ECO-GRAZING AND VEGETATION RESTORATION

in Mediterranean wetlands

Tour du Valat

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Much of his work focuses on the restoration of Mediterranean wetlands, in particular on the application of domestic grazing and its consequences for biodiversity dynamics. François Mesléard worked throughout most of his career at the Tour du Valat wetlands conservation research institute and the Institut Méditerranéen de Biodiversité et d'Écologie. He led and contributed to numerous restoration projects, consultancy missions and training courses around the Mediterranean basin. He also taught at the University of Avignon.

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FOREWORD

Context and application

How can extensive grazing be used to restore Mediterranean wetlands according to the specific features and constraints of a site and the objectives being pursued? What approach should be adopted before implementing pastoral management? What choices should be made considering medium- and long-term possibilities? How can we ensure that current restoration work is running smoothly, so that we can change the methods being used as needed? How can we measure success? This document was written to help those facing these questions. It does not, however, offer a universal recipe or one that can be applied as is. Every site is unique and is characterised by numerous specificities, which means that grazing-based management that is appropriate for one site is unlikely to be so for another if it is reproduced identically.

Because the process involves animals, grazing-based management and restoration must not be improvised. Serious attention must be paid to parameters as diverse as the nature of the host environment, environmental conditions and their possible or assumed evolution, the suitability of domestic herbivores, herd management and handling, the choice of measurement techniques, how they are applied, and the means needed for them to be continued over time.

The themes addressed and the questions raised are therefore manifold; how they are addressed, and the corresponding bibliography are necessarily incomplete. By presenting the scientific foundations and issues to be considered in the context of grazing-based conservation management, this document is meant to serve as a reference book. It invites readers to consider the various dimensions and complexity of the subject, and should enable them to complete, revise, and improve their analytical capacities.

The first, more theoretical part deals with eco-grazing (the mechanisms of vegetation succession, and the restoration of plant **communities***), which is the best scale for observing and predicting the consequences of the processes involved in herbivory. Understanding the mechanisms involved and understanding how to take advantage of or control them are two essential prerequisites for designing a restoration project.

The second section focuses on project development, from the choice of whether to use grazing, and in what ways, to the necessary and useful monitoring to be put in place.

The third section deals with the monitoring and pastoral management of several plants that are emblematic of Mediterranean wetlands in terms of their importance, interest, and the problems they are likely to pose.

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INTRODUCTION

Today, wetlands are recognised to be ecologically vital environments which provide numerous ecological and cultural functions (Zedler & Kercher 2005 **289**). However, since the beginning of the 20th century, more than half of them have been severely degraded or have simply disappeared (Millennium Ecosystem Assessment 2005 **193**, Davidson 2014 **73**, Gardner & Finlayson 2018 **107**; Fluet-Chouinard et al. 2023 **102**), and a quarter of the species dependent on these **biotopes*** are threatened with extinction (Ramsar Convention on Wetlands 2018 **235**). Mediterranean wetlands are no exception to this disturbing trend.

Wetland restoration is therefore one of the primary conservation targets for the coming decades (De Groot et al. 2013 **76**). In the Mediterranean Basin, the climatic, socio-economic (growing anthropogenic pressure), and geopolitical contexts make this a major challenge.

Grazing is a powerful means of vegetation management, commonly used in wetlands. By controlling the growth of numerous species, limiting the establishment and colonization of other vegetation, and making it more difficult for them to survive, it entails successional mechanisms that prevent or delay vegetation overgrowth (Hill et al. 1995 **134**; Dorrough et al. 2007 **84**). Through selective consumption, particularly of the most competitive species, grazing modifies plant hierarchies and by creating spatial heterogeneity within vegetation, it contributes to maintaining or increasing biodiversity (Lin et al. 2010 **163**; Nolte et al. 2014 **203**; Koener et al. 2018 **153**). It is thus a key activity for the management and conservation of open spaces, but also for their restoration (Rambo & Faeth 2001 **234**; Rosenthall et al. 2012 **241**, Chen et al. 2020 **53**). It is therefore widely used for this purpose in reserves and sites where biodiversity depends on the maintenance of herbaceous environments (Wallis DeVries et al. 1998 **278**).

The advantages and limitations of extensive grazing for environmental management and restoration have been widely discussed (Bakker 1989 **17**, Wallis DeVries et al.1998 **278**, Danell et al. 2006 **71**, Platcher & Hampicke 2010 **225**, Rosenthal et al.2012 **241**, Schieltz et al. 2016 **248**, Bakker et al. 2020 **19**; Filazzola et al. 2020 **100**).

Aa* Term defined in the glossary section
Aa Refer to the reference section

The domestic herbivore cannot be considered as a simple environmental management tool analogous to mechanical machinery in terms of simplicity of use and result. To consider it as such is to ignore its capacities and requirements, and how they vary. Reducing the domestic herbivore to a simple tool is tantamount to neglecting its needs, which can lead to tense or even catastrophic situations if these needs, whether for food or management (reproduction, movement), are not met. The impact of domestic herbivores, just as their management, differs from species to species, depending on age, sex, and group composition (Davidson 1993 **72**, Gordon 2003 **111**). Poorly managed or improvised grazing entails risks for the environment and the animals themselves.

Management by domestic herbivores to meet conservation objectives is even more acceptable to the local community when traditional grazing practices are respected or revisited. However, taking account of the historical pastoral context is not adequate for promoting the use of this management for heterogeneous habitats when the animals concerned are assigned a precise and sometimes new objective. Insofar as the effects of inappropriate management may not only fail to benefit biodiversity, but may also be difficult and costly to repair (e.g., colonization by undesirable species), any introduction or reintroduction of domestic herbivores, and any significant modification of existing grazing methods, and even more so eliminating them, must start with in-depth analysis of the possible consequences.

Ideally, the impact on vegetation of the proposed new management process should be tested beforehand. It should be compared with existing or past management over a sufficiently long period of time to take account of the variability of climatic conditions, in order to obtain reliable answers as to whether the stated objectives can be achieved. In regions where rainfall distribution varies greatly between seasons and years, such as the Mediterranean, the test period will potentially be long enough to encompass the extent of this variability. Data collected on other sites subject to comparable changes in pastoral management may also be used; however, their exemplary nature, and hence their replicability, should be considered with caution.

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1.

GRAZING WITHIN THE CONTEXT OF RESTORATION

1.1 GRAZING, ECO-GRAZING, AND ECO-PASTORALISM

1.1.1 Pastoralism and extensive grazing

Pastoralism is an extensive grazing system in which animals feed on mainly spontaneous plant resources (not introduced by sowing), within the framework of limited nomadism that is either daily (grazing) or seasonal (transhumance).

Pastoralism is based on the use of natural resources that are not subject to strong management measures such as **soil improvement***. Depending on seasonal cycles and climatic constraints, it depends on the herbivores' ability to preserve or enhance the forage quality of the rangeland, which is the key to its long-term survival. To optimize the management of both the environment and the animals, nomadic grazing requires the herd to be led by a shepherd or by mobile fencing. This type of movement management allows for the qualitative and quantitative use of space, which takes account of an herbivore's behavior and the food supply, as well as existing plant **communities*** and their possible evolution. Grazing-based management can thus aim to concentrate the action of the animals or, on the contrary, to limit pastoral pressure, if the vegetation dynamics so require, in order to increase or limit harvesting.

When grazing is not carried out as a nomadic activity, permanent fences impose spatial constraints on domestic herbivores. However, fenced-in grazing can involve large areas and correspond to low instantaneous pressure, which may be lower than that exerted by domestic herbivores grazing freely but managed by a shepherd or with the constraint of mobile fences. The distinction between grazing and pastoralism is therefore based more on whether or not the herd is led by a shepherd, and therefore the level of constraint exerted on the animals' movements, than on the grazing pressure, since both instantaneous and annual grazing pressure may be higher when led by a shepherd. In the case of extensive grazing, i.e., when low annual pressure is applied to the environment, grazing may correspond, depending on the ratio between the surface area in which domestic herbivores graze and their numbers, to a strong spatial constraint, but in this case of short duration, which favours mechanical and feeding action by the herd on the vegetation far superior to that in the absence of constraints.

1.1.2 Eco-grazing: a hierarchy of objectives

Extensive grazing is generally thought of as contributing to land management, and the terms ‘eco-pastoralism’ and ‘eco-grazing’ are often used to describe grazing methods that, in addition to feeding domestic herbivores, promote biodiversity, broadly speaking. In this case, the beneficial action of grazing to conserve the environment represents a positive **externality***, an additional service, which may have been envisaged and desired, but which did not determine the grazing methods applied. In this case, whether or not it was planned, maintaining biodiversity is merely a consequence.

Aa* Term defined in the glossary section

GRAZING WITH A PRIMARILY ENVIRONMENTAL OBJECTIVE

Strictly speaking, eco-pastoralism and eco-grazing differ from pastoralism and grazing in the hierarchy of their objectives. For eco-pastoralism and eco-grazing, domestic herbivory is first and foremost at the service of environmental and/or conservation objectives. These objectives may be aimed at conserving habitats or species (plant or animal), or even endangered domestic breeds. In this case, the domestic herbivore in question is the primary objective in terms of increasing its numbers. Other objectives, such as the feeding function which conditions the presence of domestic herbivores on the site, are also set, but only insofar as they are related, essential, or compatible.

However, these associated objectives must not supplant the primary conservation objective. Placing a conservation objective at the top of the hierarchy may therefore compromise or prohibit one or more objectives. This is the case, for example, if the grazing methods chosen to meet a specific conservation objective are not the most favourable for the growth of livestock, enabling maximum income to be derived from their presence. Generally speaking, the choices are not so clear-cut: the conservation objective can only be ensured, and above all sustained, if the socio-economic objectives and, especially, the herd's needs are met.

Tour du Valat herd © *J. Jalbert*

When there is a clear hierarchy of objectives, eco-grazing and eco-pastoralism correspond respectively to grazing and nomadic herding of domestic herbivores, which is defined by an environmental management objective, and pursues first and foremost this objective.

A GLOBAL APPROACH TO THE CONTEXT

Making a hierarchy of objectives means that they must be precisely defined, particularly the primary objective, and the biodiversity compartments targeted by pastoral management must be identified. These expectations cannot be defined without a good understanding of the site concerned and its context, if possible, in relation to other ecologically and historically comparable sites deemed to have a good conservation status. This prioritization in no way means that the herd's diet or the socio-economic context are secondary. Grazing methods, however relevant they may be for biodiversity, are unlikely to be applied, and even more unlikely to be maintained over time, if they do not respect the needs of the animals, do not correspond to any social need or demand, are not economically viable, or do not benefit from long-term sources of funding.

In wetlands, grazing is usually only one component of a conservation or restoration project, which is also dependent on hydraulic management. In such cases, we need to think in terms of overall management, with all that this implies in terms of organisation and resources.

1.1.3 Domestic and wild herbivory

DO WILD AND DOMESTIC HERBIVORES COMPETE FOR THE SAME RESOURCES?

Wetland restoration depends in part on natural, unmanaged processes such as seed dispersal, succession, and predation by wild herbivores (Bazely & Jefferies 1985 **24** Bradshaw 1997 **40**, De Lillis et al. 2004 **77**, Deliboes-Mateos et al. 2008 **79**, Esselink et al. 1997 **97**, Hayward et al. 2019 **131**, Montoya et al. 2012 **196**). The pressure exerted by wild herbivory on plant communities is often substantial *(Fig. 1, 2)*. Large or small wild vertebrates (particularly rodents) can play a decisive role in vegetation locally, although this role is not precisely assessed and therefore not integrated into management. However, insofar as the objectives assigned to domestic herbivores are not to recreate a state of original naturalness (Purschke et al. 2012 **231**) but to maintain or recover habitats and functions partly inherited from anthropogenic activities, grazing can compensate for the absence of large wild herbivores and prove compatible or even complementary with the wild herbivory present *(see box 'Wild and domestic herbivores competing for the same resources')*.

Figure 1: Exclosures for domestic herbivores (left) and domestic herbivores and rodents (right) on the Tour du Valat Reserve *© F. Mesléard*
While the exclusion of domestic herbivores alone (left-hand side of the exclosure) led to a barely perceptible change in the herbaceous vegetation dominated by the Annual Daisy *(Bellis annua)*, the exclusion of rabbits combined with that of domestic herbivores (right-hand side) led to the colonization by a bushy species *(Phillyrea angustifolia)*, and the development of a herbaceous cover whose increasing density rapidly prevented further colonization by the Phillyrea (**preemption effect***).

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Figure 2: Species richness (in annuals and perennials) in the spring of 1976, 78, 80, 82, 85, and 2001 on grasslands on the Tour du Valat Estate in plots grazed by rabbits or by domestic herbivores and rabbits and in ungrazed plots (exclosures installed in 1975). In the absence of domestic herbivores, rabbits control the number of perennial species and therefore the species richness of annuals. Domestic grazing contributes only slightly to increasing the number of annual species by controlling perennial species. However, caution should be taken in drawing conclusions about the respective roles of domestic herbivores and rabbits. On the one hand, the measures concern the number of species and not the contributions of each of the species present (*§ 2.3.2*). On the other hand, the control of vegetation by rabbits is to a large extent dependent on the presence of cattle, which by grazing create conditions favourable to their presence (control of the height of herbaceous vegetation, Mesléard et al. 2011 **185**).

REWILDING

Rewilding aims to restore food webs and populations of species essential for the conservation of the environments concerned through the establishment of large reserves (Carver et al. 2021 **50**, Perino et al. 2019 **222**, Power et al. 1996 **228**, Soulé & Noss 1998 **257**). In this sense, it can be considered as a particularly high level of restoration.

Aimed at enabling the **ecosystem*** to function autonomously solely through the presence or reintroduction of one or more keystone and/or engineer wild species (Pereira & Navarro 2015 **218**, *§ 1.5.1*), rewilding is sometimes considered to be incompatible with the presence of domestic herbivores (Du Toit & Pettorelli 2019 **269**, Klop-Toker et al. 2020 **152**). However, the reintroduction of domestic herbivores for restoration purposes, insofar as they no longer benefit from any human intervention for their feeding and the management of their numbers, can itself be analysed in terms of rewilding (Du Toit & Pettorelli 2019 **269**). This possibility of autonomy for domestic herbivores, except in large areas with large predators, is then confronted with the question of the habitat's **carrying capacity***, which requires more or less regular interventions, at the very least to control the number of animals, so that their feeding requirements do not exceed the forage supply and do not threaten the integrity of the environment (Schweiger et al. 2019 **249**).

Fire and the development of farming seem to have played a prominent role in opening up Mediterranean environments. The impact of large wild herbivores on the expansion of herbaceous patches is difficult to assess. However, livestock breeding and pastoralism developed early in the Mediterranean region, and domestic herbivores may have largely supplanted wild herbivores in the region by 5000 BC (Blondel 2006 **33**). Yet, after having largely shaped the Mediterranean landscape to the point of being identified as a threat to many habitats and soils, pastoralism has, in many parts of the Mediterranean, declined to the point becoming an activity to be preserved and promoted for both ecological and cultural reasons--a reversal of the previous paradigm (Perevolotsky & Seligman 1998 **219**). Wetlands are less concerned by the decline in grazing. The strong presence of human settlements in their immediate vicinity means that many wetlands are subject to heavy exploitation. Nevertheless, in sites where human activities are

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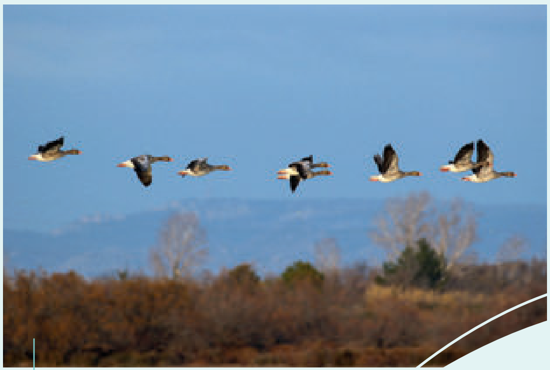
lacking, the reintroduction of herbivory by large vertebrates seems to be all or part of the answer to overgrown environments, the diminishing characteristic plant and animal species, and the resulting loss of functions. Pastoralism can then be seen as a substitute for large or mega wild herbivores, likely to satisfy conservation objectives (Duncan & D'herbes 1982 **87**, Gordon & Duncan 1988 **110**, Gordon et al. 1990 **112**, Duncan 1992 **88**, Danell et al. 2006 **71**, Rosenthal et al. 2012 **241**, Ruifrok et al. 2014 **243**, Chen et al. 2020 **53**). Domestic herbivores are thus assigned the role of shaping and maintaining more or less open environments so that they become habitats for flora and wildlife that need to be preserved.

WILD AND DOMESTIC HERBIVORES COMPETING FOR THE SAME RESOURCES:

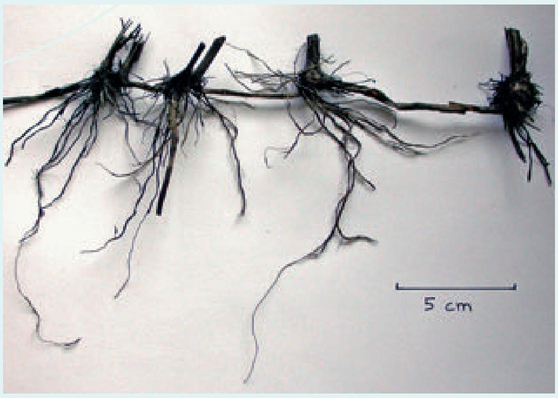
CAMARGUE CATTLE AND GREYLAG GEESE IN THE ST SEREN MARSH

Figures 3: The St Seren marsh on the Tour du Valat Estate (Camargue)
© J. Jalbert



Figures 3: Greylag Geese (*Anser anser)* frequents the St Seren marsh.
© T. Galewski

The vegetation in the St Seren marsh is dominated by Sea Club-rush (*Bolboshoenus maritimus*), which is controlled and developed by controlling the reed (*Phragmites australis*) in spring and summer using Camargue cattle.



At the end of the 1990s, the number of Greylag Geese visiting the marsh during the winter increased sharply, from around ten individuals to almost a thousand. They feed on Sea Club-rush tubers.

Figure 4: The tubers, which are underground storage organs, are linked together by connections that are broken when the tubers are uprooted by geese or trampled by cattle.
© Tour du Valat

The sudden increase in the number of Greylag Geese raised two questions for managers who wished to optimise grazing for the conservation of waterbirds and, in particular, to keep Greylag Geese in the marsh:

- Is there enough food accessible to Greylag Geese in the marsh?
- Should domestic herbivores, which eat the green parts of the same plant species as the geese, be kept in the marsh?

Sufficient food accessible to geese

(Desnouhes et al. 2013 **80**, Durant et al. 2009 **89**, Durant et al. 2009 **90**)

Observations of the feeding behaviour of the geese show that they use only 10% of the marsh surface, mainly at the edges where the Sea Club-rush is sparse (tubers are easy to extract). The food ingested by the geese in one winter is estimated to be 20 tonnes of tubers, which is much less than what is available, estimated to be 40 tonnes.

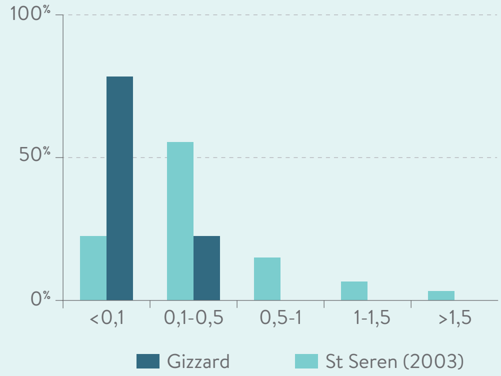


Figure 5: Distribution (%) by weight class (g) of tubers accessible in the marsh and present in the gizzards of Greylag Geese frequenting the marsh.

Greylag Geese and cattle are the driving force behind the food available to Greylag Geese

Experiments under controlled conditions on the food choices of geese show a preference for small tubers, which are more plentiful on the marsh's periphery. This preference is corroborated by the distribution of tuber sizes in the gizzards of the geese compared with their same distribution in the marsh *(Fig. 5)*.

Complementary experiments, also under controlled conditions, aimed at evaluating the consequences of breaking the connections between tubers show that each break led the following year to an increase in the production of tubers from an initial tuber (by eliminating the control of intraspecific competition) with the consequent production of smaller tubers (Charpentier et al. 1998 **52**).

Taken together, these results suggest that, far from exhausting the food it can consume in the marsh, the Greylag Goose's feeding behaviour favours the food it likes for the following year (increase in the number and reduced size of tubers). The domestic herbivore also plays a part by trampling (breaking connections) and consuming the aerial parts of the Sea Club-rush (reducing the size of the tubers by reducing the production of sugars from photosynthesis). Competition between geese and cattle for the same resource could have led the site manager to modify the grazing load applied to the marsh in the spring following the explosion in Greylag Goose numbers. However, since it was shown that this was nothing more than apparent competition, the decision not to make a change was justified. Here, as is often the case in conservation, it would (probably) have been a mistake to act (reduce grazing pressure) before understanding all the consequences of the planned action.

This demonstration is the fruit of collaboration between nature managers and researchers, the former raising questions in terms of management, the latter transcribing them into hypotheses and then research questions (e.g., what is the feeding behaviour of herbivores? the biology of a particular plant species, in particular vegetative reproduction? intraspecific competition?). The time, precision, and resources required for research are often perceived, quite rightly, as a constraint; nevertheless, research is a valuable partner in nature management.

1.1.4 Grazing and the mediterranean climate

The Mediterranean climate is characterised by contrasting seasons. Summer is hot and has the lowest rainfall. Winter is mild (average coldest month above 0°C), with varying degrees of intensity. Rainfall is subject to wide variations between seasons, with autumn and, to a lesser extent, spring being the two rainiest periods. While annual rainfall amounts can be relatively high (> 600mm), the Mediterranean climate is also characterised by high variability in the amount and distribution of rainfall from year to year (the average annual rainfall in the Camargue is 560mm, but has varied between 250 and 1200mm over the last 40 years). Some of the rainfall occurs extremely intensely in a particular year, and for the same period of another year may be very concentrated or spread out. These variations in the amount and distribution of rainfall mean that water availability, the dates at which the marshes are re-flooded, and the water levels reached are highly unpredictable.

Variability in the amount and distribution of rainfall, as well as in temperatures, particularly during the winter and early spring, determines the amount of forage, which fluctuates greatly over the course of the year and from year to year *(Fig. 6)*. Through their impact on vegetation dynamics, this variability also influence the grazing possibilities (Peco et al. 1998 **216**, Verwijmeren et al. 2019 **275**).

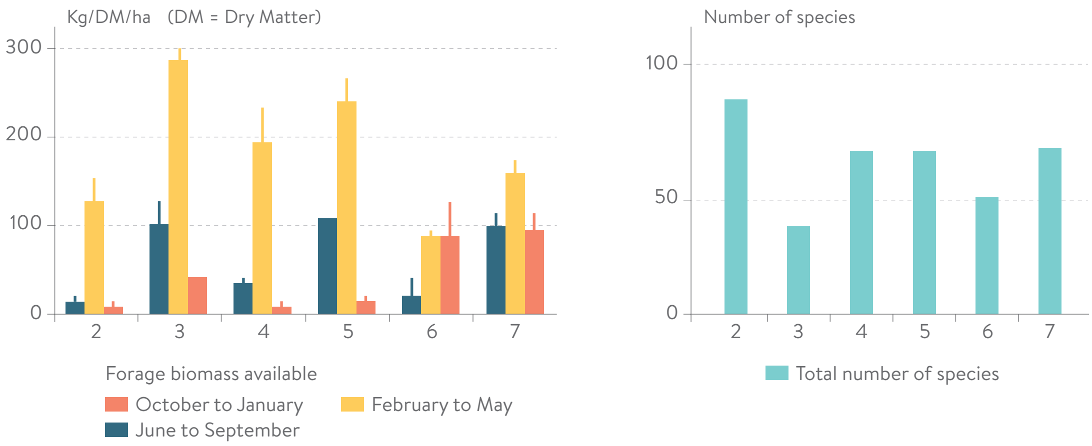


Figure 6: Forage biomass measured and total number of species recorded in spring on Camargue grasslands from 2002 to 2007. Forage availability varies from 1 to 3 kg DM/ha from February to May, 1 to 6 kg DM/ha from October to January, and 1 to 18 kg DM/ha from June to September. Variations in species richness do not appear to be directly related to seasonal or annual forage production. While species richness is dependent on favourable climatic conditions, of which production is a **proxy***-a simultaneous increase in species richness and forage production is therefore expected- other mechanisms also contribute, such as competition, which is also dependent on climatic conditions, but which tends to reduce the number of species.

The consequences of rainfall variations from one year to the next are, of course, mitigated in flooded or irrigated areas, but in most situations the seasonal forage supply is difficult to predict due to the irregular nature of the Mediterranean climate.

Tour du Valat Natural Regional Reserve © A. Granger

This unpredictability must be taken into account, as it affects grazing methods (grazing period, applicable load, pressure exerted on the environment). Depending on the context, if it is not possible to maintain stable hydraulic conditions from year to year, the grazing load will have to be adjusted not only during the same year between seasons, but also for the same season in different years, if the food supply, which depends on climatic conditions, is susceptible to becoming a limiting factor. This should be done so that the pressures applied contribute positively to the management/conservation/restoration of the plant communities in place and/or to their restoration and are compatible with the animals' medium- and long-term needs.

1.2 GRAZING AND COEXISTENCE OF SPECIES

In many environments, particularly Mediterranean wetlands, domestic grazing plays an important role in the presence and dynamics of plants, the coexistence of species, and the structuring of **communities*** (Beeftkin 1977 **25**, Crawley 1983 **67**, Crawley 1989 **68**, Gordon et al. 1990 **112**, Gough & Grace 1998 **114**, Mesléard et al. 1995 **184**, Mesléard et al. 1999 **183**, Bouhaim et al. 2010 **39**, Ferchichi-Ben Jamaaa et al. 2014 **98**). Its multiple and potentially opposing effects depend on abiotic events (environmental and climatic conditions) and biotic events (interactions between plants and with wildlife). While the use of domestic grazing for conservation management of habitats is often an appropriate response, the difficulty, in the natural environment, of precisely determining the respective roles of domestic herbivory, environmental conditions, and wildlife, complicates the task of choosing the best grazing methods to be applied. Grazing can have a direct effect on plants, causing tissue loss through defoliation, or an indirect effect through mechanical action (trampling in particular), which often has negative but sometimes positive consequences. Grazing can also affect plants by modifying their abiotic environment - the amount of light or soil fertility (Day & Detling, 1990 **74**, Milchunas & Lauenroth 1993 **191**, De Maazancourt et al. 1998 **175**, Posse et al. 2000 **227** Augustine & Frank 2001 **12**, Bakker et al. 2003 **13**, Bakker et al. 2010 **15**, Bakker et al. 2020 **19**, Rossignol et al. 2006 **242**) - and biotic – the nature and intensity of interactions between plants (Van Der Wal et al. 2000 **273**, Nash Suding & Goldberg 2001 **202**, Rosenthal et al. 2012 **241**, Nolte et al. 2014 **203**, Ruifrok et al. 2014 **243**, Koerner et al. 2018 **153**, Bakker et al. 2020 **19**, Filazzola et al. 2020 **100**).

1.2.1 Effect of grazing on plants

The effects of grazing on a plant (individual) are usually negative. Grazing affects plant dynamics through predation (especially the removal of aerial parts), with defoliation leading to a reduction in photosynthetic activity, which, if it is substantial, can cause the death of the plant. Grazing also affects plant dynamics by altering the morphological traits that largely determine their competitive capacity (Louda et al. 1990 **167**, Pecco et al. 2005 **217**). Reducing the height of a plant is generally enough to suppress its dominance over plants in its immediate vicinity, resulting in the elimination of competition for light.

Herbivory generally reduces the reproductive capacity of plants (Cargill & Jefferies 1984 **49**, Diaz et al. 2007 **81**). It influences the allocation of resources between stems and roots, notably by affecting root production and the storage capacity of underground organs (Crawley 1983 **67**, McNaugton 1983 **177**, McNaugton et al. 1997 **178**). Trampling can be destructive in wet environments on species with **rhizomes***, due to the poor **bearing capacity*** of the soil, which generally makes them sensitive to grazing. Trampling is not necessarily negative for a plant, although it can damage root tissue and storage organs. By cutting rhizomes* it can also stimulate vegetative propagation, which is partly controlled by the network of connections between **clones*** *(§ 3.1.2)*.

Through their **faeces*** and their distribution, domestic herbivores also modify the plant dynamics and therefore the dominance between species. Depending on plant requirements, faeces* have a beneficial or negative effect on their development (Steinauer & Collins 1995 **261**, Harrison, & Bardgett 2008 **126**). High concentrations generally favour **ubiquitous*** species that are demanding in nutrients (**ruderal*** and/or generally common species) and competitive in these conditions, to the detriment of more local species adapted to less favourable environments. In very high concentrations, faeces* are harmful to many plants, particularly through **eutrophication*** of the environment.

According to the herbivore involved, the faeces* will be more or less evenly distributed spatially or, on the contrary, concentrated in certain parts of the grazing area (particularly in the case of equines) for which these parts will constitute areas of greater environmental diversity but also of lower grazing pressure or even avoidance.

DIFFERENT PLANT "STRATEGIES" FOR HERBIVORY

Plants have developed various strategie to respond to the pressure exerted by herbivores. Plants that are tolerant to predation offer grazing organs that they can renew without compromising their survival or often their reproduction. For these plants, the negative effects of grazing are limited or even positive when the pressure is moderate (McNaughton 1983 **177**,Paige 1999 **212**, Corket & Moulinier 2012 **65**), and this adaptation to predation gives them a competitive advantage over plants lacking the same capacity.

Some adaptations allow plants to avoid grazing or minimise its impact (Briske 1996 **41**, Diaz et al. 2007 **81**). Low height makes a plant less accessible to domestic herbivores or less accessible than other plants present whose likelihood of being eaten is therefore higher. A contracted life cycle (can be grazed for a short time), low **palatability***, high toxicity (presence of toxic secondary compounds such as tannins, terpenes, phenols, pyrethrins, and alkaloids) or the presence of defense organs (spines, hairs, cuticles) are effective 'strategies' to avoid being grazed.

The ecological context, site history, grazing methods in place, and the herbivore present all influence the selection of adaptations developed in reaction to grazing and therefore the selection of species (Lavorel et al. 1999 **159**, Sternberg et al. 2000 **262**, Bullock et al. 2001 **43**, Adler et al. 2004 **3**, Pakeman 2004 **213**, de Bello et al. 2010 **26**). In ecologically favourable conditions, a tolerance strategy is favoured, whereas in more restrictive conditions an avoidance strategy prevails (Coley et al. 1985 **60**, Hobbie 1992 **135**, Herms & Mattson 1992 **132**, Briske 1996 **41**). When productivity is high, the relative importance of the two strategies depends largely on the pressure exerted by grazing: low grazing pressure enables the development of species that are competitive for light (large leaf area). In environments where there is low productivity or stress, the need to cope with abiotic conditions (particularly water) makes herbivory less selective (Milchunas et al. 1988 **192**, de Bello et al. 2010 **26**).

COMPENSATION

Up to a certain level of pressure, grazing stimulates growth through a compensation phenomenon (McNaughton 1983 **177**, Oesterheld 1992 **204**, Callaway et al. 2001 **45**, Callaway et al. 2006 **46**). This mechanism can be evaluated experimentally by simply cutting biomass from the same plant community in two ways: **(a)** one cut made at the beginning and one at the end of the growing season, or **(b)** successive cuts during the season; in both cases, the first cut and last cut are made on the same day. The total biomass harvested is generally higher when several cuts are made during the period **(b)**.

Several mechanisms contribute to this compensation: an increase in light intensity in low tissues after grazing, which had not been highly exposed, a loss of old tissues for which photosynthesis is less efficient, optimised water use due to the reduction in transpiration area, and a reallocation of resources towards the aerial parts (Belsky 1986 **28**, Trumble et al. 1993 **270**, Tiffin 2000 **266**). This phenomenon illustrates the complexity of interactions between herbivores and plants: while for the individual plant this interaction is often negative because it corresponds to predation (a loss of tissue), this is not always the case for the herbivore (Agrawal 2000 **5**).

Importance of the defoliation period for compensation.

The ability of plants to compensate is highly dependent on the grazing period and their phenological stage at the time of predation (Paige 1999 **212**), with early defoliation being more favourable than late defoliation (Maschinski & Whitham 1989 **171**, McIntire & Hik 2002 **176**). Compensation also depends on the state of the environment, which largely determines the productivity of the plants present; it therefore varies from year to year. The consequences of an early drought, as is often the case in the Mediterranean region, drastically reduce the possibility of compensation and can generally not be offset.

CHANGES IN PLANT-PLANT INTERACTIONS DUE TO HERBIVORY

Generally speaking, grazing has **four types of effects** on interactions between plant species.

A reversal of dominance

The herbivore suppresses the species that dominates the community by consuming different species based on their appetibility or simply their accessibility. By reducing the competition for space and light caused by these initially dominant species, herbivory facilitates the development of previously repressed species *(Fig. 7)*. This reversal of dominance is only maintained if these species are not consumed, or are only consumed to a limited extent. Excessive grazing pressure leads to the replacement of initially dominant species by species unsuitable for grazing. The dynamics of unpalatable species development corresponds to this situation *(§ 1.4.1, Fig. 23 Dynamics of richness)*.

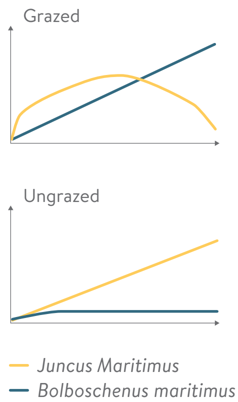


Figure 7: Saltmeadow Rush (*Juncus gerardii*) and Sea Club-rush (*Bolboschoenus maritimus*) in grazed and ungrazed former rice fields during the first four years they are reflooded (Mesléard et al. 1995 **184**). In the absence of grazing during the first few months the field was flooded, Saltmeadow Rush developed rapidly and then regressed due to the growth of Sea Club-rush. On the other hand, when grazing was used to strongly suppress the development of Sea Club-rush, the area covered by Saltmeadow Rush increased steadily over the 42 months of observation. Saltmeadow Rush is an early-growing species compared to Sea Club-rush. Implementing grazing earlier in the spring would therefore have favoured the development of Sea Club-rush and limited that of Saltmeadow Rush from the beginning of the experiment.

