HANDBOOK

FOR THE PROMOTION AND USE OF ECOSYSTEM SERVICES IN WETLANDS

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HANDBOOK

FOR THE **PROMOTION** AND **USE** OF

ECOSYSTEM SERVICES

IN **WETLANDS**

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PREMISE

Many areas share habitat degradation of Sites of Community Importance/Special Areas of Conservation (SCI/SAC) subject to human pressure and the spread of Invasive Alien Species (IAS). On both sides of the Alps, managers and research centres confronted with such issues have been restoring habitat ecology through the RestHAlp project. The project focuses on wetland ecosystem service assessment to promote, foster and support the implementation of ecological restoration policies. The approach is a good tool to enhance exchange among the players in the community because of its holistic comprehensive method by and for the socio-ecosystem. However, the difficulty in setting up case studies in the Alps, which could be practical locally acceptable examples appeared to limit stakeholder involvement in an assessment.

Indeed, the study of ecosystem services of wetlands has rarely been applied to actual case studies in the context of the Western Alps despite the many world level research projects[1]. However, the aim of the RestHAlp project is not to conduct comprehensive site assessments, but to build examples explaining the benefits of wetlands and the importance of initiating assessment so that stakeholders can become involved in their ecological restoration.
We are therefore at Step 3 of the assessment process proposed in the Ramsar Technical Report[2], namely a functional analysis of the study sites.

The ecological processes and components of wetland functioning are studied and then translated into a list of ecosystem services. The benefits of these services will then be analysed and quantified in appropriate units of value, as envisaged in Step 4 of the approach. Both steps require the collection and/or collation of biotic and abiotic data on environment functioning. We are particularly interested in the hydrological and biological features that provide the supply, support and regulation services, as well as the cultivation and amenity services.

Given the experience gleaned from the project, partners wanted to write a handbook to help project leaders better understand the concepts and methods used in undertaking the assessment of ecosystem services.

The main steps of the Ramsar assessment process

- **Step 1 -** Analysis of policy processes and management objectives: why undertake the assessment?
- **Step 2 -** Stakeholder analysis and participation: who undertakes the assessment and who for?
- **Step 3 -** Functional analysis (identification & quantification of services): what should be assessed?
- **Step 4 -** Service evaluation: how to undertake the evaluation?
- **Step 5 -** Communicating wetland values: who should the assessment results be given to?

THE RESTHALP PROJECT: **ECOLOGICAL RESTORATION OF HABITATS IN THE ALPS**

A European cross-border cooperation project (Interreg ALCOTRA Italy-France 2014-20) involving various French (CEN 73, CBNA, INRAE) and Italian (IAR, Gran Paradiso National Park, Autonomous Region of the Aosta Valley- Struttura biodiversità e aree naturali protette) partners, lasting 38 months, from 2017 to 2020. The project is intended for the ecological restoration of habitats in and around Sites of Community Importance (SIC). Actions include work-package 3 devoted to increasing knowledge of biodiversity and ecosystem services to improve habitat management.

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INTRODUCTION

This handbook is intended for **managers, community experts and project leaders** who wish to better understand, use the concept or engage in the process of evaluating ecosystem services to promote their restoration and specifically that of wetlands. The present handbook does not exhaustively cover all the methods and tools proposed in the vast international literature. Nor is it the umpteenth valuation method or step-by-step method to implement ecosystem service assessment.
The handbook is intended to provide a good understanding of a field of study that is increasingly used as a framework to exchange ideas and as an interface between and among institutional, economic and biodiversity stakeholders.
The present text is based on references from technical and scientific literature in English and French, and more specifically on three publications that we believe are references for the appropriation and implementation of the assessment approach: the **Ecosystem Services Toolkit**[3] and the **Methodological Handbook to enhance adaptation decision making**[4] or **Toolkit for Ecosystem Service Site-based Assessment (TESSA)**[5].

The subject will be discussed in the form of a list of questions to ask to use the concepts, master the approach, use study results or assess. They are classed by themes and can be represented by the following diagram.

USING **ECOSYSTEM**

WHAT ARE ECOSYSTEM SERVICES?

- What is meant by the notion of ecosystem service?
- How can ecosystem services be classified?
- What services do wetlands provide?

WHAT IS THE ADVANTAGE OF USING THE IDEA OF ECOSYSTEM SERVICE?

- What is the purpose of assessing ecosystem services?
- What are the purposes of ecosystem service assessment?
- How can it be used in the context of restoration?

HOW TO SET UP AN ECOSYSTEM SERVICES ASSESSMENT PROCESS?

- What methodology should be used?
- Who assesses ecosystem services?
- What are the frameworks for evaluation?
- What tools are available?

THE IDEA OF **SERVICES**

HOW TO ESTABLISH LINKS BETWEEN SITE FUNCTIONING AND ECOSYSTEM SERVICES?

- Which wetland functions provide services?
- How can wetland functions be measured?
- Mapping of the territorial functionality of ecosystem services

HOW TO ASSIGN A VALUE TO ECOSYSTEM SERVICES?

- Qualification when using the definition "ecosystem values"
- What type of value should be assigned?
- What value attribution method?

WHICH SERVICES DO ALPINE WETLANDS PROVIDE?

- Provisioning services
- Regulating services
- Cultural services

WHAT ARE
ECOSYSTEM SERVICES?

Ecosystem services appeared in the 1970s, as part of how Western societies perceived the environment, and have been the subject of a significant intellectual and methodological production[6] since the concept was first defined by the Millennium Ecosystem Assessment (MEA)[7] in the 2000s. Since then, and a few dozen scientific publications, we have now moved on to several thousand articles, a sizeable literature which newcomers, managers or project leaders cannot fully take in.
The scientific metaphor aiming to raise awareness, the new way of conceiving human/nature relations, became what is now a complex evaluation system to conserve or manage nature. It is necessary to briefly retrace the history of this approach to fully understand its framework. It is both simple to understand and complex to use[8]. Currently it is *a sine qua non*, seen as an effective medium to encourage inter-stakeholder exchanges and enable the implementation of operations to preserve or restore/regenerate wetlands.

What is meant by the notion of ecosystem service?

Definition

The definition *ecosystem service* is construed as a metaphor that pieces together two notions referring both to ecology and to economy. It has a human centred vision of nature, it reflects both the dependence of humans on ecosystems, but also marks the fact that such ecosystems are there to serve humans. Forged within the framework of ecological modernity thinking[9], as stated by Dufour *et al* (2016), the concept seeks to address the human-induced biodiversity crisis through technology and market-based management. In the introduction to the book *Political ecology of ecosystem services*, the authors question the status of the term «ecosystem services». To use their definitions, is it a successful keyword, a notion, a concept or a new paradigm? They believe it has become more than a keyword, that the expression marks a change in the relationship between humans and nature, that that it reflects a set of elements that are intended to generate standards, movements of opinion or governance systems. By default they use the term notion, which we will also use in the present handbook, as it gives a general idea: everyone more or less agrees on the meaning, without there being a clear shared definition.

Historical perspective of the emergence of the notion of ecosystem services

Many authors trace the term being first mentioned in a preparatory report for the 1972 Stockholm conference *(Study of*

Critical Environmental Problems, 1970 - Massachusetts Institute of Technology). *Ecosystem service* is a notion developed by North American conservation biologists[10] and economists[11], developed during the 1980s and 1990s. The definition became an established term at the turn of the 21st century, as illustrated in the figure below through the evolution of the number of scientific publications.
Various authors[12] have studied the emergence of ecosystem services concept and consider several phases. Until 1997, and the article by Costanza *et al.* in the journal Nature - undeniably a watershed - the notion of ecosystem service emerged in the field of conservation biology to justify the value of biological diversity. However, during the 1990s, following the onset of trans-disciplinary cooperation between economists and ecologists, echoing great changes in science, disciplinary barriers were overcome in the context of trade globalization. The development of a common scientific culture meant the term was picked up by the media shifting its use from the scientific to the political sphere. The appropriation of the concept by decision-makers and political players during this period was favoured by two major trends; the emergence of adaptive management in ecology[13], implemented by managers through the imple-

TWO DEFINITIONS ARE PROPOSED HERE:

- *ecosystem services are the benefits that humans derive from ecosystems [MEA];*
- *ecosystems, and biodiversity more generally, sustain and provide many services, known as ecological services or ecosystem services, generally classed as common and/or public goods, as they are vital or useful for humankind, other species and economic activities [IUCN].*

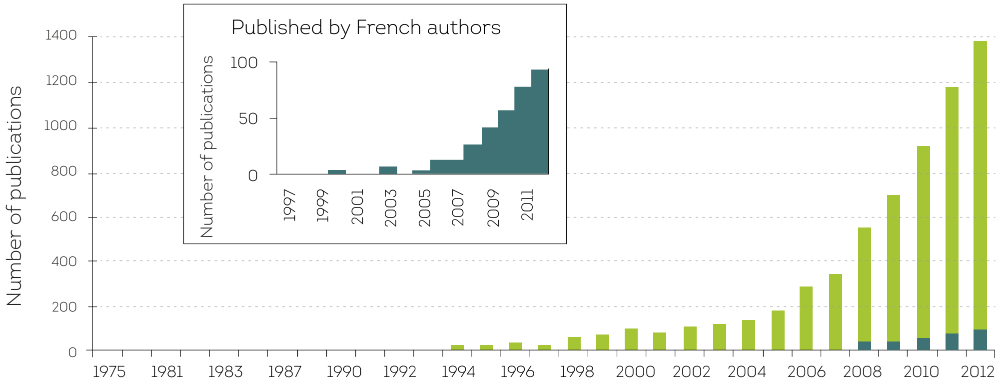


Figure 1 - Number of publications referring to ecosystem services from a Web of Science search.
International literature *French publications*

mentation of plans, and the idea of a socio-ecological system[14], which blurs the boundaries between ecological and social systems and puts human beings back into nature.

This new way of thinking about nature conservation used in scientific literature was thus mainstreamed in the years 2000-2005, and moved into the international political sphere: Millennium Ecosystem Assessment (MEA), commissioned by the United Nations, 2005, followed by Europe (Mapping and Assessment of Ecosystems and their Services, 2012), France (*Évaluation Française des Ecosystèmes et des Services Écosystémiques* since 2013) and Italy *(Rapporto sullo Stato del Capitale Naturale in Italia*, since 2017). As a result, this scientific knowledge yielded a concept that has influenced environmental policies. After the consensus around MEA's idea, the balance between economy and ecology started to change: scientific publications have multiplied in ecology journals, but this is not the case in economics ones. The economic sphere has become more prominent in public policy, as illustrated by The Economics of Ecosystems and Biodiversity (TEEB)[15] initiative. In order to make the concept fully operational for decision-makers and environmental managers, a major effort to develop methods and tools has been started and has led to the emergence of tensions between the educational use of the concept and its implementation.

As the work and the number of researchers involved in ecosystem services increase and the general public is more familiar with them, other related notions are also emerging, such as Payments for Environmental Services, for example. The scientific community has become organized in around sub-disciplines, which do not always communicate, contributing to a segmented idea of the ecosystem services.

Debates and controversies

Ecosystem services are the subject of debate and controvers[16]: criticisms are twofold, linked to the concept, with a view to improving its effectiveness, and more fundamental about the ethical dimension implied by the notion of service.

While the idea is vague enough to be effective from an educational and political point of view, it generates confusion between ecosystem processes and functions and their use (by human beings). The result is a very wide variety of definitions of services, which becomes problematic when it comes to measuring them in the assessment[17]. On the other hand, the functional links between biodiversity and ecosystem services are complex and still poorly characterized[18]. Information on the biological status of ecosystems can often be insufficient to understand and integrate interactions between ecosystem functioning, social organizations and economic systems into decision-making[19]. The implementation phase must also be also discussed: more philosophically, it is questioned because of its anthropocentric Western vision and the economic view of relationship between humans and nature that it entails[20].

Although controversial, the idea was developed to reveal in current decision-making systems what is currently invisible. This provides an effective framework for exchange among stakeholders to start preservation/conservation or restoration/reclaiming of wetlands. In a context where the protection of nature is queried, it provides an argument for its defenders.

«While this new paradigm has its own limitations and risks, it would be utopian to ignore it and base our efforts for the conservation and wise use of wetlands on entirely different values. It is therefore necessary to assess the value of the goods and services provided by wetlands if conservation is to outweigh all possible options for the use of the land or water that feeds wetlands»[21].

How can ecosystem services be classified?

As overviewed, the range of definitions, appropriation, and implementation results in services is being classed in very many different ways in literature. In addition, the literature reveals a multiplicity of service definitions[22]. For example, a study of 142 publications shows that no less than 36 different definitions have been used in the culture sector to designate the same service relating to landscapes in ecosystems. In the same article by Blicharska et al (2016), only 18% of all terms or expressions used met the definition of «ecosystem service» and 45% of them only referred to advantages. Identification and classification of services is an essential first step, as they make up the reference framework for study, and are used in the implementation of any approach to the use or valuation of ecosystem services. This choice can follow Fisher *et al.'s* (2009)[23] review of the many existing classifications. The authors give examples of decision-making contexts for managers of natural areas and propose the most appropriate classifications for each one.

For the purpose of promoting and raising awareness in the broad public, the use of the MEA classification into 4 categories (supporting, regulating, provisioning and cultural services) seems appropriate.

Table 1 – A summary of ecosystem services according to MEA.

Supporting Services Soil Formation, Photosynthesis, Primary Production, Nutrient Cycle, Water Cycle	**Provisioning Services - *direct use value*** Food (crops, animal husbandry, fisheries, aquaculture, wild plants and animal feed), fibres (wood, cotton, wood energy), gene banks, biochemistry and bio-pharmacy, fresh water.
	Regulating Services - *indirect use value or benefits* Regulations and standards on air quality, global and regional/local climate, water, erosion, water purification and waste treatment, diseases, pest regulation, pollination, and natural hazards.
	Cultural Services - *non-use or nonmaterial benefits* Cultural diversity, religious and spiritual values, knowledge systems, educational values, inspiration, aesthetics, social relationships, sense of place, cultural heritage, leisure and ecotourism.

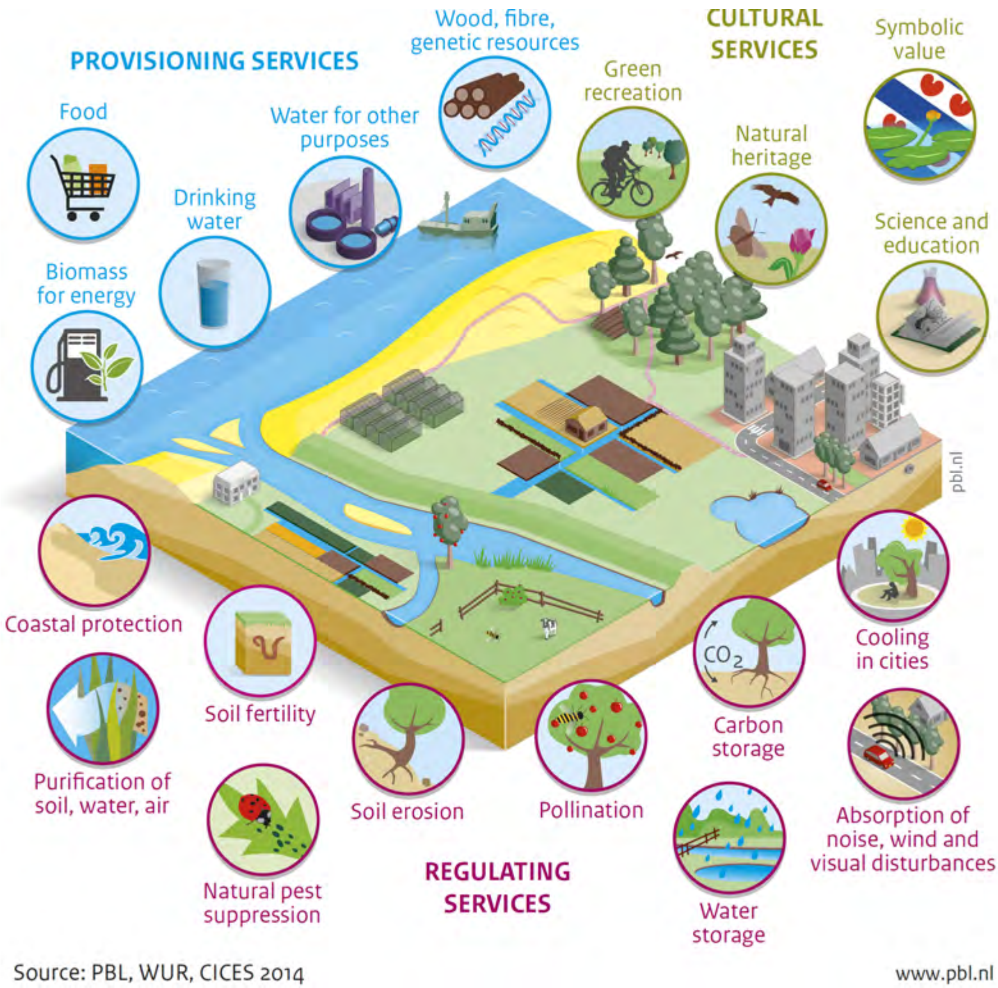


Figure 2 - Overview of different types of ecosystem services in the CICES system (PBL, WUR, CICES - 2014).

Debates on the topic by ecologists confronted with services, tend to ignore supporting services in the most recent classifications. According to ecosystems inner processes, they exist independently of their use and are sometimes considered redundant with regulating services. One of the most elaborate systems, known as the Common International Classification of Ecosystem Services (CICES)[24] updated in 2018, integrates the biotic and abiotic dimensions with 11 classes grouped in 3 themes, which we briefly present below.

Provisioning services

These cover all goods and products, whether food or non-food, derived from living organisms, but also from the abiotic constituents of the ecosystem (including water).

Regulating and maintenance services

They refer to how living organisms or abiotic features of the ecosystem can mediate or moderate the surrounding environment affecting human health, safety or comfort. These may include biochemical or physical transformations in ecosystems or the regulation of large material flows beneficial to people.

Cultural services

Anything that affects the physical and mental state of people in ecosystems. They relate to environments, places or environ ect interactions between people and living systems.

What services do wetlands provide?

