely interlinked, so change in the functioning of any one of them automatically results in change in the functioning of the others (Figure 7). Each process is just a different aspect of the same system and should be viewed from this holistic perspective. The core ecosystem processes can be thought of as four different windows on the same ecosystem.

For example, an increase in the plant (biological) growth in an area means a change in the water and mineral cycling because the plants take more water and minerals from the soil. The plant growth will also mean more solar energy is captured in the ecosystem, which leads to increases in the growth of herbivores, predators, and decomposers. This in turn results in changes in the mineral cycling and the growth of plants.

6With the exception of chemotrophic microbes.

Figure 7: Representation of the inter-relationships of the four core ecosystem processes



From a holistic perspective, the core ecosystem processes can be viewed as nested scales of functioning. For example, the water cycling through a tree influences the water cycling in the forest that it is part of, which in turns influences the water cycling in a whole river catchment.

There are other ecosystem processes which can be important to consider, such as the formation by living organisms of soils and marine substrate. The existence of such processes will be particular to specific ecosystems or localities, and can thus be seen as a second level of consideration.

Water cycling ecosystem process

Plants, animals, and microbes greatly influence the water cycle in a locality, as they take up and transpire, respire, or excrete water, as well as the physical impact of vegetation on water flows. Water is, of course, also cycled at the landscape-to-continental scale through rainfall, rivers, cloud formation, and evaporation from the oceans. The transpiration of water by forests and other vegetation can also have a critical influence on local and regional climate, affecting air temperatures and rainfall patterns.

For ecosystem management the scale of attention is focussed on how to influence the water cycling from the plants in a locality and up to the scale of river catchments and basins. Management of the soil, crops, natural vegetation, and grazing animals can affect the amount and duration of water available in the soil for the growth of plants and all living things. The physical structure and types of vegetation can also significantly affect whether rainfall flows into rivers or underground aquifers or simply evaporates.

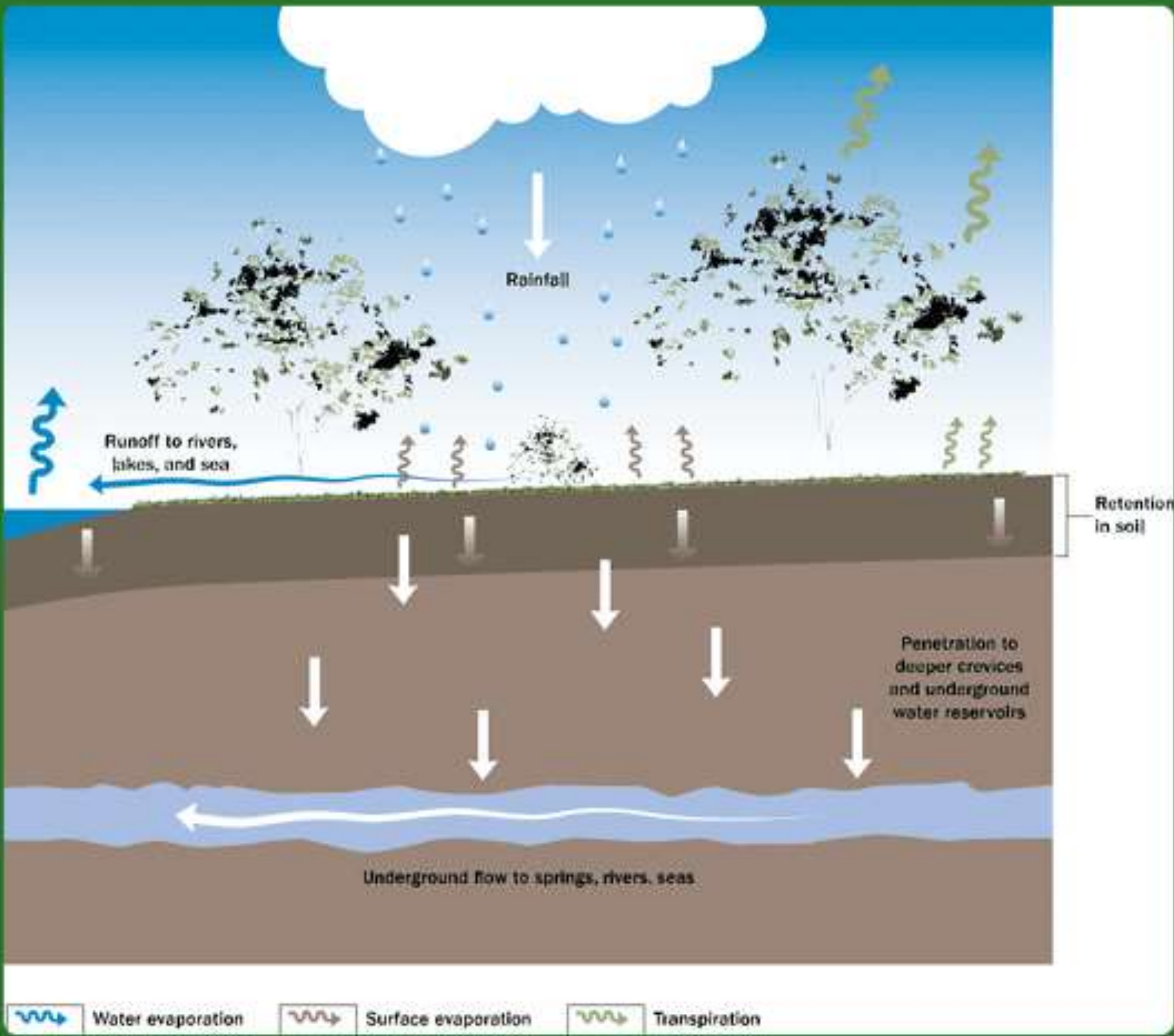
Water cycling as an ecosystem process refers to the amount of water and the speed of its movement for each of the ecosystem pathways through which water from rain or snow could flow (Figure 8). These pathways are: ƒƒ surface runoff to rivers and lakes,
ƒƒ surface evaporation,
ƒƒ infiltration into the soil,
ƒƒ evapotranspiration from the soil to the atmosphere through plants,
and ƒƒ penetration to underground water resources.

In some conditions, vegetation can capture moisture directly from clouds and fog when they are in direct contact with each other on mountain slopes, forming ‘cloud forests’.

Key questions

A description of the functioning of the water cycling ecosystem process starts with consideration of the key question, ‘What happens to the water from rain and snowfall?’ A brief description should be made of the water movement for each of the ecosystem water cycling pathways. When considering the water cycling ecosystem process, the following questions are useful for analysing the current and desired situation:
ƒƒ Is the cycling of rainfall water through the soil and vegetation high or low?
ƒƒ Is the loss of rainfall water from the ecosystem through runoff and evaporation at the soil surface high or low?
ƒƒ Is rainwater infiltration into the soil and aquifers high or low?

Figure 8: Pathways of ecosystem water cycling in a terrestrial ecosystem. Redrawn with permission from materials of Holistic Management International (www.holisticmanagement.org)



- How long is water available in the soil to enable plant growth?
- What is the role of the vegetation (including plant roots) in water cycling?

Evidence of the functioning of the water cycling ecosystem process can also be found in the extent of lakes, the flow rates of streams and rivers, and the depth of the water table or aquifers.

A fundamental consideration in ecosystem management is determining the extent of bare soil or vegetation cover required for the desired water cycling and ecosystem services. If there are few plants and large areas of bare soil, any water from rainfall is likely to quickly run off the surface into rivers and lakes or evaporate. If the soil is covered with vegetation, then rainfall is more likely to soak into the soil and be retained there. Water retained in the soil will sustain plant growth and organic decomposition (mineral cycling). Consequently, plant growth depends not just on the amount of rainfall but also on how effectively that rainfall is 'captured' and retained in the soil.

If the vegetation includes trees, then their roots will aid deeper soil penetration of rainfall and increase the transpiration of that soil moisture back to the atmosphere. The size and types of trees can have a major influence on the rates of water flow to underground aquifers and on to springs and rivers.

The severity of droughts and floods is not entirely determined by the amount of rainfall. Their severity is also strongly influenced by the functioning of the water cycling ecosystem process and the ecosystem structure. Vegetation cover and type determines the proportion of bare soil in an area and whether the soil surface is capped or is permeable for rainwater infiltration and evaporation. Evidence of soil erosion, such as gullies, also indicates problems in the water cycle.

It may be difficult to directly observe the functioning of the ecosystem process of water cycling, but it can be described with the aid of indicators, such as those described in Table 1.

Table 1: Aspects of water cycling, possible indicators, and consequences for ecosystem services

Aspect of water cycling	Possible indicators	Consequences for ecosystem services	Relationship to ecosystem structure and management
Rain water surface runoff to rivers and lakes	• Rate of rise and fall of streams and rivers after rainfall • Turbidity levels of water bodies due to soil erosion • Evidence of soil gulley erosion, soil pedestals around plants, and accumulation of leaf litter at the foot of slopes	The supply of ecosystem services from plant growth may be limited by lack of soil water and erosion of soil. The water supply and quality in periods of no rainfall may be low if there is high runoff. High surface flows of rainwater and flooding may damage infrastructure.	Bare soil without vegetation or leaf litter facilitates capping of the soil surface and rain water surface runoff. The abundance of shrubs and trees affects the impact of rain water on the soil surface and infiltration.
Evaporation of rain water and soil moisture from the soil surface	• How long the soil surface remains moist after rainfall	The supply of ecosystem services from plant growth may be limited by a lack of soil water.	Bare soil without vegetation or leaf litter facilitates the evaporation of water. The abundance of shrubs and trees affects the soil surface structure and its exposure to sun and wind.
Rain water infiltration into the soil	• How long the soil surface remains moist after rainfall • Pools of water on the soil surface after rainfall • Length of time for one litre of water poured on the soil to drain away • Ease of penetration of soil with a knife or stick • Depth of the soil moisture layer	The supply of ecosystem services from plant growth may be limited by a lack of soil water.	Bare soil without vegetation or leaf litter facilitates capping of the soil surface and poor infiltration of water. The abundance of shrubs and trees affects the soil surface structure and its exposure to sun and wind.
Evapotranspiration by plants of water from the soil to the atmosphere	• Depth of soil moisture layer • Flow of streams and rivers in low rainfall periods	The supply of ecosystem services from plant growth may be limited by lack of soil water. The water supply in periods of no rainfall may be low if there is high evapotranspiration.	The abundance, types, and form of grasses, shrubs, and trees determine the evapotranspiration rates.
Rain water penetration to underground water resources	• Flow rate of streams and rivers in low rainfall periods	The supply of ecosystem services from plant growth may be limited by a lack of soil water. The water supply from streams and aquifers in periods of no rainfall may be low if there is low infiltration in the soil below plant root depths.	The abundance, types, and forms of grasses, shrubs, and trees influences the soil structure and infiltration rates through their roots.
The amount of water available for plant growth	• Growth rate of grasses and herbs • Length of growing season of grasses and herbs, including variation in space across a locality	The supply of ecosystem services from plant growth may be limited by a lack of soil water. The water supply in periods of no rainfall may be low if there is high evapotranspiration.	The abundance, types, and growth of grasses, shrubs, and trees determines the extent of bare or covered soil and influences the functioning of the water cycle.

An excellent resource for more information on water cycling is the FAO guide on optimizing soil moisture for plant production, which includes a chapter on hydrology, soil architecture, and water movement. http://www.fao.org/docrep/006/y4690e/y4690e07.htm#TopOfPage

Mineral cycling ecosystem process

All plants, animals, and microbes need minerals, which they ingest, utilise, and release as part of their metabolism. The availability of minerals in the ecosystem is greatly influenced by the growth, activities, and death of living organisms, with the role of decomposers obviously playing a vital part in mineral cycling. Large herbivorous animals can also have a major role in mineral cycling, especially in grasslands, as they rapidly convert plant matter into dung and urine that provides accessible minerals for plant growth.

Key questions

When considering the functioning of the mineral cycling ecosystem process, the following questions may be useful for analysing the current and desired situations:

- Is the mineral cycling open, with minerals being lost from the ecosystem, or closed, with minerals remaining or increasing in the locality?
- If the mineral cycle is open, how are minerals being lost from the ecosystem (e.g., due to vegetation harvesting, fire, soil erosion)?
- Is the rate of mineral cycling fast or slow?
- Where are most of the minerals in the ecosystem? Are they in the soil, the vegetation, or animal biomass?
- How are the vegetation, herbivores and decomposers influencing the mineral cycling?

In a terrestrial ecosystem, the amounts and rates of mineral cycling can be rapidly assessed by examining the soil surface. If the soil is covered with vegetation and there is evidence of high decomposer activity, then the mineral cycling is likely to be closed and fast. If the ecosystem structure is very simple, with large areas of bare soil and little decomposer activity, then the mineral cycling is likely to be open and with low volumes and rates (Figure 9).

It is difficult to directly observe the movement of minerals in an ecosystem, but the ecosystem process of mineral cycling can be described through indicators instead, such described in Table 2.

Solar energy flow ecosystem process

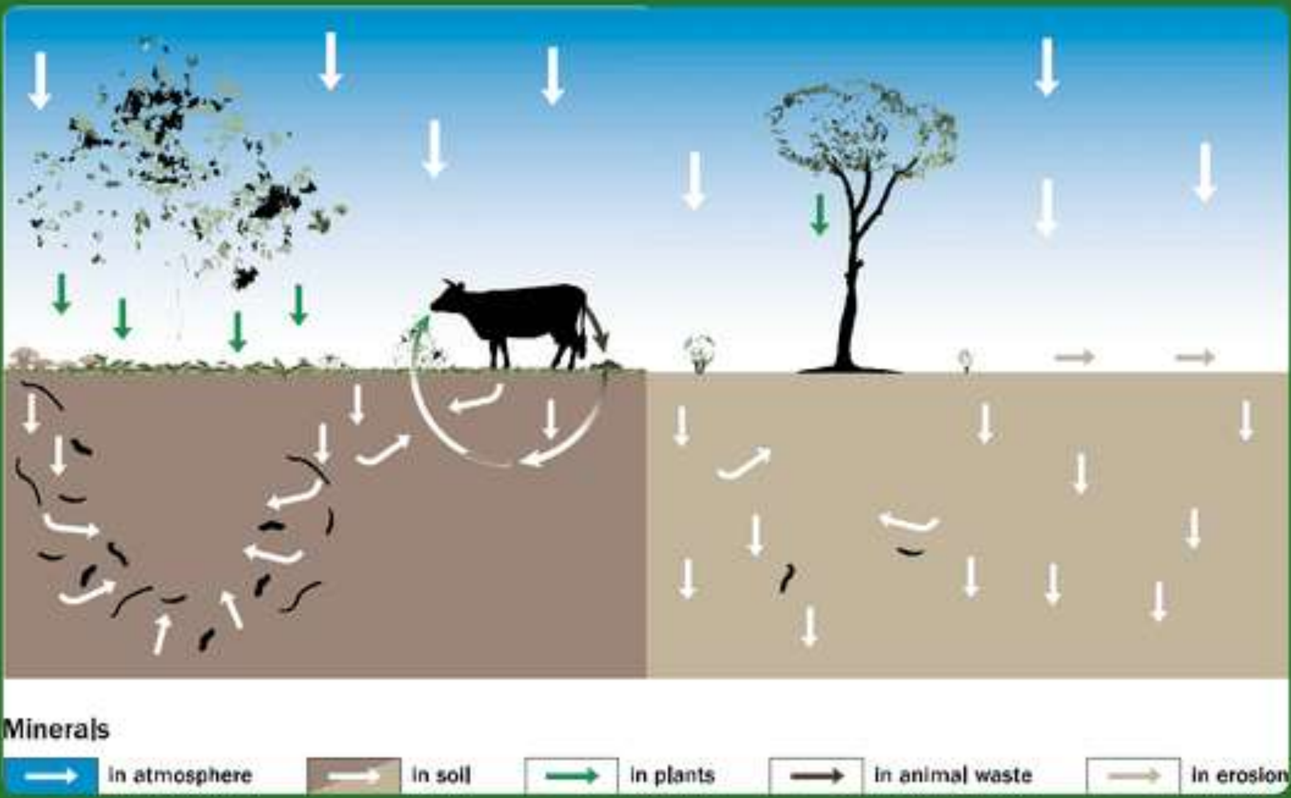
Almost all ecosystems are fuelled by the sun's energy captured by plants through photosynthesis. This solar energy in plants then passes through ecosystem food webs to herbivores, omnivores, and carnivores, and finally to decomposers. Thus, solar energy doesn't cycle within ecosystems, but is a flow through food webs, with losses at each level through respiration (Figure 10).

It is important to remember for terrestrial ecosystems that solar energy flow extends below ground. The biological soil community depends on the solar energy in dead organic matter, which is conveyed to it through plant roots, fungi, worms, termites, dung beetles, and others.

Key questions

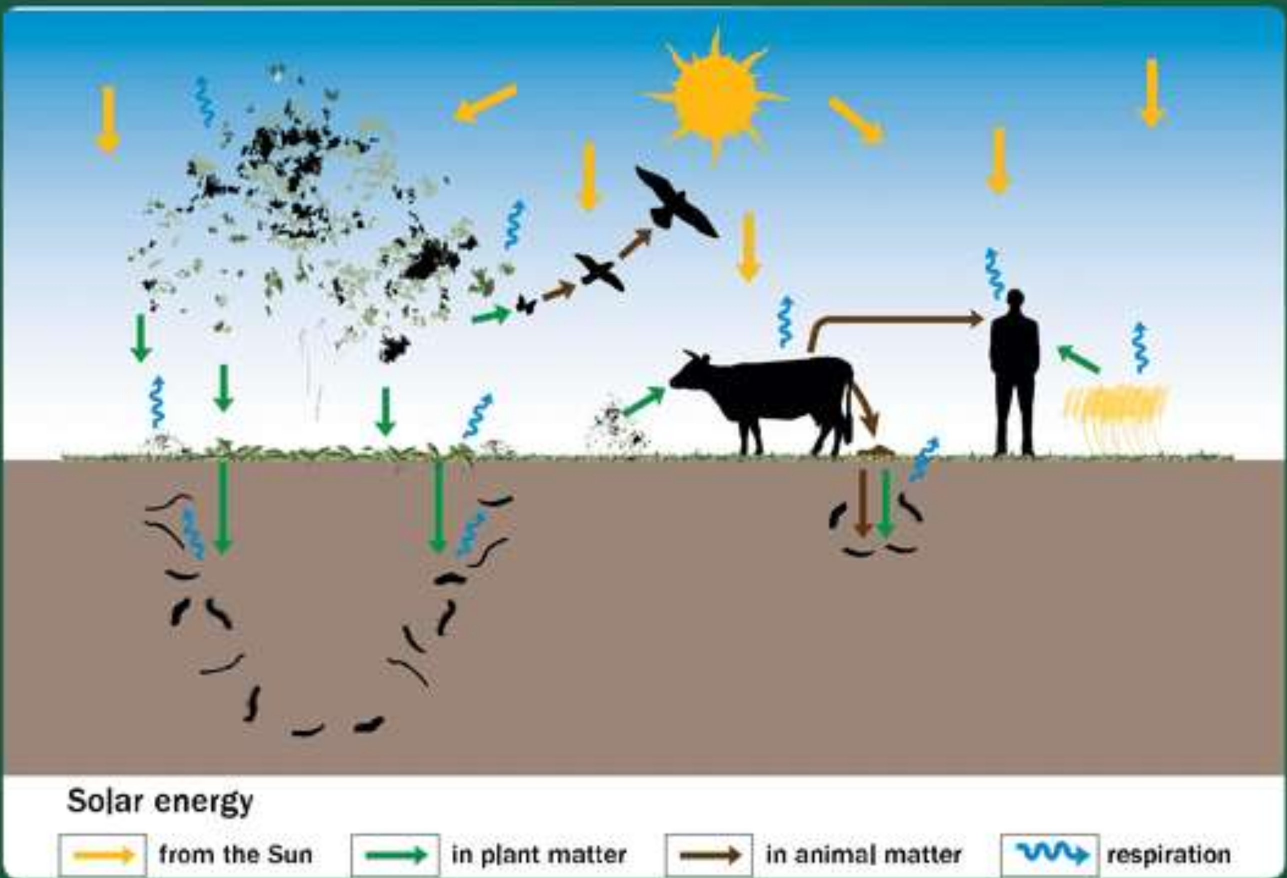
- How much capture of the sun's energy is there by plants?
- How much solar energy flows to herbivores, predators and decomposers?

Figure 9: Illustrative mineral cycling in a locality with a complex ecosystem structure (left) and a simple structure (right)



Redrawn with permission from materials of Holistic Management International (www.holisticmanagement.org).

Figure 10: The pathways of solar energy flow in a terrestrial ecosystem



Redrawn with permission from materials of Holistic Management International (www.holisticmanagement.org).

Table 2: Aspects of mineral cycling, possible indicators, and consequences for ecosystem services

Aspect of mineral cycling	Possible indicators	Consequences for ecosystem services	Relationship to ecosystem structure and management
Open or closed mineral cycling, in terms of loss of minerals from the locality	• The percentage of bare ground • The percentage of ground covered by vegetation and leaf litter • Turbidity levels of water bodies due to soil particles • Evidence of soil gulley erosion, soil pedestals around plants, and accumulation of leaf litter at the foot of slopes	The supply of ecosystem services that require plant growth may be limited by a lack of minerals. Water quality and aquatic ecosystems may be affected by soil particles and minerals from erosion. Infrastructure and tourism values may be affected by water and wind-borne soil.	Bare soil without vegetation or leaf litter facilitates capping of the soil surface and erosion by rainwater and wind. The abundance of dead and living plant matter at the soil surface determines the availability of organic matter and moisture required by the soil decomposer community. The abundance and types of herbivores, and their behaviour, determines the availability of dung and urine, which have a major impact on the rate of mineral cycling by the soil decomposer community and the availability of minerals for plant growth. The abundance of grasses, shrubs, and trees and their root structure affects the amount and types of minerals cycled from soil layers to the above-ground ecosystem.
Pathways of loss of minerals from the ecosystem	• Vegetation harvesting (timber, fuelwood, fodder, etc.) • Harvesting of livestock • Harvesting of leaf litter • Fire • Soil erosion • Soil leaching by rainwater	The supply of ecosystem services that require plant growth may be limited by a lack of minerals. Water quality and aquatic ecosystems may be affected by soil particles and minerals from erosion. Infrastructure and tourism values may be affected by water and wind-borne soil.	Vegetation harvesting removes minerals from the ecosystem, but may also stimulate increased plant growth and rates of mineral uptake from soils. Harvesting of livestock removes minerals from the ecosystem, although this may be compensated for by increased availability of minerals and plant growth if grazing is managed with this aim. Harvesting of leaf litter removes minerals and increases soil exposure to rain and sun, with increased risk of erosion and reduced soil decomposer activity. Fire releases minerals to the atmosphere and increases their availability for plant growth, with bare soil and loss of organic matter increasing the risk of erosion and reducing soil decomposer activity. The abundance of grasses, shrubs, and trees and their root structure affects the soil coverage and erosion risk and soil leaching.
Pathways of increases in minerals and their availability in an ecosystem	• Abundance of nitrogen-fixing plants • The abundance of vertebrate herbivores (for the conversion of plant matter into dung and urine) • The abundance of invertebrate herbivores • The abundance of soil-level decomposers, such as fungi, earthworms, and dung beetles • Soil surface coverage by living and dead vegetation, to provide food and moist conditions for soil decomposer community	The supply of ecosystem services that require plant growth can be increased, due to greater availability of minerals and water retention in soils with an organic matter layer. Water quality and aquatic ecosystems that require low mineral conditions will improve.	Nitrogen-fixing plants increase the availability of minerals for plant growth and the soil decomposer community. They may be able to grow in conditions of bare and degraded soils and thereby increase the amount and rate of functioning of all the ecosystem processes. The abundance and types of vertebrate herbivores, and their behaviour, determines the availability of dung and urine, which have a major positive impact on the rate of mineral cycling by the soil decomposer community and the availability of minerals for plant growth. The abundance of invertebrate herbivores (such as ants, termites, and grasshoppers) can have a major role in the conversion of plant matter into accessible minerals for plant growth, especially in limited moisture conditions. The abundance of soil-level decomposers is essential to the functioning of the mineral cycle. They require food in the form of dead plant and animal matter and moisture.

Aspect of mineral cycling	Possible indicators	Consequences for ecosystem services	Relationship to ecosystem structure and management
Where are most of the minerals in the ecosystem?	• Proportions of vegetation biomass to animal biomass to soil organic matter, per hectare	The supply of ecosystem services based on plant growth (including livestock production) may be limited by mineral availability if water, temperature, and light are not limiting. Management may seek to increase mineral availability in soils in order to increase their uptake by plants and consequent uptake by animals, if so desired.	The animal biomass may be limited by the availability of palatable vegetation biomass. The biomass may be limited by the availability of minerals in the soil, which in part depends on the soil organic layer. A significant proportion of the minerals in an ecosystem may be inaccessible for plant or animal growth if they are in the form of lignified or unpalatable plant matter.
The amount of minerals growth	• The abundance of soil-level earthworms, and dung beetles • Soil organic layer depth • Plant health and growth rates • Deep or shallow rooted plants	The supply of ecosystem services based on may be limited by mineral availability if water, temperature, and light are not limiting. Management may seek to increase mineral availability in soils in order to increase their uptake by plants and consequent uptake by animals, if so desired.	A significant proportion of the minerals in an ecosystem may be inaccessible for plant Soil-level decomposers liberate minerals from dead plant and animal matter, which enables plant growth. The depth of plant roots determines their capacity to reach deep soil layers and access more minerals.
The rate of mineral cycling	• The time for the organic decomposition of leaf litter and animal dung • The abundance of vertebrate herbivores (for the conversion of plant matter into dung and urine) • The abundance of invertebrate herbivores • The abundance of soil-level decomposers, such as fungi, earthworms, and dung beetles	The supply of ecosystem services that require plant growth (including livestock production) may be limited or increased by the availability of minerals. Water quality and aquatic ecosystems may be affected by soil particles and minerals from erosion. Infrastructure and tourism values may be affected by water and wind-borne soil.	The abundance of dead and living plant matter at the soil surface determines the availability of organic matter and moisture required by the soil decomposer community. The abundance and types of vertebrate herbivores, and their behaviour, determines the availability of dung and urine, which have a major positive impact on the rate of mineral cycling by the soil decomposer community. The abundance of invertebrate herbivores (such as ants, termites, and grasshoppers) can have a major role in the conversion of plant matter into accessible minerals for plant growth, especially in limited moisture conditions. The abundance of soil-level decomposers depends on their food in the form of dead plant and animal matter and on moisture.
The volume of mineral cycling	• The condition of the soil surface for the infiltration of rain water and organic matter – porous or capped • Deep or shallow rooted plants • Biomass of plants, herbivores, predators, and decomposers, per hectare	The supply of ecosystem services that require plant growth (including livestock production) may be limited or increased by the availability of minerals. Water quality and aquatic ecosystems may be affected by soil particles and minerals from erosion. Infrastructure and tourism values may be affected by water and wind-borne soil.	The vegetation structure and coverage of the soil will largely determine the condition of the soil surface for rain water infiltration or erosion, and organic decomposition. The presence of large vertebrates may have a significant effect on vegetation structure and soil condition. The more biomass of plants in a location, the more solar energy will be available in the plants to enable a greater biomass of herbivores, predators, and decomposers.

A useful guide on mineral cycling, of which chapters 3 and 4 are of particular interest, is available at http://www.fao.org/docrep/009/a0100e/a0100e06.htm#bm06

Being able to think in terms of solar energy flow is particularly important when managing land and water resources for provisioning ecosystem services, all of which (except freshwater supply) are products derived from living organisms. The production (biomass) of these organisms depends directly on the amount of solar energy they obtain.

One way of viewing crop farming and forestry is that they aim to modify ecosystem structure and processes to provide the best conditions for crops and trees to grow, including the capture of solar energy. Similarly, the production of domestic or wild animals depends on the amount of energy (food) available for them and the ecosystem structure to provide this food.

Solar energy flow as such can be difficult to directly observe, but it is intrinsically linked to the food web structure and can be described through indicators, such as those described in Table 3.