Maintenance of all species by alternate grazing of dominant plants

This balance of species is maintained over time, as long as the grazing pressure is neither too high nor too low, and all the species are controlled simultaneously or alternately. As environmental conditions fluctuate throughout the year and from year to year (particularly in the Mediterranean region), it is rare for this balance to be maintained without adjusting the grazing pressure to the prevailing conditions.

Accentuation of initial dominance of various plants by preferential consumption of less competitive but more appetizing species

If the grazing load does not correspond to the limited forage available, grazing leads to the disappearance of consumable species and therefore to the degradation of the rangeland. Such grazing-based management is only acceptable when the current grazing load is applied for a limited period with the aim of controlling one or more species likely to threaten the presence or development of local species or species of conservation interest. The presence of invasive species or woody plants leading to the closure of the environment corresponds to a situation where the species to be protected are capable of redeveloping or re-establishing themselves once the undesirable species have been controlled.

Relatively neutral grazing with no distinct choice between species

This relatively common situation arises when the species are all consumed in more or less the same way (they are equally **appetizing*** and have similar **phenologies***). The pressure must be sufficiently strong without destroying the plant cover, so that no significant or clear-cut choice is made between species. Insofar as dominance may nevertheless emerge over time, due in particular to the variability of environmental conditions, the final result often depends on the ability to readjust grazing pressure.

The frequent need to apply several of these types of effects simultaneously or consecutively in order to respond to the site context, and the difficulty of determining and adjusting the grazing pressures that affect them, often make restoration operations based on grazing more complex than expected when particularly precise objectives are assigned to it.

Theoretically, how **appetizing*** species are, i.e., the appetite for each of them shown by the herbivores, the current dynamics and any changes caused by grazing, as well as variations in environmental conditions, should all be taken into account when establishing the grazing methods and calendar. This is particularly true when the restoration of the plant communities on the site requires the environment to be first reopened by controlling woody plants or large, unappetizing emergent plants. The grazing loads then required, which are often destructive for other species whose development is nevertheless targeted by the restoration, mean that grazing management must have different objectives over time (opening up and then control). Management must be adjusted accordingly. These objectives may appear contradictory, and their application may lead to unsatisfactory or even negative intermediate results. They will nonetheless contribute, in the long term, to achieving the final objective.

GRAZING AND PLANT PHENOLOGY*

The changes brought about in plant interactions by herbivory depend in part on their phenological phases. Generally speaking, the **appetizing*** capacity of plants decreases over the course of the season as their nutritive qualities and **appetibility*** decline. However, this is not always the case, particularly for plants protected from herbivory by toxic or repellent compounds, the levels of which decrease over the growing season. For example, Bulrush (*Typha sp.)* can potentially be controlled by grazing during the summer when the terpene concentrations in its tissues have fallen.

Depending on the objectives, taking into account the **phenology*** of the plants can increase or reduce the effects of grazing. However, the difficulty of rigorously adjusting the grazing methods to the phenology* of all the species, or even to that of most species present, often limits the precision of the grazing.

1.2.2 Impact of grazing on plant communities

The impact is not necessarily immediate. When the grazing pressure is not too high, grazing encourages species richness and the contribution of less competitive species by consuming and therefore controlling the dominant species. The reduction in the height and proportion of dominant species may be the result of greater **palatability*** (herbivore selectivity) or simply greater access and availability of these species *(§. 1.2.1)*. For restoration purposes, the value of domestic grazing may lie in its ability to promote overall species richness, but above all to favour species of greater conservation value, previously dominant or subordinate, by controlling more common or **ubiquitous*** species.

In wetlands with few constraints (presence of water, low or zero salinity), interactions between plants (competition for light, **preemption***) are often strong and play a major role in structuring communities (Bertness & Elison 1987 **31**, Olff 1992 **205**, Merlin et al. 2015 **181**). They are exacerbated in the Mediterranean region, where high temperatures are an additional factor. These interactions contribute to zonation phenomena, even though they are largely defined by variations in physical conditions *(Fig. 8)*.

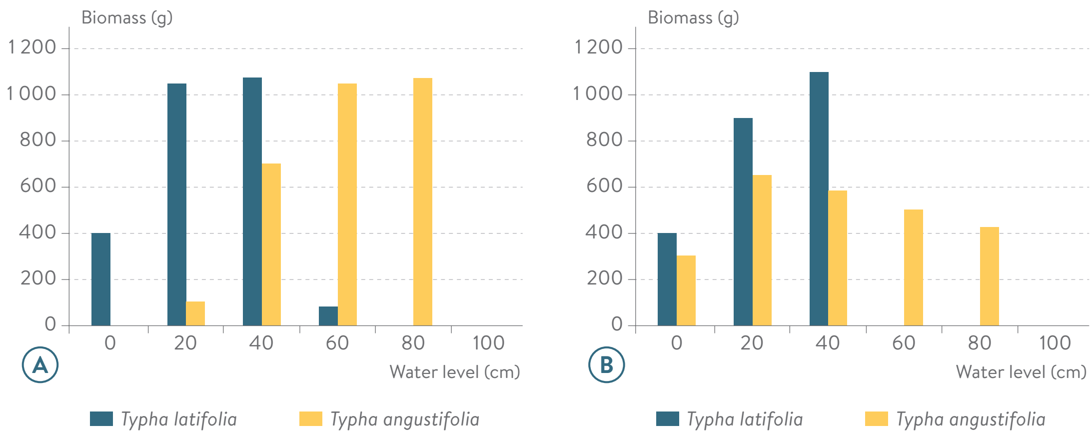


Figure 8: Biomass of two Bulrush species, *Typha angustifolia* (yellow) and *T. latifolia* (blue), mixed (A) or separate (B) in function of water level (from Weiner 1993 **283**). When both species are simultaneously present in the environment (A), the biomass of *T. angustifolia* is low or nil at the lowest water levels, which is not the case when *T. latifolia* is not present (B).

The relatively **stochastic*** establishment of species (various potentially dominant species having the capacity to establish themselves in certain conditions when these conditions are not very selective), and the ability of some species to occupy space rapidly, make it easier to predict the structure of communities in Mediterranean wetlands in the medium term than in the very short term (Mesléard et al. 2011 **185**, Mesléard et al.1999 **183**). Nevertheless, knowledge of the species and their ability to compete makes it easier to predict the fate of newly established species and the resulting community.

Domestic herbivory can both limit and accelerate competition (Louda et al. 1990 **167**). Grazing affects the relative contribution of species and the richness of the community through the selective or non-selective consumption of species and their ability to respond to changes in resources brought about by foraging (Milchunas et al. 1988 **192**, Anderson & Briske 1995 **9**). It also acts through mechanical effects, in particular trampling, which may or may not favour species with a high vegetative reproduction rate. Trampling can destroy underground structures by crushing them (in the case of reeds). On the contrary, by separating different interconnected parts, it can reduce the control of competition provided by the connections within the **rhizomes*** and thus favour the development of both underground and above-ground parts *(§ 3.1.2)*. By creating gaps in monospecific or **paucispecific*** communities, trampling can also encourage the establishment of other species for which these gaps will be **colonisation windows*** (Johnstone 1986 **147**).

More generally, the use of grazing in nature conservation aims to force the coexistence of species and enable a new assembly of communities, by controlling certain plants and preventing all or part of their succession processes.

COMMUNITY ASSEMBLY MECHANISMS AND GRAZING

Various mechanisms govern the selection of plants within groups of species, their existence, and the resulting structuring of communities (Weiher & Keddy 1995 **282**, Mason & Wilson 2006 **172**). Likewise, any passive or active vegetation restoration project *(§ 1.6.4)* is developed based on community assembly mechanisms (Weiher & Keddy 1995 **282**).

The image of a filter is commonly used to describe the different phases that follow one another or occur simultaneously during community assembly: provision of **propagules***, selection by environmental conditions, selection and organisation by competition, and disturbances or pressures that modify the environment and the interactions between species (Lortie et al. 2004 **165**, Beleyea 2004 **29**).

The capacity of plant **propagules*** not in the seed bank to reach the environment constitutes the first filter, that of dispersal *(Fig. 9)*. In order to reach the environment, these propagules* need one or more means of transport: wind, water, and/or animals.

A plant can only establish itself in an environment if it can cope with abiotic conditions there, which select species according to their traits and the aptitudes they confer (Lavorel & Garnier 2002 **158**). Environmental conditions act as a second filter, allowing or preventing the germination of species, then the development of seedlings, the survival of plants, and finally their reproduction.

The third filter is provided by interactions between plants, which develop in response to environmental conditions, eliminating some species and favouring others. Both competition and **facilitation*** between plants contribute significantly to modifying the distribution of previously selected species *(§ 1.3.1)*. In general, **facilitation*** plays a significant role when plant density is low and environmental conditions are difficult (temporary flooding, salinity). It is reduced as the density of individuals increases with the development of favourable conditions and as a result competition increases.

Verdier marshes. *© Tour du Valat*

The respective importance of the three filters in structuring the vegetation at the scale of the site to be restored determines the choice of filter or filters to manipulate to facilitate colonisation by the desired species. Seed dispersal capacity is often a determining factor in the assembly of communities; it may be greater than the role played by the internal mechanisms of plant communities – the interactions between species (Mouquet al. 2004 **198**, Clark et al. 2007 **58**). The structuring of communities may therefore depend mainly on the distance between the source species and the site.

The establishment phase is initially based on the presence of seeds in the soil or ones brought in by various vectors. This phase of *co-occurrence* between species is made possible by competition from more dynamic species, which is not yet very strong. Grazing can contribute to the first filter, that of dispersal, as a passive vector of **propagules*** that transports them to the site. Domestic herbivores carry seeds in their hair or on their hooves (exozoochory), but also transport seeds via their **faeces*** (endozoochory), the passage of seeds through the animal's digestive tract facilitates the germination of certain seeds. Domestic herbivores can thus contribute to the constitution of the seed bank to a greater or lesser extent. In wetlands, domestic herbivores are generally considered to be minor contributors to the seed bank compared with wildlife. The role of domestic herbivores in the seed bank is generally more significant at the scale of a grazed site, where their movements can facilitate the dispersal of seeds throughout the site. In this respect, the animal, depending on its behaviour and on which parts of the site it uses significantly and which ones it avoids, will contribute to the homogenisation of the seed bank or, on the contrary, to its spatial differentiation.

The second phase in structuring a community corresponds to the development of plants, particularly those characterized by dynamic development. It features a significant increase in biomass and the emergence of competition mechanisms. Nevertheless, this phase of *non-equilibrium*, in which the most competitive species have not yet saturated the space, allows for the coexistence of a significant number of species, the highest of any stage in the succession (Chesson & Case 1986 **55**) *(§ 1.3.1)*. When the aim is to promote species richness, this stage of *non-equilibrium* must be targeted based on grazing that can control the development of the most dynamic species.

Domestic herbivory is therefore likely to play a significant role in the environmental conditions (second filter), particularly through the contribution of droppings, which can be a positive factor, but often is a negative one from a conservation point of view. Most of the time, enriching the environment with a large amount of manure is undesirable when it comes to conserving or restoring native vegetation. Dung, when present in high quantities, contributes to the **eutrophication*** of the site and/or the development of **nitrophilous*** and/or **ruderal*** species of no conservation interest, but which, through their dynamics and competitive capacity, reduce the possibility of the species targeted for restoration to maintain themselves or become established. Grazing can also modify soil properties by reducing plant cover and through trampling, generally in a negative way when heavy grazing pressure is applied (modification of permeability, water storage capacity, and detachability*).

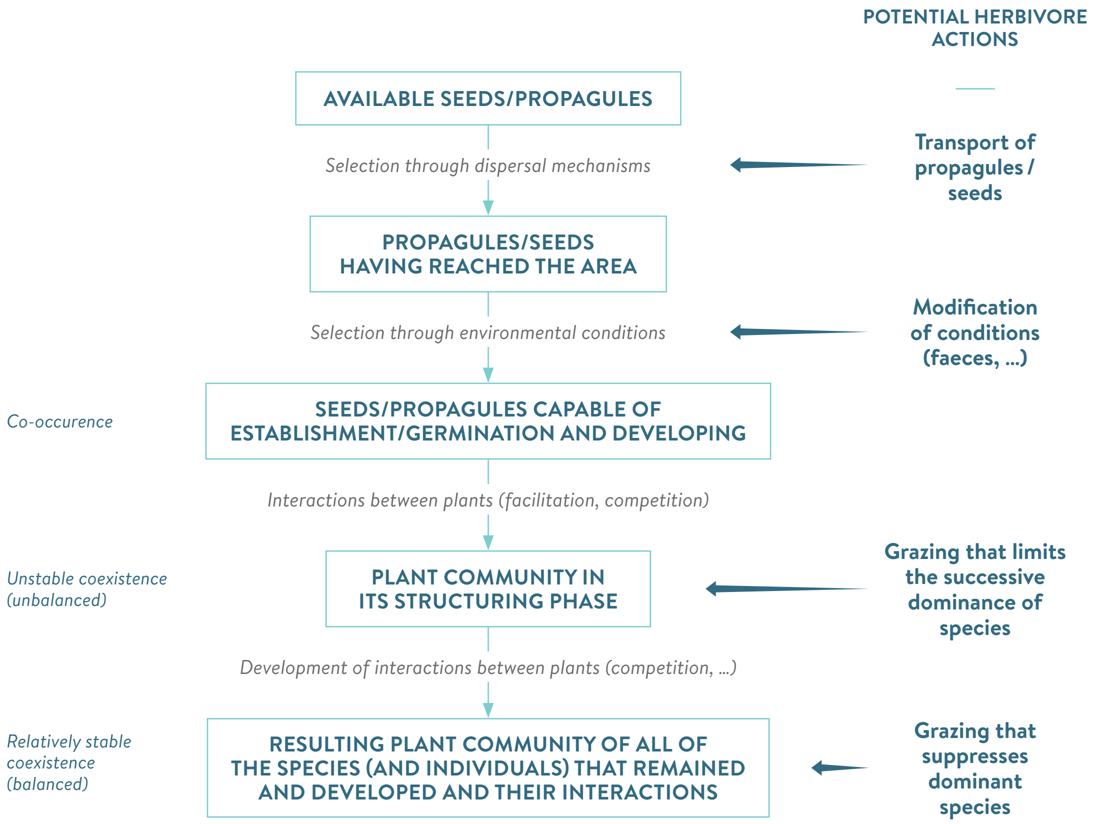


Figure 9: Mechanisms (filters) and phases determining the assembly of plant communities (from Lortie et al. 2004 **165**). Potential actions of domestic herbivores in the different organisational phases.

The third phase, known as *equilibrium*, corresponds to the full development of the most competitive species. Many of the species initially present have already been excluded or marginalised, and are only able to remain on the site because of micro-situational conditions, which are often temporary. This phase of coexistence, which is more stable than the previous two, nevertheless evolves under the pressure of the dominant species, resulting in a uniform cover and a closed habitat. Grazing at this stage reopens the habitat. Once the competition mechanisms structure the vegetation, the application of pastoral management is most often essential for the re-establishment of non-competitive species and a further increase in species richness (Louda et al. 1990 **167**, Ritchie 1999 **237**, Lavorel et al. 1999 **159**, Peco et al. 2005 **217**, Diaz et al. 2007 **81**, Moinardeau et al. 2019 **194**, Moinardeau et al 2021 **195**). In habitats prone to flooding, where succession is generally rapid and simplified (one community structuring species replaces another), grazing is most often aimed at preventing the dominance of particular species (especially large emergent plants) in favour of species present in the seed bank, but which will not express themselves or will do so very little if the larger species (more competitive, especially for light) are not controlled *(Fig. 10)*.

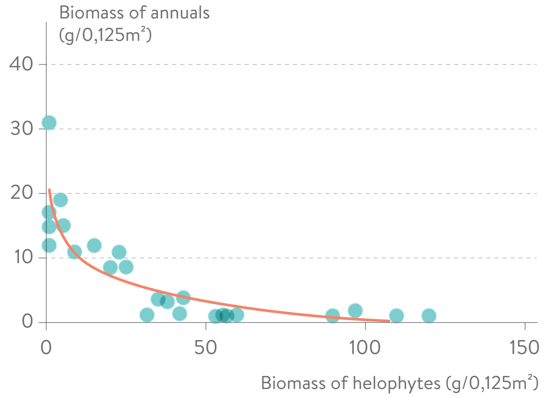


Figure 10: Biomass of submerged species in relation to the biomass of emergent plants in a Camargue marsh (from Grillas et al. 1993 **120**).

The concept of filters offers a schematic and deterministic representation of vegetation structuring mechanisms in which the effects of the three filters are largely interdependent. This breakdown into three global mechanisms can be used to determine the stages on which, depending on the context (presence or absence of seeds of desired species in the soil bank, satisfactory abiotic conditions, presence of non-target and potentially colonising species), action should be taken in the hope of restoring the environment.

Nevertheless, a plant community may be partly or very largely dependent on historical factors that are difficult to detect in the field. Furthermore, the importance of **stochasticity*** in the arrival of **propagules*** should not be overlooked. In Mediterranean wetlands, stochastic* effects and/or historical factors often predominate, as can be seen in the clear divergence in the nature of two communities, even though they are on nearby (or even adjacent) sites and subject to similar environmental conditions. The first species that become established, depending on their ability to colonise the area and prevent or facilitate the arrival of other species, can then play a decisive role in this divergence (Drake 1990 **85**). This role of stochasticity and historical factors is itself largely dependent on the selectivity of environmental factors (Kardol et al. 2013 **149**). Stochasticity is of little importance when conditions are selective and only allow the development of a few particularly well-adapted species. The stochastic* effect generally diminishes over time, as environmental conditions eventually lead to selectivity between species (Mesléard et al.1999 **183**).

Figure 10b: Phillyrea (*Phillyrea angustifolia*) bushes characteristic of non-flooded areas in the Camargue. *© L. Willm* Phillyrea has developed extensively since sheep grazing was replaced by free-range cattle grazing with low instantaneous pressure *(see Fig. 1)*. Its growth reduces the grazing area of the pastureland and leads to a loss of plant and animal diversity.

© J. Jalbert

In environments that are not or only temporarily flooded, and where succession is characterised by a dominance of woody species *(Fig. 11)*, the aim of grazing is to reopen the habitat to favour communities of species or particular species that are in their early stages of succession. In this case, one or more herbivores best suited to the task must be selected *(§ 2.2.3)*, and grazing methods applied on an ad hoc basis. The need to constrain the animals makes this operation complicated. It is imperative not to endanger the animal's health and to respect its needs. Furthermore, the restraint applied on the animals must not lead them to harm certain species that we want to favour. These risks often lead to ineffective grazing pressure that is considered too risky, and to apply pressure that is too low, leaving the herbivores free to choose the most palatable species to the detriment of opening back up the area.

Figure 11: Once the Phillyrea is established, it is difficult to control. The horse controls Phillyrea seedlings, which cattle cannot do very well.

Many Mediterranean landscapes bear witness to the consequences of the disappearance of grazing as it was practiced in the 19th or first half of the 20th century. The drastic reduction in the surface area of certain types of open spaces and the increasing scarcity of the species that characterise them have led to the development of restoration projects involving the reintroduction of domestic herbivory. However, this process is often difficult due to changes in environmental conditions (hydraulic conditions, scarcity of desired species in the vicinity) or local socio-economic conditions (no interest shown for the project). From a technical point of view, it is essential to know whether current and future environmental conditions will allow restoration. The objectives to be pursued will depend on the answer to that question. Knowledge of the selectivity of herbivores for vegetation, whether between species (positive or negative selectivity) or in function of dominance and/or height, enables relatively precise grazing objectives to be set while maintaining an *unstable* coexistence of species, a phase in which many species are likely to express themselves.

SEED BANK AND GRAZING

Seed banks play a major role in the structure and dynamics of vegetation by influencing the number of species and the number of individuals of each species that can express themselves. Because of its diversity and the capacity of the **propagules*** in it to respond to changes in environmental conditions, the seed bank is often an essential link in any restoration project. This is particularly true in the case of passive restoration (no introduction of propagules*).

In the Mediterranean region, plants often survive the most severe conditions, including summer drought, in the form of seeds. The seed bank constitutes a storage compartment (Chesson 1983 **54**), which, depending on how long the seeds remain viable, enables a species or community to be maintained over time, despite conditions that suppress germination for one or more successive years. Generally, several generations of seeds are simultaneously present in the soil, at different depths and with different germination capacities, which enables them to respond to favourable conditions. Selection between species, induced by years without germination opportunities, can be greatly reduced if a single favourable year is sufficient to reconstitute the seed stock to a greater or lesser extent. Favourable conditions may correspond to the appearance of favourable abiotic conditions (rainfall, humidity, flooding of marsh), grazing pressure that makes gaps in the plant cover, and therefore the possibility for seeds, previously inhibited, to germinate (Grime 1979 **121**, Loydi et al. 2013 **168**). The burial of seeds by trampling is an important element in the maintenance of species that only occasionally encounter conditions suitable for germination. While the depth at which seeds are buried reduces their ability to germinate, it increases their viability. This 'refrigerator' effect can be put to good use when the soil is manipulated.

While grazing limits the constitution of seed banks through the consumption of flowers, the reduction of area dedicated to photosynthesis, and the allocation of resources for reproduction (Sternberg et al. 2000 **262**), it contributes to their diversity through the transport of **propagules***
and the modification of the dormancy of ingested seeds (Saatkamp et al. 2018 **245**).

Transient and persistent seed banks

The breaking of seed dormancy induced by environmental conditions differs not only between species, but also between **ecotypes*** of the same species. Specific conditions such as low temperatures will induce dormancy in some species, whereas they will interrupt it in others, favouring germination, all within the same seed bank. Consequently, depending on the diversity of the species it contains, a seed bank may or may not provide a wide range of responses to the environmental conditions of the moment and of the year. This variability will be even greater in environments where inter- and intra-annual conditions are themselves variable and have selected a seed bank capable of responding to the range of conditions encountered.

The dormancy capacity of the seeds determines whether the seed bank is *transient* or *persistent*. Transient seeds, with little or no dormancy, germinate in their entirety before the next crop of seeds is produced, virtually depleting the stock of **propagules*** each year. This strategy is primarily used by long-lived perennial species or species that disperse over long distances. On the other hand, persistent seed banks are widely found in plants for which survival is not guaranteed (annuals) or which only occasionally benefit from conditions favourable to their development.

Seed dispersal

All plant species have a mobile phase in their life, but this is generally limited in time. **propagules*** alone are generally only capable of moving limited distances, and a vector is needed to transport them further.

Wind disperses seeds directly, and it also creates currents on the surface of the water. It is considered a hazardous means of dissemination in that it makes no choice as to the nature of the site to which the seed is transported, making it unlikely that the seed will reach a site with favourable conditions for germination. Counter-intuitively, wind is more likely to be an agent of short or even very short-distance dispersal. To compensate for this limited capacity, some plants have developed special adaptations *(Fig. 12)*. **Anemochory*** is not the primary means of dispersal for species in Mediterranean wetlands.

Hydrochory* (transport by water) is a means favoured by aquatic plants to disperse **propagules***. It is a relatively effective dispersal mechanism within a wetland or between wetlands that are hydraulically connected because it is directed and can possibly cover long distances, but it usually favours a few directions according to the current and the surface wind. Dispersal is ineffective, however, when the environments are not connected. Hydrochory* is therefore not the most efficient mechanism for transporting propagules* in Mediterranean wetlands, where zoochory is generally much more effective. Zoochory is a means of directed dispersal, enabling propagules* to be transported over long distances without the need for sites to be hydraulically connected. A wild boar, for example, using a wetland as a wallow, collects numerous propagules* in its hair, and then exports them to one or more other wetlands that may be far away but have similar environmental conditions.

Figure 12: Adaptation of light Typha seeds with feathery structures that facilitate wind dispersal.
© Klein / Hubert / Bios

Domestic herbivores are also dispersal vectors. However, their role is limited in wetlands compared with the potential of wildlife, particularly avifauna, in Mediterranean wetlands and beyond (Brochet al. 2009 **42**). Anatidae and waders are two particularly effective groups for dispersing seeds, thanks to their mobility over both short and very long distances, ensuring exchanges between regions. The diet of many wetland avian species includes seeds from aquatic plants, and their ability to transport them means that domestic herbivores play a very limited role in propagating seeds. The proven presence of wildlife means that there is generally little interest in adding seeds to the environment, even for plants whose seeds are absent before restoration. Rapidly (a few years) after favourable physical conditions have been restored (presence of surface water at a favourable period), the passage of wild animals is sufficient to ensure the importation of enough seeds to restore the plant communities. Nonetheless, the provision of seeds may be justified or even essential when the aim is to cover bare soil as quickly as possible in order to limit the establishment of undesirable species, particularly if invasive species are present near the site.

The seed bank: a key black box for restoration

The study of the seed bank, even if it is tedious, provides valuable information on the potential of communities and/or populations (Silvertown & Charlesworth 2007 **255**) that is not necessarily apparent from observing the vegetation. It is therefore a relatively essential compartment to understand in restoration to be able to define the objectives and the means to be implemented. The implementation of ad hoc management alone cannot ensure the development of species targeted by restoration if seeds are not present on the site and have a very low probability of reaching it. Joint studies of the seed bank and of the arrival of seeds on the site will determine whether or not **propagules*** should be added *(Fig. 13, § 1.6.4)*. The presence of seeds from old plant communities can also reveal a site's past and environmental conditions that are very different from present or known conditions.

ASSESSING THE SEED BANK

The most accurate way of measuring the seed bank is, of course, to count the **propagules*** directly from soil samples. This involves harvesting all the seeds, even the smallest ones *(Fig. 14.1)*. It also means being able to recognise which species each seed harvested corresponds. Finally, the viability of each seed must be tested, since the difference between the number of seeds present and the number of seeds able to germinate can be significant and vary greatly between species. It's a complicated, time-consuming endeavor, and most of the time it cannot be done.

Potential site for recreating a marsh after the abandonment of farming (Camargue) *© L. Willm*

Collection of seeds arriving via hydraulic management (installation of filters) or wind (sticky patches placed on the ground) *© I. Muller and L. Willm*

© I. Muller

Figure 13: When recreating a marsh, the question often arises of whether or not to bring seeds of the target species into the environment. The study of the seed bank by collecting samples from the top centimetres of soil and allowing them to germinate, supplemented by measurements of the supply of seeds brought by the wind (sticky patches on the soil) and water (filters) has, in this case, show that none of the target species are present in the soil or are likely to arrive by wind or water (Muller et al. 2013 **200**).

It is generally easy to study the seed bank using only germinations recorded in the field, but as the conditions at that time are not representative of all possible conditions, the germinations observed correspond to only part of the viable stock, i.e., the seeds capable of expressing themselves under the conditions observed *(Fig. 14.2)*.

In addition, competition between plants generally limits both the species capable of germinating and the number of individuals per species that express themselves. To overcome these problems, it is therefore crucial to be able to observe germination not only under different conditions, but also, if possible, by reducing competition through the removal of individuals as soon as they are likely to compete.

An easier way of measuring the bank is to observe germination in controlled conditions (pots or trays), using soil samples. Germination monitoring must then be continued (at least for several weeks) until no new germination occurs *(Fig. 14.3)*. However, in this case, the seed stock expressed, represented by the number of individuals of each species counted, is very generally lower than the number of truly viable seeds in the samples.

The stock of viable seeds can be significantly better assessed by reducing competition between individuals and species, i.e., by eliminating seedlings and the **preemption effect*** they exert, as soon as a species name can be assigned to them *(Fig. 14.4a)*. In this case, the number of individuals and often the number of species recorded are greater than that obtained by carrying out the same experiment without removing the individuals as soon as they can be identified *(Fig. 14.3)*. The distribution is then closer to that of the bank of viable seeds in the soil *(Fig. 14.1)*, and much closer to that obtained from direct observations in the field *(Fig. 14.2)*.

Another germination of the soil samples already germinated *(Fig. 14.4a)*, this time under various conditions also present from time to time in the field, makes it possible to obtain new germinations *(Fig. 14.4b)*. The sum of the germinations obtained by monitoring operations *Fig. 14.4a* and *Fig. 14.4b* makes it possible to approximate the stock of viable seeds in the soil without, however, having the possibility of knowing their degree of similarity. Here a species is absent in type 4 monitoring of the soil seed bank without it being known whether its seeds, which were counted in the soil, are viable or not.

In this theoretical example, the presence of grazing substantially modifies the distribution of germinations (number of species and number of individuals per species *(Fig. 14-2b)*) by bringing in new species. Using soil samples to monitor the stock expressed can therefore make a major contribution to highlighting the impact of grazing and the way it is applied on the plant communities *(Tab. 1)*.

Vegetation types	Grazing pressure	No. of germinated seeds	No. of annual species	No. of perennial species	Similarity between seed stock and plants expressed (%)	
					Annual /	Perennial
Short grass	+++	1 184	44	16	40	42
Open grassland	++	921	35	18	30	24
Overgrown grassland	+	698	28	25	26	25
Ungrazed	0	581	15	22	9	25

Table 1: Vegetation types, grazing pressure, number of germinated seeds in germinated soil samples (concentrated soil), *cf. tab 5***), number of corresponding annual and perennial species, similarity in species between the bank of viable seeds (determined after germination) and the vegetation expressed in the field (Sorensen index in %,** *§ 2.3.2***). Study carried out on grasslands in the south of France grazed by Konik-Polski horses** (from Moinardeau et al. 2021 **195**). A parallel study of the vegetation in the field and the expressed seed stock highlights two positive effects of grazing linked to the pressure applied: enrichment of the seed bank and an increase in the ratio of annuals to perennials. The similarity between the seed bank and the vegetation expressed reflects the ability of herbivory, through its capacity to modify interactions between plants, to facilitate the expression of the seed bank in the field.

Figure 14: Theoretical germinations observed from a theoretical seed bank with different treatments.

- **(1)** Seeds of different species present in the wetland soil (viable and non-viable seeds).
- **(2)** Germinations observed in the wetland.
- **(3)** Germinations observed in controlled conditions (greenhouse) in flooded conditions deemed favourable.
- **(4a)** Germinations observed under controlled conditions, in flooded conditions similar to those in treatment 3, with each newly germinated individual removed as soon as it can be identified.
- **(4b)** Additional germinations observed under controlled conditions (after stopping the counting of germinations in the soil subjected to treatment 4a), with a modification of the flooding conditions of treatment 4a, removing each newly germinated individual as soon as it can be identified.
- **(2b)** Germinations observed in the wetland after the introduction of domestic herbivores.

VEGETATIVE REPRODUCTION AND GRAZING

Seeds are not necessarily the preferred means of plant reproduction in wetlands. Many potentially dominant plants can develop from vegetative elements such as **rhizomes***, buds, or root parts, which enable them to duplicate the individual from which they originate and colonise the surrounding area more rapidly and densely than by seed. This ability enables them to compete intensely, creating patches of monospecific vegetation where the density of above-ground and below-ground parts compromises the establishment of any other species. In some plants, the production of **stolons*** facilitates long-distance propagation (e.g., reeds *Fig. 15*).

Figure 15: Stolons* of reed (*Phragmites australis*) greatly help the species to colonise an area, particularly in sandy soil.

As a result, any action by domestic herbivores likely to affect vegetative reproduction can cause profound changes to the vegetation. Grazing affects vegetative reproduction mainly via trampling, which can either favour the spatial extension of the grazed species by breaking the connections between the reserve organs, which enables the control of intraspecific competition to be broken (as in the case of Sea Cub-rush), or compromise its development or even its survival by altering the underground parts and thus making the species more sensitive to the presence of surface water (as in the case of reeds) *(Fig. 16, § 1.4.2 Trampling)*.

Figure 16: Heavily grazed reedbed inhibiting the full development of *Phragmites australis* © A. Olivier

1.2.3 Effect of grazing on an ecosystem

Through its impact on various interacting mechanisms, grazing modifies ecological processes linked to material cycles at the **ecosystem*** scale (Huntly 1991 **142**, McNaughton et al. 1997 **178**, Milchunas & Lauenroth 1993 **190-191**, Frank et al. 2002 **103**, Bakker et al. 2003 **13**, Bakker et al. 2006 **14**, Rossignol et al. 2006 **242**, Conant et al. 2017 **63**). The impact of grazing on primary production is linked to its effect on the nitrogen cycle (Huntly 1991 **142**, Milchunas & Lauenroth 1993 **191**, Hobbs 1996 **136**, McNaughton et al. 1997 **178**, Aerts & Chapin 1999 **4**, Frank et al. 2002 **103**, Singer & Schoeneker 2002 **256**, Guidi et al. 2014 **124**). Herbivores also modify the carbon content of the environment by reducing the quantity of litter and facilitating its incorporation into the soil (Polley & Detling 1989 **226**, Green & Detling 2000 **118**, Olofsson & Oksanen 2002 **209**, Conant et al. 2017 **63**, Abdalla et al. 2018 **1**, Matzek et al. 2020 **173**). Grazing provides organic matter (manure) that is rapidly mineralised and can be mobilised by plants (Hatch et al. 2000 **129**). In wetlands, the conditions generated by the hydrological regime also have an impact on the decomposition of litter, the **mineralisation*** of nitrogen, and the processes of nitrification and **denitrification*** (Baldwin & Mitchell 2000 21). Depending on the period, duration, and frequency of flooding, the nature and intensity of these different processes vary greatly (Ritchie et al. 1998 **238**, Olofsson & Oksanen 2002 **209**, Semmartin et al. 2004 **251**. Water transfers matter and nutrients (Baldwin & Mitchell 2000 **21**) modifying the physico-chemical properties of the soil, in particular the redox potential and the pH (van Oorschoot et al. 2000 **210**).

1.3 SUCCESSION AND GRAZING

1.3.1 Succession

Succession is a directional and sequential process of species replacement over time, punctuated by the successive dominance of species of characteristic sizes and shapes, taking place in more or less distinct phases. The species that dominate at a particular point in the process will not be able to dominate again without the control of the species that have replaced them or established themselves later. The nature and structure of the vegetation characterising the most advanced phases of succession depend on the constraints of the habitat. While in many cases succession, particularly in the absence of domestic herbivory, results in plant formations dominated by woody species, demanding environmental conditions, such as those found in Mediterranean wetlands with temporary or permanent flooding, and high salinity, are likely to restrict the succession mechanisms to less advanced stages (dominated by Poaceae, Juncaceae, Amaranthaceae, and others *Fig. 17, 18*).

Compared to the powerful means of controlling succession such as fire, mowing, and herbicides, grazing has several advantages that often lead to it being favoured, particularly in the context of conservation: it is an alternative to the use of carbon-based energy, the historical context, economic valorisation, and its ease of use in site conditions.

