Ecological Restoration
of Fish Nurseries in Shallow Coastal Areas of the Mediterranean Basin

Guidelines and Principles

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A Word from the Funders

AERMC

Ecological Restoration of Mediterranean coastal waters is relatively new and emerging, both as a scientific endeavour and as an area of activity. The first projects were conducted in highly urbanised sectors such as ports and harbors. In one program, "Save the Water", the Rhone-Mediterranean and Corsica Water Agency (RMC Water Agency) decided to support the development of this new management approach for the benefit of the marine environment. This led to applied research, diffusion of information regarding the functioning and scientific nomenclature of the marine environment and new restoration projects in shallow coastal areas. This Guide presents the current status of technical and scientific knowledge regarding the restoration of shallow coastal zones in Mediterranean areas. The operational recommendations contained herein have made this Guide an important reference for the entire Mediterranean Basin.

Var Departmental Council

For several years, the Var Department has been committed to the preservation of its coastal and marine ecosystems and habitats, and developed a Departmental Strategy for the Sea and the Coast that was implemented in 2011. The Strategy highlighted the challenges of managing this rich and fragile environment and defined five priorities which were shared with coastal communities and included in the “Departmental Charter of the Sea and the Coast for a collective management scheme of the Var coastal zone”. This was agreed upon and officially recognized by a large number of partners and stakeholders, yet nevertheless there were infringements. It is therefore necessary to emphasize the importance of the marine ecosystems that border our territories. Decision makers, primarily elected officials from the Var, should begin complementing their management and conservation efforts with restoration projects. These combined efforts will facilitate a transition towards policies aimed at sustainable development of the coastal zone of the Var. This Guide can help in attaining this objective. Those involved in the emerging sectors of marine ecological engineering and ecological restoration will also find that the Var Department provides ideal conditions in which this field can develop and expand.

Pôle Mer Méditerranée

The Sea Innovation Cluster - *Pôle Mer Méditerranée* has identified coastal ecological engineering and restoration as strategically important for restoration, rehabilitation and sustainable development of ecosystems linked with the marine environment and for sustainable development of the coastal region. This challenge is part of a medium to long-term perspective.

This emerging sector within France has developed R&D projects conducted by innovative companies in collaboration with leading research laboratories. After just 4 years, they are already beginning to show positive results. For the moment, the results are qualitative, but research continues in order to determine the benefits of this restoration work. Communities and municipalities have begun restoration efforts based on these initial results. Coastal ecological engineering and restoration are also becoming important competitive criteria for companies having or bidding for construction projects on the coast. This Guide was designed to become a fundamental tool and aid for the development of future work involving coastal ecological engineering and ecological restoration of shallow coastal areas. By supporting this Guide, *Pôle Mer Méditerranée* has reinforced its commitment to the promising future of the coastal ecological engineering and restoration sectors as well as promoting French expertise worldwide to environmentally engaged countries.

CREM

Today, we are confronted with the obligation to reconcile economic development and environmental conservation. The "environment" is among other things provider of a large number of **ecosystem services** which make food resources available and allow the sustainable development of human activities. To better understand the mechanisms of these services, information in various domains is needed. Above and beyond simple descriptions of species, it is now important to understand how maintaining ecological functions will in turn ensure the smooth progression of each stage of the life cycle of individuals, especially within fragile zones such as shallow coastal regions where juvenile fish live and grow. The first management tools put into place focused on conservation through the creation of Marine Protected Areas (MPA). These MPA are centers of biodiversity and biomass dispersion yet cover only a small percentage of the coast. However, the human footprint extends over significant portions of the coast: from several hundred metres for the smallest marinas, to several dozen kilometres for large commercial ports. They are more often built in the most protected sites along coasts with strong swells, precisely where natural fish nurseries were initially found. It is within this context, and with 20 years of solid experience in fish ecology (particularly the study of juveniles), that the scientists at CEFREM (Centre of Education and Research on Mediterranean Environments) and the CREM Platform (Centre of Research on Marine Ecosystems) developed ecological restoration projects. Thus, while providing support for societal questions and issues, they contribute to the emergence of the interlinked fields of ecological engineering and ecological restoration. Both theoretical and practical aspects of these projects have been incorporated into this Guide.

Preface

Concerns about the state of our global environment have led scientists to sound the alarm, particularly for problems relating to climate change and massive destruction of biodiversity. Concerns for the marine environment were also voiced, including the Mediterranean, which is one of the most sensitive marine zones on the planet.

This sensitivity is mainly due to the pressures that the Mediterranean area has had to endure: flows from rivers and watersheds, massive tourism, marine traffic, natural resource exploitation, urbanisation of the coastal fringe, and more.

Awareness of this situation began in the 1970s at both national and European levels, when a first series of measures were taken to reduce pressures and bring the ecological state of water masses to an acceptable level. In addition to taking action to protect sites with strong heritage value, ecological engineering measures were also implemented to restore degraded environments. It was therefore necessary to review existing knowledge in the field of restoration, as well as actions already performed, the state of technical resources and current political will.

Thanks to a call for ideas on "ecological restoration of shallow coastal regions of the Mediterranean", initiated in 2013 by the Rhone-Mediterranean & Corsica Water Agency, the Var Departmental Council and the *Pôle Mer Méditerranée*, the various contributors and authors of this Guide were able to provide their vision, knowledge and experience on this important topic.

This Guide is written by university-trained ecologists specialising in marine environments and ecological restoration, entrepreneurs who have invested in ecological restoration measures in the Mediterranean, and decision-makers and funders in charge of applying public policy. It presents the fundamental aspects of the ecology of shallow coastal areas, their role in the life cycle of fish as well as for human society, and all of the major issues and challenges that currently exist in the Mediterranean region.

The objective of this Guide is to become a reference work for the Mediterranean region, thereby providing key information needed to develop and implement shallow coastal water restoration or rehabilitation projects. It provides a review of what ecological restoration is, and what is possible to do or not do within a restoration project. It provides a foundation for starting a restoration project and sheds light on public policy investments in this domain, as well as on the development of the sector.

The Guide is essential reading for anyone who wishes to be informed about ecological restoration and ecological engineering of marine environments and the functioning of shallow coastal areas. It also describes the challenges and what is at stake in the context of expanding knowledge and knowhow in this emerging field. It will be of interest to researchers, funders, managers, businesses and engineering consultants who have projects or programs that focus on the marine environment.

Brown seaweed "forest"(*Cystoseira crinita*)

Part 1

Restoration for Biodiversity
Ecological Framework and Challenges

School of Salema porgy (*Sarpa salpa*)
and *Cystoseira* algae (*Cystoseira brachycarpa*)

Introduction

1. The importance of the Mediterranean and the issues at hand

Oceans occupy 71% of the Earth's surface and contain a large proportion of its **biodiversity** [1]. According to recent assessments (Coll *et al.*, 2010), the blue portion of our planet is home to approximately 230,000 marine species, of which 12% are fish.

The Mediterranean is a semi-enclosed sea with a temperate and warm environment, and has always been an ecologically abundant area. Although it represents only 0.8 % of the surface area of the Earth's oceans, it contains 8 to 9 % of global marine biodiversity and has very high rates of endemism for many groups of organisms. The Western basin, a part of which is under French jurisdiction, is one of the most diverse areas of the Mediterranean with nearly 350 species of fish. Given the exceptional diversity and ongoing threats to species and their habitats, the entire Mediterranean region, including the Sea itself, is considered a global biodiversity "hot-spot".

Among the vast expanses of marine waters, coastal regions are the most productive. Due to the contribution of coastal watersheds and frequent **upwelling**, these waters are rich in nutrients. Once these nutrients reach the **euphotic** zone of the coast, they trigger the start of the **food chain**. The coastal fringe is also home to numerous so-called nursery zones, which are vital for the renewal of populations of many marine organisms, especially fish.

However, human activities are developing very rapidly along the coastal regions of the Mediterranean, with dire consequences for these nurseries and other **habitats**. Over the past two centuries, the coastal regions have been progressively urbanized and professional fishing and maritime transport sectors extensively developed, all of which has led to the construction of numerous and elaborate ports. Also, due to the favorable climatic and ecological conditions of the Mediterranean, it has become the number one tourist destination worldwide, and the human population triples every year during the summer months.

All of this has accelerated the development of coastal infrastructures of all sorts, including resorts, marinas, and coastal embankments. Occupancy rate in

Rocky shallow areas

1 *The bolded words are defined in the glossary*

the low-lying coastal regions, from shoreline to 10 m above sea-level in the French Mediterranean coastal area has grown threefold since 1975 (Figure 1).

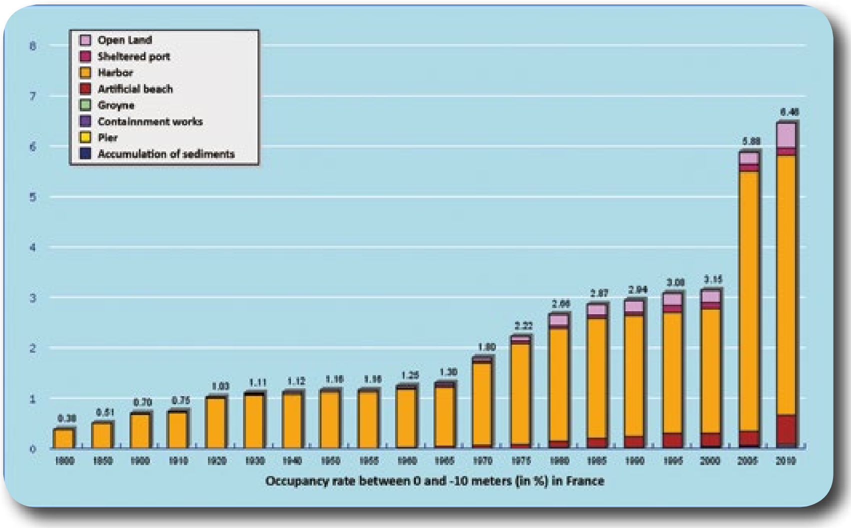


Figure 1 - Occupancy rate of shallow coastal areas (from 0 to 10 meters deep) along of the French Mediterranean coast, from 1800 AD to the present. Data from MEDAM website.

All of this has major consequences for biodiversity. Today, the destruction of habitats is considered the primary cause of the loss of **biodiversity** on the planet (Balmford & Bond, 2005). Therefore, and not surprisingly, the current status of coastal marine systems in the Mediterranean is one of the worst in the world (Coll *et al.*, 2010). Awareness of this horrific situation has led to calls – and some funding – for urgent actions to halt or reduce the negative impacts on coastal **ecosystems** in order to maintain biodiversity and the beneficial role these ecosystems provide for human health and well-being.