Table 3: Aspects of solar energy flow, possible indicators, and consequences for ecosystem services

Aspect of solar energy flow	Possible indicators	Consequences for ecosystem services	Relationship to ecosystem structure and management
Capture of the sun's energy by plants (photosynthesis)	• Percentage ground cover by plants • Leaf Area Index • Plant biomass • Plant growth rates • Duration of plant growth • Sugar and protein content of forage for herbivores	The amount of the sun's energy that plants can capture through photosynthesis determines their growth and therefore the supply of ecosystem services that require plant growth. These services include provisioning services from plants such as timber and livestock fodder, regulating services of vegetation structure and growth, and cultural services from use and interactions with plants and vegetated landscapes.	Vegetation structure depends on the growth of plants. The amount of leaf area in a location determines the amount of potential for photosynthesis. Grasslands and some wetland ecosystems have co-evolved with vegetation growth dependent on grazing by herbivores and vice-versa. Plant growth depends on the favourability of soil structure for their growth, including the availability of minerals and water and conditions for root growth.
Solar energy flow from plants to other levels of the food web	• Biomass of all herbivores/ unit area • Biomass of large vertebrate herbivores / unit area • Growth rate of herbivores • Biomass of vertebrate predators /unit area • Growth rate of vertebrate predators • The abundance of soil-level decomposers, such as fungi, earthworms, and dung beetles	Provisioning ecosystem services from livestock depend on the availability and growth of forage plants. Provisioning or cultural services from vertebrate predators (e.g., hunting, tourism) depend on the availability of prey species which rely on the capture of solar energy by plants. Mineral cycling and availability for plant growth depends on the decomposer soil community, which requires solar energy from plant and animal wastes and dead organisms.	The amount of solar energy flow from plants to other levels of the food web is a function of the structure of the food web, with herbivores, predators, and decomposers. Management for a particular species or group of animals should include consideration of what they need to obtain their solar energy (food), and what role they play as a source of energy for other parts of the food web, including decomposers.

Biological growth ecosystem process

The concept of biological growth as an ecosystem process relates to both the process of physical growth of individual organisms through their life cycle and the increase in biomass and ecosystem complexity in a location over time. Obviously, the longer the conditions in a locality are suitable for the growth of vegetation and the food web it supports, the greater the increase in biomass and ecosystem complexity (Figure 11).

Key questions

- What is the rate of biological growth at each level of the food web?
- Which of the other ecosystem processes are limiting the biological growth of each level of the food web?

Figure 11: Illustration of the biological growth of a tree and the associated growth in ecosystem structure and interactions

Produced by UNEP-WCMC for this Manual.

Biological growth as an ecosystem process is also linked to the response of an ecosystem to a disturbance, such as a fire or clearance of vegetation by people. The tendency of vegetation and ecological communities to grow after a disturbance, and their patterns, can be considered a form of the biological growth ecosystem process. This aspect of biological growth may be desired for its impact on other ecosystem processes, such as mineral cycling.

At a basic level, biological growth is simply the population growth rates of valued species, whether domesticated or wild. An estimate of the biomass and growth of each trophic level of the food web is also an important indicator of its functioning.

Over a growing season in a location the amount of solar energy captured in organic matter will tend to increase, along with the diversity of organisms and complexity of interactions between them and their environment. Obviously, the longer the conditions are beneficial for biological growth, the greater the biomass and ecological complexity will be. Compare, for example, a tropical rainforest to a temperate zone seasonal forest in terms of the size of the trees and the diversity of species and ecological interactions.

Biological growth at the scale of a landscape depends on the growth of individual organisms and populations of species. From the perspective of ecosystem management, managers for provisioning ecosystem services will be seeking to promote the growth of valued species, whether domesticated plants and animals or wild species. Managers may also be working with biological growth to encourage growth of soil, vegetation, and animal communities for regulating and cultural ecosystem services such as flood mitigation and landscape values.

Biological growth can also be seen in the process of ecological succession, which occurs after an ecosystem has been simplified in some way by a disturbance, such as a storm or people clearing forest for crops. Ecological succession develops after a disturbance of increasing ecosystem structural complexity, diversity, and biomass until some limit to growth is reached. Farmers have long used this process when they leave a farmed area fallow to recover soil fertility.

Biological growth is the growth rate of individual organisms and of groups such as plants and animals. It can be described through indicators, such as those described in Table 4.

Table 4: Aspects of biological growth ecosystem process, possible indicators and consequences for ecosystem services

Aspect of biological growth	Possible indicators	Consequences for ecosystem services	Relationship to ecosystem structure and management
Growth of plants	• Leaf Area Index • Plant biomass • Plant growth rates • Duration of plant growth	The supply of ecosystem services involving plants depends on their growth rate. These services include: provisioning services from plants, such as timber and livestock fodder; regulating services involving vegetation structure and growth, such as water flow regulation and carbon sequestration; cultural services from use and interactions with plants and vegetated landscapes.	Growth of plants is a determinant of vegetation structure. Management may aim to favour a particular vegetation structure for the growth of desired species. The growth of some plants, including grasses, may be stimulated by the removal of leaves, so the amount of capture of the sun's energy is increased per unit area and there is greater solar energy flow (food) for other parts of the food web. Grasslands and some wetland ecosystems have co-evolved with vegetation growth that is dependent on grazing by herbivores and vice versa. Plant growth depends on the favourability of soil structure for their growth, including the availability of minerals and water, and the conditions for root growth.
Growth of animals	• Biomass of desired species for production • Biomass of large vertebrate herbivores / unit area • Growth rate of herbivores • Biomass of vertebrate predators /unit area • Growth rate of vertebrate predators • The abundance of soil-level decomposers, such as fungi, earthworms, and dung beetles	The supply of ecosystem services involving animals depends on their growth rate. These services include provisioning services such as livestock, harvested wild animals, and fish; regulating services of crop pests; pollination; and cultural services from use and interactions with wild animals.	The growth of a particular animal species depends in part on the structure of the food web of which they are a part. Growth will be influenced by the availability of food, the abundance of competitors, and the abundance of predators. Management for growth of a particular species or group of animals should include consideration of what they need to obtain their solar energy (food) and what role they play as a source of energy for other parts of the food web, including decomposers.

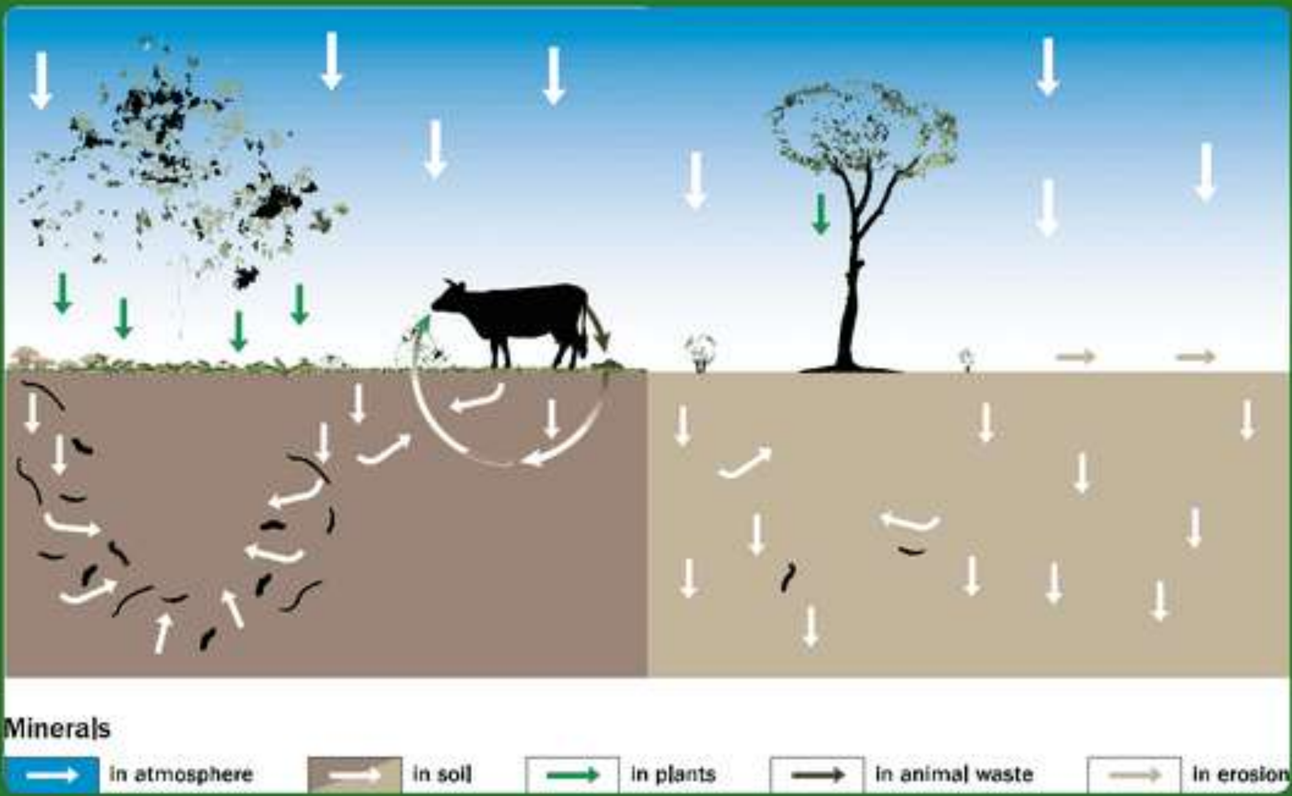
2.9 Ecosystem structure

For the purpose of management for ecosystem services, the most useful types of ecosystem structure to consider are:

- vegetation structure,
- food web structure, and
- soil structure.

Ecosystem structure is the aspect of the ecosystem that can be physically seen and altered by management. After describing the current or desired functioning of ecosystem processes, managers should determine the necessary vegetation structure for the desired ecosystem services because this is the most obvious type of ecosystem structure; then they should determine the food web and soil structures. Figure 12 is an illustration of how the ecosystem structure can influence the functioning of the ecosystem processes in a grassland. The differences in vegetation, food web, and soil structure will also affect the water cycling, solar energy flow, and biological growth.

Figure 12: Illustration of mineral cycling in a grassland ecosystem with a relatively complex (left-hand side) and a simple (right-hand side) ecosystem structure.



Redrawn with permission from materials of Holistic Management International (www.holisticmanagement.org).

Vegetation structure

The physical structure of the vegetation has a major effect on the functioning of the ecosystem processes, and is an aspect of ecosystem structure that can be managed relatively easily. Vegetation structure can be considered in the following ways:

- grass and herb coverage of the soil,
- shrub layer,
- tree layer and canopy cover,
- root depth,
- abundance of dead and decaying vegetation,
- plant biomass and leaf area at ground level, in shrubs and trees, and below-ground (roots).

Table 5 describes the aspects of vegetation structure, how they can be described using indicators, their consequence for ecosystem services, and their relationship to ecosystem processes and management.

Food web structure

Managing for ecosystem services requires consideration of the particular structure or composition of the food web required for the desired services. A detailed analysis of the food web is not required, but the four main food web categories (or trophic levels) can be broadly described. The descriptions should consider the current and desired situation for each of the food web categories, in the following order:

1. *Decomposers* – They are fundamental to soil formation and mineral cycling but are usually overlooked. Consider their role and abundance for soil formation and the availability of minerals for plant growth and water quality. Scavengers of dead animals, such as vultures and foxes, may provide an ecosystem service by reducing the spread of diseases.
2. *Plants* – They are the foundation of the food web. Consider the amount of growth necessary for crop production and food provision (solar energy) for herbivores, predators, and decomposers. Consider also the physical role of plants in water and mineral cycling.

Table 5: Aspects of vegetation structure, possible indicators, consequences for ecosystem services, and their relationship to ecosystem processes and management

Aspect of vegetation structure	Possible indicators*	Consequences for ecosystem services	Relationship to ecosystem processes and management
Grass and herb coverage of the soil	Percentage ground cover by plants (grass, forage) Leaf Area Index at ground level	The supply of ecosystem services from plant growth may be limited by a lack of soil water if there is little vegetation coverage of the soil. The water supply in periods of no rainfall may be low if there is high evapotranspiration by ground-level plants. Provisioning ecosystem services from livestock depend on the availability and growth of forage plants. Soil surface coverage can significantly influence the functioning of the water cycling ecosystem process and thus the water supply and flow regulation ecosystem services. Soil surface coverage is a major determinant of erosion control and regulation of soil quality. Provisioning or cultural services from vertebrate predators (e.g., hunting, tourism) depend on the availability of prey species, which rely on the capture of solar energy by plants. Particularly in grasslands, the abundance of herbivorous prey species is influenced by the grass and herb coverage of the soil. Grasslands have major cultural ecosystem service values as sources of livelihoods and places to live, and they offer many aesthetic, spiritual, cultural, educational, and recreational values.	Bare soil without vegetation or leaf litter facilitates capping of the soil surface and rain water surface runoff. The abundance, types, and forms of grasses affect the water cycling ecosystem process through evapotranspiration, volume of rainfall infiltration, and water retained in the soil or that evaporates to the atmosphere from the soil. Grass cover influences the amount of soil surface erosion and whether the mineral cycling is open or closed. Mineral cycling and availability for plant growth depend on the decomposer soil community, which requires solar energy from plant leaves and roots. Management for ecosystem services should always involve paying attention to the soil surface coverage. Where there is bare soil, there is no plant growth and so no basis for an ecosystem and functioning of the ecosystem processes. Changes in grass and herb coverage of the soil have immediate effects on the functioning of all the ecosystem processes.
Shrub or forest understorey layer	Percentage ground cover by shrubs Leaf Area Index at shrub or understorey level	The water supply in periods of no rainfall may be low if there is high evapotranspiration by shrubs. Shrubs may have deeper roots than ground-level vegetation and may thus access more soil moisture for evapotranspiration, but they may also facilitate greater rainfall infiltration. Some major crop species are shrubs, such as tea and coffee.	The abundance, types, and forms of shrubs affect the water cycling ecosystem process through evapotranspiration, volume of rainfall infiltration, and water retained in the soil or that evaporates to the atmosphere from the soil. The abundance of shrubs affects the impact of rain water on the soil surface and its infiltration. The abundance of shrubs affects the soil surface structure and its exposure to sun and wind, which determines rain water infiltration and evaporation rates. In areas exposed to overgrazing or frequent fires, there may be an increase of shrubs that are unpalatable to livestock and are fire-resistant, especially on areas of bare soil.

Aspect of vegetation structure	Possible indicators*	Consequences for ecosystem services	Relationship to ecosystem processes and management
Tree layer and canopy cover	Leaf Area Index at canopy level Percentage ground cover by tree canopy	Trees provide many provisioning ecosystem services, such as timber, fruit, fibre, resins, and fuelwood. The water supply in periods of no rainfall may be low if there is high evapotranspiration by trees. Trees have a significant influence on water supplies and flow regulation. Having and shrubs enables them to access more soil moisture for higher leaf area and deeper roots than ground-level vegetation evapotranspiration and facilitates greater rainfall infiltration. Tree growth and storage of carbon is a major component of climate regulation. Forests can impact regional rainfall patterns in some tropical regions. many aesthetic, spiritual, cultural, educational, and recreational Trees and forests have major cultural ecosystem service values, as sources of livelihoods and places to live, and they offer values.	The abundance, types, and forms of shrubs affect the water cycling ecosystem process through evapotranspiration, volume of rainfall infiltration, and water retained in the soil or that evaporates to the atmosphere from the soil. The abundance of trees affects the soil surface structure and its evaporation rates. exposure to sun and wind, which influences rainfall infiltration and Since trees have such a major influence on ecosystem structure and functioning, management for ecosystem services involving trees needs to consider both the necessary functioning of the ecosystem processes for their growth and the influence of their growth on and seed dispersal for their reproduction, so management needs to ecosystem functioning for other services. Some trees species rely on key ecological interactions of pollination provide the necessary ecosystem structure and functioning for their co-evolved pollinators and seed dispersers.
Root depth	Soil organic layer depth Abundance of deep or shallow rooted plants	The depth and biomass of plant roots will have a major influence on the growth of plants and therefore on the supply of ecosystem services that depend on plants. Plant roots can have a significant influence on the functioning of the water cycling ecosystem process. The water supply from streams and aquifers in periods of no rainfall may be low if there is low infiltration in the soil below plant root depths. The growth of plant roots is a means for sequestration of atmospheric carbon dioxide for global climate regulation. Plant roots have a major role in soil erosion control and regulation of soil quality.	Plant roots are a major part of the mineral cycling ecosystem process, as they access and transport minerals from the soil layers to the ecosystem above ground. Equally, the growth of plant roots is a means for minerals and solar energy to be transported to the soil decomposer community. The abundance, types, and forms of grasses, shrubs and trees significantly influences the soil structure through their roots. The depth of plant roots determines their capacity to reach deep soil layers and access more minerals. Management for ecosystem services involving plant growth needs to consider the requirements for the growth of the plant roots as much as the requirements of the above-ground plant.
Abundance of dead and decaying vegetation	Soil surface coverage by dead vegetation Length of time for decomposition of dead plants at the soil surface	Ecosystem services that depend on plant growth will be promoted by an active soil decomposer community that lead litter and dead plants at the soil surface enables. Regulation of water flows and water quality will be influenced by the coverage of soils by dead vegetation as well as living plants.	The abundance of dead plant matter at the soil surface is a major source of organic matter (solar energy) for the soil decomposer community, and helps to maintain soil moisture at levels suitable for bacteria and fungi. Management of livestock grazing and the use of fire should consider if there is sufficient dead plant matter at the soil surface for the desired ecosystem functioning.

* FAO has developed useful manuals on indicators and assessments of vegetation. http://www.fao.org/fileadmin/templates/nr/kagera/Documents/LADA_manuals/part2_d.pdf

3. *Herbivores* – These include domesticated and wild animals and insects. Consider the requirements of people for harvest and their use of grazing animals, herbivores' roles in grazing for desired vegetation growth and landscape value, their influence on the functioning of mineral cycling, and as prey for predators.
4. *Predators* – These include invertebrates. Consider their role in regulating the populations of desired species and pest species, as well as for any cultural ecosystem service values from the existence of predators and hunting.

Each of the four food web categories can be described in terms of the abundance of key or dominant species groups. A description of the food web structure is very similar to that of the solar energy flow ecosystem process, since the flow of energy is through the food web.

Loss of large animals alters ecosystem functioning

Estes et al. (2011) consider that the widespread loss of large-bodied predators and herbivores may 'may be humankind's most pervasive influence on nature'. They document the cascading effects of the loss of top-down influence by large predators and herbivores on food webs, resulting in transformations in the structure of ecosystems. This 'trophic downgrading' can radically alter ecosystem processes and interactions, as well as the occurrence of disease and wildfires, and cause the collapse or explosion of native and invasive species' populations.

Table 6: Aspects of food web structure, possible indicators, consequences for ecosystem services, and their relationship to ecosystem processes and management

Aspect of food web structure	Possible indicators	Consequences for ecosystem services	Relationship to ecosystem processes and management
Abundance of dominant and key decomposers	• Abundance of earthworms per square metre • Earthworm burrows and cast material (faecal) on the soil surface • Abundance of fungi • Abundance of dung beetles • Soil organic layer depth • The length of time for decomposition of leaf litter and dung	Ecosystem services that depend on plant growth require a soil decomposer community to decompose dead plant matter that would smother new growth and to liberate minerals. Fungi harvested for food are part of the decomposer community. Scavenging animals, such as vultures and foxes, remove dead animals and reduce the spread of disease. The soil decomposer community degrades animal waste products, making them harmless to humans.	Mineral cycling and mineral availability for plant growth depends on the decomposer soil community. Soil microbes and fungi require a minimum amount of moisture to be active, and so are influenced by the functioning of the water cycling ecosystem process and soil structure and cover. Management may seek to promote the soil decomposer community and mineral cycling through the availability of dead plant and animal matter (solar energy and minerals) and a favourable soil structure and coverage. This may include considerations of the timing and intensity of livestock grazing and fires.
Abundance of dominant and key plants	• [*Indicators are likely to be the same as for the vegetation structure*] • Total biomass of plants per unit area • Percentage ground cover by grasses and by other plants • Leaf Area Index at ground level • Percentage ground cover by shrubs • Leaf Area Index at shrub or understorey level • Percentage ground cover by trees • Leaf Area Index at tree canopy level • Abundance of nitrogen-fixing plants	The biomass and types of plants will determine the supply of provisioning services from plants, the regulating services from vegetation structure and growth, and the cultural services from use and interactions with plants and vegetated landscapes. Provisioning ecosystem services from livestock depend on the availability of forage plants. Mineral cycling and nutrient availability depends on the soil decomposer community, which largely relies on the availability of plant material.	Plant growth is a determinant of vegetation structure. Management may aim to favour a particular vegetation structure for the growth of the desired species. Growth of some plants may be stimulated by the removal of leaves, increasing the capture of solar energy per unit area and the flow of energy to other parts of the food web. The greater the biomass of plants in a location, the more solar energy is available to enable a greater biomass of herbivores, predators, and decomposers. Vegetation structure and coverage of the soil will largely determine the condition of the soil surface for rain water infiltration or erosion and organic decomposition.

Aspect of food web structure	Possible indicators	Consequences for ecosystem services	Relationship to ecosystem processes and management
Abundance of dominant and key herbivores	• Population size and biomass of vertebrate herbivores per unit area • Population size and biomass of ants and termites per unit area • Population size and biomass of defoliating caterpillars per unit area	The supply of ecosystem services and functioning of the ecosystem processes of grasslands is strongly influenced by herbivory, and therefore by the abundance and movements of vertebrate herbivores. All domesticated livestock are herbivores. Wild herbivores are commonly hunted for meat and skins. Many harvested wild fish species, as well as some farmed fish, are herbivores. Particularly in forest ecosystems, many wild herbivores also disperse seeds from trees and shrubs, including fruit and timber species used by people. The production of livestock and hunting of wild herbivores are central to many cultures and livelihoods, as well as cultural ecosystem services from use and interactions with grassland landscapes and animals.	When herbivores modify vegetation structure, particularly in grasslands, this influences the water cycling ecosystem processes. Large mammal herbivores can also significantly affect water cycling through compaction of soil or breaking of capped soils with their hooves. Herbivores have a major influence on the rate and volume of mineral cycling through their waste products and trampling of vegetation. Herbivores are a central part of the solar energy flow ecosystem process, as food for predators (including humans). The abundance of herbivores will be influenced by the availability of food and water and the abundance of competitors and predators. Management for the abundance of a particular species or group of herbivores should include consideration of what they need to obtain their food and of what role they play as a source of energy for other parts of the food web, including decomposers. A population explosion of an undesired herbivore, such as rodents, crop-eating insects, or tree-defoliating caterpillars, may be the result of the population reductions of their predators.
Abundance of dominant and key predators	• Population size and biomass of vertebrate predators per unit area • Population size and biomass of invertebrate predators per unit area	The top-down influence of predators on food web structure and ecological interactions means that they can influence the functioning of all the ecosystem processes and the supply of all ecosystem services. Most provisioning ecosystem services are from plants and herbivores, and so their abundance can be influenced by the abundance of predators. Some predatory fishes are caught for food. Many regulating ecosystem services are dependent on plant growth and vegetation structure, which can be influenced by the abundance and behaviour of herbivores, which are influenced by the abundance of predators. Predators have a major influence on the populations of pests of livestock and crop plants. Many cultural ecosystem services are provided through hunting, tourism, and cultural identity associated with vertebrate predators, including fishes.	Particularly in grasslands, large predators can influence the functioning of water and mineral cycling processes through impacts on the abundance and behaviour of mammal herbivores and their impact on vegetation and soil structure. Growth of animals will be influenced by the availability of food and the abundance of competitors and predators. Growth of a particular species or group of animals should include consideration of what they need to obtain their food and what role they play as a source of energy for other parts of the food web, including decomposers. Management for populations of desired predators will be influenced by the availability of prey. If predator populations are reduced by human actions, whether intentionally or not, managers should consider the cascading impact on populations of prey species and the ensuing impact on vegetation structure.

Table 6 describes the aspects of food web structure, how they can be described using indicators, their consequence for ecosystem services, and their relationship to ecosystem processes and management.

Soil structure

The most important aspects of soil structure for ecosystem functioning and ecosystem service supply are:

ff whether the surface is bare or covered with vegetation,

ff whether the soil surface has formed a hard cap that is resistant to water and air flow, ff the depth of the organic layer, and

- the soil crumb structure (aggregated soil particles held together with 'glue' provided by decomposing organic matter) – the space around each crumb provides room for water and air, and this in turn promotes plant growth and organic decomposition.

Table 7 describes the aspects of soil structure, how they can be described using indicators, their consequence for ecosystem services, and their relationship to ecosystem processes and management.

Table 7: Aspects of soil structure, possible indicators, consequences for ecosystem services, and their relationship to ecosystem processes and management

Aspect of soil structure	Possible indicators	Consequences for ecosystem services	Relationship to ecosystem processes and management
Condition of soil surface	• Percentage ground cover by plants (grass, forage) • Leaf Area Index at ground level • Soil surface coverage by dead vegetation • Length of time for one litre of water poured on the soil to drain away • Ease of soil penetration with a knife or stick • How long the soil remains moist after rainfall	The water supply from streams and aquifers in periods of no rainfall may be low if there is low infiltration in the soil below plant root depths. The supply of ecosystem services from plant growth may be limited by a lack of soil water and erosion of soil.	The condition of the soil surface for rain water infiltration, erosion, and organic decomposition will be determined largely by the vegetation structure and coverage of the soil. The presence of large herbivores may have a significant effect on vegetation structure and thus soil condition. The abundance and movements of large mammal herbivores can also significantly affect the soil surface and water cycling by compacting soil or by breaking of capped soils if the animals are running (e.g., to avoid predators). If there are areas of bare soil, this increases the range of temperature variations experienced by the microbial soil community and so slows organic decomposition, and also increases evaporation of soil moisture.
Depth of organic soil layer	• Soil organic layer depth. • Abundance of nitrogen-fixing plants. • The abundance and growth rate of deep or shallow rooted plants.	The supply of ecosystem services that require plant growth will be influenced by the availability of minerals and water retention in soils, which is very dependent on the depth of the organic matter soil layer.	The depth of the organic soil layer is a major factor in the functioning of the water and mineral cycling ecosystem processes and the structure of the soil decomposer community. The depth of the organic soil layer can be improved by increasing the availability of dead plant matter, such as leaf litter and crop wastes, and animal wastes from grazing or compost.
Soil crumb structure	• Length of time for one litre of water poured on the soil to drain away • Ease of soil penetration with a knife or stick • How long the soil remains moist after rainfall • The abundance and growth rate of deep or shallow rooted plants	Both the supply of ecosystem services dependent on plant growth and water-related ecosystem services are greatly influenced by whether soil crumb structure is favourable for plant root development and water infiltration and retention.	The condition of the soil crumb structure for rain water infiltration, plant growth, and organic decomposition will largely be determined by the vegetation structure and coverage of the soil. The presence of large herbivores may have a significant effect on vegetation structure and thus soil condition. The abundance and movements of large mammal herbivores can also significantly affect the soil surface and water cycling by compacting soil or by breaking of capped soils if the animals are running (e.g., to avoid predators). Soil crumb structure is influenced by the abundance of dead and living plant matter at the soil surface, which determines the availability of organic matter and moisture for soil decomposers and plant growth.

2.10 Key ecological interactions

Central to the concept of an 'ecosystem' is that there are interactions between organisms and their environment which result in system properties. The functioning of ecosystem processes is influenced by ecosystem structure and vice versa, and this relationship is determined by ecological interactions.

There are several types of ecological interactions between species and individual organisms in an ecosystem, but when describing necessary ecosystem functioning for specific ecosystem services, it is usually possible to determine some key species and interactions. For management, the aim is to identify and promote *the key types of ecological interactions and species groups that determine how the ecosystem processes work and the ecosystem structure for the desired services*.

Major types and examples of ecological interactions that can greatly influence the functioning of ecosystem processes and the ecosystem structure include:

1. Herbivory – e.g., herbivorous mammals and termites eat grasses in grasslands; birds and small mammals eat seeds of grasses and trees.
2. Predation – e.g., large-bodied carnivorous mammals influence the abundance and behaviour of herbivorous mammals and small-bodied carnivores.
3. Decomposition – e.g., soil invertebrates and microorganisms decompose dead vegetation.
4. Pollination – e.g., insects and birds (and to a lesser extent, mammals, including bats) pollinate flowering plants in grasslands and canopy trees in forests.
5. Seed dispersal – e.g., insects, birds, and mammals disperse seeds of pioneer and canopy trees.

Key species composition

The description of ecosystem structure and key ecological interactions will enable the identification of which species are ‘key’ in generating the structure and interactions. A guiding question for identifying key species is:

Are there key species whose growth is required for the desired ecosystem service(s)?

It may be easiest to first identify the dominant species for the vegetation structure that is required for the ecosystem service(s), then identify the key species for the food web structure and key ecological interactions.

2.11 Spatial and landscape considerations in management for ecosystem services

The supply of ecosystem services in an area is a result of not only the condition of ecosystems but also their extent and spatial configuration within a landscape. Understanding the spatial aspects and scales over which ecosystem services occur is essential to developing landscape-level conservation and land management plans. For example, water-related ecosystem services such as flow regulation and water provision vary spatially according to topography and vegetation structure, and ecosystem management actions in the upper parts of a catchment have an impact on ecosystem service supply downstream.