Figure 17: A reed bed (*Phragmites australis*) can be a phase in plant succession very quickly reached and relatively stable if it is not grazed.
© Tour du Valat

During succession, three types of interaction occur between species:

- **Facilitation***, which consists in the protection of plants from various elements such as wind, and predation by herbivores, or the contribution of elements facilitating their development by larger and/or previously established species, is more characteristic of the early stages of succession. Nevertheless, it remains present throughout the succession. Facilitation* contributes to the presence of many secondary and/or less competitive species, and therefore to a relatively good maintenance of species richness. This positive interaction is frequent or even dominant in highly constrained environments where plant cover is low *(Fig. 18)*.

Figure 18: Salicornia bushes (*Artrocnemum sp. Salicornia sp.*) facilitate the development of various species like Poaceae. Difficult environmental conditions (saline soil, winter flooding, summer drought) do not allow succession to develop beyond the Salicornia bushes. The litter they produce as they get established subsequently protects other species from grazing and wind exposure, thereby enabling them to get established and develop in this hostile environment. *© A. Granger*

- **Tolerance** corresponds to an absence of effect between species, and therefore allows the establishment and development of new species. This neutral interaction becomes negligeable as soon as the plant cover develops.
- **Inhibition** impedes the establishment of new species by saturating space via the above-ground and/or below-ground parts, creating light conditions or producing substances that are unfavourable to germination and/or survival. Its importance increases during succession and as environmental conditions become less restrictive. By preventing species previously represented by numerous individuals from surviving or re-establishing themselves, it largely determines the sequential and directional nature of the succession.

During succession, plant biomass increases *(Fig. 19)*. There is a dip in this increase, corresponding to the full development of late-successional species, whether woody in less restrictive terrestrial environments, or large non-woody **helophytes*** in many environments subject to prolonged flooding. Species richness, particularly in species characteristic of open habitats, increases rapidly at the beginning of succession when the mechanisms of **facilitation*** by species already established are still important and competition is relatively low.

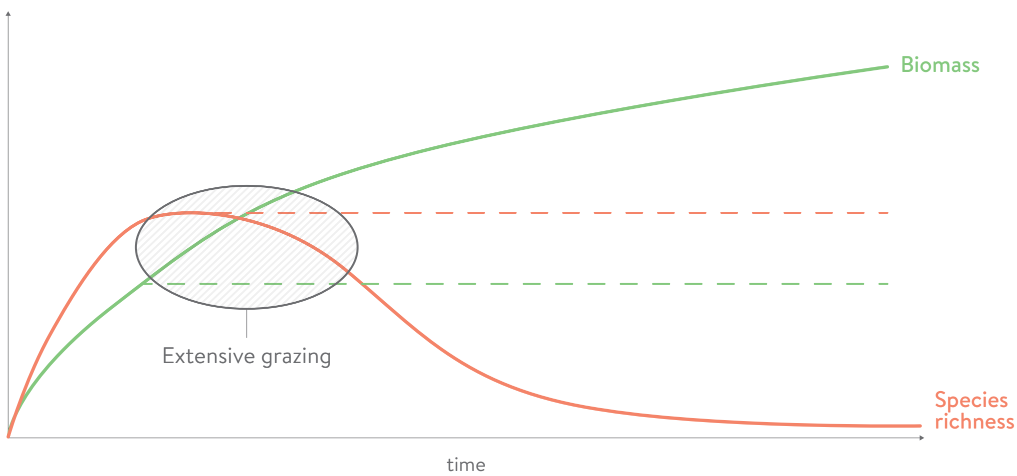


Figure 19: Theoretical dynamics of biomass and species richness over time in the absence of grazing (— — —), and the theoretical impact expected on these two parameters from the introduction of grazing (———). This increase is only temporary, as the intensification of competition concomitant with the increase in biomass leads to a more or less continuous reduction in species richness. By reducing the competition from mid- or late-successional species, grazing allows species characteristic of open vegetation to develop again or re-establish themselves. By reducing biomass and controlling certain plants, grazing is a factor that encourages species richness.

1.3.2 Disturbances

A disturbance can be defined as a discrete event leading to a reduction in biomass and a change in the availability of resources (Pickett & White 1985 **224**). It characterises events of multiple intensities, durations, spatial scales, and natures. Temporary changes in hydraulic conditions, resulting in exceptional dryness or a fire, are examples of disturbances. Temporary cultivation (brief or for several decades) and/or herbivory on a massive scale, but limited in time (invertebrates or vertebrates), can also be analysed as disturbances in terms of how they occur and their impacts *(Fig. 20, 21)*.

Figure 20: Disturbance of Sea Club-rush (*Bolboschoenus maritimus*) by wild boar looking for tubers © *Tour du Valat*

Through their impact on the structure of the vegetation (height, density, dominance), disturbances create open habitats favourable to the coexistence of plants (unstable equilibrium, *§ 1.2.2*), some of which are those initially present during the first stages of succession, if the seed bank allows it or if seed-bearing plants are located nearby *(Fig. 21)*.

Through their impact on plant interactions, survival, and reproduction, disturbances reinitialise plant community assembly processes and thus play a major role in maintaining or increasing diversity in communities (Levin & Paine 1974 **162**, Connell, 1978 **64**, Sousa 1984 **258**, Hobb & Huneke 1992 **138**, Wilson 1994 **287**, Questad &Foster 2008 **232**, Hall et al. 2012 **125**).

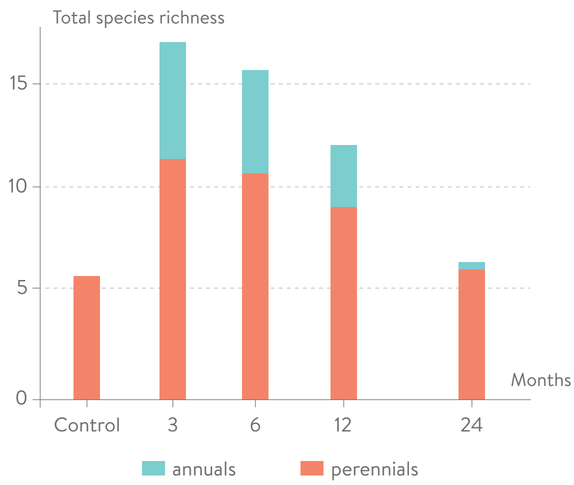


Figure 21: Species richness (annuals and perennials) within the disturbed area and outside this area (control) in a patch of Sea Club-rush after disturbance by wild boar. Disturbance favours species richness, particularly annual species. However, this increase is only temporary due to the ability of Sea Club-rush, a clonal species, to rapidly recolonise the area starting at the periphery of the disturbance.

However, by reducing the biomass and partially or totally destroying the plant cover, disturbances also facilitate colonisation by opportunistic species (as in the case of many invasive species) that were previously absent, which can lead to profound and more or less irreversible changes in the succession trajectories *(Fig. 22)*.

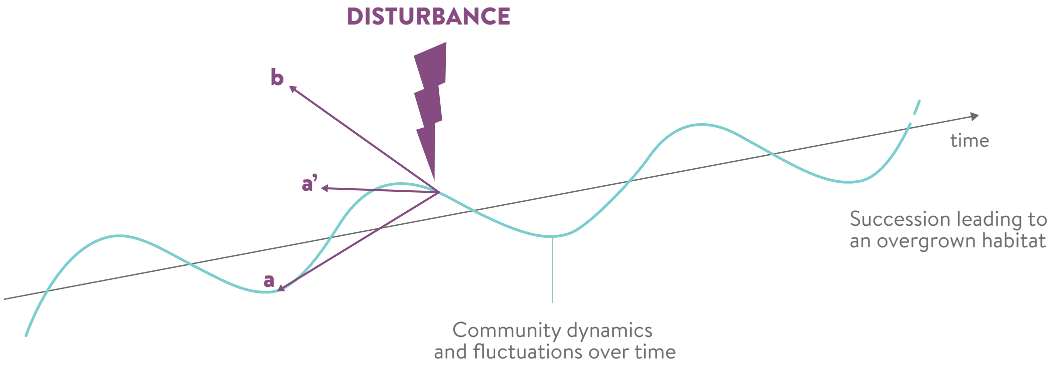


Figure 22: The result of the disturbance can be interpreted as a relative step backwards in the succession process. The communities obtained are rarely similar (a), but most frequently close to those of earlier phases (a'). However, by allowing the installation of new species (whether desired or not), they can lead to the development of communities that differ from those of earlier phases (b).

In humid habitats, the vegetation near the disturbance, through its capacity to participate in recolonisation, often limits the impact of disturbances over time *(Fig. 21)*. Only disturbances of high intensity or frequency, involving large areas, can prevent competition from leading to a further reduction in the number of species present and a rapid re-establishment of the previous community, which is often made up of few or only a single species.

DISTURBANCES AS A MANAGEMENT TOOL

Disturbance is a tool widely used in conservation to modify ecosystem dynamics. Various objectives such as increasing biodiversity can be effectively achieved in this way. For example, by significantly reducing the biomass a controlled burn enables the return or establishment of plant species associated with open habitats.

The restoration of previous disturbance regimes, or the mixing of different disturbances characterised by their size, frequency, and intensity, can be crucial tools for managing the biodiversity of specific sites.

Disturbances as a tool in very early phases of restoration

Disturbances are generally used in the early phases of projects, when the main aim is to produce a massive and rapid effect on the existing community. They make it possible to restrict or eliminate certain current dynamics (e.g., control or eradication of woody vegetation) and facilitate the development of new dynamics (wide gaps in the plant cover that create **colonisation windows***). More detailed and adaptive management can then be put in place that corresponds to the newly established communities.

Disturbances as long-term management tools

Disturbances can also make a major contribution to maintaining biodiversity by controlling plant community dynamics on a more or less regular basis at different stages of restoration. Applying a disturbance (for example high instantaneous grazing pressure) at regular intervals or when necessary (problematic development of species), can thus be used as part of adaptive management.

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However, disturbances should not only be seen as potential management tools. They can also be the cause of serious habitat degradation such as changes in hydraulic conditions, and the over-abstraction of resources. Any restoration project must therefore first identify whether disturbances are not partly responsible for the degradation of the ecosystem it seeks to restore. **If this is the case, it will then be necessary to ensure:**

1. that it is possible to eliminate the disturbance,
2. that the disturbance will really be eliminated when the restoration begins, otherwise the restoration project will be pointless and doomed to failure. Removing the disturbance that caused the degradation is often the first action carried out in the field for a restoration project.

1.4 MANAGING BIODIVERSITY THROUGH DOMESTIC GRAZING

The consequences of the loss of diversity on the functioning of ecosystems and their possible effects on functional processes have been the subject of a great deal of research, the results of which are sometimes contradictory. A high level of species richness is thought to facilitate the proper functioning of an ecosystem or community insofar as it ensures complementarity between species in the use of available resources. Diversity could therefore influence the stability and **resilience*** of ecosystems and communities confronted with disturbances and their capacity to avoid invasions. The presence of numerous species, through their differentiated responses to changes in the environment, means that functions previously carried out by other species can be maintained after disturbance (the '*insurance*' hypothesis). Nevertheless, the hypothesis that the stability and functioning of a system is strictly dependent on the number of species (Ehlich & Elrich 1981 **94**) does not always fit with what is observed in the field. The frequent '*redundancy*' in terms of the functional role between species, and the absence of a particular functional role for others, imply that the linear relationship between the number of species and functioning has a critical threshold. Numerous studies have shown that an increase in properties (**resilience***) or functions (trophic level) does not coincide with an increase in species richness, as the dominant plants provide these properties and functions. When there are few constraints (little or no flooding, limited salinity, and drought), and in the absence of grazing, the dominant species, by their very nature and their ability to occupy and conquer space, provide the vast majority of habitat or trophic functions. Similarly, in environments exposed to significant saline or xeric stress, only a few species play a decisive functional role, and in this case the presence of grazing cannot greatly increase the number of species that play this role.

1.4.1 Grazing to maximise biodiversity

For a nature manager, maximising biodiversity often means creating and/or maintaining mosaics of plant communities in order to increase the number of habitats, since these habitats provide the conditions necessary for the presence of a certain number of characteristic or target species. Management may be more or less targeted and may or may not be precisely adjusted to the presumed requirements of the single or multiple species whose maintenance or recruitment is expected. Grazing is one way of creating these mosaics, through the number of gaps it can make in the vegetation cover.

Except in extreme conditions, vegetation dynamics lead to an accumulation of biomass (overgrown habitat), and a manager who applies grazing seeks above all to reduce this biomass to encourage the coexistence of species *(§ 1.3.2, Fig. 19)*. However, the impact of grazing depends on how it is applied (duration, frequency), the intensity of the instantaneous grazing pressure (number of animals per unit area for a given time), and its nature (species, breed) (Savory, 1988

247, Ralphs et al. 1990 **233**, Hart & Ashby 1998 **127**, Fynn & O'Connor 2000 **105**, Dumont et al. 2012 **86**). Grazing pressure that is too low does not sufficiently reduce dominance and does not open back up the area enough to clearly favour diversity *(Fig. 23)*.

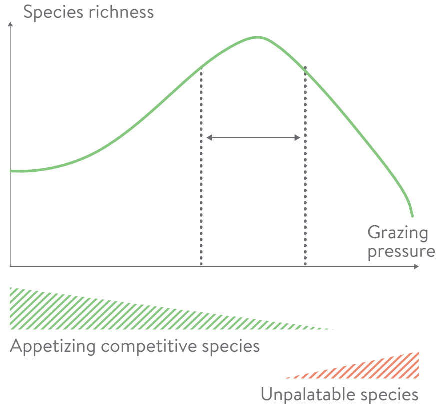

Figure 23: Dynamics of species richness, of the most competitive species and of unpalatable ones according to the grazing pressure applied, intensity of the pressure to be applied to maximise species richness (← →)

On the other hand, excessive grazing pressure results in overconsumption of appetizing species and to their replacement by unpalatable species that are not much grazed. The pastoral interest (interest of forage for herbivores) in function of the grazing pressure, evolves in a relatively similar way to that of species richness (or diversity): low grazing pressure promotes the development of species that are not necessarily of pastoral interest, while high grazing pressure causes appetizing forage species to be replaced by unpalatable ones. However, greater species richness does not necessarily imply greater pastoral interest, as this is generally obtained, in comparable environments, at higher grazing pressures than those that are optimal for species richness *(§ 1.4.5, Fig. 34 & 35)*.

In the Mediterranean climate, it is often difficult to define the grazing pressure to be applied over time. The variability of the forage supply may require the grazing pressure to be modulated by reducing the herd or withdrawing it as soon as the effect on the vegetation is judged to be strong enough, or, on the contrary, by maintaining it or increasing it if its effect is judged to be too weak *(§ 1.4.3)*. This context, which is largely unpredictable, requires managers to be able to finely control the entry and exit of the animals in a reactive manner, and to organise their actions accordingly (capacity to manage and move the herd, establishment of refuge areas and/or available forage), failing to do this will make it impossible or difficult to control the vegetation. This lack of control is problematic when a threshold of irreversibility is likely to be reached due to too much or too little pressure.

1.4.2 Effects of grazing pressure

Moderate grazing intensity is expected to favour plant richness and diversity by reducing the intensity of competition for light (Collins et al. 1997 **61**, 1998 **62**, Grace & Jutila, 1999 **116**), whereas high grazing intensity is expected to strictly limit the contribution of consumed species and create **colonisation windows*** by creating gaps in the plant cover (Watt and Gibson, 1988 **281**, Bullock et al. 1994 **44**). At the intra-plot scale, it is therefore expected that the relationship between grazing intensity and plant richness (or diversity) will be illustrated graphically in the form of a non-symmetrical 'bell curve' (Gauss curve) *(Fig. 23)* according to the theory of *intermediate disturbance* (Connell, 1978 **64**, Pickett & White, 1985 **224**, Hutson, 1994 **143**).

The theory of intermediate disturbance predicts that the maximum biological diversity of a system is obtained when the frequency and intensity of a disturbance (grazing) are of average intensity and the productivity of the area (affected by the disturbance) is also average, i.e., when the disturbance opens up the vegetation without being excessively destructive and when the environmental conditions allow species to settle and develop without causing an immediate resumption of negative interactions between them (Hilbert et al. 1981 **133**, Catford et al. 2012 **51**).

It is not easy to give a precise definition of an intermediate disturbance (Wilkinson 1999 **286**). Applying this theory in the field can only be approximate because of the complexity of defining, for a given site, what constitutes an intermediate disturbance and average productivity, even more so in a context where climatic conditions vary greatly from year to year.

While grazing, through its differentiated use of the environment, is one of the determining factors in floristic composition and diversity (Milchunas et al. 1988 **67**, Crawley, 1997 **192**, Bakker, 1998 **18**, Collins et al. 1998 **62**, Van der Walk et al. 2000 **273**, Alados et al. 2004 **6**, Amiaud et al. 2008 **8**), its effect obviously depends on the pressure applied over the course of a year and the methods used to apply this annual pressure (instantaneous pressure and how long it is applied).

The grazing rate can be broken down by day, period, or year (annual grazing rate). The grazing pressure is applied according to how well plants can tolerate the direct and indirect effects of grazing. An increase in the grazing rate, when this increase remains moderate, generally leads to an increase in the number of species and an increase in the number of annuals in Mediterranean environments with little or no flooding. On the other hand, low grazing pressure favours an increase in perennials *(Fig. 24)*, while the exclusion of grazing leads, except in conditions of very low environmental productivity and/or stress, to their dominance, in particular by Poaceae (Milchunas & Lauenroth 1993 192) or woody plants (Milchunas & Lauenroth 1993 **192**).

Figure 24: The exclusion of domestic grazing leads to the dominance of a perennial species that grow in tufts. *© F. Mesléard*

However, increasing the grazing pressure can also favour highly dynamic species for which the high input of nutrients through urine and **faeces*** ensures growth. When this pressure is such that all consumable species are strongly controlled, it facilitates unpalatable plants that are only slightly eaten or not consumed and indirectly selected by their appearance (rosette), or their unpalatability *(Fig. 23)*.

TRAMPLING

Trampling is one of the consequences of increased grazing pressure. It creates gaps in plant cover through the mechanical destruction of vegetation. These gaps allow seeds to germinate or species to become established that were previously prevented. In a way that may seem paradoxical, trampling is thus potentially an indirect vector for maintaining or increasing species richness, but which does not necessarily correspond to the desired species. When the vegetation cover is dense and the **preemption effect*** exerted by the vegetation in place is strong, the creation of gaps is essential for making new species recruitment possible (Grubb, 1977 **122**). However, colonisation of a patch of bare ground is a largely **stochastic*** mechanism, since it depends on the presence or arrival of propagules*. It is also dependent on the size of

Figure 25: In the Rhône delta, the local Camargue horse breed is particularly well adapted to the environment.

the patch (Shumway and Bertness, 1994 **254**). Small gaps are most often recolonised by species with high vegetative reproduction that are already present, particularly in wetlands *(§ 1.3.2, Fig. 21)*. Larger gaps facilitate recolonisation from seed and therefore generate greater biodiversity, but also stochastic* effects. **Invasion/colonisation windows*** are also ideal places for the arrival of unwanted species because they are of no interest in terms of biodiversity or forage, or because they are dangerous to animals (toxic, possible injuries, particularly to the eyes). The development of these species in a grazing area is a sign of extreme pastoral pressure. Trampling is therefore often feared, for good reasons.

Trampling is potentially harmful for many **rhizome*** species and therefore for certain species that are well represented in wetlands. The impact of trampling depends on the **bearing capacity*** of the soil, linked to the nature of the soil, its water retention capacity (clay) and the humidity at the time. It also depends on the weight of the animals and the surface area of their hooves. Horses appear to be better adapted than cattle to the wettest environments *(Fig. 25)*.

HIGH VERSUS LOW INSTANTANEOUS PRESSURE

Grazing as a means of management aims to interrupt and/or modify the dynamics of succession, which, without intervention, would lead to a reduction in herbaceous biodiversity and/or the local disappearance of desirable species.

The continuous use of domestic herbivores in the environment in the form of low instantaneous pressure can, in some respects, be considered as the re-establishment of a ‘natural’ balance between vegetation and herbivores (Gordon & Duncan 1988 **110**, Wallis De Vries et al. 2007 **279**, Wallis De Vries et al. 2013 **278**), and therefore the preferred grazing method for conservation or restoration. Low-intensity grazing over long periods has thus been widely used for many decades, as an alternative to heavy environmental management practices such as mowing (Bakker 1989 **17**, Tälle et al. 2016 **263**). Grazing in this way has demonstrated its capacity to widen the habitat gradient and favour the concomitant presence of species characteristic of early and later successional phases (Rosenthal et al. 2012 **241**). However, it sometimes fails in the field, because the difficulty of adapting grazing pressure and animal behaviour to the context and fluctuations in forage availability make the conservation objectives unattainable (Rosenthal et al. 2012 **241**), with the corollary risk of irreversible colonisation by woody species (Mesléard et al. 2011 **185**).

Grazing used as a disturbance

Applying high grazing pressure for short periods of time is a management method based on disturbances that are intense and discrete in nature (Collins et al. 1998 **62**, Bakker 1998 **18**, Proulx & Mazumder 1998 **230**, Todd & Hoffman 1999 **268**, Holechek et al. 2000 **140**, Savory 1988 **247**, Ralphs et al.1990 **233**, Hart & Ashby 1998 **127**, Fynn & O'Connor 2000 **105**, Cingolani et al. 2007 **57**, Bakker et al. 2006 **14**, Klimek et al. 2008 **151**, Dumont et al. 2012 **86**, Kolos & Banaszuk 2013 **154**). Through its mechanical action and the feeding constraints imposed on the animals, it frequently proves effective in limiting the development of unappetizing species that are sensitive to the mechanical effects of grazing (Savory 1988 **247**, Perevolotsky & Seligman 1998 **219**, Mesléard et al. 2011 **185**). However, it also tends to favour the homogeneity of the environment compared to grazing in the form of low instantaneous pressure over a long period of time, which generates more variability in the vegetation structure in a given area (Olff & Ritchie 1998 **206**, Wallis de Vries et al. 2007 **279**, Platcher & Hampcke 2010 **225**).

Grazing fragmented into small paddocks, which facilitates rotation and the presence of a high number of animals per unit area, can thus force domestic herbivores to consume otherwise neglected plants and exert a destructive mechanical effect on them (Savory 1988 **247**, Perevolotsky & Seligman 1998 **219**). It allows fine control of the herd and is therefore closer to **shepherded grazing*** than grazing in a large plot where the animals are under little or no constraint.

Combination of low and high instantaneous pressure in a restoration project

When colonisation by unappetizing plants (woody plants) is identified as the most immediate threat, high grazing pressure applied over a short period of time should be favoured to reopen the area that is in the process of being overgrown. However, in a relatively open environment, low instantaneous pressure applied over a long period can maintain or even increase the relative heterogeneity of the vegetation. Thus, in the same restoration project, the two forms may be applied successively, and should be considered in terms of adaptive management.

Low instantaneous grazing pressure is not without risks when the intra- and inter-annual variability of the forage supply is high, requiring frequent adjustment of the herd numbers to respond to the temporal mismatch between the pressure and the availability of forage *(Fig. 26)*. The co-occurrence of numerous species by keeping the environment open can also be achieved by applying grazing in the form of a disturbance alone, whose frequency can be adjusted based on field observations. In the medium and long term, this may present less risk of colonisation by undesirable species not consumed by domestic herbivores than continuous grazing. It is nevertheless important to ensure, over the long term through regular monitoring of the vegetation *(§ 2.3)* that the high instantaneous pressure applied does not encourage unpalatable or **nitrophilous*** species by enriching the environment and does not jeopardise the maintenance of numerous species, including those that we wish to encourage.

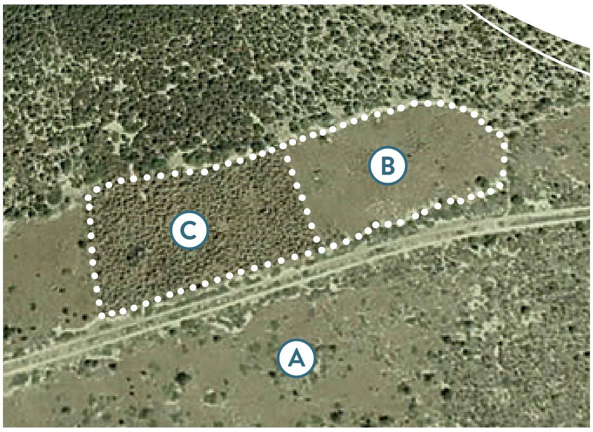

Figure 26: Restoration of a grassland in the Rhône delta colonised by woody plants
(aerial view at 90 m altitude © GoogleEarth)

- (A) Grazing (control) with low instantaneous pressure for 6 months for several decades,
- (B) Annual grazing pressure equivalent to **(A)** applied in the form of high instantaneous pressure (high density of animals present for only a few days),
- (C) Elimination of grazing by installing exclosures.

After eight years of restoration activities, the woody plants (in dark green) are no longer present in zone **(B)**, whereas they are still observable in zone **(A)**. However, there is no significant difference in the composition of the herbaceous cover (species richness, perennial/annual ratio, contribution of dominant species and species characteristic of the habitat). The cessation of domestic grazing in **(C)** leads, as usual, to the development of a perennial grass that grows in tufts, which is accompanied by a sharp reduction in species richness.

THRESHOLD EFFECT, OVERGRAZING* AND UNDERGRAZING*

The effects of abiotic and biotic factors may be additive but are also likely to influence each other through a feedback effect (Bertness & Ellison 1987 **31**, Mulder & Ruess 1998 **199**, Belovsky & Slade 2019 **27**). Thus, in low-salinity marshes, the reduction in plant cover due to predation (wild or domestic herbivory), by causing an increase in evaporation, can indirectly affect the salinity of the environment, which in turn accelerates the reduction in plant cover. This type of mechanism can lead to radical changes in communities (Cargill & Jeffries 1984 **49**, Mulder & Ruess 1998 **199**). It is frequently the cause of threshold effects observed (Bestelmeyer et al. 2013 **32**), particularly in wet environments (De Angelis 1992 **78**, Michaels et al. 2022 **189**).

Observation of the plant cover does not always reflect the situation. For species that favour carbon acquisition mechanisms (green parts) to the detriment of storage mechanisms (underground parts), vegetation that is judged to be in satisfactory condition by observation of the above-ground parts alone may in fact be threatened by an ongoing degradation process. This is the case when vegetation subjected to heavy grazing pressure must also cope with a deterioration in environmental conditions or, conversely, when grazing pressure is increased at a time when the vegetation is already under significant stress. The term **overgrazing*** is therefore frequently used to describe grazing methods which, in the environmental conditions encountered, cause changes in the vegetation that are deemed to be negative.

Overgrazing* implies that the pressure, through its direct effects (consumption of vegetation) and/or indirect effects (mechanical effects including trampling, matter from **faeces*** and urine), does not allow the vegetation to maintain itself (composition, structure) in the prevailing environmental conditions, which may themselves be altered by the pressure exerted by the herbivores present. Overgrazing leads to a reduction in vegetation cover and height, the disappearance or reduction in the contribution of species including foraging species, and an increase in not very appetizing or unappetizing species (unpalatable, invasive species). The destruction of the cover can lead to increased erosion (e.g., remobilisation of dunes) *(Fig. 23)*.

On the contrary, **undergrazing*** implies that its direct and/or indirect effects are not sufficient to contain the dynamics of the vegetation, with the corollary of closing the vegetation cover and accentuating competition. Undergrazing* leads to an accumulation of biomass and a reduction in **net productivity*** and a decrease of annual species, as well as a reduction in species richness. It favours the closure of the habitat to the detriment of pastoral species and, if conditions allow (low salinity and flooding) colonisation by woody species.

For both **overgrazing*** and **undergrazing***, the reversibility of the process underway defines the reality of the phenomenon. For example, a grazing area characterised by low cover and low species richness may be described as overgrazed, whereas a simple change in the grazing methods will lead to the redevelopment of plant communities that are of conservation and pastoral interest, demonstrating that it was more a case of heavy pressure than overgrazing. In the same way, a pasture dominated by dense vegetation and poor in species could be described as undergrazed, whereas the introduction of appropriate grazing would make it possible, in the short term, to obtain the desired vegetation, if there is no irreversible process present such as the establishment of species that cannot be controlled by grazing.

Figure 27: Removal of *Baccharis halimifolia* shrub using a draught horse *© F. Mesléard*
If control of a species is not possible or can no longer be achieved by grazing, a more disturbing intervention is necessary. Here, the use of a draught horse reduces the impact of the operation.

SEASONALITY OF GRAZING

The seasonality of grazing obviously plays a significant role in vegetation and the respective cover of different species (early or late ones depending on whether the grazing is itself early or late (Metzger et al. 2005 **188**). Knowledge of the **phenology*** of the main species is therefore a valuable asset. However, the variability of inter-annual conditions also comes into play, and it is difficult to define grazing periods that can be exactly replicated from year to year if we want to manage the vegetation with extreme care.

In a Mediterranean climate, many annual species in non-floodable environments or on the edges of wetlands germinate in autumn, so grazing at the end of winter and in spring, which controls the vegetation, particularly perennials, is favourable to them. Conversely, on sites that are temporarily flooded, conditions are often not conducive to the presence of domestic herbivores in winter. Depending on their hardiness and aptitudes, it may be advisable for the animals to be kept on high, non-floodable land, where young, inexperienced mothers will run less risk of exposing their newborns to particularly difficult conditions (low temperatures, risk of drowning).

On the other hand, grazing in the presence of surface water can cause serious damage to certain plants, as eating their parts above the surface of the water can make the plant rot. For these plants, grazing with the presence of surface water or the successive application of grazing and then surface water should therefore be avoided, or, on the contrary, encouraged, depending on whether we wish to maintain or reduce their biomass. Therefore, marshes will often be grazed in spring and summer.

CROSS MANAGEMENT OF WATER AND GRAZING

In wet environments, water and grazing are the two essential means of habitat management, each of which can be adapted in function of the type of vegetation desired. In the Mediterranean region, their simultaneous management helps to ensure essential functions (**feeding ground***, **rest area***, nesting) throughout the year for many emblematic species.

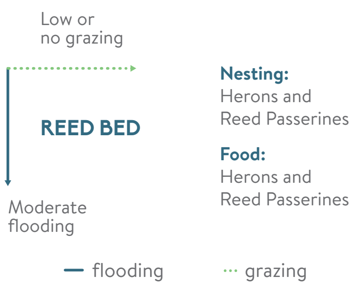

Figure 28: Intensity of water-based and grazing-based management favourable to reed beds and the associated avifauna

The more or less regular maintenance of a low surface water level (10-20 cm) from autumn to the end of spring, followed by a more or less pronounced dry spell during the summer, allows large emergent species to develop, such as reeds (*Phragmites australis*), which are ideal for feeding and nesting for various species of Heron and Reed Passerines *(Fig. 28)*. Grazing is not necessary to obtain and maintain reed-dominated communities and, if present, must remain extremely moderate to avoid any regression of the species *(§ 3.1.1)*.

Figure 29: Intensities of water-based and grazing-based management favourable to emergent plants (Sea Club-rush) and the dependent avifauna.

Similar flooding conditions, supplemented by significant grazing pressure, ensuring the control of large emergents, such as reeds, allows the development of more open mono- or **paucispecific*** emergent vegetation, in particular Sea Club-rush. In the Rhône delta, Sea Club-rush is a particularly popular food for granivorous ducks and wildlife that eat the underground reserves (tubers), particularly Greylag Geese (*Anser anser*) and Wild Boar (*Sus scrofa*) *(Fig. 29)*.

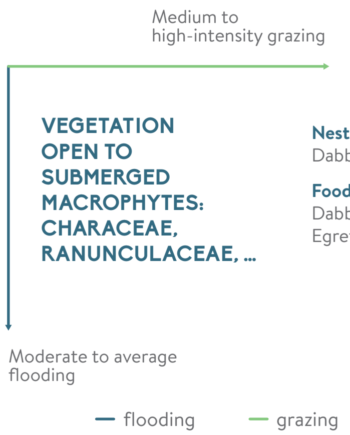

Figure 30: Intensity of water-based and grazing-based management favourable to vegetation in open areas and to the avifauna dependent on shallow marshes in the Camargue

Maintaining a shallow to medium depth of water and applying grazing pressure that controls large emergent plants favours open environment species, in particular, submerged plants, which benefit from light that is conducive to their development. This vegetation (vegetative part, seeds) is appetizing to Dabbling Ducks, some species of which also find a suitable habitat for nesting *(Fig. 30)*.

Figure 31: The St Seren marsh (nearly 70 ha), located in the centre of the Tour du Valat Estate, is an emblematic Camargue marsh in terms of the avifauna that frequents it.
© J. Jalbert

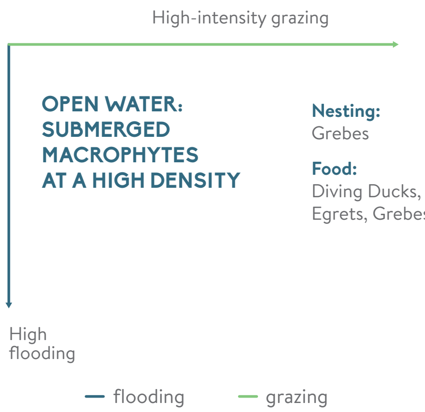

Figure 32: Intensities of water-based and grazing-based management favourable to plants in open environments where the water level is relatively deep and the avifauna dependent on these areas.

Grazing by Camargue cattle in spring and summer ensures the development of a dense patch of rush *(Fig. 31)*.

In marshes where the water level is relatively high from autumn to spring, high grazing pressure ensures the control of emergent species and the development of a substantial amount of submerged vegetation *(Fig. 32)*, particularly favourable to diving birds that can collect food at depths of up to several feet.

1.4.3 Diversity indices

SPECIES RICHNESS, DIVERSITY, AND EVENNESS

Species richness (SR)

Total species richness generally corresponds to the total number of species recorded (no. sp.) within a community, an ecosystem, or a plot of land. Formally, it corresponds to the number of species recorded - 1:

SR = (Σn.sp) - 1

In this case, the ***SR*** index = 0 when a single species is recorded.

Average species richness corresponds to the average number of species present per unit area. It is calculated from replicated samples of the same area.

Species richness and its dynamics must be considered in terms of species composition. It may be stable (relatively constant over time), while species composition has changed. A decrease in species richness should be seen as a sign of degradation if the species that have disappeared are among the target species. It is of little importance, or even a positive factor, if it corresponds to the disappearance of undesirable species. Similarly, an increase in richness should also be seen as a deterioration if most of the new species are undesirable.

Species richness is often confused with diversity. However, species richness alone does not fully express diversity, because it does not take into account the relative share of each species within a community or patch of vegetation. For example, two communities with 10 species, one in which each species represents 10% of the cover, the other in which one species represents 91% and the other nine each represent 1% of the cover, will be considered equivalent if only species richness is measured.