The range of wetland services

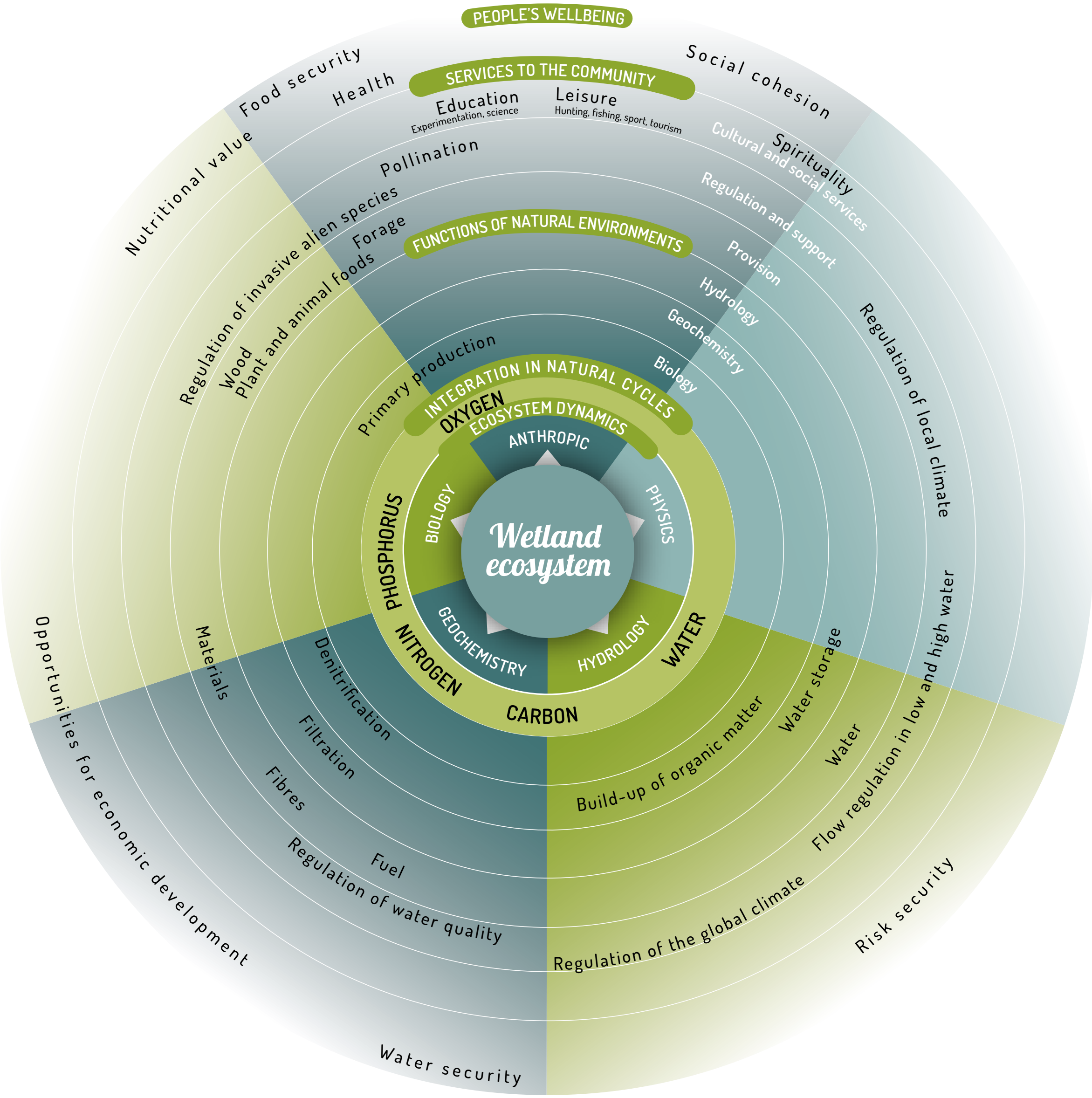
There is a great variety of wetlands. Various studies suggest that they are likely to account for about 25 of the 43 recognised ecosystem services in France[25]. These include their role in flood control, groundwater recharge, water purification, recreational practices, the mitigation of global change or coastal stabilization as well as other. The Ramsar Technical Report *Valuing Wetlands: guidance for valuing the benefits derived from wetland ecosystem services*[26] presents a broad overview of the services they provide, distinguishing between inland and coastal wetlands. However, the diversity of ecological functioning and interactions with human societies considering marshes and peat-lands, alluvial or coastal zones, makes it impossible to formulate a single answer on wetland ecosystem services. Although examples of assessment by wetland type are still few and far between, some are now available for managers, benefiting from the knowledge and studies carried out, as is the case for peatlands.[27]

Proposal for wetland adapted classification

In the framework of the RestHAlp project, we have used the following classification built around three categories taking into account the recent evolutions presented above, and the specificities of the wetland ecosystem.

REGULATING AND MAINTENANCE SERVICES resulting from the regulation of natural processes and basic ecosystem functions. Such services include, «Regulation of the global and local climate» which among other things comes from the carbon storage in wetlands. The service of «Purification and maintenance of water resource quality» is provided by retention/degradation of suspended matter and other substances such as phosphorus or nitrates. Other services concern biodiversity, such as «Conservation of species and genetic diversity», which refers to the role of wetlands as breeding and feeding habitats for certain species.

PROVISIONING SERVICES that produce «end products» from the ecosystem. Wetlands can provide fibre, fodder for agriculture, timber, fisheries resources, etc.

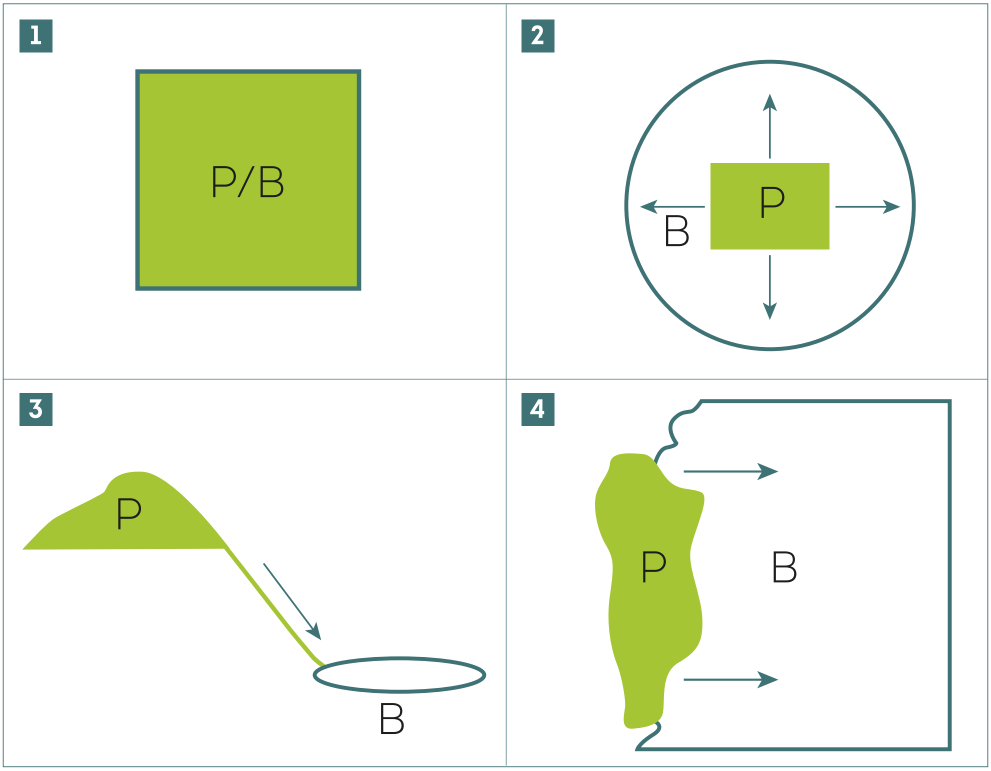


▲ Figure 3 - Links between wetland ecosystem functioning and services.

▶ Figure 4 - Spatial relations between service production areas (P) and areas benefiting from services (B) according to Fisher et al. (2009).

CULTURAL SERVICES: defined as the non-material benefits that ecosystems can provide through spiritual enrichment, cognitive development, reflection, creation, aesthetic experiences. This category includes services such as «Opportunities for research» related to their role as environmental archives (reconstitution of past climate through paleo-ecology, archaeology, etc.), «Landscape amenities» that make use of the aesthetic quality of wetlands, or the place of wetlands in the cultural heritage of the population (contributions to cultural identity).

Other types of classifications of services that integrate their spatial characteristics also appear to be well suited to the study of wetlands. Indeed, wetlands provide services at different scales, often beyond their strict boundaries (e.g. flood protection services or global climate regulation services)[28]. We will not discuss them in more detail here, but will address the consideration of spatial and temporal scales in the following chapters.



1 - production and beneficiaries in the same place
2 - the service is provided in all directions and benefits the surrounding landscape
Specific benefits due to its location in the area
3 - downstream area benefiting from upstream product services
4 - area benefiting from its location because of the protection of the production area.

WHAT IS THE ADVANTAGE OF USING THE IDEA OF ECOSYSTEM SERVICE?

What is the purpose of assessing ecosystem services?

This question brings us back to the debates on the definition of ecosystem service (see «Debates and controversies»). Wolf et al (2017) and J-M Salles (2010) addressed this issue in literature which we draw the following statement from: the interest of the assessment approach is not to *«give an economic value to nature, which is unnecessary, but to translate the value of losses resulting from the destruction of ecosystems in terms that allow ecosystem services to be compared to other societal issues»*. It is a response to the pressures on biodiversity to influence decisions by making nature's values explicit.

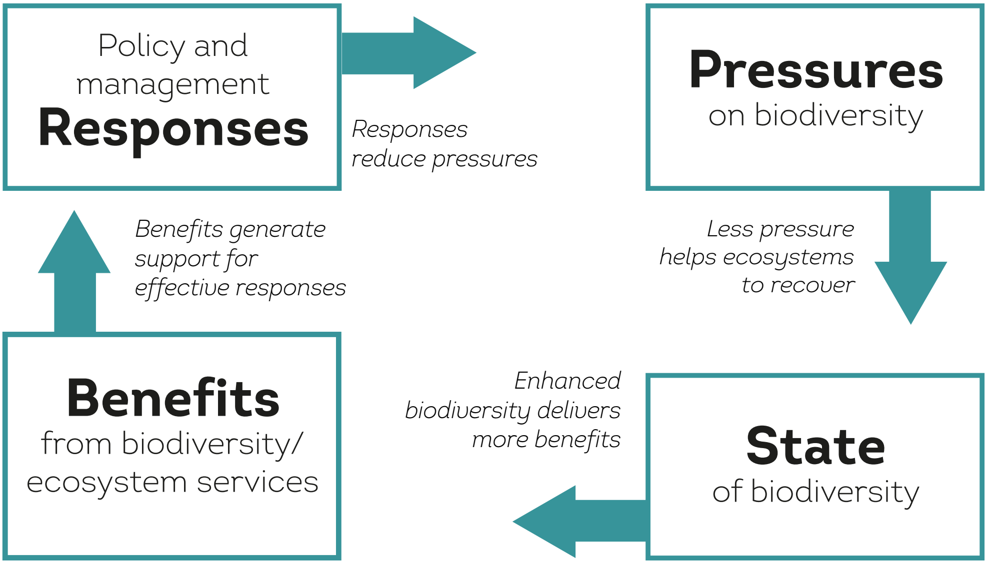


Figure 5 - Relationships between ecosystem services, the state of biodiversity, the pressures it faces and the responses to these pressures, in TESSA (2013). Adapted from Sparks et al. (2010) Linked indicator sets for addressing biodiversity loss. Oryx 45(3): 411-419.

What are the purposes of ecosystem service assessment?

Four issues concerning the use of the concept can be put forward in the light of the experience feedback studied in the scientific literature.

Management: monitoring and policy implementation

One of the oldest approaches is to streamline biodiversity conservation strategies to maximize the effectiveness of public policies, a use in nature management. This management issue is also of interest to economic and financial players. The approach is used as a management tool for biodiversity policy other than image issues that lead companies to try and understand the material nature of environmental issues in terms of risk, impact and dependence. Since 2002 in France companies listed on the stock exchange have been required *(Nouvelles Régulations économiques)* to present «the measures taken to preserve or foster biodiversity»[29] (Decree No. 2012-557), and the approach has often been initiated with a request for a standardised methodology.

Ecosystem services are increasingly used as tools for territorial planning and development. Taking the spatial dimension through cartographic methods into account makes it possible to translate the changes in a territory, on a global scale but even more so on a local scale. At the regional scale it is consolidated and the mapping of ecosystem services can be a winning formula for truly sustainable planning. It appears to be a key instrument for raising awareness of the subject and providing practical tools directly applicable to technical and political decision-makers operating in the area[30].

Decision-making support - organization

Ecosystem services assessment tools are now used by project leaders for scenario analysis and decision-making support with the aim of improving project acceptability[31]. It makes it possible to take the costs and benefits of each option into account and evaluate the loss of social well-being caused by a project[32]. This makes it possible to conduct decision-making processes by putting economic sustainability, human well-being and ecosystem conservation on a par[33].

Paying for ecosystem services, compensation – financing

By monetizing services it is possible to consider the evaluation of their potential, in order to fund the management or restoration of ecosystems favouring their maintenance. From this perspective, managers of natural environments (farmers, associations, communities) could develop new sources of income/financing through the development of market instruments such as payments for ecosystem services. This issue leads to an interest in ecological equivalence, as developed in compensation mechanisms.

Communication - awareness-raising

Ecosystem services are widely used to communicate and raise the awareness of stakeholders and users on the issues at stake for the preservation of ecosystems. In this sense, they contribute to forging the prerequisites for individual decision-making in favour of ecosystem preservation and obtaining the support of local stakeholders and the public in implementing policies or management operations based on factual data.

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How can it be used in the context of restoration?

Here we wish to develop the discussion on a specific use framework, that of ecosystem restoration, which was at the heart of the RestHAlp project.

As an example to convince people of the value of using it in the restoration of ecosystems

In the space of about thirty years, ecological restoration has come into its own as a means of action in favour of biodiversity in France and throughout the world. However, given its cost, the difficulties in implementing it or the uncertainties about its results, it is still necessary to convince local stakeholders of its merits, despite growing support from public policies.
The idea of services in raising awareness and convincing the public is quite an interesting approach. It is a matter of communicating and alerting how strong the dependence of societies on natural environments is and making their value visible. Using examples of ecosystem services assessment in a comparable geographical context is particularly useful. These are archetypal examples, as was the case in the field of water management in the New York metropolitan area and the preservation of the environment in the Catskills region[34].

The general message disseminated through its educational dimension is the most important thing, and it is all the more effective if it presents a situation like that experienced by the actors whom the message is addressed to. Indeed, presenting the example of the investment of nearly 1.5 billion dollars over ten years to reduce pollution in a catchment area located 150 km north of a town of 22 million inhabitants and avoiding the construction of a 7 billion dollar water treatment plant can at the very least arouse scepticism among the elected representatives of small mountain communities.

As a method of assessing profits

This corresponds in part to a local variation of the above use, but it goes beyond it. The idea here is to use the notion of ecosystem services to facilitate discussions among stakeholders and to facilitate a decision support process in initiating restoration.
This use requires the identification of services and beneficiaries and leads to the assessments in their numbers and types (qualitative or quantitative evaluation). Initially it was seen as a «gateway» so that several stakeholders with different scientific backgrounds and individual paths could exchange ideas. It is also a multi-use reading grid where the different values associated with ecosystems are taken into account.

Such exchanges make it possible to clearly establish the link between biophysical processes and services, to locate the natural environments to be analysed, to assess their value and discuss the nature of possible interventions. By allowing stakeholders in the territory and in management to express themselves and locate the values they attribute to wetlands, it enhances their support in the restoration project.

The implementation of participatory or collaborative assessment approaches enables each stakeholder to measure the impact of restoration actions on each service. To do this, each «expert» stakeholder uses a score system based on an ordinal system or on economic estimates of the services analysed (see: *What tools are available?*).

HOW TO SET UP AN ECOSYSTEM SERVICES ASSESSMENT PROCESS?

Assessing the value of ecosystem services means adopting an interdisciplinary approach to understand how ecological functions intersect with human actions. It is also a collaborative examination of the different disciplines that contribute to value attribution.

4.1 What methodology should be used?

Currently there are several methodologies and guidelines to carry out assessment studies of ecosystem services. These methods may propose different approaches, depending on the scale of the study, proposed use, and the availability of data on ecological functioning. We refer the reader to three proposals:

THE **ECOSYSTEM SERVICES TOOLKIT** (310 pages), for managers and analysts. It was developed in Canada to support policy development and decision making, and is a practical guide for conducting and using ecosystem services assessment in a national approach. It has many worksheets to help set up the assessment.

THE ECONOMIC VALUATION OF ECOSYSTEM GOODS AND SERVICES IN A CLIMATE CHANGE CONTEXT (218 pages) *(L'évaluation économique des biens et services écosystémiques dans un contexte de changements climatiques)* to ensure maximum homogeneity and standardization in the use of tools in Quebec. These tools should make it possible to assess changes in the economic use and non-use values related to variations in the quality of ecosystems and the ecosystem services they provide to society in the context of climate change.

THE **TOOLKIT FOR ECOSYSTEM SERVICE SITE-BASED ASSESSMENT (TESSA)** (150 pages, 27 pages on methods, 7 Q&A and 23 appendices) was designed to provide practical advice on assessing and monitoring ecosystem services at the site level. It helps users identify the services to be assessed, the data needed to measure them, the methods or resources that can be used to obtain these data, and how to communicate the results in order to better conserve biodiversity.

The above are very extensive documents, and we propose here to summarise the main common methodological elements.

- Assessment is an interdisciplinary approach to understand all the topics and implement a multi-criteria analysis. It involves different stakeholders, a project team that conducts the study, and experts in the human and environmental context.
- The various methods distinguish several steps in the evaluation process: 6 steps for the **Ecosystem Services Toolkit** and 8 for **TESSA**. These include the defini-

tion of the evaluation framework which is crucial as it requires knowing the ecological and political context in which the study takes place to identify the questions that the assessment will have to answer.

- There is usually a preliminary assessment step to identify ecosystem functions, stakeholders, services, beneficiaries, which will help organize the assessment process.
- A dissemination step to inform stakeholders for a common understanding of terms and issues is often necessary.