> The MEDAM Program

This network aims to identify the physical pressures that affect the coastal aeras of the French Mediterranean region. The data collected shows that more than 11% of the Mediterranean coastline has been denaturalized, but in an uneven way:

> *Languedoc-Roussillon region - 19.51%, including 40.6 % of the coastline of the Gard Department,*

> *Provence-Alpes-Côte d'Azur region (not including Monaco or the Berre lagoon) – 19.05%, including 27.4 % of the littoral of the Alpes-Maritimes Department,*

> *Corsica - 2.21 %*

This network is financed by the Rhone-Mediterranean and Corsica Water Agency, the DREAL of Provence-Alpes-Côte d'Azur, the Provence-Alpes-Côte d'Azur Region and the University of Nice Sophia Antipolis.

The areas for which this Guide was developed include not only the shallow coastal strip, or littoral, but also transitional zones such as estuaries and lagoons that also play vital ecological roles (Figure 2). These zones are all rich in diverse habitats used as nurseries by many marine species.

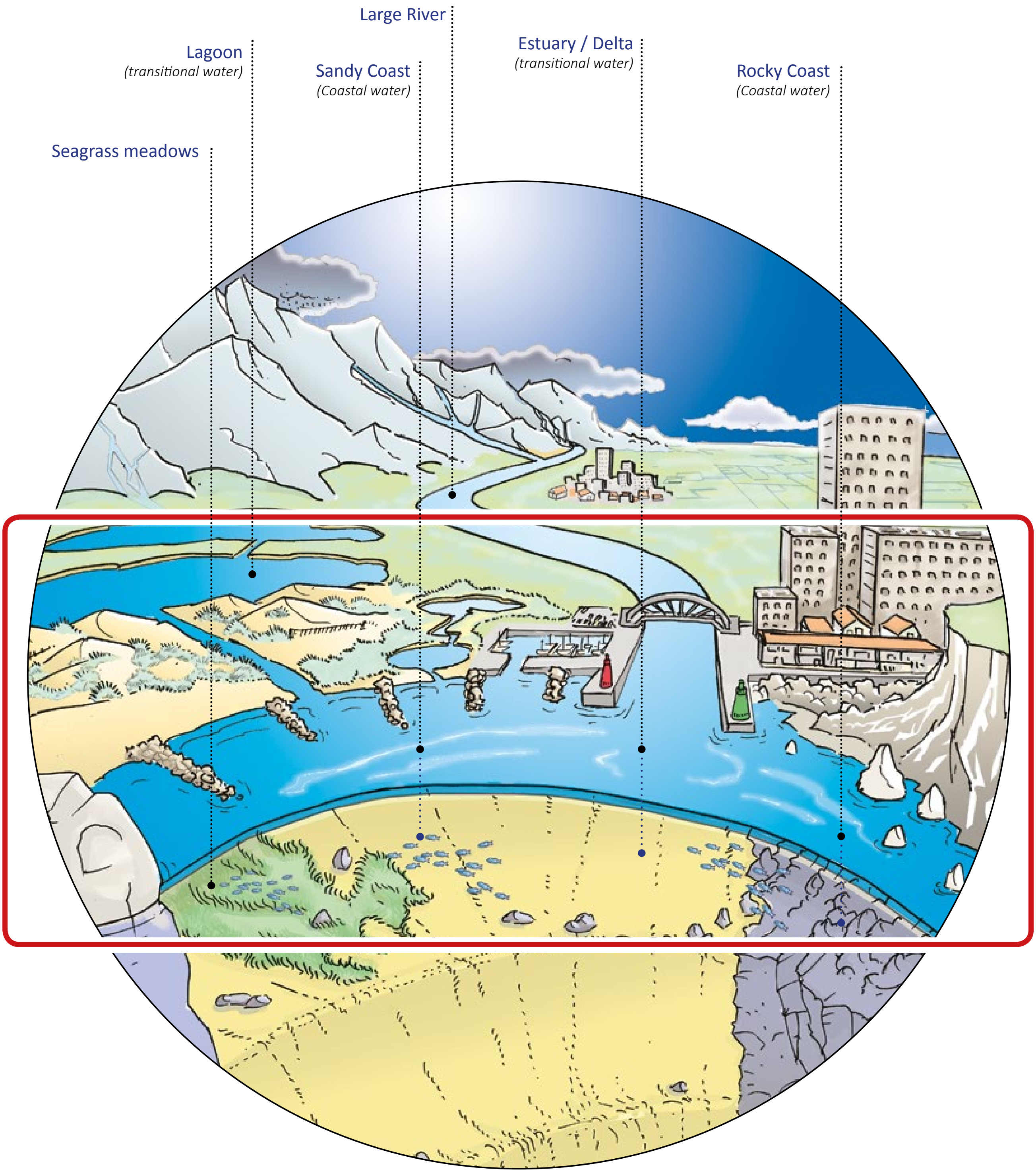


Figure 2 - Schematic representation of the Mediterranean coast.
The area for which the Guide was developed is represented by the red box.
The main physical components as well as the principal coastal habitats are also shown.

2. Regulation to protect the seas and oceans

Since the 1970s, international, European Union and national laws of many nations have evolved rapidly, and increasingly reflect the importance of integrating the environment into the legal framework. To illustrate, we summarize the principal legislative texts related to our specific theme.

At the international level, RAMSAR (1971), the Barcelona convention (1976) and various summits including Stockholm (1972) and Rio +20 (2012) have raised awareness of the need to better preserve the health of our ecosystems and to manage our natural resources more sustainably. However, this is rarely translated into concrete action: of the 90 decisions taken at the Rio summit, only 5 have been effectively applied.

Nevertheless, **in the European Union**, actions towards the implementation of a coherent EU policy for the preservation of a significant portion of all ecosystems and habitats have progressed rapidly over the last 20 years.

In 1992, thanks to the Habitats Directive (92/43/EEC), the Natura 2000 network was implemented in member states for the protection of terrestrial and marine sites of importance for the rarity or vulnerability of resident populations of rare and threatened species, or where such habitats were deemed threatened. Today, the French portion of the network includes 1758 sites, of which 200 have a maritime component. It should be noted that not all Natura 2000 sites have an operational management system in place as yet.

In 2000, the European Council adopted the Water Framework Directive (WFD) (2000/60/EC), thereby establishing a firm framework for the management and protection of bodies of water by catchment basin with the aim to help recover and guarantee their "good ecological condition" by 2015. For the first time, marine coastal waters and transitional zones (lagoons and estuaries) were targeted within this ambitious framework, specifically in the zone between the coastline and 1 nautical mile off-shore.

In 2004, the Environmental Liability Directive (ELD) (2004/35/EC) aimed at reducing the environmental impact of human activities, by making those who engage in activities that degrade the environment legally responsible for the repair of such damage, i.e. "the polluter pays ". The EDL is mainly concerned with damages caused by industrial accidents that impact the environment and the ecosystem services rendered to the public. This directive is, therefore, intended to evaluate and impose adequate compensation for all damages that have impacted a zone protected by the Habitats Directive (92/43/EEC). Additionally, damages to populations of a species protected under the Birds Directive (2009/147/EC), or those leading to the degradation of water and aquatic ecosystem resources as defined by the Water Framework Directive (2000/60/EC), may also require compensation.

According to this Directive, compensation must be made "in kind" through ecological restoration projects, whereas previously offenders were only required to provide financial compensation for moral and material damage to victims of the accident. Notably, in France, efforts are underway to promote legal recognition of environmental damages, in addition to those caused to people as a result of environmental damage (Neyret & Martin, 2012).

In June 2008, the Marine Strategy Framework Directive (MSFD) (2008/56/EC) was enacted, thereby establishing a framework of community actions specifically for the marine environment across marine sub-regions. Its objective is "the sustainable use of seas and the conservation of marine ecosystems" by 2020. The coastal regulations issued by the MSFD take into account the obligations of previous regulations (Water Framework Directive (WFD) or Natura 2000). The French government has transcribed this directive into a Plan named PAMM (*Plan d'Actions pour le Milieu Marin*, Action Plan for the Marine Environment) at each of its sub-maritime metropolitan regions, which includes the western Mediterranean. The preservation of functional zones is a theme of one of the environmental objectives identified in the marine sub-regions of the western Mediterranean.

In France, the first Water Act dates back to 1964. The aim was to better organize the decentralized management of water basin watersheds and to protect drinking water catchments. The act corresponds to the anthropocentric vision of the time when it came to protecting aquatic **ecosystems**: "there is a need to protect nature in order to facilitate the uses that people draw from it". Meanwhile, it became evident that the necessity to protect coastal areas needed to be weighed against financial considerations, and in response the "*Conservatoire du Littoral*" (Conservatory of the Coast) was created in 1975. The objective was to acquire coastal territories in order to avoid their urbanization and to protect their ecological heritage. Today, the Conservatoire is a member of the International Union for Conservation of Nature (IUCN) and owns 12% of the French coastline.

In 1986, the Coastal Act reinforced this philosophy and imposed regulations with regard to the urbanization of the coast. It is now forbidden to build any structures within 100 meters of the coast. The main objective of this law is to preserve coastal ecosystems and to ensure that the aquatic economy is sustainable.

In 1992, the second Water Act laid down the principle that "water forms part of the common heritage of the nation". This act initiated and institutionalized the preservation of aquatic ecosystems and the protection of water quality. Conservation of water resources was given priority over unlimited development. The resulting guidelines and management plans (SDAGE, *Schéma Directeur d'Aménagement et de Gestion des Eaux*) released in 1996 was the first set of planning documents to take into account the environment and the preservation of land/sea continuity within its objectives.

In 2006, the WFD was rewritten into French law and the Water and Aquatic Environments Act (LEMA) was conceived. The Act reformed the global framework defined by previous Water Acts by setting out integrated objectives that would need to be met in order to obtain good ecological status of water masses, such as coastal and transitional waters.

The Grenelle Act I, or Act no. 2009-967 of 3 August 2009 is a French planning law which formalized the 268 environmental commitments of the Grenelle of the Environment[1]. This law (article 1), fixes objectives by defining a framework of action, long term governance and policy in order to apply the principles of sustainable development. The Act also requires the revision of decision-making procedures to give priority to solutions that take the environment into consideration.

1 Grenelle has no linguistic or legal equivalent in the English-speaking world but can be best defined as an open-ended multi-party accord or round table with legal powers

This Act was finalized through the Grenelle Act II or Law No. 2010-788 of 12 July 2010, which established a national commitment to the environment. This law implements objectives with more detailed provisions (248 articles) in six major projects, which include the preservation of biodiversity.

In 2009, the Grenelle of the Sea was created to supplement the provisions of the Grenelle Acts I and II, and covers the larger thematic field of sustainable development and use of the sea. It has helped to define national strategies for the sea and the coast, and to identify short to long-term objectives. The coastal regions and marine biodiversity are, of course, included in its remit.