In addition to species richness, other indices, such as the number of individuals of each species, are needed to provide a satisfactory characterisation of diversity and its dynamics over time. The choice of indices depends on what we want to compare (e.g., changes within one community or between different plant communities).

Diversity

Species diversity takes into account both the number of species and the relative abundance of each species *(Fig. 33)*. Diversity increases when the number of species increases and/or when the abundance of species is more evenly distributed. Maximum diversity is therefore reached when all the species are present in equal numbers.

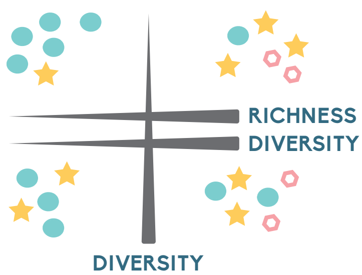

Figure 33: Number of species and number of individuals of each species in four theoretical plant communities and increase in species richness and diversity in each of the four communities.
Species richness increases from left to right. Diversity increases from left to right, but also from top to bottom. A community with a more diverse distribution is not necessarily richer in species.

Diversity can be characterised by various indices whose specific features give them a relatively precise framework for being used. The Shannon-Wiener index is the most common.

Shannon-Wiener index (H')

The Shannon-Wiener index is based on the probability of encountering a species among all the species in the community or patch of vegetation. It is calculated using the formula:

$$H' = -\sum_{i=1}^{S} pi.\log_2 (pi)$$

where ***pi*** corresponds to the relative abundance of a species compared to all the species present ***(pi = ni/N)***, ***ni*** corresponds to the number of individuals of the species (or the plant cover), ***N*** corresponds to the total number of individuals whatever the species. ***S*** is the number of species present. The index can also be calculated using plant cover (species cover and total cover).

If the community contains only one species, then ***H'*** is equal to 0. ***H'*** increases logarithmically as the number of species increases. The Shannon-Wiener index is sensitive to variations in species richness; it increases as the number of species increases. The isolated presence of a species can therefore cause the index to vary without this corresponding to a tangible change in the community in the field. The Shannon-Wiener index is primarily used to compare the dynamics of a community's diversity over time. It loses its relevance when comparing different communities.

Evenness

Evenness expresses the distribution of species abundance within a community. The Piélou and Simpson evenness indices are among the most common:

The Piélou evenness index (E)

It is calculated based on the Shannon-Wiener index, using the formula:

$$E = \frac{H'}{Hmax}$$

where ***Hmax*** corresponds to the Naperian logarithm of the total number of species present in the community. ***E*** tends towards 0 when a single species accounts for most of the population.

The Simpson evenness index (L)

Simpson's index measures the probability that two individuals in the community are of the same species, using the formula:

$$L = \frac{\sum_{i=1}^{S} ni\,(ni-1)}{N\,(N-1)}$$

where ***ni*** corresponds to the number of individuals of the species, ***N*** corresponds to the total number of individuals whatever the species, and ***S*** corresponds to the total number of species.

Simpson's evenness index is most often calculated according to the formula:

$$ED = \frac{D}{Dmax}$$

where ***D = 1 – L*** and ***Dmax = 1- (1/S)***.

Simpson's evenness index expresses the dominance of a species when ***ED*** tends towards 0. The Simpson index gives more weight to abundant species. The presence of rare species has little effect on the value of the index. This index is suitable for comparing communities.

1.4.4 Levels of diversity

Diversity depends on the surface area of the site under consideration: the larger the area, the greater the probability of hosting a high number of species (in a non-linear fashion). It can be assessed at several nested levels, in particular the Alpha, Beta, and Gamma levels (Whittaker, 1972).

ALPHA (α) DIVERSITY

Alpha diversity (α) refers to the species present in the same habitat. It is used to characterise diversity at the community or vegetation patch level.

BÊTA (β) DIVERSITY

Beta diversity (β) refers to the rate at which species are replaced along a gradient (water level, salinity, xericity). It reflects the changes in diversity caused by extending observations beyond a community or patch of vegetation. β diversity characterises the diversity between communities or patches of vegetation.

GAMMA (γ) DIVERSITY

Gamma Diversity (γ) refers to the gains in species obtained by sampling the same type of community or vegetation patch at different sites. γ diversity corresponds to a measure of diversity at the scale of a large area (region).

Whatever the scale studied, species composition must also be analysed when considering these indices, because diversity does not take account local, characteristic, **ubiquitous***, and undesirable species.

1.4.5 Plant diversity and pastoral value

The pastoral value of an area is closely linked to the presence of grazing. In the absence of grazing, vegetation overgrowth leads not only to a reduction in diversity, but also in the pastoral interest, as forage species are replaced by species that are barely edible or inedible *(§ 1.4.1)*. The introduction of grazing, to open up an area, generally leads to an increase in pastoral value, whose progression more or less follows that of the opening up of the vegetation *(Fig. 34)*. Maintaining high pressure on the environment is often detrimental to diversity, and then to pastoral activities. It can lead to the collapse of these activities, as soon as non-appetizing species have colonised the area *(Fig. 23)*.

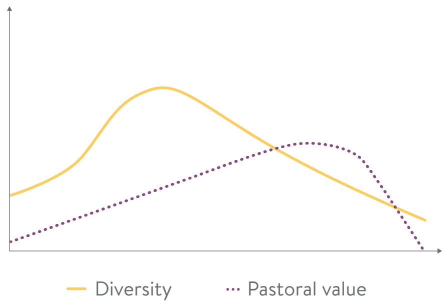

Figure 34: Convergence between plant diversity and pastoral value under increasing grazing pressure

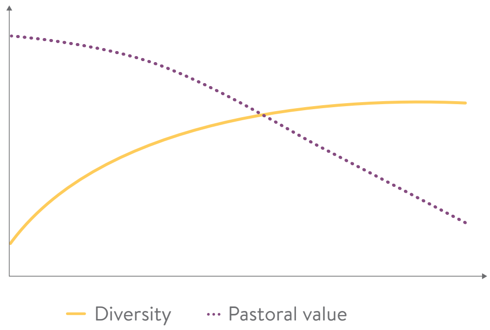

Figure 35: Discrepancies between plant diversity and pastoral value with decreasing grazing pressure

When the vegetation has high pastoral value (in the case of a well-managed pasture), changing the grazing methods to promote diversity will, with a few exceptions, reduce this value *(Fig. 35)*. The gain in species or species cover (α diversity) of conservation interest is achieved at the expense of pastoral species. While maintaining high pastoral value is generally the result of the (almost exclusive) dominance of forage species in a way that homogenises the vegetation cover, applying distinct grazing methods leads to an increase in diversity by creating varied patches of vegetation (β diversity) or by accentuating their differences.

Pastoral management for conservation purposes is likely to favour or guarantee the pastoral value of a site at a substantial level, but the simultaneous pursuit of two differing objectives necessarily has its limits. This pursuit may also prove to be unrealistic, making it inevitable to give priority to one of the two objectives *(§ 1.1.2)*.

Camargue

1.5 DIFFERENT DOMESTIC HERBIVORES FOR DIFFERENT EFFECTS ON VEGETATION

1.5.1 Are domestic herbivores ecosystem engineering species?

Ecological engineering is the capacity of certain organisms to contribute more than others to restoring the environments they use, because of their specific characteristics, aptitudes, and behaviour. Due to their place in the ecosystem, the functions in which they participate, their impact on the **biotope*** or biocenosis, and their ability to act as a filter on the composition of communities, these organisms are referred to as *engineering species* (Jones et al. 1994 **148**). Depending on the environment considered, many herbivores, including domestic herbivores, which are capable of partly shaping their environment, may correspond to this definition (Reichman & Seabloom 2002 **236**).

The impact of domestic herbivores and their capacity to be good engineers varies according to many parameters such as species, sex, age, grazing period, nature of the vegetation, food supply, and the **phenology*** of the plant species present in the environment. In an ecological engineering approach, which requires knowledge of what the domestic herbivores used can do and how to manage them, these parameters must necessarily be considered.

1.5.2 Different behaviours have different impacts

The choice of animal is one of the major decisions in any restoration project. It is even more complex given that it depends on the specific characteristics of the site and that most of the time there are few references available locally on the impact of domestic herbivory. Nonetheless, the specificities and aptitudes and their limits between species (and between breeds) are significant and generally make the choice easier.

CONTRASTING ADAPTATIONS TO WET ENVIRONMENTS

Various breeds of horses and cattle are suitable for managing and restoring wet environments, because of their ability to move in lightly flooded conditions. However, in most cases, the horse appears to be the species best suited to flooded or waterlogged environments due to its food preferences (graminoids) as well as the low **bearing capacity*** and fragility of the substrate *(Fig. 36, 37)*.

Figure 36: The Camargue horse is an ecosystem engineer for wetlands and mosaic environments (ones with floodable and non-floodable areas). *© F. Mesléard*
The Camargue horse is used to manage many sites in wet environments because of its capacity to move in areas where soil has a low **bearing capacity*** due to its moderate weight and large hoof surface, its ability to take advantage of vegetation and modify its selectivity according to the food available and its quality, and its impact on the structure of the vegetation (control of **helophytes*** in marshes and dominant species in grasslands).

Horses prefer high quality forage with high nutrient content (Fleurance et al. 2001 **101**) and select those they can ingest quickly. Unlike cattle, they show little attraction for dicotyledons, which are rich in secondary metabolites (Ménard et al. 2002 **180**), and therefore show a strong preference for Poaceae. Equines are generally **grazers***: they eat mainly the parts of plants close to the ground (generally green). Goats are mainly **browsers***, consuming the distal parts of plants. Cattle and sheep are grazers* and browsers* *(Fig. 37)*.

	EQUINES	CATTLE	SHEEP	GOATS
Feeding strategy				
Grazer				
Browser				
Food preferences				
Monocotyledons:				
Poaceae				
Juncaceae, Cyperaceae				
Dicotyledons:				
Woody: leaves, stems	*			
Seedlings				
Buds				

* Donkeys eat bark, but ingesting bark is toxic for horses.

Figure 37: Feeding strategy and food preferences of equines, cattle, sheep, and goats (from Gordon et al. 1990 **112**)

The length of the blades makes it easier for cattle to access the grass, however they are less able to eat tall plants (large **helophytes***). Whereas cattle tear off the blades with their tongue, horses cut them with their teeth. This capacity to select low cover for feeding (Rook et al.

2004 **240**, *Fig. 38*) gives horses a relatively good capacity to control woody seedlings, which cattle are unable to do. However, the capacity of horses to consume very young herbaceous woody plants remains well below that of sheep.

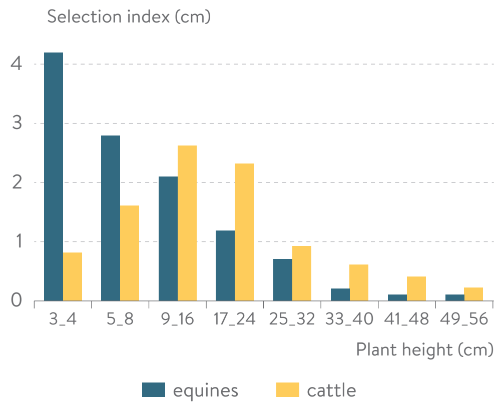

Figure 38: Selection index for horses and cattle according to plant height (Ménard et al. 2002 **180**)

Contrary to cattle, horses avoid grazing in areas where there are faeces (Edwards & Hollis 1982 **93**). By creating areas of short vegetation, as well as avoiding other areas of vegetation, equines induce a wider range of effects on vegetation. Because of their dietary requirements for monocotyledons and their behaviour, they are more effective for conservation management in the wettest areas (Loucougaray et al. 2004 **166**) (*Fig. 39*).

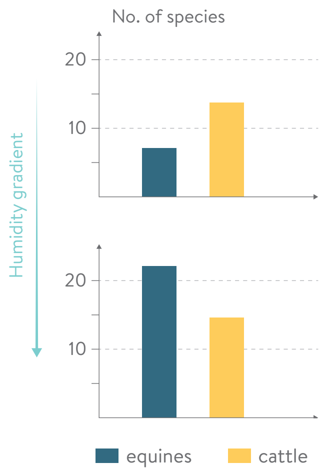

Figure 39: Total number of species appearing after three years of management as a function of the humidity gradient. Study carried out in habitats on the French Atlantic coast (from Amiaud, 1998 **7**)

Donkeys consume bark and can therefore cause the death of many woody species without it being necessary to apply high grazing pressure. On the other hand, for cattle or horses to be able to significantly control mature woody species and limit their recruitment, heavy grazing pressure (high instantaneous pressure) must be applied.

Sheep show a great capacity to select certain parts of plants such as flowers and young shoots. They are therefore better at controlling young plants, particularly woody plants, than cattle (Olivan and Osoro 1997 **207**). Sheep determine the foraging routes they take according to the structure of the herbaceous cover, biomass, nutritional quality, and also compounds such as **anthelmintics*** (Amiaud et al. 1998 **8**, Aerts & Chapin1999 **4**). By completely cutting back the limbs and thus limiting interactions between plants, they help to maintain the vegetation in place and make it more homogenous, but not necessarily more diverse.

Because of their tolerance for tannins and alkaloids, and their ability to modify their choice according to the food supply, goats are more opportunistic than other domestic herbivores (Osoro et al. 2013 **211**). Their mobile upper lip, prehensile tongue, and agility give them the ability to reach food at great heights (> 2m). Thanks to their specific digestive capacities (recycling of nitrogen in the form of urea in their saliva) and their capacity to consume coarse, nutrient-poor elements,

Figure 40: The water buffalo is used on the shores of Lake Kerkini (Greece) where it feeds on water grass, a species native to Central America. © P. Grillas

they prefer the woody parts of plants. Although they prefer young tissue, they also consume older parts of woody plants and are therefore particularly effective at controlling and reducing overgrowth in fields.

The use of herbivores, other than goats, to manage overgrowth appears to be more effective after mechanical cutting than as a primary means of managing woody vegetation. However, it does reduce the frequency of mowing. While food choices, and therefore capacity to influence the environment, depend on the species and breed, they also depend on sex and time of year (a **suckled cow*** cannot be exposed to the same constraints as an adult male), as well as on the animal's condition.

GRAZING BY SEVERAL DOMESTIC SPECIES

Taking advantage of the aptitudes and specificities of different domestic herbivores, multi-species grazing may be set up to optimise grazing-based management. In this case, the behaviour of the herbivores, and therefore their impact on the habitat, remains largely conditioned by the characteristics of the vegetation in place and its productivity (Lamoot et al. 2005 **157**, Bakker et al. 2006 **14**). When several species graze the same area, their effects are usually additive. These effects obviously depend on the assemblage of herbivores, but also on the composition of the habitat area. The benefits of multi-species grazing seem to increase with the richness of the vegetation. Multi-species grazing regimes are therefore considered to be particularly well-suited to the management and restoration of systems with a high potential for plant diversity (Liu et al. 2015 **164**).

1.6 RESTORATION AND GRAZING

1.6.1 Restoration

RESTORATION IN THE STRICT AND BROAD SENSE

The Society for Ecological Restoration (SER 2004 **92**) defines ecological restoration as *a process that intentionally accompanies the re-establishment of a degraded or destroyed ecosystem.* Generally, restoration aims to re-establish structures and/or functions and processes of plant communities, habitats, parts of ecosystems, or entire ecosystems. For the local restoration of species or populations, restoration as such is carried out in function of these local habitats and environmental conditions. The species-level approach is more the domain of conservation biology.

Ecosystem restoration can target a range of different objectives, most commonly one or several compartments of degraded ecosystems, the re-establishment of plant communities close to those present before the degradation, or the recovery of functions (restoration in the broad sense). Ecological restoration in the strict sense, which aims to re-establish the biotic integrity of a pre-existing ecosystem prior to degradation, remains a theoretical objective (Choi 2007 **56**), because it is not possible to take account of all the compartments of a system to be restored, or to restore them simultaneously.

Ecological restoration can be carried out without strictly following all the SER criteria *(§ 2.3.1)*, but it must be based on a rigorous approach, as much in terms of assessing the state of degradation of the habitat and defining the objectives and resources to be implemented, as in evaluating how successful a project is.

AN ECOSYSTEM-FOCUSED OR MORE GLOBAL APPROACH

The perception of the level of degradation and its causes, a clear definition of the objectives to be achieved, the means to be implemented, and the setting up of means to meet the objectives and assess their degree of success may only respond to the conservation and/or technical part of the project and not correspond to the scale at which it is to be carried out. Successful ecological restoration often requires a comprehensive and **holistic*** approach, which takes into account not only the environmental parameters involved in the dynamics of the ecosystem to be restored, but also the socio-economic context and history of the site to which it belongs. These aspects are often overlooked (Wortley et al. 2013 **288**).

In many cases, however, the objectives are circumscribed and concern only a small area with no socio-economic issues at stake. For example, there may be a desire to reopen the vegetation on a parcel of land by grazing, in order to restore an open environment and favour remarkable species of flora. In this case, once the objectives have been set and the corresponding methods for applying grazing have been determined, the monitoring should be put in place to enable adaptive management. This information will help determine the desired times and the desired duration of the grazing (availability of animals).

THE COMMUNITY: THE PREFERRED SCALE

The **community*** is the preferred scale for observation because that is where all the vegetation structuring mechanisms take place. For its own sake and/or as a habitat likely to provide favourable conditions for the target species, community is most often the focus of restoration. However, this scale is not always relevant. It is not appropriate for complex or mosaic systems. If several communities and compartments other than the vegetation are considered, restoration can be envisaged over larger areas, which is often more coherent from a management point of view.

There is a twofold challenge for any restoration project that targets a plant community:

1. to understand the assembly mechanisms at play and the factors underlying them at all stages of development,
2. to control them by forcing or thwarting intrinsic colonisation and structuring processes (Muller et al. 2014 **201**).

Dispersal mechanisms, environmental conditions, and plant-plant interactions (filters, *§ 1.2.2*) are the three levers of action to be used individually, simultaneously, or successively to position or reposition the community on the trajectory that will eventually enable it to achieve or come close to achieving the desired objectives.

A range of actions can induce or rectify the trajectory of a community *(Fig. 41)*. The reshaping of environmental conditions (filtering of abiotic conditions) ensures the installation and development of plants selected by dispersal, which then benefit from a favourable abiotic environment. The introduction of target species **propagules*** ensures their presence beyond what is guaranteed by natural dispersal (forces the dispersal filter). The **removal*** of a few centimetres of soil limits the impact of the initial seed bank (biotic conditions filter). It also reduces the overall productivity of the environment (abiotic conditions filter), which, by favouring a small number of competitive species, restricts the development of species that are characteristic but not very competitive in highly anthropised environments (Muller et al. 2014 **201**). The biotic filter, especially through the implementation of appropriate grazing methods (control of mostly negative biotic interactions), ensures the maintenance of non-competitive species in the absence of grazing but targeted by the restoration.

1.6.2 Reference ecosystem(s)

REFERENCE STATE

Ecological restoration is deemed to be necessary when the **resilience*** capacity of an **ecosystem*** or **community*** - the possibility of returning to a state close to that before degradation - proves to be impossible without targeted interventions. This state, before degradation, is called *the reference state*. It corresponds to the historical state of the ecosystem (or community) before degradation and to the restoration objective.

To establish this reference state, we need to understand the mechanisms that led to the degradation, as well as those that would enable the system to 'self-repair.' This comprehension also implies having knowledge of the environment prior to its degradation. The availability of data from previous observations and eyewitness accounts is therefore invaluable, but insufficient for developing concrete restoration objectives and defining a relevant reference model. Assessing restoration needs, specifying objectives, determining the actions likely to meet them, and later being able to assess the degree of success all require a model that is close to the reference state in terms of environmental conditions and historical background. Taking a particular site (or sites) as a reference model means assuming that the site to be restored corresponds more or less to a degraded version of it.

While it is obviously essential to ensure that the reference site is in good condition, and even if it corresponds to a non-degraded part of the degraded ecosystem, it is also essential to ensure that it is similar to the historical ecosystem, otherwise it will no longer be restoration in the strict sense of the term.

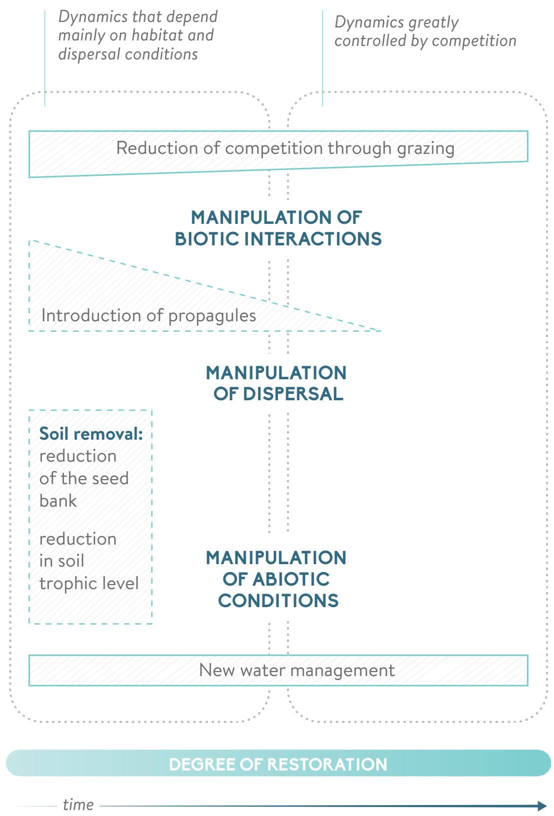

Figure 41:
Chronology and intensity of use of the three levers (manipulation of dispersal, abiotic conditions and biotic interactions) during the different phases of restoration.
Abiotic conditions are modified at the start of a project (establishment of ad hoc water conditions possibly requiring earthworks), but water management may still be necessary. It is a priority to conduct dispersal (introduction of **propagules***) at the start of the project. Control of biotic interactions (grazing) should be implemented once the vegetation has become structured. This manipulation (grazing pressure) may be strong at the start (when the area is opened up) and then reduced. On the other hand, it may be low at the beginning and then increase as biotic interactions develop.

Spatial and temporal contexts strongly influence the functional processes of ecosystems and the composition of the communities that develop in them (Turner et al. 1995 **272**). The similarity between two ecosystems potentially decreases according to their geographical distance. If no site is perfectly identical to another, then no site is an absolute reference (Pickett & Parker 1994 **223**, White & Walker 1997 **284**). The physical proximity of two sites, because it increases the probability that the environmental and historical conditions are similar, is an important parameter which, although it provides no guarantee, should nevertheless be sought *(Fig. 42)*.

It is often difficult to distinguish between all the causes of degradation, whether they are anthropogenic or result from natural and/or **stochastic*** events. Aiming for the historical reference state is usually pointless (Aronson et al. 1995 **11**, Pickett & Parker 1994 **223**, Hobbs et al. 2009 **137**, Balaguer et al. 2015 **20**). Most of the time, the pressures are cumulative, and the historical reference state may simply be unattainable due to changes that are sometimes

Figure 42: Marshes in protected areas are often used as reference ecosystems for restoration.
© A. Ackermann - Petit Saint-Jean Marsh

irreversible, particularly in the context of changes in climate or how an area is used (Hobbs et al. 2009 **137**, Jackson & Hobbs 2009 **144**). Taking only one reference model at a particular point in its development means assuming that the state observed and taken as a reference is broadly representative of all the states in which the ecosystem may be found. This pitfall can be partially circumvented by simultaneously considering several reference ecosystems, even if they are individually imperfect (Gann et al. 2019 **106**). By taking into account their dynamics in relation to current conditions, such as variations in inter-annual conditions, it is then possible to define a reference range, rather than a reference state (Shackelford et al. 2021 **252**, Olivier et al. 2023 **208**).

The reference ecosystem selected must, of course, take account of recent and long-established practices, especially grazing, and the way in which it is applied *(Fig. 43)*. In this regard, the soil seed bank is the memory of the ecological conditions. Its relatively laborious study, which cannot be carried out without a good level of expertise, can be particularly informative *(§ 1.2.2)*. It provides information about the history of the site and facilitates comparison with other sites.

Figure 43: Development of a method to manipulate the dispersion filter during the restoration of temporary marshes. *© I. Muller*
The reference ecosystem is also used here as a donor site (**propagules***). Identifying the distribution of target species during the flooded period facilitates collection during the dry period. Dispersion tests of soil samples from the reference site were carried out on experimental plots before being applied on a marsh to be restored. The small quantities of soil required and the response of the vegetation confirm that the technique is valid (Muller et al. 2014 **201**)

The grazing methods applied in a reference ecosystem can be used to design those that will have to be applied to restore the plant communities in the degraded ecosystem, and sometimes even more strongly than those in place or those previously applied at the site to be restored. However, it is vital to be able to distinguish between the state of degradation stemming from current, directly observable conditions, and the state of degradation that results from historical conditions. This process prevents any misinterpretation of the role of current management. Attributing to current management, including grazing, an impact that is partly the result of previous conditions may lead to changes being proposed whose effects in the short or longer term will be far from, or even contrary to, those expected.

NEGATIVE REFERENCE STATE

It is always desirable to have a reference state, however imperfect, for the purposes of comparison (Gann et al. 2019 **106**, Balaguer et al. 2015 **20**, White & Walker 1997 **284**, Aronson et al. 1995 **11**). The non-degraded state of the ecosystem to be restored may have disappeared or persist only in the form of fragments that are themselves subject to various pressures (Guerrero-Gatica et al. 2019 **123**, Rodrigues et al. 2019 **239**). Degraded forms of the same ecosystem can also be used profitably by measuring the differences between these degraded forms, and the ecosystem to be restored, and how they have evolved at the different phases of restoration (Marchand et al. 2021 **169**).

The lack of any positive or negative reference state does not fundamentally compromise a restoration project. The introduction of detailed monitoring throughout the process to assess the distance between the pre-restoration state and the current state, during restoration, is sufficient for drawing up a clear trajectory of the current ecosystem and the positive or negative nature of this trajectory, even if with no reference state it is more difficult to aim for precise objectives and to predict the results of the actions implemented.

A list of target species can also be used as a reference for restoration insofar as these species, by virtue of their ecological requirements, are likely to have been present in the ecosystem prior to its degradation.

1.6.3 How far should restoration go?

PRE-EMINENCE OF HABITAT CONDITIONS

Changes in environmental conditions are one of the major causes of ecosystem deterioration. Assessing whether these conditions can or cannot be restored to their original state is the first step to take to avoid trying to restore an ecosystem in the strict sense when this is no longer feasible. The possibility of recovering the original environmental conditions is often difficult to assess. It is based on a minimum amount of knowledge of the management methods used before the degradation and on the resources available compared with those needed for the project. This knowledge may not be sufficient because environmental conditions depend on processes involving different scales: bigger or smaller disturbances such as climate change, atmospheric nitrogen deposition, changes in sediment circuits, dams, and dykes are likely to rule out any possibility of restoring a degraded ecosystem.

EXTINCTION DEBTS

A particularly complex point to consider because it requires targeted studies or the existence of scientific documentation on the subject, concerns the possibility for several targeted species to re-establish themselves or simply to remain on the site in the long term because of their local and/or regional disappearance, the alteration of the landscape matrix which no longer allows gene flow between sites and populations, or ongoing global changes. In this case, the restoration of the environment, by introducing or changing grazing methods, could aim to bring back species by opening up the environment, but not those which, for reasons other than those relating to the management applicable to the site, are destined to disappear locally. These extinction debts are not generally considered for species with very low numbers when the species concerned are still present on the site or even nearby, even though they could

St Seren marshes – Tour du Valat © J. Jalbert

lead to consider differently the references used to re-specify the objectives (depending on their status), or even to change the references (Tilman et al. 1994 **267**).

Extinction debts, i.e., the temporary presence of certain species or **communities***, can distort our judgement of the relevance of abiotic conditions, by suggesting that these conditions are characteristic of these species or communities and therefore those that prevailed prior to the degradation.

RESTORATION THROUGH GRAZING AND THRESHOLD EFFECTS

Threshold effects occur when the degradation of an environment is such that the addition of an extra pressure, however small, causes the system to tip, which leads to a rapid and profound change in plant communities *(§ 1.4.2)*. Without continuous observation and assessment of appropriate structural parameters (density, height, underground apparatus, seed bank) it is very difficult to perceive when a threshold is imminent. The cause may be abiotic, the trophic or physico-chemical characteristics of the soil, biotic, in the form of a lack of **propagules*** arriving in the system, or predation. Threshold effects, when they are still only expressed in terms of blockages in vegetation dynamics, can be partially (or even totally) lifted. In the most favourable cases, once the biotic conditions have been modified, it will be necessary to wait (non-equilibrium phase, *§ 1.2.2*) until the species corresponding to the expected vegetation have re-developed and the competition mechanisms have been re-established (beginning of the equilibrium phase) before introducing grazing, if the objective is to enable the expression of a high diversity of flora and/or the recruitment of non-competitive but characteristic species (particularly for light). In this case, grazing should be modulated according to the degree of recovery of abiotic conditions and their variability. When this recovery is only partially possible, the restoration objectives and/or grazing methods must be redefined. Achievable targets should be sought, which take account of the new conditions. The grazing pressure and grazing methods will then be readjusted based on the community's structure and productivity. Even more than in other restoration situations, this adaptive management requires the introduction of appropriate monitoring (reading the vegetation, measuring production within exclosures) carried out at short intervals (annual or even seasonal).

The aim of introducing or maintaining grazing during the initial phases of restoration is usually to control the most competitive plants (woody plants, **helophytes***), to open up the habitat, or to keep it open. Grazing should be introduced or increased when abiotic conditions (particularly hydraulic conditions) are restored, leading to strong vegetation dynamics, which is generally the case in Mediterranean wet environments. However, through its selective effect and intensity, grazing can also put the vegetation on an undesirable trajectory. By drastically altering the proportions between species and opening up the habitat, grazing can introduce **stochastic*** effects (the arrival of **propagules*** of various species) and colonisation by undesirable species with a high rate of vegetative reproduction. In extreme situations, when the environmental conditions alone jeopardise the correct trajectory of communities and potentially the survival of structuring species, applying or maintaining grazing (in the short term) should not be considered.

THE SOCIO-ECONOMIC AND/OR CULTURAL CONTEXT

The local socio-economic and/or cultural context(s) can also compromise the implementation of specific management and the use of the resources needed to restore a site, undermining any objective aimed at returning the environment to its state before degradation. Because of their impact on water resources, agricultural activities can greatly restrict the possibilities for hydraulic management, making it impossible to imagine any positive changes. Social acceptance of the practices that need to be put in place may be low or non-existent, because they are a source of potential nuisances, an expression of an undesirable return to the past, or simply negatively perceived.

The use of a particular herbivore may therefore be entirely appropriate, and correspond to the local breed previously present, and yet not meet the wishes of the inhabitants or institutions that prefer a less local herbivore, but one deemed appropriate, for functional reasons, status, or even tourism (Georgaudis et al. 1999 **108**, Perrino et al. 2021 **222**) *(Fig. 44)*. On the other hand, it may be difficult to gain support for an herbivore, even though it is particularly appropriate, because it is not local. Finally, grazing may simply no longer be popular because other agricultural activities have supplanted it, and there are no longer any local resources, animals, or people able or willing to get involved. Traditional domestic herbivores can also be used for conservation purposes. However, this can only be considered if the restoration objectives are not called into question or compromised (*§ 1.1.2*). If the effectiveness of this traditional herbivore is questionable, but does not pose a threat to restoration, it could be used in conjunction with another more suitable species or breed.

1.6.4 Active or passive restoration

A central issue in ecological restoration is whether to restore actively or to let things evolve without intervention once the main causes of degradation have been remedied (passive restoration).

Most Mediterranean wetlands and their species richness are, to a large extent, the expression of how they have been used, but also of the landscape environment and changes in biogeochemical cycles, which are themselves the consequence of human activities (Jackson & Hobbs 2009 **144**). As cultural legacies, these environments bear witness to century-old practices that are often essential to the human communities living nearby. Restoration based solely on naturalness, i.e., the absence of any human activity, ignores the role of past or ongoing practices which, although questionable, also play a part in biodiversity and have often contributed to and enabled the maintenance of a certain level of diversity and functionality in these ecosystems.

For many abandoned, little-used or, on the contrary, over-used sites, the factors favourable to the maintenance or restoration of ecosystems are generally known but difficult to quantify precisely, particularly those relating to anthropogenic activities, which are often decisive at different levels - from community to landscape - and vary greatly in nature and intensity (Dutoit et al. 2014 **91**).

If grazing is already present, its continuation or the relevance of the current methods may be questioned, but the changes to be made should not be implemented until their scope and consequences have been assessed. Withdrawing grazing without implementing another means of intervention on the vegetation could correspond precisely to passive restoration when grazing has been identified as the sole cause of the degradation, therefore the cause of the dysfunction will be removed.

However, insofar as grazing is an intrinsic component of the habitat concerned, which ensures its nature and survival, changing the way it is applied can be likened to passive restoration. In this case, the aim is not to modify an external management element, but to enable the system to repair itself by modifying one of its internal parameters (vital to its existence). In this sense, the reintroduction of herbivores to areas where grazing has been abandoned can also be considered as passive restoration, when this abandonment has not yet overly degraded the pastoral base, which enables the gradual reestablishment of plant communities selected by grazing methods close to those previously applied (irreversibility threshold not exceeded) (Aronson et al. 1995 **11**, Palmer et al. 2016 **214**).

Figure 44: Restoration of wet meadows around Lake Mikri-Prespa (Greece). *© F. Mesléard*
After a return to appropriate water management, the water buffalo was used successfully instead of the local cow. In addition to its effectiveness in controlling the reed belt and restoring diverse, functional wet meadows that are favourable to animal biodiversity (feeding and nesting areas for birds that are emblematic of the site, and spawning areas for fish), it is an undeniable tourist attraction.

When the habitat area can no longer recover a considerable part of its integrity and functions by simply restoring the environmental conditions that prevailed before the damage was done (**resilience***capacity exceeded), occasional or regular interventions become necessary. In addition to the engineering work required to restore the original hydraulic conditions, this active restoration can take on a number of different forms: the introduction of hydraulic management according to precise procedures (level, duration, frequency), the control of competition (mechanical intervention or grazing at different frequencies), and the introduction of **propagules*** (at the start of or during several phases of the restoration project).