Assessment is based on the collection of both ecological and socio-economic data, which is not always easy to implement. Several metrics or indicators are used: for example the panel of possible data can be used with the table below.

Table 2 - Example of indicators of ecological functions, natural capital, ecosystem services and benefits of ecosystem services for wetlands (adapted and modified from the Ecosystem Services Toolkit).

ECOSYSTEM SERVICE	INDICATORS FOR NATURAL CAPITAL AND ECOLOGICAL FUNCTIONS	HUMAN BENEFITS INDICATORS
PROVISIONING SERVICES		
FOOD	Total stock (t/ha)	Number of people employed, including self-employment, in harvesting, processing and distribution of these goods
	Net productivity (kcal/ha/year)	
	Presence of edible plants/animals	
CROPS	Total area cropland (ha)	
	Realized crop production (t/ha/year)	
LIVESTOCK	Total area of grasslands suitable for grazers	
	Density of grazing livestock	
	Fodder production (t/ha/year)	
CAPTURE FISHERIES	Size of catch	Number of fishing licenses (rights of access)
WILD FOODS	Amount of game meat caught	Number of wild foods harvested in an area
	Animals killed	Number of licensed hunters (rights of access)

TIMBER AND BIOMASS FUEL	Total biomass (t/ha)	Number of people employed, including self-employment, in harvesting, processing and distribution of these goods
	Net productivity (t/ha/year)	
	Presence of species or biotic components with potential for use	
FRESH WATER	Total amount of water (m^3/ha)	Number of people with access to clean water
	Amount of water extracted per year per area	Cost to clean water where ecosystem is degraded
	Presence of water reservoirs	
GENETIC MATERIAL	Total number of species and sub species	
	Total biomass (t/ha)	
BIOCHEMICAL AND MEDICINAL RESOURCES	Quantity of native species harvested for this purpose	Number of native species used by the pharmaceutical industry
		Sales or profit from development of products
REGULATING SERVICES		
EROSION REGULATION	Amount of sediment captured	Incidence, cost or risk of harm and damage to persons or property from flooding (e.g. due to wetland loss)
	Soil (e.g. organic matter, permeability)	
WATER PURIFICATION	Retention time of water in ecosystems	Volume of effluent released per geographical area
	Comparison of pollutant concentrations between water flowing in and out of the system	
	Biochemical degradation capacity of COD (g/m^3/day)	Cost of having to build wastewater treatment plants
	Amount of N and P stored (kg/ha/year)	
NATURAL HAZARD REGULATION	Wetland area/depth	Incidence of harm and damage to property from natural hazards (landslides and floods)
	Water storage capacity	Associated costs to property, healthcare system, worker productivity
	Reduction in flow/runoff	Sense of security expressed in relation to natural hazards
	Delay of flood peaks	

WATER-FLOW REGULATION	Water retention capacity in soils	Incidence, cost or risk of flooding
	Peak flows	
	Infiltration rates in soil	
	Floodplain water storage capacity (mm/m)	
	Area coverage of wetlands	
	Flood events per year	
CLIMATE REGULATION	Carbon stocks above and below ground	Security of regional food sources if regional production declines due to climate change or other climate-related impacts
	Evapotranspiration and photosynthesis (e.g. leaf area index)	Risk of drought/flooding associated with agricultural production
	Soil organic matter in volume or percentage	
CULTURAL SERVICES		
CULTURAL IDENTITY AND HERITAGE	Number of species or area of culturally important ecosystem/landscape features	Level of satisfaction expressed with the ecosystem
	Number of people using the ecosystem for cultural heritage and identity	
SPIRITUALITY AND RELIGION	Species or ecosystem/landscape features with spiritual value	Access to and use of known sacred places
	Number of people who attach spiritual or religious significance to the ecosystem	Expressed sense of peace from being in nature
		Expressed spiritual significance of the ecosystem
INSPIRATION FOR HUMAN CREATIVE THOUGHT AND WORK	Number of species or area of ecosystem/landscape features with inspirational value	Extent of literary/artistic work (e.g., number of writers, photographers, etc. or number of products, such as publications, websites)
	Number of books, paintings, etc. using the site as inspiration	Number of courses, workshops, events devoted to art

RECREATION AND TOURISM	Area of the site with stated recreational value	Participation (number of people) in nature tourism, nature-based recreation
		Number of events or facilities
	Site accessibility	Visitors (number or hours) to the site
		Money/time invested in performing activities on the site
		Expressed appreciation for recreation opportunities
SENSE OF PLACE	Number of people who consider the site as important to their sense of place	Marketing targeting the site
		Local involvement in nature protection activities
		Events linked to the site contri-buting to community identity
KNOWLEDGE SYSTEMS AND EDUCATION	Number of school classes visiting	Number of participants in voluntary conservation and citizen science actions
	Number of scientific studies	Number or percentage of population employed in site-related professions
COGNITIVE DEVELOPMENT, PSYCHOLOGICAL AND PHYSICAL HEALTH AND WELLBEING		Use of the site in health programmes
		Participation rates in nature groups
		Number of people who have chosen to live close to the site
		Benefits expressed by users
AESTHETIC EXPERIENCE	Number/area of landscape features with stated appreciation	
	Expressed aesthetic value	

The diagram below, also from the **Ecosystem Services Toolkit**, summarizes the framework and steps for the assessment.

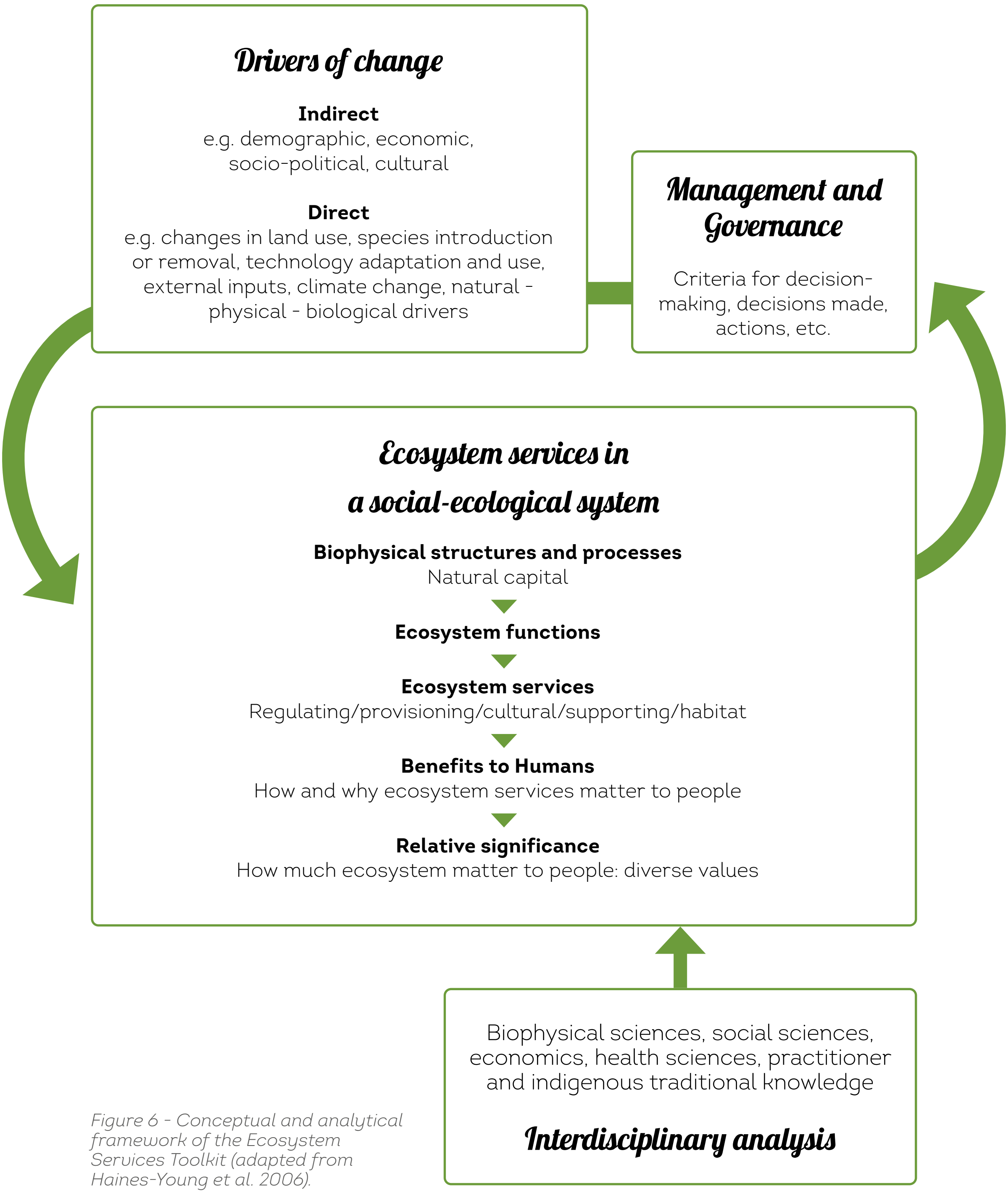


Figure 6 - Conceptual and analytical framework of the Ecosystem Services Toolkit (adapted from Haines-Young et al. 2006).

Who assesses ecosystem services?

This question is crucial as it determines the results and their use, especially when the approach is used to promote the implementation of restoration projects. In defining who should be involved at a stage of the process in assessing ecosystem services, we refer to stakeholders. Stakeholders must become involved and have a stake in the results for a positive outcome.

To define the list of stakeholders, an analysis matrix can be used to define them according to the following criteria:

- their characteristics (type of organisation/individual);
- their main interests in the site;
- their site title (owner, manager, farmer, other users, etc.);
- their impact on the site and its services (actual and potential);
- their priorities with regard to ecosystem services and projects for the site.

We have identified 3 groups of stakeholders that we detail below.

The advisory group

The steering committee is a broad study group that must ensure a clear direction of work, the participation of all stakeholders and the progress of the evaluation process. It generally includes the assessment sponsor, all decision-makers and funders of the study, but may also involve external consultants to the project, such as members of the scientific board of protected natural areas or universities, for example.

The technical or expert group

Evaluation is carried out by an interdisciplinary technical team. This group, or technical committee, aims to bring together all the necessary expertise. The members of this group should be able to contribute to:

- identify key habitats, species and services;
- suggest the most plausible alternative state for the site;
- provide existing data;
- design protocols for the collection of new data;
- collect new data;
- interpret the results.

Skills range from ecology to economics, modelling, geography, etc. It brings together all available knowledge holders, academics, nature, community or company experts, and more generally any well-informed and recognized local person with traditional knowledge.

The review panel

In an approach wishing for the assessment results to be reused more broadly, it may be useful to have a review panel. The review panel provides advice on methods and results. It brings in experts from outside the project for peer validation of the work to support the credibility and relevance of the approach.

What are the frameworks for evaluation?

It is not always easy to clearly define the scales of analysis for the evaluation. However, results are often sensitive to the temporal and spatial scale at which services are studied. A number of parameters and indicators of ecological functions, such as consumption of ecosystem services, are not uniformly distributed in space and time. For example, it is well understood that the use of attendance data for a mountain wetland, indicating the service of attractiveness for recreation and tourism, is highly variable, both over time being highly seasonal, and in space, the whole site not being visited in the same manner.
Ecosystem services should be studied at different scales, relevant to decision-makers and sensitive to the variability of processes.

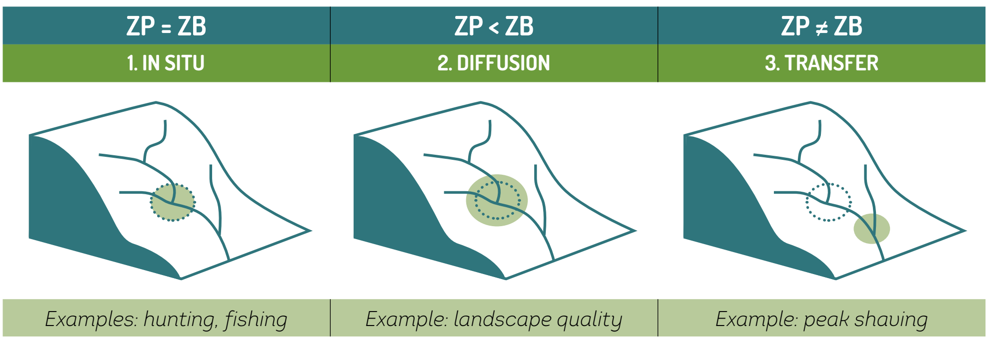
What is the time scale?

The notion of time is key to ecosystem services: the functioning of ecosystems and communities responds to cycles, thresholds and cumulative effects which means they do not evolve in a linear fashion, and also because assessment is very often part of a scenario that aims to simulate the effects of future actions. It is necessary to question and pay particular attention to the timeliness of the information used assessing and to stakeholders' temporal perspective when they attribute a value to services.

What is the space scale?

An increasing number of studies spatialize ecosystem services[35]: there is a dynamic between zones of services production and zones of consumption, and flows are organised between and among them. The following diagram illustrates the importance of considering the spatial relations between service producing and service receiving zones to assess, both to build the necessary data sets (functioning of the environment, cost of protection work, catchment area, etc.) and to identify the relevant stakeholders.

Such approaches supply us with community specific arguments for awareness-raising, negotiation and/or monetarization. The major interest of spatialization is based on its ability to question the notion of ecosystem services using



ZP : service production area = wetland
ZB : area benefiting from the services

Figure 7 - Spatial relationships of the service analysis, adapted from Fisher et al., 2009.

the perspective of the physical processes and their underlying ecological functions. However, a certain caution must be observed with regards to spatialization methods. The geographical information that can be used to complete this type of study is very often limited, especially as the working area is vast. Land use is very often used as the basis for assessing services and as an indicator of ecosystem services but if it is the only modelling variable it can lead to oversimplification.

Nevertheless, following a spatial approach, it is essential to take into account the spatial relationships between areas of production and benefits of services. As such, an ecosystem such as a wetland in its watershed plays an important role in the diffusion or transfer of services in the territory and the notion of hydro-system is part of it and can be translated into that of connectivity in the blue-green infrastructure.

What tools are available?

In recent years, various projects have emerged to provide tools for assessing or mapping ecosystem services. First of all, research laboratories have had to respond to the assessment needs of international (IPBES) and national (EFESE) platforms. Next, there was a strong involvement of economic and financial players in the development of assessment tools. Recent publications, such as the one by Wolff *et all*[36] (which analyses eighteen assessment tools) illustrate the range of players involved - inter-governmental organisations, national consortia, consultancy firms, environmental associations or research organisations – and their development with very varied methodological approaches, levels of technicality and purposes of use.

The present text does not list all existing proposals, but presents some tools that aid assessment by facilitating or objectivising the value assignment process. These tools also make it possible to resolve the challenge of understanding the complexity of ecosystem, for which the collection of quantitative local data is not always possible (use of models or of territorial or sector-specific expertise).

Capacity matrix[37]

Thanks to its expertise in conducting assessment projects (wetlands in the Scarpe Escaut NRP and natural environments in the Baronnies Provençales NRP), the Mediterranean Institute of Marine and Continental Biology and Ecology (IMBE) has developed an «expert opinion» method using capacity matrices.

A capacity matrix is a table cross-referencing the list of ecosystem services and the types of habitats/environments that can provide these services on the territory. This matrix is used for scoring by the «expert» participants in the assessment workshop. The latter have theoretical and/or practical knowledge of ecology, and are selected to represent the various stakeholders in the community, users, managers, and scientists. The matrix is filled in individually, then completed with the pooling of the scores of the different stakeholders, exchanges, sharing of visions, new compromises and, to conclude, the development of a common culture with a shared assessment that is credible for all stakeholders.
This simple method creates semi-quantitative data linking ecosystems and the services rendered, avoiding the problem of acquiring data on how environments function. It makes it possible to have an

evaluation for each service using the same unit so they become comparable and bundles of services can be identified as can even trade-offs between services.

ASPIRE

The method called ASPIRE, for **«Appreciation of the Success of Ecological Engineering and Restoration Projects»** ***(Appréciation du Succès des Projets d'Ingénierie et de Restauration Écologiques)***, is a methodological framework, a simple method for the global assessment of a project with multiple objectives by different players. The principles of this method mean it can be applied in approaches to evaluate ecosystem services and is also an online calculation platform. It was tested within the framework of the RestHAlp project, and is described in more detail in the article by Jaunatre *et al* (2017)[38].

Most ecological restoration projects have multiple objectives (multi-pronged), which can make it difficult to gauge the success of single projects. This is especially true in the case when project stakeholders do not share expectations. The evaluation phase is important because it can determine whether the management of the project needs to be adjusted to increase its chances of success, and whether a similar project can be replicated. The ASPIRE methodological framework appears particularly appropriate for the assessment of

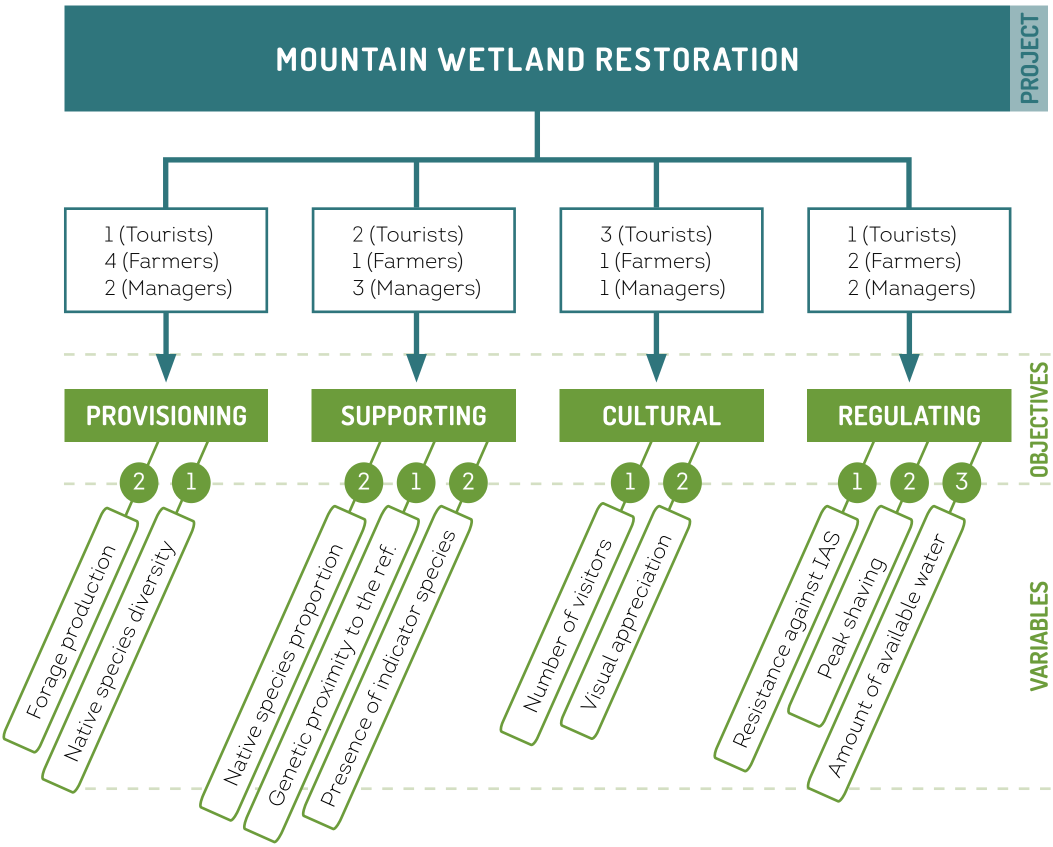


Figure 8 - Chart of the ASPIRE framework.

ecosystem services within an ecological restoration project. It is a three tier system: (1) the variables, (2) the objectives and (3) the project. The measurement of the overall project score is based on the scores of the project objectives, which in turn are based on the scores of the variables of these objectives (Figure 8). In order to assess the restoration of ecosystem services within a project, an interesting approach may be to equate different groups of ecosystem services with objectives, and measures that contribute to accounting for these services can be equated with variables.