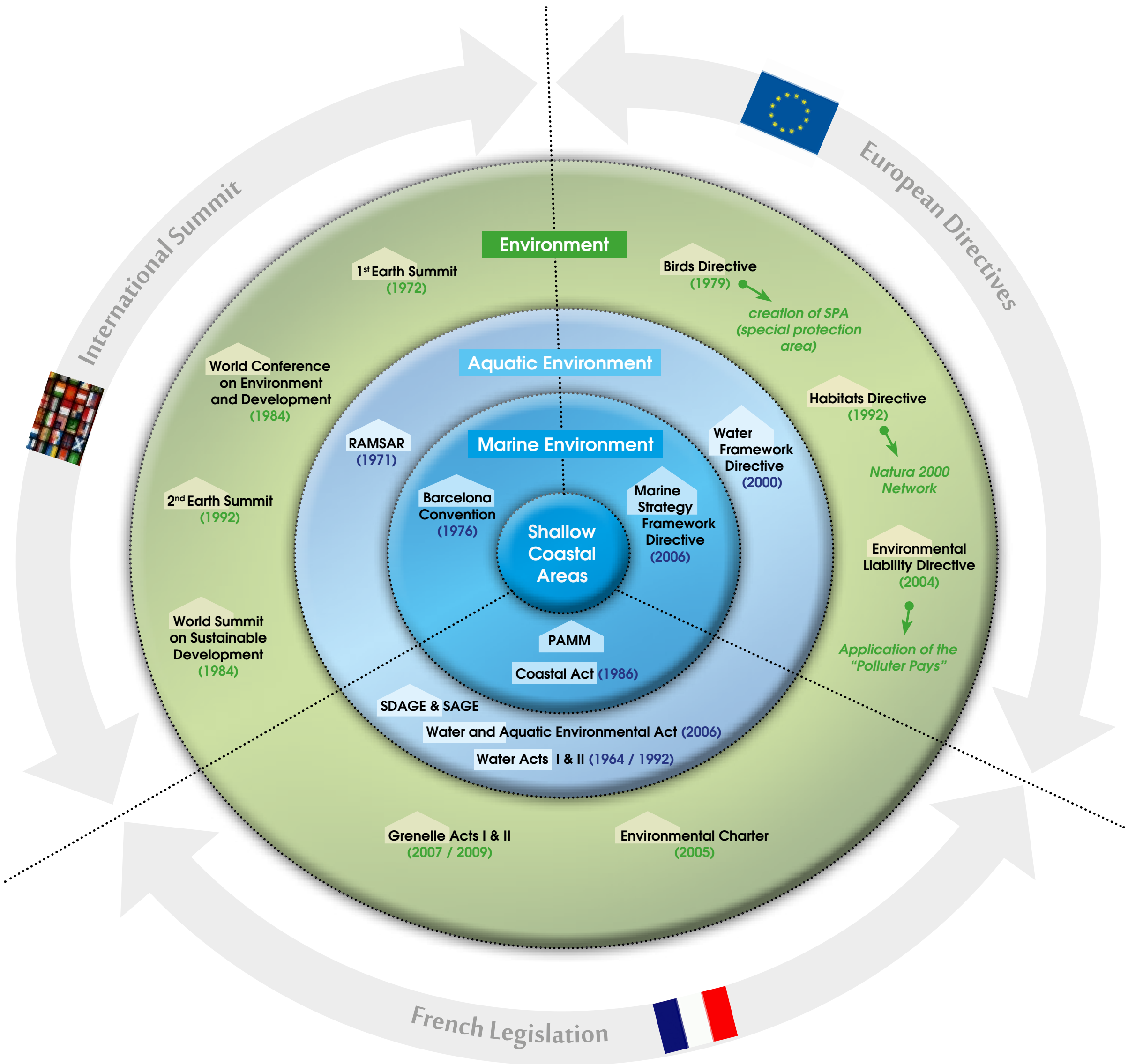


Figure 3
The evolution of legal regulations for the environment,
the marine environment in general, and shallow coastal areas in particular.

> **Conservation of Fishery Resources Zones (ZCH)**
>
> *The objective of this new tool that will be enacted in 2016 is to create locally protected functional zones which provide habitats for the reproduction and growth of species, including spawning grounds and nursery areas. These areas are defined according to their importance in the management of stocks, as well as their conservation status and risk of degradation. A follow-up plan will be created for each zone to reconcile the different uses and introduce measures that prohibit or regulate human activities that could have a negative impact. Depending on the situation, this plan will also include an experimental component in order to enable and test environment restoration strategies and innovative solutions in the zones. In contrast to natural reserves, these ZCH will not have permanent management structures. The perimeters of each zone will be a marine boundary up to 12 nautical miles from the coast (distance according to specific need) and an estuarine boundary where river water meets sea water and become salinized.*
>
> Article 43, Biodiversity Law Project (DEVL1400720L), adopted at second reading at the French National Assembly on 26 March, 18th 2016 and currently discussing at the French Senate.

Over the past 50 years, the social demand for environments to meet quality standards has evolved rapidly. We have gradually developed a balanced and practical approach to coastal conservation which will provide the impetus to implement preservation and restoration projects for the benefit of the various ecosystems along the coasts.

3. The specific context of a marine environment project: a story of land

In France, the coastal region is not divided into private and public parcels like land, but rather belongs exclusively to the State. Accordingly, it is called Publicly-owned Coastal Land (DPM, *Domaine Public Maritime*) for legal purposes, and includes the soil and subsoil of the **foreshore, inland waters, territorial sea** and salted lagoons in direct, natural and permanent communication with sea. It also includes any biological materials cast up on beaches (e.g. algae, sea-grass, seaweed, shells, driftwood), littoral zones in some Overseas Departments, and land reserved for the public interest (maritime, seaside or touristic). The DPM is divided into 2 categories: artificial DPM, which includes ports, security installations, safety installations and navigational facilities; and natural DPM, which includes all the rest (internet source: MEDDE, Atlantic Maritime Prefecture).

This DPM, in which the resources are common property, is highly regulated. For activities that fulfill a public need or have a public use, and for which immediate proximity to water is necessary, the State can occasionally provide DPM occupancy title deeds through the maritime prefect. Examples include seaside recreation and tourism, mariculture, building port facilities or maritime security, and the preservation of the DPM as a natural area.

Obtaining an occupancy title deed does not exempt the applicant from current regulations. In fact, depending on the nature and extent of the activities or construction put into place on the DPM, an environmental impact assessment will be necessary (impact analysis, analysis resulting from the Water Act, exceptions for protected species, etc.). If the activities generate negative impacts on the ecosystem, it is necessary to put preventive or reductive measures into place, and if these negative impacts occur, then compensatory measures are required.

Introduction

> SUMMARY

The Mediterranean Coast …	*The Mediterranean Basin is a biological cornucopia, by any standards. Although it contributes less than 1 % of the Earth's surface water area, it contains 8% to 9% of global marine biodiversity. It also has a very high rate of endemism. This attribute makes the Mediterranean sea hot-spot of biodiversity.*
… is a zone with significant challenges.	*Significant pressures (urbanization, tourism, maritime uses, etc.) exerted on the seabed located close to the coasts (shallow coastal areas) have caused the destruction and fragmentation of habitats, which is the leading cause of global biodiversity loss.*
The political landscape …	*The regulatory context of the marine environment has evolved over the past 40 years at both European (WFD, MSFD, etc.) and French (Water Acts, PAMM) levels. Growing numbers of experts and local residents are concerned about the health and proper functioning of the marine environment, and public pressure for better environmental management is increasing.*
… is at times complex …	*In France, the Coastal Land Regulation system, DPM, which administers shallow coastal areas, is complex and involves a large number of potential regulators, actors, and other stakeholders. It is essential to fully understand the DPM before embarking on any coastal development activity as all projects there are subject to authorization, which usually involves consultation with multiple stakeholders.*
… especially due to its land-sea interface characteristic.	*Shallow coastal areas of the Mediterranean are situated at the volatile interface of land and sea, and this needs to be taken into account in order to better understand their various components.*

Chapter 1

Ecological Framework of Shallow Coastal Areas

Every **ecosystem** is composed of a group of living organisms and their respective habitats. In this guide, we will discuss the **necto-benthic (demersal)** coastal fish, so named because a portion of their life-cycle is spent on soft or rocky substrates. Here we focus on the different stages in the life cycles of fish, as well as the requirements of each stage, and the importance of certain coastal habitats for the survival of fish.

1. The normal functioning of fish populations

a. The life cycle of fish

In the reproductive stage, mature fish gather in specific habitats in open water or near the bottom of the sea where fertilization takes place and eggs are then spread. Eggs are generally deposited in open water; only a few species use rudimentary nests to provide some measure of protection. After the eggs hatch, the larvae are dispersed with the current over a certain period of time (e.g., about 30 days for white seabream, *Diplodus sargus*). The dispersion phase in the pelagic zone allows the **colonization** of new **habitats** and genetic mixing. The larvae then enter into an active phase called the "**post-larva**l" stage. These post-larvae, which are in the last pelagic larval stage, tend to move towards the coast to colonize seabed habitats best suited for their survival (**settlement phase**). Once the post-larvae have settled into their new habitats, they are considered juveniles, or "Young of the Year" (**YOY**). These juveniles will grow within the **nursery**, which provides them with food and shelter for several months until they reach a **size** called "**refuge size**". This corresponds to a dimension greater than the mouth opening of predators, where the rate of mortality due to predation decreases dramatically. The juveniles, after several months or years depending on species, integrate into populations occupying adult habitats. This is called the **recruitment** stage. In their new habitats, juveniles continue to grow until they reach sexual maturity (Figure 4).

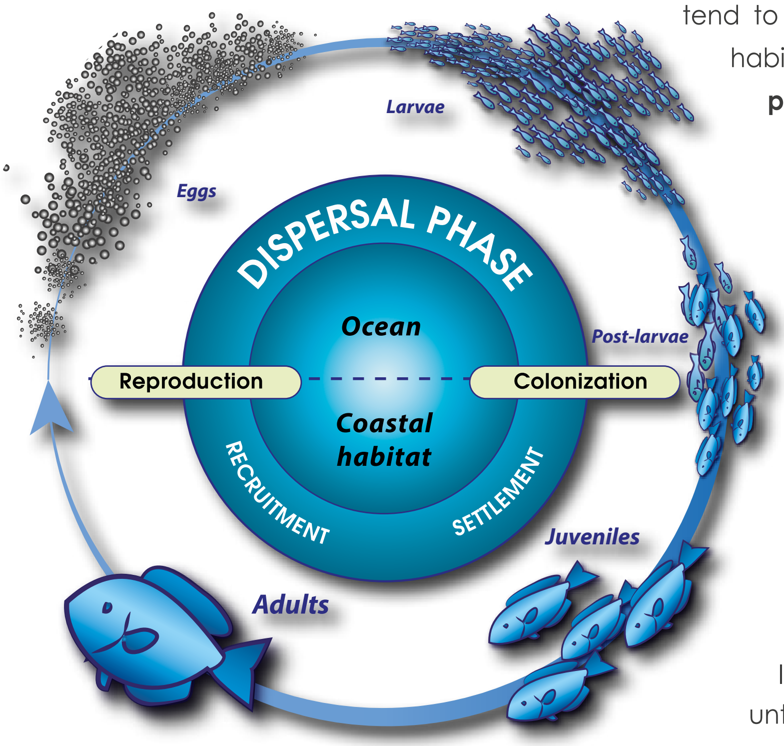


Figure 4 - The life cycle of coastal fish.
Source: Lecaillon, modified from Pastor (2008).