Scale

A key spatial consideration in management for ecosystem services is the scale over which they occur, which varies from a farmer’s field to a water catchment or region for different ecosystem services. Since ecosystem services are a result of ecosystem functioning, the scale at which these services occur depends on the scale at which the ecosystem processes are functioning. The supply of provisioning ecosystem services depends at first glance on just the spatial location of the ecosystem structure that provides the services, such as crops for food or trees for timber. However, some of the ecosystem processes and ecological interactions on which the structure depends are likely to operate at a wider spatial scale. For example, crop production may depend on water flows and therefore on the functioning of the water cycling ecosystem process in forested parts of the wider landscape. Similarly, crop pest control by birds and pollination by insects probably also require forested areas in the wider landscape. Planning for the supply of ecosystem services should include an assessment of the combination of land uses and habitats for all aspects of ecosystem functioning.

The supply of water-related ecosystem services is particularly dependent on the spatial and scale aspects of ecosystem distribution and structure. The functioning of the water cycling ecosystem process has a nested scale dimension, through the scales of:

- the form and growth of each individual plant,
- the vegetation composition and structure at the scale of a farmer’s field or a forested slope, and

- the cumulative effect of land uses and ecosystem types over a catchment and their wider influence on downstream water flows.

The influence of the mineral cycling ecosystem process on the supply of ecosystem services such as regulation of soil quality may seem to be generally limited to smaller scales such as fields. However, daily and seasonal management of the spatial movements and density of livestock can have major impacts on soil quality, through changes in soil compaction and quantities of dung. Farmers may collect forage from forests for stall-feeding of livestock, as well as firewood from forests, and in effect be transporting minerals and solar energy from one ecosystem to another. If compost is made from the dung of stall-fed animals and cook stove ash, then the application of this compost to fields is a further spatial movement of minerals.

In addition to considerations of scale within an area being managed, ecosystem interactions, flows, and linkages outside the area should be acknowledged. This could include the flows of water, the seasonal migrations of livestock or wild animals, or management of habitat for animals with large ranges. This is particularly important for cross-boundary collaboration.

Trade-offs and synergies

While management interventions can enhance the output of some services, in some situations not all services can be delivered or improved simultaneously. These ‘trade-offs’ can change the type, volume, and mix of services delivered by an ecosystem and they often have a spatial dimension. All the services from a location come from the same ecosystem processes, structure, and interactions, so trade-offs in the biophysical supply of services are in effect trade-offs in these aspects of ecosystem functioning.

For example, planting trees on slopes with little vegetation may increase the regulating ecosystem services of soil erosion and water flow control, but decrease the area available for the provisioning service of forage for livestock. Trade-offs can also occur within measures to increase an ecosystem service. For example, planting trees to increase infiltration of water also increases the water use by the vegetation, so there may be little or no net gain in water supply, although other services such as erosion control may have increased. For example, in seasonally dry tropical areas of Africa, optimum recharge of groundwater by rainfall occurs at intermediate tree cover density, due to trade-offs between surface runoff and transpiration by vegetation at very open or closed vegetation densities (Ilstedt et al. 2016).

Figures 13 and 14 illustrate some spatial considerations for management of water and mineral cycling ecosystem processes and related services in a mountain landscape. Further guidance on assessing the role of vegetation on water cycling and flows in the tropics is provided by Ponette-González et al., (2015).

The EcoAgriculture partners publication, ‘Spatial Planning and Monitoring of Landscape Interventions: Maps to Link People with Their Landscapes: A Users Guide’, provides steps on producing and using maps with stakeholders in landscape planning, and complements the management for ecosystem services approach in this Manual. It is available at http://ecoagriculture.org/publication/a-landscape-perspective-on-monitoring-evaluation-for-sustainable-land-management/spatial-planning-and-monitoring-of-landscape-interventions-maps-to-link-people-with-their-landscapes/

Figure 13: Spatial considerations for management of water cycling and water-based ecosystem services in a mountain landscape

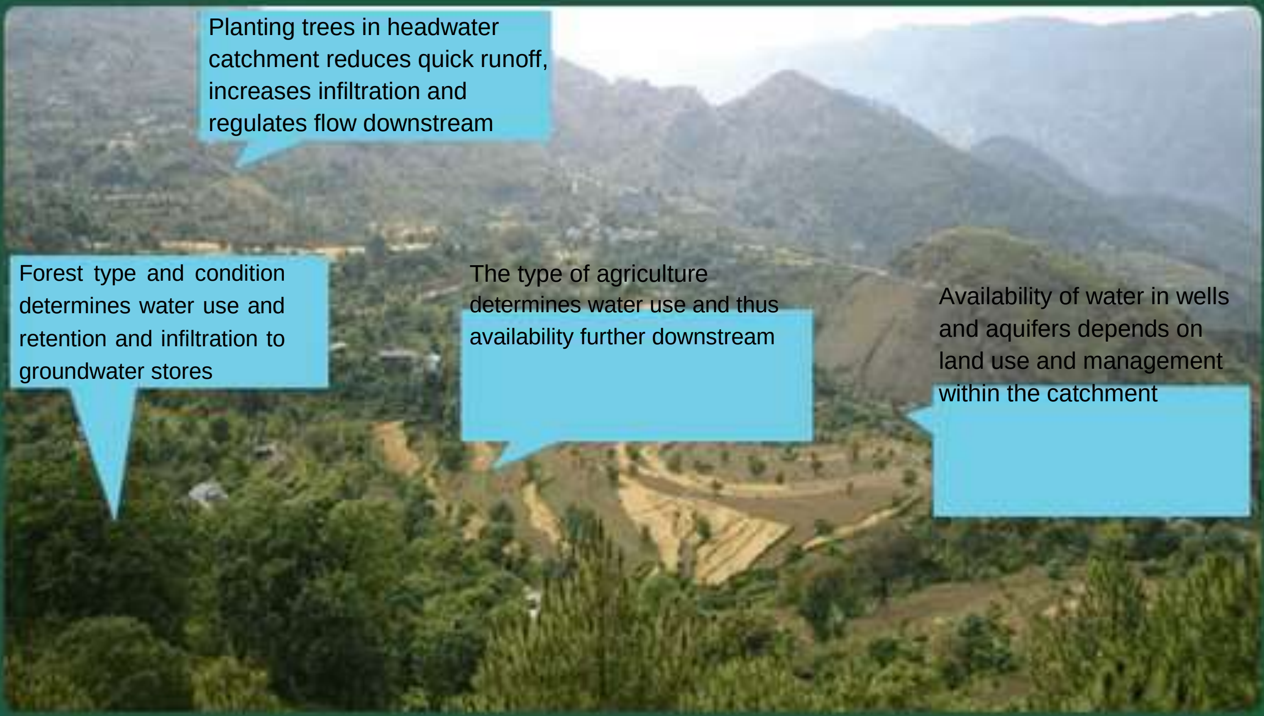


Figure 14: Spatial considerations for management of mineral cycling and related ecosystem services in a mountain landscape.

3. Six Steps in Planning Management for Ecosystem Services

This section of the Operations Manual explains six steps that are recommended in planning management for ecosystem services. The names of the steps are presented in Figure 15 and the main actions for each step are summarised in Figure 16. This chapter then gives guidance on how to conduct each step. It is necessary to read Section 2, 'Key concepts and knowledge for describing and working with ecosystem functioning', before being able to understand and use the approach in this section.

Figure 15: Steps in planning management for ecosystem services

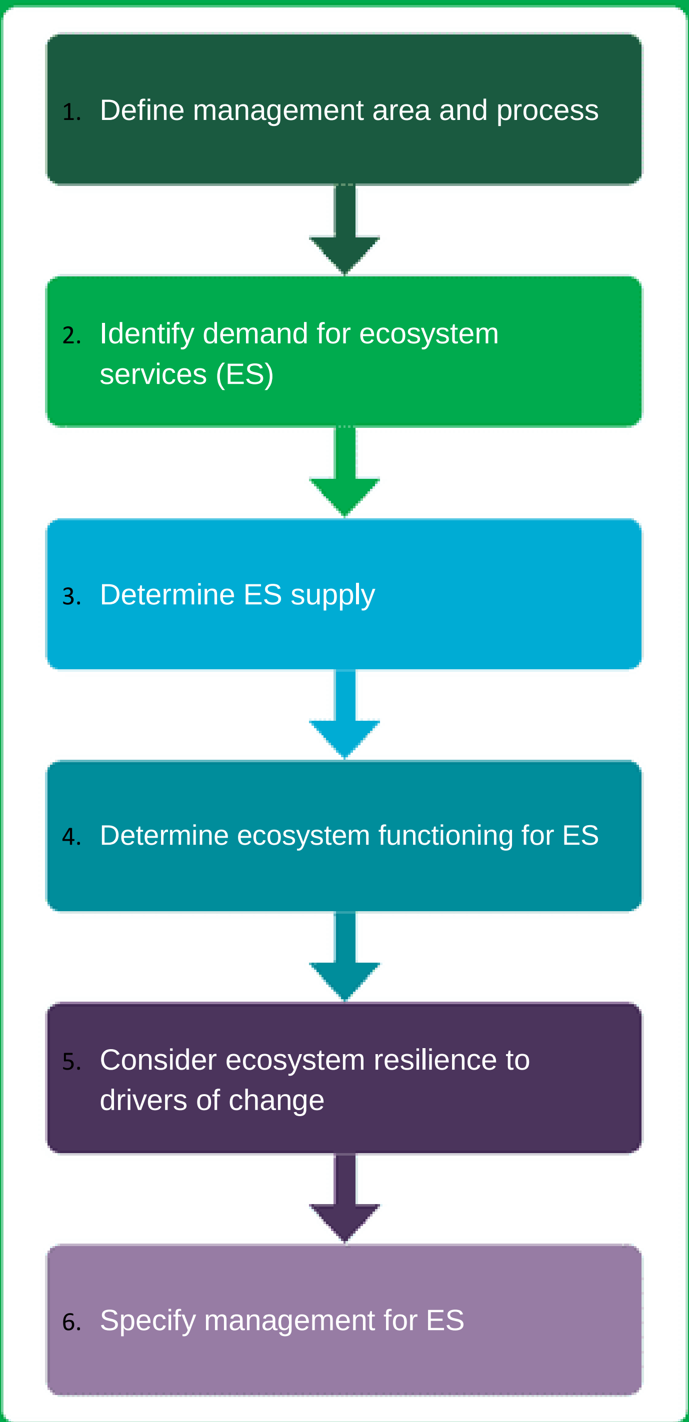
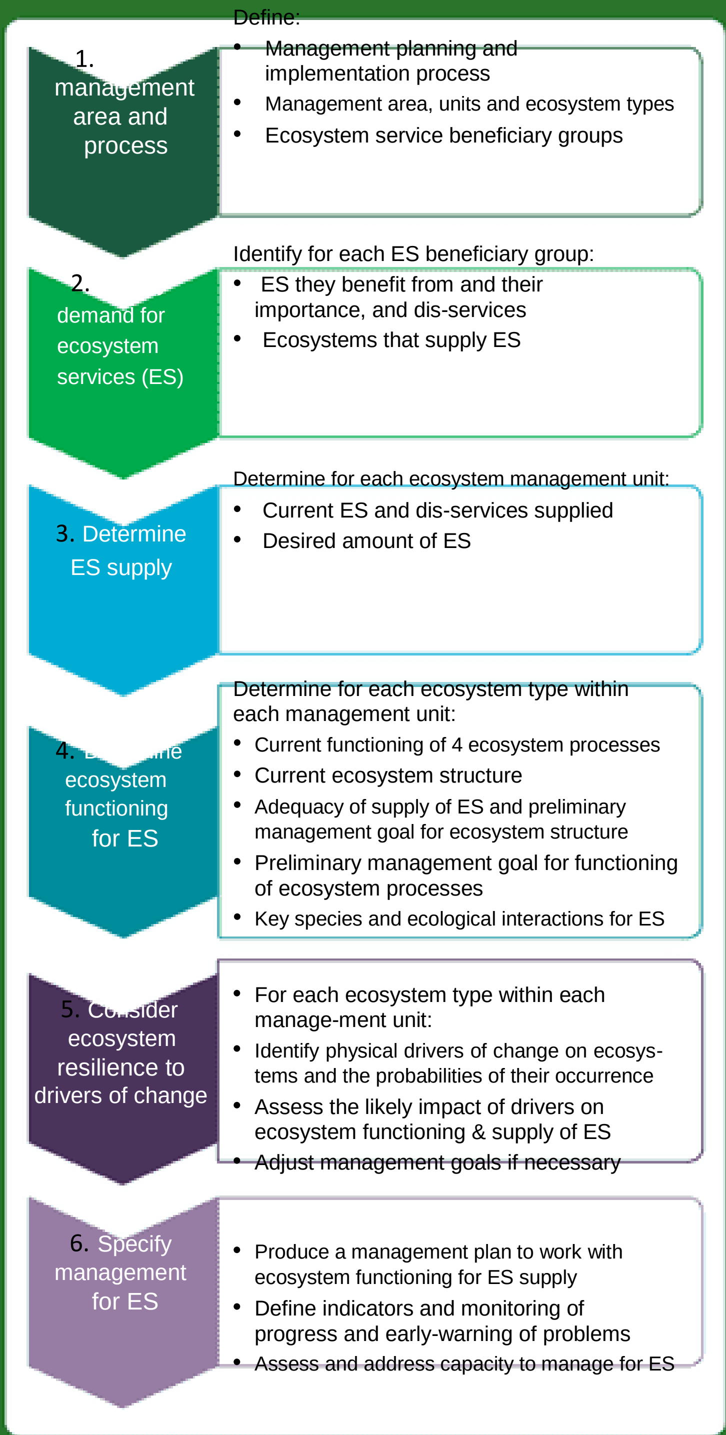


Figure 16: Steps and actions in planning management for ecosystem services



Step 1: Define management area and process

1. Define management area and process

Define:

- Management planning and implementation process
- Management area, units and ecosystem types
- Ecosystem service beneficiary groups

This Operations Manual helps people and institutions that manage the natural environment to include management for ecosystem services based on ecosystem functioning in their objectives and actions. Management is a pro-active process and this Manual supports the definition of objectives and plans, the implementation of activities, the monitoring of results, and the adaptation of plans and activities as necessary. A management plan document is a key tool for this process, so an example structure of a management plan is included in Annex 2 as a template that can be adapted as required. A workbook to guide documenting the results of each of the steps is included in Annex 3.

A management process for an area could be established with the specific aim of ensuring the supply of desired ecosystem services. In many cases, though, existing management of an area will include objectives which do not use the term ecosystem services, but which in fact do include this concept using other words. For example, a farmer may have objectives and plans to produce food and products for sale, or there may be a village plan for use of common forest resources, or a district land use plan, or a state-owned protected area for biodiversity conservation including ecotourism. In all of these cases the management objectives for an area may be widened and strengthened to include the supply of a suite of ecosystem services. This is desirable not only because more benefits may be obtained from an area, but because management will be more sustainable when it is based on understanding the environment as an ecosystem and the ways in which people can work with it to supply goods and services.

a) Define the management planning and implementation process

The first step in planning management for ecosystem services is to define the area being managed and the management planning and implementation process. Management for ecosystem services will always be management of a particular place for a particular group of people.

The definition of the spatial boundaries of the management area will be determined to a great extent by the access or tenure rights to the area. For example, the management area boundaries and process for an individual farmer who owns the land will be different from those for a village's communal grazing or forest land or for a district land use or water resources plan. Management planning may even be for transboundary areas and so involve different countries. Access and tenure rights to land and natural resources may be well-defined through cultural as well as legal controls.

Whether a new management process is being established explicitly for ecosystem services, or the concepts of ecosystem services and functioning are being integrated into existing management mechanisms, the management process needs to be defined. The stakeholders in the area being managed need to be defined. Primary stakeholders are the people and institutions who have decision-making power or authority to: ff set management objectives and plans,

ff choose the actions to be followed, and

ff manage the implementation of the actions.

It is useful to make a distinction between managers and users of an area. Managers are the people and institutions that intentionally make decisions and act to alter the area for particular aims. Users harvest products or visit the area, but they do not have decision-making power, although they may be important stakeholders in management planning. Users could also be called secondary stakeholders in the area.

The definition of the management planning and implementation process should describe the mechanism for making decisions about the use of the area, such as a village committee or district-level government planning body. This definition should identify the managers with decision-making power and the users who should be consulted and informed. Successful management planning has to be a participatory process with all key stakeholders, seeking equitable involvement of all groups.

b) Define the management boundaries, units and ecosystem types

A management plan needs to have a description of the area being managed, including its location, boundaries, area, land uses, and ecosystems. The plan also needs to define the management units, which are the separate areas for which management objectives will be defined. Management units should ideally contain just one ecosystem or land use type, such as agricultural or grazing land, forest, or wetlands. The boundaries of a management unit will be determined partly by who has ownership or management rights of the area and partly by the boundaries of the ecosystem or land use type. The management units should be logical areas for planning and carrying out management decisions.

This information is best presented in the form of maps and data tables. The categories of land uses and ecosystems can follow the existing terms used by local people and government agencies.

c) Define the ecosystem service beneficiary groups

Whether people use an area to sustain their livelihoods or simply to visit, both could be termed ecosystem service beneficiaries. Management planning should identify the groups of ecosystem beneficiaries so that their needs and interests for ecosystem services can be considered in the next planning step.

Ecosystem service beneficiaries include people anywhere who may benefit from the services from a particular ecosystem. For example, people in lowland cities may benefit from water and forest products from a highland area. Ecosystem service beneficiaries may even be located in other countries or continents if goods are exported and if climate regulation services are considered.

The identification of ecosystem beneficiary groups may follow the existing classifications of people or social groups in use by local people, development agencies, or government departments. Such categories could be established according to livelihood strategies, social class, gender or age-based roles, or by external institutions and groups that benefit from the ecosystem services in the location.

The number of people or households within each ecosystem beneficiary group should be estimated.

Step 2: Identify demand for ecosystem services

2. Identity demand for

Identify for each ES beneficiary group:

- ES they benefit from and their importance, and dis-services
- Ecosystems that supply ES

The overall aim of ecosystem management can best be described as modifying and using land and water resources to improve the well-being of people. Therefore, in planning for ecosystem management, it is necessary to define the needs and demand for ecosystem services that management should aim to satisfy on a sustainable basis. For example, management's goals could be to obtain food, fuel, and products to sell, as well as for more intangible aims such as personal satisfaction or community status.

a) Identify for each ecosystem service beneficiary group the services they benefit from, their importance, and dis-services

For each group of ecosystem service beneficiaries their dependence on ecosystem services can be assessed in a general manner, considering the contribution of ecosystem services to aspects of their well-being. There are many ways of categorising people's well-being, and the choice of a classification for this step may well follow existing descriptions in use by the management planners. The following MEA categories (MEA, 2005) for well-being may be a useful classification (but the use of other classifications is equally valid): ƒƒ basic material for adequate livelihoods;
ƒƒ basic material for sufficient nutritious food;
ƒƒ basic material for shelter;
ƒƒ security from disasters;
ƒƒ health – strength;
ƒƒ health – feeling well.

For each ecosystem service beneficiary group, the current importance of each type of ecosystem service to their well-being can be estimated as:
ƒƒ essential,
ƒƒ very important,
ƒƒ slightly important, or
ƒƒ unimportant.

The list of ecosystem services in Annex 1 can be used to help with this step. All the provisioning, regulating and cultural services that are at least slightly important should be recorded, along with the reason for their importance. The descriptions or names used for the ecosystem services should give some detail, such as specific crops or tourism to the forest and farm landscape by people from nearby cities, rather than just generic categories such as food or recreation. This enables an adequate description of the ecosystem functioning for these services. For describing cultural ecosystem services it is useful to define not only the benefit obtained but also the features of the ecosystem that provide the benefit, which may include a holistic perspective of the ecosystem.

The importance of each type of ecosystem service to a beneficiary group is not only a question of the group's need for and use of the service, but also whether they have access to the service and control over its supply and use. Particularly for the poorest groups, the latter issue can be more important for their well-being than the total available supply. Fisher et al. (2014) present a conceptual framework for understanding the relationships between ecosystem services and poverty alleviation.

This step may also consider likely changes that would affect the demand for ecosystem services, such as population growth, outmigration, or changes in livelihood strategies and economies.

It is also important to consider if there are ecosystem dis-services which management may wish to reduce, such as loss of crops and livestock to wild animals, or diseases transmitted by wild animals and insects.

b) Identify the ecosystems that supply the ecosystem services

For each ecosystem service that is slightly important, very important, or essential, the principal ecosystem types that supply the service, such as forest or grassland, should be determined. This information is required to determine the ecosystem service management goals for each ecosystem management unit.
An example of the results of Step 2 for a fictitious village in a mountain region of a tropical country, with forests and grasslands, is presented in Table 8.

Table 8: Example of the important ecosystem services and their sources for a fictitious tropical village

Name of Management Area: Forest village

Ecosystem Service (ES) Beneficiaries: Maize and coffee farmers

Number of Beneficiaries: 1,500

Ecosystem Services they benefit from	Importance of these ES to them and why	Ecosystems that supply the ES
Maize and beans food crops	Essential, for food	Farmland
Coffee beans	Essential, primary income	Farmland
Cattle, chickens	Essential, for food and sale in times of need	Pastureland
Timber	Essential, house building	Forest and farmland
Fuelwood	Essential, for cooking	Forest and farmland
Freshwater	Essential, for drinking, cleaning	Springs and stream in forest
Medicinal plants	Very important, for domestic use	Forest, farmland
Regulation of water flows	Very important, to maintain water supply and quality	Forest, farmland, cropland vegetation
Erosion control	Very important, to maintain water supply and quality and farmland	Forest, farmland, cropland vegetation
Sacred forest sites, such as springs	Very important, for spiritual and cultural practices	Forest and springs

Step 3: Determine the ecosystem services supply

3. Determine ES supply

Determine for each ecosystem management unit:
- Current ES and dis-services supplied
- Desired amount of ES

a) Determine for each management unit the current supply of ecosystem services and dis-services

Each management unit needs to have goals for both the desired supply of ecosystem services (this Step) and the desired ecosystem functioning for these services (Step 4).

For each management unit or ecosystem type, list the current ecosystem services and dis-services it supplies over a year and the beneficiary groups of the services, using the information from Step 2. This can be in the form of a table, as in Table 9.

Then estimate the current level and trends of the supply of ecosystem services. In producing a management plan, initially it is best to produce estimates of ecosystem services supply and trends using only readily-available knowledge of local managers. This will enable the completion of all the management planning steps quickly, so managers will have a preliminary plan. Doing so will permit identification of any issues and locations that require more detailed quantitative measurements and analyses.

The measures of ecosystem services supply will be different for provisioning, regulating, and cultural services. Since provisioning ecosystem services are physical goods, it is necessary to estimate both the stock and the harvest rate, in order to have information on sustainable harvest levels. As provisioning services are already the conventional focus of management of the environment, knowledge of their supply and harvest levels is likely to exist. Regulating services are mostly measured in terms of flow rates, as they are measures of the consequences of ecosystem processes such as water cycling. Cultural ecosystem services arise from the interactions of people with the natural environment, so their 'supply' can be estimated by the desirable features of the environment, or ecosystem structure, for these services.

b) Determine the desired amount of ecosystem services supply

Management goals for the desired ecosystem services supply are determined not just in response to the demand of the beneficiaries, but also on the basis of what is biophysically possible for the ecosystem to sustainably provide. For this Step in management planning, begin by proposing individual goals for each type of ecosystem service. These preliminary goals are then revised in Steps 4 and 5, as they provide an understanding of where conflicts occur in the ecosystem functioning that supplies the services.

Not only are there trade-offs in the supply of different ecosystem services, there are also likely to be some potential conflicts and trade-offs between beneficiaries in their access to services. The book *Sharing Power* (Borrini-Feyerabend et al., 2004) is recommended for guidance on social consultation and the decision-making process for community and government management of natural resources.[7]

Another consideration in determining ecosystem service supply is whether objectives should be for a minimum level or an ideal level. This may depend on what is physically possible for the conditions of the ecosystem and trade-offs between services and beneficiaries.

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7 https://www.iucn.org/about/union/commissions/ceesp/ceesp_publications/sharing_power.cfm

Completion of this Step will result in a description of the existing management objectives for an area, but these objectives may be expanded or modified after consideration of the full range of ecosystem services and beneficiaries.

Table 9: Illustration of important ecosystem services and desired supply for a fictitious tropical mountain forest management unit

Ecosystem service	Beneficiaries and importance of the ES to them	Current ES supply and trend (stock and harvest rate, flow, or ecosystem property)	Desired sustainable supply (harvest rate, flow, or ecosystem property)
Timber	Villagers (Essential, house building); Town (slightly important, construction)	Stock – 300 m^3/ha Harvest rate - 30 m^3/ha/yr Trend – declining stock and harvest rate	Harvest rate - 50 m^3/ ha/yr
Fuelwood	Villagers (Essential, for cooking); Town (slightly important, construction)	Stock – 80 m^3/ha Harvest rate - 20 m^3/ha/yr Trend – declining stock and harvest rate	Harvest rate - 30 m^3/ ha/yr
Freshwater	Villagers (Essential, for drinking, cleaning); Town (very important, drinking)	Dry season streamflow - 5 m^3/sec Trend – declining	Dry season streamflow - 10 m^3/sec
Medicinal plants	Villagers (Very important, for domestic use)	Stock – 1 m^3/ha Harvest rate - 1 m^3/ha/yr Trend – declining stock and harvest rate	Harvest rate - 1 m^3/ha/yr
Regulation of water flows	Villagers and Town (Very important, to maintain water supply and quality)	Maintain a base flow of 5 m^3/sec and reduce peak flows	Maintain a base flow of 10 m^3/sec and reduce peak flows
Erosion control	Villagers and Town (Very important, to maintain water supply and quality and farmland)	Maximum erosion of 5 t/ha/yr	Maximum erosion of 2 t/ ha/yr
Sacred forest sites, such as springs	Villagers and Town (Very important, for spiritual and cultural practices)	Current spring sites maintain permanent flows.	Current spring sites maintain permanent flows.

Step 4: Determine the ecosystem functioning for the ES

4. Determine ecosystem functioning for ES

Determine for each ecosystem type within each management unit:

- Current functioning of 4 ecosystem processes
- Current ecosystem structure
- Adequacy of supply of ES & preliminary management goal for ecosystem structure
- Preliminary management goal for functioning of ecosystem processes
- Key species and ecological interactions for ES

Step 4 is to determine, for each ecosystem type within each management unit, the necessary ecosystem functioning to supply the desired ecosystem services. Ecosystem functioning is described in terms of four core ecosystem processes, the ecosystem structure, and ecological interactions. This then supports the definition of goals and management actions for ecosystem services, including the consideration of trade-offs and the impact of drivers of change (Step 5). This Step also involves an approximate assessment of whether the current supply of ecosystem services is adequate.

For this Step the term ecosystem is used to mean both an ecological system and a physical area, such as a forest or grassland. The physical management unit may be a farmer's field or an area of forest or all the forests in a region, but due to land tenure systems and past management, the boundaries of the area being managed may cut across and subdivide the ecological boundaries of ecosystems.

A summary of how to describe the functioning of the four core ecosystem processes, structure, and interactions is given in Sections 2.8, 2.9, and 2.10, with additional examples in Section 4. This knowledge can be used to determine the current functioning of the ecosystem processes of each management unit, and then the intended situation for the desired supply of each ecosystem service.

a) Determine for each management unit the current functioning of the four ecosystem processes

Setting management goals for ecosystem functioning and the desired supply of services must be based on a description of the current situation, so that any necessary changes can be identified. Table 10 is an example description of the current functioning of the four core ecosystem processes in a forest; it illustrates the use of terms and the suggested level of detail that an initial assessment of ecosystem functioning involves. Note that the description is only of the current biophysical ecosystem functioning and should not include current or desired management actions.

Table 10: Example description of the current functioning of the four core ecosystem processes for a fictitious forest ecosystem

Ecosystem process	Current functioning
Water cycling	On slopes with bare soil, rainfall causes significant soil surface runoff On areas with soil covered by vegetation and leaf litter, slow rainfall infiltration into the soil and slow penetration to underground water resources Some surface evaporation of rainfall from leaves Transpiration of water from the soil to the atmosphere through trees is high
Mineral cycling	A moderately open mineral cycle with loss of soil organic matter in heavy rainfall events, and some loss of minerals through timber and fuelwood harvesting. There is little leaching to underground water sources. Most minerals are in the organic soil and trees Fairly rapid organic decomposition of leaf litter and animal dung
Solar energy flow	Moderate capture of solar energy by trees, and moderate capture by shrubs and herb layer Some of the solar energy in plant matter is exported in timber and fuelwood; most plant energy flows to moderate populations of soil decomposers through dead leaves Low populations of herbivorous insects; low populations of insectivorous birds and mammals and vertebrate predators
Biological growth	Medium growth rate of tree species, shrubs, and herb layer Low growth rate of soil decomposers Low growth rate of herbivorous insects

Since the functioning of ecosystem processes is intimately linked to the ecosystem structure, and vice versa, the descriptions of processes and structure tend to overlap. For this reason it may be necessary to produce the descriptions of the current functioning of ecosystem processes and current structure at the same time, but for the purposes of management planning the processes should be considered first.