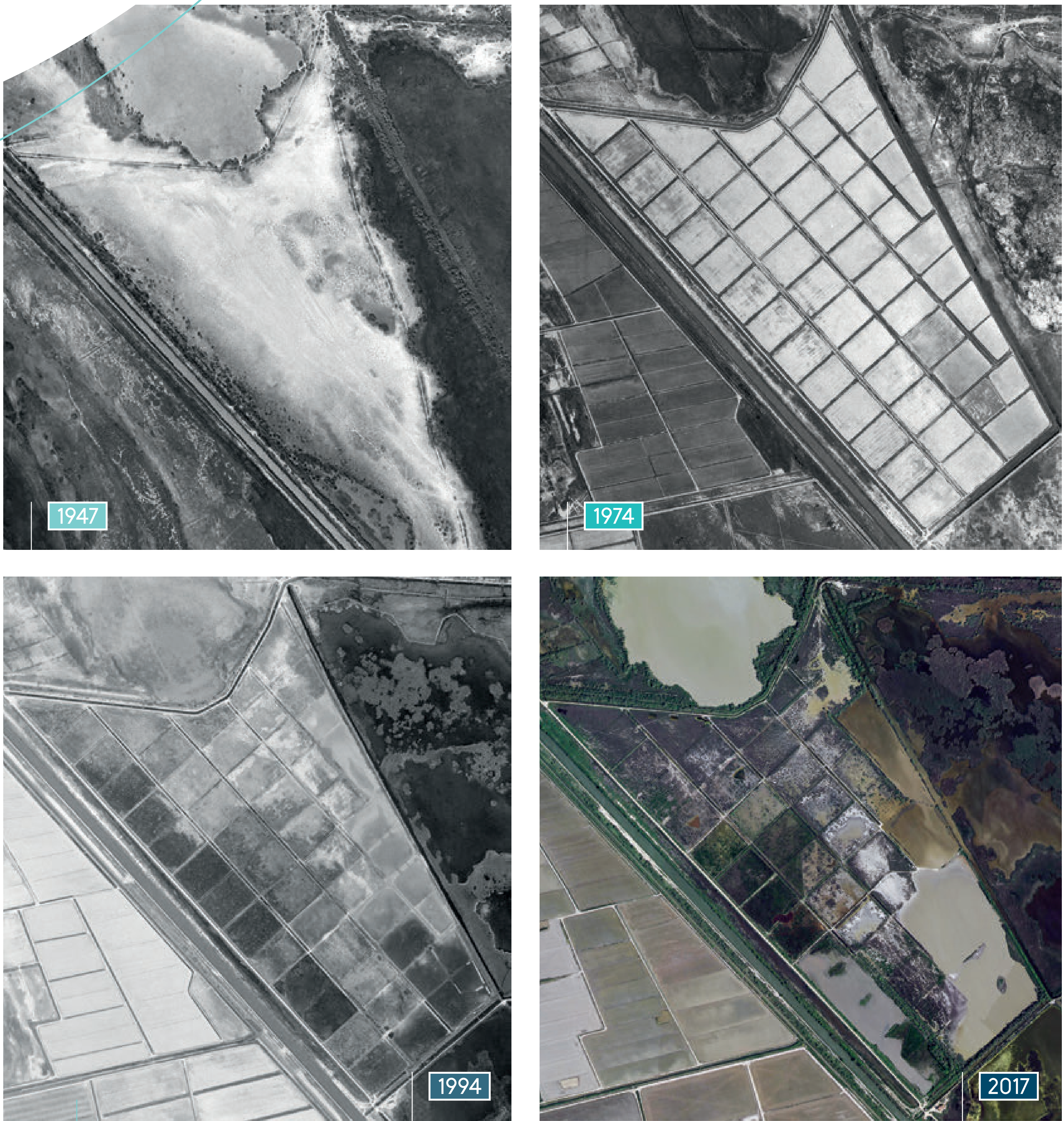

Figure 45: Rehabilitation of temporary marshes from abandoned rice fields in the Camargue: before destruction of the wetland (1947), during the rice-growing period (1974), during the rehabilitation phase (1994), and more recently (2017). *© Bdortho® 2017, IGN*
The presence of canals that are still functional has made it possible to combine different water management methods (flooding at different times / no flooding) and different grazing methods to obtain a range of Mediterranean wet environments that are favourable to a diversity of flora and wildlife.

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2.

CONDUCTING RESTORATION BASED ON OR WITH HELP FROM GRAZING

2.1 PLANNING RESTORATION AND THE ROLE OF GRAZING IN IT

Like any restoration project, a restoration project based on or assisted by grazing needs to be planned. It can vary enormously in ambition and size. Planning will therefore be a complex or a relatively simple first step. Nevertheless, the success or failure of the project will largely depend on the precision of this planning. **It must therefore be explicit and present:**

1. the elements, arguments, and data which motivate the rationale behind the project,
2. the elements, arguments, and data which determine the choices of how it will be carried out.

2.1.1 Planning restoration and the role of grazing in it

The decision to restore and use grazing is based on a general objective (e.g., opening up the habitat, controlling undesirable species), which in turn is a response to an observation (e.g., reduction in the contribution or disappearance of species characteristic of the habitat). This observation must be based on a detailed assessment of the state of the site/ecosystem/community, if possible substantiated by observations and measurements made in the field. However, this assessment is not sufficient. It must be supplemented by analysis of the context, which includes a description of the specific features of the site and local and regional ecological issues that justify the need to restore it. In this respect, the possibility of tracing the history of the site, in particular the place previously occupied by domestic herbivory, provides valuable information that can be used to define the nature and methods of grazing to be applied.

2.1.2 Defining the objectives

A restoration project responds to a general objective, which must, if possible, be defined in relation to one or more references *(§ 1.6.2)* with which comparisons will be made at different phases of the restoration, including the initial phase. The general objective must itself be broken down into more specific objectives relating to the various management elements involved, especially grazing, while specifying what is to be restored (species richness, diversity, particular species, type of vegetation) and the expected impact on these elements.

Aa Refer to the following text

2.1.3 The reference model

CHARACTERISING THE REFERENCE MODEL

It is highly desirable, but not essential, to have a reference model *(§ 1.6.2)*. Restoration implies, in its historical definition, repairing what is being repaired based on its original state, before deterioration, and if possible, seeking to make it converge towards this state. Ideally, the reference model will be one part of the site that has not yet been damaged, and which is representative of the site as a whole and of its diversity before degradation.

Tour du Valat estate *© A. Granger*

Reference models must be described in detail, in particular with regard to the components (vegetation, hydrological conditions) and the biodiversity compartments targeted by the restoration and/or on which the restoration will be based (hydrology, grazing). The history of the site and the socio-economic context, which provide information on the possibilities for applying restoration actions and the chances of success, particularly in terms of grazing, should also be taken into account as far as possible.

RESTORATION WITHOUT A REFERENCE MODEL: THE IMPORTANCE OF CHARACTERISING THE BASELINE STATE

Restoration without any precise reference model does not obviate the need to define precise, well-argued objectives, even if they are partly subjective. Without a reference model, it may be difficult to determine what constitutes restoration, in the strict sense of the term, and what is more a matter of management. In the case of an objective assigned to grazing, it may, for example, be a question of opening back up the area or controlling one or more species, in order to favour vegetation characteristic of the type of site, proposing grazing methods that are supposed to meet this objective. Appropriate measurements of the vegetation carried out before the start of the restoration (*baseline state*) and continued throughout the project at ad hoc periods and frequencies would make it possible to describe, in relation to the baseline state: (1) the dynamics of this restoration, and (2) the qualitative and quantitative changes and achievements obtained. However, this monitoring will not be able to indicate whether the path being followed is the right one for achieving or approaching the state of the environment before it was degraded.

2.1.4 Description of a restoration project

The restoration project and its scientific foundations, based on our current ecological knowledge of the site and available documentation (scientific literature, reports of various experiments), must also be described as precisely as possible (Gann et al. 2019 **106**, Prach et al. 2019 **229**, *Fig. 46*). The description of the project must describe in detail the resources deployed and the management methods proposed for the various restoration phases. It must specify

Aa* Term defined in the glossary section
Aa Refer to the reference section
Aa Refer to the following text

how these measures take account of local environmental conditions and their variability and integrate the landscape and its flows of organisms (transport and arrival of **propagules***). In the case of grazing, this process will involve specifying how grazing is expected to contribute to achieving the objectives and what risks its use entails. This may involve, for example, the occasional removal of plant cover, or the risks incurred by certain species due to trampling. The project must propose relevant monitoring protocols. When possible, a strategy should also be proposed for the long-term protection and maintenance of the site after restoration, a strategy often missing. Specifying it in the draft of the project reminds the stakeholders of its importance, and even its necessity, given the context, and therefore the need to find the necessary means for applying it.

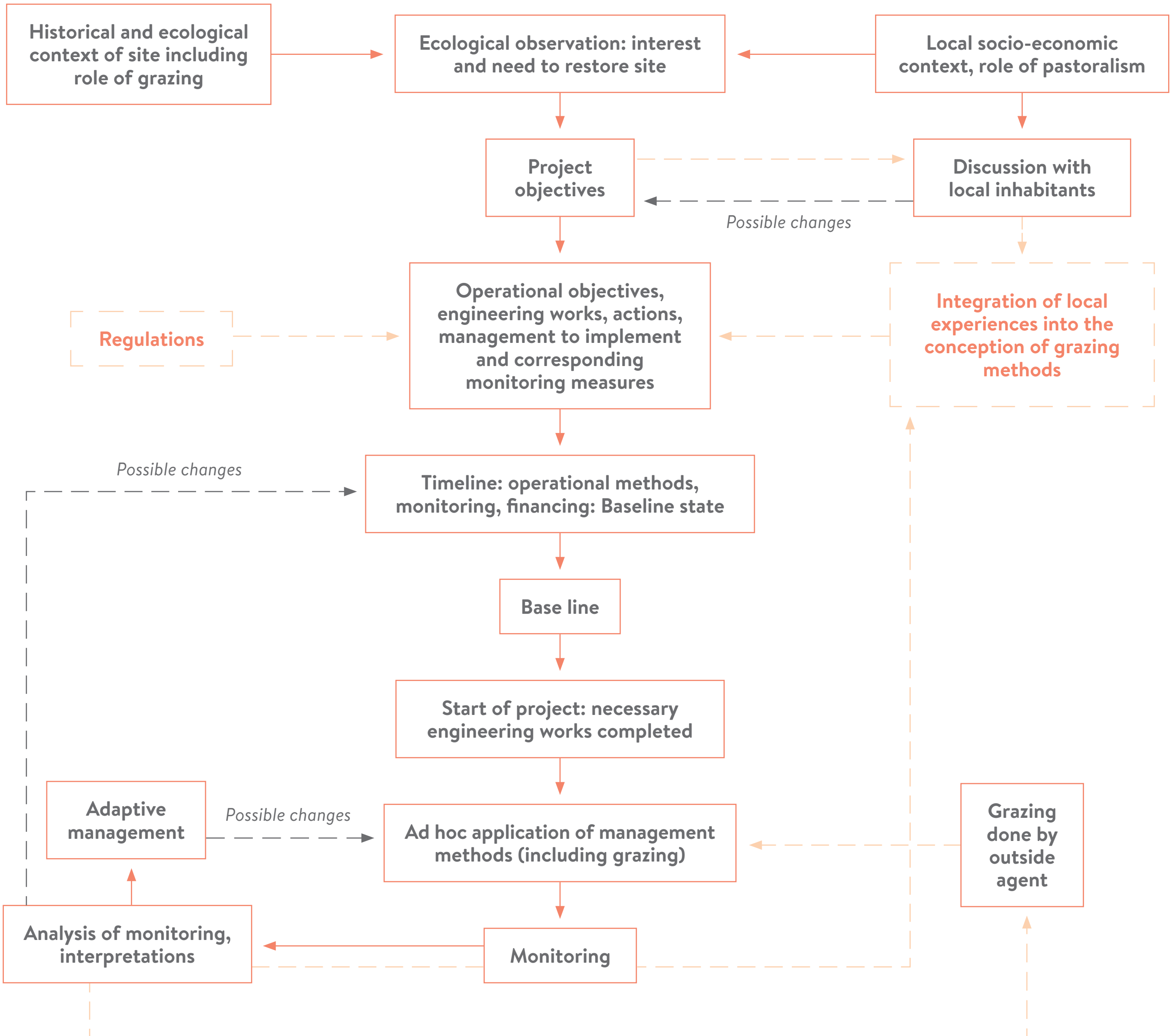

Figure 46: Theoretical development of a (global) restoration project

2.1.5 Calendar and budget

A PRECISE CALENDAR

A significant proportion of restoration projects fail or are abandoned due to the initial absence of a calendar or to unrealistic programming. A project cannot succeed without a precise calendar that specifies:

1. the duration of the various phases,
2. the preparation of the site,
3. the creation of favourable conditions (hydrological conditions in particular),
4. the management measures to be applied over time, up to and including those to be maintained after restoration,
5. the monitoring measures before, during, and after restoration.

A CALENDAR OPEN TO CHANGES

Ideally, the timeline should incorporate any changes, particularly in terms of management (adaptive management process), which could stem from the analysis of the monitoring conducted throughout the project.

A CALENDAR WITH A FINANCING PLAN

A restoration project must present a realistic financing plan, which takes into account all the phases defined in the calendar. In particular, it must cover the financial requirements for the initial work (potentially high engineering costs), the implementation of management measures (grazing, hydraulic management) and their long-term maintenance (if necessary). It must also ensure that funding is available for ongoing monitoring, i.e., if possible, after the restoration phase itself (or at least in the medium term).

2.1.6 Beyond the technical issues

AN OVERALL VIEW OF THE PROJECT

Restoration is generally not confined to strictly technical issues, but also includes socio-economic aspects that can have a decisive impact on the success of the project, or even on whether it can be implemented at all. Getting people involved beyond the managers and scientists is good idea, and often a necessity. As well as being vital to the success of the project, taking account of the socio-economic context helps to raise local awareness of the issues and challenges. It is also an opportunity to share and exchange experiences, which can prove particularly beneficial in refining the project, particularly in the case of domestic grazing, where local knowledge and practices can be used to describe or adjust the ways it is applied.

Developing an overall vision of a project and its implications enables the various possible options to be mapped out and the favourable or unfavourable moments or sequences for its

A successful cohabitation on the Tour du Valat estate © J. Jalbert

implementation to be identified. This may involve overcoming opposition by pinpointing the stakeholders who are hostile to the project or do not wish to see it implemented, or those who could benefit from or participate in it. Without fundamentally altering the spirit and aims of the project, taking account of the objections may help it to run smoothly and increase the interest/ benefits for the local inhabitants.

A restoration project must seek to connect with the present and, if possible, the cultural and social past of the site, but also with the past and present socio-economic and cultural realities of the local inhabitants and those potentially affected by the project. The reasonable integration of proposals made by local people into the project can be one of the keys to its success in the medium and long term.

Extensive pastoralism, which is often necessary for the conservation of wetlands, is a major activity in Mediterranean environments, but one that is in part a thing of the past (Perevolotsky & Seligman 1998 **219**) and often perceived as such. On a given site, it can hinder intensive pastoral activities or other agricultural ones that are more profitable and/or considered to be more modern. To be accepted and/or succeed in the context of restoration that involves the local population, it will therefore have to be geared towards a contemporary view of society, which is potentially different from what it was locally in the middle of the 20th century.

Aa Refer to the reference section

2.2 AN ECO-GRAZING PROJECT AS PART OF A RESTORATION PROJECT

2.2.1 Objectives of applying grazing

GAINS TARGETED

The objectives influence the grazing methods used and the changes that need to be made over time. The overall aim, with help from or based on grazing, is to re-establish a state close to the one before degradation, for which more or less relevant references are available. This may involve restoring one or more types of habitat/landscape simultaneously: open habitats and a mosaic of habitats *(§ 1.4.4)*. The expected gains and potential losses must be evaluated. A habitat that is considered degraded may nevertheless be a habitat for heritage species or species of interest that may be adversely affected by the presence of grazing. This habitat may also provide services that are threatened by the introduction of domestic herbivores (e.g., species dependent on **helophytes*** or woody plants).

At site level, the objectives are expressed by:

1. a spatial delimitation of a certain number of plant communities and/or habitats (patches) to be covered in vegetation or obtained,
2. a somewhat substantial list of the corresponding species to be favoured or, on the contrary, limited or even eliminated.

This list will determine the grazing methods to be applied (intensity, duration, and frequency). The choice may consist of applying grazing only outside particular periods of time (reproduction period for flora and/or wildlife), or over short or spaced-out periods *(§ 1.4, 2.2.3 Determining the pressure: flora and wildlife constraints)*.

PRIORITISING OBJECTIVES AND TRADE-OFFS

Prioritising objectives is necessary for both the design and the implementation of the project. In an eco-grazing project, the primary objective is conservation - increasing the conservation interest of the site and/or safeguarding threatened wild or domesticated species. A single project may have several conservation or non-conservation objectives, targeted jointly and ranked in order of importance *(§ 1.1.2)*.

The ranking must be reviewed when certain objectives are clearly unattainable and/or when conditions, whose variability has been poorly assessed, require management changes which make it impossible to pursue all the initial objectives simultaneously *(§ 1.1.2)*. The monitoring carried out during a project will confirm or infirm the validity of multi-objective management and whether it is adapted to local conditions. It reveals whether it is necessary to make changes to management and/or to give priority to certain objectives.

Aa* Term defined in the glossary section
Aa Refer to the following text

In any case, grazing requires that the conditions necessary for the well-being of domestic herbivores be ensured. **An eco-grazing project cannot ignore:**

1. the forage value of the area,
2. the quantity and quality of the food available,
3. what the planned grazing methods will involve in terms of animal handling.

The following questions need to be answered:

- How much of the feed requirements can the area covered by the project provide?
- What kind of handling can the people taking part in the project carry out themselves (technical skills, zootechnical knowledge)?
- With what resources?
- For what operations is the participation of a third party necessary?

2.2.2 The habitat and its constraints

The habitat type influences the development of the grazing plan (choice of grazers, possible breeds and grazing methods) through:

1. the structure of the vegetation,
2. the **palatability*** of the species,
3. the environmental conditions (height and duration of flooding and/or saturation of the soil, **bearing capacity*** of the soil).

All the factors likely to have a significant influence on this plan during the course of the project, all the internal threats and constraints (possibilities and limits of management based on water and grazing), which jeopardise the restoration of the site, as well as external pressures (presence of undesirable species in the vicinity, regulations, agricultural and landscape dynamics, pressure on land) should therefore be examined as scrupulously as possible during the design phase of the project, and taken into account according to their importance. **For that purpose, it is valuable to have the history of the site:**

1. the activities that have taken place there,
2. the pressures they have exerted on the habitat,
3. the reasons that have led to their modification or abandonment,
4. the consequences on the ecological interest of the site.

WATER: HUMIDITY AND FLOODING

A large proportion of domestic herbivores live outdoors all year round, where they are subject to various constraints depending on the season. These constraints need to be considered in herd management. Herbivores are more sensitive to humidity than to cold. Humidity weakens their bodies and facilitates the development of pathogens, increasing the risk of infection. However, there are significant differences between species and breeds in their response to humidity and the presence of water *(§ 1.5.2)*. Variations in the **bearing capacity*** of the soil are a potential nuisance for herbivores, but can also represent a threat to the plant cover. If the risks are significant, it is advisable, if possible, to choose a more suitable species (and breed): equine rather than bovine.

It is essential for the animals not to be kept permanently in flooded or soggy parts of the site. They need to be able to move freely to higher ground, if possible, other than just the edges of canals where they mark the boundaries of the grazing area (e.g., former crop fields).

The presence of considerable surface water and/or nearby canals may prove risky or incompatible during the breeding season, because they represent a risk of drowning for the livestock, particularly for the young whose mothers are inexperienced. The availability of high ground can therefore be an essential asset for ensuring accident-free breeding that respects animal welfare.

AVAILABILITY AND VARIABILITY OF THE QUANTITY AND QUALITY OF FOOD RESOURCES

Favouring the availability of food for domestic herbivores is not the primary objective of an eco-grazing project *(§ 1.1.2)*. However, before the animals arrive on the site it is imperative to be able to estimate the capacity of the site's vegetation to cover the herd's needs, both qualitatively and quantitatively, during the various phases of restoration. **The need to satisfy the food requirements of the herbivores influences:**

1. the spatial-temporal organisation of the grazing methods to be applied on the site,
2. the possible provision of supplementary fodder,
3. whether or not it is necessary to move some or all of the livestock off the site for periods of varying length.

Herbivore management must not only be adapted to the specific characteristics of the species and breed, but must also take account of age, needs during the growth period (young animals, maintenance animals) and sex (males, pregnant or **suckling*** females). Castrated males and non-breeding females have lower forage requirements.


Tour du Valat estate *© A. Granger*

Assessing the food supply on the basis of the available biomass provides an initial indication of the applicable pressure, but is not sufficient for establishing a grazing calendar *(Table. 2)*. Not all species are consumed, and it is necessary to determine which species are actually consumed within this biomass. The nutritional value of plants and how **appetizing*** they are varies throughout the year, depending on the phenological stage. The phenological stage and the relative abundance of plants thus determine plant consumption. Feeding behaviour for the same breed, which is partly the result of the animal's learning process, can therefore differ substantially. This learning process is particularly marked in goats: depending on the farm, the control of woody plants by goats depends to a greater or lesser extent on the quantity of herbaceous plants available, and varies from one goat family to another within the same herd.

AVAILABILITY OF WATER FOR LIVESTOCK

Water resources and access to them must be ensured by the presence of surface water or canals on the grazing land or plot or, failing that, by a regular water supply. The difficulty of providing this resource can influence the choice of herbivore. Sheep are more resistant to a lack of water than large domestic herbivores.

2.2.3 Livestock management

INTRA-ANNUAL AND ADAPTIVE MANAGEMENT: MODULATING GRAZING PRESSURE

The management objectives, their interrelationships, and the constraints they impose, all contribute to the complexity of pastoral management. The availability of food over time, the difficulties animals have in accessing the site (periods of flooding and drought vary from year to year) can temporarily affect grazing-based management by making it necessary to exclude animals. On the other hand, it may require an increase in the grazing pressure because the excessive availability of standing forage leads herbivores to be more selective and therefore less able to control species that are not very **appetizing***.

The difficulty lies in applying the management methods (period, duration, frequency) that correspond to the objectives in potentially changing conditions, and in being able to adjust them (adaptability) according to the presence or absence of water, climatic conditions, and the food supply at a given time, which fluctuate and vary for the same period from year to year.

In order to respond to this constraint as effectively as possible, it may be necessary to:

1. adjust the grazing pressure *(Table 2)*,
2. vary the length of time the herbivores are present and their numbers,
3. provide forage,
4. move them to refuge areas, which may be areas of standing forage, **feeding*** areas and/or ones dedicated to breeding during climatically unfavourable periods.

Particular conditions such as:

1. the presence of a significant amount of surface water, over all or part of the site, for a more or less substantial period of time,
2. floral or wildlife factors (reproduction period for example),
3. management requirements (**allotment***) may force the herbivores to move to other parts of the site, to another site, and/or to another breeder's site.

Depending on the predictability of events (flooding, intra-annual or exceptional drought) and the actions and movements they involve, sites or parts of sites other than those to be restored will have to be integrated as refuge (safety) zones. The grazing calendar will then have to include these areas as integral parts of the total grazing area required for pastoral management. They will only be an asset if there are no constraints (conservation issues) on these areas when the herbivores use them and on the grazing pressure during this period (guarantee of forage availability). If this is not the case, they will make the management more complex.

DETERMINING GRAZING PRESSURE: CONSTRAINTS LINKED TO FLORA AND WILDLIFE

Extensive grazing is characterised by low annual pressure, which can be distributed over a more or less substantial period of time, with potentially different results in terms of species control, depending on how **appetizing*** they are and their sensitivity to grazing *(§ 1.4.3)*.

In an eco-grazing project, the presence on the site of rare species or species of heritage interest conditions the way in which domestic grazing is applied, either because they are the objective of the project, or because there can be no question of these species being endangered or simply disadvantaged by the presence of domestic herbivores. Grazing may have a temporary impact on individuals or the dynamics of these species, through consumption or trampling, but in the long term, the presence or introduction of animals should be beneficial to the target species because of how they control the vegetation dynamics. When rare species or species of heritage interest are present on a site, whether or not they are the target of restoration, it is imperative to assess the possible impact of the presence of domestic herbivores on these species and to choose the grazing methods by estimating the short-, medium-, and long-term benefits and risks *(Fig. 48)*.

The instantaneous pressure applied to a site depends on the species, breed, age, and weight of the individual.

The Livestock Unit (LU) is used to quantify the daily pressure applied by the domestic herbivores present on the site, based on the nutritional or food requirements of each species, taking into account their weight and age.

The value attributed to 1 LU varies according to the authors. Generally speaking, 1 LU corresponds to an **adult bovine** weighing 450 kg for which the daily requirements, given its weight, are estimated to be around 12 kg of dry matter. By calculating the number of LUs in a herd, it is therefore possible to estimate the dry matter required per day to meet its needs.

Quantity of forage required per day (in kg dm. ha-1. D-1) = Number of LU x 12

At equivalent weight, the needs of an adult **equine** are estimated to be **1.2 to 1.5** times those of an adult bovine. Given its average weight, the needs of an adult **sheep** are estimated to be **0.15** LU.

The feed required in kg per day for each domestic herbivore, taking into account species and weight, can therefore be estimated using the following formulae:

- **Cattle:** Dry matter required (kg) = No. of livestock units x 12 kg
- **Equine:** Dry matter requirement (kg) = No. of livestock units x 15 kg
- **Sheep:** Dry matter requirement (kg) = No. of animals X 1.8 kg

Modulation according to age

The pressure applied and therefore the requirements also depend on the age of the herbivore, so they must be corrected if young animals are present.

Similarly, the needs of a **suckled*** cow can be corrected by adding the needs of a young individual to those of a non-suckled* cow.

Age *(months)*	Adult equivalent *equine, cattle*	Adult equivalent *sheep*
0-2	0	0
2-6	0	0,5
6-12	0,4	0,8
12-24	0,6	
24-36	0,8	

Adult equivalent according to age

Modulation according to breed

The LU equivalent and therefore the daily dry biomass requirements of a domestic herbivore according to breed are estimated by taking into account the respective average weights of the breeds and species and their equivalence in LUs (there is a correction by a factor of 0.6 and 0.8 for Camargue cattle and horses, which are two relatively light breeds for the species).

Table 2: Estimation of grazing pressure and forage biomass requirements

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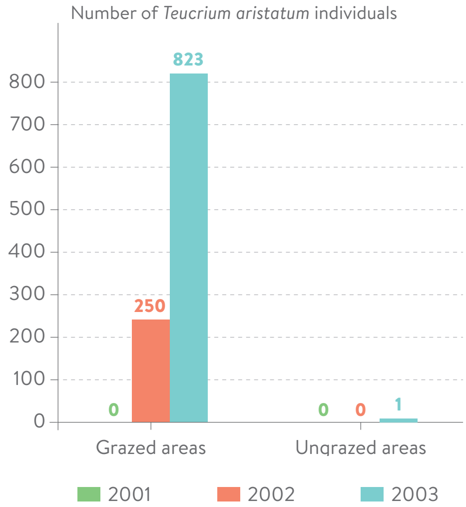

Figure 48: Dependence of Germandrée aristée (*Teucrium aristatum*) in the Lanau pond in Crau, the only refuge for the species in France. Protection of the pasture by a fence led to the disappearance of this species. The reintroduction of grazing in part of the pond led to the restoration of the population in three years.

A choice can be difficult to make, and often results in a compromise. This is particularly true when herbivores threaten the physical integrity of plants or animals and/or their reproduction (disturbance, trampling) but, by opening up the habitat, they also create a habitat that is favourable to them. Grazing can then be organised so that its presence, outside key periods of time, favours the habitat of the species to be protected, by controlling more competitive species, and so that its exclusion during these same key periods will reduce the threats to their populations *(Fig. 49, 50)*.

Concerning the grazing period, two strategies are possible and the choice of one or the other depends on the type of impact sought and the cost-benefit ratio of grazing at critical periods for the species to be protected.

1. **No specific period when grazing is excluded because these species are present.**

   Grazing at a set period is likely to damage the reproduction or survival of some individuals of the species to be protected, but through its various actions, such as opening up the habitat, the overall benefit/damage ratio is positive for the populations of these species.

Figure 49: European Pond Turtle whose shell has been severely deformed by trampling. © A. Olivier

2. **Modification of the grazing period due to the presence of these species.**

   The presence of grazing during the planned period is deemed incompatible with the needs of the species to be protected or at risk (high mortality, threat to reproduction). In this case, the grazing period is limited to the periods that are least problematic for these species.

It may seem reasonable, for safety's sake, to choose grazing methods in which individuals of the species to be protected will not be directly impacted by the grazing. However, if these species are not competitive enough with other species (plants) and/or are strictly dependent on open habitats (plants and animals), they may disappear, whereas a certain level of survival and therefore reproduction of the population would have been ensured by the presence of grazing, even though it is potentially destructive for individuals.

Figure 50: An open reed bed that is favourable to the European Pond Turtle that was created by grazing (*Emys orbcularis*). © A. Olivier
A reduction in the intensity of grazing during the autumn and winter greatly reduces the risk of trampling, which has an impact on the survival of the species, without having any significant impact on the structure of the reed bed which is beneficial to the European Pond Turtle (Ficheux et al. 2014 **99**).

DETERMINING GRAZING METHODS THAT SATISFY RESTORATION OBJECTIVES

The consumption of plants by domestic herbivores varies according to the spatial and other constraints to which they are subject.

Rotational grazing (with high instantaneous pressure)

Directed, rotational grazing, which requires the animals to cope with a restricted area and a limited food supply, leads them to become less selective and therefore to increase their control of species that are not very appetizing. It can even, through a mechanical effect, enable the control of **unpalatable*** species *(§ 1.4.2)*. While effectiveness depends to a large extent on the intensity of the instantaneous grazing pressure applied, and therefore on the constraints placed on the animals, it is necessarily the result of a compromise between effectiveness and the food requirements of the herbivores. It also depends on the phenological stage of the plants. Young leaves, shoots, and buds may be browsed, and shrubs destroyed by animal rubbing or trampling, but in most cases, it will be unrealistic to hope for the eradication of adult plants or **stands***, unless pressure is applied that is difficult to sustain.

In the case of woody plants, when colonisation reaches an irreversible stage, grazing, even when used in the form of high instantaneous pressure, cannot be the only means of management, and mechanical processes, which have a significant impact on the habitat, must necessarily be used. However, regular, controlled grazing will make a significant contribution to limiting recolonisation by extending the period between two mechanical interventions, thereby limiting the use of fossil fuels.

- **Toxicity risks**

The toxicity of certain plants may not pose any problem as long as domestic herbivores are relatively unconstrained spatially but may prove problematic (or even fatal) if food choices are severely restricted. Before applying high instantaneous pressure, it is therefore essential to ensure the absence of any potentially toxic plants.

- **Fixed-period rotational grazing as a management method**

Rotational grazing, at relatively low pressure, is also a means of year-round management based on the possibility of moving animals at a chosen time and for a chosen period. The rotation periods can remain fixed from year to year, determined by the restoration objectives, the requirements of remarkable species present in the area, and predictable seasonal forage availability. Rotational grazing at fixed periods means that the pressure applied can be chosen and therefore assumed to correspond to ‘average’ conditions. The fact that the period and the pressure are adapted to average conditions is nevertheless the main weakness of this management method: it is unsuitable for very low or very high forage conditions. Depending on the conditions of the year, predetermined grazing pressure, calculated for average conditions, will turn out to be too high or too low.

This dilemma often leads to opting for low fixed grazing pressure, which is likely to ensure sufficient forage availability most years. In the context of rotational grazing, this is rarely a wise choice. It is equivalent to negating the specific nature of rotational grazing (reducing the feeding selectivity of herbivores). In most years (except for the ones most unfavourable for fodder production), grazing will not be able to meet the objectives in terms of vegetation control, and chronic **undergrazing*** can lead to a structuring of the vegetation that is difficult to reverse *(§ 1.4.2)*.

- **Rotational grazing at variable periods**

Whenever possible, this type of grazing is the most effective within restoration to meet the various objectives assigned to grazing. In theory, it avoids both over- and **undergrazing***. It requires the state of the vegetation and the herd, as well as the forage provided, to be assessed continuously or at least at crucial periods, to decide when grazing should be temporarily started and stopped. This means being able to introduce and remove animals (in whole or in part) at the right time. This requirement can be difficult to meet when domestic herbivores are managed or owned by a third party, or when the site manager has neither the means nor the expertise to carry out proper management alone, including moving the herd.

Continuous grazing or grazing over a long period (with low instantaneous grazing pressure)

This method involves keeping animals on the site for all or part of the year. In theory less restrictive, it is often appropriate when the aim is to maintain open habitats, with the herbivores playing a role in maintaining the community. As instantaneous pressure is low, this type of grazing is likely to create heterogeneity *(§ 1.2.1, 1.2.2)* due to the low level of pressure exerted on the herbivores. It is therefore advantageous when this objective is sought. However, the behaviour of the animals and their choice of food often leads to a differentiated use of the site, with some areas being highly frequented and others largely abandoned, with the corollary development of unpalatable vegetation, **nitrophilous*** species and woody vegetation, which are signs of both **overgrazing*** and **undergrazing***. Most often this type of management requires long-term adjustments, which must be implemented to avoid situations that are difficult to reverse.

The sensitivity of certain species to herbivory, insofar as the reasons that explain their reduction, or, on the contrary, their appearance or development, are identifiable, gives these species the status of *indicators* of habitat conditions and/or grazing pressure that are problematic for achieving the management objectives. Many species can play this role, but for the most part, their development reflects the existence of an already degraded habitat that will be difficult to put back on a satisfactory trajectory. By focusing on the dynamics of these species, monitoring should alert us to any undesirable trajectory as soon as it becomes apparent.

Figure 51: The cattle on Tour du Valat's Natural Regional Reserve. *© H. Hôte*
Male cattle are effective for managing a habitat area because they can be more constrained than pregnant or **suckling*** cows. However, the danger they represent must be considered.

LIVESTOCK MANAGEMENT

If you want to set up an eco-grazing project and manage the herd yourself, it is essential to have a minimum amount of zootechnical knowledge *(Tables 3, 4)* concerning:

- the nutritional requirements of the chosen herbivores and their feeding behaviour;
- their reproduction and the care they require;
- their behaviour and social needs;
- the resulting care required, how it is carried out, and the means for providing it;
- **prophylaxis***, whether compulsory or optional, and its possible consequences on the habitat area.

Assessing an animal's health

Knowing how to assess an animal's overall condition enables us to judge whether the food supply is sufficient and can provide an early warning of health problems. This knowledge is invaluable for adaptive management. Under ideal conditions, weighing at regular intervals or at specific times during the grazing calendar enables the health and development of individuals within the herd to be monitored accurately. You need to be able to assign a body index and estimate an animal's condition by its appearance or behaviour, which requires experience. It may be a good idea to ask professionals, if possible local ones, to get input from them.