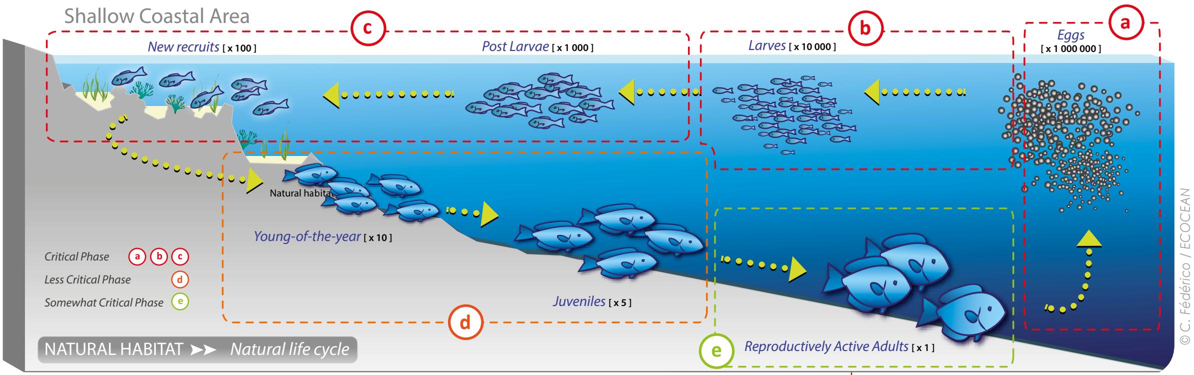
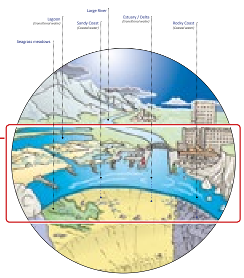
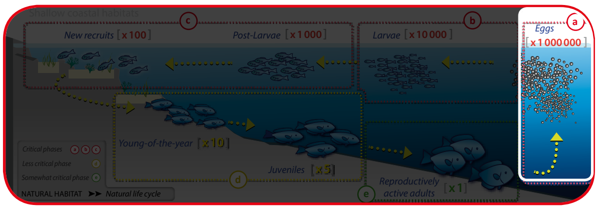


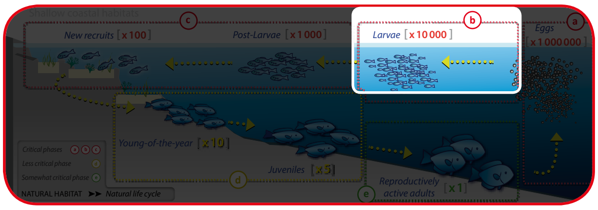
Figure 5

Relative fish mortality rates at different stages of development.

The most critical phases are in red, moderately critical in yellow, and marginally critical in green.

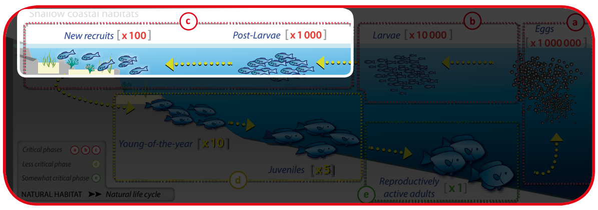






(Fig 5, a and b)

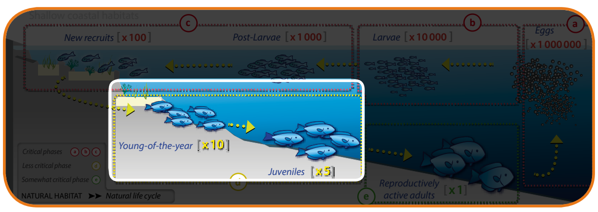
Mortality decreases throughout the life cycle. The first period of high mortality (90%) occurs during the **pelagic larvae stage**, from the moment eggs are formed. Causes of high mortality are predation, a lack of adequate nourishment and/or inadequate environmental conditions for survival (temperature, salinity, etc.).



(Fig 5, c)

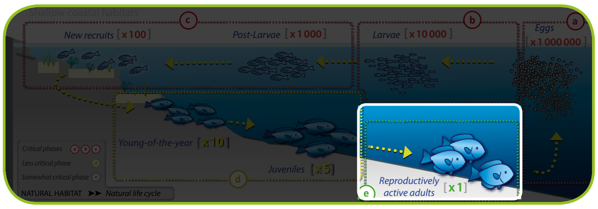
At the **post-larvae** stage up until the **settlement phase**, each individual will have to radically adapt to new habitats and diet in order to colonize the shallow coastal regions. This very short settlement phase (Fig. 5b), which only lasts a few days, is also a period of high mortality rates, of up to 80 to 95% (Doherty *et al.*, 2004).

Once the new recruits have settled, they compete for food and for the best habitat niches between themselves (intra-specific competition), or with other species (inter-specific competition). They are also at high risk of predation due to their small size. In certain species, cannibalism has also been observed. Mortality at this stage is close to 90% (Planes *et al.*, 1998).



(Fig 5, d)

The individuals come out of the critical benthic phase the moment they reach their **refuge size** several months (depending on the species) after **settlement**.



(Fig 5, e)

e

They integrate into the adult population and in most cases change their habitats. Mortality rates decrease and the principal cause of mortality at this stage is fishing. The surviving fish will then reach sexual maturity and reproduce. In order to have one adult fish that is capable of renewing the cycle, roughly a million eggs are needed.

Mortality before reaching the **refuge size** may vary by a factor of 30 from one year to the next and from one site to the next (Pastor, 2008; Pastor *et al.*, 2013). The importance of taking action to reduce high mortality rates during these vulnerable phases - so that more individuals can reach their refuge size - should be apparent to all stakeholders.

Not surprisingly, the least well understood parts of the life cycle are the pelagic phases, when larvae are dispersed over large areas and thus are difficult to locate and assess (Figure 5b).

> LIFE+ SUBLIMO Program

The objective of this program is to analyze, monitor and reduce the loss of marine biodiversity through a series of concrete actions that aim to improve the knowledge concerning the life cycle of fish, in particular the larval and post larval phases. The process consists of three stages: 1) the capture of live larvae in open water (with the aid of light traps called CARE), 2) tank-rearing captured larvae over several months, and 3) releasing reared refuge-size juveniles into specific micro-habitats.
Actively repopulating in this way reduces the mortality rate of fish species captured by a factor of 10 because the released juveniles are more likely to avoid high predation.

Figure 6 - Captive Rearing Release procedure

The program partners are CREM (the Centre of Research on Marine Ecosystems - CEFREM Laboratory– UMR 5110 CNRS/UPVD) and the SPE Laboratory – UMS Stella Mare of the University of Corsica. This process was developed by ECOCEAN and patented under the name BioRestore®.

Access to fish in the post-larval phase (Figure 5 c) is recent and was made possible for a certain number of species thanks to innovative techniques developed by French companies.

The post-larval phases and new recruits are stages where mortality rates are high due to natural causes, exacerbated by the degradation of coastal nurseries. Scientific knowledge and current technology allows us to intervene during these vulnerable stages in order to help to sustain and maintain fish populations.

> GIREL_3R Program

The GIREL_3R program aims to rehabilitate marine nursery functions in certain harbor zones in the Grand Port Maritime of Marseille using two complementary methods:

> *Artificial nurseries (Biohut®) installed on the dock: these temporary habitats offer food and shelter for young recruits entering the port. They are thus better able to avoid the majority of predators, and have better chances of reaching sexual maturity. This method could be an effective way to contribute to the re-population of fish within the broader environment (i.e., the harbor of Marseille).*

> *BioRestore® is a tool to assist in the restoration of marine ecosystems based on an innovative and sustainable technique of capturing and rearing post-larvae to reduce high mortality rates inherent in their life-cycle. Post-larvae are captured in the open sea before the advent of high predation linked to their settlement in new habitats and then grown in tanks on land before being released into shoreline habitats® adapted to the species and to their respective release sizes.*

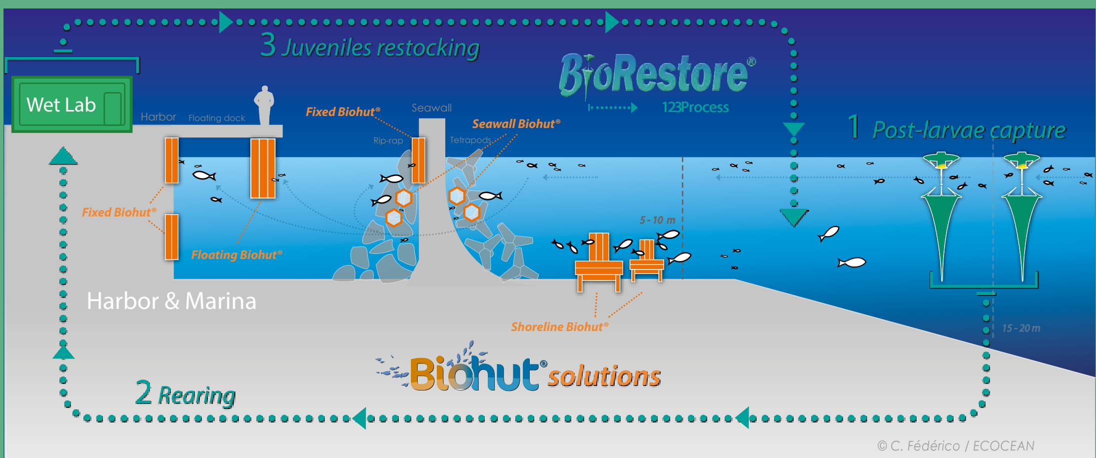
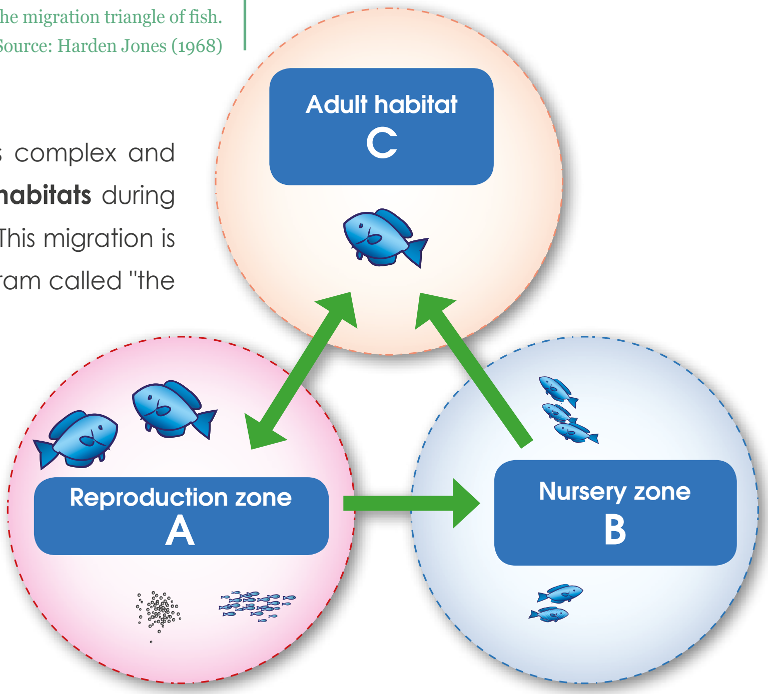


Figure 7 - The patented processes Biohut® and Biorestore®, and how they work.