After characterizing each of these levels, the ASPIRE framework allows to score variables, objectives and project for each stakeholder. It also can generate graphs illustrating the relative values of these different scores. The framework has been developed on R software and can be used via a Shiny[39] platform available online (https://restoration.shinyapps.io/aspire/).

CASES

Let us imagine a case study of wetland restoration in the mountains, the different variables used can be grouped

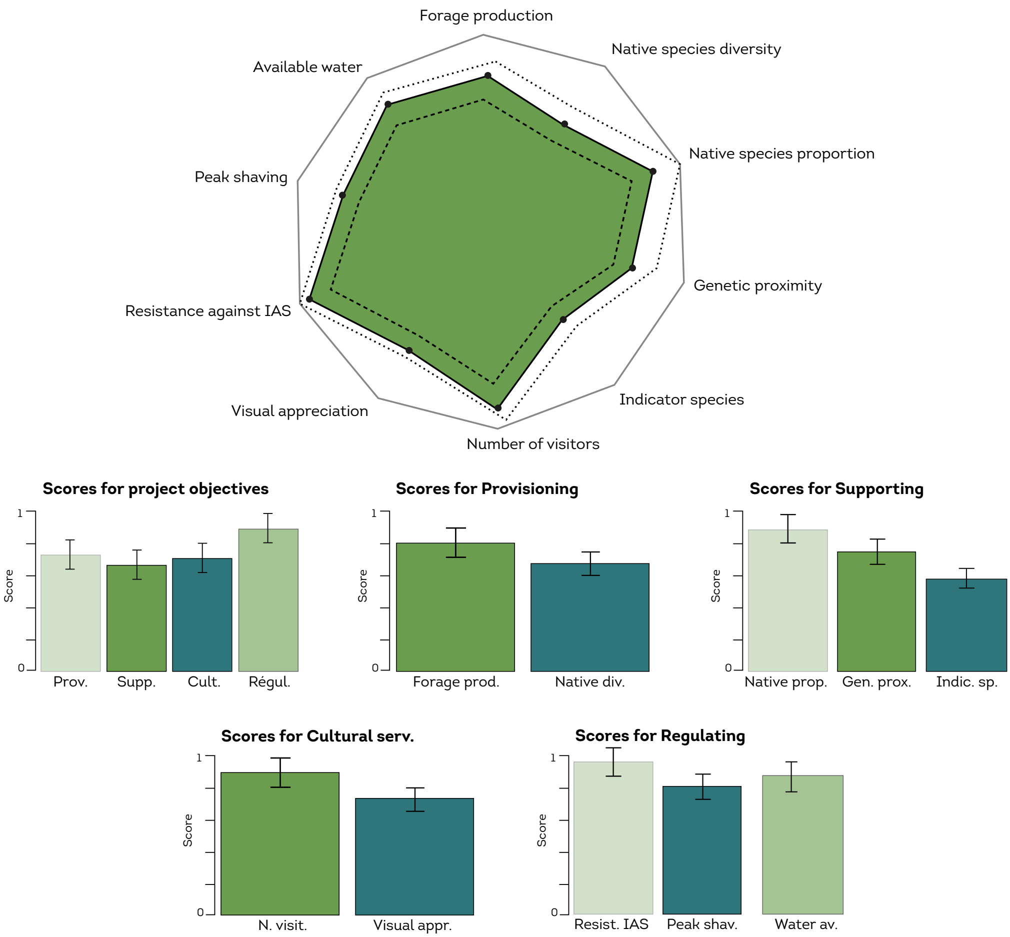


Figure 9 - Examples of graphs generated by ASPIRE. Bar charts and radar charts can be automatically generated, presenting results by objective.

to measure ecosystem services listed under broad categories of services: supplies, support, culture and regulations. Once the data have been collected in the field, it is possible to produce graphs summarizing variables, objectives and project scores by stakeholder (Figure 9). These graphs provide both an overview of the project but also help identify the variables or services where ecological restoration has worked very well and where there is room for improvement.

InVEST[40]

InVEST is a downloadable software tool to assess and map terrestrial, aquatic and marine ecosystem services and quantifying the impacts of various development or planning scenarios developed by the Natural Capital Project (www.naturalcapitalproject.org), a partnership between The Nature Conservancy, WWF and the Universities of Stanford and Minnesota. Ecosystem services included in the 17 available models (one per service) can be assessed biophysically (tons of carbon sequestered, volumes of water purified...) or socio-economically (social value of CO_2, emission reduction, avoided water treatment costs...). The software models both the spatial distribution and volumes as well as the current and future economic values of the services. It includes services such as carbon storage and sequestration, pollination, water treatment, sediment retention, coastal protection and habitat for biodiversity. Most InVEST models use a GIS tool (ArcGIS).
Four levels of modelling complexity are available for each ecosystem service. The simplest models generally assign biophysical reference values to types of land cover and land use. However, they only require a limited amount of data input and thus lead quickly to results. Conversely, more complex models require a large amount of information to operate, but give very accurate results.

RECORD[41]

The *REseau COopératif de Recherche sur les Déchets et l'Environnement* (RECORD) was created in 1989 by French Ministry of the Environment: it is a tripartite cooperation between industrialists, public authorities and academic researchers. The main objective is to finance and carry out studies and research in the field of waste and industrial pollution. Following the now many restoration experiments and the evolution of regulations related to polluted sites and soils, RECORD aimed to contribute by taking into account ecosystem services and their evaluation within the framework of restoration measures. The action was the result of the will to preserve and restore biodiversity, in the absence of a tailored method specifically adapted to this type of site.
In order to enable the use of available methods to analyse and measure biodiversity, both for the aerial compartment and for water and soil, the report proposes a review of the main indicators known to measure key ecosystem functions. In a second step, the 142-page report (with a 19 page summary) which includes the regulatory context, key concepts and methodology, lists indicators to assess the services rendered by the environment. The study focuses on restored environments, looks at wetlands and grasslands; a grid to select indicators to evaluate and monitor the impact of the restoration measures implemented is also included. It presents 3 case studies detailing the implementation of the method.

Cross-referencing geographical information: matrix approach

Burkhard *et al.*[42] developed a methodology to assess the capacity to provide/support ecosystem services in terms of landscape, based on the creation of territorial functionality maps. It is a flexible approach easily transferable to several

contexts, based on matrices of supply, demand and flows of different ecosystem services, divided by land-use classes.
The CORINE Land Cover (minimum mapping unit 25 ha, scale 1:100,000), available for Europe and downloadable free of charge from the European Environment Agency website (https://www.eea.europa.eu/data-and-maps/) was used to identify the different land cover/land use categories and build matrices.
The «supply-demand-flow» approach lends itself to identifying an appropriate «demand-supply» balance of ecosystem services for a given territory and is a valuable tool in guiding entire communities towards true environmental sustainability.
The matrix for the supply of ecosystem services considers a value from 0 to 5 for each land use category where 0 corresponds to a negligible capacity to provide a given service, while 5 corresponds to a very high capacity.
Similarly, the demand matrix for ecosystem services is based on the same values, where 0 means that the demand (consumption or use) for a given service for the land-use category is insignificant (e.g. demand for water in a coniferous forest) and 5 corresponds to a high demand for that service (e.g. demand for water in an industrial area).

THE INTERREG ALPINE SPACE **PROJECT ALPES 2015 – 2018**

One of the results of the AlpES[43] project is the creation of an interactive web GIS portal for the entire Alpine region.
The portal is organised according to the «supply-demand-flow» principle and municipalities are the territorial unit of reference, presenting the mapping (cartography) of numerous ecosystem services.

SUPPLY

The potential capacity of the land use category to provide a specific ecosystem service.

DEMAND

Potential demand for the ecosystem service expressed by all stakeholders operating in the given land-use category.

FLOW

Quantity of ecosystem service actually consumed.

Finally, the flow matrix has values ranging from -5 to +5 and corresponds to the superposition of the two previous matrices, so as to obtain a balance of ecosystem services by land-use category, where -5 corresponds to a demand that greatly exceeds the supply of a given service for a land-use category, while +5 indicates a supply much higher than the demand.

The values proposed by the authors are based on several case studies in many European regions[44], and on expert assessments[45], the selection of the appropriate indicators for each ecosystem service being probably the most important aspect for a correct assessment[46].

The published matrices refer to 22 ecosystem services (9 regulatory, 11 supply and 2 cultural), selected from different lists of services[47], and 7 indicators of ecological integrity, representative of the main components of ecosystem functionality[48], all attributed to the 44 CORINE land use categories considered by the authors.
In the GIS system, this information is technically simple to plot and it is possible to produce effective territorial functionality maps, which can be immediately understood and interpreted.

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HOW TO ESTABLISH LINKS BETWEEN SITE FUNCTIONING AND ECOSYSTEM SERVICES?

The correct functioning of ecosystems guarantees the provision of services. Such ecological functions are the supply: humans determine the demand and assign a value. This concept of function has been widely studied by the scientific community[49] applied to wetlands, and describes the natural processes of functioning and maintenance of ecosystems. It is also fruitfully used by managers of natural environments. The following paragraphs describing the main functions of wetlands are largely based on the synthesis proposed in the National Wetland Function Assessment Methodology (*Méthode nationale d'évaluation des fonctions des zones humides*, Gayet *et al.* 2016).

Which wetland functions provide services?

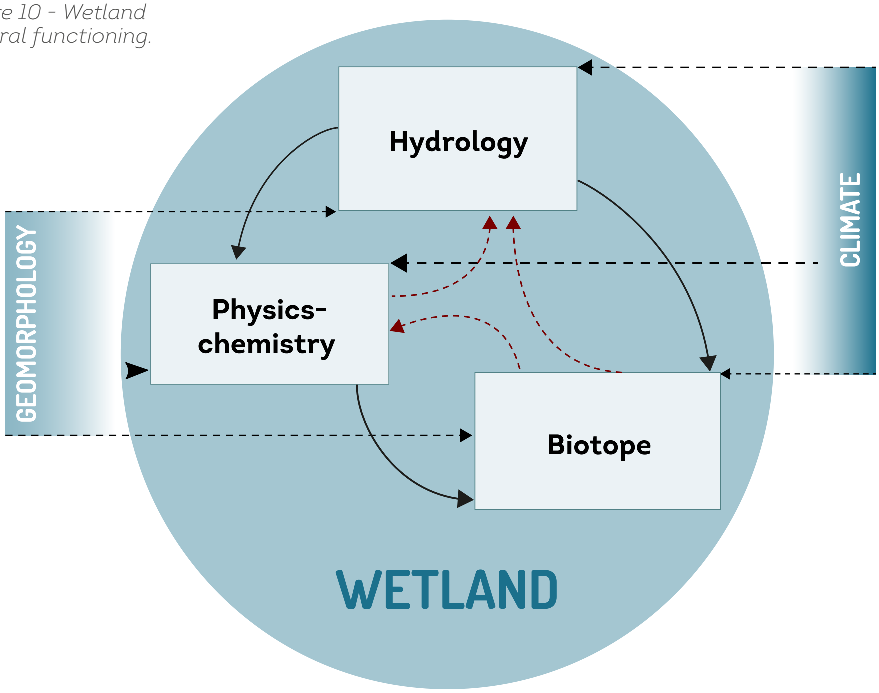
There are three essential elements that characterize wetlands as a whole, as illustrated in the diagram below, inspired and modified according to those by Mitsch and Gosselink[50] and Gayet *et al.*[51]

The various hydrological, physical, chemical and biological parameters interact to ensure the correct functioning of the system. Hydrological conditions often appear to be a key factor in the dynamics and structure of wetlands, as they influence biological and physico-chemical parameters (aerobic and anaerobic conditions that determine the availability of nutrients and oxygen, vegetation structure, etc.). There are also feedback processes (nutrient retention by plants, accumulation of organic matter, etc.) that influence the hydrological parameters in how the environment works.
Behind this general functioning pattern, however, there is a range of functions and the combination of hydrological, physico-chemical and biological parameters results referring to diverse wetland physiognomies. The large range of different types makes it difficult to classify them. While wetlands, in general, perform a multitude of functions (see below) the fact remains that, as mentioned, these functions may be absent or expressed to a greater or lesser extent depending on the role of the wetland or wetland type concerned.

Hydrological

Hydrological conditions, i.e. the amount of water, its distribution over time (hydro-period) and space (above and below ground), determine the presence of wetlands. Such conditions influence many abiotic and biotic factors in the wetland, such as soil anaerobiosis and nutrient availability, as well as influencing the composition and structure of microorganisms, fauna, flora and fungi.
Wetlands are hydrosystems, i.e., portions of space in which water flows in all three dimensions. This system approach enables us to focus on the processes and modes of water circulation[52].

Figure 10 - Wetland general functioning.



Hydrology can be described and studied through water balance. This approach aims at establishing a balance between water inflow and outflow in the hydrological unit over a given period of time[53]. The following formula is proposed for wetland[54]:

$$(P + Qe_{su} + Qe_{so}) - (Ev + Qs_{su} + Qs_{so}) = \Delta R$$

Where: **P =** rainfall
Qe = surface ($_{su}$) and underground ($_{so}$) inflow
Qs = surface ($_{su}$) and underground ($_{so}$) outflow
Ev = evapotranspiration
ΔR = variation in reserves

The main sources of water supply are therefore rainfall, flows on surface (runoff, floods, springs) and in the soil (groundwater flows, water table connected to watercourses). Losses are related to evapotranspiration, surface and underground runoff. Flows differ greatly depending on the type of wetland. The result is a variation in the water table, which allows temporary or permanent water saturation of the wetland, reflected in the types of hydrology of wetlands. Since water that flows through wetlands is stored there for varying lengths of time, slowing of runoff in wetlands fulfils several hydrological functions: flow regulation through flood control and support of river baselines, groundwater recharge, sediment retention, and climate regulation.

FLOW REGULATION

Whether they are non-channelled or free flows (surface runoff, groundwater flow) or flows concentrated in channels (streams), wetlands, as shown by their water saturation, receive flows, which they slow down or decrease by storing water. In a wetland, a range of physical and biological factors can influence this process. These include land use, which determines the roughness of the vegetation cover, micro-topography (oxbow lakes, depressions, levees, infrastructures), the kind of hydrographical network (drainage ditches, longitudinal and transverse shape of runoff) and its connection to watercourses (drainage ditch, bends and cuts), and the hydraulic properties of the soil. Wetlands are also an environment where water transfers to the atmosphere are very important, with evapotranspiration only very rarely limited by the availability of water in the soil.
Jointly these processes enable wetlands to perform two hydrological functions that are often mentioned, flood control and adding to low water levels or at least to waterway base-flows[55]. They influence volumes, but above all the dynamics of water flows and can store water and contribute to reducing or spreading flood peaks in catchment areas on the surface (flood expansion field, temporary storage of rainfall) and in the soil (variation of the saturated zone). The time lag intervening between water entering and leaving the wetland helps sustain river flows, especially during low-water periods by delaying water flows.

GROUNDWATER RECHARGE

Water-saturated soil in wetlands that forms an aquifer where water infiltrates and circulates slowly may be linked to other deeper aquifer reservoirs. They help recharge these aquifers, but may also act as discharge zones for them. This function depends mainly on the hydraulic characteristics of the soil, the geometry of the aquifer, its granulometric composition (mineral and organic matter, particle size) and its porosity, which determines hydraulic conductivity.

SEDIMENT RETENTION AND ACCUMULATION

Wetlands accumulate sediments whether they are exogenous, transported by rivers and runoff (*alluvium*), gravity (*colluvium*) or wind, but also endogenous, i.e. produced *in situ*, as is the case for the accumulation of organic matter (peat).
Sediment dynamics are crucial to the wetland functioning. Specifically, it determines the dynamics of nutrients and organic matter. Several physical factors can influence sediment inputs, the connectivity of the wetland to watercourses (submersion) or the characteristics of the land immediately surrounding the wetland, but also the importance of sources of sediment produced upstream in the catchment area such as cultivation or construction. The physical characteristics pertaining to the wetland micro-topography such as slope, river system, nature and density of vegetation cover also influence sediment retention and production capacity.

CLIMATE REGULATION

The role of wetlands in climate regulation, i.e. the atmospheric component of the water cycle, is twofold: on the global scale, it is mainly related to their role in the carbon and methane cycles, as discussed below; on a local scale, by evapotranspiring large amounts of water, wetlands contribute to water saturation in the air and influence local microclimate.