The descriptions of ecosystem functioning should be brief, providing a concise overview of the situation that can guide the definition of management objectives. The use of subjective terms such as low, medium, or high in categorising the situation is sufficient to provide general management objectives. The definition of what is a low, medium, or high rate of functioning of an ecosystem process will depend on the local situation and knowledge. In general, a reference for a high categorisation would be an ecosystem in a largely natural state, with a full complement of species and all levels of the food web. A low categorisation could be an ecosystem in a largely modified conditions, perhaps with little natural vegetation and very low populations of herbivores and predators.

It is desirable to further define the descriptions in quantitative terms for the final definition of management objectives and indicators of progress. The tables in Section 2.8 give possible indicators for the functioning of ecosystem processes; management goals could define minimum acceptable and desirable values for these indicators. Examples would be a minimum acceptable organic soil layer depth of 2cm and a goal of 5cm depth, or a minimum acceptable extent of bare soil in survey plots of 20% and a goal of 0%.

b) Determine for each management unit the current ecosystem structure

For this part of Step 4, it is recommended to first describe the vegetation layers because they are most obvious to identify, then describe the food web and soil structure. An example description of the current ecosystem structure of a forest is provided in Table 11.

Table 11: Example description of the current ecosystem structure of the forest of a fictitious village

Current vegetation structure	Current food web structure	Current soil structure
The tree canopy is open in most places due to the harvesting of trees. The shrub layer is thin and the herb layer covers the soil in most areas, but there is some bare soil. There is a low abundance of dead trees and plant matter.	There is a moderate abundance of decomposers in the soil. The plants are as described in vegetation layers structure. There are moderate population levels of herbivorous insects and insectivorous birds and mammals. There is a low presence of vertebrate predators.	The organic soil layer is relatively shallow; subsoil is penetrated by tree roots.

c) Determine for each management unit preliminary management goals for ecosystem structure

For each management unit the results of Step 3 are used to make an assessment of the adequacy of the current supply of each ecosystem service compared to the desired supply. This may involve the use of local knowledge and/ or models of ecosystem service supply from different land uses. At this initial scoping stage of defining management goals it is only necessary to determine if the supply of each ecosystem service is adequate or inadequate. If the supply of a service is considered to be inadequate then analysis of the reasons for this, and the needs and feasibility of management actions, can be conducted.

For each desired ecosystem service a definition is made of preliminary management goals for the desired ecosystem structure to supply these services. Table 12 is an example description of the desired ecosystem structure in a forest to supply desired ecosystem services, and further guidance on how to describe ecosystem structure in relation to ecosystem services is provided in Section 2.9.

Note how the differences in the desired ecosystem structure for the ecosystem services enables clarity about where bio-physical trade-offs between services may be required.

Table 12: Example description of the desired ecosystem structure of the forest of a fictitious village

Ecosystem service	Current adequacy of supply	Desired vegetation structure	Desired food web structure	Desired soil structure
Timber – from wild trees in the forest	Adequate	Low tree species diversity with timber species predominating Mostly closed canopy with mature trees, but some areas of regeneration. A few old trees remain as seed sources and as habitat for insectivorous and pollinating birds and bats. Shrub layer thin Herb layer covering soil and abundance of dead plant matter for soil formation.	Abundant decomposers in the soil. Plants as described in vegetation layers structure. Populations of herbivorous insects regulated by insectivorous birds and mammals. Presence of vertebrate predators to regulate populations of tree seed predators and crop herbivores.	Deep organic soil layer, and subsoil penetrated by tree roots for water infiltration and mineral cycling.
Fuelwood	Inadequate -- harvest levels are unsustainable	Low tree species diversity with preferred fuelwood species, otherwise as for timber ES.	As for timber	As for timber
Freshwater	Adequate	Closed canopy tree layer with mature trees with deep roots to assist water infiltration; the shrub layer is thin and the herb layer covers the soil.	As for timber	As for timber
Medicinal plants	Adequate	Closed tree canopy to provide shade for medicinal plants in herb layer	As for timber	As for timber
Regulation of water flows	Adequate	As for freshwater	As for freshwater	As for freshwater
Erosion control	Adequate	As for freshwater	As for freshwater	As for freshwater
Sacred forest sites, such as springs	Adequate	As for freshwater	As for freshwater	As for freshwater

d) For each management unit, determine preliminary management goals for the functioning of ecosystem processes

For each management unit, use the results of Step 3 to assess the adequacy of the current supply of each ecosystem service compared to the desired supply. This may involve the use of local knowledge and/or models of ecosystem service supply from different land uses. At this initial scoping stage of defining management goals, it is only necessary to determine if the supply of each ecosystem service is adequate or inadequate. If the supply of a service is considered to be inadequate, then analysis of the reasons for this, and the needs and feasibility of management actions, can be conducted.

For each desired ecosystem service, define the preliminary management goals for the functioning of the core ecosystem processes to supply these services. Table 13 is an example description of the desired functioning of the ecosystem processes in a forest to supply desired ecosystem services. Note how the differences in the desired functioning of the ecosystem processes for the ecosystem services enable clarity about where trade-offs between the supply of services may be required.

e) Determine the key species and ecological interactions for the desired ecosystem structure and processes

- Review the descriptions and preliminary management goals of the desired ecosystem processes and structure to identify any key species for the desired ecosystem functioning. Such species could be timber or crop species, or grass or other food species, or threatened or culturally important species.
- For these favoured or ecologically key species, identify the ecosystem conditions and ecological interactions which are particularly influential on their populations, such as the abundance of predators or the presence of pollinators. There may be situations where such key ecological interactions are the result of coevolution between

Table 13: Example description of desired functioning of the four core ecosystem processes for a fictitious forest ecosystem

Desired functioning of ecosystem processes for ecosystem services

Ecosystem service	Current adequacy of supply	Desired water cycling	Desired mineral cycling	Desired solar energy flow	Desired biological growth
Timber – from wild trees in the forest	Adequate	Rainfall produces very little soil surface runoff, with some surface evaporation from leaves and mostly infiltration into the soil, and slow penetration to underground water resources. Transpiration of water from the soil to the atmosphere through trees is high.	A mostly closed mineral cycle, with most minerals in the organic soil and trees, and little leaching to underground water sources. Some loss of minerals through timber harvesting. Rapid organic decomposition of leaf litter and animal dung.	High capture of solar energy by trees, moderate capture by shrubs and herb layer. Some export of solar energy in plant matter as timber, some flow to low populations of herbivorous insects, but the majority of plant energy flows to abundant decomposers in the soil. Significant populations of insectivorous birds and mammals and vertebrate predators. High populations of soil decomposers.	High growth rate of favoured timber tree species. High growth rate of soil decomposers. Low growth rate of herbivorous insects.
Fuelwood	Inadequate -- harvest levels are unsustainable	As for timber	As for timber	As for timber, except a major part of solar energy flow is exported in fuelwood, but at levels that still ensure an abundant flow of plant matter to soil decomposers.	High growth rate of favoured fuelwood species. Moderate growth rate of soil decomposers.
Freshwater	Adequate	Rainfall produces very little soil surface runoff, with some surface evaporation from leaves and mostly infiltration into the soil, and moderate penetration to underground water resources. Transpiration of water from the soil to the atmosphere through trees is moderate (due to open tree canopy and moderate tree density).	A mostly closed mineral cycle, with most minerals in the organic soil and trees, and little leaching to underground water sources. Rapid organic decomposition of leaf litter and animal dung.	High capture of solar energy by trees, moderate capture by shrubs and herb layer. Some solar energy flow from plants to low populations of herbivorous insects, but the majority of plant energy flows to abundant decomposers in the soil. Significant populations of insectivorous birds and mammals and vertebrate predators. High populations of soil decomposers.	Medium growth rate of tree species, shrubs, and herb layer. Moderate growth rate of herbivorous insects.
Medicinal plants	Adequate	As for timber	As for timber	As for fuelwood	As for fuelwood, including high growth of medicinal plants.
Regulation of water flows	Adequate	As for freshwater, except high transpiration of water from soil to the atmosphere through trees.	As for freshwater	As for freshwater	As for freshwater
Erosion control	Adequate	As for freshwater	As for freshwater	As for freshwater	As for freshwater
Sacred forest sites, such as springs	Adequate	As for freshwater	As for freshwater	As for freshwater	As for freshwater

species, such as between grasses and grazing mammals, or between fruiting trees and vertebrates that disperse their seeds.

- Revise the preliminary management goals of the desired ecosystem processes and structure to ensure that the necessary conditions for any key species and ecological interactions are included.

An example of the results of this review for the key species in the supply of ecosystem services of a mountain forest is shown in Table 14.

Table 14: Example of key species and key ecological interactions for a fictitious mountain forest

Key species	Key ecological interactions
Timber trees	Abundant soil decomposer community to liberate minerals for plant growth
Fuelwood trees	Fruit-eating birds and mammals to disperse timber tree seeds and medicinal plants
Medicinal plants	Pollinating insects and birds for reproduction of timber trees and medicinal plants
	Insect-eating birds and bats to regulate insect herbivores of desired tree species' leaves

Step 5: Consider ecosystem resilience to drivers of change

5. Consider ecosystem resilience to drivers of	For each ecosystem type within each management unit: • Identify physical drivers of change on ecosystems & the probabilities of their occurrence • Assess the likely impact of drivers on ecosystem functioning & supply of ES • Adjust management goals if necessary

When planning management of an area to supply ecosystem services at a landscape scale, the areas defined as 'ecosystems' cannot be treated as static or isolated units. Managers must consider natural drivers of change in ecosystems and unintended human drivers of change, like pollution and climate change. Management planning should determine if resilience to these drivers of change is required. For the purpose of this Manual, ecosystem resilience is defined as the ability of an ecosystem to cope with and respond to disturbance and retain its structure and functioning. There are three actions in planning management of an ecosystem for resilience:

a) Identify physical drivers of change on ecosystems and the probabilities of their occurrence

Identify any drivers of change that the ecosystems may be exposed to, of which the most widespread are:

- human-induced climate change, at the regional to global scales;
- pollution of water, air, and land; and
- the spread of invasive alien species.

When considering climate change impacts, as well as changes in climate parameters such as average temperatures and rainfall, management planning should take into account the likelihood and impacts of extreme weather events and variability, such as droughts, storms, and floods.

For any single event, the likelihood of its occurrence at a particular level or impact can be described either in terms of chance or as a return period. For example, 'a one in 100 chance of a 2m high flood in any year', or 'a once-every-100-years return period of a 2m high flood'. The estimation of the chance or probability of an event occurring can be made on the basis of historical information as well as modelling of what might occur in the future. There may be scientific data and expert capacity for this, as well as traditional knowledge.

Information on the probability of changes in average temperatures, rainfall, and snow cover is a useful start to assess the impacts of these changes on ecosystem functioning and the supply of services. However, there are likely to be other parameters of climate which have a greater ecological impact, such as number of frost-free days or length of the dry season. Which climate parameters are most significant for a particular situation will depend on the aspects of ecosystem functioning for ecosystem services identified in Step 4. For example, in a grassland, the critical climate parameters for grass growth could be total annual rainfall, periods longer than ten days without rainfall, and number of days above 12°C. The search for relevant climate projections can then focus on these critical climate variables.

The probability and impacts of pollution will be specific to particular locations and sources of pollutants, including whether they are from a point source such as a waste pipe or a non-point source such as airborne pollutants.

Invasive alien species (IAS) affect the supply of ecosystem services as they become part of and alter ecosystem structure, processes, and interactions. As with all species, IAS are favoured by particular conditions of soil, climate, vegetation, and food web structure. To assess the reasons for establishment of current populations of IAS, it is helpful to examine how current management may have unintentionally created the ecosystem conditions for the IAS. Future management and climate change may also alter the likelihood of IAS presence. Many IAS have evolved as pioneer species in disturbed ground, so management such as crop cultivation, overgrazing, and fires may promote the spread of IAS.

b) Assess the likely impact of the drivers on ecosystem functioning and supply of services

There are two different aspects or properties of a system that have been called resilience:

Resistance – One view of a resilient system is that it resists high levels of external pressure and maintains a certain state and characteristics. (Resistance is the inverse of sensitivity to a pressure.)

Ability to recover – Another view is that a resilient system has an ability to recover to its original state if it is altered by a disturbance. Ability to recover is very similar to 'adaptive capacity', which is also used in the resilience literature.

Sometimes the system components that have low resistance to external influences may have a high ability to recover their former state after disturbance. For example, in a grassland that is regularly exposed to fire, many of the grass species may burn easily (i.e., have low resistance) but also regrow quickly (i.e., high ability to recover). Managing such a grassland for species that resist fire might make it more vulnerable to substantial change in the event of a severe fire that kills species with high fire resistance and low recovery properties.

Table 15 provides a possible format for the identification and recording of the impacts of drivers of change on ecosystem functioning and services.

Table 15: Format for identification of impacts of drivers of change on ecosystem functioning and services

Important driver of change	Intensity	Probability of occurrence	Likely impact on ecosystem functioning	Likely impact on ecosystem service supply
Extreme drought	3 months duration	Once every 2 years	Water cycling Mineral cycling Solar energy flow Biological Growth Vegetation structure Food web structure Soil Structure Key Species and Ecological Interactions	

The results of Table 15 help to assess whether aspects of ecosystem functioning are particularly limiting the desired ecosystem service supply.

When assessing the impacts of a driver of ecosystem change, management planners should remember that some of the impacts may be beneficial, so management may not aim to increase resilience to them. For example, in some circumstances a flood could result in:

- recharge of underground aquifers and lake levels;
- increase in fish population; and
- deposition of silt and increased agricultural productivity.

c) Adjust management goals if necessary

If the likely impacts of drivers of change are significant, then the preliminary descriptions of management goals for ecosystem processes and structure may need to be adjusted. This should address both resistance to and ability to recover from drivers of change. The justification for alterations to objectives in order to increase resilience could be documented in a format such as shown in Table 16.

Table 16: Example description of management objectives to increase resilience to drivers of change of a forest

Driver of change	Desired ecosystem functioning for resistance to the driver	Desired ecosystem functioning for ability to recover from the driver
Extreme rainfall event	High diversity of vegetation structure from canopy, shrubs to herb layer Complete soil surface cover (vegetation and litter) Deep organic layer in soil	High production of organic matter for decomposition and mineral cycling Deep organic layer in soil High diversity of vegetation structure

To continue with the village forest ecosystem services example, this Step could result in a specification or management objectives such as:

- To increase the resistance/reduce the sensitivity of the forest to wind damage, the forest structure could be managed to avoid large cleared areas and exposed forest edges.
- To increase the resistance/reduce the sensitivity of the forest to soil erosion from high rainfall events, management will seek to maintain a good vegetation cover at the soil surface and to consider risks of erosion gullies from logging trails.
- To increase the ability of the forest to recover from severe storms, management could seek to maintain a diverse forest structure in terms of vertical vegetation layers and species composition.
- In the event of storm damage, some rapid-growth pioneer tree species may be allowed to develop, in order to provide soil cover and conditions for seedlings of slower-growing timber species.

Step 6: Specify management for ecosystem services

6. Specify management for ES

- Produce a management plan to work with ecosystem functioning for ES supply
- Define indicators and monitoring of progress and early-warning of problems
- Assess & address capacity to manage for ES

a) Produce a management plan to work with ecosystem functioning for ecosystem services supply

This is the Step when decisions are made and documented in a plan about how to alter or manage the land or management unit to supply the desired ecosystem services. In many cases, the area will already be modified by human actions or even transformed from its original state, as in the case of agricultural land cleared from forest. Decision-making on the goals, actions, and indicators for ecosystem services and functioning is a social process, which should be transparent and involve the participation of all key stakeholders.

The objectives of management will be to supply the desired provisioning, regulating, and cultural ecosystem services. The management plan will include descriptions for each management unit of the desired functioning of the ecosystem processes, ecosystem structure, and key ecological interactions. This description could include consideration of resilience to undesirable drivers of change. The description may be pictorial and will probably include maps.

The management plan may include strategies and actions for:

- management of plants and animals,
- harvesting and grazing practices,
- institutional and governance arrangements (including equity considerations),
- skills and capacity development,
- research and monitoring, and
- risks to success and how they are addressed and monitored.

An example structure of a management plan is given in Annex 2.

The supply of ecosystem services and the definition of management goals for a landscape requires consideration of the spatial relationships of ecosystems and ecosystem functioning. Section 2.11 provides a brief introduction to these issues.

The preliminary management goals from Steps 3, 4, and 5 may result in some conflicting conditions for the desired ecosystem functioning in some management units. Such conflicts need to be resolved as trade-offs in the supply of services from each management unit. The results of Step 2 will inform the prioritisation of which ecosystem services to manage for, in terms of their importance for each beneficiary group. A single description of desired ecosystem functioning for each management unit needs to be agreed to by all relevant decision-makers and stakeholders.

The physical actions and resources needed to manage the ‘ecosystem’ for the desired ecosystem services will be case specific, but Section 4 gives some guidance on working with ecosystem functioning in grasslands, forests, and agricultural lands. The actions and methods that are chosen will also be strongly determined by cultural values and conditions, as well as technological and resource options. In some cases, general policies and guidelines for management, as well as site-specific plans, may need to be developed.

b) Define monitoring and indicators of progress and early warning of problems

Why monitor?

Effective ecosystem management has to be conducted in the manner of adaptive management. This means carrying out monitoring to intentionally gather information on the results of management, to identify and address early-warning signs of problems, and to learn more about the ecosystem and socio-economic environment and how to work with them. The results of this monitoring also provide evidence of progress, which can be used to gain external support and investment for management of the area.

Definition of monitoring

Monitoring can be defined as:

> '*The collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective*' (Elzinga et al. 2001).

Therefore, in management for ecosystem services, monitoring is carried out to determine progress towards the objectives of desired ecosystem functioning and supply of ecosystem services.

Selection of indicators

What is actually measured for monitoring may be a direct measure of the subject, such as tree density for standing timber supply. In many cases, however, it will not be possible to directly see or measure an aspect of ecosystem functioning, such as the rate of flow of water or minerals through plants and soils, but an indicator of this can be measured. For example, the percentage of bare ground in a grassland is an indicator of the functioning of the water and mineral cycling ecosystem processes.

The selection of indicators should take into account the criteria or desirable features of being:

- Effective – What is being measured should be an effective indicator of the status or functioning of the subject of interest, and it should be responsive to change in that subject within an appropriate timescale for management decision-making.
- Achievable – The indicator can be measured with the resources and tools available.
- Easy to understand – The conceptual relationship between what is being measured and the subject of interest is easy to understand for the managers or other users of the information. Similarly, how the indicator result is presented and explained should be appropriate for the users.

The management plan for each management unit should include indicators for the desired ecosystem functioning of the ecosystem processes, ecosystem structure, and key species and ecological interactions. Equally, these indicators may be used to provide early warning of problems in ecosystem functioning. In Section 2, the tables of the different aspects of ecosystem functioning include possible indicators, which can be used as a starting point for the selection of appropriate indicators. Section 4 also gives guidance on key aspects of ecosystem functioning and structure for management of grasslands, forests, and agricultural lands. This information can assist in the identification of indicators for monitoring.

There are potentially many aspects of ecosystem structure and functioning which could be monitored with indicators, but monitoring for adaptive management should not attempt to describe the general ecology of the area or measure things that may merely be of interest. It is only necessary to regularly collect information on a few key aspects of the ecosystem which are major components of the desired ecosystem structure and functioning, as well as the focus of management actions. These key aspects include the status of key species and key ecological interactions identified in the management plan. Similarly, the choice of indicators should seek measures of ecosystem functioning which respond rapidly to management actions. For example, the coverage of bare soil or the abundance of soil invertebrates can change within a season, but changes in the abundance of large animals or the growth rate of trees may not be evident for a few years.

Monitoring and research

A monitoring programme as part of adaptive management needs to produce sufficient information to guide decision-making and actions. However, such monitoring should not be confused with research studies that are designed to establish why something is happening (i.e., to test a hypothesis) or to monitor long-term environmental change as part of scientific assessments (e.g., vegetation composition and climate change). If monitoring for management detects a problem, but the cause is not known, it may then be necessary to conduct research and further data collection.

Some of the field methods and scientific principles of monitoring for management may be used in research, but their purpose is different. In particular, research methods may often need to be more detailed, sensitive, and scientifically rigorous than those required for adaptive management. For example, it may be adequate for management to measure the percentage of bare soil in a grassland by periodically walking a transect and making estimations by eye of bare soil in quadrats. This would indicate if the desired vegetation coverage is being achieved. For long-term research and monitoring of the effects of climate change on grassland vegetation, the use of permanent plots and more intensive methods of recording vegetation composition may be necessary.

ICIMOD has developed an interdisciplinary implementation framework for Long-Term Environmental and Socio-Ecological Monitoring (LTESM) in transboundary landscapes (Chettri et al. 2015). This focuses on improving understanding of spatial and temporal changes to the biodiversity and ecosystems of the Hindu Kush Himalaya, the drivers of these changes, and the consequences of these changes on human well-being in the region. Some of the LTESM survey methods and results may be useful for site-specific management decision-making, although planners need to consider the different purposes and scales of interest of LTESM.

Data collection and recording

The selection of indicators of ecosystem functioning and services in the management plan also needs to consider the feasibility of the data collection methods and to define these methods. Tucker et al. (2005)[8] provide guidance on the steps in the design of a biodiversity monitoring programme, which are also relevant to ecosystem management and monitoring. These steps are summarised in this section.

The design and implementation of monitoring for management should be appropriate and practical for the people who work with and manage the area, and should not be dependent on outside experts. The ANSAB guidance on 'Participatory Biodiversity Monitoring in Community Managed Forests'[9] in Nepal includes six stages in the establishment of a community-based biodiversity monitoring system, including methods and sample formats, and is highly relevant to management for ecosystem services.

Review existing data and methods – There may be previous or current monitoring programmes or surveys with relevant data and methods, which could provide baseline and trend data, as well as knowledge of relevant methods.

Define the geographical area to be monitored – Is the whole area under management to be monitored, or a sample area, or key areas for important features such as key habitat for rare species?

Assess available monitoring resources and budget – Monitoring needs to be repeated and carried out consistently over time to be useful, and so needs to be affordable and sustainable in its requirements for people's time, expertise, equipment and transport, and funding.

Determine the monitoring frequency – The likely rate of change in each indicator as a result of natural events and management should be estimated, to decide how often monitoring visits should be carried out. For example, it may be appropriate to visit a forest without management interventions once a year to assess ecosystem functioning, but a grassland with livestock grazing may need to be visited weekly to monitor for evidence of overgrazing.

8 https://archive.org/details/guidelinesforbio05gtuc

9 http://www.ansab.org/wp-content/uploads/2010/10/5.-Participatory-Biodiversity-Monitoring.pdf

Select indicator measurement methods – A key consideration is to seek the most cost-effective method that provides the appropriate type of measurement. Measurement methods may produce data that is quantitative (e.g., direct counts) or qualitative (e.g., presence or absence of a species). Consideration also needs to be made of sources of bias in the method that produce inaccurate results, such as variation in observer skills or in the detectability of species. How the data will be analysed and communicated also needs to be decided at this step, in order to ensure that the field measurements are suitable for this purpose.

Establish the appropriate time to carry out surveys – The time of day and season when monitoring is conducted will depend on the subject and the indicator, including considerations such as seasonal and daily variation in the detectability of species, and the need for repeat surveys to be done in the same conditions.

Devise a sampling scheme – In some situations it may be desirable and possible to measure the full extent or population of a subject, such as vegetation extent from remote sensing information. In many cases, it may be most efficient or even the only option to survey samples of the subject and then make extrapolations from the observations. The design of a sampling scheme includes deciding if the sample locations should be permanent or temporary, the positioning of sampling units, and the number of samples.

Devise data recording forms and document methods – Survey forms help to ensure that all necessary data are consistently collected and not forgotten. A monitoring protocol should document the measurement methods and sampling scheme, to promote consistency of subsequent surveys.

Test methods – It is highly recommended to test proposed monitoring methods before their final adoption, to ensure their feasibility and refine their design.

Produce a monitoring work plan – Resources, plans, and responsibilities need to be agreed upon for carrying out the surveys, analysis of the data, communication of the results, and storage of the data.

c) Assess and address capacity to manage for ecosystem services

It is necessary to determine if there is sufficient management capacity to carry out the management plan. For each category of manager of the area, their capacity to implement management for ecosystem services can be analysed in terms of:

- Knowledge – Do they have the necessary information on ecosystem functioning, services, and management impacts?
- Understanding – Do they have the necessary understanding of the environment and their relationship with it, in terms of ecosystems, ecosystem functioning, and services?
- Goals and objectives – Do their aims include management for ecosystem services with an understanding of ecosystem functioning?
- Values – Do they value learning new approaches, collaboration, and adaptive management?
- Methods and tools – Do they have the necessary methods and tools for planning and management for ecosystem services?
- Skills – Do they have the necessary abilities to conduct management of land and water resources with ‘ecosystem thinking’?
- Resources – Do they have the resources to implement their management decisions, such as money, political influence, or people to work with?
- Access – Do they have adequate and secure access or tenure for land and water resources?
- Institutional structures – Are the organisations and mechanisms for making decisions and implementing actions effective or suitable for ecosystem management?

4. Management for Ecosystem Services in Grasslands, Forests, and Agricultural Lands

This section provides guidance on the specific ecosystem functioning that management may seek to promote for the ecological characteristics of grasslands, forests, and agricultural lands. It is intended in particular to support the determination of current and desired ecosystem functioning for ecosystem services (Step 4) and the specification of management actions (Step 6). For each ecosystem type there is a diagram of the major components of ecosystem structure, ecological interactions, and their influence on the ecosystem processes. The principal ecosystem services supplied are identified, along with the key aspects of ecosystem functioning and management considerations. Common management problems are also explained in terms of ecosystem functioning.

4.1 Management of grasslands for ecosystem services

Summary of key aspects of ecosystem functioning in managing grasslands for ecosystem services

Figure 17 represents the major components and interactions to be considered in managing grasslands for ecosystem services. The timing and intensity of livestock grazing (herbivory) is the most significant aspect of ecosystem functioning that management of grasslands can influence. The climate, topography, and soil types are also major determinants of grassland vegetation, but they cannot be altered by management. The abundance and types of herbivores, and especially the frequency and timing of their grazing, is a major factor in determining the structure and growth of grass. Equally, the abundance and growth of the herbivores, including domesticated livestock, is dependent on the biomass and growth of palatable plants. For management for water-related ecosystem processes, grazing and animal hooves affect the grass and soil structure, and particularly the amount of bare soil, and so influence the functioning of the water cycling ecosystem process.

Overgrazing occurs when plant leaves that are regrowing from an earlier grazing event are grazed again at a rate faster than the plant can recover from. Overgrazed plants, and areas of bare soil where plants have died, result in less capture and flow of solar energy in the ecosystem, and thus reduced functioning of the other ecosystem processes and less supply of ecosystem services. Overgrazing may also result in insufficient leaf litter to cover bare soils, as well as reduced rates and volumes of the mineral cycling ecosystem process.

Management of grazing and the impact of hooves on soil structure are also major determinants in creating ecosystem functioning conditions that favour or discourage the growth of unpalatable plants.