Program supported by Ecocean in partnership with CREM (CEFREM UMR 5110 CNRS-UPVD). Co-financed by the Rhone-Mediterranean and Corsica Water Agency and certified by the *Pôle MER Méditerranée.*

b. **Essential habitats**

Figure 8
The migration triangle of fish.
Source: Harden Jones (1968)



The life cycle of **coastal fish** is complex and in most cases the fish must change their **habitats** during certain stages, requiring them to migrate. This migration is detailed by Harden Jones (1968) in a diagram called "the migration triangle" (Figure 8).

Migration occurs in the juvenile and adult state and the objective is dependent on the behavior and the life-cycle stage of the species. Depending on the species, migration occurs either as part of the search for prey or for shelter to avoid predation.

The habitats necessary for the survival of fish are called essential habitats (Benaka, 1999), defined as the environment and substrate necessary for acquiring food to grow until maturity and to reproduce. It should be noted, however, that essential habitats can be separated or combined depending on the specific life cycle of the species under consideration.

> **Definition of essential habitats**

> ***Refuge habitats*** *provide individuals with shelter from predators and from various risks within the environment. The objective is to increase their chances of survival and their rate of growth. Depending on the level of activity or inactivity of a given species, the refuge zone can vary spatially throughout the life of an adult fish.*

> ***Feeding habitats*** *are found within a refuge zone or zones, but may also occur outside of the refuge habitat. Feeding habitats will also vary according to the energy requirements of fish and their life cycle phases. During the juvenile phase, fish require a high energy intake, but are also vulnerable to predation and require a specific habitat called a nursery (Gillanders* et al., *2003).*

> ***Reproduction habitats*** *are zones where males and females gather in more or less large groups. During these reproductive gatherings, the pressure from fishing is particularly high.*

As nurseries in shallow coastal areas correspond to refuge and feeding zones, which are vulnerable and essential for the life cycle of coastal fish, we propose to include them as essential habitats in the current document.

The nursery habitats *(figure 9) varies according to the morphology and needs of each species (Beck* et al.*, 2001):*

- ***(1)*** *diverse foods adapted to the needs of fish,*
- ***(2)*** *an ideal habitat for post-larvae to settle and which protects them from predators and pressures during the juvenile stage up until they reach their refuge size,*
- ***(3)*** *an environment where juveniles grow more rapidly and have a better rate of survival than other environments,*
- ***4)*** *an area that allows fish to migrate to adult habitats.*

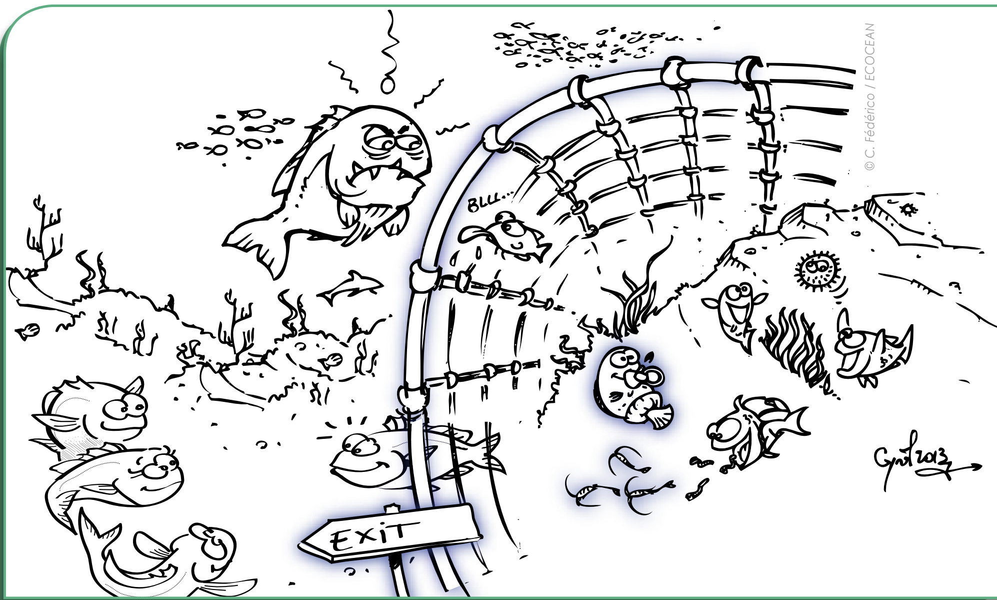


Figure 9 - Shallow coastal nurseries. © Ecocean.
This humoristic drawing depicts the 4 main elements constituting an effective juvenile fish nursery: 1) diverse food sources, 2) protection from predators, 3) better rate of survival and better growth, and 4) possible routes of migration to adult habitats.

> Evaluation of the Connectivity Between Protected Marine Areas and the Role of Essential Habitats

The eCATE program aims to evaluate the connectivity of populations of fish in the adult stage between three MPAs of the French and Spanish Catalan coastal areas, and the role of essential habitats. An evaluation of the spatial distribution of nurseries and their relative value is carried out in a zone that includes the three MPAs, from Leucate (France) to Rosas (Spain). An estimation of the connectivity between the MPA of Banyuls and the Cape of Creus is carried out through acoustic tagging programmes. Two key species of the Mediterranean coastal ecosystem serve as models: the White seabeam (Diplodus sargus) *and the dusky grouper* (Epinephelus marginatus)*. This study is intended to elucidate the role of the connectivity of adult fish populations in the context of species recolonization and more importantly to maintain marine biodiversity.*

Project supported by CREM (CEFREM laboratory, University of Perpignan).
Financed by TOTAL Foundation, the Foundation of France and the Departamental Council of the Pyrénées Orientales.

In summary, the modification of coastal **habitats** by people can have important negative impacts on the conservation of populations and of species, especially in nursery zones.

c. Connectivity and fragmentation of habitats

The marine environment has zones that are naturally homogeneous and others that are heterogeneous and fragmented. Not surprisingly, ongoing modifications due to human activities tend to accentuate fragmentation (Jones, 2007). The result is that connectivity between ecosystems is reduced in two ways: 1) limited migrations between individuals of remote populations and 2) limited migrations of individuals between the different essential habitats throughout their life cycle. Contrary to a continuous ecosystem where exchanges occur freely, movement between essential habitats of a fragmented ecosystem are limited and are only possible through "ecological corridors". These corridors are less than ideal, but vital for exchanges to occur when fragmentation has become prevalent. The establishment or re-establishment of ecological corridors is a key requirement of the Grenelle of the Environment through Green and Blue Corridors (TVB). The objective is to "reconstruct a coherent ecological network at the national level to allow animal and plant species to circulate, feed, reproduce, and rest..." (MEDDE).

The proper functioning of coastal fish populations occurs through:

1 - reproduction, which determines the number of eggs and larvae,

2 - settlement, which determines the number of juveniles,

3 - recruitment, which determines the number of adults in a population at a given time. These different stages have distinct spatial distributions and are regulated by specific processes within each stage.

In the following diagram (Figure 10) of a typical Mediterranean coastal area, "reproduction" habitats are represented in red, "nursery" habitats in yellow, "rest" areas in green, and "feeding" habitat in blue. Red arrows indicate migrations between habitats via ecological corridors that provide a minimum of connectivity for fish populations.

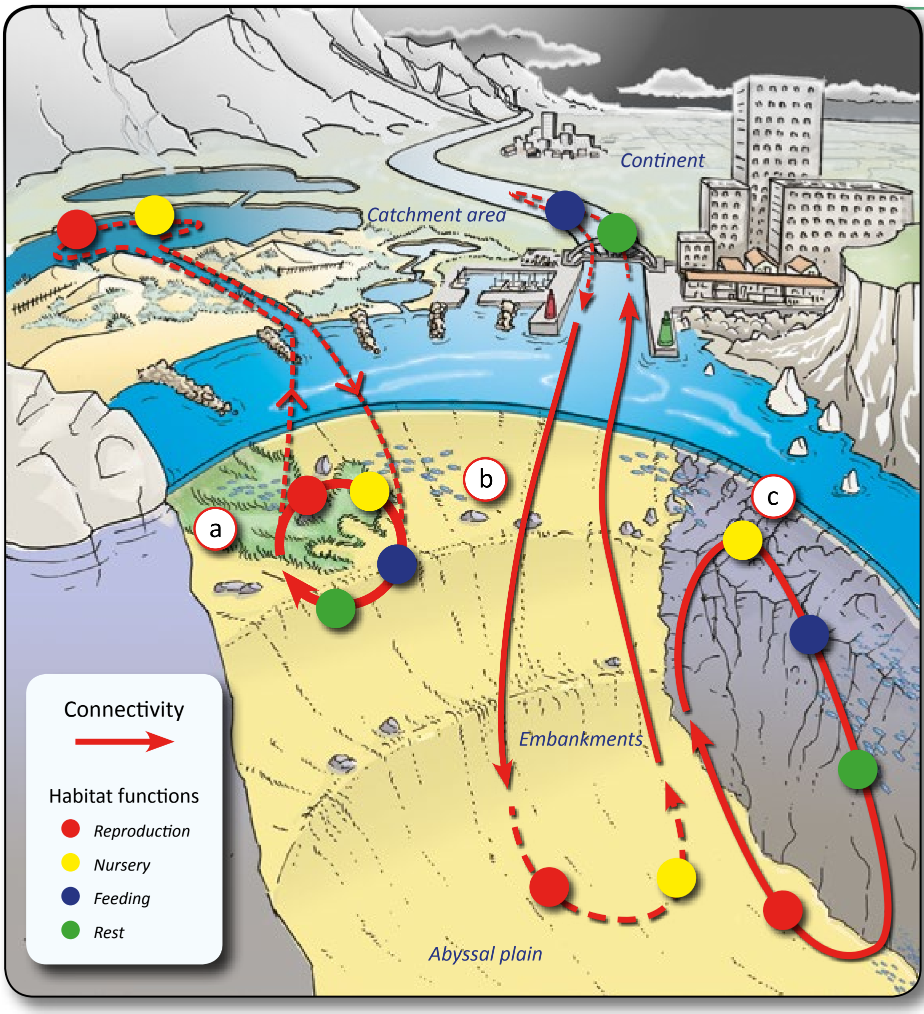


Figure 10

The essential habitats of a typical shallow coastal areas with port infrastructure, lagoons, groynes, rocky zones, and other habitats.