Physical and biogeochemical

Wetland physical and chemical processes underlie their strong influence on the flow of mineral and organic matter. Microorganisms - that is bacteria, fungi and the like in water-saturated, oxygen-depleted soils – trigger oxidation-reduction processes that enable them to

breathe and transform oxygen-containing compounds (nitrates, iron oxide, sulphates, etc.) into minerals that can be assimilated by animals and the underground plant organs (roots, and the like). They play a key function in major biogeochemical cycles.
In the nitrogen cycle, wetlands contribute to denitrification through the action of bacteria in hydromorphic conditions. Plant uptake is also an important means when mowing, cutting or grazing practices exist that contribute to the export of existing vegetation.
The role of wetlands in the phosphorus cycle is linked to hydrological dynamics that alternately switch them from being a sink to a source. Phosphorus can be stored relatively permanently in sediments when it combines with other ions (mainly iron, aluminium, calcium) and contributes to soil particle fixation.
Currently, the role of wetlands in the carbon cycle is the one most often referred to. Carbon is found in soils, some source rocks, the atmosphere and plant biomass. Photosynthesis, respiration and oxidation are the main carbon exchange mechanisms. Compared to other environments, wetlands are often considered as carbon sinks because of the anaerobic conditions that inhibit the decomposition of organic matter, their relatively high productivity (storage in above- and below-ground plant compartments) and their role in retaining exogenous organic sediments. Carbon storage in a wetland depends on the plant compartment (habitat type, above- and below-ground biomass and organ life span) and its hydrology (soil

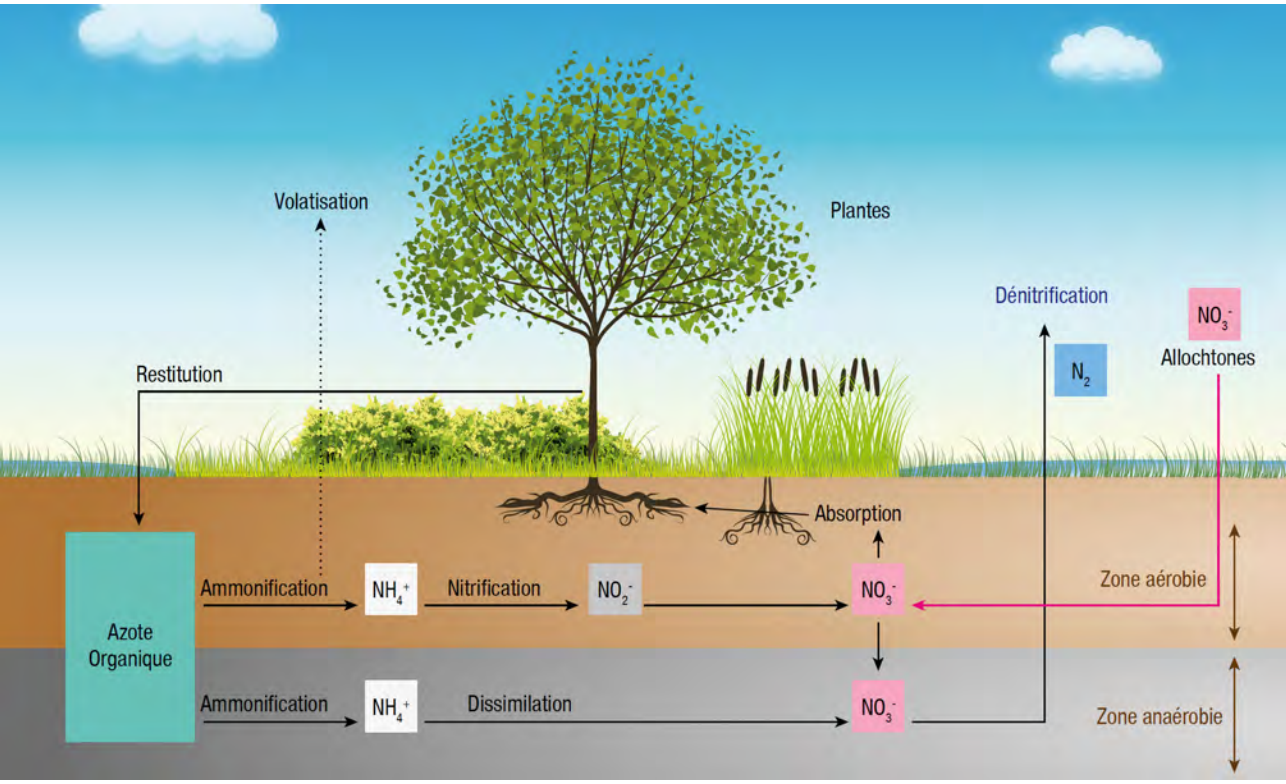


Figure 11 - Role of wetland plants in the nitrogen cycle[56].

hydromorphy, thermal conditions).
The thickness and type of horizons that make up the humic episolum, that is the upper soil horizons containing organic matter, can be taken as an indication of the amount of the stock of carbon sequestered in the soil of a wetland. The larger the horizon, the higher the carbon stock. Histic (H) or peaty horizons, consisting mainly of organic residues accumulated because of the partial decomposition of organic matter, have carbon contents of nearly 60% of the dry mass.

Ecology

Wetland composition and structure of plant and animal communities are the result of interactions between abiotic environmental conditions (e.g., climatic, hydrological, geomorphological variables) and human activities. In turn, these communities affect the hydrological and biogeochemical characteristics of the wetland, which includes biotic feedbacks.
Wetlands play an important role in the completion of the life cycle of species. This determines breeding, feeding and location and generates a range of species. Wetlands are home to countless species of plants and animals: they contain 30% of French noteworthy and threatened plant species. Furthermore, a large number of species that complete part of their life cycle in a wetland, such as birds (50%) and amphibians, also use the neighbouring habitats for feeding, resting or breeding. It also provides a functional link for species.

How can wetland functions be measured?

Without being exhaustive, we would like outline guidelines for staff who would like to build the data sets necessary for a good understanding of the function and role of a wetland and offer a minimum assessment of the functions it performs.

Water balance data

Data can be acquired from data providers or collected in situ after site instrumentation. To establish balances in the changes of the water volumes flowing through the wetland, decadal to monthly figures are used. Hourly to daily data are required to further understanding hydrological dynamics and analyse the response of the environment to different types of meteorological phenomena.

According to the standards and recommendations of the World Meteorological Organization, the meteorological stations of the large national measurement networks have metadata to characterize the validity and quality of the measurement of the various parameters. In this case, the longest possible data series should be available because of the large inter-annual variations in climatic conditions. Three parameters are required:

- **precipitation in millimetres,**
- **evapotranspiration in millimetres or the parameters for its calculation (temperature, humidity, sunshine, etc.), and**
- **flow in millimetres (i.e. related to the same unit of time and surface area as precipitation).**

Instruments are useful, even necessary, when it is not possible to have data collected under comparable conditions at the study site. However, this does not generally yield for long time series of data.
In the absence of meteorological and flow data, the measurement of the water table dynamics (piezometry), which makes it possible to observe the variation in water storage, and of the physical properties of the environment (micro-topography, volume of hydromorphic soil, hydraulic

properties of the soil) enables the storage and regulation function of wetlands to be properly understood.

Biogeochemical data

The biogeochemical processes we are interested in occur in the first few centimetres of soil, which act as an interface between the atmosphere, the hydrosphere and the lithosphere. Particular attention will be paid to the soil, as hydromorphic dynamics need to be both well described and understood.
Soil needs to be well understood and can be classed into two broad categories for wetlands. While hydromorphy, i.e. the physical evidence of regular water saturation, is common to all wetlands, it results either in the accumulation of organic matter or in iron oxidation-reduction processes. The following information is required:

- **the description of the stratigraphy and the different soil horizons;**
- **hydromorphic soil depth sounding and mapping;**
- **analysis of the physical properties of soil, water content, porosity, organic and mineral matter content, pH.**

Mineral and organic matter presence are a key factor in the hydraulic behaviour of the soil and reflect the dynamics of matter accumulation. To determine the proportions of these different parts, samples are analysed in the laboratory by loss on ignition.
Porosity corresponds to the presence of interstitial voids, interconnected or not, in a soil or rock and is expressed as the ratio of the volume of these voids to the total volume of the medium. For peat, for example, it is rarely less than 0.8, whereas for mineral soil it varies between 0.4 and 0.6. The amount of water the soil can hold depends on this porosity. The water content of the soil can be expressed as the ratio of the volume of water contained in a given volume.

Biodiversity

An understanding of biodiversity requires the acquisition of the following data:

- **naturalist inventories,** such as a list of all known species on the site (fauna/flora) or a list of habitats (and mapping if it exists);
- **indicators of operational status,** such as the Wetland Condition Monitoring Toolkit *(Boîte à outils de suivi des zones humides)* for example. It is a collection of indicators, combining a data collection protocol, a method for calculating indicator values *(Calculette RhoMéO)* and elements for analysis and interpretation, developed and implemented by the Rhône-Mediterranean-Corsica Water Agency since 2010.

On the basis of these data, it is possible to use the concepts of landscape ecology by describing the composition of habitats using indices of richness, diversity or evenness:

- **habitat richness;** this consists of counting the types of habitats present in a given space[57];
- **habitat diversity** can be measured with indices such as that of Shannon and Weaver (1949); it reveals, for example, whether or not the relative abundance of habitats (area) is homogeneous over a space;
- **evenness** is the comparability between the representation of different habitat tesserae in a mosaic; it is the ratio between observed diversity and maximum theoretical diversity.

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HOW TO ASSIGN A VALUE TO ECOSYSTEM SERVICES?

Stakeholders involved in the management of natural environments assign values to ecosystem services by addressing notions and concepts drawn from the economic and social sciences with which they are not always very familiar. If we take a wider view of the issue here, we will refer readers to chapter 5 of Chevassus-au-Louis et al. (2009). The many meanings of the term *value* and its use in different fields, such as philosophy, mathematics, art (painting, music), law, linguistics, finance or economics, requires us to clarify here the meaning(s) underlying its use in the assessment of ecosystem services.

Qualification when using the definition "ecosystem values"

The value attributed to ecosystem services is measurable, i.e. its usefulness to society is assessed, and has economic implications.
It is a question of defining the subjective equivalence relationship between goods, supplies and demand, i.e. in this case the relationship between the physical, biotic and abiotic components of environmental role on the one hand, and how an individual sees these elements on the other. This relationship depends on its usefulness and availability, but does not require the existence of a market. Consequently, for a certain number of services the value is not necessarily monetary. Moreover, given its anthropocentric nature, it echoes the interests of future generations or other living species in terms of their influence on human well-being.
In a value attribution approach, each individual player and subject is considered to be the best judge of their own preferences. Values - in the case in point ethical, moral and philosophical - which individuals refer to in accounting for their choice may belong to different orders. This is why one must increase awareness and educate individuals to help them shape their preferences. All approaches to assigning value go through a preliminary phase of data collection on the role and functions of the ecosystem to explicit the supply of services whose demand is determined by the stakeholders both in terms of types and amounts.

What type of value should be assigned?

The set of benefits that the ecosystem can provide to individuals and societies, whether monetary or not, corresponds to the notion of total economic value (TEV). As well as productive resources, ecosystems provide amenities, i.e. they can be directly used by human beings whatever their motivations. TEV includes these different types of values, which are illustrated in the diagram beside. For technical and ethical reasons, all the values attributed to the different components cannot be summed. It is divided into two main categories, use values and non-use values.

Use value

DIRECT USE
Direct use value refers to the value traditionally attributed by economic markets. It can be referred to any natural good or service which can be purchased with money. A distinction is sometimes made between direct consumption uses (food, biomass energy, medicinal plants) and those that are part of a productive system (industrial resources, energy sources, building materials). Other direct uses do not involve consumption of the ecosystem (recreational or aesthetic uses, tourism, science and education).

INDIRECT USE
Indirect uses refers to the benefits derived from the regulatory and support functions performed by ecosystems that individuals benefit from without interacting with them and often without being clearly aware of it. This use value does not depend on traditional markets. For example, one can refer to natural services generated by the climate regulation capacities, the contribution to the productivity of agrosystems, the prevention of extreme events, biological control, aesthetic functions, habitats for fauna or spiritual functions that contribute positively to users' utility.
It should be stressed that these values do not correspond solely or necessarily to real current uses. They also relate to future uses.

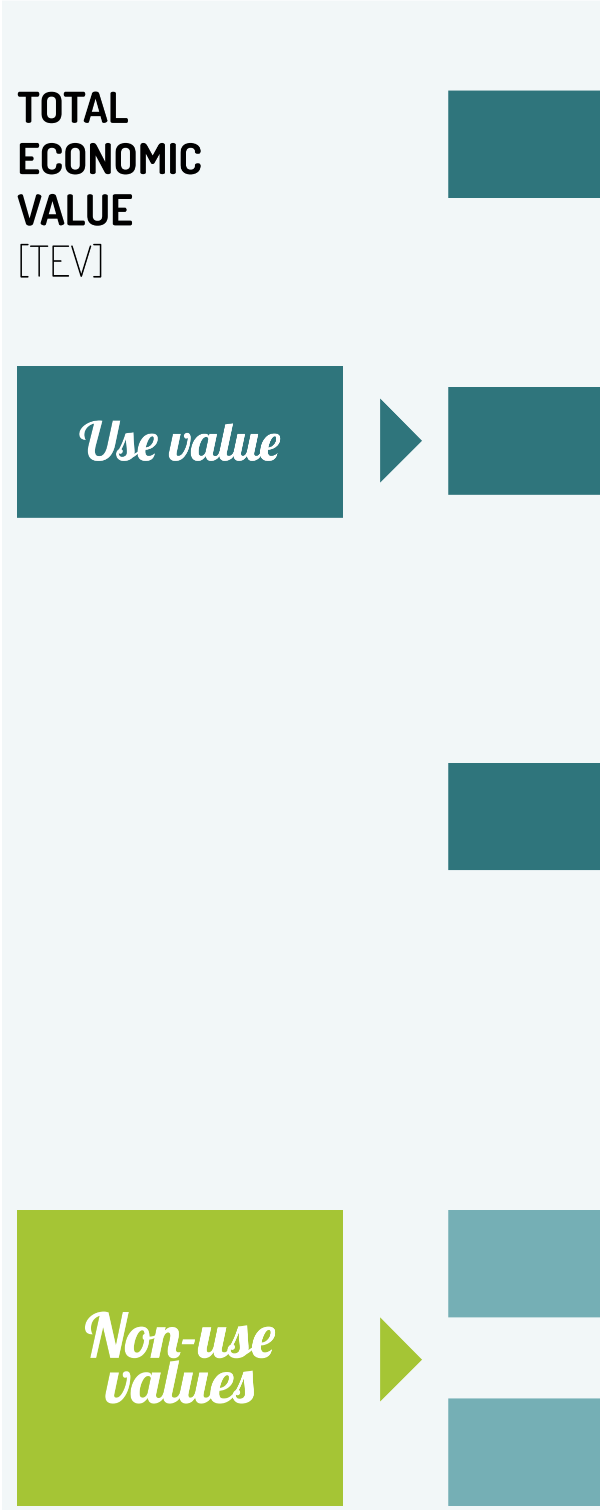

Figure 12 - Economists' reference framework to understand the different dimensions of the value of an ecosystem[58].

DIRECT USE VALUE

Provisioning services:
drinking water, food, fibres, wood, hunting & fishing produce, harvest, biomass, energy.

Other Nature-based economic activities:
tourism (outstanding natural places, protected areas), use for leisure and open air activities.

INDIRECT USE VALUE

Regulating services:
regulation of climate, floods, diseases, pests, of the effects of storms, and plant pollination.

Supporting services:
soil fertility, water, nitrogen and carbon cycles, wild plant pollination.

Cultural services:
artistic inspiration, education, physical activity, return to the roots.

Quality of life:
landscape, soundscape and the smells of Nature.

OPTION VALUE
potential future use

- Unidentified ecological functions
- Unexploited genetic resources
- Plants, algae, insects and animals that can become food resources
- Chemistry of living beings as a future source of drugs
- Mechanisms of living beings applied to industry (biomimetics)
- Species whose study will provide knowledge on the origin of life or the origin of humans (great apes)

LEGACY VALUE
heritage

Species, habitats, landscapes, natural spaces to be passed down to future generations: natural heritage.

EXISTENCE VALUE

Species, habitats, landscapes, natural spaces whose existence is important to us beyond any use.

TANGIBILITY

MARKET VALUES

NON-MARKET VALUES

OPTION VALUE

Regardless of current or future use, ecosystems have a choice element that translates into increased value attributed to options that do not diminish future possibilities for choice. An example is the value of future use of natural resources. There are two option values today, depending on whether the uncertainty concerns future behaviour - for instance decision-makers not knowing at the present time whether they will consume the goods or not - or the utility that will actually derive from its use in a context of increasing information and choice between more or less reversible options.

Non-use value

Non-use values are difficult to quantify, but are very real in contributing to human well-being. They often determine people's preferences and willingness to pay. They are part of a perspective of respect and trans-generational equity. They mirror the idea that the individuals consider their motivations or well-being ethical values that appeared not integrated into an anthropocentric framework, such as the altruistic dimension towards other human beings, non-human species or Nature in general.

Values related to altruism are listed below:

- **referred to our contemporaries (others who benefit from ecosystems - proxy use value),**
- **referred to our direct descendants or more generally future generations (legacy value),**
- **referred to non-human species which we attribute some form of moral right to exist (existence value).**

What value attribution method?

The evaluation of different value-types is performed through a variety of methods that are related to the theories of economics. They are based on the costs associated with the loss of ecosystem services or analyse people's preferences and behaviour. For more details on the implementation of these methods, we refer the reader to the handbook by Revéret et al. (2013), which is largely echoed herein.

Direct markets

In general, these methods are simple and the data required for analysis is readily available, but their implementation is limited to traded goods or services that have an actual price. One should also consider that there are market imperfections or policies that can distort market prices which is why they do not reflect the economic value of goods or services in society as a whole. There are also seasonal variations and effects on prices of other factors that need to be considered when market prices are used in economic analysis.

The direct use value of market ecosystem goods and services can be assessed by referring to the value they have in markets. This is the simplest method: it measures the economic benefits of marketed goods based on the quantity of those goods that consumers obtain at different prices and, on the producer's side, the quantity offered at a range of prices.

Continuing on markets, there are also methods that look at the impact of changes in the quality and quantity an ecosystem service has on production. They are based on calculating the difference in production of a marketed good or service that can be measured between the two scenarios to assess the variation in benefits in relation to the evolution of the ecosystem.