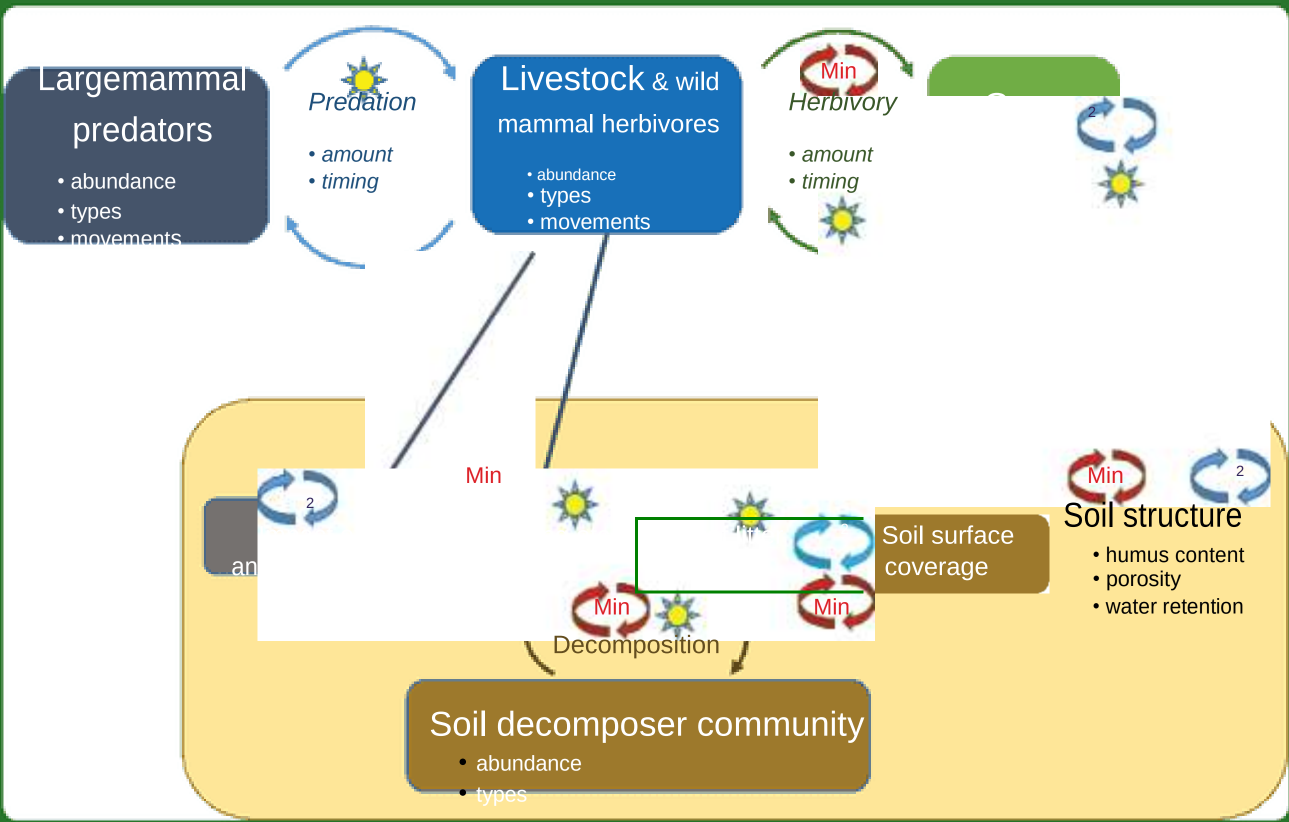
In grasslands, the growth of vegetation and abundance of herbivores is more likely to be limited by the functioning of the water cycling ecosystem process than the functioning of the mineral cycling ecosystem process.

Definitions and Categories of Grasslands

Grassland ecosystems in mountain regions may be either natural or human-derived. In alpine regions, above the treeline, grasslands are often the predominant ecosystem type up to about 4,500 masl (Rawat, 1998). A defining feature of grasslands is the dominance of grass species and forbs, typically forming a closed vegetation layer over the soil surface. Equally, grasslands are characterised by populations of herbivores, whether they are insects, or small or large mammals.

Grasses may be annual or perennial in their life cycle and form a close sward or tussocks. There may be an abundance of forbs or herb plants. Where grasslands exist due to human clearance of forests, there may be bushes or trees present, depending on management practices such as the frequency and intensity of grazing by domesticated livestock and the use of fire to clear vegetation.

Figure 17: Major components of a grassland ecosystem structure and ecological interactions.



The boxes represent major ecosystem components, the straight arrows represent major influences, and the curved arrows represent major ecological interactions. Major direct influences on the water cycling (H_2O) ecosystem process, the mineral cycling (Min) ecosystem process, and the solar energy flow (☼) are identified.

The vegetation of grasslands has co-evolved with grazing animals, so the growth of individual plants is adapted to regrow leaves eaten by herbivores, if conditions permit. Equally, the abundance of herbivores depends on the biomass and palatability of the plants.

Common Management Practices

The most common management practice of grasslands is the introduction and herding of domesticated livestock, such as cattle, horses, sheep, and goats. Livestock herding may involve simply allowing the animals to roam freely without human attendance on open rangeland, or close management and control, including in fenced pastures.

In some cases, fire may be used as a management tool to clear old or woody vegetation and promote new grass growth.

Grassland management can include seeding with grass species that are more palatable for livestock.

Harvesting of wild plants and animals rarely involves management of the habitat for these species, but there may be controls on harvest levels and timing.

Streams, rivers, and lakes in grassland ecosystem areas may be modified and used as water sources for human or livestock use.

Table 17: Principal ecosystem services from grasslands, and key aspects of ecosystem functioning and management considerations for them

Ecosystem services	Key aspects of ecosystem functioning	Management considerations
Water for drinking and livestock and irrigation	Soil surface cover by vegetation and leaf litter, and soil structure, which are affected by levels of herbivory	Livestock grazing timing and intensity, to promote desired vegetation and soil structure and coverage
Grass as fodder for livestock	Soil structure and functioning of water and mineral cycling ecosystem processes, to influence grass growth rate Levels of herbivory that affect over- or under-grazing of grasses and promote mineral cycling	Livestock grazing timing and intensity, to avoid overgrazing and promotion of unpalatable species Fire management to avoid killing plants and bare soil
Livestock growth	Grass growth Availability of drinking water	Livestock grazing timing and intensity, to avoid overgrazing and promotion of unpalatable species
Medicinal plants	Levels of herbivory Soil surface cover and structure	Grazing and fire management to promote favourable habitat conditions for desired species
Game meat	Grass growth for desired herbivore and predator species Competition with domestic livestock for grass growth	Grazing and fire management to promote favourable habitat conditions for desired species
Water flow regulation	Vegetation structure and soil structure	Livestock grazing timing and intensity, to promote desired vegetation and soil structure and coverage
Climate regulation	Vegetation structure and growth Soil structure and mineral cycling	Livestock grazing timing and intensity, to promote desired vegetation and soil structure and coverage
Means of livelihood for local people – livestock, medicinal plants, tourism, etc.	Populations of livestock, wild herbivores, and predators, which depend on grass growth and structure	Grazing and fire management for grass growth, considering needs of wild herbivores
Recreational and spiritual values and place for local people and visitors	Populations of livestock, wild herbivores, and predators, which depend on grass growth and structure	Grazing and fire management for grass growth, considering needs of wild herbivores
Habitat for rare and culturally valued species	Grass growth and structure Populations of wild herbivores and predators	Grazing and fire management as appropriate for the desired species

Management Problems

Overgrazing

The most widespread management problem in grasslands is overgrazing of plants by domestic livestock. Overgrazing is the removal of plant leaves that are regrowing from an earlier grazing event at a rate faster than the plant can recover from. Overgrazing results in reduced size or the death of plants of palatable species. The shorter the growing season, which is due to climate, topography, and soil structure, then the more likely it is that overgrazing will occur and plants will die and areas of bare soil will increase. Overgrazed plants and bare soil result in less capture and flow of solar energy in the ecosystem, and thus reduced functioning of the other ecosystem processes and less supply of ecosystem services (Figure 18).

Whether a plant is overgrazed depends on whether it has recovered from the previous grazing event. Therefore, overgrazing is a function of both the ability of the plant to regrow and of how soon thereafter it is grazed. Plant regrowth includes not only the leaves but also the roots. A plant that has had most of its leaves removed will regrow from energy stored in its roots rather than from photosynthesis, so root mass decreases. Overgrazing is, in effect, the grazing of plant roots, which results in small or dead plants (Savory & Butterfield, 1999).

The avoidance of overgrazing is dependent on managing the timing of livestock grazing on the same plants. A high number and density of livestock in a location at one time may graze most of the plant matter, but overgrazing only

Figure 18: Severely overgrazed grass and bare soil. Human-created pasture, 1,500 masl, Uttarakhand, India, March 2015. Photo P. Bubb.

occurs if the animals are still present and grazing the plants whilst they are regrowing. Thus, avoiding overgrazing depends on both promoting favourable conditions (ecosystem functioning) for plant growth and managing the timing or frequency of grazing. Wild herbivores rarely over-graze grasslands because they frequently move to avoid predators and to avoid areas fouled by dung and urine.

Growth of unpalatable plants

Management practices can unintentionally create the conditions for the establishment and spread of unpalatable forbs and shrubs, and thus reduce the supply of fodder for livestock. In many areas, these unpalatable plants are non-native species which have evolved to colonise bare and disturbed ground, and some species may also release biochemicals that inhibit the growth of other plants. Continuous grazing favours the growth of unpalatable plants (Figure 19), and if overgrazing or fire results in areas of bare soil, this may create favourable conditions for the establishment of woody and unpalatable plants, whether they are native or not.

Whilst unpalatable and woody plants in grasslands do not provide fodder, and may reduce habitat for other desirable species, their role in ecosystem functioning may still provide other ecosystem services such as regulation of soil erosion and water flows and development of soil structure.

Management of grasslands for livestock production should first aim to avoid creating the ecosystem functioning that favours the establishment of unpalatable species. This includes avoiding continuous grazing (Figures 19 and 20) and overgrazing that creates bare and compacted soils. Once unpalatable plants have become established, management for their reduction and removal must first stop the practices that favour their growth. Otherwise, the removal of undesired plants by use of physical or chemical means or fire will not be effective. Management

Figure 19: Under continuous grazing, relatively unpalatable species gain an advantage for water and nutrients

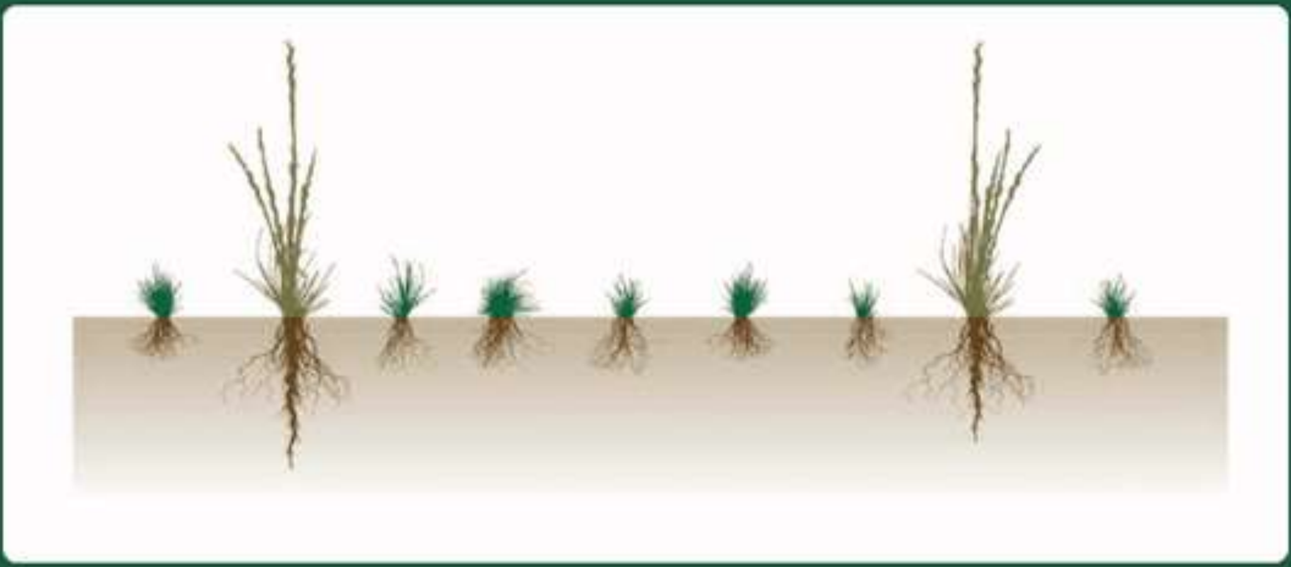
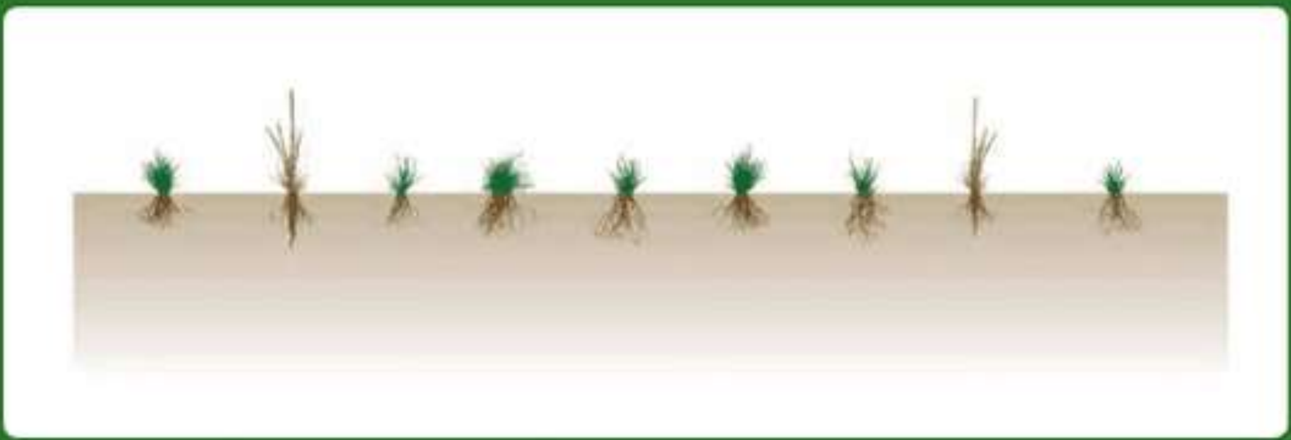


Figure 20: Regular short periods of grazing, burning, herbicide, or mowing reduce the biomass of all plants above and below ground



may then aim to create an ecosystem structure and functioning that is unfavourable for the undesired species, with particular consideration of soil coverage and structure, and the functioning of the water and mineral cycling ecosystem processes (Figure 21).

Soil erosion and loss of minerals

Soil erosion in grasslands is mostly a risk on slopes, with overgrazing and the impact of grazing animals' hooves on soil structure increasing the risk (Figure 22). The use of fire to clear woody vegetation or old, unpalatable grass results in a loss of organic matter and minerals from the ecosystem, although in the short term, the ash increases the availability of minerals for plant growth. If fire results in areas of bare soil, it increases the risk of erosion and the establishment of unpalatable plants.

Figure 21: Long rest periods and short, heavy graze periods enable desirable plants to form vigorous root systems and out-compete less desirable plants

Adapted from: Christine Jones, Proceedings Stipa Inaugural National Grasslands Conference 'Better Pastures Naturally'. Mudges, NSW, Australia. Cited at http://managingwholes.com/grazing-soils.htm

Figure 22: Aerial view of grassland and livestock paths on human-created grassland. Uttarakhand, India, 1,500 masl, March 2015. Photo P. Bubb.

Table 18: Descriptions of desired grassland ecosystem functioning to supply ecosystem services

Ecosystem service	Water cycling	Mineral cycling	Solar energy flow	Biological growth
Water supply for drinking and livestock and irrigation	Rainwater and snowmelt produce very little soil surface runoff, with some surface evaporation from leaves and mostly infiltration into the soil, and slow penetration to underground water resources. Transpiration of water from the soil to the atmosphere through grasses is low or moderate.	A closed mineral cycle, with no soil erosion and little leaching to underground water sources Most minerals are in the organic soil, with significant amounts in the grass and forbs vegetation, and the herbivorous mammals. Rapid organic decomposition of leaf litter and animal dung	Moderate to high capture of solar energy by grasses and herb layer, low capture by shrubs and tree layer Moderate to high flow of solar energy to herbivorous mammals Low flow to herbivorous insects Low flow to insectivorous birds and invertebrates, and other vertebrate predators Moderate flow to decomposers in the soil	High growth rate and biomass of grass and forb plants Low growth rate and biomass of shrubs and trees Medium growth and high biomass of herbivorous mammals Low growth rate and biomass of herbivorous insects Medium to high growth rate and biomass of soil decomposers
Grass as fodder for livestock	As for water supply	As for water supply	As for water supply	As for water supply
Livestock growth	As for water supply	As for water supply	As for water supply, although high flow to herbivorous mammals mostly for livestock, but also low to medium flow for wild herbivorous mammals may be desired. Some export of solar energy in harvested livestock	As for water supply, although medium growth and high biomass of herbivorous mammals mostly for livestock, but also low to medium growth and biomass of wild herbivorous mammals may be desired.
Medicinal plants	As for water supply	As for water supply	As for water supply	As for water supply
Wild animal products, e.g., meat and fur	As for water supply	As for water supply	As for water supply, except possible high flow to herbivorous and predatory mammals	As for water supply, except possible high biomass of herbivorous and predatory mammals
Wild foods, e.g., berries and mushrooms	As for water supply	As for water supply	As for water supply	As for water supply
Water flow regulation	As for water supply	As for water supply	As for water supply	As for water supply
Erosion control	As for water supply	As for water supply	As for water supply	As for water supply
Climate regulation	As for water supply	As for water supply	As for water supply	As for water supply
Erosion control	As for water supply	As for water supply	As for water supply	As for water supply
Erosion control	As for water supply	As for water supply	As for water supply	As for water supply
Means of livelihood and individual and cultural identity	As for water supply	As for water supply	As for water supply	As for water supply
Recreational and spiritual values and place	As for water supply	As for water supply	As for water supply	As for water supply
Habitat for rare and culturally-valued species	Probably as for water supply, but depends on the habitat requirements for particular species	Probably as for water supply, but depends on the habitat requirements for particular species	Probably as for water supply, but depends on the habitat requirements for particular species	Probably as for water supply, but depends on the habitat requirements for particular species

Ecosystem service	Vegetation structure	Structure of the food web	Soil structure
Water supply for drinking and livestock and irrigation	Predominately grass vegetation with some forbs. Taller grasses have deeper root structures than short grasses and so aid water infiltration, although they may have higher transpiration rates of soil water. No (or scarce) shrubs and trees.	Abundant and diverse soil decomposer community, for soil formation and structure that retains water, and for plant growth Abundant plants in the form of grasses and forbs	Covered soils by vegetation and leaf litter Deep organic soil layer Porous soil structure
Grass as fodder for livestock	As for water supply	As for water supply	As for water supply
Livestock growth	As for water supply	As for water supply	As for water supply
Medicinal plants	As for water supply	As for water supply	As for water supply
Wild animal products, e.g., meat and fur	As for water supply	As for water supply	As for water supply
Wild foods, e.g., berries and mushrooms	As for water supply	As for water supply	As for water supply
Water flow regulation	As for water supply	As for water supply	As for water supply
Erosion control	As for water supply	As for water supply	As for water supply
Climate regulation	As for water supply	As for water supply	As for water supply
Means of livelihood and individual and cultural identity	As for water supply	As for water supply	As for water supply
Recreational and spiritual values and place	As for water supply	As for water supply	As for water supply
Habitat for rare and culturally-valued species	Probably as for water supply, but depends on the habitat requirements for particular species	Probably as for water supply, but depends on the habitat requirements for particular species	Probably as for water supply, but depends on the habitat requirements for particular species

Key ecological interactions

Decomposition of leaf litter and dead plants is an ecological interaction that has a major influence on the structure and functioning of forest ecosystems and the services they supply. The availability of minerals and the soil structure are key determinants for tree growth. The actions of the soil decomposer community not only liberate minerals for plant growth, but also create the organic soil layer and spaces between soil particles that hold moisture required by plants. The growth of plant roots provides food and habitat for the soil decomposers.

In a natural forest, the influence of herbivory on the growth of established trees is likely to be low, due to the high tannin content and other defences against herbivores in tree leaves and the low populations of large mammal herbivores. However, herbivory can have a significant effect on the establishment of tree seedlings. In some forests, herbivory by defoliating caterpillars or damage to trees by bark beetles may be significant. If domestic livestock are grazed in a forest, this will significantly affect the ground plants and tree seedling survival, and so change the tree structure and composition.

The reproduction of many tree species relies on pollination of their flowers by insects, birds, or bats, and on the dispersal of their seeds by mammals and birds. The most vulnerable life-cycle stage for trees is for seeds to reach suitable conditions for germination and then to grow sufficiently to survive any herbivory and competition with other plants. The abundance of pollinators depends on the availability of nectar, habitat for reproduction and shelter, and the population size of predators.

Compared to grasslands, predation is likely to have a low to moderate impact on the abundance of herbivorous mammals and insects, in part due to lower populations of herbivores and increased cover to avoid predators. The number of large mammal predators can influence the behaviour of herbivorous mammals and, consequently, their grazing impact on tree regeneration.

4.2 Management of forests for ecosystem services

Summary of key aspects of ecosystem functioning in managing forests for ecosystem services

As is shown in Figure 23, in a forest, the major influences on the functioning of the ecosystem processes and supply of ecosystem services are the type, size and density of trees. The most significant aspect of ecosystem functioning that management can influence is the conditions for the growth of trees, as they are the largest organisms and dominant form of vegetation structure. After climate and topographic conditions, the condition of the soil is likely to be a major factor in the growth of trees. Tree growth itself creates a favourable soil structure for trees, through the actions of roots and the production of leaf litter as food for the soil decomposer community.

The reproduction of many tree species relies on pollination of their flowers by insects, birds or bats, and on the dispersal of their seeds by mammals and birds. The most vulnerable life-cycle stage for trees is for seeds to reach suitable conditions for germination, and then to grow sufficiently to survive any herbivory and competition with other plants.

In a natural forest, the influence of herbivory on the growth of established trees is likely to be low, due the high tannin content and other defences against herbivores in tree leaves and low populations of large mammal herbivores. However, herbivory can have a significant effect on the establishment of tree seedlings. If herbivory, including by defoliating caterpillars or bark beetles, is at undesirable levels, we need to consider if the populations of predators have been reduced. If domestic livestock are grazed in a forest, this will significantly affect the ground plants and tree seedling survival, and so change the tree structure and composition.

If management is for the growth and harvest of particular trees and other plants, then forestry practices, such as the removal of competitor plants and the planting of seedlings, alter vegetation structure. Such practices should consider their impact on water-related ecosystem services, as well as the impact on soil structure of harvesting practices.

Vegetation structure is the largest influence on the water cycling ecosystem process and the supply of water-related ecosystem services. Although the soil structure is also important in this regard, it is much more affected by the roots of trees and plants and by the amount of leaf litter. Since evapotranspiration by trees can have a major influence on cycling water from the soil to the atmosphere, decisions about the desired vegetation structure for downstream water supply may depend on the average amount and timing of rainfall over the year, and whether tree evapotranspiration is likely to majorly affect water flows.

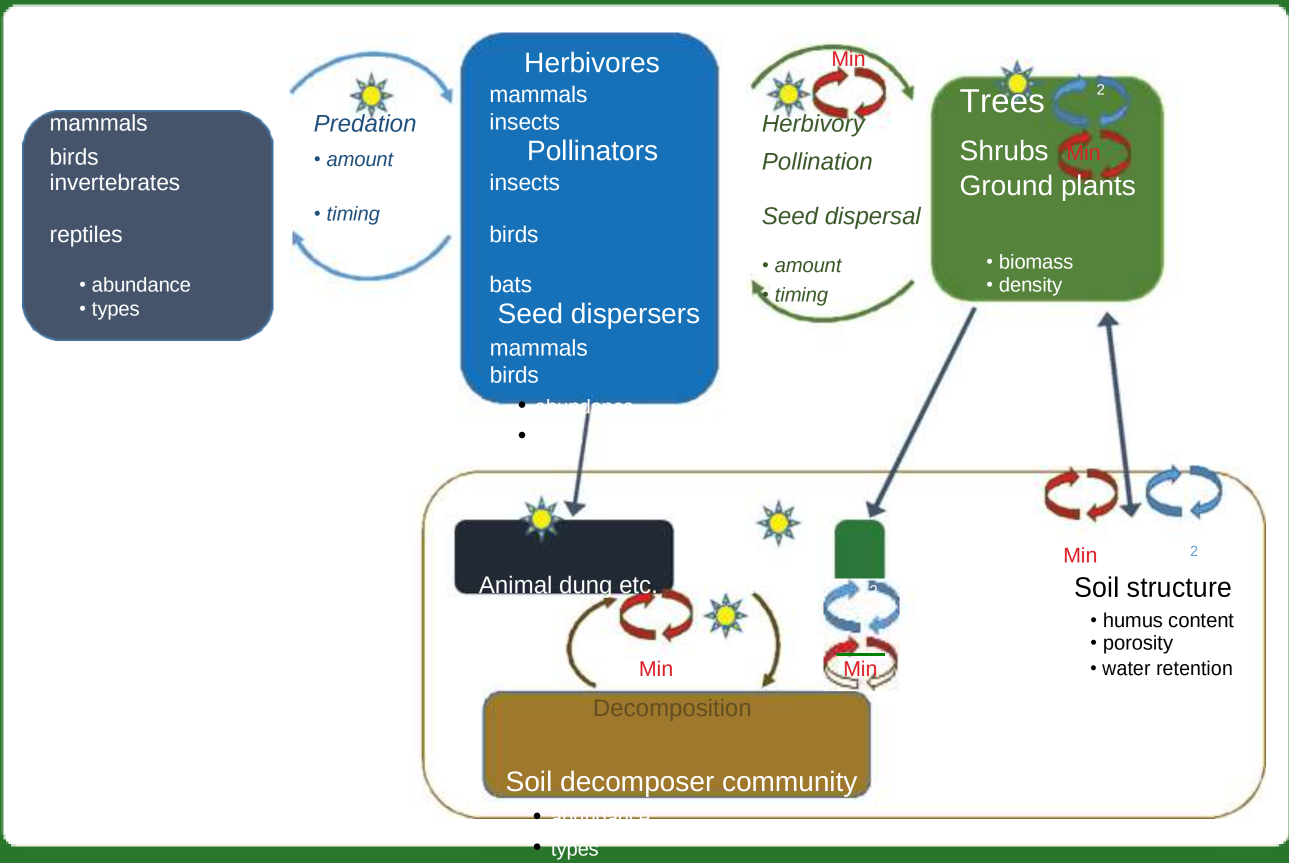
Fire not only damages or kills adult trees and seedlings, and reduces the amount of minerals in the ecosystem, but also creates bare ground and reduces the soil decomposer community. Forest regeneration after fire tends to favour coniferous species. Bare ground in a forest may also be colonised by undesirable non-native plants.
In forests, the growth of vegetation is more likely to be limited by the functioning of the water cycling ecosystem process than the functioning of the mineral cycling ecosystem process.

Definitions and Categories of Forests

The diverse types of forest ecosystems in mountain regions depend on a combination of climate, topography and soils. The forest types of the Himalayan region are classified by (Negi, 2000), as: ƒƒ Sub-tropical semi-desert forests

ƒƒ Sal forests
ƒƒ Montane sub-tropical forests
ƒƒ Montane wet temperate forests
ƒƒ Moist Himalayan temperate forests
ƒƒ Himalayan dry temperate forests
ƒƒ Sub-alpine scrub
ƒƒ Moist alpine scrub
ƒƒ Dry alpine scrub

Figure 23: Major components of a forest ecosystem structure and ecological interactions.



The boxes represent major ecosystem components, the straight arrows represent major influences, and the curved arrows represent
major ecological interactions. Major direct influences on the water cycling (H_2O) ecosystem process, the mineral cycling (Min)

In terms of ecosystem functioning, a key factor in determining the type of forest is the length of the plant growing season, which may be limited by temperature and the availability of moisture. The fertility and porosity of the soil are also major determinants of the vegetation type/s.

Common Forest Management Practices

Some forests are managed for production of provisioning ecosystem services such as timber and fuelwood, and this involves cutting and removing trees and altering the vegetation structure. Regrowth of harvested species may be from natural seedlings, or from planted trees from nurseries if natural regeneration is insufficient. Pruning and coppicing of trees may be practiced, particularly for firewood and fodder, which enables regrowth from stems. If harvesting results in a more open or simplified vegetation structure this may allow more sunlight to lower vegetation layers and initially reduce competition between the remaining trees. If this results in increased capture and flow of solar energy in the ecosystem there may be increased rates of functioning of the other ecosystem processes and the supply of ecosystem services.

Some forests are managed for the regulating ecosystem services of water flow regulation and global climate regulation by sequestration of atmospheric carbon dioxide. Such forests may have little human intervention as natural ecosystem functioning provides the desired vegetation structure and growth. Forests managed for provisioning ecosystem services may also include objectives for vegetation and soil structure for water and climate regulating ecosystem services. Similarly, forests managed for cultural ecosystem services, such as of conservation of culturally-valued species and landscapes, may or may not involve alteration of vegetation structure.