The various loops (a, b and c) represent different scenarios of the localization of essential ecosystem functions with regard to fish life cycles.

Source: Cheminée *et al.* (2014), modified.

Species group (a): benthic or nektobenthic species (e.g., Gobies and Porgies) that inhabit the coastal zones. The essential habitats are located in shallow coastal areas (dotted line shows possible variations), only the larval stage is more or less dispersive in the pelagic environment. The majority of coastal fish belong to this group and are the principal focus of the current document.

White Seabream (*Diplodus sargus*)

Species group (b): diadromous species, of which the most common is the European eel. This species has a transoceanic larval phase. It then returns to the coastal region where it changes into an elver to enter estuaries and lagoons (nursery zones). It spends its adult life in the water courses of continental river runoff for approximately 10 years. On reaching sexual maturity, it migrates to the Sargasso Sea (Atlantic Ocean) to reproduce.

European Eel (*Anguilla anguilla*)

Species group (c): certain coastal species spend part of their life cycle in deep waters in remote areas of the continental shelf, along the continental slope or the underwater canyons. In the case of hake, for example, these areas are their reproductive habitats.

Hake (*Merluccius merluccius*)

> **ROC CONNECT Program**
> Connectivity of rocky fragmented habitats of the Gulf of Lion (south of France)

The objective of this program is to quantify the potential connectivity of populations of different species present in fragmented rocky habitats in the Gulf of Lion (from Marseille in France to the Cape of Creus in Spain) and its role in the regional persistence of these species. It aims to provide a scientific basis for local government actions to establish a network of ecological corridors between Marine Protected Areas (MPA) within the Gulf of Lion (Côte Bleue Natural Marine Park, Natura 2000 site "Posidonies du cap d'Agde", Gulf of Lion Marine Park, Cerbère-Banyuls Natural Marine Reserve, and the Cape de Creus Natural Park). This effort is based on close collaboration between program scientists and the respective MPA managers.

Coordination: Arago Laboratory / Partners: Côte Bleue Natural Marine Park, The National Scientific Research Centre (CNRS), Cerbère-Banyuls Natural Marine Reserve, Gulf of Lion Natural Marine Park, Pays d'Agde Association for the Protection of the Environment and Nature, Instituto de Ciencias del Mar, University of Bologna – LITEAU program, 2013-2016.

These examples demonstrate the importance of the coastal strip and shallow coastal regions, given that these zones are where most species migrate during their life cycle.

2. The role of the coastline in the life cycle of coastal fish

a. The definition of the framework of shallow coastal regions

Among all of the essential habitats, the "nursery" habitat is particularly fragile and vulnerable to natural perturbations and anthropogenic pressures. For coastal fish, this habitat is generally situated in shallow coastal areas and therefore provides the framework within which this Guide could be applied. Shallow coastal areas of the Mediterranean form an integral part of France's Publicly-owned Coastal Land (DPM). The area of interest (in red in Figure 11) is the infralittoral zone, corresponding to the distribution area of light-loving algae and flowering plants (Pérès, 1961). This zone, where anthropogenic pressures are most significant and widespread, is also where most of the essential habitats required for each phase of the coastal fish life cycle are found. It extends from 0 to 20-40 metres in depth, although the area that receives the most light (usually the greater part of the shallow coastal area), is generally located between 0 and 20 metres deep. Lagoons and estuaries (transitional zones) also have shallow coastal areas that have vital functional roles. These zones also show the effects of anthropogenic climate change most rapidly.

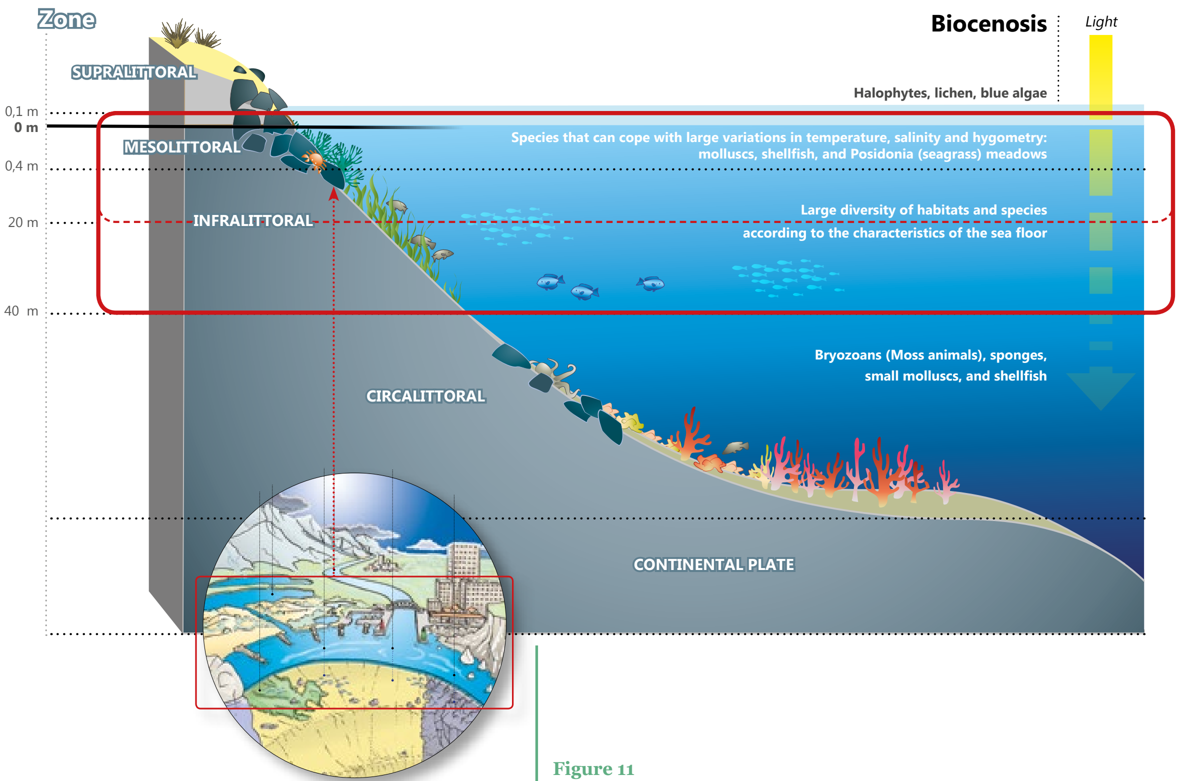


Figure 11
Marine terraces in coastal zones.
The area for which this Guide was developed is represented by the red box.
Modified after Marine Observatory
(Association of municipalities of the Gulf of Saint-Tropez).

> Underwater terracing

In underwater layering, there is a spatial distribution according to a depth gradient:

> *supralittoral* *level or sea spray zone.*

> *mediolittoral* *level or zone of tidal influence, generally only 40 cm in width, in the Mediterranean region, but up to 1.3 m in the Venice lagoon*

> *infralittoral* *level: zone that stays submerged during low spring tides and where light intensity is adequate for the development of macrophytes. Generally located between 0 and 20 m in depth depending on turbidity, but can reach 40 m in certain zones of the Mediterranean.*

> *circalittoral* *level: lowest zone extending from the lowest limit of* Posidonia *seagrass meadows. This is where coralligenous formations develop, namely assemblages of red calcareous algae that form bioconstructions containing a significant amount of animal and plant biodiversity. This level is not covered in the current Guide.*

b. **Typology of habitats of shallow coastal regions**

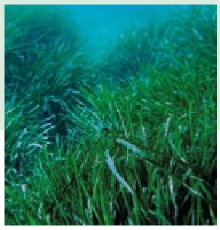
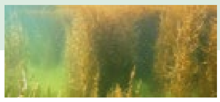
Coastal zones have a multitude of habitats characterized by diverse substrates and terracing influence. A European classification (Code CORINE Biotope) (Table 1) was defined by member states to harmonise the typologies of natural (terrestrial and aquatic) habitats, especially those in areas with ecological continuity such as the northwestern Mediterranean Basin. This typology includes shallow zones and also transitional waters such as estuaries and lagoons, because of their connectivity to the marine environment and their important potential for providing nursery habitats. The CORINE Biotope typology only covers natural habitats. It is equally important to establish a comparable typology for artificial marine structures because they also contain **essential habitats** that fulfill vital functions such as nurseries (Pastor *et al.*, 2013).

In this guide, 10 important habitat categories are taken into account:

1 - Sandy shallow areas (SA),
2 - Gravelly SA,
3 - Rocky SA,
4 - **Organogenic** formations,
5 - Seagrass meadows,
6 - Estuaries and lagoons,
7 - Mudflats,
8 - Rocky banks,
9 - Artificial infrastructures,
10 - Ports.

Though certain habitats are found at depths of up to 50 meters (e.g., shipwrecks) the majority are found between 0 and 10 metres.

Table 1 - Typology of habitats of shallow coastal areas of the Mediterranean Basin listed according to the CORINE Biotope classification and modified according to the needs of the current Guide.