BEHAVIOURAL CHARACTERISTICS	RESTRAINT	PROPHYLAXIS
Equines		
Strong social needs and behaviour Can penetrate high, dense vegetation Relatively non-destructive hooves in wet environments	Respect fences Squeeze chute required for young animals Handling potentially complex and risky	Prophylaxis mandatory but relatively limited Trimming hooves potentially necessary Sensitive to haematophagous insects
Cattle		
Need regular handling Can penetrate high, dense vegetation Destructive hooves for wet environments Can destroy woody plants mechanically Aggressive (males, heifers)	Solid fences required High quality squeeze chute needed, Handling is complex and dangerous according to the breed	Prophylaxis mandatory
Sheep		
Behaviour adapted to small areas Fearful and vulnerable to stray dogs Not adapted to flooded habitats	Easy to use mobile fencing, permanent fencing is expensive Daily movements required due to foraging habits Particularly vulnerable to predators, need to be guarded accordingly (night paddock, guard dog) Squeeze chute necessary Handling not very risky	Strict health monitoring (prone to epidemics, sensitive to humidity) Complex prophylaxis Daily surveillance required
Goats		
Behaviour in rangeland use and composition of herbaceous/woody plants in diet are complex and potentially different between individuals (families) Can penetrate closed habitats (bushes) and consume woody plants Not adapted to flooded habitats	Daily surveillance required Not very vulnerable to predators Handling not very risky	Prophylaxis mandatory

Table 3: Behavioural characteristics, restraint and **prophylaxis*** of horses, cattle, sheep, and goats

Tour du Valat estate. © H. Hôte

Manage grazing or entrust it to a third party

The site's assets, particular features, and constraints are all factors which, after having influenced the choice of herbivore, will determine the grazing calendar for the entire site and the seasonal distribution of the animals over the different vegetation units throughout the year. In this respect, local livestock farmers should be called upon to share their invaluable experience and knowledge of feeding behaviour, the forage value of plants or, on the contrary, their toxicity.

Given the complexity of the operations to be conducted, the zootechnical knowledge and technical skills required, the choice may be made to entrust pastoral management to a third party via grazing contracts or agreements. In addition to lightening the manager's workload in terms of the zootechnical management of the animals, this approach is also a way of integrating the site and its activities into the local social environment. However, this partnership is not without its constraints. It often involves a compromise in the grazing arrangements, in terms of the number of animals available for grazing and above all the grazing periods, between those desired and those achievable by the farmer. This point must be discussed and fully clarified before any agreement is made.

To meet the ecological objectives, it is essential for the animals to be present, but also absent, at key periods of time. These periods are likely to be adjusted from year to year according to fluctuations in climatic conditions and the results of monitoring the vegetation and/or the animals. Livestock farmers therefore need to be able to tailor their overall grazing calendars, and not only on the site, to not simply consider the site as providing additional forage, as a kind of adjustment variable that can be used when the resources on their own farms are insufficient for their herd. On the contrary, they must consider the site as part of the whole range of habitats to be used by their herds and include it in their grazing calendars. If the compromise is not satisfactory, particularly as regards grazing periods, the transfer of pastoral management should not be done, as the vegetation objectives (priority objectives) cannot be achieved. If, for various reasons, the decision to delegate pastoral management to this third party is nevertheless taken, the entire project, in particular the vegetation and/or habitat objectives, will have to be revised in light of the constraints imposed on the availability of animals.

MALE	Aggressive behaviour towards fellow animals and towards humans: potentially problematic if open to the public. **Cattle:** More effective at opening up the habitat than cows because they can be more constrained (with high instantaneous grazing pressure applied the mechanical effects of their hooves is more effective). Need for specific fencing depending on breed. Not necessary to be part of the herd even if breeding is the aim (temporary introduction). **Equine:** Rarely used, to be avoided.
CASTRATED ANIMAL	To make an animal placid and easy to be handled. Can be more constrained than a female (potentially greater exploitation of the habitat). Prophylaxis less complex than for a female. **Cattle:** No breeding (advantage: no breeding management, disadvantage: no future product to sell). Better quality beef product. **Equine:** Widely used for their behaviour and impact.
FEMALE	Less aggressive than the male. **Cattle:** Aggressiveness depending on age, experience, and breed. Depending on the management of breeding, the need to use lots, which can make it complex to manage the space.

Table 4: Specific features of castrated female and male herbivores

2.3 MONITORING AND ASSESSMENT

All restoration projects must include monitoring. It enables qualitative and quantitative measurements to be made of the differences between the baseline state, the reference state, and the current state of the ecosystem (or communities concerned) at different stages of the restoration. Monitoring, if possible before, during, and after the restoration of a site or part of a site, is therefore essential in any restoration project, without which the restoration cannot be evaluated, completed, or modified on the basis of objective criteria.

Each ecological restoration project is also a 'full-scale' experiment, likely to contribute, through the production of data, to research (restoration ecology: feedback testing (Bradshaw 1987 **40**, *§ 1.6*)) and to other restoration projects.

2.3.1 Monitoring strategies and methods

Monitoring of ongoing restoration, with analysis of its successes and failures, is generally carried out first on the vegetation (Ruiz-Jaen & Mitchell 2005 **244**, Shackelford et al. 2021 **252**, *§ 1.6.1*).

Community or habitat monitoring is the most direct way of measuring the impact of restoration activities, even if the aim is to restore/conserve particular plant or animal species. The impact of restoration measures on these species depends on those on the habitat.

Of the criteria, referred to as attributes by the Society for Ecological Restoration, SER (Gann et al. 2019 **106**, *cf. Box*) to assess the success of a restoration project, the first three can be used to characterise the effects of the grazing methods applied to the habitat. Depending on the grazing pressures applied, their duration and period, plant communities develop with different structures, particularly in terms of the contribution of the main structuring species.

In addition to considering the relative contribution of the species, the assessment must also examine their local character, the relevance of their presence, and therefore the proximity of the communities to those of the reference model. Particular attention may be paid to the contribution of plants that share certain characteristics (**functional groups***) likely to perform specific functions (prevent colonisation by undesirable species, production, forage interest).

The development of pastorally interesting species that are not local or Mediterranean can be sought as long as the hierarchy of objectives is respected, and the dynamics of these species is contained so that they do not jeopardise the presence of species and/or the target habitat.

Grazing is only one element of the six other attributes proposed by the SER. Abiotic conditions, the availability of target species **propagules*** in the immediate vicinity or nearby, and the structure of the surrounding landscape play predominant roles.

MONITORING

Observations and monitoring

Observations (such as inventories) are carried out 'by eye' and rely heavily on the skills of the observer. Most of the time, they can only take account of clearly visible changes (surveillance).

Monitoring is based on the use of tools that are more or less elaborate but which, in part, counterbalance the observer effect and can be repeated in exactly the same way. The data collected can be used for statistical purposes.

Monitoring is the uniform collection of data in accordance with a pre-established protocol designed to answer one or more questions. The relevance of monitoring is therefore defined by its capacity to answer the questions that led to it being implemented, but also by the complexity of executing it, and the possibility of continuing it in the same way throughout and beyond the project. This constraint means that monitoring cannot claim to answer an infinite number of questions but will necessarily be constrained by medium- and long-term possibilities.

The capacity to answer the questions at stake remains the first filter for selecting a monitoring protocol. Its feasibility in the field comes next. If feasibility is in doubt (the protocol is deemed too cumbersome, or difficult to maintain over time), a new protocol will have to be drawn up. This new protocol will have to pass through the same two filters (capacity to answer the questions and long-term feasibility).

The observer effect

The use of similar tools and methods, irrespective of the observer, counterbalances the role played by personal skills but does not eliminate it. This difference between observers must be considered and, if possible, estimated if different people are involved in the same monitoring. The aim is to be able to assess whether differences in the data collected are indeed the expression of real differences in the field, or in part the result of different degrees of expertise. The existence of a difference between observers is a frequent cause of interpretation error, particularly when the variations are slight and possibly inferior to the precision of the data collected.

FROM REFERENCE ECOSYSTEM TO EXCLOSURE

Monitoring depends on the observation site: there is no universal monitoring system that provides satisfactory answers to questions that are partly determined by the local context. Knowledge of the site, of the issues at stake, and its specific features, which enable the right questions to be asked and the right variables to be considered, is a fundamental prerequisite for the development of relevant monitoring.

Ideally, the first measurements should be taken before any restoration operations. They constitute the baseline state for future monitoring. This first field campaign, before the restoration measures are put in place, is also a test of whether the protocols can be applied, based on which readjustments can be made if necessary. If adjustments are made, a new baseline state will have to be established to assess whether the new measurement protocol can be applied and to enable comparisons to be made with the measurements that will be taken during and after the restoration project (identical protocols). The monitoring protocol(s) must therefore be established before the very first restoration operations, which may include preparatory engineering work, implementation of the new hydraulic management, and the introduction of new grazing methods. They are contingent on the existence and quality of reference data, or the absence of a positive reference *(§ 1.6.2)*.

Monitoring with no positive reference or control

On protected sites, where the environmental stakes are high, it may be considered inappropriate to exclude part of the site from restoration and from the introduction of new management. This exclusion may not be possible because there is no differentiation by hydraulic compartment or no partitioning of the site into different grazing paddocks. Management changes may have begun without it having been possible to carry out measurements characterising the initial or baseline state.

The absence of a reference **ecosystem*** and a baseline state are constraints that restrict restoration assessment criteria, but in no way make restoration completely irrelevant. It is no longer a question of comparing the vegetation of the degraded site (control) and/or what can be observed on the reference site(s) with that undergoing restoration and then restored (all the plant communities concerned), but of measuring the evolution of the different communities over time (trajectories) and assessing how, according to what criteria (meeting the objectives) this evolution corresponds to gains.

1. The restored ecosystem contains a characteristic assemblage of species found in the reference ecosystem which produces an appropriate community structure.
2. The restored ecosystem contains mainly native species.
3. All the functional groups* necessary for the continued evolution and/or stability of the restored ecosystem are represented or, if they are not, the missing groups have the capacity to colonise it naturally.
4. The physical environment of the restored ecosystem is capable of maintaining the reproductive populations of species necessary for its stability or continuing evolution along the desired trajectory.
5. The restored ecosystem appears to be functioning normally during its ecological development phase and there are no signs of dysfunction.
6. The restored ecosystem is appropriately integrated into a wider ecological matrix or landscape, with which it interacts through biotic and abiotic flows and exchanges.
7. Potential threats from the surrounding landscape to the health and integrity of the restored ecosystem have been eliminated or reduced as much as possible.
8. The restored ecosystem can maintain its integrity because it is sufficiently resilient to cope with normal periodic stress events in the local environment.
9. The restored ecosystem is maintained in the same condition as its reference ecosystem and has the capacity to persist under existing environmental conditions. Nevertheless, aspects of its biodiversity, structure and functioning may change in line with the normal evolution of an ecosystem and may fluctuate in response to normal periodic stress events or occasional disturbances.

Success criteria according to the Society for Ecological Restoration (SER 2004 92)

Exclosures

In general, exclosures are invaluable, especially when no reference is available. Depending on the context (surface area involved, type of domestic herbivore), it may not always be desirable or possible to set them up and, even less, to maintain them over time.

By making it possible to compare grazed and ungrazed areas, an exclosure helps to answer various questions relating to the structure of the vegetation and to characterise the ongoing processes (particularly biotic ones), including herbivory *(Fig. 52)*.

Figure 52: Exclosure in the Gediz Delta (Turkey). *© F. Mesléard*

The questions that it can help to answer must therefore be stated before it is constructed, as they will influence its design. The mechanisms at play and the nature of the herbivores involved (domestic but also wild if appropriate) will define the structure, the fencing material used (barbed wire, fine mesh), its size and location(s), and whether it can be replicated. It must be designed to last, since its role is to bear witness over time.

Replicating exclosures

Replication is essential for statistical analysis. The simultaneous installation of several exclosures, if possible under comparable but sufficiently distant conditions (chosen or, on the contrary, randomly distributed), will make it possible to counterbalance the importance given to isolated phenomena *(Fig. 53)*.

© F. Mesléard

Figure 53:
Effect of exclosure location on the dynamics observed *(cf. Fig. 1)*.

While the exclosures installed on the grasslands of the Tour du Valat Estate are relevant for highlighting the importance of wild herbivory in controlling Phillyrea, their capacity to characterise the actual speed of the phenomenon is questionable.
P. angustifolia is an **ornithochorous*** species whose establishment has been facilitated by the presence of exclosures. Their posts are the few perches available on the grasslands, and have therefore been greatly used by Passerines, which spread seeds via their droppings. The location of the exclosures close to a rabbit warren favoured predation by the rodent, which was greater than it would have been at more distance from this warren. It would have been possible to limit these two effects by increasing the size of the exclosures. The provision of seeds by Passerines would then have been lower in the centre of the plots and probably close to what it is without the 'perch' effect. The installation of exclosures at locations far from the warren would also have reduced the 'warren' effect for these remote exclosures, making it possible to characterise it (by comparing it with the exclosure close to the warren).

VEGETATION MONITORING

Numerous methods for monitoring vegetation have been developed. One of the most common relies on two techniques, known as **transects** and **quadrats**, which are used alone or in combination. They can be used to varying degrees of complexity and can complement each other, each having advantages and disadvantages depending on the context and the questions being asked. When used correctly and in the right situations, they counterbalance the observer effect, but do not eliminate it.

Point reading or sampling involves surveying the vegetation at a series of points (generally 33, 50, or 100) that are evenly distributed and generally along transects *(Fig. 54)*.

The interval, which corresponds to the distance between each point, depends on the distribution and structure of the vegetation. It will be shorter when dense vegetation contains most of the community's species in a restricted area.

For example, transect sampling in Mediterranean grasslands is generally conducted using an interval of a few centimetres, whereas it can be over 1 metre when the vegetation is sparse, with bare ground occupying a large area (e.g., a community dominated by Salicornia growing in floodable saline soil).

Point quadrat readings are carried out by considering areas contained within squares, which can be divided into sub-quadrats *(Fig. 54)*.

To meet statistical requirements, both quadrats and transects must be distributed systematically or randomly. The quadrats themselves can be distributed along transects. To characterise specific, localised dynamics within the vegetation, all or some can be placed in areas that are characteristic of these dynamics (depending on the objective of the study).

MEASUREMENTS AND CALCULATIONS

Simple measurements and calculations using transect line point sampling
(Daget al. 2010 **69**).

- **Presence point**

For each measurement point determined by the interval, the *presence point* consists of counting the species in contact with the sampling rod (a single presence point per species at each interval point). The presence point corresponds to a flat projection of the vegetation.

- **Point-contact**

The *point-contact* means counting, for each point along the transect line and for each species touching the sampling rod the number of times that species is in contact with it (1 or more points of contact per individual of the species at each point on the transect line). The point-contact corresponds to a three-dimensional projection of the vegetation (biovolume). Compared with the presence point, it is better for taking account of the importance and biomass of the different species.

- **The relative contribution (presence/contact) of a species or contribution to vegetation cover** *(specifies presence/contact contribution)*

It is calculated by dividing the number of points (presence or contact) where this species is recorded by the total sum of points recorded for all species:

$$CSp = \frac{\sum \textit{presence points species}}{\sum \textit{presence points n species}} \qquad CSc = \frac{\sum \textit{point-contacts species}}{\sum \textit{point-contacts n species}}$$

Vegetation cover (frequency) is thus equal to the Σ points with species / no. of measurements.

- **Contribution of a species to total cover**

It is calculated by multiplying the vegetation cover by the relative contribution of the species:

Rec Sp = RecTot x CSp

This contribution is equivalent to the plant cover (frequency of a species) calculated by dividing the number of points where the species is recorded by the total number of measurements (33, 50, 100).

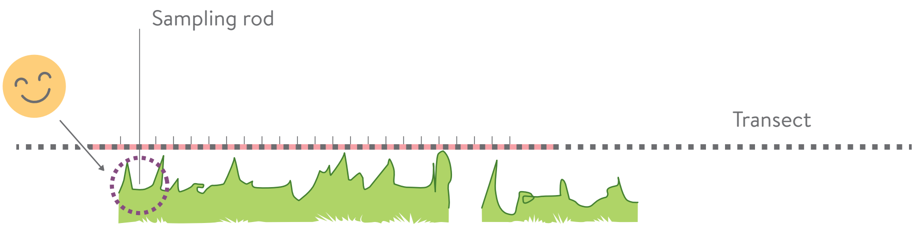

Figure 54: Point readings along a transect. Point readings are taken using a fine sampling rod (the point of contact between the sampling rod and the vegetation theoretically having no surface area) at regular intervals along a transect whose length is defined by the number of points and the interval length (number of points x distance between two points).

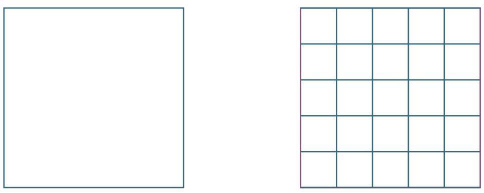

Figure 55: Quadrat and quadrat divided into subquadrats.

Total cover includes bare soil. The contribution of one species to total cover is therefore less than or equal to its contribution to (relative) cover, depending on whether or not bare soil is present.

The pastoral value of vegetation

Many species are assigned a pastoral value (PV) ranging from 0 to 5 (or 0 to 10). The contribution of each forage species to the total cover can therefore be used to make a rapid estimate of its pastoral value, without the need for any additional operations (cutting, drying, sorting of forage species or measurement of their biomass).

The overall pastoral value of the plot is obtained by multiplying the PV attributed to each species by its cover, then totaling the PVs obtained for all the species and relating this figure to the number of sampling points (no. of points along the transect line).

$$\text{Vegetation PV} = \frac{\sum_{i=n} RecSpi \times Vpi}{n}$$

where n = number of sampling points along the transect line

The pastoral value of the vegetation varies from 0 to 5 or 10. The maximum value of a patch is reached if one or more species of maximum pastoral quality contribute 100% of the cover: for example, if the Poaceae (*Dactylis glomerata*) with a PV of 5 occupies the entire cover.

The capacity of this value to accurately reflect the forage interest of a site is debatable; nevertheless, it is useful for comparing the pastoral interest of different communities, patches, and plots.

Simple measurements and calculations using quadrats

Unlike transects, quadrats have a surface area. They are therefore particularly well-suited for recording all the species present. They are also a quick way of assessing vegetation cover when the species that make it up are (mostly) distributed in patches *(Fig. 57)*. Quadrats can also be used to assess stem density (e.g., in reed beds or stands of Sea Club-rush). They are generally quicker to set up than transects and are often better suited to flooded habitats.

However, estimating species cover using quadrats is more of an estimate than a real measurement. It is largely dependent on the observers and their interpretations. This estimate can be complex and subject to error according to the structure of the plant communities.

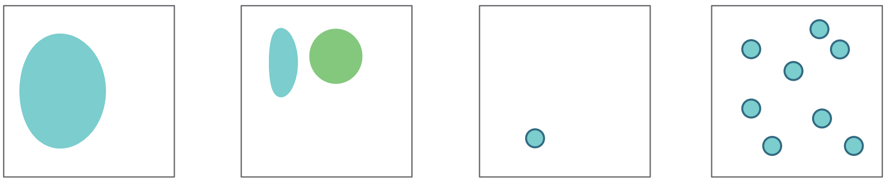

Figure 57: Increasing difficulty in estimating cover from quadrats in function of the surface area occupied by individuals or patches of vegetation, and their distribution within the quadrat.
Inaccuracy increases according to the type of species (clonal or non-clonal, especially if they are distributed in patches of vegetation) as the surface area occupied by individuals of these species diminishes. When the individuals occupy small areas but are distributed over the whole quadrat, their contribution to cover becomes difficult to estimate.

In order to reduce estimation errors or observer bias, the estimate can be made by classes of plant cover (*e.g., I =<1%; II=1<5% ; III=5<25 ; IV=;25<50 V = >50%*). However, this operation leads to a loss of information and precision. To avoid this loss of information, it would be preferable for the transformation of the percentage into a cover class to be carried out retrospectively and not at the time of sampling in the field (initial percentage data remain available if necessary).

Dividing the quadrat into subquadrats *(Fig. 57)* makes it easier to estimate cover visually. The cover of each species in the quadrat can then be calculated by summing the percentage of cover in each subquadrat. It can also be calculated by totaling the number of subquadrats in which a species is present, independently of the surface area it occupies in each subquadrat. The cover of a species recorded in 16 of the 64 subdivisions of the quadrat is thus considered to be 25%.

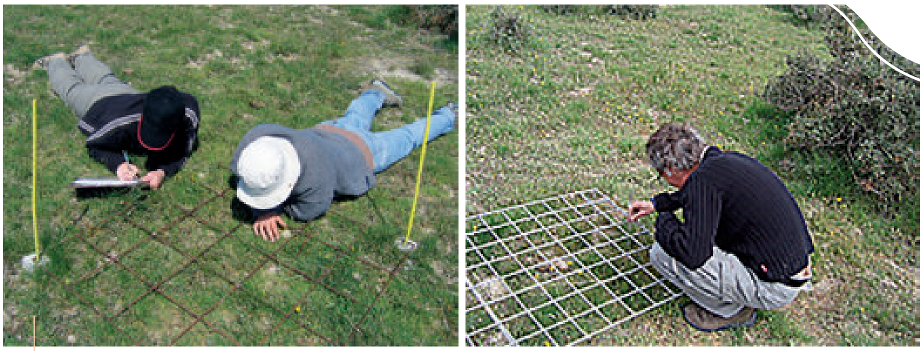

Figure 58: Dividing the quadrats into subquadrats reduces the observer effect considerably.
© Tour du Valat

However, the validity of this estimate remains largely dependent on the distribution of the species *(Fig. 58)*. The estimate is even more valid when the species occupies more area (as in the case of clonal species).

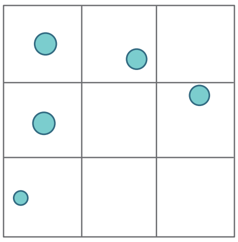

Figure 58B: Bias in estimating the percentage cover of a species when only its presence or absence per subquadrat is considered.
Here, the species cover is estimated at 66% of the total cover, whereas it is less than 10%. This bias is caused by equating species cover with species frequency. The lower the species cover, the less the frequency is a good **proxy*** for cover.

CHOICE OF PROTOCOL AND ADAPTATIONS

The protocol is influenced by:

- **the surface areas involved:** if they are too large to be considered in their entirety, a choice may be made to give priority to certain parts of the site or plot.
- **the characteristics of the habitat**, in particular the hydrological conditions (dry, floodable, flooded) and their consequences on plant distribution.
  In a pond, for example, it might be decided to focus on the edges and the centre of the pond where ecological conditions contrast, or to focus on the distribution of vegetation in a belt in order to assess the impact of the gradual drying out on this distribution.
- **the distribution of vegetation:** the presence of patches of the same species or, on the contrary, a mixture of species.
- **the phenology* of the species:** importance of species with a short life cycle. The presence of species with a short life cycle may require measurements to be repeated during the growing season.

When should quadrats be used?

When the aim is to count all the species. Quadrats can be used spatially; therefore, they are useful for:

1. determining the species richness of the site per unit area;
2. measuring density (number of stems);
3. mapping species distribution;
4. when the target species are poorly represented or small in size.

When should line transects be used?

The line transect method, which depends less on the observer, is particularly suitable for accurately estimating the cover (abundance) of the main species. However, this method underestimates species that are poorly represented.

SAMPLING

A small number of samples can compromise statistical analyses; the greater the number of samples, the more closely the results reflect the reality in the field. The choice of sampling is usually a compromise between the need to characterise the vegetation accurately and the time available for monitoring.

Ultimately, however, characterisation must be the priority. Monitoring that reflects reality imperfectly or poorly can lead to false interpretations *(Fig. 59)*.

Random sampling

Random sampling is the most rigorous, but it requires a relatively large number of samples to counterbalance spatial heterogeneity *(Fig. 60)*. It is better to have more quadrats than large ones.

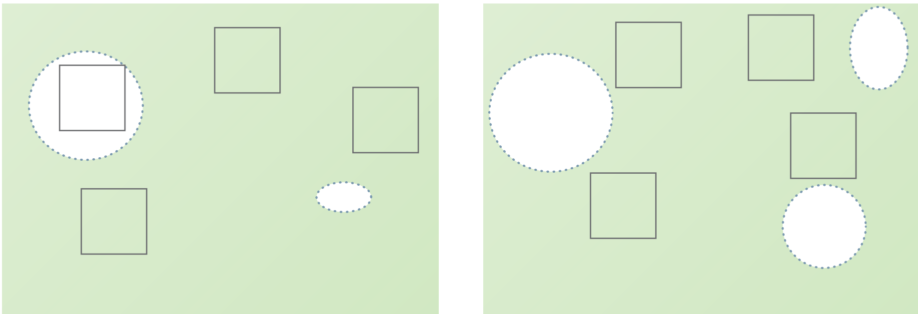

Figure 59: Random sampling using four quadrats in a reedbed with three patches of bare soil representing approximately 5% of the cover in year n (left) and approximately 15% in year n+1 after the introduction of domestic grazing (right).
Sampling using randomly placed quadrats leads to an estimate of 75% reed cover in year n, and 100% in year n+1, and therefore to the conclusion that reed bed cover increased by 25% in a single year in the presence of grazing, whereas it decreased by about 10%. In this example, in which the quadrats were not fixed but redistributed every year, the quality of the measurements could have been greatly improved without increasing the area sampled. Using smaller but more numerous quadrats would have minimised the risks linked to random sampling.

Systematic sampling

It can be considered as random sampling in that the starting point for systematic sampling is decided randomly and covers a relatively large part of the area to be sampled *(Fig. 60)*. Its superiority over random sampling has been demonstrated for assessing the population sizes of species (Perret al. 2022 **221**).

Tour du Valat's Natural Regional Reserve. © *J. Jalbert*

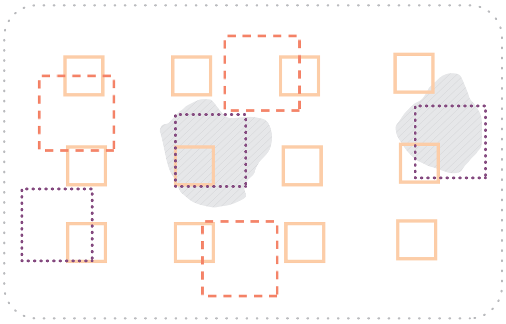

Figure 60: Impact of sampling on cover estimates. Systematic sampling of 12 equally spaced quadrats gives an estimate of vegetation cover (in white) that is relatively close to reality. Bare ground (shaded) is estimated at 15% of the total cover, whereas random sampling of the same area from just three large quadrats results in an estimate of bare ground of 0 or more than 50% depending on the two randomly chosen initial sets (dashed or dotted lines).

Stationary measurements (repeated at the same places)

Monitoring carried out at strictly identical locations from year to year (between or during a season) eliminates the biases made possible by randomly placed quadrats when the number of replicates is low *(Fig. 60, 61)*. With this type of sampling, the quadrat locations can be randomly selected during the first campaign, or systematically placed, as is usually the case. They can also be placed at particular locations, chosen on the basis of assumptions made about the vegetation dynamics (e.g., possible displacement of a contact zone between two belts of vegetation in a marsh, reduction of the **helophytes*** along the edge of a body of water as a result of grazing).

Choosing stationary locations from year-to-year means giving priority to characterising the vegetation dynamics *over time* rather than characterising the plot, since the locations chosen may not accurately reflect the distribution of the vegetation over the whole plot. The validity of monitoring carried out from stationary locations depends on the possibility of carrying out sampling at *precisely the same place* over time, as a shift of just a few centimetres could significantly alter the results and lead to incorrect interpretations.

Quadrats and transects cannot be located using GPS coordinates. Although GPS is sufficiently accurate to locate the study site, it does not provide sufficiently precise information to identify the exact location. Markers will have to be installed and remain in place throughout the monitoring period or be replaced when necessary. Domestic herbivores can compromise the maintenance of measurement equipment or markers. These specific points may be of particular interest to the animals (e.g. rubbing against a stake) and increase the pressure exerted on the vegetation, which at this location can no longer be considered as representative of that exerted on the entire plot. It is essential to take account of the behaviour of the animals in relation to the markers installed in the plot. Often, the data from one or more locations defined by the study protocol, due to domestic and/or wild herbivores, can no longer be used, reducing the number of replicates and possibly the statistical analysis. This risk can be greatly reduced by slightly increasing the number of replicates from what was initially planned (deemed statistically sufficient), so that abandoning certain replicates does not jeopardise the analysis of the data.

Figure 61: Aerial view of a project to rehabilitate abandoned rice fields into marshland, testing the joint effect of maintaining surface water with the presence of domestic grazing (yes/no), with three replicates (plots) for each treatment. *© J-L. Lucchesi*
Due to the low degree of complexity of the vegetation, only nine fixed 1 m^2 quadrats per 2 ha plots (i.e.,162 quadrats for the 18 plots) were used to characterise the impact of the treatments. Their systematic distribution enabled statistical analysis of the data. In this case, where only a few species make up most of the cover, observation (less than 5/10,000 of the total surface area of the experiment) was sufficient to demonstrate the effect of the six different treatments. Only eight species, present in very small numbers on the sites, were not observed in the quadrats. On average, less than 15 minutes were needed per quadrat, or around four full days per sampling campaign (Mesléard et al. 1999 **183**).

Seed bank monitoring

The seed bank is a key element for understanding plant community dynamics. The seeds present reflect the history of the site, the vegetation selected by abiotic and biotic filters *(§ 1.2.2)*. Grazing can greatly modify the soil seed bank (Thompson & Grime 1979 **265**, Loydi et al. 2012 **168**, Saatkamp et al. 2017 **245**). A comparison of the seed bank between periods during the restoration project and with the reference data set can be used to assess the progress made.

Seed bank monitoring techniques

Even simplified, seed bank monitoring is a relatively complex, time-consuming operation requiring a minimum amount of expertise. Depending on the level of detail required, the process can be more or less difficult to implement. But even simplified, it is of particular interest because of its capacity to provide information on the availability of seeds in the habitat (Thompson & Grime. 1979 **265**, Ter Heerdt et al.1996 **264**, Grillas et al. 1993 **120**, Bonis et al. 1995 **35**, Muller et al. 2013 **200**, Moinardeau et al. 2021 **195**, *Table 5*)

SAMPLES TAKEN	Harvesting of samples including the first few centimetres of soil for each patch of vegetation/or management method with several samples (replicates): the number of samples depends on the presumed heterogeneity of the seed bank. Harvesting can be carried out using core sampling if the soil is saturated with water.
TECHNIQUES	**Direct counts:** The soil is generally wet sieved (4mm to 200 µm sieve), then each **propagule*** is identified and counted. *This identification can be extremely difficult for some species. It does not enable us to estimate seed viability* **Measurement of the seed stock expressed (germination count):** samples placed directly in trays/pots/flats (without prior treatment) and application of one (or more) germination-promoting treatment(s). **Measurement of the seed stock after concentration:** Each soil sample is floated in water (30') then concentrated by wet sieving. The soil is then spread out in a thin layer in trays/flats lined with vermiculite (approx. 2 cm) to facilitate water retention, combined with compost (30%). A medical compress (2µ) is placed on top to prevent the seeds from getting buried.
MANAGEMENT OPERATIONS APPLIED	**Types of treatment applied:** • Maintain a few centimetres of standing water at different times of the year, preferably corresponding to field conditions in late autumn-spring or targeted by management. • Maintain saturated soil • Maintain humidity After a first treatment (applied until no new germinations occur), a second treatment (after soil dries out) can be applied to estimate the total number of viable seeds in the soil: those germinating after one treatment or the other. Mixing the soil samples, then drying them out before applying the second treatment, facilitates further germination. *If possible, the temperatures should correspond to those of the treatments applied in the field. Samples should be protected from bad weather and, if possible, from the introduction of **propagules*** (greenhouse with fine mesh). An estimate of the influx of external propagules* can be made by adding pots or trays with previously sterilised soil (free of viable seeds).*
MONITORING	**Technique 1:** Direct determination by counting the seeds of each species present in the soil. *A high level of expertise is required to determine the seeds potentially present.* **Techniques 2 or 3:** Germinations counted at regular intervals (a few days to a week) and immediately removed after counting to avoid any competition between plants *(§ 1.2.2, Seed bank and grazing, Fig. 12).* Monitoring can be stopped after a period of time in which no germination is observed. *Seedlings that are not immediately identifiable can be grown in pots for later identification.*

Table 5: Examples of sample harvesting, germination, management, and monitoring techniques likely to be applied when studying a seed bank.

2.3.2 Parameters for assessing vegetation

PARAMETERS FOR DESCRIBING A COMMUNITY

- **Species richness** (§ 1.4.3): This parameter is of limited value if the species are not specified and classified: expected, of heritage interest or characteristic, unwanted. Monitoring this parameter and its variations over time without clearly defining the species can lead to erroneous interpretations (increase in the number of species when these species are of no interest or even problematic, maintenance of species richness but notable change in species or species contribution).
- **The contribution (abundance) of species:** (§ 2.3.1)
- **Diversity (including evenness)** (§ 1.4.3): Often confused with species richness, it also takes account of the contribution of individuals within species.

Vegetation can also be described by parameters such as:

- **The density of individuals or stems**, particularly for clonal species where it is difficult to distinguish each individual.
- **The height of individuals or of the community** (average height of individuals).
- **The basal diameter of individuals.**

When one of the desired objectives, in particular through the introduction or change of grazing methods, is the regression of one or more species, particularly woody species, the following indices are commonly used.

- *The number of individuals* (Fig. 62),
- *The number of seedings,*
- *Crowding, height of individuals,*
- *The number of stems browsed,*
- *The intensity of browsing (often by class).*

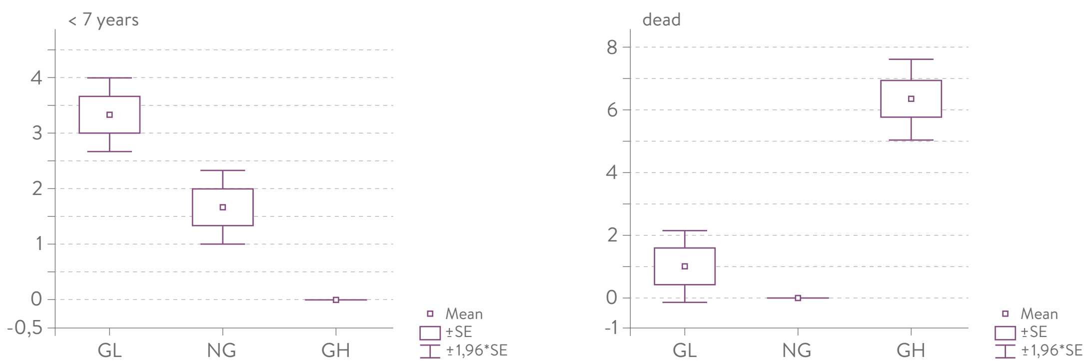

Figure 62: Average number of woody plants (*Phillyrea angustifolia*) less than 7 years old and number of dead adult woody plants per 100m² and standard errors, after 7 years of applying three different grazing treatments on grasslands colonised by the species: low instantaneous pressure for 6 months (LG), high instantaneous pressure for a few days, equal to the annual LG pressure (HG), and exclusion of domestic grazing (NG).
The same annual pressure but applied over a short period of time (high instantaneous pressure), results in the absence of woody recruitment and high mortality of adult woody plants, which is not possible with low instantaneous pressure, as recruitment of *P. angustifolia* is higher in this case than in the absence of grazing: **preemption*** due to the development of dense herbaceous cover after grazing has been excluded (Mesléard et al. 2017).