Table 19: Principal ecosystem services from forests and the key aspects of ecosystem functioning and management considerations for them

Ecosystem services	Key aspects of ecosystem functioning	Management considerations
Timber for construction and others	Vegetation and soil structure for growth and reproduction of harvested species	Harvest levels that maintain mature trees as seed sources Harvest practices that maintain soil structure for regeneration of desired vegetation and water cycling
Fuelwood and charcoal	Vegetation and soil structure for growth and reproduction of harvested species	Harvest levels that maintain mature trees as seed sources Harvest practices that maintain soil structure for regeneration of desired vegetation and water cycling
Fodder for livestock – tree leaves & undergrowth	Vegetation structure and functioning of water and mineral cycling ecosystem processes, as influences on tree growth Soil surface cover & disturbance that promote desired or undesired plants	Harvest levels of foliage from tree lopping that maintain tree growth, vegetation and soil structure Livestock grazing timing and intensity to avoid overgrazing and promotion of unpalatable species Possible use of prescribed fires to reduce regeneration of trees, or favour coniferous species, and promote a grass understorey
Edible fruit, nuts, and fungi	Vegetation structure as habitat for harvested species Pollination and seed dispersal of harvested plant species	Timber and fuelwood extraction, livestock grazing and fire, may promote an undesirable vegetation structure, species composition and soil coverage.
Wild animal products, e.g. meat and fur	Vegetation structure as habitat for hunted species	Hunting intensity and sustainable harvest levels Management for vegetation structure necessary for hunted species
Water supply for people, livestock and irrigation	Soil surface cover by vegetation and leaf litter and soil structure	Effects of vegetation harvesting, livestock grazing timing and intensity, and fire, on vegetation structure and soil structure and coverage
Livestock growth	Vegetation structure and growth Availability of drinking water	Livestock grazing timing and intensity to avoid undesired vegetation and soil structure and promotion of unpalatable species
Medicinal plants	Vegetation structure Levels of herbivory	Vegetation harvesting and fire management to promote favourable habitat conditions for desired species
Water flow regulation and soil erosion control	Vegetation structure and soil structure as influences on water cycling ecosystem process	Harvest levels of vegetation, fire pattern and livestock grazing timing and intensity, which may alter soil structure and coverage to undesirable levels of functioning of the water cycling ecosystem process, including water infiltration and loss from evapotranspiration
Climate regulation	Vegetation structure and growth Soil structure and mineral cycling	Harvest levels of vegetation, fire pattern, and livestock grazing timing and intensity, which can affect plant growth rates and carbon capture
Means of livelihood for local people – timber, medicinal plants, and etc.	Vegetation structure and composition	Harvest levels of vegetation, fire pattern, and livestock grazing timing and intensity
Recreational and spiritual values and place for local people and visitors	Vegetation structure and composition, populations of wild herbivores and predators	Harvest levels of vegetation, fire pattern, and livestock grazing timing and intensity, considering needs of wild herbivores and predators
Habitat for rare and culturally valued species	Vegetation structure and composition Populations of wild herbivores and predators	Vegetation harvesting, grazing and fire management as appropriate for the desired species

In some cases fire may be used as a forest management tool, to clear vegetation and promote grass growth for grazing. The regeneration of some tree species, such as conifers and Sal (*Shorea robusta*), may be promoted by occasional fires.

Grazing of domestic livestock in forests can significantly alter the vegetation structure and composition. The shrub understorey and ground flora are likely to be reduced in density and diversity. If grazing is present over long periods this is likely to reduce tree seedling establishment and alter the age structure of the trees.

Harvesting of wild plant and animals rarely involves management of the habitat for these species, but there may be controls on harvest levels and timing.

Forests may be the sources of springs and pools, and management may seek to maintain these locations as clean water supplies with sufficient vegetation cover and control of livestock to reduce soil erosion.

Management Problems

Overharvesting of desired tree species

Overharvesting can be defined as the removal of trees and foliage at a rate faster than the population of that species or the plant can recover from. Overharvesting of trees can result in a change of the forest tree species composition to fewer desired species. It may result in a simplified vegetation structure and areas of bare soil, with a consequent reduced capture and flow of solar energy in the ecosystem, reduced rates of functioning of the other ecosystem processes, and reduced provisioning, water regulation and cultural ecosystem services.

The shorter the growing season, which is due to climate, topography and soil structure, the more likely it is that overharvesting will occur, because plants have a shorter period in which to recover, or to become established as seedlings and young trees.

Rates of harvest of foliage, branches and trees need to be at levels which do not damage the soil structure and functioning of the mineral and water cycling ecosystem processes, to maintain the conditions for tree growth and regeneration. If harvested species depend on pollination and dispersal of seeds by animals for their reproduction, the vegetation structure and composition needs to be maintained with areas that are suitable for populations of the pollinators and seed dispersers.

Avoiding overharvesting depends on both promoting favourable conditions (ecosystem functioning) for plant growth, and managing the timing or frequency of harvesting. Forest restoration may require enrichment planting with nursery-grown tree seedlings.

Reduction of water regulation ecosystem service

Overharvesting of trees and vegetation, livestock grazing, and forest fires can all result in a simplified and open vegetation structure and consequent simplified soil structure, with reduced water flow regulation ecosystem services. Critical factors in the functioning of the water cycling ecosystem process are the amount of bare soil, the depth and biomass of plant roots, and plant evapotranspiration rates. Management for rain water infiltration to the soil and regulation of soil erosion should aim to ensure soils are covered with plants and leaf litter. A multi-layered vegetation structure will reduce the erosion impacts of rainfall, but may increase evapotranspiration rates.

Crop and livestock losses from forest animals

Human-wildlife conflict due to loss of crops and livestock from wild animals that live in forests is a growing problem in many areas. Problem species for crop raiding include boar, monkeys, deer, porcupine, and bear. Wild predators that can cause losses of domestic livestock include leopards, wolves and eagles. There are no easy solutions to this problem, or ecosystem dis-service. One approach is to create physical protection of crop fields from wild animals, and to reduce suitable habitat or cover for crop-raiding animals that is close to crops. Another approach is to improve the habitat for the wild herbivores by planting of fruit trees and other favoured food plants in the forest, and the provision of water sources, so that the animals are less attracted to crop areas. Hunting of problem animals may be practised in some cases. If populations of herbivores have reached problem levels, we need to consider if the abundance of their predators has been reduced.

Growth of undesirable plants

Management practices can unintentionally create the conditions for the establishment and spread of unpalatable or otherwise undesirable forbs, shrubs and trees. In many areas these undesirable plants are non-native species which have evolved to colonise bare and disturbed ground, and some species may also release biochemicals that inhibit the growth of other plants. Any management practice that creates bare or disturbed soil may create favourable conditions for the establishment of unpalatable and fast-growing plants, whether they are native or not. Fire in forests can particularly create bare ground. Continuous grazing by livestock also favours the growth of unpalatable plants (see the section on management of grasslands).

Whilst unpalatable and fast-growing plants in forests may reduce the habitat suitability for desirable species, their role in ecosystem functioning may still provide other ecosystem services such as regulation of soil erosion and water flows, and development of soil structure.

Once undesirable plants have become established, management for their reduction and removal needs to first stop the practices that favour their growth. Otherwise, the removal of undesired plants by use of physical, chemical or fire means will not be effective. Management may then aim to create an ecosystem structure and functioning that is unfavourable for the undesired species, with particular consideration of soil coverage and structure, and functioning of the water and mineral cycling ecosystem processes. In the case of forests, consider whether the process of biological growth of trees and increasing vegetation structure will create unfavourable conditions for the growth of undesirable plants. If there is a source of seeds of desired species, consider if the vegetation structure is favourable for their germination and establishment.

Soil erosion and loss of minerals

Soil erosion in forests is mostly a risk on slopes, with soil cover by plants and leaf litter a key factor. A more complex vegetation structure, including the root structure, will reduce the risk of soil erosion. On soils with low organic matter, or which are naturally low in available minerals, the harvest of wood products may result in a significant loss of minerals from the ecosystem. This may include the harvesting of fodder for animals and of leaf litter for compost on agricultural fields. Management should aim to maintain a soil coverage and leaf litter abundance sufficient to reduce the risk of erosion and maintain fast mineral cycling by the soil decomposer community.

Key ecological interactions

Decomposition of leaf litter and dead plants is an ecological interaction that has a major influence on the structure and functioning of forest ecosystems and the services they supply. The availability of minerals and the soil structure are key determinants for tree growth. The actions of the soil decomposer community not only liberate minerals for plant growth, but also create the organic soil layer and spaces between soil particles that hold moisture required by plants. The growth of plant roots provides food and habitat for the soil decomposers.

In a natural forest the influence of herbivory on the growth of established trees is likely to be low, due to the high tannin content and other defences against herbivores in tree leaves and low populations of large mammal herbivores. However, herbivory can have a significant effect on the establishment of tree seedlings. In some forests herbivory by defoliating caterpillars or damage to trees by bark beetles may be significant. If domestic livestock are grazed in a forest this will significantly affect the ground plants and tree seedling survival, and so change the tree structure and composition.

The reproduction of many tree species relies on pollination of their flowers by insects, birds or bats, and on the dispersal of their seeds by mammals and birds. The most vulnerable life-cycle stage for trees is for seeds to reach suitable conditions for germination, and then to grow sufficiently to survive any herbivory and competition with other plants. The abundance of pollinators depends on the availability of nectar, habitat for reproduction and shelter, and the abundance of predators.

Table 20: Descriptions of desired forest ecosystem functioning to supply ecosystem services

Ecosystem service	Water cycling	Mineral cycling	Solar energy flow	Biological growth
Timber for construction and others	Rainwater and snowmelt producing very little soil surface runoff, with some surface evaporation from leaves and mostly infiltration into the soil, and slow penetration to underground water resources Moderate to high transpiration of water from the soil to the atmosphere through trees and other plants	A mostly closed mineral cycle, with no soil erosion and little leaching to underground water sources Some export of minerals in harvested trees High availability of minerals for plant growth in the organic soil, and significant amounts in the tree vegetation Rapid organic decomposition of leaf litter and animal dung	High capture of solar energy by trees and moderate to low capture by understorey shrubs and herb layer Low to moderate export of solar energy in harvested products Low to moderate flow of solar energy to soil decomposer community Low flow of solar energy to herbivorous mammals Low flow to insectivorous birds and invertebrates, and other vertebrate predators	High growth rate and biomass of trees, especially harvested species Low to medium growth rate and biomass of shrubs and herb layer Medium growth rate and biomass of soil decomposers Low growth rate and biomass of herbivorous insects and mammals Low growth and biomass of invertebrate and vertebrate predators
Fuelwood and charcoal	As for timber	As for timber	As for timber	As for timber
Edible fruit, nuts, and fungi	As for timber	As for timber	As for timber	As for timber
Wild animal products, e.g. meat and fur	As for timber	As for timber	As for timber except moderate flow of solar energy to herbivorous and predatory mammals	As for timber except moderate growth rate and biomass of herbivorous and predatory mammals
Water supply for drinking and livestock and irrigation	As for timber	As for timber	As for timber, except perhaps low to medium capture of solar energy by trees, in order to have low evapotranspiration	As for timber, except perhaps low to medium growth by trees, in order to have low evapotranspiration
Livestock growth	As for timber	As for timber	As for timber, although moderate to high capture by understorey shrubs and herb layer Low solar energy flow to herbivorous mammals, including livestock, to maintain flow for tree growth and soil decomposers	As for timber
Medicinal plants	As for timber	As for timber	As for timber	As for timber
Water flow regulation	As for timber	As for timber	As for timber	As for timber.
Erosion control	As for timber	As for timber	As for timber	As for timber.
Climate regulation	As for timber	As for timber	As for timber	As for timber.
Means of livelihood and individual and cultural identity	As for timber	As for timber	As for timber	As for timber.
Recreational and spiritual values and place	As for timber	As for timber	As for timber	As for timber
Habitat for rare and culturally-valued species	Probably as for timber, but depends on the habitat requirements for particular species	Probably as for timber, but depends on the habitat requirements for particular species	Probably as for timber, but depends on the habitat requirements for particular species	Probably as for timber, but depends on the habitat requirements for particular species
Ecosystem Service	Water cycling	Mineral cycling	Solar energy flow	Biological growth

Ecosystem service	Vegetation structure	Structure of the food web	Soil structure
Timber for construction and others	Predominately tree vegetation with a mainly closed canopy and high populations of timber species, but some areas of regeneration after harvesting of timber A few decaying trees remaining as seed sources and as habitat for insectivorous and pollinating birds and bats Shrub layer thin Herb layer covering soil and abundance of dead plant matter for soil formation	Abundant decomposers in the soil Plants as described in vegetation layers structure Populations of herbivorous insects regulated by insectivorous birds and mammals Presence of vertebrate predators to regulate populations of tree seed predators and crop herbivores	Covered soils by vegetation and leaf litter Deep organic soil layer Porous soil structure, with deep tree roots
Fuelwood and charcoal	Predominately tree vegetation with an open canopy, and many areas of regeneration after harvesting of firewood A few decaying trees remain as seed sources and as habitat for insectivorous and pollinating birds and bats Shrub layer dense, with regenerating trees Herb layer covering soil and abundance of dead plant matter for soil formation	As for timber	As for timber
Edible fruit, nuts, and fungi	As for timber	As for timber	As for timber
Wild animal products, e.g. meat and fur	As for timber	As for timber	As for timber
Water supply for drinking and livestock and irrigation	As for timber	As for timber	As for timber
Livestock growth	As for timber	As for timber	As for timber
Medicinal plants	As for timber	As for timber	As for timber
Water flow regulation	As for timber	As for timber	As for timber
Erosion control	As for timber	As for timber	As for timber
Climate regulation	As for timber	As for timber	As for timber
Means of livelihood and individual and cultural identity	As for timber	As for timber	As for timber
Recreational and spiritual values and place	As for timber	As for timber	As for timber
Habitat for rare and culturally-valued species	As for timber	As for timber	As for timber
Ecosystem service	Vegetation structure	Structure of the food web	Soil structure

Compared to grasslands, predation is likely to have a low to moderate impact on the abundance of herbivorous mammals and insects, in part due to lower populations of herbivores and increased cover to avoid predators. The abundance of large mammal predators can influence the behaviour of herbivorous mammals, and consequently their grazing impact on tree regeneration.

Management of forests for water-related ecosystem services

The structure and functioning of forest ecosystems can have a major influence on the supply and quality of downstream water flows. This section describes the principal aspects of ecosystem functioning to manage forests for water-related ecosystem services.

Critical factors in the functioning of the water cycling ecosystem process in forests are the amount of bare soil, the depth and biomass of plant roots, and plant evapotranspiration rates. Management for rain water infiltration to the soil and regulation of soil erosion should aim to ensure soils are covered with plants and leaf litter. A multi-layered vegetation structure will reduce the erosion impacts of rainfall, but may increase evapotranspiration rates. There can be large differences in the rates of evapotranspiration by different tree species.

Soil structure is a major influence on water flows and quality. Its porosity to rainfall and its capacity to retain water are greatly influenced by the humus content and the size of spaces between the soil particles. Humus is decomposed organic matter, so the amount of humus depends on the types and abundance of the soil decomposer community, such as earthworms, nematodes, dung beetles, bacteria, and fungi. The food of the forest soil decomposer community is principally plant roots and leaf litter, and to a lesser extent, animal dung.

Fire, livestock grazing, and overharvesting of trees and vegetation can all result in a simplified and open vegetation structure and consequent simplified soil structure, with reduced water flow regulation ecosystem services.

Management of forests for ecosystem services that depend on the mineral cycling ecosystem process

Tree growth depends on the availability of suitable minerals in the soil, as well as the availability of water and sunlight. The quality of drinking water flows from forest areas may be negatively affected if there is soil erosion or high leaching of soil minerals. Figure 18 identifies the principal aspects of forest ecosystem structure and ecological interactions that are likely to influence the functioning of the mineral cycling ecosystem process.

Soil structure is a major influence on the mineral cycling ecosystem process and, in particular, the humus content as a source of accessible minerals for plant growth. The amount of humus depends on the composition and abundance of the soil decomposer community, and on the availability of food for this community. In forests, the plant roots, leaf litter, and dead plants are the major sources of solar energy for the decomposers. Forest management should aim to ensure the availability of plant matter for the decomposers, including growing roots. Similarly, the harvesting of forest products should aim to leave sufficient organic matter as food for the decomposer community. Management should also aim to avoid creating areas of bare soil, partly because the rate of decomposition of organic matter by the microbial soil community is very sensitive to the soil temperature and moisture. Bare soils experience higher rates of evaporation and ranges of temperature fluctuation than soils with vegetation or leaf litter cover.

Fire in a forest not only reduces vegetation structure but also results in a major loss of minerals in the plants and soil through combustion and from erosion of bare soils. The ash from a fire enables a short-term growth in plants adapted to colonise bare ground.

Management of forests for ecosystem services that depend on the solar energy flow ecosystem process

All provisioning ecosystem services from forests are either direct products from the capture of solar energy by plants or from the flow of solar energy through the food web. Similarly, forest regulating and cultural ecosystem services depend on the growth of trees as the basis of the food web. Figure 23 identifies the major aspects of forest ecosystem structure and ecological interactions that are likely to influence the functioning of the solar energy flow ecosystem process.

The amount of solar energy capture in a forest ecosystem principally depends on the growth of trees, and this ecosystem process is largely influenced by the availability of water and minerals in the case of adult trees. Thus, soil structure and the functioning of the mineral cycling ecosystem process are major determinants of tree growth. The soil decomposer community requires solar energy in the form of leaf litter, roots, and dead plants.
In a natural forest, the influence of herbivory on the growth of established trees is likely to be low, but herbivory can have a significant effect on the establishment of tree seedlings and consequently on tree species composition.

The reproduction of many tree species relies on pollination of their flowers by insects, birds, or bats, and on the dispersal of their seeds by mammals and birds. The abundance of pollinators and seed dispersers depends in large part on the availability of solar energy in the forms of nectar and seeds.

4.3 Management of agricultural lands for ecosystem services

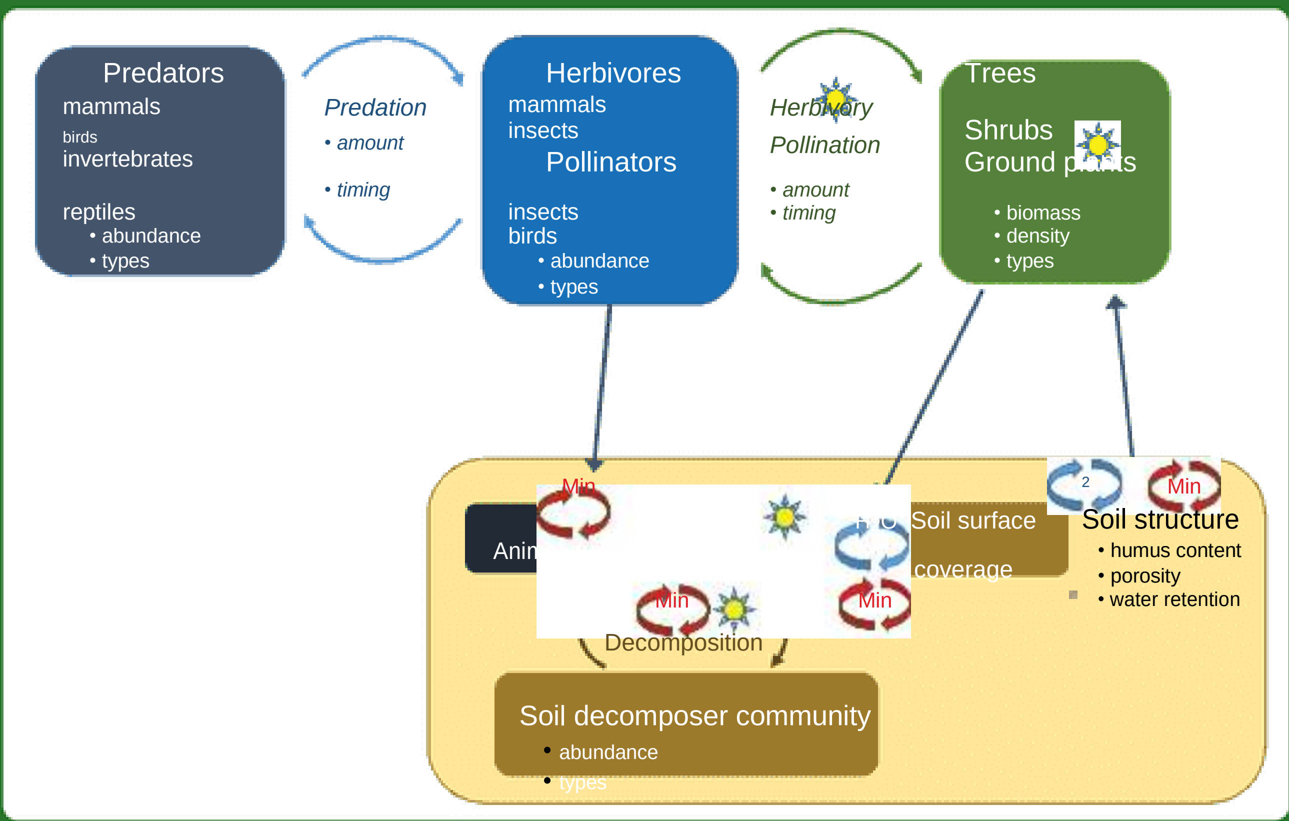
Summary of key aspects of ecosystem functioning in managing agricultural lands for ecosystem services Figure 24 represents the major components and interactions to be considered in managing agricultural lands for ecosystem services.

Agricultural lands are managed primarily for the provisioning ecosystem services of crops and fruits, and they often include livestock production as part of the farming system. Agricultural ecosystems also have a large influence on the water cycling ecosystem process and water flows, due to their large extent and areas with short vegetation or bare soil in some seasons.

The means of soil preparation for crops can have a major influence on ecosystem functioning and productivity. If natural or regenerating vegetation is cleared by fire, this results in a high loss of minerals from the ecosystem, a reduced soil decomposer community, and a high risk of soil erosion, although it provides a brief availability of minerals in the ash. Land that is ploughed to improve the soil structure for crops may also reduce the soil decomposer community and increase the risk of erosion. Multicropping and agroforestry can increase the diversity of vegetation structure and functioning of the water and mineral cycles, especially if nitrogen-fixing plants are included.

The harvesting of crops and livestock is a significant export of solar energy and minerals from the agro-ecosystem. If harvesting leaves behind no organic matter as food for the soil decomposer community, then other means are needed to import or mobilise minerals for future crops. A fundamental aspect of ecosystem functioning to promote soil fertility is to ensure that all the soil is covered with vegetation or leaf litter. Such cover provides food and favourable temperature and moisture conditions for the soil decomposer community, as well as reducing soil erosion and evaporation of moisture (Labriere et al., 2015).

Figure 24: Major components of an agricultural (crop) ecosystem structure and ecological interactions



The boxes represent major ecosystem components, the straight arrows represent major influences, and the curved arrows represent major ecological interactions. Major direct influences on the water cycling (H_2O) ecosystem process, the mineral cycling (Min) ecosystem process, and the solar energy flow ( ) are identified.

Crop losses from insect pests, such as moth caterpillars, aphids, or grasshoppers may be reduced by promoting a vegetation structure (habitat) that is favourable to their predators, such as wasps, spiders, frogs, and insectivorous birds. Excessive use of pesticides can kill the predators of pest species and result in 'predator-release' of pest populations, as well as risks of evolving resistance to pesticides.

If the agricultural cycle creates bare and disturbed soil, such areas may be vulnerable to colonisation or invasion by plants that are unwanted (weeds). The most effective way to avoid the establishment of unwanted plants is to remove them at the most vulnerable stage of their life cycle, when they are seedlings.

In agricultural ecosystems, decomposition is likely to be the ecological interaction that has the biggest influence on the functioning of the ecosystem and its supply of services to ensure soil fertility. The ecological interaction of pollination is critical for crops, shrubs, and trees that require animal pollinators such as bees and other insects, birds, and bats.

Definitions and classifications of agricultural ecosystems

A basic definition of agriculture is 'the growing of crop plants and the raising of animals for food and other human needs, including for economic gain'. In terms of ecosystem functioning, agriculture could be viewed as a way of modifying and harnessing ecosystem processes, structure, and interactions to provide products for people. Similarly, agriculture could be described as a means of harvesting the Sun's energy in the form of plants and animals that are useful for people. The growing of crops and animals is essentially working with the ecosystem process of biological growth, which depends on the functioning of the water and mineral cycling and solar energy flow ecosystem processes.

There are many classifications of agricultural or farming systems, such as those described in http://www.fao.org/ farmingsystems/. In mountain regions, one of the characteristics of agriculture is the great diversity of crops and practices that are adaptations to the diversity of climate and topographical conditions. This section of the Manual aims to help managers consider how a holistic perspective of ecosystem functioning can assist in designing and practicing agriculture for sustainable production and multiple ecosystem services.

Types of Agriculture Management Practices in relation to ecosystem functioning

The cycle of agricultural production involves many practices, but the main activities or steps in the production of crops are the preparation of the soil, planting seeds, tending the growing plants, and harvesting the crop.

The means of soil preparation can have a major influence on ecosystem functioning and productivity. If natural or regenerating vegetation is cleared by fire, this results in a high loss of minerals from the ecosystem, a reduced soil decomposer community, and a high risk of soil erosion, although it provides a brief availability of minerals in the ash. If the land is ploughed to improve the soil structure for crops, this may also reduce the soil decomposer community and increase the risk of erosion. Soil preparation may include the addition of fertiliser. Chemical fertilisers are effective in increasing the short-term availability of minerals for plants, but they reduce the community of soil microbial decomposers, and fertiliser run-off can pollute surface water bodies and ground water. Organic fertilisers or composts can improve soil structure for crops, as well as mineral availability.

In addition to the choice of crops to plant, one of the main choices in production is whether they will be grown as monocultures or intercropping. Monocrops may increase the ease of tending the crop and harvesting, but they can increase vulnerability to pests or other crop failure. Multicropping and agroforestry can increase the diversity of vegetation structure and the functioning of the water and mineral cycles, especially if nitrogen-fixing plants are included. An example of such practices is Sloping Agricultural Land Technology (SALT).[10]

Tending of crop plants includes the removal of competing plants -- weeds – by hand, mechanically, or with herbicides. Crop management may also involve the application of measures to reduce crop pests and diseases.

10 http://lib.icimod.org/record/21492/files/Sloping%20Agricultural%20Land%20Technology%20(SALT).pdf

Table 21: Principal ecosystem services from agriculture and agricultural lands, and the key aspects of ecosystem functioning and management considerations for them

Ecosystem services	Key aspects of ecosystem functioning	Management considerations
Food from crops, including fruits	Suitability of soil structure Functioning of water and mineral cycling ecosystem processes for crops Levels of herbivory by crop pests Pollination of crops requiring insect pollinators	Cultivation of soil to produce a structure suitable for selected crop species, considering water retention and availability of minerals Management of mineral cycling to ensure that the soil decomposer community is sufficiently active for minerals to be available to crops(e.g., managing the availability of crop and animal wastes, use of nitrogen-fixing plants, and physical measures such as terraces to reduce soil erosion) Management of water cycling through the vegetation structure and soil coverage, to ensure rain and snow water are retained in the soil and evaporation is minimised Maintenance of habitat in the landscape for pollinators and for predators of crop pests
Fodder for livestock	Suitability of soil structure Functioning of water and mineral cycling ecosystem processes for growth of grass and foliage on shrubs and trees	Production of fodder from agroforestry trees and field margins Livestock grazing timing and intensity, to avoid grazing of growing and unharvested crops, but promotion of mineral cycling by eating crop wastes in fields or stalls, and production of dung Use of fallow lands with periodic grazing to assist soil fertility improvement
Timber and fuelwood	Vegetation and soil structure for growth of desired species	Possible integration of trees and shrubs with crops in agroforestry systems, with pruning to reduce shading of crops and competition for soil moisture and minerals *Trees and shrubs have a significant role in increasing mineral cycling volume and rate by accessing deep soil minerals through their roots and bringing them above ground, and then making them available for decomposition via leaf litter. Nitrogen-fixing species can significantly increase the availability of minerals. Trees and shrubs may provide habitat for pollinators and for predators of crop pests.
Medicinal plants	Vegetation and soil structure for growth of desired species	Inclusion of desired plants as part of agroforestry systems and use of field margins
Drinking water for humans and livestock and for irrigation	Soil surface cover by vegetation and leaf litter and soil structure, which are affected by cultivation practices and the timing of any herbivory by livestock	Management of water cycling through the vegetation structure and soil coverage, to promote rain and snow water infiltration, soil water evaporation is minimised, and reduction of soil erosion
Water flow regulation and soil erosion control	Vegetation structure and soil structure	Management of water cycling through the vegetation structure and soil coverage, to promote rain and snow water infiltration, soil water evaporation is minimised, and reduction of soil erosion
Means of livelihood for local people – crops, livestock, waged labour, etc.	Biological growth of crops and livestock, dependent on soil structure and functioning of water and mineral cycling ecosystem processes, and populations of pollinators and predators of pests	Management of mineral cycling ecosystem process to maintain soil fertility despite losses in harvested products and from soil erosion or leaching, including availability of plant matter for soil composers, and the management of livestock grazing and/or dung
Recreational and spiritual values and place for local people and visitors		Maintenance of soils covered by vegetation or leaf litter, to promote slow water cycling and reduce erosion Maintenance of habitat in the landscape for desirable populations of pollinators and predators of pests
Habitat for rare and culturally valued species	Vegetation structure as required by the species	Maintenance of habitat in the landscape for the species

For crops that require insect pollination, bee hives may be introduced and/or suitable habitat for wild pollinators maintained in the landscape.