Costs

Estimation of the costs of avoided damage, replacement, avoidance and opportunity costs are related methods for estimating the values of ecosystem services. They estimate the value of ecosystems through payment for alternatives to the services provided. These are referred to as avoidance or replacement costs. There are many simple examples, such as the cost of constructing a flood-control basin to replace the water storage service of a wetland. These methods are widely used because it is easier to measure the costs of producing protection or replacement goods and services than to estimate people's willingness to pay for certain ecosystem services. However, it is difficult in integrating goods and services in a holistic way, usually focusing on a single ecosystem function.

Revealed preferences

These are indirect methods based on the current behaviour of economic players in economic markets and therefore represent their actual willingness to pay directly or indirectly for environmental amenities.
For example, the transport cost method deducts the value of a change in the level of resources or the environment from the data observed in the markets for certain ordinary goods. It is based on the principle that consumers express the intensity of their interest in a site according to the expenses they incur to get there. This method is used to assess the value of a tourist site.
The hedonic price method assesses the value of changes in the quality of the environment or natural resources that can affect market prices. For example this applies to the case of landscapes or more generally to the quality of the environment which influences the value of a property. The method aims to assess the contribution of a specific characteristic among a set a balance in a multi-factorial price.
Very often, however, actual market transactions fail to illustrate the total value of that change although they may directly or indirectly reveal certain use values of a change in the environment through consumer market behaviour. The latter very often includes a significant proportion of passive use value, which is not associated with any observable behaviour, and of non-use value.

Expressed preferences

Preference-based methods are used to measure the value of the environment and natural resources through non-market behaviour. The aim is to create a simulated market and through the survey to identify the trade-offs of individuals, between the price to pay and the improvement of the environment. The strength of these stated preference methods is their ability to capture the different components of total economic value.
Potential valuation based on stated preferences is the most commonly used method. It is based on the presentation of future scenarios to a group of respondents who will assess the ex ante change in their welfare in relation to the nature of those scenarios and will do so in monetary terms. The interviewee can always opt for a status quo scenario that reflects a state of satisfaction with the existing situation.
The multi-faceted approach presents respondents with a series of alternatives that are defined by attributes (one of which is price or payment). These alternatives are presented through a range of choices and the aim is to obtain an estimate of the value for each attribute.
Special care is required in the use of these methods. People's willingness to pay, and therefore the well-being they can derive from it, often refers to their perception of the good or service and not necessarily to its ecological functionality.

Benefit transfer

Where it is not possible to study a site directly to assign a monetary value based on local data, benefit transfer methods can be used. This may be due to time or resource constraints, for example. It is therefore a question of transferring a value or, more broadly, a given result to a site already studied and transposing it to another site for which one wishes to value ecosystem services.

While this approach has been widely used to communicate the value of conserving environments, to ensure that this transfer is relevant, it is necessary to use very specific methods and protocols, which are well detailed in the handbook for economic valuation of ecosystem goods and services in a climate change context (Dupras et al., 2013). The authors note that there remains a considerable gap between the definitions in literature, which present complex methods, and the practice of benefit transfer. In general, a distinction is made between unit or fixed value transfer methods and function transfer methods.

Value transfer consists in directly using a willingness-to-pay value in the form of an average per household/individual or per unit of area estimated at the site analysed to apply it to the target site. As there are always differences between the characteristics of the site(s) where the original study was carried out and those of the target site, it is preferable to make value adjustments that are transferred according to the characteristics of the site (surface area, income of the population means, etc.). The choice of the baseline study is of prime importance here.

The transfer of function does not consist in using value, but the relationship between an individual's willingness to pay and the characteristics of the individual or the site under analysis. It is a matter of applying the model of a reference study, elaborating or explaining the monetary value. In this way, the socio-economic and demographic characteristics of the site population, as well as the physical characteristics of the site and its use, can be integrated into the function.

Where multiple baseline studies exist, it is possible to construct a transferable value of an ecosystem service to another similar site, using meta-analyses that employ statistical methods. The most obvious advantage of such an approach over the function transfer method is that meta-analysis reduces potential bias in the choice of the site analysed.

Various tests for evaluating the quality of these methods are proposed. The correct application of these methods appears to require advanced technical skills and that behind their apparent ease of implementation (reduction of time and cost), the risks of assigning a biased value are very high. It therefore appears that the benefit transfer technique should not be used when a precise value is needed for decision making.

WHICH SERVICES DO ALPINE WETLANDS PROVIDE?

In order to promote the protection of wetlands, the RestHAlp project partners have identified the objective of improving knowledge about the benefits that humans derive from ecosystems in the alpine context. The crossing of qualitative and perception data with quantitative figures collected on seven sites in Savoy (France) and Aosta Valley (Italy) made it possible to produce summaries that provide examples of the services offered by alpine wetlands. These fact sheets are tools to promote the interest of these environments among elected officials and local economic stakeholders.

SITES FOR THE **EVALUATION** AND PROMOTION OF ECOSYSTEM SERVICES

SAVOY

- Marais des Chassettes;
- Marais de Chautagne;
- Marais de la Plesse;
- Tourbière de Montendry;
- Tourbière du Plan de l'Eau.

AOSTA VALLEY

- Riserva Naturale Les Îles di Saint Marcel;
- Pra Suppiaz peat bog.

Conservation of species and genetic diversity

Wetlands are involved in supporting and maintaining species and genetic diversity, as breeding, feeding, etc.

THE TOURBIÈRE DU PLAN ALONE HOUSES:

- **351 different plant species,**
- **5 species of amphibians and reptiles,**
- **3 species of mammals,**
- **25 species of birds.**

These censuses, carried out by the Savoie CEN, are not exhaustive lists. This service is well understood by community players, who place it among the top 5 services of the site.

Some species are restricted or closely dependent on these wetlands. Wetlands enable the life of species that participate in the ecosystem balance and functioning. The preservation of biological diversity is also one of the major current concerns on our planet. This conservation contributes to the resilience of ecosystems in the face of the changes affecting them, especially climate change, but is also important for the provision of services that are directly dependent on these biological and genetic resources: supply of food resources, pollination, heritage (linked to natural heritage), regulation of hydrological cycles (role of vegetation in slowing down water levels), or climate regulation (role of sphagnum mosses on peat bogs contributing to carbon storage), etc.

©V. Bourgoin/CEN Savoie

Figure 13 - Utricularia minor ©A. Fleischmann

Wetlands are home to a large number of animal and plant species: birds, amphibians, molluscs, fish, aquatic plants, mosses, and others. It is estimated that 30% of the noteworthy and threatened plant species live in wetlands, and about 50% of the avifauna depends on them. The different types of wetlands provide shelter for very different species associations. The Marais des Chassettes and the Tourbière du Plan de l'Eau are both wetland sites, but they are nevertheless home to very different species, due to the diverse habitats offered by each site. The reed beds in the Marais des Chassettes house the reed warbler on the site, as well as a series of forest species that live in these dense wet woodlands such as great spotted woodpecker, song thrush, among others. The Tourbière du Plan de l'Eau benefits from other habitats sheltering different species such as the lesser bladderwort *(Utricularia minor)* (Figure 13), in the water holes in the peat bog, or Lepidoptera (49 species have been recorded on the site) such as the little Apollo *(Parnassius phoebus)*, a protected species that lives on the banks of mountain streams.

Amphibians are also species that need wetlands to live and reproduce. Savoy wetlands are home to a wide range of amphibian species: common toad, natterjack toad, agile frog, fire salamander, yellow-bellied toad, palmate newt, alpine newt (Figure 14). The common frog *(Rana temporaria)* is on the Red List as a near-threatened species and is present at all five sites studied.

Figure 14 -Alpine newt ©M. Bouron/CEN Savoie

The survey conducted among the inhabitants of the Marais des Chassettes showed that all respondents agreed that the marsh plays a key role as a refuge for biodiversity. However, the role of the marsh in hosting «rare» species was perceived in a more mixed manner. Twelve of the 18 responded positively, 2 negatively, and 4 did not know.

Regulation of hydrological cycles and protection against flood risk

Flood protection is one of the major and well-known services provided by wetlands. All the surveys, questionnaires and other approaches carried out prove this and the service is mentioned, placed at the top of the list of services rendered, regardless of the actual physical situation phenomena involved.

Areas recognized as strategic

THE MARAIS DE CHAUTAGNE: FLOOD PLAIN OF THE RIVER RHÔNE

The severe flooding of the Rhône in 2003 (estimated at 1 billion € in damages) raised awareness of having global flood prevention policy. The Chautagne-lac du Bourget plain was listed as a Rhône Flood Plain, thanks to its storage and spreading capacities. When Rhône overflows in this zone there is less damage as is it better adapted to such events, there is a reduced flow rate and the maximum flow rate spans over time, thus protecting the city of Lyon located downstream by reducing the extent of the flood.

THE RHÔNE FLOODS OF JANUARY 2018

The data collected by the CEN Savoie on a plot under restoration illustrate the hydrological role. The Rhone floods that occurred on 4 and 22 January reached the levels of the two-year flood and the five-year flood respectively. During the second flooding episode, the Rhône reached a height of 3.59 m (1930 m^3; 238.21 asl) at the La Loi bridge. Given the size of the Flood Risk Prevention Plan (23.8 km^2), the volume of water that spread over the Marais de Chautagne can be estimated at 415,000,000 m^3 at the height of the flood. The plot is submerged by a 74 cm water level (233.94 m). The water was stored on the southern Marais de Chautagne for 4 to over 30 days (Figure 15).

Figure 15 - January 2018 floods on plot D705 (J. Porteret / CEN Savoie).

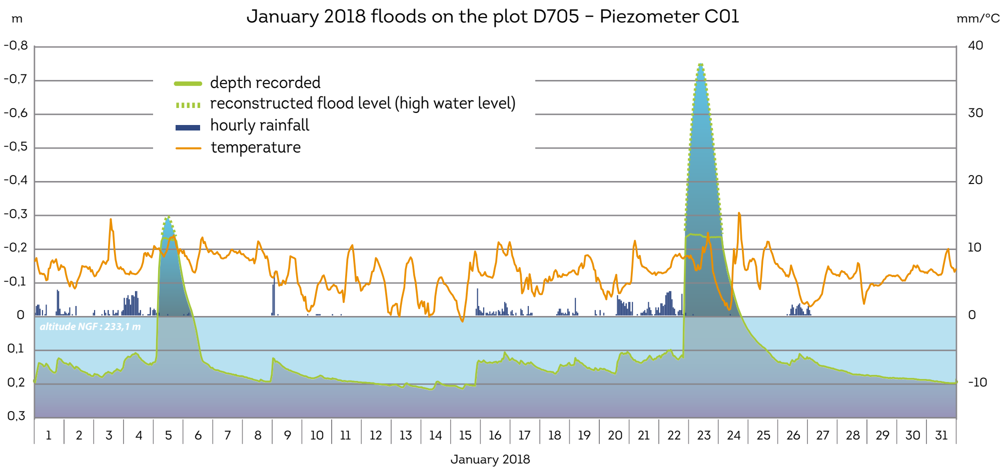

Figure 16 - Flood on the Marais de la Plesse ©V. Bourgoin/CEN Savoie

THE MARAIS DE LA PLESSE: A «PROTECTED SPACE».

The Marais de la Plesse is in the municipality of Saint-Offenge in the Albanais region and is much smaller than the Marais de Chautagne. It plays a role as a service against flood risk for the municipality and those located downstream.

The mayor of Saint-Offenge is in no doubt about the protective role played by the marsh. Since he is adamant about the importance of the marsh in shielding his municipality, he triggered the procedure to zone the marsh as a "Protected space" in the Local Town Plan. In 2008, he began work to channel rainwater to the marsh, in order to restore its «natural» hydraulic capacity. In a shallow depression, the marsh and its peaty layer (about 1 m deep) act as a reservoir that fills up with water during rain and slowly releases it to the watercourse (Figure 16). As a result, the heavy rainfall of winter 2018 flooded the marsh for nearly 4 months.

WHAT WAS THE RESIDENTS' **OPINION**?

Surveys among residents could be carried to know what they felt about this service provided by the wetlands, having experienced and undergone the Chautagne floods. As for the Marais de la Plesse, the elected authorities questioned expressed doubts about local residents being aware of this service.

Although the experience could lead to awareness, the interviews conducted in Chautagne with farmers did not validate it. Indeed, no farmer mentioned the role of the marshland in reducing flood risk. Farmers with the centre of their farms in the marshland did not mention flooding either.

«A huge natural retention basin used during the ten-year floods».
Bernard Gelloz, Mayor of Saint-Offenge, May the 30th, 2018

Climate regulation

On a local and global scale, wetlands play a significant role in climate regulation. While in the current context of climate change the role of wetlands for climate regulation is well known at the global scale, their impact at a more local scale is less well documented.

Globally

The role and importance of wetlands in regulating the global climate is because they store CO_2, the main greenhouse gas. Studies have shown that despite their very small surface area, peat bogs concentrate 30% of the carbon contained in the soil, and their average storage capacity is estimated at 1400 tonnes of CO_2 per hectare[59]. On the Marais de Chautagne, the volume of carbon stored on the entire peat surface of the wetland (which covers an area of 1700 hectares) has been estimated at **10 million tonnes**. However, this service remains sensitive to the changes that affect it: the drying up of the wetlands, in addition to causing the loss of this storage function, causes a release of this stored carbon into the atmosphere[60].

Locally

Locally, wetlands impact the climate by modifying rainfall, temperature, air humidity, among other parameters[61]. Nevertheless, the difficulty of understanding this service explains the scarcity of data available on this subject in the literature. Some observations could be made on the sites studied.

©J. Porteret/CEN Savoie

THE MARAIS DE CHAUTAGNE

Data were collected via a meteorological station installed by the *Conservatoire d'espaces naturels Savoie* on a plot of land in Chautagne (known as Marais - D705). Data were compared with those gathered by another meteorological station located in the municipality of Chindrieux, also located in Chautagne, a few kilometres from the other station. The first figure (Figure 17) shows the maximum (Tx), average (T) and minimum (Tn) temperatures recorded per month by the two stations over the period July 2017 - June 2018. It shows that average temperatures on the marsh were consistently lower than those in the village. The second figure (Figure 18), which is more complete, includes solar radiation, temperature, and relative humidity data over 3 days (28, 29, 30 July 2018). Air humidity in the marsh at night was clearly higher than that in Chindrieux. Temperatures were also always lower. Temperature differences could be the result of evapotranspiration, the type of vegetation present on the marsh, etc.[62]

THE MARAIS DES CHASSETTES

A peri-urban marsh, very close to houses and inhabited areas. During the survey on the marsh, residents living close to the marsh edge alluded to the cool it let off, especially during the summer, and the higher than average humidity of the air. While some people appreciated the cool, other inhabitants were irritated by nuisances caused by flies and mosquitoes and considered this atmosphere as a health hazard. To date, no quantitative climatic data have been collected that would allow us to compare individual perceptions with data collected in the field.

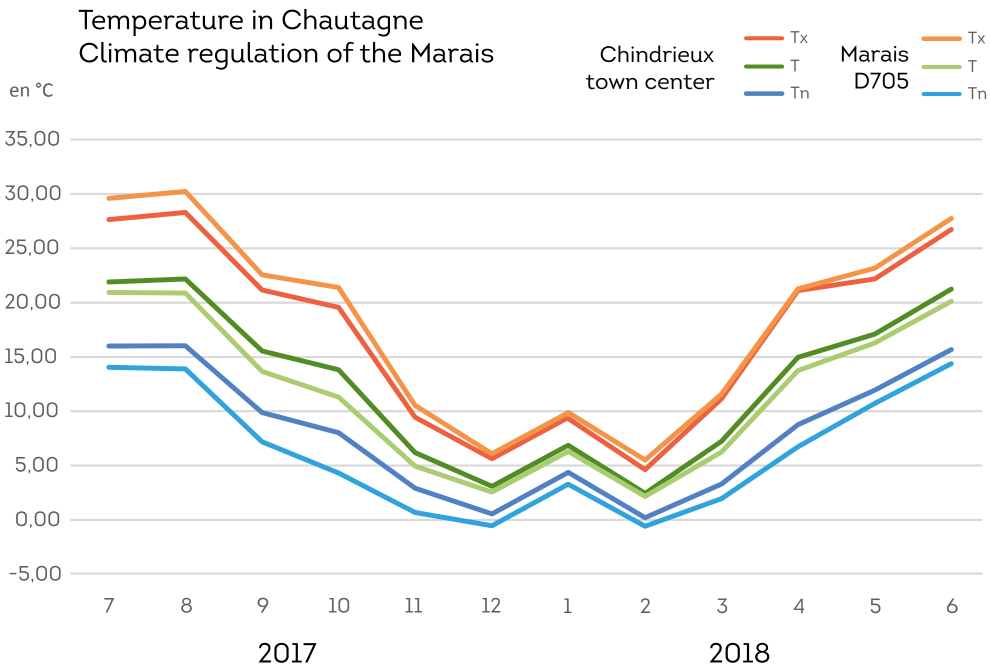

Figure 17 - Temperature trends in Chautagne ©J. Porteret - CEN Savoie

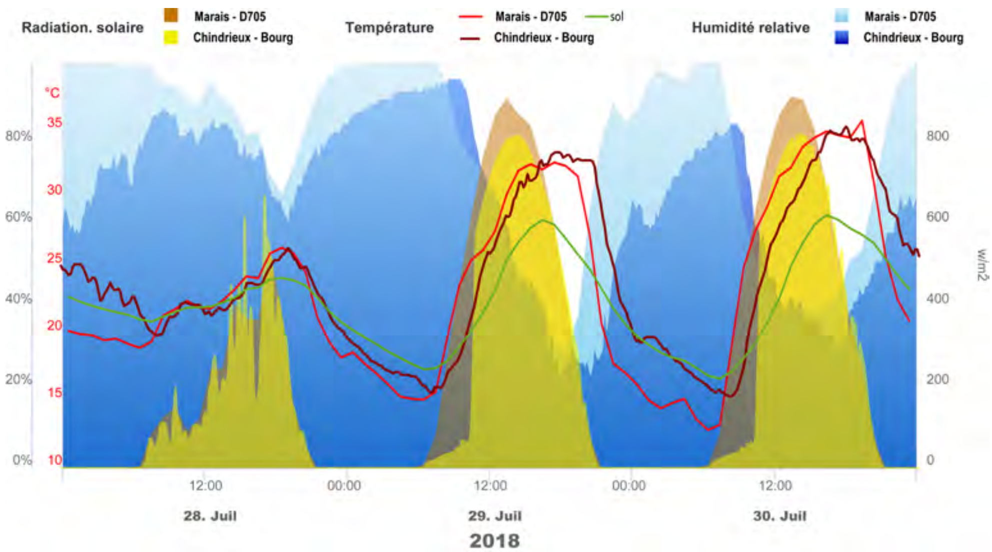

Figure 18 - Comparison of climatic parameters between two weather stations in Chautagne ©J. Porteret/CEN Savoie

Groundwater recharge

In the RestHAlp project, a first attempt was made to extend the evaluation of some ecosystem services to the territories of the Aosta Valley and the Gran Paradiso National Park. For this purpose the matrices proposed by Burkhard *et al.*[63] were used for the whole regional territory covered by the CORINE Land Cover map. The method lends itself very well to be contextualised to each territory studied, adapting the cartographic layers and the values attributed in the matrices by using the information from monitoring, measurements, statistics or interviews carried out on a regional scale.