INDICES FOR COMPARING COMMUNITIES

Various indices of varying ease of use have been developed to compare communities. The formula for each index can be found in the literature cited.

Similarity/dissimilarity indices quantify the success of restoration in relation to a reference data set - the initial state or community of a reference ecosystem (Jaunatre et al. 2013 **145**). Three of them are as follows:

- **The Bray-Curtis index of dissimilarity**(Borcard et al. 2011 **36**) assesses the dissimilarity between two communities based on species composition and abundance.
- **The Sorensen similarity index** assesses the similarity between two communities based on species composition alone (presence/absence data).
- **The community structure integrity index** is calculated based on the average proportion of abundance of species present simultaneously in the reference community or communities and the community for which we are seeking to assess the degree of restoration (Jaunatre et al. 2013 **145**, *Fig. 63*).

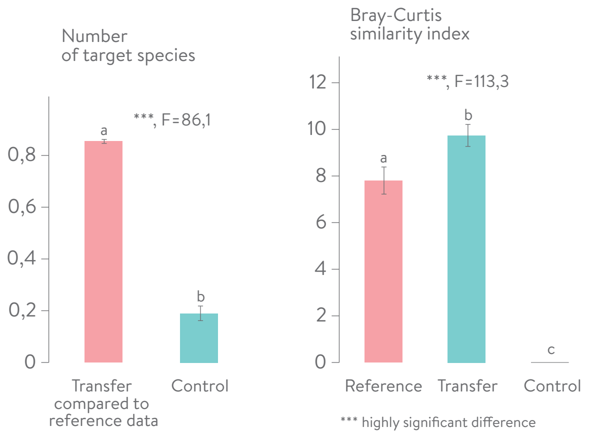

Figure 63: Number of target species in the reference data set, the marsh being restored, and the control marsh (without restoration), similarity index (Bray-Curtis) between the marsh being restored and the reference data set, and between the control (without restoration) and the reference data set, one year after soil transfer (Muller et al. 2014 **201**, Jaunatre et al. 2013 **145**).

ECOSYSTEM FUNCTION INDICATORS

The good condition of an ecosystem and its maintenance depend on conserving the various ecosystem functions involved, which are the result of interactions between the different compartments in the form of exchanges of matter and energy. When assessing restoration, these functions are rarely measured and are often estimated in an approximate way via the structure of plant communities (de Bello et al. 2010 **26**). Some of these functions can be analysed in terms of **ecosystem services***: for example, for the water purification function (particularly by large **helophytes***), CO_2 capture or the availability of food for dependent wildlife *(§ 1.4.2, Water-grazing cross-management)*.

When domestic herbivores are involved in restoration, the functional parameters directly related to livestock feeding (forage production and forage quality), which are two **ecosystem services***, must be considered.

Forage production

Forage production is generally easy to assess, although measuring it can be a difficult undertaking. It is based on cutting the standing biomass during the year at key periods, which does not require any particular technical skills or complicated, expensive equipment. Total annual fodder production and forage availability (during the grazing season) is obtained by summing all the biomass of forage/fodder species consumed by the livestock, obtained from the cuts made and the sorting of forage and non-forage species.

Use of cages

The use of cages allows production to be measured when the animals are present. The advantage of cages over exclosures is their mobility. However, depending on the herbivore and its behaviour, their presence is not always possible, and the installation of more solid structures is then necessary (exclosures). However, measurements inside exclosures that are always in the same place are not desirable over time. This is because the vegetation inside these fixed exclosures is no longer subject to grazing but to cutting, the effect of which can vary considerably from that of grazing on the structure of communities.

Biomass cuts

Biomass cuts can be made at the beginning and end of the grazing season - this will be the case if there are no cages or exclosures - and they can be repeated for greater precision *(§ 1.2.1, compensation)* during the grazing season, if cages are present at characteristic periods (early spring, late spring, late summer, late autumn, every month). The cuts must harvest the green parts of the plant but must not be made too close to the ground.

Sorting and drying

Sorting is necessary to separate forage species from those not consumed. More detailed sorting can be done by distinguishing species by **functional group*** or family, for example by separating:

a. Poaceae,

b. Fabaceae,

c. and other forage species of lesser interest.

In flood-prone areas, this sorting is often oversimplified, because a few species or even a single species dominate(s) the area.

Plant biomass can only be compared dry, as the water content of plants is strongly influenced by the water conditions in the environment. Drying is carried out in ovens at relatively low temperatures (<40°), to constant weight. Drying for 48 hours is generally sufficient. If an oven is not available, drying can be carried out in the open air (in places sheltered from bad weather), but in this case the drying time will be extended depending on the weather conditions (how dry the air is).

Variations in the amount of biomass available

The variability between seasons makes it possible to assess the acceptable grazing pressure over the seasons. This is essential information, but it is not sufficient. The inter-annual variability of forage production *(§ 1.1.4)* is also a key parameter, making it possible to assess when and under what pressure grazing should be used, depending on the grazing objectives (e.g., maintenance, opening up of the vegetation). Knowing this can help determine the adjustments to be made from year to year:

- At what periods is it desirable/possible for the livestock to be present?
- When should the animals be removed or are they likely to have to be removed?
- How much supplementary fodder should be anticipated for safety reasons?

Consumption by livestock

It is calculated by subtracting the fodder biomass produced (forage biomass available when the animals arrive + sum of the fodder biomass obtained by cutting during the grazing season) from the forage biomass not consumed (last cut).

Consumption is a good indicator of the pressure exerted on the habitat, particularly when compared with the biomass produced. If these two values are close in a given year, it is advisable to ensure that the year is representative of average conditions - which are only theoretical. If the year in question is favourable in terms of biomass production, the food available may not be sufficient in some years, and the grazing pressure may exceed what is acceptable for the habitat. Conversely, if the biomass consumed is much less than what is available, this may mean that, depending on the vegetation (how **appetizing*** it is), the pressure exerted by domestic herbivores is too low to meet the grazing objectives.

Biomasse includes both harvested and grazed fodder.

Fodder / forage quality

It is assessed on the basis of different variables measured in the plants:

- protein content
- phosphorus content
- potassium, magnesium, and calcium content
- cellulose content
- digestibility

The methods used to measure these parameters are complex and cumbersome. They are laboratory-based and costly and can only be carried out with the involvement of specialists.

The quality of forage is assessed based on the energy it supplies, and the proteins and minerals provided (Van Soest 1994 **274**), and their availability to herbivores, which depends on the digestibility of the plants (Baumont et al. 1999 **23**).

Fodder (dry matter) is made up of a mineral part and an organic part, which itself includes non-nitrogenous compounds that provide energy and nitrogenous compounds that form proteins.

The mineral part is obtained by calcination of plant samples at high temperatures (>500°) for several hours.

Nitrogenous matter (crude proteins) is determined using the Kjeldal method, which includes a digestion phase in which the nitrogen is broken down using a concentrated acid solution, a distillation phase in which a base is added to convert the NH_4 + into NH_3, and titration to quantify the quantity of ammonia ions in the receiving solution. This method requires a specific mineraliser and distiller. The digestibility of the fodder is obtained by measuring the cellulose residues after a double acid and alkaline hydrolysis followed by dehydration.

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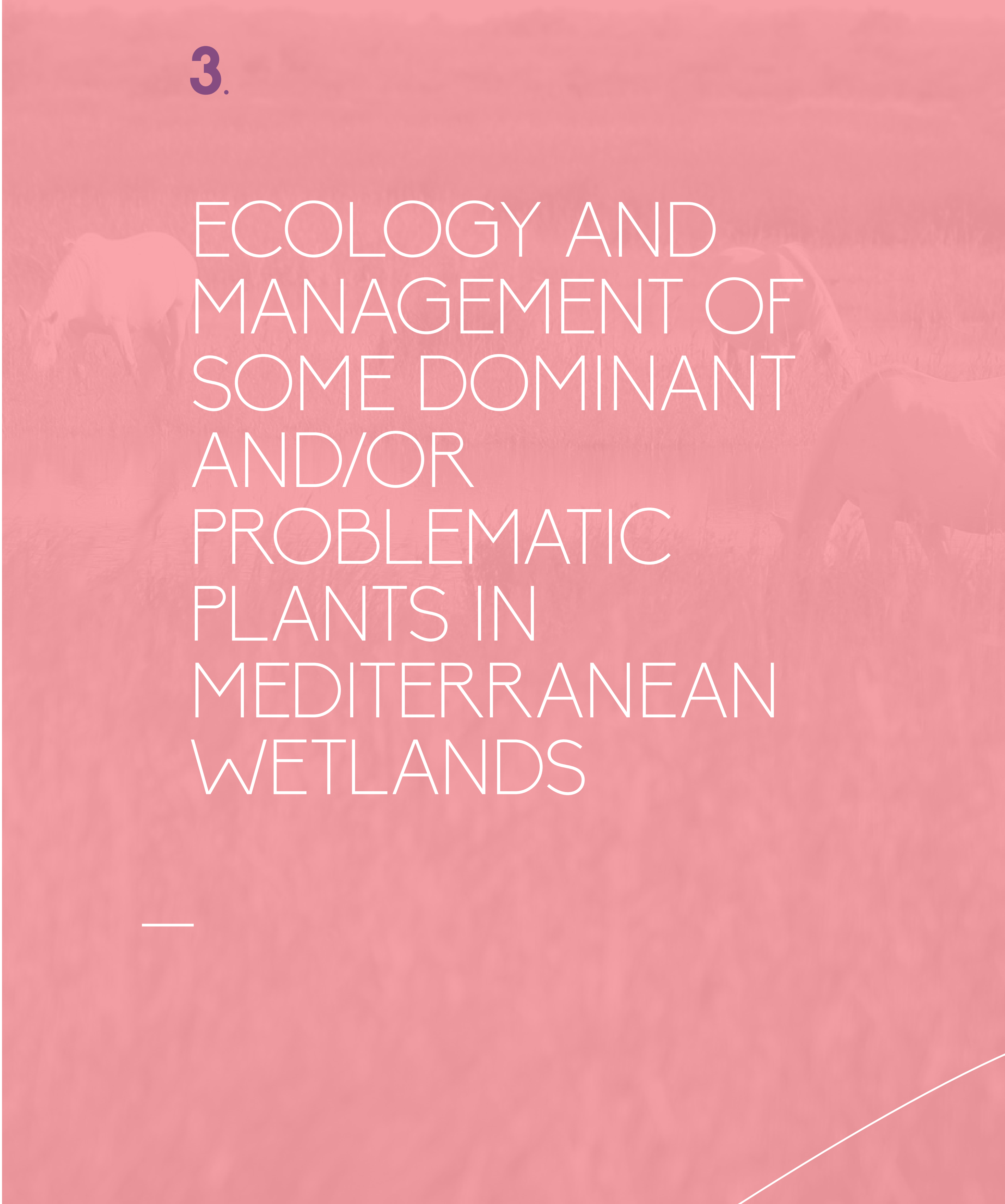


3. ECOLOGY AND MANAGEMENT OF SOME DOMINANT AND/OR PROBLEMATIC PLANTS IN MEDITERRANEAN WETLANDS

In Mediterranean wet environments, grazing is often a key management tool. However, for some plants, grazing is not an option and should be avoided. Nonetheless, these species and, more generally, species that are rarely or never eaten by domestic herbivores should not be neglected, on the pretext that herbivores have no direct impact on their dynamics. If left unchecked, they are likely to take on an undesirable role.

The species presented in this section have all been the subject of various management experiments, including grazing. The results are sometimes contradictory and underline the fact that any management or restoration project, because it takes place in conditions that are always specific, is also an experiment and as such can provide its own unique answers.

Unpublished work is not referenced in this document, but the results of the most recent studies can be accessed on the web by their Latin or vernacular name and a few key words (grazing, management).

3.1 PASTORAL SPECIES

3.1.1 The reed *Phragmites australis*

The reed is a key plant in Mediterranean wet environments, exploited as part of the traditional economic activity of reed harvesting (sagne). Reed beds are home to remarkable biodiversity, particularly avian species (Haslam 1971 **128**, Mauchamp & Mesléard 2001 **174**, Greenwood & Macfarlane 2006 **119**, Engloner 2009 **96**, Vulink et al. 2000 **277**).

BIOLOGICAL CHARACTERISTICS

Figure 65: Exploited Reed beds in the Rhône Delta © B. Poulin

The reed is a clonal species. Its strong vegetative growth enables it to rapidly conquer space and form dense communities that limit the possibility of establishment of other plants. Over time, the reed generates a thick layer of litter which reduces the availability of oxygen around the roots and eventually leads to the decline of the **stand***. A reed bed may be the product of just a few individuals. The lack of genetic diversity has been cited as a possible cause of the poor condition of many reed beds.

Aa* Term defined in the glossary section
Aa Refer to the reference section

Figure 66: The reed is particularly appreciated by the Camargue horse.

ECOLOGICAL REQUIREMENTS

Outside the growing season, the reed tolerates water depths of over 1.5 metres, and up to several metres for very large **polyploid*** individuals. However, it grows best when water depths are between 10 and 30 cm. It benefits from a dry period of one to several months in spring or summer, as long as the soil remains relatively moist. The reed prefers mild habitats and, depending on the **ecotype***, has difficulty tolerating salinities of more than 10 g/l during the growing season. Outside this period, it is relatively less demanding in terms of the salt content of where it grows. Excessively high salinities, unfavourable flooding conditions - permanent flooding or lack of water during the growing season, prolonged dry periods - or, even more so, a combination of these conditions, lead to a decrease in the height and density of the reed bed and can make it disappear.

PASTORAL VALUE

The reed is a forage species rich in nitrogen (up to more than 30% crude proteins), calcium, and phosphorus. It is appealing to domestic herbivores, particularly horses *(Fig. 66)*. As its forage qualities diminish over the growing season, it is preferentially grazed when it is green (spring-summer) and substantially less when it dries out (winter).

Aa* Term defined in the glossary section
Aa Refer to the following text

GRAZING-BASED MANAGEMENT

The reed is particularly sensitive to grazing:

The consumption of its apical **meristems*** makes the plant stop growing. After the aerial parts have been reduced by grazing, the presence of a layer of water above the vegetation contributes to the rotting of the **rhizomes***. Trampling, particularly when the soil **bearing capacity*** is low, can severely damage the rhizomes* and jeopardise the plant's survival when the flooding period is long. The impact of herbivores depends partly on their weight and the surface area of their hooves. A heavy water buffalo with relatively narrow hooves will have a more destructive impact through trampling than a small Camargue horse with wide hooves.

The objective pursued - disappearance, opening up, or maintenance - determines the choice of herbivore and the intensity of the grazing pressure.

The green parts are consumed to a greater extent on land with little or no flooding, particularly by cattle, apart from water buffalo, which remain very effective in controlling reed beds at great depths. Depending on the conditions of the habitat, the season, and the year, maintaining the reed bed may be incompatible with the presence of grazing or may require extremely low grazing pressure. Rotation every two or three years is often a good compromise, allowing both mechanical or pastoral grazing and the maintenance of a high-quality reed bed. Grazing pressure of no more than two cattle per hectare in the spring and less than one cattle per hectare in the summer is often compatible with maintaining the reed bed, provided it is in a satisfactory state (good development conditions). However, early grazing during the growing season, depending on water availability, can have different consequences. For example, for the same reed bed, grazing pressure equivalent to 0.5 cattle per hectare applied in March/April could be destructive in a dry spring and have no major effect in a wet spring.

In an old reed bed, grazing alone will not bring about rejuvenation, and fire, the removal of clumps, or the export of organic matter may be necessary.

3.1.2 Scirpus

SEA CLUB-RUSH, *SCIRPUS (BOLBOSCHOENUS) MARITIMUS*

Like the reed, Sea Club-rush is one of the major species that structures Mediterranean wetlands. In many marshes, control of reed by grazing leads to Sea Club-rush dominance. Conversely, if grazing pressure on Sea Club-rush is too low, the reed will develop at its expense (Charpentier et al. 1998 **52**, Durant et al. 2009 **89-90**).

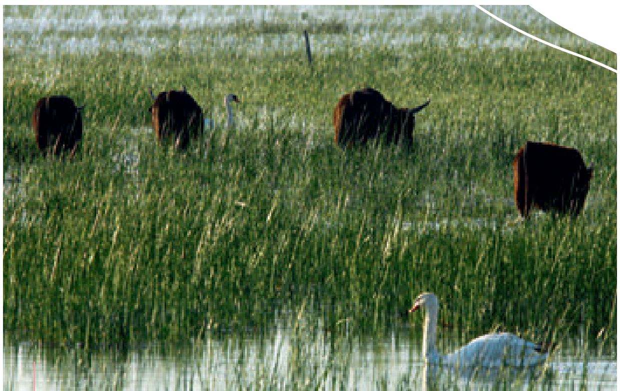


Figure 67: Patch of Sea Club-rush maintained (control of reeds) and kept open by the presence of cattle in spring and summer *© J. Jalbert*

Aa Refer to the reference section
Aa Refer to the following text

Biological characteristics

Sea Club-rush has particularly effective vegetative and sexual reproduction (§ 1.1.3). The seeds, which float, have a long lifespan; they can therefore germinate after more than two decades without favourable conditions. This dual reproductive capacity means that Sea Club-rush can rapidly colonise a site as soon as favourable conditions are present, even if these conditions have been absent for many years.

Ecological requirements

Sea Club-rush thrives best in shallow marshes where the water level varies from 10 to 40 cm during the spring, particularly in late spring. Its optimum growth corresponds to a water depth of around 20 cm.

When conditions are drier, it competes with Juncaceae and Poaceae. In water deeper than 40 cm, it gives way to taller club-rushes (*S lacustris*, *S. littoralis)* in the presence of grazing, and to reed in its absence.

Sea Club-rush benefits from the presence of surface water during its growing season, from March to May, but it tolerates highly variable periods of flooding. It can thrive in marshes where flooding does not exceed two months, as well as in habitats that are flooded for eleven months of the year. It requires a dry period, in spring, summer or winter, to avoid the deoxygenation of its substrate, which damages it.

Beyond three months, the dry period represents stress for the species, which is expressed by a reduction in the height and density of the **stand***.

Salt concentrations up to 10 g/l have little impact on Sea Club-rush. Above this level, its growth is reduced, and it quickly gives way to species characteristic of saline habitats.

Pastoral value

Sea Club-rush is a species of good pastoral quality, both in terms of **palatability*** and protein content. It continues to thrive relatively well into early summer if favourable conditions (flooding) persist. It is highly productive in spring. The biomass produced (400-700 kg of dry matter per ha per month) can be higher than that provided by a dense reed bed (250-600 kg).

Grazing-based management

Sea Club-rush tolerates relatively high grazing pressure in spring (1.5 to 2.5 cattle/ha). However, grazing pressure must be reduced in summer (0.2 to 0.6 cattle/ha) and even more in autumn (< 0.3 cattle/ha). Grazing delays flowering and, thanks to the regrowth, maintains the good grazing value of plants beyond the spring, if hydrological conditions remain favourable.

Heavy pressure, leading to a drastic reduction in above-ground parts, may have no major impact if it is temporary, as the reserves contained in the underground tubers guarantee the production of new ramets. However, depending on the habitat conditions, increased pressure can affect tuber size. This impact, which is primarily observed on the underground parts and corresponds to the cost to the plant of maintaining its above-ground production intact, should be seen in relation to the threshold effects (§ 1.4.3) to which Sea Club-rush is highly susceptible. The combination of grazing pressure followed by an unfavourable change in habitat conditions

Aa* Term defined in the glossary section
Aa Refer to the following text

when reserves are insufficient or depleted can rapidly lead to the replacement of the Sea Club-rush by species that are less appetizing or not appetizing to herbivores. Similarly, the application of a low grazing pressure on Sea Club-rush that is apparently in good condition can have a detrimental effect if it is added to unfavourable habitat conditions. Such effects have been observed when wild herbivores graze Sea Club-rush **stands*** in areas of high salinity. Like the increase in salinity, the presence of too much water after grazing is unfavourable to Sea Club-rush.

Sea Club-rush resists trampling well and can even benefit from it. Tubers are reserve organs linked by connections. When these connections are destroyed by trampling, Sea Club-rush produces more new **shoots***, resulting in an increase in the density of aerial parts the following year *(§ 1.1.3)*.

TALL RUSH SPECIES: COASTAL *SCHOENOPLECTUS LITTORALIS*, AND LACUSTRINE *S. LACUSTRIS*

Figure 68: Tall rushes grow in the deeper parts of rush marshes.
Taller than Sea Club-rush, they are more tolerant to flooding and occupy deeper parts of rush marshes where they are less accessible to grazing, although a subspecies of *S. lacustris* (subsp. glaucus = *Schoenoplectus tabernaemontani*) also grows in temporary shallow marshes in the Mediterranean. Coastal rush is less appetizing than Sea Club-rush, and only the young shoots are widely eaten. Lacustrine rush, with its rigid stems, is avoided by domestic herbivores unless they are under strong pressure.

3.1.3 Saltmeadow Rush, *Juncus gerardii*

Saltmeadow Rush is short (15 to 50 centimeters) and forms dense mats on the edges of marshes or in very shallow temporary marshes (Mesléard et al. 1995 **184**, Charpentier et al. 1998 **52**, Mesléard et al. 1999 **183**).

BIOLOGICAL CHARACTERISTICS

Saltmeadow Rush is a relatively early flowering species in the Mediterranean, as its germination, growth, and flowering can take place at relatively low temperatures. However, it is capable of flowering late (until the end of June) if water conditions are favourable. Its high rate of vegetative reproduction means that it forms a dense aerial cover and root mat, greatly limiting the possibility of other species to establish themselves (**preemption***). Its capacity to colonise by means of sexual reproduction is considered low.

Figure 69: Saltmeadow Rush has slender, round stems, opposite leaves, and terminal inflorescences.

Aa* Term defined in the glossary section
Aa Refer to the reference section
Aa Refer to the following text

ECOLOGICAL REQUIREMENTS

Saltmeadow Rush shows a rather high tolerance to salt but can only tolerate short periods of water above its aerial parts. It grows mainly on the edges of marshes, where it colonises the transition zone between the part of the marsh that is not usually flooded and the part where there is standing water in winter and spring during rainy spells.

PASTORAL VALUE

In early spring, Saltmeadow Rush (*Juncus gerardii*) has a relatively high protein content and is highly **palatable***. It is therefore a particularly interesting species at that time of year, even if on its own, given its limited production, it is generally insufficient for feeding livestock.

GRAZING-BASED MANAGEMENT

It is favoured during the initial phases of restoration if the first flooding operations are at low levels (10 cm) and/or if early grazing is avoided. If there is no grazing at all, it will quickly disappear and be replaced by taller species, Poaceae in the highest parts, and Sea Club-rush in the parts where flooding is more frequent.

Saltmeadow Rush (*Juncus gerardii*) tolerates trampling because of the density of its root mat and because it often grows in areas with little or no flooding. This trampling can help other species to get established. Once this rush has been allowed to colonise the area, very high pressure can open up the habitat (**colonisation windows***) without the need for major engineering works. In this case, raising the water level greatly facilitates colonisation by other emergent species.

3.1.4 Water grasses, *Paspalum paspalodes* water grasses, *P. distichum* and dallisgrass *P. dilatatum*

P. paspalodes and *P. dilatatum* are cosmopolitan Poaceae native to Central America. Their introduction is mainly attributed to rice growing. They are highly productive species, widely consumed by domestic herbivores and, when heavily grazed, can become potential **feeding areas*** for livestock. As such, they have been relatively popular and have been recommended both for their pastoral and conservation value. They are nonetheless introduced species that have a high colonisation potential in mild habitats. They are now considered invasive alien species in France (Huang & Hsiao 1987 141, Mesléard et al. 1993 182, Kamiris et al. 2016 150, Perrino et al. 2021 222).

Figure 70: Inflorescences of *Paspalum paspalodes.*

BIOLOGICAL CHARACTERISTICS

Paspalum or water grasses are tropical plants that thrive in high temperatures. Their growth starts late in the season in the Mediterranean but proceeds rapidly.

These plants can easily reach distant sites when parts of them are transported. Their vegetative and sexual reproduction enables them to rapidly colonise an area when conditions are favourable.

ECOLOGICAL REQUIREMENTS

In favourable conditions (high temperatures, low or zero salinity) water grasses can grow in relatively deep water (> 30 cm). Productivity appears to be optimal in water depths close to 30 cm in early spring. They are not very tolerant when the marsh soil dries out early in the season but are favoured by the maintenance of moist soil or even when the soil dries out in the summer.

As freshwater plants, they do not survive saline conditions beyond 4g/l. From 2 g/l their competitive capacity becomes mediocre. They are then replaced by taller or more salt-tolerant species such as Indian walnut (*Aeluropus littoralis*) when the marsh soil dries out in late spring or summer.

PASTORAL VALUE

Water grasses are commonly used to feed livestock in wet environments and may even be sought for this reason. Although they are highly productive, their low protein content (<10%/DM) and high fibre content (>30% crude fibre) make them poor forage.

Nevertheless, these species are appreciated by livestock, particularly in late spring and summer if other species are no longer available or have lost much of their **palatability***.

Figure 71: Water grasses provide a significant proportion of the food for water buffalo on Lake Kerkini (Greece). *© P. Grillas*

GRAZING-BASED MANAGEMENT

Both water grass species tolerate heavy grazing pressure (up to 4 cattle per hectare in spring and 2.5 in summer) and are largely dependent on it. Grazing controls the other emergent species, which are more competitive for light, and encourages vegetative reproduction of these two clonal plants through trampling. Domestic grazing is therefore not an effective way of reducing the cover of these two species.

© H. Hôte

OTHER MANAGEMENT TECHNIQUES

There are two possible methods for limiting the presence or eliminating water grasses: completely drying out the area from late spring to autumn or increasing the salinity of the habitat by introducing salt water. Since both methods are restrictive, they can rarely be applied. In marshes and meadows, the abundance of *P. distichum* depends on water management, but the species also colonises the banks of permanent or semi-permanent freshwater bodies. Once the plant has become established, unfavourable water management (summer drought) does not always allow it to be eliminated if the land is not very salty.

The difficulty of controlling these introduced species highlights, once again, the effort required for implementing effective management to combat undesirable species when they are already present. In this case, as is often the case in Mediterranean wet environments, it is important to assess the possible consequences for the site of maintaining surface water well beyond the natural period before setting up water management operations.

3.2 SPECIES THAT CAN AT TIMES BE MANAGED BY GRAZING

3.2.1 Tall bulrush species: *Typha angustifolia, T. domingensis, T.latifolia*

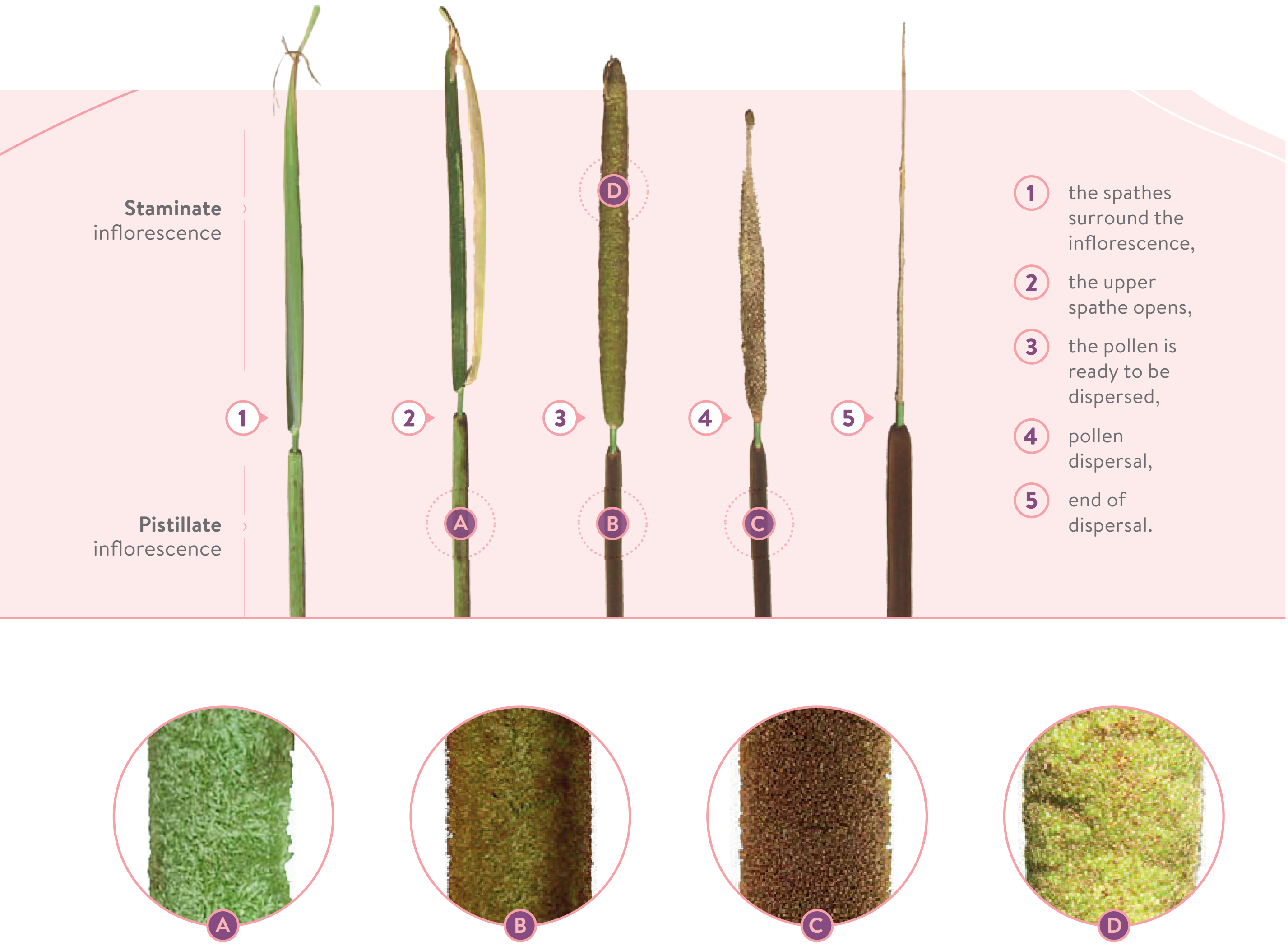
Bulrushes are tall perennials (up to over 2 m) with a high rate of vegetative reproduction, characteristic of open wet environments. They colonise ponds, marshes, and the edges of shallow lagoons, preferably where the water is stagnant. Adult stems are round and robust. The linear leaves (wider for *Typha latifolia*) are arranged in a single plane (Sharma & Gopal 1978 **253**, Dickerman & Wetzel 1985 **82**, Salathé 1986 **246**, Mesléard et al. 1999 **183**, Watt et ali. 2007 **280**, Squalli et al. 2020 **259**).

Figure 72 : Inflorescence characteristic of bulrush. *© L. Wilm*

Their inflorescence consists of two superimposed spikes, with a short-lived male spike below.

Bulrushes can be distinguished by the colour of their mature female spikes: cocoa for *T. angustifolia*, lighter brown for *T. domingensis*, and blackish for *T. latifolia*.

The photos below show the **change in color of the Bulrushes' inflorescence**, indicating the state of the rhizomes' energy reserves. The moment of weakness is between stages 2 and 3, shortly before the pollen is formed.



A › B › C | The cutting should take place when the pistillate inflorescence turns from green to brown.

D | Pollen formed and ready to be disseminated

Figure 73: Evolution of the Bulrushes' inflorescence

Bulrushes often form dense paucispecific or monospecific **stands***. In the Mediterranean, depending on the region and the wildlife likely to be found there, the aim may be to restore or, on the contrary, to reduce these stands*.

BIOLOGICAL CHARACTERISTICS

Their establishment is favoured by their considerable production of seeds (up to 250,000 seeds per spike), which are dispersed by the wind and whose germination is stimulated by high temperatures. Above-ground growth starts early in the year, but **rhizomes*** do not develop until early summer, after flowering has begun. Flowering generally starts in May and continues until the end of July. Their network of rhizomes* and the stock of reserves they contain enable bulrushes to multiply rapidly by propagation by **cuttings***, ensuring that they quickly occupy the site in which they are planted.

ECOLOGICAL REQUIREMENTS

Bulrushes grow at low salinity (less than 1.5 g/l), preferably when there is residual surface water and the soil is saturated until early summer. Tolerance to water depth varies between species, but all three tolerate significant seasonal variability.

They can survive in water up to two metres deep and withstand dry spells better than the other large emergents found in Mediterranean wetlands. Their vegetative development is favoured by high temperatures.

PASTORAL VALUE

Bulrushes are poorly **palatable*** species, particularly in spring due to the presence of terpenes in their green parts. As the terpene content diminishes over the course of the season, they become edible at the end of summer, but are of little pastoral value and seem to be avoided by equines.

GRAZING-BASED MANAGEMENT

Some wild herbivores are better able to consume bulrushes efficiently, as in the case of the Coypu (*Myocastor coypu*) and the Muskrat (*Ondatra zibethicus*), which prefer the base of the stems and the chlorophyll-free leaves. Unless cattle are highly constrained, their effect on bulrush **stands*** is generally limited and does not significantly control the species.

On the contrary, the presence of domestic herbivores in late spring or summer in very open and/or already degraded habitats, and the presence of residual water, can greatly facilitate the rapid colonisation of the habitat by bulrushes, by stimulating their germination. The presence of mud due to trampling creates conditions of light (quality), which, in the presence of high temperatures (25°C and above), are particularly favourable to their germination.