The harvesting of livestock and the seasonal removal of livestock from an area are a significant export of solar energy and minerals from the agro-ecosystem. If harvesting leaves no organic matter as food for the soil decomposer community, then other means are needed to import or mobilise minerals for future crops. After crops have been harvested, management may include the use of livestock to eat crop remains and so provide dung to improve soil fertility. Cultivated land may be left to rest as fallow and allow biological growth of wild plants to improve the soil structure and mineral availability.

Management Problems related to ecosystem functioning

Loss of soil fertility

Soil fertility is the availability of minerals required for plant growth. As plants grow they incorporate minerals into their biomass, removing minerals from the soil. If harvesting or fire removes the plant biomass from the cropland, these minerals are lost from the ecosystem. Soil minerals can also be lost through soil surface erosion due to water and wind, especially on slopes, and through leaching to the subsoil and ground water as rain water passes through the soil.

Whilst soil fertility and formation is very much dependent on the composition of the soil's parent rock material and the rainfall and temperature patterns, it can also be greatly increased by the structure and functioning of the ecosystem, and especially through the mineral cycling ecosystem process. As plants and their roots grow, they access and mobilise soil minerals. Deep-rooted trees may access minerals from the subsoil and make them available for further plant growth.

The dead parts of plants above and below ground are organic matter which feeds the soil decomposer community, liberating the minerals for plant growth. A basic measure of ecosystem functioning to promote soil fertility is to ensure that all the soil is covered with vegetation or leaf litter, to provide food and favourable temperature and moisture conditions for the soil decomposer community, as well as to reduce soil erosion and evaporation.

Agricultural practices tend to reduce soil fertility through the harvesting of products and the preparation of soil, so measures need to be taken to restore soil minerals, in addition to soil conservation measures such as terracing. Chemical fertilisers can be applied as an import to the ecosystem. Organic composts, leaf mulch, and animal manure can be applied to the soil, which will improve its structure and water retention for plant growth, as well as its mineral content. The growth of nitrogen-fixing plants as crops, or in agroforestry associations with crops, can significantly increase soil fertility.

Losses due to crop pests

Crop losses from insect pests, such as moth caterpillars, aphids, or grasshoppers, may be reduced by promoting a vegetation structure (habitat) that is favourable to their predators such as wasps, spiders, frogs, and insectivorous birds. Excessive use of pesticides can kill the predators of pest species and result in 'predator-release' of pest populations, as well as risks of evolving resistance to pesticides. Agricultural practices such as avoiding monocultures and rotation of crops in fields also reduce the build-up of populations of pest species and diseases.

Losses of crops from wild mammals and birds may require measures such as scaring, hunting, and reducing their physical access to crop fields. The amount of favourable habitat for crop-raiding animals may need to be reduced or made more attractive so that the animals are not forced to leave these areas. The abundance of mammal and bird predators should also be considered.

Losses due to water shortage

Whilst rainfall is obviously the primary determinant of water availability for crop growth, soils with a high organic matter content and a covered surface will retain soil moisture for plant growth longer than eroded soils. Vegetation and leaf litter or mulch coverage of soils are central to the functioning of the water cycling ecosystem process and formation of an organic soil layer.

Invasive plants

If the agricultural cycle creates bare and disturbed soil, then such areas may be vulnerable to colonisation or invasion by plants that are unwanted (weeds). Such plants may be a problem because they may be unpalatable to livestock, may compete for resources with desired plants, or may rapidly establish roots and woody growth, making them difficult to remove when preparing the soil for planting. In many areas, these problem plants are non-native species which have evolved to rapidly colonise disturbed ground, and some species may also release biochemicals that inhibit the growth of other plants and have negative impacts on livestock and human health.

Table 22: Descriptions of desired agricultural lands ecosystem functioning to supply ecosystem services

Ecosystem service	Water cycling	Mineral cycling	Solar energy flow	Biological growth
Food from crops, including fruits	Rainwater and snowmelt produce very little soil surface runoff, with some surface evaporation from leaves and mostly infiltration into the soil, and slow penetration to underground water resources. Transpiration of water from the soil to the atmosphere through crops is low or moderate.	A mostly closed mineral cycle, with no soil erosion and little leaching to underground water sources Some export of minerals in harvested crops Most minerals are in the organic soil, with significant amounts in the crops, and low amounts in herbivorous insects and mammals. Rapid organic decomposition of leaf litter and animal dung	Moderate to high capture of solar energy by crops, low capture by shrubs and trees Some export of solar energy in harvested crops Moderate flow of solar energy to decomposers in the soil Low flow of solar energy to herbivorous insects and mammals Low flow of solar energy to insectivorous birds and invertebrates, and other vertebrate predators	High growth rate and biomass of crops Low growth rate and biomass of shrubs and trees Medium to high growth rate and biomass of soil decomposers Medium growth and high biomass of herbivorous mammals Low growth rate and biomass of predatory insects and vertebrates
Fodder for livestock	As for food from crops	As for food from crops	As for food from crops, except perhaps medium capture of solar energy by shrubs & trees	As for food from crops, except perhaps medium growth and biomass of shrubs & trees
Timber and fuelwood	As for food from crops	As for food from crops	As for food from crops	As for food from crops
Medicinal plants	As for food from crops	As for food from crops	As for food from crops	As for food from crops
Water supply for drinking and livestock and irrigation	As for food from crops	As for food from crops	As for food from crops	As for food from crops
Water flow regulation	As for food from crops	As for food from crops	As for food from crops	As for food from crops
Means of livelihood for local people – crops, livestock, waged labour, etc.	As for food from crops	As for food from crops	As for food from crops	As for food from crops
Recreational and spiritual values and place	As for food from crops	As for food from crops	As for food from crops	As for food from crops
Habitat for rare and culturally-valued species	Probably as for food from crops, but depends on the habitat requirements for particular species	Probably as for food from crops, but depends on the habitat requirements for particular species	Probably as for food from crops, but depends on the habitat requirements for particular species	Probably as for food from crops, but depends on the habitat requirements for particular species

Ecosystem service	Vegetation structure	Structure of the food web	Soil structure
Food from crops, including fruits	Predominately crop vegetation layer. Maybe adjacent shrubs and trees in agroforestry association.	Abundant and diverse soil decomposer community, for soil formation, mineral availability, and structure that retains water Abundant plants in the form of crops, and maybe shrubs and trees Low populations of invertebrate and vertebrate herbivores and predators	Soil surface covered year-round by either crops or mulch Deep organic soil layer Presence of some deep-rooted shrubs or trees, for water infiltration and mineral cycling Porous soil crumb structure
Fodder for livestock	As for food from crops	As for food from crops	As for food from crops
Timber and fuelwood	As for food from crops	As for food from crops	As for food from crops
Medicinal plants	As for food from crops	As for food from crops	As for food from crops
Water supply for drinking and livestock and irrigation	As for food from crops	As for food from crops	As for food from crops
Water flow regulation	As for food from crops	As for food from crops	As for food from crops
Means of livelihood for local people – crops, livestock, waged labour, etc.	As for food from crops	As for food from crops	As for food from crops
Recreational and spiritual values and place	As for food from crops	As for food from crops	As for food from crops
Habitat for rare and culturally-valued species	As for food from crops	As for food from crops	As for food from crops

The most effective way to avoid the establishment of unwanted plants is to remove them at the most vulnerable stage of their life cycle, when they are seedlings (always before the flowering stage). Soil cultivation, mechanical measures, herbicides, or grazing and trampling by livestock may be used to achieve this. These measures may still be effective once unwanted plants have become established, but the intensity and costs of their application may need to increase.

Key ecological interactions in agriculture

In agricultural ecosystems, decomposition is likely to be the ecological interaction that has the biggest influence on the functioning of the ecosystem and its supply of services. Crop production depends on soil fertility and structure, which are diminished by soil preparation, erosion, and harvesting of products. The actions of the soil decomposer community build soil structure, the availability of minerals, and retention of soil moisture. Agricultural practices need to provide the organic matter and favourable micro-climate for soil decomposers to function.

In human-managed agro-ecosystems, the ecological interaction of herbivory is not desired during the growth and maturation of crop plants, but losses due to herbivory by invertebrates and mammals may be significant. The ecological interaction of predation may be significant in the regulation of undesired herbivores, especially insects. The ecological interaction of pollination is critical for crops, shrubs, and trees that require animal pollinators such as bees, birds, and bats. The ecosystem structure and habitat in the agriculture landscape needs to maintain the populations of necessary pollinators.

Management of agricultural lands for water-related ecosystem services

Agricultural lands can have a major influence on the supply and quality of downstream water flows, due to their extent, modification of soil structure, potential amount of bare soil in some seasons, and in some instances due to the runoff of nutrients and chemical fertilizers applied to the fields. Figure 24 identifies the principal aspects of agricultural lands ecosystem structure and ecological interactions that are likely to influence the functioning of the water cycling ecosystem process.

Soil structure and coverage are the largest direct influences on water flows and quality. Agricultural practices are likely to promote the porosity of soil to rainfall, but its capacity to retain water is greatly influenced by the humus content and the size of spaces between the soil particles. The formation of humus depends on the amount of organic matter available for decomposition and on the types and abundance of the soil decomposer community, such as earthworms, nematodes, dung beetles, bacteria, and fungi. The food of the agricultural land soil decomposer community is principally plant roots, crop waste, and leaf litter. Grazing animals on the land post-harvest will provide animal dung as well.

If harvested crop lands are left with bare soil, this can greatly increase the evaporation of moisture from the soil and so reduce downstream flows.

Management of agricultural lands for ecosystem services that depend on the mineral cycling ecosystem process

Crops and fruits depend on the availability of suitable minerals in the soil. Figure 19 identifies the principal aspects of agricultural lands ecosystem structure and ecological interactions that are likely to influence the functioning of the mineral cycling ecosystem process.

Soil structure is a major influence on the mineral cycling ecosystem process, particularly the humus content as a source of accessible minerals required for plant growth. The formation of humus depends on the amount of organic matter available for decomposition and on the types and abundance of the soil decomposer community, such as earthworms, nematodes, dung beetles, bacteria, and fungi. The food of the agricultural land soil decomposer community is principally plant roots, crop waste, and leaf litter. Grazing animals on the land post-harvest will provide animal dung as well.

The rate of decomposition of organic matter by the microbial soil community is very sensitive to soil temperature and moisture. Bare soils experience higher rates of evaporation and ranges of temperature fluctuation than soils with vegetation or leaf litter cover.

Management of agricultural lands for ecosystem services that depend on the solar energy flow ecosystem process

All provisioning ecosystem services from agricultural lands are direct products of the capture of solar energy by plants or the flow of solar energy through to livestock. Similarly, the regulating and cultural ecosystem services from agricultural lands come from the growth of crops and livestock. Figure 24 identifies the major aspects of agricultural lands ecosystem structure and ecological interactions that are likely to influence the functioning of the solar energy flow ecosystem process.

Crop growth, as the capture of solar energy, is very dependent on soil structure and the availability of minerals, which depends on the abundance and types of soil decomposers. The solar energy that the decomposers require principally comes from the organic matter in plant roots, leaf litter, and animal dung, which are dependent on the agricultural practices to provide this food for the decomposers.

The production of honey and other bee products depends on the availability of nectar, which is a concentrated form of solar energy from plants, including many crop species.

5. Communicating and Building Capacity for Management for Ecosystem Services

A challenge in practising management for ecosystem services based on ecosystem functioning is how to obtain the involvement and support of key stakeholders, and then to develop their capacity to implement the approach. Currently, the approach in this Manual is still in development and testing, so there is limited experience to build on. However, some guidance and considerations for establishing management for ecosystem services include:

Define who the stakeholders are

Step 1 in Management for Ecosystem Services is 'Define management area and process', which includes defining who are the managers of the land and water resources, as they are the primary stakeholders. They may be male and female farmers, along with the village organisations and governance bodies that determine land use. On public lands the managers may be government officials, such as from agencies for forest management or biodiversity conservation. Other key stakeholders include the organisation promoting and supporting management for ecosystem services, and local government and development agencies.

Explain why management for ecosystem services is beneficial

In order for someone to decide they will try something new, they need first to be presented with evidence that it meets a need or desire. Management for ecosystem service needs to be explained in terms of how it helps land managers to be more effective in achieving their aims for production of goods and benefits. This should be described in relation to the aims of specific stakeholders, such as increased production for farmers, improved water supply for a village, or a method for better ecosystem and landscape management for a development agency.

Section 1.3.1 provides some text for such an explanation, which could be adapted and built on for particular situations and stakeholders.

Explain what management for ecosystem services is

Section 1.3.1 gives a definition of management for ecosystem services, but this needs to be related to the actual circumstances in which management is being carried out. It is important to explain how this approach aims to build on, or be integrated with, existing methods for planning the management of natural resources. The six steps in the approach need to be related to any existing methods and processes for management planning, such as community forest management.

The practice of management for ecosystem services requires at least a basic understanding of the concept and types of ecosystem services, and of ecosystem functioning in terms of four core processes, three types of structure, and ecological interactions. Section 2 is one way of presenting this knowledge. However, appropriate ways for explaining and learning this way of working with the environment need to be developed for each stakeholder group. Step 6, 'Specify management for ecosystem services', includes actions to assess and address stakeholders' capacity to manage for ecosystem services. The guidance text for this Step includes a framework of the elements of capacity required, in order to guide the definition and assessment of capacity needs of various groups.

Ways to communicate and build capacity for management for ecosystem services

Completing a management plan of the type in Annex 2 requires a level of knowledge and information that is presented in Sections 2 and 4 of this Manual. In such a situation, this may require the assistance of an externally trained person. However, it may not be necessary for local people and government officials to have a full technical understanding of all the concepts in order to be able to analyse their situation and plan their actions with an understanding of ecosystem functioning. ICIMOD has developed a picture series to help the users of this Manual to work with local communities.

The essence of the approach in this Manual is captured in the key questions for working with ecosystem functioning in Section 2.2. If the managers can learn to seek answers to these questions in each situation they are working with, using local terms and knowledge, then they will develop a good understanding of and skills for working with ecosystem functioning. The sequence of the key questions in Section 2.2 is important, as they build on each other to develop a kind of story of ecosystem functioning. The questions start with water as an essential element for life on Earth, and ask what happens to rainfall and whether it is available for plant growth or lost, and the role of vegetation in this. Then questions are asked about the availability of minerals for plants and the role of water in this. Then plant growth is considered as a means to capture the Sun's energy for our benefit and the growth of other organisms we want to exist.

This Manual is written in English and uses scientific terms such as ecosystem and resilience. However, its use with stakeholders in rural areas will require translation of much of the material to local languages and explanation of terms such as ecosystem in relation to relevant local terms and knowledge. For this, and especially for illiterate people, the use of the figures in Section 2 may be of assistance.

Reading – It is hoped that this Manual will provide a good overview and knowledge of planning management for ecosystem services, but it is not expected that just from reading that this skill can be learnt. The Manual aims to serve as a learning resource, guide and reference material. If further case studies of this approach can be developed then these will help people understand its application, provide evidence for its benefits, and serve as teaching resources.

Training courses and workshops – Management for ecosystem services requires learning and using new concepts, methods and skills, which can only be really learnt through practice. A training course led by someone experienced in this approach, and skilled in the design and delivery of adult learning activities, is an effective way to achieve this capacity. The explanation of the approach needs to be illustrated with actual examples as much as possible. Such training needs to combine the delivery of key knowledge with practice in its application in a real situation. Participants may practice the six steps in the natural environment around the venue of the course, completing the workbook. This would preferably be with local stakeholders and involve different types of ecosystems, to increase the learning opportunities. They may then further practice the steps in the course using knowledge for their own management situation.

PowerPoint presentations and videos – A suite of PowerPoint presentations and short videos could be developed and translated to different languages. These could cover the purpose and benefits of management for ecosystem services, learning the key concepts and steps through examples, use of the key questions, and an introduction to learning and implementation resources such as workbooks. The videos could include testimonials of the application of the approach by key stakeholders.

Development of a community of practice and technical support – The development of a new approach to ecosystem management can be supported by facilitating learning and support between the people who are practising it. A website, social media and meetings can be structures for this.

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Annex 1. List of ecosystem service types

This list is adapted from the WRI Ecosystem Services Review for Impact Assessment (ESR for IA) Dependence Scoping Tool Version 1.1 http://www.wri.org/publication/ecosystem-services-review-for-impact-assessment
Note that the MEA category of Supporting ecosystem services is treated in this Manual to be the same as ecosystem functioning and so is not included in this list (see Section 2.4).

Provisioning services: The goods and products obtained from ecosystems

Food from crops, livestock, capture fisheries, aquaculture, and wild foods	Cultivated plants or agricultural produce harvested by people for human or animal consumption as food Examples: grains, vegetables, fruit Animals raised for domestic or commercial consumption or use Examples: chicken, pigs, cattle Wild fish captured through trawling and other non-farming methods Examples: cod, crabs, tuna Fish, shellfish, and/or plants that are bred and reared in ponds, enclosures, and other forms of fresh- or salt-water confinement for purposes of harvesting Examples: shrimp, oysters, salmon Edible plant and animal species gathered or captured in the wild Examples: fruit and nuts, fungi, bushmeat
Biological raw materials from timber and other wood products, fibres and resins, animal skins, sand, and ornamental resources	Products made from trees harvested from natural forest ecosystems, plantations, or non-forested lands Examples: industrial roundwood, wood pulp, paper, construction materials Non-wood and non-fuel fibres and resins Examples: cotton, hemp, silk, twine and rope, natural rubber Processed skins of cattle, deer, pig, snakes, sting rays, or other animals Examples: leather, rawhide, cordwain Products derived from ecosystems that serve aesthetic purposes Examples: Tagua nut, wild flowers, coral jewellery
Biomass fuel	Biological material derived from living or recently living organisms – both plant and animal – that serves as a source of energy Examples: fuelwood, charcoal, dung, grain for ethanol production
Freshwater	Inland bodies of water, groundwater, rainwater, and surface waters for household, industrial, and agricultural uses Examples: freshwater for drinking, cleaning, cooling, industrial processes, electricity generation, or mode of transportation
Genetic resources	Genes and genetic information used for animal breeding, plant improvement, and biotechnology Example: genes used to increase crop resistance to disease
Biochemicals, natural medicines, and pharmaceuticals	Medicines, biocides, food additives, and other biological materials derived from ecosystems for commercial or domestic use Examples: echinacea, ginseng, garlic; paclitaxel as basis for cancer drugs; tree extracts used for pest control

Regulating services: The benefits obtained from an ecosystem's influence on natural processes

Regulation of air quality	Influence ecosystems have on air quality by emitting chemicals to the atmosphere (i.e., serving as a 'source') or extracting chemicals from the atmosphere (i.e., serving as a 'sink') Examples: lakes serve as a sink for industrial emissions of sulphur compounds; vegetation fires emit particulates, ground-level ozone, and volatile organic compounds
Regulation of local, regional, and/or global climate	Global: Influence ecosystems have on the global climate by emitting greenhouse gases or aerosols to the atmosphere or by absorbing greenhouse gases or aerosols from the atmosphere Examples: forests capture and store carbon dioxide; cattle and rice paddies emit methane Regional, local: Influence ecosystems have on local or regional temperature, precipitation, and other climatic factors Example: forests can impact regional rainfall levels, mountains have an effect on rainfall patterns
Regulation of water timing and flows	Influence ecosystems have on the timing and magnitude of water runoff, flooding, and aquifer recharge, particularly in terms of the water storage potential of the ecosystem or landscape Examples: permeable soil facilitates aquifer recharge; river floodplains and wetlands retain water – which can decrease flooding during runoff peaks – reducing the need for engineered flood control infrastructure
Erosion control	Role vegetative cover plays in soil retention Examples: vegetation such as grass and trees prevents soil loss due to wind and rain; forests on slopes hold soil in place, thereby preventing landslides
Water purification and waste treatment	Role ecosystems play in the filtration and decomposition of organic wastes and pollutants in water; assimilation and detoxification of compounds through soil and subsoil processes Examples: wetlands remove harmful pollutants from water by trapping metals and organic materials; soil microbes degrade organic waste, rendering it less harmful
Regulation of diseases	Influence ecosystems have on the incidence and abundance of human pathogens Example: intact forests reduce the occurrence of standing water – a breeding area for mosquitoes – and thereby can reduce the prevalence of malaria
Regulation of soil quality	Role ecosystems play in sustaining soil's biological activity, diversity, and productivity; in regulating and partitioning water and solute flow; and in storing and recycling nutrients and gases Example: some organisms aid in decomposition of organic matter, increasing soil nutrient levels; some organisms aerate soil, improve soil chemistry, and increase moisture retention; animal waste fertilizes soil
Regulation of pests	Influence ecosystems have on the prevalence of crop and livestock pests and diseases Example: predators from nearby forests – such as bats, toads, snakes – consume crop pests
Pollination	Role ecosystems play in transferring pollen from male to female flower parts Example: bees from nearby forests pollinate crops
Regulation of natural hazards	Capacity for ecosystems to reduce the damage caused by natural disasters such as hurricanes and to maintain natural fire frequency and intensity Examples: mangrove forests and coral reefs protect coastlines from storm surges; biological decomposition processes reduce potential fuel for wildfires

Cultural services: The nonmaterial benefits obtained from ecosystems

Recreation and ecotourism	Recreational pleasure people derive from natural or cultivated ecosystems Examples: hiking, camping, bird watching, scuba diving, and going on safari
Ethical and spiritual values	Spiritual, religious, aesthetic, intrinsic, 'existence' or other values people attach to ecosystems, landscapes, or species Examples: spiritual fulfilment derived from sacred lands and rivers; belief that all species are worth protecting regardless of their utility to people – 'biodiversity for biodiversity's sake'
Educational and inspirational values	Information derived from ecosystems used for intellectual development, culture, art, design, and innovation Examples: the structure of tree leaves has inspired technological improvements in solar power cells; school field trips to nature preserves and parks aid in teaching scientific concepts and research skills

Annex 2. Outline structure of a management plan for ecosystem services

Title of the Management Plan:

Lead or Responsible Agency:

Authors of, or contributors to, the Management Plan:

Date of production of Management Plan:

[Guiding Principles for implementation of the Management Plan]

[Process of Management Planning]

Executive Summary

- key features of the area and beneficiaries of the plan
- principal ecosystem services to be managed for
- any major management problems to be addressed
- key features of ecosystem functioning of concern for management of each ecosystem type
- principal features of strategies and actions in the plan

A. Area being managed

Name of the area

Location (with a map)

Extent

Main land uses or ecosystem types (with a map)

Features and infrastructure

Land ownership

Institutional and legal arrangements for planning management and conducting management of the area

B. Beneficiaries of ecosystem management and demand for ecosystem services

Ecosystem Service (ES) Beneficiary group:
Number of Beneficiaries:

Ecosystem services they benefit from	Ecosystems that supply the ES	Importance of these ES to them and why

[repeat this section for each Beneficiary Group]

C. Current situation

Ecosystem or Management Unit:
[repeat this section for each Ecosystem or Management Unit]

Current Functioning of Ecosystem Processes	Current Ecosystem Structure	Current Supply of Ecosystem Services and Dis-services
Vegetation Structure Main plant species		
Food Web (including insects and soil community)		
Soil Structure (including decomposers)		

Current Management Problems

Biophysical / Ecosystem problems

Social / Governance / Capacity problems

External Drivers of Change and Resilience Considerations

(e.g., climate change, human population change, etc., and their current and likely future trends and impacts)

D. Ecosystem management objectives = Desired state

[repeat this section for each Ecosystem or Management Unit]

Ecosystem or Management Unit:

Time period for achievement of the Objectives:

Desired Ecosystem Services supplied by the Area (provisioning, regulating, cultural)	Desired Amount of Ecosystem Service supply	Who benefits

Spatial Plan of Desired State (maps):

Desired functioning of ecosystem processes	Indicators of ecosystem processes and minimum acceptable level	Justification for desired functioning of ecosystem processes (effect on ecosystem structure, supply of services, and resilience to drivers of change)
Water cycling		
Mineral cycling		
Solar energy flow		
Biological growth		

Desired ecosystem structure	Indicators of ecosystem structure and minimum acceptable level	Justification for desired ecosystem structure (effect on ecosystem processes, supply of services, and resilience to drivers of change)
Vegetation structure Main plant species		
Food web (including insects and soil community)		
Soil structure (including decomposers)		

Key species for desired ecosystem functioning and services	Indicators of key species status and minimum acceptable level	Justification for choice of key species (effect on ecosystem processes and structure, supply of services, and resilience to drivers of change)
[Species A]		
[Species B]		

Key ecological interactions for desired ecosystem functioning and services	Indicators of key ecological interactions status and minimum acceptable level	Justification for choice of key ecological interactions (effect on ecosystem processes and structure, supply of services, and resilience to drivers of change)
[key ecological interaction A]		
[key ecological interaction B]		

E. Strategies to achieve objectives

[repeat this section for each Ecosystem or Management Unit]

Management Unit or Ecosystem:

Strategies to achieve supply of services and desired ecosystem functioning	Justification or logic for the strategy	Lead institution or person
Management of plants and animals:		
Harvesting and grazing practices:		
Institutional and governance arrangements (including equity considerations):		
Skills and capacity development:		
Monitoring and research:		
[other strategies]		
Risks to success, and how they are addressed and monitored:		

F. Action plan

Management of plants and animals, including harvesting and grazing practices

Priority activities	Outcomes	Time period	Lead institution or person	Budget

Institutional and governance arrangements

Priority activities	Outcomes	Time period	Lead institution or person	Budget

Skills and capacity development

Priority activities	Outcomes	Time period	Lead institution or person	Budget

Monitoring and research

Priority activities	Outcomes	Time period	Lead institution or person	Budget

[other strategies]

Priority activities	Outcomes	Time period	Lead institution or person	Budget

Annex 3. Workbook for planning management for ecosystem services

Purpose of this Workbook

This workbook is designed to accompany the Operations Manual 'Planning Management for Ecosystem Services'. It is structured to aid the gathering of information necessary for producing a management plan, and its sections follow the six steps in the Operations Manual.

Persons completing the Workbook:
Contact details:

Date:

Define:

1. Define management area and process	• Management planning and implementation process • Management area, units and ecosystem types • Ecosystem service beneficiary groups

Name of the area being managed:

Location (with a map):

Extent:

Land uses and ecosystem types:

Features and infrastructure:

Who owns the land:

Type of land ownership (e.g., private, public):

Who makes the land management decisions:

Institutional, cultural, and legal arrangements for planning and conducting management of the area:

Who are the managers of the area?
(the people and institutions that intentionally make decisions and actions to alter the land and water resources for particular aims)

Local users and beneficiaries of ecosystem services from the area:
(Who are the users of the area that benefit from its ecosystem services and are affected by any dis-services? Categorise each group of people in a way that is meaningful to them and how they make decisions about the area. This may be according to livelihood strategies, social class, gender-based roles, etc.)

Users and beneficiaries of the area's ecosystem services who live elsewhere:

2. Identity demand for

Identify for each ES beneficiary group:

- ES they benefit from & their importance, & dis-services
- Ecosystems that supply ES

For each beneficiary group, determine the ecosystem services which the area currently supplies. This will cover provisioning, regulating, and cultural ecosystem services.

Estimate the importance of each ecosystem service to the group (essential, very important, slightly important, or unimportant), and describe why it is important.

Determine the principal ecosystem types that supply the services, such as forest or grassland.