In order to build a «container» of information, which can be updated and improved over time, one way forward is to:

- develop a more detailed land cover/ land use map;
- input the values of the original matrices into the land use categories of the selected map layer.

A more accurate map, on a larger scale, makes it possible to update the matrix values based on the results of research and monitoring carried out directly on the study area or in comparable areas.

Land use as baseline data

In the case of the Aosta Valley the 2004 «Nature Map» (*Carta della Natura* - CdN), drawn from a national project coordinated by ISPRA (the Italian Higher Institute for Environmental Protection and Research) was used. This map was created at a 1:50,000 scale and has 56 land cover classes for the Aosta Valley territory, details much improved compared to the CORINE Land Cover map, a 1:100,000 scale and showing 24 different classes in the regional territory.
For the Gran Paradiso National Park, the 2015 «Map of habitat typologies» (*Carta delle tipologie di habitat* - CtH), reduced at a 1:10,000 scale, but created by photo-interpretation at a 1:2,500 scale, with further details also at a 1:1,000 scale. This mapping was carried out for the entire 71,000 hectares of the Park. It classifies the territory into 54 land use

categories and is therefore the most detailed of the maps used. This cartographic layer makes it possible to go beyond the main limit of the CORINE map, whose scale leads to the pooling of very diverse land use categories: for example, there is no specific category for roads, which are therefore never identified, being included in other categories. The CdN also suffers of the same inaccuracy as the CORINE map, but to a lesser degree.

Mapping of the watertable recharge

Correspondence between the CORINE land-use categories with the ones by the CdN and the CtH required the complete understanding of the different classification systems.

Matching of classification was carried out on the basis of a consolidated expert evaluation, checking doubtful or more complex cases with photo-interpretation, crossing the three cartographic layers and, above all, thanks to direct knowledge of the area.

Although CdN and CtH categories were often combined into macro-classes, their detailed coding was retained. The reason for this choice is that, when adequate local information will be available, it will be possible to distinguish values in the detailed land cover categories.
Once the mapping work was completed, the territorial functionality maps could be represented in GIS using simple table joins.

The following maps, using the «**supply-demand-flow**» model (see *Cross-referencing geographical information: matrix approach*), illustrate the situation of the regulating ecosystem service «Groundwater recharge» in the Aosta Valley.

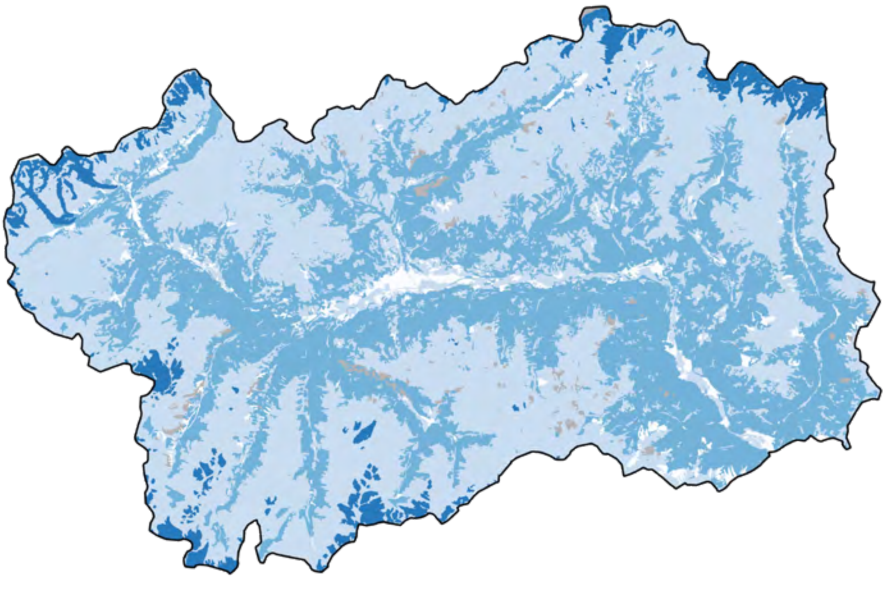

Figure 19 - Map of the supply of the Aosta Valley ecosystem service «Groundwater recharge». The colour ranges from light to intense blue according to the availability of groundwater (higher in areas of perennial glaciers).

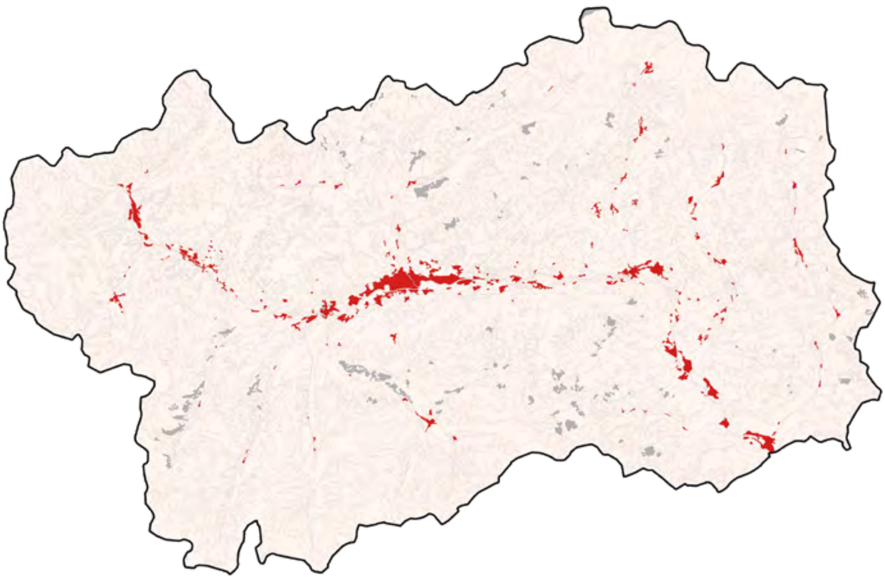

Figure 20 - Map of the demand for the ecosystem service «Groundwater recharge» in the Aosta Valley. Colour gradation increases from light pink to intense red, according to the need for groundwater (higher in inhabited centres).

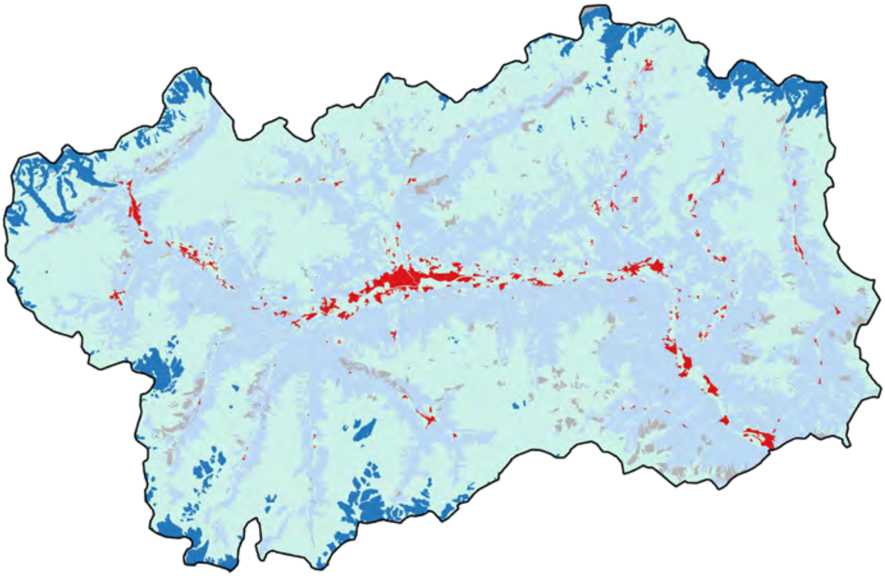

Figure 21 - Map of the flow of the ecosystem service «Groundwater recharge» in the Aosta Valley. The intense blue colour corresponds to supply exceeding demand, while the red colour corresponds to a demand that far exceeds the supply of this ecosystem service.

Fodder and bedding production

The fodder and bedding supply service is connected with the production of wetland biomass. Although these ecosystems appear to be less productive than purely agricultural environments, there are some advantages in using wetlands. The material harvested from wetlands is traditionally called «*blache*» in the French Haut-Rhône[64].

©CEN Savoie

Of the seven sites studied, three supply this service: the Marais de Chautagne, the Marais de la Plesse and the Marais des Chassettes.

THE CASE OF THE MARAIS DE CHAUTAGNE

The cartographic analysis led to the identification of 580 hectares used for agricultural purposes on the Marais de Chautagne, all crops combined (maize, barley, wheat, etc.), including **350 ha listed as grasslands** (CAP 2015 applications). The data collected during interviews with farmers made it possible to approximate the amount of dry matter harvested from the entire marshland to more than 800 tons for the year 2017 (2.25 t/ha of DM).

FIGURES FOR WETLAND FARMING IN THE SAVOY TERRITORY:

- **32%** of the wetlands inventoried are used for agricultural purposes;
- **More than half of the farmers** have at least one wetland cluster completely or partly in a wetland, according to CAP applications;
- **3% of the agricultural land** of the territory is located in wetlands (Savoy-Mont Blanc Chamber of Agriculture, 2016).

What use is made of the harvested material?

According to statements by Chautagne farmers, the marsh *blache* is mainly used for bedding and personal use. The use of the material as fodder depends on its palatability therefore according to the year and the area: it is a quality fodder when there are the right conditions.

A climate governed utilisation

Given how these environments work, their utilisation requires some adaptations compared to conventional hay meadows. The farmers interviewed all referred to the need to adapt to weather conditions, which governs the soil load capacity, among other things.

A necessary utilisation

The utilisation of wetlands by mowing or grazing guarantees a supply of material, and is also necessary for their maintenance, avoiding the area to be colonized by woody plants. On the Marais de Chautagne, the implementation of Agri-environment-climate measures (AECMs) has made it possible to maintain regular mowing leading to the safeguard of open wetlands. Such agro-environment measures also make it possible to carry out mowing while respecting the biological cycles of the susceptible species found there thanks to a lag in mowing and the establishment of refuge areas.

The Marais de Chautagne, key for farmers

The area covered by AECMs is a total of 187 ha of marshland and has allowed a number of farmers to remain on the marsh, as they recognize the benefits it provides them, despite lower yields than other plots and the delicate work sometimes involved in mowing wetlands.
For farmers, the Marais de Chautagne represents a back-up plan, especially in dry years when hay is scarce: it offers **security**. Although only one farmer from Chautagne acknowledged the specific importance of the *blache* as fodder, most interviewees recognised that the marsh gives them a degree of **self reliance**. The *blache* from the marsh means they save on the hay purchases. This is all the more appreciated in organic farming. The purchase price of organic straw is a significant cost for farmers.

Figure 22 - Bales on the Marais de Chautagne ©M. Bouron/CEN Savoie

Areas which periodically may be not easily accessible due to humidity; they are not easily accessible, and must be respected».

Farmer's definition of a wetland, June 2018

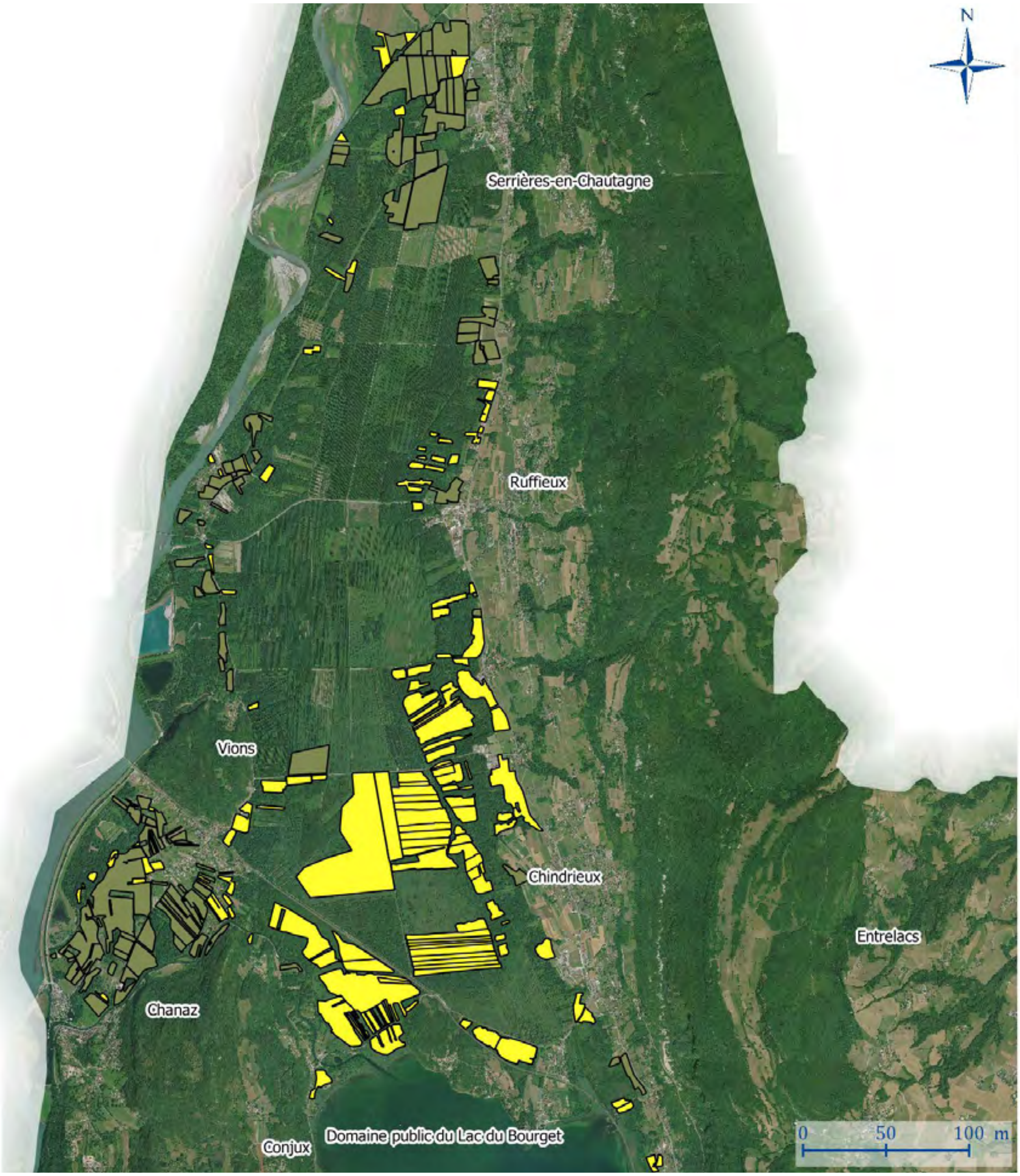

Figure 23 - Grasslands on the Marais de Chautagne.

«Lakes and bogs are the two best sources in my field, paleoecology.»
Scientist interviewed, June 2018

Opportunities for research

This service refers to the interest of a site for research and studies. Wetland research can cover a wide range of disciplines[65]. The interviews conducted with the scientists in the framework of this study confirmed this wide range of approaches. Research themes included: ecology, hydrology, paleo-ecology, bio-geo-chemistry, etc.
Here is a summary of some examples of studies that can be carried out in wetlands.

PEAT BOGS, RESOURCES FOR PALEOECOLOGY

Peatlands conservation properties makes them important for paleo-environmental studies. Anoxia means organic elements, such as pollen, wood, insects, and so on, are preserved in peat. They are also important for archaeological studies. Research on peat bogs can lead to studies on vegetation, climate or past human practices. The ability of peat bogs to provide us with information about the past is at risk because of drying out, which leads to peat mineralization and thus a loss of information.

ECOLOGY & BIODIVERSITY

The special conditions of wetlands make them of particular interest for the study of biodiversity. The Tourbière de Montendry (Figure 24), for example, has been the subject of a comprehensive study of its flora and ecology[66]. It was also compared with the Tourbière des Creusates by Manneville and Baïer in their study[67]. The Marais de Chautagne has also been the subject of a lot of research on its vegetation and fauna by Walthert[68], Fossati & Pautou[69], Dufay[70]. Many studies related to butterfly monitoring are still conducted by the CEN to this day.

Figure 24 - Tourbière de Montendry ©M. Maussin

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BIO-GEO-CHEMISTRY

Many wetlands are the subject of research related to their bio-geo-chemistry because they can be sinks, sources and transformation sites for various chemical elements: bio-geo-chemistry of nutrients, microbial contaminants, sources of dissolved phosphorus, etc.

NEW RESEARCH PERSPECTIVES FOLLOWING RESTORATION

Researchers have repeatedly mentioned that much of the current wetland research is taking place in the context of restoration. These studies can be carried out before, during or after restoration actions, in order to monitor changes in the environment and its responses: effects of these changes on plant dynamics, study of amphibian populations in restored environments, etc. The Marais de Chautagne has undergone numerous changes and has been the subject of a number of studies related to its restoration: study of its hydro-geology in the context of the restoration of the large marshes of the Haut-Rhône[71] or studies carried out by the CEN in the project *Hydraulic and agri-environmental restoration of 60 ha of open wetlands in the Marais de Chautagne* (Figure 25). Five scientists from different laboratories also took the opportunity to conduct a study called DynaMO on the *Transfer dynamics and effects of persistent organic micro-pollutants.*

Figure 25 - Plot under restoration in the Marais de Chautagne ©CEN Savoie

«From an educational point of view, a wetland is excellent because it is a good tool to understand an ecosystem. »
Teacher-researcher interviewed, May 2018

Educational opportunities

Wetlands can be used as a tool for environmental education. This service can develop in various ways: educational panels on the site, observation points, theme trails, on-site explanations, information leaflets, etc. Four of the seven sites are equipped with educational panels.