Habitat classification (CORINE biotope 1997)	Classification of habitats in shallow coastal areas	Depth	Nomenclature	
11.22 - Benthic **subtidal** zones on soft sediments	Sandy shallow coastal areas (different granulation)	0 - 10 m	Sandy SA	
11.23 - Benthic **subtidal** zones on gravel	Shallow coastal areas with gravel and shingle	0 - 5 m	Gravelly SA	
11.24 - Benthic **subtidal** zones on rocky bottoms	**Rocky shallow coastal areas:**	0 - 20 m	Rocky SA	
	Continuous rocks	0 - 40 m		
	Continuous rocks with large blocks	0 - 20 m		
	Rocks with sandy areas	0 - 10 m		
	Posidonia dominated rocks	0 - 40 m		
	Photophilious macrophytes dominated rocks	0 - 10 m		
	Cystoseira dominated rock	0 - 5 m		
11.25 - **Subtidal organogenic** formations	**Organogenic formations:**	0 - 40 m	Organogenic formations	
	Coralligenous formations	15 - 40 m		
	Encrusted algae formations	2 - 75 m		
	Lithophyllum formations	0 - 1 m		
	Reef-forming gastropods and polychaete	0 - 1 m		
	Mussels or oysters reefs	0 - 5 m		
11.33 - Mediterranean *Cymodocea nodosa* and *Zostera sp*.	Phanerogam meadows: *Cymodocea nodosa* and *Zostera sp*.	0 - 10 m	Seagrass	
11.34 - Oceanic *Posidonia* seagrass meadow	*Posidonia* seagrass meadow	0 - 40 m	Seagrass	
	Meadow beds	0 - 40 m		
13.2 - Estuaries	Estuaries	0 - 20 m	Estuaries/Lagoons	
21 - Lagoons	Lagoons	0 - 10 m	Estuaries/Lagoons	
14 - Mudflats and sandflats without vegetation	Mudflats	0 - 2 m	Mudflats	
19 - Islands, coral and rocky banks	Rocky banks	0 - 40 m	Rocky banks	
	Artificial infrastructures:	0 - 50 m	Artificial infrastructures	
	Structures	0 - 10 m		
	Acropodes (breakwaters)	0 - 10 m		
	Floating structures	0 - 2 m		
	Artificial reefs	0 - 30 m		
	Wrecks	0 - 50 m		
	Docks	0 - 10 m	Ports	
	Mooring dolphins (port pillars)	0 - 20 m		

> Nurseries, Habitats, Ecological Engineering (**NUhAGE**) project

The aim of the NUhAGE project is to identify recruitment zones, characterize nursery structures, and describe the juvenile fish populations that have settled in shallow coastal areas of the Var Department (South of France).

This work is based on data collected in the field (diving and capture of post-larvae) from pilot sites in the Gulf of Saint-Tropez, Trois Caps and Brusc Lagoon. It will need to be complemented by interviews with professional fishers.

Approaches for managing nurseries in the study sites should also be developed and, if necessary, proposals for the restoration of certain ecosystem processes and functions

The project is supported by GIS Posidonie, MOI laboratory of Aix-Marseille University and P2A Development. It is financed by the Rhône-Mediterranean and Corsica Water Agency and the Var Department Council and approved by Pôle Mer Mediterranée.

> **RESPIRE** – Monitoring Network of Fish Recruitment

The study of coastal nurseries, a relatively recent and expanding field, requires a particular focus on the collection of data. Within this context, the RESPIRE project, financed and implemented by Ecocean and the Rhone-Mediterranean and Corsica Water Agency, will collect data on spatial and temporal evolution of larval colonization of coastal areas over a period of several years. 23 ports are currently being studied and data is collected between 3 (Low Frequency) and 24 (High Frequency) times per year. The aim of this network is to characterize populations of post-larval and juvenile fish recruitment, assess their spatial variation in time, and estimate long-term evolution of adult populations. A standardized method of observation was put into place for artificial habitats that are ideal for protecting young fish. The study of sessile fauna and flora was also initiated in 2015.

Contracting authority: Ecocean
Partners: Rhone-Mediterranean and Corsica Water Agency, CEFREM-CNRS-CREM, IFREMER Institute, STARESO, University of Rabat, Andromede Oceanology

School of young barracuda (*Sphyraena sp.*)

c. Spatial and temporal synchronisation of the needs of species

Essential habitats must be able to meet all the habitat needs of each species, not merely their dietary requirements. At the juvenile stage, the species divide the use of habitats in both time and space, which limits competition (Figure 12).

(figure 12.a)) At the spatial scale, the characteristics of a habitat must correspond to the needs of a species within each stage of development: *Posidonia* seagrass meadows for certain wrasses, **ecotone** (transitional region) of small stones/coarse sandy beaches for certain porgies, etc. Due to the great diversity of species within these habitats, all bordering shallow coastal regions could be considered as potential nurseries.

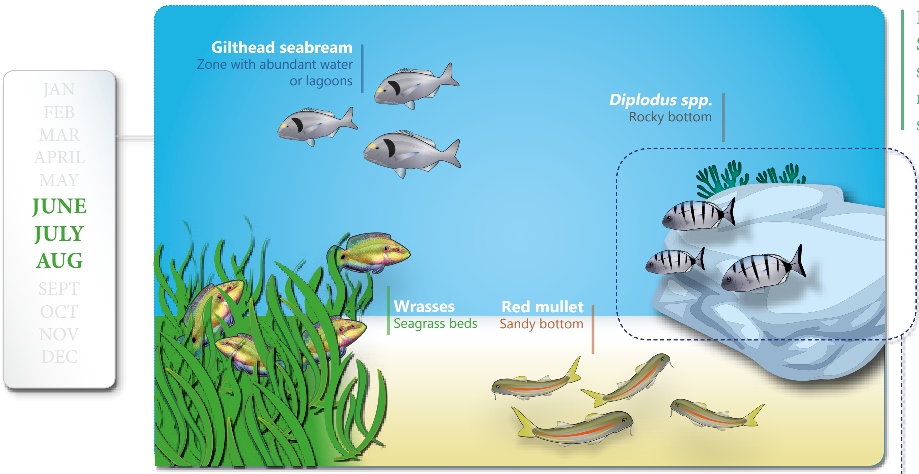


Figure 12.a
Spatial distribution of juveniles of several fish species in different coastal nursery habitats (seagrass meadows, sand, and rocks).

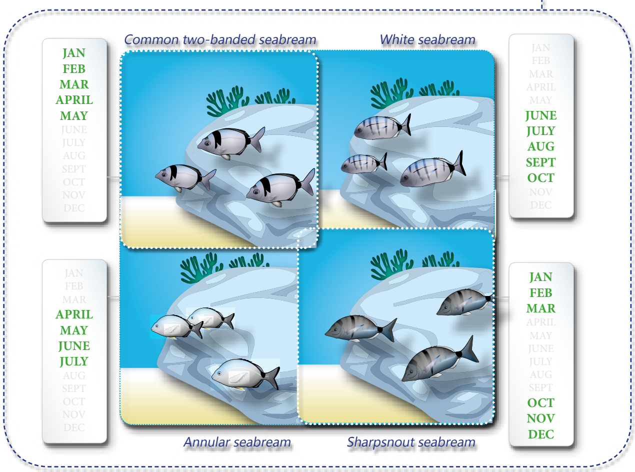


Figure 12.b
Temporal distribution of porgies (Sea bream).

(figure 12.b) At the temporal scale, reproduction periods are well defined for each species and occur over different seasons - spring, summer, autumn and winter. The optimum nursery site for a given species varies according to the time of year. The same zone could be considered a nursery for an entire year if there is species turnover throughout the year: for example, this is the case for various porgie species from the genus *Diplodus*, which replace one another in this habitat from spring to winter. Such species turnover also limits competition for resources.

Table 2 provides information on the periods when certain species of post-larvae arrive at the Mediterranean coast and shows that spring is the ideal period for recruitment of a majority of species.

Identification			**Months of capture of post-larvae in 2011 and 2012**											
Family	***Genus***	***Species***												
Families captured and grown			**Jan**	**Feb**	**Ma**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Ammodytidae	*Gymnammodyte*	*sp*				█	░	░						
Anguillidae	*Anguilla*	*Anguilla*									░			
Apogonidae	*Apogon*	*imberbis*						░	░	█	█	░	░	
Atherinopsidae	*Atherina*	*sp*			░	░	░	░	░					
Bothidae	*Bothus*	*podas*					░	░	░	░	░		░	
Blennidae	*Parablennius*	*pilicornis*				░	░	░	█	░	░	░		
Blennidae	*Parablennius*	*zvonimiri*					░	░	░	░	░			
Blennidae	*Parablennius*	*gattorugine*				░	░	░	░	░	░			
Blennidae	*Parablennius*	*sanguinolentus*						░	░	░	░			
Blennidae	*Parablennius*	*rouxi*						░	░	█	░			
Blennidae	*Aidablennius*	*shpynx*						░	░	░	░			
Caranguidae	*Trachurus*	*sp1 (grosse PL)*					░	░	█	█	░	░		
Caranguidae	*Trachurus*	*sp2 (petite PL)*		░	░	░	░	░	░	░	█	█	░	░
Caranguidae	*Seriola*	*dumerili*							░	░				
Caranguidae	*Trachinotus*	*ovatus*							░	█	░			
Caranguidae	*Lichia*	*amia*									░	░	█	
Centracanthidae	*Spicara*	*sp (smaris)*					░	░						
Centracanthidae	*Spicara*	*melanurus*							░					
Congridae	*Conger*	*conger*				░	█	░	░	░				
Gadidae	*Gaidrosparus*	*mediterraneus*			░	█	█	░						
Labridae	*Thalassoma*	*pavo*							░	░	░			
Moronidae	*Dicentrarchus*	*labrax*				░	░							
Mugilidae	*Mugilidae*		█	█	░				░	░	█	█	░	░
Mullidae	*Mullus*	*surmuletus*					░	░	█	█	░			
Mullidae	*Mullus*	*barbatus*							░	░				
Pomacentridae	*Chromis*	*chromis*						░	░	█	░			
Scophtalmidae	*Scophtalmus*	*sp*					░							
Scorpaenidae	*Scorpaena*	*porcus*								░	░	░		
Serranidae	*Epinephelus*	*marginatus*									░	░		
Serranidae	*Serranus*	*scriba*					░	░	░					
Sparidae	*Dentex*	*dentex*						░	░	░				
Sparidae	*Diplodus*	*annularis*					░	█	░					
Sparidae	*Diplodus*	*sargus*					░	█						
Sparidae	*Diplodus*	*puntazzo*	░	█	░							░	░	
Sparidae	*Diplodus*	*vulgaris*				░	░							
Sparidae	*Lithognatus*	*mormyrus*					░	░						
Sparidae	*Sparus*	*aurata*			░	░								
Sparidae	*Oblada*	*melanura*					░	█	█	░				
Sparidae	*Pagellus*	*acarne*	░			░	░	░	░			░	░	░
Sparidae	*Pagrus*	*pagrus*		░	█	░	░	░						
Sparidae	*Pagellus*	*erythrinus*					░	░						
Sparidae	*Spondyliosoma*	*canthare*					░	░						
Sparidae	*Sarpa*	*salpa*	█	░									░	░
Other families			**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Syngnatidae	*Hippocampus*	*sp*							░	░	░	░		
Gobidae	*Gobidae*	*spp*						░						
Gobiesocidae	*Lepadogaster*	*sp*						░						
Uranoscopidae	*Uranoscopus*	*sp*							░					
Dactylopteridae	*Dactyloptera*	*volitans*									░			

Table 2
Recruitment calendar of dominant coastal fish species in the western Mediterranean (Lecaillon *et al.*, 2012).
Light green squares indicate the periods during which the larvae were fished for, and the darker squares indicate the months in which the maximum quantity of larvae were captured.