Ecosystem service (ES) beneficiary group and number of beneficiaries	Ecosystem services and dis-services	Importance of the ES to the beneficiaries and why	Ecosystem types that supply the ES

3. Determine ES supply

Determine for each ecosystem management unit:

- Current ES & dis-services supplied
- Desired amount of ES

(Duplicate this section for each management unit)

Management Unit and Ecosystem Type:

Ecosystem services and dis-services	Beneficiaries and importance of the ES to them	Desired supply

4. Determine ecosystem functioning for ES

Determine for each ecosystem type within each management unit:

- Current functioning of 4 ecosystem processes
- Current ecosystem structure
- Adequacy of supply of ES & preliminary management goal for ecosystem structure
- Preliminary management goal for functioning of ecosystem processes
- Key species and ecological interactions for ES

(Duplicate this section for each management unit)
Management Unit: Ecosystem Type:

Ecosystem Processes: Current Situation

<table>
<tr><td colspan="4">current Water cycling</td><td></td><td colspan="4">current Mineral cycling</td></tr>
<tr><td></td><td>Hi</td><td>Med</td><td>Low</td><td>Evidence</td><td colspan="4">Is the mineral cycle open or closed?</td></tr>
<tr><td>Soil surface runoff</td><td></td><td></td><td></td><td></td><td colspan="4">If open, how are minerals being lost?</td></tr>
<tr><td>Surface evaporation</td><td></td><td></td><td></td><td></td><td colspan="4"></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="4">Where are most of the minerals in the ecosystem?</td></tr>
<tr><td>Evapotranspiration through plants</td><td></td><td></td><td></td><td></td><td colspan="4"></td></tr>
<tr><td>Rainfall infiltration to soil</td><td></td><td></td><td></td><td></td><td></td><td>Fast</td><td>Slow</td><td>Evidence</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>Rate of mineral cycling</td><td></td><td></td><td></td></tr>
<tr><td colspan="5">For how long is there water available in the soil to enable plant growth?</td><td colspan="4"></td></tr>
<tr><td colspan="5">How is the vegetation influencing current water cycling?</td><td colspan="4">How are they influencing the mineral cycling?</td></tr>
<tr><td colspan="5"></td><td>Vegetation</td><td colspan="2">Herbivores</td><td>Decomposers</td></tr>
<tr><td colspan="5"></td><td colspan="4"></td></tr>
<tr><td colspan="5">current Solar energy flow</td><td colspan="4">current Biological growth</td></tr>
<tr><td colspan="5">How much capture of the Sun's energy is there by plants (photosynthesis)?
(*Indicator: Plant biomass)</td><td colspan="4">Which of the other ecosystem processes is most limiting the biological growth at each level of the food web? and Why?
Decomposers:</td></tr>
</table>

How much flow of solar energy is there from –
Plants to Herbivores (*Indicator: Herbivore biomass/ Presence signs):

Herbivores to Predators (*Indicator: Predator biomass/ Presence signs):

To Decomposer ((*Indicator: Decomposer biomass/ Presence signs):

Primary producers (Plants):

Herbivores:

Predators:

Ecosystem Structure: Current Situation

current Vegetation structure

	<25%	25-50%	>50-75%	>75%	Mainspe
Grasses and herbs					
Shrubs					
Tree saplings					
Canopy tree layer					
Dead & decaying vegetation					

Notes:

current Food web structure

How abundant are the populations of?
Decomposers:

Plants:

Herbivores:

Predators:

current Soil structure

What is the percentage of bare soil?

Has the soil surface has formed a hard cap that is resistant to water and air flow?

Depth of organic layer?

Is the soil compacted?

Key species for current ecosystem functioning and key ecological interactions:

Key species and why?	Key ecological interactions for growth of this species and why?

Ecosystem Structure: Desired Situation

Ecosystem service	Current adequacy of supply	desired Vegetation structure	desired Food web structure	desired Soil structure

Ecosystem dis-service	desired Vegetation structure	desired Food web structure	desired Soil structure

Desired Functioning of Ecosystem Processes for Ecosystem Services

Ecosystem service	Current Adequacy of Supply	desired Water cycling	desired Mineral cycling	desired Solar energy flow	desired Biological growth

Ecosystem dis-service	desired Water cycling	desired Mineral cycling	desired Solar energy flow	desired Biological growth

Key species and ecological interactions for the desired ecosystem structure and processes:

Are there key species whose growth is required for the desired ecosystem services?

Key species and why?	Key ecological interactions for growth of this species and why?

5. Consider ecosystem resilience to drivers of

For each ecosystem type within each management unit:

- Identify physical drivers of change on ecosystems & the probabilities of their occurrence
- Assess the likely impact of drivers on ecosystem functioning & supply of ES
- Adjust management goals if necessary

(Duplicate this section for each management unit)

Management Unit: Ecosystem Type:

5.1 Define the ecosystem services for which resilience is desired and then the desired minimum supply (from Step 3)

Ecosystem service	Minimum supply level

5.2 Identify for each driver of change, pressure or disturbance factor its intensity, probability of occurrence, and likely impact on ecosystem functioning and services

(Duplicate this section for each driver of change)

Driver of change	Intensity	Probability of occurrence	Likely impact on ecosystem functioning	Likely impact on supply of ecosystem services
			Water cycling: Mineral cycling: Solar energy flow: Biological Growth: Vegetation structure: Food web structure: Soil structure: Key species and ecological interactions:	

5.3 Identify any aspects of ecosystem functioning that are particularly limiting the desired ecosystem functioning for the supply of ecosystem services.

5.4 Determine any changes to the descriptions of desired ecosystem functioning so as to increase resistance to, or ability to recover from, the pressures or disturbance factors.

Order the drivers of change in terms of importance

Driver of change	Desired ecosystem functioning for resistance to the driver	Desired ecosystem functioning for ability to recover from the driver

6. Specify management	• Produce a management plan to work with ecosystem functioning for ES supply • Define indicators and monitoring of progress and early-warning of problems • Assess & address capacity to manage for ES.

6.1 List possible management actions to maintain or restore ecosystem structure and functioning for the desired ecosystem services

6.2 Develop management capacity for the range of desired ecosystem services

Considering each of the following components of decision-making and management, assess the current capacity, and suggest some possible measures to develop capacity where required.

Component of decision-making and management	Current capacity (low, medium, high)	Possible measures to develop capacity
Awareness of the environment in terms of ecosystem functioning and services		
Knowledge of the current situation and trends of ecosystem services supply and functioning		
Understanding of ecosystem functioning and services concepts in relation to management of the environment		
Goals and objectives for management for ecosystem services		
Values for adaptive and collaborative management		
Methods and Tools for management of natural resources		
Skills for management of land and water resources with ‘ecosystem thinking’		
Resources to implement management decisions		
Access to land and water resources		
Institutional structures for organisation and implementation of management plan		

6.3 Develop management plan for the desired ecosystem services for each management unit (see template)

The management plan will include indicators of desired ecosystem structure and functioning.

Annex 4. Example ecosystem description and management lessons for a mountain village

This Annex presents some example ecosystem descriptions and lessons from an ecosystem management planning process led by WII, with GBNIHESD and ICIMOD, and technical support from UNEP-WCMC. This was an activity of the Kailash Sacred Landscape Conservation and Development Initiative.

The descriptions of current and desired ecosystem functioning for ecosystem services were produced in March and April 2015 for the village of Bans-Maitoli in Pithoragrah District, Uttarakhand, India. These descriptions were produced following guidance from Steps 1 to 4 of this Operations Manual on Planning Management for Ecosystem Services.

Bans-Maitoli village forms a part of the Kailash Sacred Landscape in India. It is spread over about 438 hectares, with a population of about 1,350 people, and ranges in altitude from 1,000 to 1,800 masl. Major ecosystems and land use/land cover classes include agricultural land (ca. 169 ha), banj oak forest (86 ha), chir pine forests (68.53 ha), and sal forest (11.77 ha). A considerable proportion of banj oak forest is managed by the village forest committee (Van Panchayat). Table 23 gives information on the major land use/land cover classes and a spatial depiction of these categories is shown in Figure 25.

Table 23: Area across various land use/land cover of the Bans-Maitoli village

Land use/Land cover	Area (ha)
Agriculture	168.93
Banj oak forest	86.08
Chir pine forest	68.53
Sal forest	11.77
Scrub land open	30.03
Grassland	59.80
Built up	12.54
Total	437.68

Lessons for planning management for ecosystem services

The preparation of the management plan for ecosystem services of Bans-Maitoli village included descriptions of current ecosystem functioning and services for the principal ecosystem types of grassland, agro-ecosystem, oak forest, and pine forest. These descriptions were produced by students of the Wildlife Institute of India with the villagers, using tools of participatory rural appraisal. Some lessons from this activity and its results are:

- Using the list of ecosystem service types helped to have a comprehensive view of the objectives for management, going beyond provisioning ecosystem services such as food and firewood, to consideration of the role of ecosystems in water supplies, and promoting recognition of important cultural values and uses.
- Management planning tended to focus as much on addressing problems and ecosystem dis-services, such as invasive unpalatable plants and crop-raiding animals, as it did on objectives for ecosystem services supply such as water or

fuelwood. Short-term actions and pilot studies were needed to address these urgent problems, whilst working towards longer-term objectives such as restoration of degraded pastures.

- The descriptions of the current and desired functioning of the water cycling ecosystem process helped to increase awareness and understanding of the role of vegetation and grazing management in affecting the supply of water. This also helped to have a whole catchment view in the management planning.
- The descriptions of the mineral cycling ecosystem process and soil structure raised awareness of the reasons for declines in soil fertility associated with agricultural and grazing practices. Management recommendations included measures to prevent soil erosion and increase fertility, including mulching in croplands and increased agroforestry.
- Consideration of solar energy flow through the food web helped to raise awareness of the need to provide organic matter for soil decomposers as part of agricultural and pasture management.
- The problem of increasing areas of grazing land and exploited forest being colonised by the unpalatable non-native plant *Eupatorium adenophorum* was better understood through consideration of the aspects of ecosystem functioning. Over-grazing of pastures and fires in forests create bare ground, which promotes the establishment of *Eupatorium*. Promotion of biological growth of a diverse vegetation structure can create conditions that prevent the spread of *Eupatorium* and can reduce its abundance (refer to Figure 8 again).
- The first versions of the descriptions of the desired situation for ecosystem structure and functioning often included management recommendations, such as to increase tussock-forming grasses or to construct soil bunds. It is recommended to first describe the desired ecosystem condition, such as 100% soil cover by vegetation, and then separately determine the management actions to promote this desired state.
- The management planning process started with the formation of a stakeholders forum and coordinating agency, and recognised the need to develop the capacity of the Van Panchayat members, Women's Self Help Groups, and youth club to implement the management plan.

Descriptions of current and desired ecosystem functioning in Bans – Maitoli Village

Oak Forest

Extent: 86 hectares

Vegetation features: Banj oak (*Quercus leucotrichoptora*) is the dominant tree species.

Who owns the land: Villagers (Van Panchayat)

Type of land ownership: Communal

Who makes the land management decisions: Van Panchayat (Committee for Community Forestry)

Current management or use: Over 60% of oak forests are lopped and cut for fodder and fuelwood. Villagers also collect leaf-litter from the forest floor to spread under cattle shed and use it as manure. Open forests and forest edges are used for livestock grazing. Nearly 40% of forests have been protected by the villagers in the last 25-30 years, resulting in better regeneration. Some patches have recently been dedicated to local deities as sacred groves.

Management problems: Heavily lopped and grazed oak forests, especially along edges and stream courses, have been infested by an alien invasive plant *Eupatorium adenophorum*, which is unpalatable and may reduce regeneration of the forest. Poorer households cannot afford to buy cooking gas and thus depend heavily on forests for fuelwood and fodder. However, they have limited access to forests.

Ecosystem services obtained from the ecosystem	Current supply	Current harvest	Who benefits
Fuelwood	Ca. 7,200 Quintal per year (@11 kg per day per household)	Ca. 500 Quintal per year. Fuelwood collection is primarily during November to March.	Villagers, especially poorer families. Harvested by women.
Fodder	200 MT per year from forests	150 MT per year	Villagers, especially poorer families. Harvested by women.
Medicinal plants	Not assessed	Limited demand for a few species	Villagers, especially poorer families. Harvested by women.
Regulation of water flows	Stream flow from forested catchments.	Data under compilation	Villagers and downstream villages.

Ecosystem dis-services from the ecosystem	Current impact	Who are affected
Habitat for crop-raiding mammals	Financial loss of INRs. 1,000-2,000 per year per family	Villagers, especially poorer families.

A. Current Status of Ecosystem Functioning

Water cycling	Mineral cycling	Solar energy	Biological growth
Rainfall mostly infiltrates to the soil, with significant transpiration to the atmosphere; some surface run-off in high rainfall events. Fairly open water cycling in the few areas of bare soil; mostly closed water cycling in areas with high diversity of understorey vegetation and significant organic soil layer and tree roots. No evidence of lack of soil moisture for shrubs and tree growth in the dry season	Mineral cycling is fairly open in areas with collection of leaf litter from the forest floor and harvesting of fodder and fuelwood. In regenerating forest the mineral cycling is closed, with increasing soil organic matter. The rate of mineral cycling is fairly slow, with medium levels of litter decomposition, no evidence of dung from mammal herbivores, and little evidence of fungi. Medium cycling of minerals from deeper soil layers by tree roots Most of the minerals are in the trees and organic soil layer.	High rate of capture of solar energy by shrubs and trees Limited flow of energy to mammal and insect herbivores and predators In regenerating forest there is high flow of solar energy to soil decomposers through dead leaves and roots. Most of the biomass in the food web is in the trees and shrubs, with low populations of herbivores and predators, and probably significant biomass of soil decomposers. There is high flow of solar energy (biomass) from the ecosystem, where there is collection of leaf litter from the forest floor and harvesting of fodder and fuelwood.	High growth rate of regenerating oak trees and high diversity of understorey vegetation Heavily lopped and grazed oak forests have developed high density of Kala Bansa (*Eupatorium*) understorey. Low populations and growth rate of vertebrate herbivores, although populations of wild pigs and rhesus macaque are increasing. Significant populations of insectivorous birds indicate significant populations of invertebrates Rich organic soil indicates good habitat for growth of soil organisms.

Vegetation structure	Food web structure	Soil structure
Herb layer – low cover Shrub cover – high and dense (90%), with a rich diversity of shrub species. The major shrubs are *Myrsine africana* (7770 individuals/ha), *Daphne papyracea* (738 individuals/ha), and *Berberis asiatica* (687 individuals/ha). Forest fringes, especially along stream courses, are heavily colonized by Kala Bansa. Tree layer – mostly oak trees, 10% canopy cover. Density of oaks is moderately high (up to 528 individuals/ha with total basal area of 14m2/ha). Banj oak is mixed with other broadleaf species such as *Rhododendron arboreum, Neolitsea pallens, Myrica esculenta, Lyonia ovalifolia* and *Daphniphyllum himalayense*. There is a high proportion of lower girth-class trees. Free grazing by livestock and lopping has affected regeneration of native tree species.	Decomposers – low populations in soil, including earthworms and fungi Plants – vegetation is predominantly oak trees, many of which have been lopped. Many other tree species have been removed or reduced, especially wild fruit-bearing species. Dense shrub layer under open canopy includes regenerating oaks, with dominance of Kala Bansa until canopy closes. Herbivores -- low populations of vertebrate herbivores, although populations of wild pigs and rhesus macaque are increasing and rodents are present. Insect herbivores have low populations. Predators – insectivorous birds are fairly common. Small cats and leopards are present.	Heavily grazed areas have very low humus and soil is compacted. Ungrazed areas with trees and shrubs have porous soil with organic layer

Key ecological interactions: Decomposition of leaf litter by soil micro-organisms, to liberate minerals for plant growth and soil formation.

B: Desired Ecosystem Functioning for Oak Forest

Management objectives	Key aspects of ecosystem functioning for management	Indicators of success
Regulation of water cycling to avoid soil erosion and promote infiltration to ground water for springs	Influence the pathway of rainfall at the soil surface, by its coverage of herbs, shrubs, and leaf litter	Percentage cover of bare soil in forest sampled plots Silt load and turbidity of streams originating from oak forest areas Stream flow originating from oak forest areas Number of days per year when streams originating from oak forest areas are dry
Provide habitat and food for wild herbivores and birds throughout the year, to reduce crop raiding	Vegetation structure and composition favourable for fruit-bearing trees Soil surface structure suitable for germination and establishment of fruit-bearing trees	Abundance of fruiting tree species, including saplings

Water cycling	Mineral cycling	Solar energy	Biological growth
Rainfall mostly infiltrates to the soil, with moderate transpiration to the atmosphere; no surface run-off.	Mineral cycling is closed, with no soil erosion or export of minerals in wood products. The rate of mineral cycling is medium to fast. Most of the minerals are in the organic soil layer, with some in the trees.	Medium to high rate of capture of solar energy by shrubs and trees Moderate flow of energy to mammal and insect herbivores and predators High flow of solar energy to soil decomposers through dead leaves and roots Most of the biomass in the food web is in the trees and shrubs, with low populations of herbivores and predators, and medium biomass of soil decomposers.	Medium to high growth rate of oak trees and other native trees, including fruiting species Medium populations and growth rate of vertebrate herbivores Medium populations of invertebrates and insectivorous birds Low to medium populations of mammal, bird, and insect predators High growth and populations of soil organisms

Vegetation structure	Food web structure	Soil structure
Herb layer – low cover Shrub layer – high cover and dense, with high diversity of species, including regeneration of native trees Tree layer – mostly oak trees with over 50% canopy cover and mixed age structure. Diversity of trees, including fruiting species.	Decomposers – high populations in soil, including earthworms and fungi Plants – vegetation is predominantly oak trees, plus wild fruit-bearing species. Dense shrub layer under open canopy includes regenerating oaks, with limited presence of Kala Bansa under closed canopy and covered soils. Herbivores -- Low to medium populations of vertebrate herbivores Predators – insectivorous birds fairly common. Small cats and leopards present	Porous soil with deep organic layer, covered by leaf litter, herbs and shrubs

Key ecological interactions: Decomposition of leaf litter by soil microorganisms, to liberate minerals for plant growth and soil formation.

Pine Forest

Extent: 68.53 hectares

Features: Conifer forest dominated by Chir Pine (*Pinus roxburghii*)

Who owns the land: Villagers (Van Panchayat)

Type of land ownership: Communal

Who makes the land management decisions: Van Panchayat Committee

Current management or use: Over 50% of pine forests are exploited for fuelwood and heavily grazed by domestic livestock. Frequent fires favour growth of grass and regeneration of pine over oak. Pine forests support low shrub cover in the understorey.

Management problems: Heavily grazed, burnt, and cut pine forests have areas of bare soil or little soil coverage on slopes, resulting in high rainfall surface runoff, loss of minerals and soil structure, and reduced growth and regeneration of ground-level and tree vegetation.

Ecosystem services obtained from the ecosystem	Current supply	Current harvest	Who benefits
Fuelwood	Ca. 2,000 Quintal per year (@11 kg per day per household)	Ca. 1,000 Quintals per year. Fuelwood collection is primarily during November to March.	Villagers, especially poorer families. Harvested by women.
Fodder	5,000 Quintals in the form of grass fodder per year from the pine slopes	1000 Quintals per year	Villagers, especially poorer families. Harvested by women.
Medicinal plants	Not assessed	Limited demand for a few species	Villagers, especially poorer families. Harvested by women.
Regulation of water flows	Stream flow from forested catchments.	Data under compilation	Villagers and downstream villages.

A. Current Status of Ecosystem Functioning

Water cycling	Mineral cycling	Solar energy	Biological growth
Rainfall mostly infiltrates to the soil in moderate rainfall, but with significant runoff in high rainfall, especially on steep slopes. Moderate transpiration to the atmosphere through pine trees. Significant evaporation from soils with little herb or shrub cover. Very open water cycling in the areas with thin and exposed soil.	Mineral cycling is very open, with losses due to surface run-off, fires, leaching, and harvesting of fuelwood. The rate of mineral cycling is slow. Most of the minerals are in the soil subsurface, with some in the trees.	Moderate rate of capture of solar energy by trees Very limited flow of energy to mammal and insect herbivores and predators Little flow of solar energy to soil decomposers through dead leaves and roots. Most of the biomass in the food web is in the trees, with low populations of herbivores and predators, and low biomass of soil decomposers. There is high flow of solar energy (biomass) from the ecosystem, where there is harvesting of fuelwood.	Medium growth rate of pine trees in response to lopping Low populations and growth rate of vertebrate herbivores Low populations of insectivorous birds indicate low populations of invertebrates. Thin organic soil indicates limited habitat for growth of soil organisms.

Vegetation structure	Food web structure	Soil structure
Herb layer – grasses dominate, with bare soil areas Shrub cover – <5% Tree layer – mostly Chir Pine trees. Open canopy.	Decomposers – low populations in soil, including earthworms and fungi Plants – vegetation is predominantly pine trees Herbivores – barking deer, goral; grassland birds such as partridges, cheer pheasant, kalij pheasant, and pipits Predators – Himalayan yellow-throated marten, common leopard, raptors	Thin soils on steep slopes

Key ecological interactions: Decomposition of leaf litter by soil microorganisms, to liberate minerals for plant growth and soil formation

Predation of herbivorous mammals and insects, to regulate their population

B: Desired Ecosystem Functioning for Pine Forest

Management objectives	Key aspects of ecosystem functioning for management	Indicators of success
Provide firewood	Vegetation structure and composition favourable for desired fuelwood tree species Soil structure with sufficient organic matter and conditions suitable for growth of fuelwood trees and their seedlings Export of minerals and solar energy (biomass) in fuelwood does not reduce decomposition (mineral cycling) in the soil to levels that limit fodder tree growth.	Biomass harvested of firewood Biomass of pine and other trees suitable for harvest of fuelwood
Provide limited grazing land if no alternatives exist and desired tree growth not affected	Vegetation structure of palatable grasses and shrubs in areas not managed for tree growth Soil structure with sufficient organic matter and conditions suitable for growth of grasses or palatable shrubs	Grass coverage and growth rate in areas assigned for grazing Growth of shrubs and trees in areas assigned for grazing
Regulation of water cycling, to avoid soil erosion and promote infiltration to ground water for springs	Pathway of rainfall at the soil surface determined by coverage of herbs, shrubs, and leaf litter	Percentage cover of bare soil in forest sampled plots Silt load and turbidity of streams originating from pine forest areas Stream flow of streams originating from pine forest areas Number of days per year when streams originating from pine forest areas are dry

Water cycling	Mineral cycling	Solar energy	Biological growth
Rainfall mostly infiltrates to the soil, with moderate transpiration to the atmosphere and surface evaporation. Low surface run-off	Mineral cycling is fairly closed, with low soil erosion. Export of minerals in fuelwood and some erosion. The rate of mineral cycling is medium. Most of the minerals are in the organic soil layer, with some in the trees.	Medium to high rate of capture of solar energy by shrubs and trees Low flow of energy to mammal and insect herbivores and predators Moderate flow of solar energy to soil decomposers through dead leaves and roots Most of the biomass in the food web is in the trees, with low populations of herbivores and predators, and medium biomass of soil decomposers.	Medium to high growth rate of pine trees and other native trees Low populations and growth rate of vertebrate herbivores Low populations of invertebrates and insectivorous birds Low populations of mammal, bird, and insect predators High growth and populations of soil organisms

Vegetation structure	Food web structure	Soil structure
Herb layer – medium cover Shrub layer – medium cover, including regeneration of pines and broadleaved trees Tree layer – mostly pine trees, with open canopy and mixed age structure	Decomposers – medium populations in soil, including earthworms & fungi Plants – vegetation is predominantly pine trees with medium density shrub layer Herbivores - low populations of vertebrate herbivores Predators – insectivorous birds fairly common. Small cats and leopards scarce.	Porous soil with moderate organic layer, covered by leaf litter, herbs, and shrubs

Key ecological interactions: Decomposition of leaf litter by soil microorganisms, to liberate minerals for plant growth and soil formation

Hillside Grassland

Extent: 60 hectares

Features: The steeper hill slopes towards lower end of the village have been managed by the villagers for hay and fibre-yielding grass, i.e., Babiyo (*Eulaliopsis binata*). Gently sloping areas are grazed by cattle, while steeper slopes are occasionally grazed by goats. Slightly moist, northwest-facing grassy slopes are under secondary scrub vegetation dominated by thorny species such as *Berberis asiatica*, *Rubus ellipticus*, *Rubus niveus*, *Pyracantha crenulata*, and a few others. The canopy gaps are heavily infested by Kala Bansa.

Who owns the land: Community land

Type of land ownership: Public, dual ownership of Bans-Maitoli as well as Jajurali villagers.

Who makes the land management decisions: Van Panchayat, Bans-Maitoli

Current management or use: Unplanned grazing by goats and cattle except in the monsoon season (3-4 months)

Management problems: Low productivity of grass and low growth of livestock. Increasing spread of unpalatable plants, especially *Eupatorium*. Reduced water infiltration and reduction of downstream water supplies. Disputed or unclear land ownership or management arrangements.

Ecosystem services obtained from the ecosystem	Current supply	Current harvest	Who benefits
Grass for livestock	About 60 cattle and 35 goats graze on these grasslands for about 10 months.	From steep slopes 30–35 Quintals of grass are harvested during autumn season	Villagers of Bans-Maitoli as well as Jajurali
Regulation of water flows	Stream flow from forested catchments	Data under compilation	Villagers and downstream villages

A. Current Status of Ecosystem Functioning

Water cycling	Mineral cycling	Solar energy	Biological growth
Rainfall mostly runs off the soil surface, especially during spells of high rainfall. Some rainfall infiltration to the soil. High evaporation from the soil in sunshine conditions. Open water cycling, due to sparse vegetation cover and soil structure	Mineral cycling is very open, with losses due to surface water run-off, leaching, and export in livestock. The rate of mineral cycling is slow. Most of the minerals are in the soil subsurface, with some in the soil organic layer	Low to moderate rate of capture of solar energy by grasses and shrubs Moderate flow of energy to domestic livestock, which is mostly exported from the ecosystem, except for dung Very little flow of energy to mammal and insect herbivores and predators Little flow of solar energy to soil decomposers through dead leaves and roots and dung Most of the biomass in the food web is in the grasses and shrubs, with low populations of herbivores and predators, and low biomass of soil decomposers.	Low growth rate of grasses Low to moderate growth of unpalatable shrubs Low growth rate of domestic and wild herbivores Low populations of insectivorous birds indicate low populations of invertebrates Thin organic soil indicates limited habitat for growth of soil organisms

Vegetation structure	Food web structure	Soil structure
Herb layer – 50% grass cover of native species, but only <10% tussock-forming species, with bare soil areas Shrub cover – 40% cover of Kala Bansa and other unpalatable species, especially along stream courses and roadside water channels, increasing Tree layer – none	Decomposers – very low populations of soil decomposers in grass areas, perhaps slightly higher in shrub areas Plants – vegetation is predominantly grasses and 40% cover of unpalatable shrubs Herbivores – high population of domestic livestock for eight to nine months Predators – very low populations of vertebrate and invertebrate predators	Compacted, thin soils on steep slopes, with thin organic layer

Key ecological interactions: Herbivory by domestic livestock and wild animals, affecting the growth of grasses, whether bare soil appears, and the availability of dung for mineral cycling

Decomposition of grass litter by soil microorganisms, affecting the availability of minerals for plant growth and soil formation

B. Desired Ecosystem Functioning for Grasslands

Management objectives	Key aspects of ecosystem functioning for management	Indicators of success
Provide grass growth for livestock food	Vegetation structure and composition for desired tussock-forming perennial grasses Functioning of water and mineral cycling to provide soil moisture and minerals for grass growth Flow of solar energy to soil decomposers to provide minerals and soil structure for grasses Growth of grasses and shrubs as food for livestock Soil structure for grass growth or growth of unpalatable shrubs, including amount of bare areas Intensity and frequency of herbivory by domestic livestock, affecting growth and survival of grasses, creation of bare ground, and soil compaction	Biomass of gras Harvest of hay Proportion of tussock-forming perennial grasses
Regulation of water cycling, to avoid soil erosion and promote infiltration to ground water for springs	Pathway of rainfall at the soil surface determined by coverage of grass, shrubs and leaf litter	Percentage cover of bare soil in sampled plots Infiltration rate of water to soil in sampled plots Silt load and turbidity of streams originating from grassland areas Stream flow of streams originating from grassland forest areas Number of days per year when streams originating from grassland areas are dry

Water cycling	Mineral cycling	Solar energy	Biological growth
Rainfall mostly infiltrates to the soil, with moderate transpiration to the atmosphere and surface evaporation. Low surface run-off	Mineral cycling is fairly closed, with low soil erosion. Export of minerals in livestock and some erosion The rate of mineral cycling is medium Most of the minerals are in the organic soil layer, with some in the grass	Medium rate of capture of solar energy by grasses Low flow of energy to mammal and insect herbivores and predators Moderate flow of energy to domestic livestock, which is mostly exported from the ecosystem, except for dung Moderate flow of solar energy to soil decomposers through dead grass and dung Most of the biomass in the food web is in the grass, with low populations of herbivores and predators, and medium biomass of soil decomposers	Medium growth rate of grasses Low growth rate of shrubs Medium populations and growth rate of domestic herbivores Low populations of invertebrates and insectivorous birds Low populations of mammal, bird, and insect predators High growth and populations of soil organisms

Vegetation structure	Food web structure	Soil structure
Herb layer – >90% cover of grasses, with predominance of tussock-forming perennial species Shrub layer – <10% cover Tree layer – absent	Decomposers – medium populations in soil, including earthworms & fungi Plants – vegetation is predominantly grasses, with predominance of tussock-forming perennial species <10% cover of shrubs Herbivores - low populations of wild herbivores, medium population of domestic livestock Predators – insectivorous birds fairly common. Small cats and leopards scarce	Porous soil with moderate organic layer, covered grasses with leaf litter

Key ecological interactions: Decomposition of leaf litter by soil microorganisms, to liberate minerals for plant growth and soil formation

Herbivory by domestic livestock and wild animals, affecting the growth of grasses, whether bare soil appears, and the availability of dung for mineral cycling

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