WHY ARE WETLANDS OF EDUCATIONAL INTEREST?

- **Wetlands are very special natural areas in terms of their development**, enabling students to understand how an ecosystem works as a whole: formation of a wetland (geo-morphological processes, pedogenesis, and so on) variability of environment evolution, species adaptations. Moreover, their limited size means they can be «simplified» educational tools, compared to other types of ecosystems.
- **Contended areas**: the destruction of wetlands over the last century led to a decrease in the number of these environments. As a result, wetlands are becoming increasingly rare. Despite an awareness of their importance in recent years, they are still subject to major pressures (urbanisation, waterway management, etc.). Residents also have a very negative image of wetlands and see them as unhealthy, undesirable areas, causing health problems, and so forth. Raising public awareness of these environments is important to improve knowledge of these areas and raise awareness of the need to preserve these ecosystems and the environment in general.

The interviews conducted with teacher-researchers showed that wetlands were used as examples during their lessons to illustrate various concepts: variability,

Figure 26 - Educational panel on the Marais des Chassettes ©CEN Savoie

environmental management - for example, the management of recreational activities in wetlands - naturalistic aspects, biological diversity, population dynamics, etc. Six researchers out of eight stated that they regularly talk about wetlands and that they had already organized field trips to them with their students. In general, researchers also noted that the work carried out on these environments is greatly appreciated.

«Students enjoy working on these environments»
Teacher-researcher interviewed, May 2018

THE EXAMPLE OF THE MARAIS DES CHASSETTES

The educational service of the Marais des Chassettes is key for all those involved in environmental education, organising explanations on the marsh, and the Department, which is the landowner.

To date, there are three educational panels on the site (Figure 26). The site has so-called «authorised» paths, located on the outer marsh, and other «unauthorised» paths, in the heart of the marsh, as shown on the map (Figure 27). An eco-counter installed on one of these trails has made it possible to evidence a limited but regular

use of the marsh. Over approximately one month from July 24 to August 27, 2018, the eco-counter recorded a total of 23 one-way and 14 in the other way passages. Data are obviously to be taken with a grain of salt because of installation inherent biases: round trips, passage of wildlife or other animals such as dogs.
An information brochure was printed in 2014. The site is also the subject of descriptions by two associations: between 4 and 8 on site events per year are organised as follows:

- **Nature trails:** discovery of the marsh (how it functions and develops) and its species (insects, amphibians, birds, and so forth).
- **Undergrowth clearing and cleaning** in connection with site management (on-site waste collection, removal of woody material, etc.).
- **Other events in partnership with local institutions:** inventory work with HND students, works to secure the access to the marshland in partnership with a local agricultural college.

Participants vary: schoolchildren (middle schools, high schools and colleges), leisure centres, members of associations, residents of the districts around the marshland, or parents of students. Activities are of course adapted to the target public: for the youngest they appeal to the imagination or the senses. The activities in schools near the marsh area are of great interest for local resident education: the children will play a role in disseminating information to their parents, who will in turn come to discover the site. Site visitors and stakeholders agree: awareness and communication are important levers for the marshland. The role of this service is important for several reasons, which came up again and again in the interviews with stakeholders. The Marais des Chassettes is home to **an interesting natural heritage** in terms of the species found there (the common frog, common toad, four species of woodpecker, and other remarkable birds such as the reed warbler, ...) and the habitats it offers for a highly urbanised valley bottom. This geographical situation and its peri-urban context make it close and easily accessible.

Because it is so close, the marsh is seen as a unique opportunity for residents to benefit from a real environmentally sensitive area space next to their homes.

Nevertheless, this context and proximity to housing are also the reasons why the marsh presents challenges:

- pressures from **urbanization;**
- **conflicts of interest** with the residents closest to the marsh: the study of their perception showed that a part of the population had a very negative view of the marsh, and was suffered because of mosquitoes, flies, shade, etc.;
- **uncivilised behaviour:** many such incidents occur in the marsh: dogs left off the leash wandering in the marsh, garbage dumps, motorized vehicles passing by, etc.

There is a mismatch between the perception of the managers and the situation perceived by local residents. For all these reasons, the service of educational opportunities is a key aspect of site management for local stakeholders. By continuing to invest in this service through educational actions, the stakeholders hope to change local residents' opinion on the site and thus limit conflicts of interest and uncivilised behaviour. The questionnaire on the marsh suggested residents are aware of its educational role: 15 out of 19 people stated that the marsh is of educational interest. Sixteen of the 19 had visited the marsh and read the educational panels, and the majority of people had brought their children.

«It allows to show people what a real natural space is with completely different dynamics compared to a park, it is not a gardened, landscaped space.»

«It plays its role as a space of nature,
of proximity as well as being a place for discovery.»
Department of Savoy in an interview, June 2018

Figure 27 - Educational trails and panels on the Marais des Chassettes.

Support for recreational activities and tourism

Wetlands can be used for a variety of activities: green tourism because of their environmental richness, outdoor sports activities, hunting (waterfowl), etc.

THE CASE OF THE TOURBIÈRE DU PLAN DE L'EAU

The Tourbière du Plan de l'Eau, in the heart of the Ménuires ski resort, is an illustration of this service. Its geographical position offers tourists a choice natural area very close to the resort. In 2006 the downstream section of the site was developed as an artificial lake *(Plan d'eau des Bruyères*). Thanks to this strategic location the site has become an important attraction. Today, the layout offers visitors the possibility of picnicking, barbecuing on equipped designated areas, fishing in the lake, taking advantage of the pontoons, and enjoy a walking path suited for people with reduced mobility. These facilities complete the range available throughout the area.

The Tourbière du Plan de l'Eau was granted a protected status following the creation of the Plan d'eau des Bruyères: it

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has been placed under the protection of a Prefectural Biotope Protection Order *(Arrêté Préfectoral de Protection de Biotope APPB)*. Its status does not limit it in supporting various activities, as can be seen on the map that summarises what can be carried out on the site:

- numerous walking marked out by educational panels so visitors can learn more about the site: built heritage, natural heritage, etc.; other panels also delimit the site and recall the regulations in force;
- starting point for a trek which is the flagship of the resort: the hike to the refuge and the Lake Lou. The first part of the hike offers a panoramic view of the entire peat bog;
- numerous mountain bike activities, with a marked discovery trail for children;
- paraglide landing area;
- "Mountain Adventure": activities for children, including zip line-wires, rope bridges;
- in addition to the summer activities, the site hosts winter activities, including cross-country skiing on tracks and slopes maintained by the municipal government.

Fishing is also available on the site. Visitors can fish on the Plan d'eau des Bruyères and on the Doron River. The activity is regulated by the *Préfecture* (APPB): licence and government stamps are required, walking in water is not allowed, only one standard size fish per day and per angler. Local decision-makers are aware of the importance of the support service for recreational and tourist activities in the peat bog, placing it in second place among the services most rendered by the site during the participatory meeting (following the service «regulation of hydrological cycles and protection against flood risk»). They are obviously faced with the problem of reconciling human activities with the preservation of a sensitive ecosystem. All the subjects discussed during the last part of the participatory meeting revolved around the reception of the public. Observations made in the field during the high summer tourist season revealed that the Plan d'eau des Bruyères made it possible to channel visitors to this area thanks to the many facilities such as tables and benches. The Tourbière du Plan de l'Eau then appeared rather as a place dedicated to walking and calm.

©F. Biamino/CEN Savoie

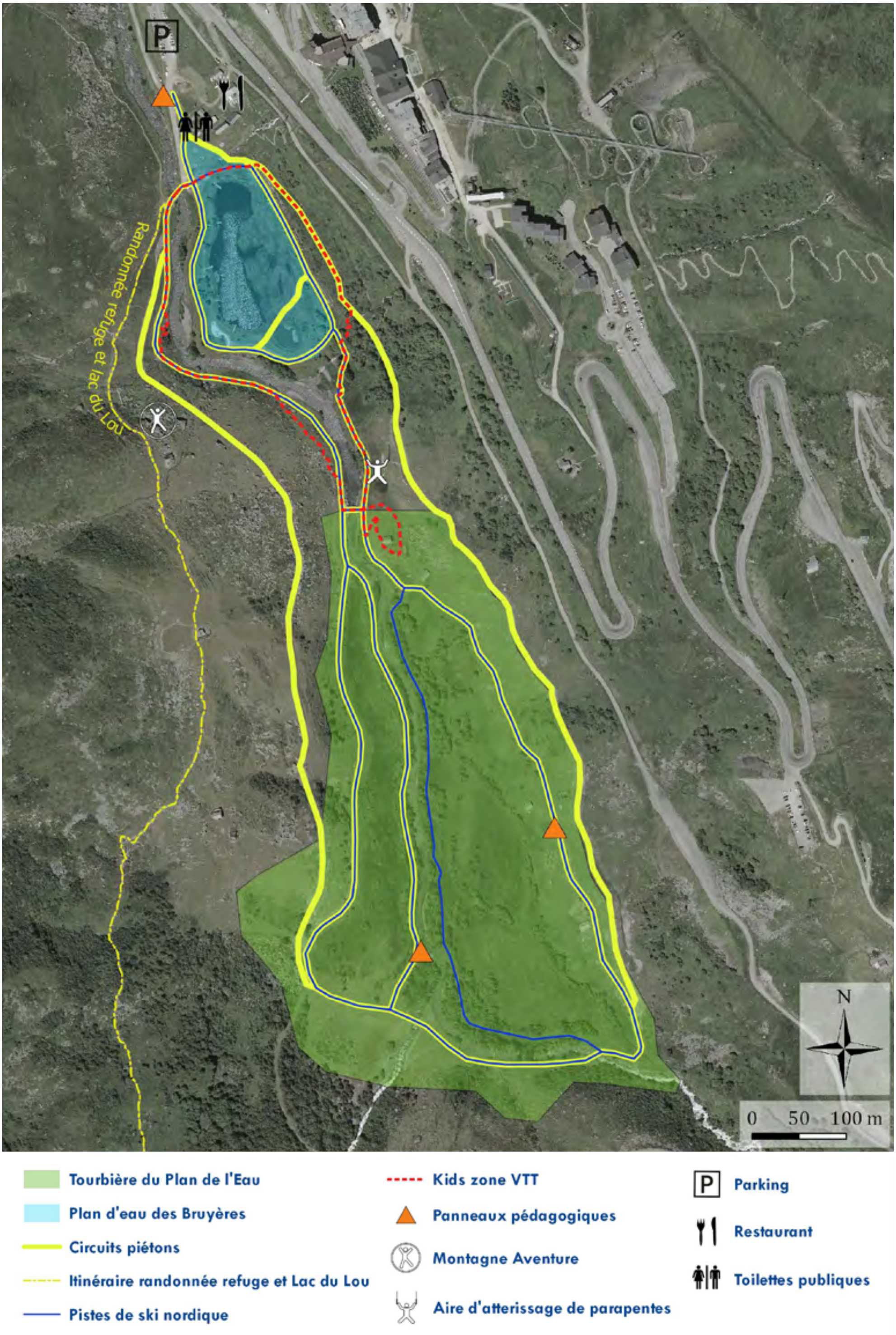

Figure 28 – Recreational and tourist activities on the Plan de l'Eau site.

Cultural heritage

Like any natural area, wetlands can be part of the cultural heritage of residents or users. Cultural heritage can refer to a number of different values: identity, relational or spiritual which can be expressed through the presence of so-called «heritage» species on the site (emblematic, rare, endemic species, etc.), particular processes (erosion phenomena, reproduction of a species in a given place, etc.), cultural practices (ancestral agricultural practices for example), or other «heritage» objects present on the site such as built heritage for example. These features can be translated into art or gastronomy, participate in the territorial identity, by protection regardless of their use[72].

Heritage echoes the «singularity» of each wetland and the relationships that individuals have with it. The «heritage» of the considered wetlands was expressed in different ways during the interviews. A wetland can be part of heritage because it is associated with local history and the practices that were carried out there (hydraulics, supply, use, etc.):

PEAT EXPLOITATION IN THE MARAIS DES CHASSETTES

Peat was **extracted** from the Marais des Chassettes during the Second World War. The marsh, which still bears the traces of this period, speaks to those difficult times.

HYDRAULIC ROLE AND AGRICULTURAL EXPLOITATION ON THE MARAIS DE LA PLESSE

The Marais de la Plesse has been the subject of several layouts over the centuries. Already identified as a location in itself on the Map of the Kingdom of Sardinia, the marsh belonged to the owner of the castle of Saint-Offenge, the municipality where it is located. The lord allowed the servants to go **and gather the *blache* on the marsh**. Farmers still gather *blache* to this day. The development of the marsh during the past centuries was linked to its hydraulics. Indeed, the outgoing water of the marsh was rechanneled to feed the mills located downstream.

BUILT HERITAGE ON THE PLAN DE L'EAU

The «heritage» features of the Plan de l'Eau aux Ménuires site can be appreciated in its **traditional buildings**: the Plan de l'Eau site is marked out by old chalets, built in local stones and testifying to the ancient transhumance on the Ménuires, contributing to the identity of the valley (Figure 29). In meetings with locals, they have consistently placed this at the top of the list of services provided by the marsh, proving that the heritage value of the wetland goes beyond any utilitarian aspect. The strong presence of the heritage may explain the fears evoked by the locals during the early stages of the layout of the Plan d'eau des Bruyères.

Figure 29 – Heritage building on the Plan de l'Eau ©J. Porteret/CEN Savoie

In addition to these historical features, a wetland can also have heritage value because of the species it houses.

PRESENCE OF HERITAGE SPECIES

Heritage may relate to **the number of endangered species** present in a wetland. The rarity of these species can be part of the site's heritage with regard to its role in the preservation of these species, which are sometimes dependent on such an environment. For example, the Plan de l'Eau aux Ménuires site is home to two species of reptiles classified as near-threatened on the IUCN Red List: the common frog (regionally) and the grass snake (nationally). Fewseeded bog sedge *(Carex microglochin)*, growing on the site, is listed as a vulnerable species in Europe. The short-toed snake eagle and the squacco heron, both passing through the bog, are listed in Annex I of the Birds Directive. The wet grasslands of the Marais de Chautagne are home to no less than 12 species of butterflies protected at a European level including the large copper *(Lycaena dispar)*, the false ringlet *(Coenonympha oedippus)*, the marsh fritillary *(Euphydryas aurinia)*, the scarce large blue *(Maculinea teleius)*. AECMs and the targeted management make it possible to conserve these fragile species on the site.

Heritage species can also be approached via **the value attributed to it by residents** other than the rarity of the species. For example, criteria can be based on aesthetics, danger, abundance, and practices associated with the species.

On the Marais de la Plesse, frog fishing has long been an activity practiced on the site. Despite the discontinuation of this practice due to the disappearance of frogs, it remains in residents' memories and childhood recollections.

VESTIGIAL ENVIRONMENTS

Peat bogs may contain species that sometimes **bear witness to the cold periods of the past** linked to these environments: sundew (Figure 30), butterwort, cottongrass. *Drosera rotundifolia* (round-leaved sundew) and *Pinguicula vulgaris* (Common butterwort), are both carnivorous plants present on the acidic Montendry peat bog.

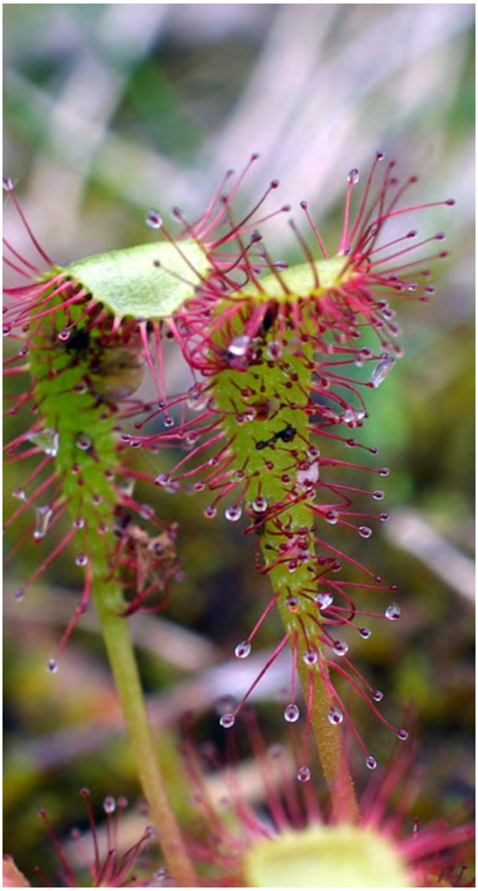

Figure 30 – Sundew ©V. Bourgoin/CEN Savoie

RECOGNISING HERITAGE: PROTECTION MEASURES

The recognition of this heritage can be expressed through **specific protection measures** such as the establishment of Prefectural Biotope Protection Orders or the classification as a Sensitive Natural Area as is the case of the Marais des Chassettes. In Savoy, the ecological value of the wetlands in the area is fairly well recognised: 50% of the APPBs, which require the presence of one or more protected species, are wetlands (marshes and peat bogs). They are the

Figure 31 – General view of the Chautagne with its mosaic of landscapes ©CEN Savoie

best represented environments in this type of protection. The Drosera on the Tourbière de Montendry is one of the species that justified the classification of the peat bog in the APPB.

WETLANDS AS PART OF THE CHAUTAGNE LANDSCAPE

Heritage can also be linked to the **landscape considering its identity value for residents**. In the Chautagne, wet meadows are part of the mosaic of its characteristic environment: forests, vineyards, lake, mountains and meadows (Figure 31). Farmers mowing the marsh are aware of their essential role, that enables the environment to remain open thus conserving these grasslands that have been there and exploited for centuries. The heritage value of agricultural practices on the marsh was identified in the interviews. Most of the farmers interviewed learned how to farm the marsh from their predecessors and elders, who taught them to «respect the marsh» and to «identify areas at risk of sinking». One farmer said that before the mowing of the marsh was discontinued, there was a trade with the farmers of Cessens (a municipality in the Albanais), who brought wheat down to the marsh and then went back up with *blache*.


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