OTHER MANAGEMENT TECHNIQUES

These techniques are difficult to implement. Mechanical destruction of the **rhizomes*** is necessary to make the plant disappear, but to be effective, most, if not all, of the plant's reserves must be exhausted. The introduction of salt into the habitat is also harmful to the plant, leading to the deterioration of the stand and colonisation by more tolerant species. However, this dynamic is slow to take hold and the hydraulic modifications required (draining) to destroy a stand are such that they can compromise, at least temporarily, the possibility for other wetland species to get established. The difficulty of controlling this species, because of its ability to withstand considerable stress, means that when its development is undesirable, the conditions leading to its establishment (degraded cover, residual water in late spring and summer) should be avoided.

3.2.2 Great Fen-Sedge, *Cladium mariscus*

The Great Fen-Sedge, which is in the Cyperaceae family, has umbellate inflorescences along its stem. In just a few years, the species can form dense **stands*** unfavourable to plant diversity. Nevertheless, the Great Fen-Sedge is of great intrinsic interest in the Mediterranean context and its control favours abundant wet meadow flora if the hydraulic conditions are favourable (Haslam 1971 **128**).

Great Fen-Sedge stands are home to characteristic vertebrate and invertebrate wildlife and are designated as being of community interest in Europe. As they age, this habitat function can diminish or disappear, particularly for certain invertebrates, but also for nesting birds that are emblematic of **helophyte*** **stands***. Rejuvenation may then be desirable.

Colonisation by the Great Fen-Sedge can be problematic, particularly when its uncontrolled dynamics threaten the grassland **ecosystems*** adjacent to the marsh.

Figure 74: Great Fen-Sedge (*Cladium mariscus*) inflorescences.

BIOLOGICAL CHARACTERISTICS

Sexual reproduction does not occur until several years after its installation. It requires days with hot day time temperatures and cool nights. These requirements seem, in part, to explain the low presence of the Great Fen-Sedge outside sites where it is already well established.

The Great Fen-Sedge colonises space vegetatively. Its **rhizomes*** develop at a shallow depth below the soil surface and spread horizontally over a short distance (less than 50 cm). The plants have a short lifespan, less than a decade, during which time they produce young shoots that contribute to a dense, centrifugal growth of a few dozen centimetres per year. Great Fen-Sedge is sensitive to frost and its vegetative development takes place mainly at high temperatures.

ECOLOGICAL REQUIREMENTS

The Great Fen-Sedge prefers organic, mesotrophic, and calcareous substrates. It requires a regular supply of fresh water with slight fluctuations throughout the year. It thrives best in waterlogged soils.

PASTORAL VALUE

Great Fen-Sedge stands are of little pastoral interest. Only the young shoots are of forage value and are therefore eaten by domestic herbivores. As they age, forage production is limited to that provided by a few individuals of other species that may be **palatable***.

GRAZING-BASED MANAGEMENT AND/OR RESTORATION

At young stages, grazing can be considered, but its effectiveness will be limited. Due to the unpalatability of adult Great Fen-Sedge which has leaves with hard serrated edges, grazing alone cannot regenerate a stand of Great Fen-Sedge, even if strong instantaneous pressure, due to the mechanical effect of trampling, can damage it. Grazing can, however, be used as a complement to mowing if the regrowth is consumed. In addition, by compacting the soil, domestic herbivores can increase the surface **hydromorphy***, making it easier for other species to get established or re-established, depending on how open the cover created is.

Both cutting and grazing force the plant to draw on its reserves: a single year's rest after cutting without grazing is enough for the plant to replenish its stock of sugars.

OTHER MANAGEMENT AND RESTORATION TECHNIQUES

Cutting

Because of the presence of a cell multiplication zone (**meristem***) just above ground level, cutting followed by flooding is enough to kill off the regrowth. Cutting is therefore a way of regenerating an area of Great Fen-Sedge, but it is also a way of causing it to regress: for example, it can be used to restore a partially colonised wet meadow.

Fire

Many criticisms have been levelled at fire management, including the risk of it burning out of control, its impact on wildlife, its role as a germination factor for invasive alien species, the enrichment of the soil through **mineralisation***, and its heterogeneous impact.

Figure 75: 'Regeneration' of Great Fen-Sedge stands by fire in the Camargue.
© F. Mesléard

Fire, a traditional practice, nevertheless appears to be an alternative to cutting and its carbon footprint may be less negative than cutting. As far as wildlife is concerned, the few results available and their variability make it risky to generalise about fire. As far as the emblematic Bittern is concerned, studies on the subject suggest that the unburnt parts of Great Fen-Sedge stands provide a complementary habitat which is used especially for feeding. From a microfaunal point of view, Great Fen-Sedge stands seem to be rapidly recolonised after fire, offering a vegetation structure favourable to diversity in the first few years. For the spider community, a group that is also emblematic of Great Fen-Sedge stands, fire appears to have had the greatest impact on juvenile individuals and specialised species.

3.2.3 Pampas Grass, *Cortaderia selloana*

Pampas Grass is a perennial Poaceae that grows in dense, large clumps (up to 3 m). The leaves are evergreen, long (up to 2 m), and narrow (around 1 cm) with sharp edges. Native to South America, it was introduced as an ornamental plant and continues to be used as such despite its invasive nature (Lambrinos 2002 **156**, Paussas et al. 2006 **215**, Domenech & Vilà. 2008 **83**).

Its rapid growth, combined with substantial above-ground and below-ground biomass production, enables it to preempt light, water, and nutrients, to the detriment of other species, and thereby to rapidly occupy the plots of land in which it settles if there are gaps in the existing vegetation.

Figure 76: *Cortaderia sellona.*

BIOLOGICAL CHARACTERISTICS

It flowers in summer and early autumn. The flowers are pollinated by the wind and produce a considerable quantity of seeds (over 10 million per individual), almost all of which are viable. These seeds are dispersed by wind and water. Germination occurs in the spring following dispersal and individuals grow rapidly.

Vegetative reproduction from plant fragments is possible in humid conditions. Although marginal, it should nevertheless be taken account of during control operations to avoid any risky operations.

ECOLOGICAL REQUIREMENTS

Pampas Grass thrives best on moist, soft, poor, and preferably well-drained (particularly sandy) soils. This versatile species can withstand both relatively long periods of flooding and severe drought. It mainly colonises recently disturbed areas, reworked soils, wasteland, and cleared scrubland.

PASTORAL VALUE

Due to its low forage value and low **palatability*** to domestic herbivores, this species is of no real pastoral value.

EFFECTS OF GRAZING

To be effective, the animals must be highly constrained, which can quickly cause problems given their lack of appetite for the species. Although domestic herbivores, particularly cattle, appear to be able to control young individuals, grazing does not appear to be a means for really controlling *C. sellona*.

OTHER MANAGEMENT TECHNIQUES

Young plants are easy to uproot due to their shallow root system. Removed plants must not be placed in conditions likely to encourage them to grow again (it is preferable to burn their stumps). Larger plants should be removed mechanically. It is advisable to intervene before flowering and to monitor the situation afterwards to avoid any new growth.

Cutting does not appear to be an effective means of controlling the species. Individuals subjected to repeated cutting generally show no significant reduction in their growth capacity.

3.2.4 Saltbush, *Baccharis halimifolia*

Saltbush, also called Cotton-seed Tree because of the appearance of its fruit (feathery **achenes***), is a deciduous or semi-evergreen Asteraceae. Originally from North America, it was introduced in Europe as an ornamental plant, and its use to stabilise soil has largely contributed to its spread. Saltbush is an invasive species in the Mediterranean (Cano et al. 2013 **48**, Cano et al. 2014 **47**, Fried et al. 2014 **104**, Lazaro-lobo et al. 2020 **160**).

Figure 77 : Saltbush or Cotton-seed Tree (*Baccharis halimifolia*) and its characteristics achenes. *© L. Wilm*

BIOLOGICAL CHARACTERISTICS

Saltbush grows rapidly (several dozen centimetres per year). Because female and male flowers are borne by separate individuals (dioecious species), sexual reproduction can only take place if both sexes are in close proximity. Flowering takes place from August to October and fruiting lasts until the end of November.

The seeds, which are abundantly produced - up to more than a million per individual - and spread by the wind thanks to their feathery pappus, can float for several weeks. Their capacity to survive (up to 5 years) enables them to build up a large reserve in the soil, ready to germinate after a cold period, as soon as conditions allow (opening up of the habitat). The speed and rate of germination are high in favourable conditions: moist soil, daytime temperatures between 15 and 20°C. In addition, *B. halimifolia* can sprout after being cut.

© Hellio - Van Ingen

ECOLOGICAL REQUIREMENTS

B. halimifolia has low soil requirements, although it prefers soils rich in organic matter. It is highly tolerant to salt stress, both in terms of soil salinity (up to 20 g/l) and exposure to sea spray. However, growth and seed production are higher in milder habitats.

On the other hand, it can only tolerate small amounts of standing water for short periods. It is therefore more likely to colonise uplands, dunes, salt meadows, grasslands, and the edges of marshes.

PASTORAL VALUE

B. halimifolia is not, strictly speaking, a pastoral species and is only consumed to a significant extent when forage supplies are relatively limited. It is possibly toxic in large doses. Domestic herbivores show a strong preference for the youngest shoots.

GRAZING-BASED CONTROL

Grazing alone is not an effective means of control. Goats, cattle, and equines consume *B. halimifolia* but show little interest in the species (goats are naturally the most suitable for this type of control).

Grazing is only relevant if it complements mechanical control. Rotary mowing followed by grazing at a high pressure for several years can be an effective combination for reducing the number of individuals, or even eradicating the species.

OTHER MANAGEMENT TECHNIQUES

Uprooting these plants by hand or with a machine (depending on the extent of colonization), is the most effective way of controlling the species. This treatment is even more effective if it is carried out soon after the plant has become established. If there are only a few plants present and they are small, it will be easier to pull them out and the disturbance caused by this activity will be reduced. Removal should be carried out before flowering and the plants removed should be placed in conditions that prevent them from growing again (completely dry).

One of the main risks of this method of control is the establishment of new individuals from germination because of the disturbance caused by uprooting the plants. Once the plants have been uprooted, strict monitoring is required until the plant cover has completely recovered.

Figure 78 : Colonisation of a reed bed by Cotton-seed Tree (*Baccharis halimifolia*).
© L. Wilm

3.3 SPECIES NOT CONSUMED

3.3.1 Sharp Rush, *Juncus acutus*

Sharp Rush is a robust plant that can grow to over 1.5 metres in height. Its aerial part forms a dense, circular tuft. The stems and leaves end in a rigid, prickly **bract***. Dried leaves are replaced continuously (Boiscaiu et al. 2007 **37**, Boiscaiu et al. 2011 **38**, Mesléard et al. 2016 **186**).

Their short **rhizomes*** have buds from which new stems emerge. Vegetative propagation occurs slowly from the periphery. This makes a marginal contribution to colonisation, which occurs essentially from seeds. The fragmentation of rhizomes* can eventually lead to the growth of new individuals.

BIOLOGICAL CHARACTERISTICS

It does not flower until the third year. Sharp Rush produces large quantities of seeds (up to 30,000 per inflorescence). Mature at the end of summer, they can remain attached to the parent plant for several months. They are transported mainly by water and animals. Seeds can germinate as early as autumn of the year of production if the soil is moist or saturated and temperatures are mild (autumn or mild winter conditions).

Vegetative growth is weak, particularly in the first year.

ECOLOGICAL REQUIREMENTS

Sharp rush is characteristic of marshy, temporarily saturated, or flooded areas. It develops in degraded or poorly covered soils. Not very demanding in terms of habitat conditions, it tolerates soils that are poor in organic matter and relatively salty, as well as low levels of flooding. Late irrigation or the presence of residual water on rangelands with patches of bare soil facilitate its establishment.

Germination of Sharp Rush is optimal in fresh water and is little affected by salinities below 10g/l. It is delayed and reduced above 15 g/l in function of the **photoperiod*** and temperature. An increase in temperature up to 25°C accelerates germination and limits the effect of salt in delaying or inhibiting germination.

Similarly, a **photoperiod*** alternating 14 hours of daylight and 8 hours of darkness (spring) largely buffers the effect of salt on germination, whereas this effect is more pronounced with a 12:12 photoperiod* (autumn). The temperature and light conditions of late spring and early summer are therefore particularly favourable for its germination.

Figure 79: Colonisation by Sharp Rush of a former rice field that is now grazed. © L. Wilm

PASTORAL VALUE

Sharp rush is **unpalatable*** to domestic herbivores. By damaging the plant cover through trampling, herbivores can encourage its establishment.

GRAZING-BASED MANAGEMENT

Young clumps of Sharp Rush may be damaged by heavy trampling; however, grazing cannot be used to control this species once it has become established.

In areas that are ecologically favourable for its establishment (e.g., marsh edges), alternating periods of high instantaneous pressure and relatively long periods without grazing should be avoided, as the species would then have ample opportunity to germinate without the seedlings being destroyed. In this respect, late flooding causing residual patches of water on bare ground should be avoided.

MANAGEMENT TECHNIQUES

Mechanical uprooting is a particularly tedious method if there are many individuals and the clumps are large, but it is all the more effective if it is carried out on young individuals. However, this method of control has the disadvantage of damaging the site by creating holes and exposing large areas of soil, the mixing of which facilitates further germination. Poorly conducted mechanical digging can thereby favour the species.

Cutting low to the ground (less than 5 cm high) destroys all the buds from which new stems can grow. It is therefore important to ensure that the peripheral parts of the individual plants, which may have been overlooked because they are usually at slightly lower heights, have also been cut. These cuts require heavy-duty equipment such as a forestry mulcher.

Slash and burn methods should be avoided, because burning clumps in spring only damages the above-ground parts and new stems reappear in autumn.

Regrowth can be observed the first spring in the periphery of the part that was cut off.

Figure 80 : Ineffective cutting of Sharp Rush. © L. Wilm

3.3.2 Sea Rush, *Juncus maritimus*

Sea Rush is a perennial plant producing numerous stems up to 1 m high. The inflorescence ends in a prickly but not very stiff **bract***. Its high capacity for vegetative propagation means it can quickly colonise an area (Boiscaiu et al. 2007 **37**, Boiscaiu et al. 2011 **38**, Mesléard et al. 2016 **186**).

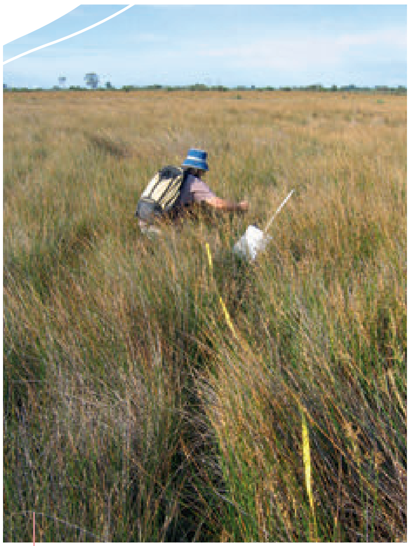


Figure 81 : Monitoring vegetation in a Sea Rush (*Juncus maritimus*) stand. © L. Wilm

BIOLOGICAL CHARACTERISTICS

Flowering takes place in early summer and the seeds mature in August. Their number varies greatly from year to year.

The presence of trailing **rhizomes*** gives Sea Rush great potential to spread. This aptitude, combined with a strong competitive capacity through **preemption***, results in the development of monospecific Sea Rush meadows over large areas.

ECOLOGICAL REQUIREMENTS

Sea Rush settles and develops on bare or degraded, temporarily flooded or damp, mild to brackish soils (water table close to the surface).

The germination capacity of seeds varies greatly from year to year. The optimum temperature for germination is around 25°; it is inhibited at temperatures below 10° and above 35°. Germination is only slightly affected by increased salinity in spring and summer, and it is stimulated by alternating fresh and salt water. At **photoperiods*** close to 14 hours of daylight and 10 hours of darkness, germination rates are still very high for salt concentrations of 20 g/l, but the reduction in daylight to 12 hours is enough to make germination very sensitive to salinity. Sea Rush tolerates high salinities for its development (above 9 g/l). Its growth only stops at salinities close to 30 g/l.

Sea Rush mainly colonises low-lying land and/or land that floods in winter, whether natural - behind dune belts or along the edges of marshes - or formerly used for farming. On higher ground, it can also be found in scattered clumps, in which case its colonisation capacity is limited.

PASTORAL VALUE

Even if its young shoots are browsed, Sea Rush must be considered unpalatable. Heavy trampling can cause serious damage to a stand of this rush, but to be effective, this management method requires high pressure from herbivores and can therefore only be applied to small areas. Reducing the area colonised by Sea Rush or controlling its spread has little chance of succeeding through grazing alone.

MANAGEMENT TECHNIQUES

The methods involved are difficult and costly to implement, and the benefit/interest of such an operation needs to be assessed beforehand.

If it is possible to completely dry out the soil, doing so throughout the spring and repeating this operation several years in a row can have a major impact on Sea Rush. The addition of mowing in early spring increases the effectiveness of the treatment. Early mowing (at the end of winter) subsequently repeated throughout the year for several years in a row is likely to reduce the growth of Sea Rush and facilitate the establishment of other species of conservation and pastoral interest. The effect can be significantly improved if it is supplemented in the spring by grazing the regrowth. In this case, the instantaneous grazing pressure must be high, as the herbivores will only consume the regrowth to a significant extent if they have no other choice.

Uprooting plants can only be done in small areas in response to specific issues such as a threat to individuals of a protected species. It can be carried out manually for young plants but must be done mechanically for older clumps. Exposing the soil can encourage further sprouting of Sea Rush, so it is essential to monitor the area after the intervention.

Controlling Sea Rush by **removal*** of 10 to 20 cm of topsoil and exporting it is only effective if the hydraulic conditions that led to the colonisation by Sea Rush are modified and if future sprouts on the removed soil are eradicated.

Ploughing causes the clumps to be uprooted, leading to their death if conditions are not favourable for their survival - a dry period of several months is then required. As with all treatments that remove plant cover and rearrange the soil, there is a high risk of the species itself or other undesirable species re-establishing itself/themselves. Vigilance is therefore required until the plant cover has fully recovered.

Topsoil removal* and ploughing are particularly disturbing methods for the habitat.

3.3.3 French Tamarisk, *Tamarix gallica*

French Tamarisk is a shrub whose slender branches bear scale-like leaves that excrete salt crystals. It grows rapidly (more than a metre a year), reproduces sexually and has vegetative reproduction mechanisms that enable it to spread quickly.

The presence of tamarisk prevents the growth of other plants by producing litter that creates limiting conditions for species whose seedlings require light. The sap it secretes, which contains salt, accumulates on the soil surface as the leaves fall, forming a surface crust that prevents the germination and survival of seedlings of other species. In addition, these tamarisk trees modify the hydric conditions in their immediate vicinity by reducing water availability.

BIOLOGICAL CHARACTERISTICS

French Tamarisk does not generally flower until the third year (between May and August). An individual can produce more than 500,000 seeds, but these seeds have limited viability (2 months). Therefore, there is no persistence of tamarisk seeds between years *(transitory seed bank, § 1.2.2)*.

Figure 82: *Tamarix gallica.* © L. Wilm

French Tamarisk has a root system capable of drawing water from the soil's superficial reserves as well as deep down, thanks to its vertical root, which can descend more than three metres, and an adaptive network of more or less horizontal secondary roots. This dual system makes it highly resistant to periods of drought or when the water table dries up, but also enables it to take advantage of saturated soils.

During its development, numerous **shoots*** are produced from the stump. This production is encouraged by events such as fire or the use of herbicides. Vegetative reproduction takes place from root buds on superficial roots, which can produce **suckers***. Branches capable of producing adventitious roots can also reproduce by **layering*** or **cuttings*** if the soil is damp in spring or autumn.

ECOLOGICAL REQUIREMENTS

Tamarisk is favoured by a high level of **hydromorphy***. It thrives in habitats subject to temporary, low-intensity flooding with a summer drop in water levels. Germination and growth are little affected by salinity levels of up to 30 g/l. It is therefore particularly well suited to conditions in flooded areas on the edges of marshes, along canals, or near the coast in brackish water. Germination takes place from spring to autumn in saturated soils, preferably between 15 and 30° C. In favourable conditions, its survival rate is high.

Figure 83: French Tamarisk is a species capable of rapidly colonising space by sowing seedlings that are difficult to control once established. *© L. Wilm*

PASTORAL VALUE / EFFECTS OF GRAZING

Tamarisk is unpalatable to domestic herbivores. The risk of it growing, particularly in the early stages of restoration when there is still no cover, is therefore not reduced by the presence of grazing. On the other hand, high levels of trampling can encourage Tamarisk establishment by creating the micro-conditions sought after by the species.

MEANS OF CONTROL

It is vital to uproot young plants before their central root develops, taking advantage of a period when the soil is still damp. This is an easy operation, but it does require some workforce. It should be carried out systematically and regularly, and care must be taken to remove all seedlings.

Cutting young plants, followed by a prolonged (one month or more) flood that covers the entire area, is also effective. However, this operation must be carried out before the seeds are disseminated in early spring.

Only burning plants is a risky practice that can only be effective during the dry season when the heat is at its peak. It must then be carried out slowly (in light winds) so that the base of the Tamarisk is really damaged. Otherwise, the fire will stimulate the production of new **shoots***.

Mechanical uprooting, in addition to burning, is a method that disturbs the habitat but is effective for older individuals. **It involves three steps:**

- cutting, followed by burning of the above-ground parts to prevent re-growth by **cuttings***,
- ploughing (to a depth of 40 cm) to cut off the root crowns,
- removal of the stumps, which may be left in place if the habitat is dry and remains dry enough to cause mortality. However, burning them avoids any risk of them starting to grow again.

Continuous monitoring must be carried out as long as the cover by other species does not guarantee a sufficient **preemption effect*** that will prevent any new Tamarisk from sprouting.

Figure 84: Flowering Water Primrose. *© P. Grillas*

3.3.4 Water Primrose, Floating Primrose-willow, *Ludwigia grandiflora, L. peploides*

Primrose are aquatic plants native to South America, introduced in France in the 19th century for ornamental purposes. Since then, they have colonised many wetlands, calm watercourses, and their edges (Ellmore 1981 **95**, Dandelot et al. 2005 **70**, Lambert et al. 2010 **155**, Haury et al. 2014 **130**). In addition to their invasive nature and their capacity to eliminate other species, their ability to invade irrigation canals poses major water management problems.

BIOLOGICAL CHARACTERISTICS

They are capable of taking root at a depth of several metres from pieces of **rhizomes***. They develop dense mats of long floating or submerged stems with aerenchyma*. On these stems, **adventitious roots*** develop from the nodes, contributing to the individual's diet and capable of regenerating tissues and providing **cuttings*** in the event of fragmentation. This capacity to reproduce makes control methods much more complex, with the risk, on the contrary, of facilitating their expansion.

L. peploides produces large quantities of seeds suitable for germination, but the contribution of the sexual pathway to colonisation by the two species in the Mediterranean is considered to be negligible.

ECOLOGICAL REQUIREMENTS

Water primrose is not very shade tolerant. They prefer fresh water with a slow current. They can establish themselves in deep water as well as in alluvial areas, and can colonise banks as long as the soil remains moist. They are tolerant to soil richness and pH.

Ludvigia grandiflora can withstand long dry periods, even in relatively salty soil, developing a prostrate form that is resistant to the conditions imposed. *L. peploides* is more hygrophilic.

PASTORAL VALUE

Water primrose is considered to be of little interest for forage. The few studies available on whether domestic herbivores consume these two species are contradictory. Generally speaking, without any constraint, domestic animals seem to not eat Water Primrose.

EFFECTS OF GRAZING

The application of high instantaneous grazing pressure, considered promising by several studies, seems difficult to implement over a sufficiently long period to be effective, if only because of the lack of interest shown by the animals.

On the contrary, domestic grazing can encourage the expansion of Water Primrose, as trampling creates fragments that can easily escape from the site via the canals resulting in new colonisation points at other locations.

MEANS OF CONTROL

Given the biology of the two species and their strong capacity for colonisation, corrective management is in most cases temporary and, in the long term, illusory.

The application of particularly significant and repeated dry periods (several consecutive years) is effective but rarely feasible. On canal banks and adjacent habitats, tests aimed at preventing colonisation by Water Primrose by sowing other species have proved inconclusive.

Figure 85: Manual removal of Water Primrose. *© Tour du Valat*

Preventive action must therefore be favoured. This involves limiting the formation and dispersal of **propagules*** by uprooting/mowing or introducing saline water.

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GLOSSARY

A.

- **Aerenchyma:** modified parenchymatous tissue having large intracellular air spaces that is found especially in aquatic plants where it facilitates gaseous exchange and maintains buoyancy, and is necessary for photosynthesis and respiration
- **Achene:** a small dry indehiscent (non opening spontaneously) one-seeded fruit (as of a sunflower) developing from a simple ovary and usually having a thin pericarp attached to the seed at only one point
- **Adventitious root:** root that appears on the rhizomes or aerial parts of a plant
- **Allotment:** division of a herd into groups according to age or sex to facilitate management
- **Anemochory:** behaviour of a plant that has seeds or spores adapted (as by pappi) to distribution by wind
- **Anthelmintic:** remedy for certain worms (Helminthes)
- **Appetibility:** cf. palatability
- **Appetizing:** a food's capacity to stimulate the desire to consume it

B.

- **Bearing capacity:** the capacity of soil to withstand the pressure exerted by the hooves of a herbivore
- **Biotope:** cf. ecosystem
- **Bract:** a type of small leaf that grows from the area just below a flower and is sometimes different in shape or colour from the main leaves
- **Browser:** herbivore feeding on both low and high vegetation (monocotyledons or dicotyledons), grasses as well as tree buds or leaves in open or closed habitats

C.

- **Carrying capacity:** number of herbivores acceptable to a habitat, given the forage available and without habitat degradation
- **Clone (clonal):** population formed by vegetative propagation from a single individual
- **Colonisation/invasion window:** opening in the vegetation that allows species to establish themselves, and from where they can subsequently colonise the surrounding area
- **Community:** all the organisms belonging to different populations living together in the same habitat
- **Cuttings:** method of propagating plants from a piece cut off from a plant that can be used to grow another plant of the same type

D.

- **Denitrification:** anaerobic process playing a major role in the nitrogen cycle, occurring in the soil, particularly in wet environments, during which bacteria reduce nitrate ions (NO_3^-), to nitrite ions (NO_2^-), then nitric oxide (NO), nitrous oxide (N_2O), and finally dinitrogen (N_2).

- **Detachability (of soil):** A soil's capacity to be broken up (by rain), with the particles becoming transportable

E.

- **Ecological trajectory (SER definition):** the evolutionary path of an ecosystem over time. In restoration, it starts with the unrestored ecosystem and progresses towards the expected state of self-repair (reference ecosystem)

- **Ecosystem:** a complex made up of a biotope (habitat conditions) and a biocenosis (all the species using the biotope)

- **Ecotype:** an individual (population) genetically distinct from the typical individuals of the species, selected by the environmental conditions (habitat) but able to interbreed with other ecotypes of the species

- **Eutrophication:** accumulation of nutrients in lakes and rivers, which causes a change in biological balance and a depletion of oxygen

- **Externality:** effects (benefits or costs) generated by an activity and not taken into account by the objectives which led to this activity

- **Ecosystem services:** functions of an ecosystem exploited or used by humans: provisioning services, such as fodder production; regulation services, such as flood control; cultural services and more

F.

- **Feeding:** supplying forage to grazing livestock

- **Facilitation:** positive interaction between one plant and another that reduces the negative (abiotic or biotic) effects of the growing environment

- **Faeces:** animal excrement

- **Feeding ground:** feeding area for animals (particularly birds)

- **Functional groups:** a complex of populations of different species, usually phylogenetically close, which, in a community or ecosystem, perform the same function and can therefore be grouped together

G.

- **Grazing with a shepherd present/shepherded grazing:** a way of shepherding livestock throughout the day, handling them according to forage availability and the desired vegetation exploitation objectives
- **Grazer:** herbivores which feed on herbaceous plants (particularly Poaceae) in open habitats

H.

- **Helophyte:** plants in wet environments whose vegetative and reproductive systems are largely aerial. Large helophytes: reeds, bulrushes
- **Holistic (approach):** an approach aimed at treating the whole of something and understanding a mechanism in its entirety
- **Hydrochory:** propagule dispersal mechanism via water
- **Hydromorphy:** the condition of soil that is saturated with water

L.

- **Layering:** production of a new individual from a layer - part of the plant which separates from the mother plant after having differentiated all the necessary plant parts

M.

- **Meristem:** embryonic cell tissue forming a growth zone in plants
- **Mineralisation (of nitrogen):** decomposition of organic matter in soil, (organic nitrogen) by micro-organisms, into nitrogen that can be assimilated by plants

N.

- **Nitrophilous:** plant that grows preferentially on sites rich in nitrogen
- **Net productivity:** gain in organic matter obtained over a given period of time. Net productivity between t0 and t is calculated by subtracting the biomass measured at t0 from that measured at t

O.

- **Ornithochorous:** a plant whose spores, seeds, or fruits are dispersed by birds
- **Overgrazing:** excessive grazing pressure leading to degradation of the habitat through destruction of the plant cover and the development of species that are not grazed

P.

- **Palatability:** physical and chemical characteristics of a plant that influence the desire to eat it
- **Paucispecific:** having or composed of a low number of species
- **Population:** all the different populations present in the same habitat
- **Phenology:** the successive phases in the development of plants
- **Photoperiod:** relative duration of daylight (proportion day/night hours)
- **Polyploid:** living being with at least three complete sets of chromosomes (3 n)
- **Preemption:** negative interaction (competition) exerted by a plant already present, preventing the establishment of individuals of the same or another species
- **Propagule:** a plant's asexual dissemination structure. By extension, any dissemination structure (including seeds)
- **Prophylaxis:** all treatments aimed at preventing the onset, spread, or aggravation of diseases
- **Proxy:** substitution variable that can be used to replace a variable that we wish to consider but which cannot be directly observed

R.

- **Rest area:** animal resting area (particularly for birds)
- **Resilience:** capacity of an ecosystem or community to recover its structure and functions after being damaged
- **Rhizome:** a network of stems of some plants that grow along or under the ground
- **Ruderal:** a plant that grows on a site that has been heavily impacted by human activity

S.

- **Shoot:** new growth that appears at the base of a stem or trunk, often after a disturbance
- **Soil improvement:** action aimed at increasing the productivity of soil by adding fertilising products or materials
- **Stand:** a growth of plants in a particular area
- **Suckling/suckled cow:** a lactating cow giving milk to her calf
- **Stochastic (events):** changes considered to be random insofar as their origin is external to the plant population/community in which they occur (e.g., uncontrolled addition of seeds)
- **Stolon:** creeping (or arching) above-ground stem that takes root and produces a new plant (layering)
- **Sucker:** new growth on an existing plant that develops under the ground from the root or the main stem, or from the stem below a graft

T.

- **Topsoil removal:** operation consisting of removing a superficial layer of soil

U.

- **Ubiquitous (plant):** able to establish itself and develop in a variety of biotopes
- **Undergrazing:** grazing pressure too low, leading to degradation of the habitat through the development of the most competitive species

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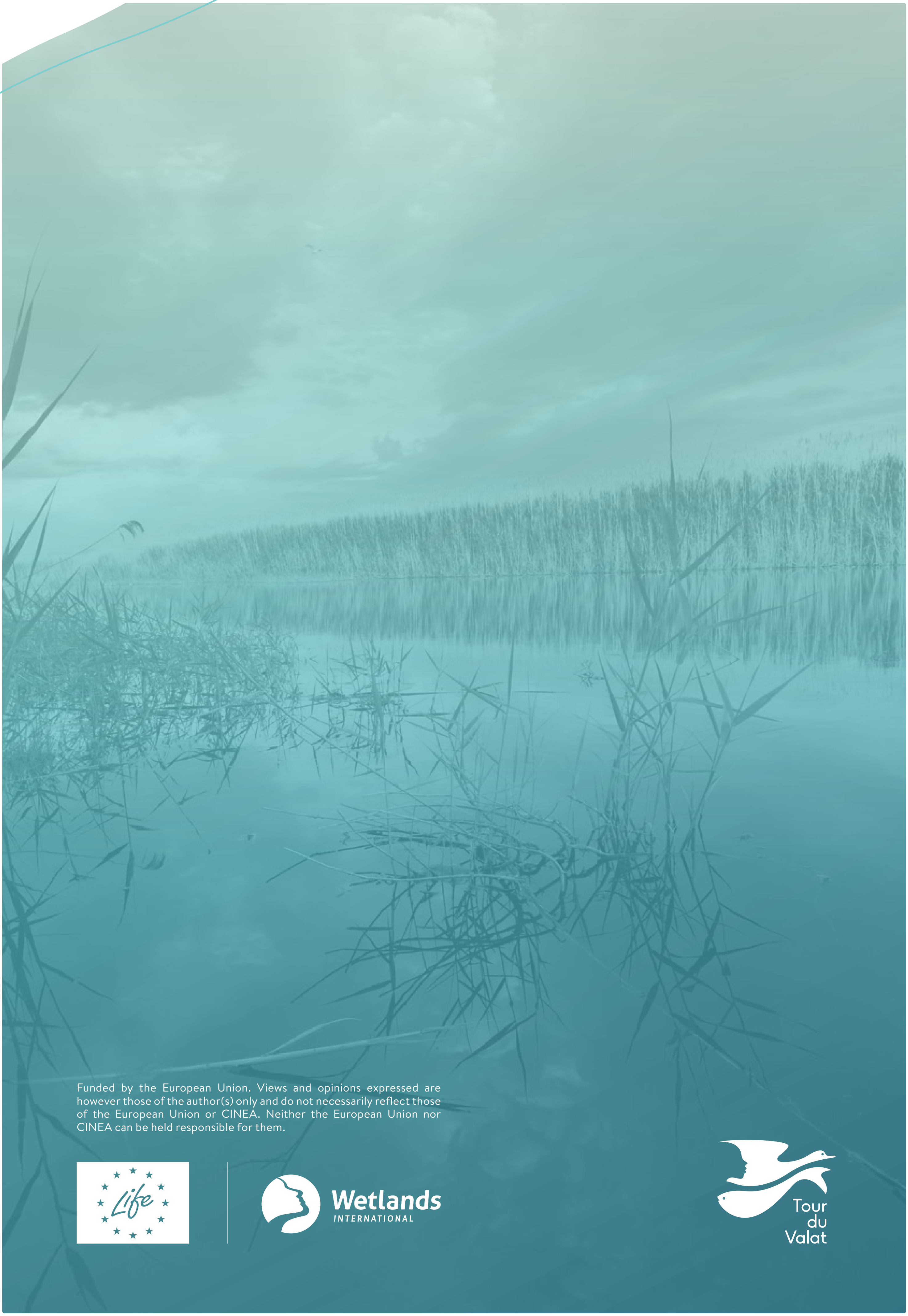

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