Chapter 1 :
Ecological Framework of Shallow Coastal Areas

> SUMMARY

The life cycle of fish …	*The life cycle of coastal fish is composed of different stages (eggs, larvae, post-larvae, recruits, YOY, juveniles and adults) that require specific essential habitats (nursery, refuge, nutrition, reproduction). Each stage has its own characteristics and specific requirements.*
… has critical phases …	*Mortality due to natural causes decrease throughout the life cycle and the larval stage is the most critical (more than 90% mortality). It is also very difficult to intervene at the larval stage. Current techniques make intervention possible in the post-larval and juvenile stages (the next most critical stages).*
… and requires the use of nurseries …	*Coastal fish, during their recruitment and young juvenile stages, use "nursery" habitats located in shallow regions, (generally between 0 and 20 m) within shallow coastal zones. These areas must have certain characteristics in order to serve as nurseries: a refuge role; provision of appropriate nutritional elements; connectivity with the adult stage habitat; and improvement of survival rates.*
… located in shallow coastal regions …	*Shallow coastal regions contain as large a diversity of species as they do of habitats. Nurseries, which are fundamental to the life cycle of fish, could potentially include all of the coastal habitats, depending on species and time of year.*
… vulnerable to human-mediated impacts.	*Nurseries in shallow coastal regions are located very close to the coast and have been greatly impacted by human activities. Before proceeding with construction projects, it would be wise to first analyze and map the habitats present in order to estimate the value of the nurseries in the targeted sites. Using existing typologies, it is possible to identify the species that are the most impacted by built infrastructure as well as the type of stresses and disturbance construction cause for the fish.*

Shallow coastal areas with pebbles

School of White seabream *(Diplodus sargus)*

School of Salema porgies *(Sarpa salpa)*

White seabream *(Diplodus sargus)* in shallow rocky areas

Chapter 2

The Contribution of Shallow Coastal Areas to Human Society: Ecosystem Services

1. The definition of Ecosystem Services (ES)

The European Environment Agency (EEA) has made efforts towards finding an international consensus for the classification of ecosystem services and ecosystem contributions and resources. In this Guide, we discuss services provided to society by ecosystems characterized by health and integrity (i.e., ecosystems in good functioning condition and which still possess all or almost all of their native biodiversity). In this chapter, we focus specifically on services provided by shallow coastal regions and highlight their importance in the context of public policy affecting coastal zones.

a. **General context**

Ecosystem services is a concept that has developed rapidly over the last few decades. Back in the 1970s, scientists began to describe society's ultimate dependence on the natural environment (Costanza & Daly, 1992; Balmford *et al.*, 2002). However, it was not until 2005, when the results of the Millennium Ecosystem Assessment (**MEA**) were published, that the notion of ecosystem services became widely accepted (MEA, 2005). The MEA was an assessment project launched by the G8 countries and the United Nations and was the first to evaluate interactions between **ecosystems** and social and economic well-being on a global scale. Other organizations further developed the concept of ecosystem services, most notably The Economics of Ecosystems and Biodiversity (**TEEB**) research group in 2007 and the European Environment Agency, through the Common International Classification of Ecosystem Services (**CICES**) in 2013. In 2008, the French Ministry of Ecology, Energy, Sustainable Development and the Sea (MEEDDM) initiated a national evaluation of the

> **> Classification of ecosystem services**
>
> *The **MEA** classifies ecosystem services into 4 categories:*
> *1 - provisioning services / 2 - supporting services /*
> *3 - regulating services*
> *4 - cultural services*
>
> ***TEEB** added another category, namely habitat services, to emphasize that healthy ecosystems are vital for the survival of other species apart from humans.*
>
> ***CICES** lists "support" and "regulation" services together in the same group within their classification scheme, while other organizations, such as the Ecosystem Services Partnership (**ESP**) combine "habitat" and "support" services as one category.*

status of all **ecosystems** in France, as well as the services these ecosystems provide. This evaluation was based on the conceptual framework of the **MEA** (CREDOC *et al.*, 2009).

In order to help standardize the actions taken in France and those adopted by the European Union, we use the nomenclature described in the CICES list. This nomenclature was also applied in the document which describes ecosystem services in France (see Annex 1a):

> **Provisioning Services**: the production of goods made possible through materials provided by an ecosystem and which are potentially available to people for direct use, including consumption (e.g., food, fibre, fuelwood, etc.).

> **Regulating Services**: processes that channel specific natural phenomena, and that are required to ensure the occurrence of biochemical processes (water, nutrients, organic matter, etc.). These processes also have a positive impact on the well-being of people (protection against natural catastrophes, mitigation of the effects of pollution, etc.).

> **Social Services:** intangible benefits that people obtain from ecosystems for health, freedom, identity, knowledge, aesthetic pleasure, and leisure activities (fishing, outdoor sports, research support, etc.).

The benefits of certain ecosystem services are directly available to people, while the benefits of other services can only be acquired through modifying natural materials or landscapes. It is possible to classify the resources and services provided by ecosystems in the following manner (CREDOC *et al.*, 2009):

> Services that are immediately available and directly beneficial for people are those where the natural materials needed are directly linked to a healthy, well-functioning ecosystem, such as clean water that is self-purifying, nature-based tourism, fishing, etc.

> Services that only provide benefits following modifications or extractions that generally lead to environmental degradation (hydroelectricity, aquaculture, etc.)

> Services that mitigate the effects of "negative" natural phenomena, for which the provision of materials that are needed are directly related to a well-functioning ecosystem (protection against erosion, violent wave action, or the control of invasive species)

> Services for which the supply of materials needed require a modification of ecosystems or extractions that lead to a reduction of certain natural functions and optimize other functions (seaweed farming for biotechnologies and agro-fuel).

The notion of ecosystem services is based on the hypothesis that any alterations in **biodiversity** and ecosystems will logically change the capacity of the natural environment to provide the materials and natural processes that contribute to the socio-economic well-being of people. The value of the natural environment is, from this perspective, quite clear and multifaceted: on the one hand, the environment provides natural materials which meet the immediate nutritional needs of people and also provides materials and processes that contribute to the long-term well-being of societies (socio-economic benefits). A detailed and holistic analysis of different services provided by ecosystems that are undergoing restoration provides an assessment of the economic benefits as compared to the costs for society as a whole (Peh *et al.*, 2014).

b. **The relationship between the ecosystem and human society**

The concept of Ecosystem Services provides a clear conceptual link between the natural environment and human society. To explain this link, the next schema uses standard terms from economics, such as "capital", "work", "flow" or "stock".

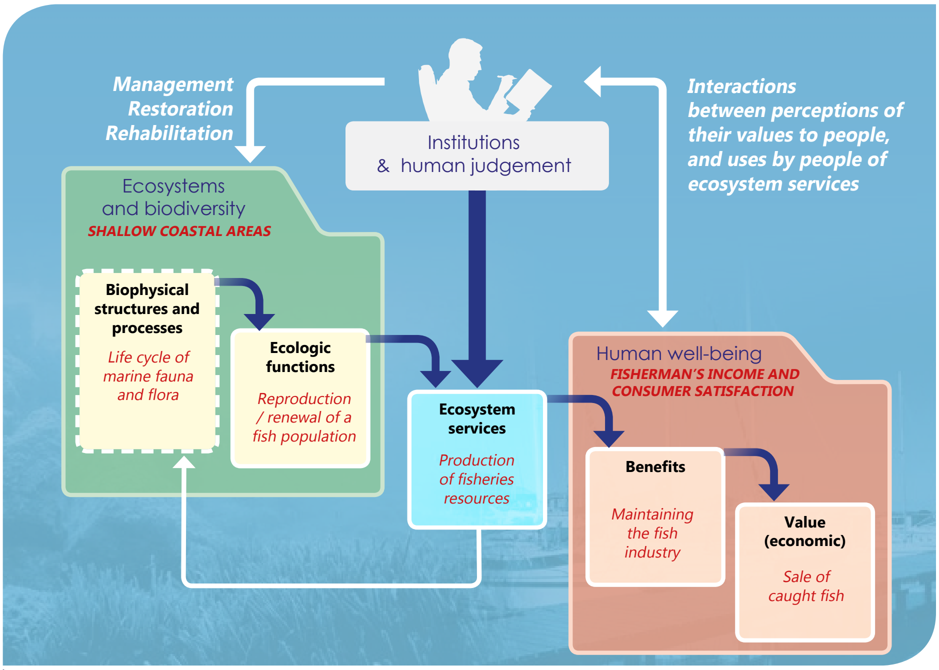


Figure 13 - Schematic figure in the form of a waterfall illustrating the relationships between ecosystem functioning and biodiversity, ecosystem services, and human society. To maintain the quality and quantity of ecosystem services, enlightened management, including restoration, rehabilitation, conservation, etc., is required. Source: de Groot *et al.* (2010), modified and adapted for marine environments.

In Figure 13, the green box, upper left, represents ecosystems and biodiversity, i.e., renewable and cultivated natural capital as those terms are used in both the **MEA** and **TEEB**. In economic terms, ecosystems do "work" that maintains and preserves their integrity and also provides services to human society. The biophysical structures and processes, provide the means by which this work is achieved. Work that is accomplished without human intervention is known as **ecological function(s)**.

If these functions are made use of by people (orange box), then they can be considered as Ecosystem Services (ES) (pale blue box). In general, **ecosystem services** are made available as a result of a group of **functions**, and that a single function may be essential to the flow of several services.

In environmental economics, ecological functions, or more broadly, well-functioning ecosystems with their native biodiversity, are known as **natural capital**, defined in terms of finite stocks. In contrast, ecosystem services are defined in terms of flows. ES provide **benefits**, either directly or indirectly, which satisfy a need or a desire, and which can be described in terms of social or societal **values** (monetary and non-monetary). These values may be used as indicators of well-being.

In Figure 13, shallow coastal areas provide habitats that are rich in nutrients and shelter, making them ideal for the survival of larvae returning from the open sea to colonize coastal areas. Among the many fish species that live within the shallow coastal areas in the juvenile stage, some are commercially fished. There is, therefore, a flow of economic resources (Ecosystem Services) collected through fishing, which in turn ensures revenue for fishermen and maintains the fishing industry (Benefit) thanks to the sale of caught fish (Economic Value). This ES benefits not only fishermen, but also many others. The fishing industry supplies restaurants and the food industry, so these markets also benefit indirectly from this ES. This ecosystem service has not only an economic value, but also a social and cultural value. Bouillabaisse, for example, is a traditional seafood dish from the southern coastal regions of France. The value of this dish, like many traditional aspects of any society, is social and cultural. Certain fish like the grouper or brown meagre also have a specific cultural heritage value in France.

The societal dimension is, therefore, very important when discussing ecosystem goods and services, as well as their benefits and the values assigned to them by social scientists. Indeed, the existence of an ecosystem service depends just as much on the **ecological processes** as the social practice which determines how people use them. The **value** given to a service would, therefore, be defined differently according to how it is used and by whom.

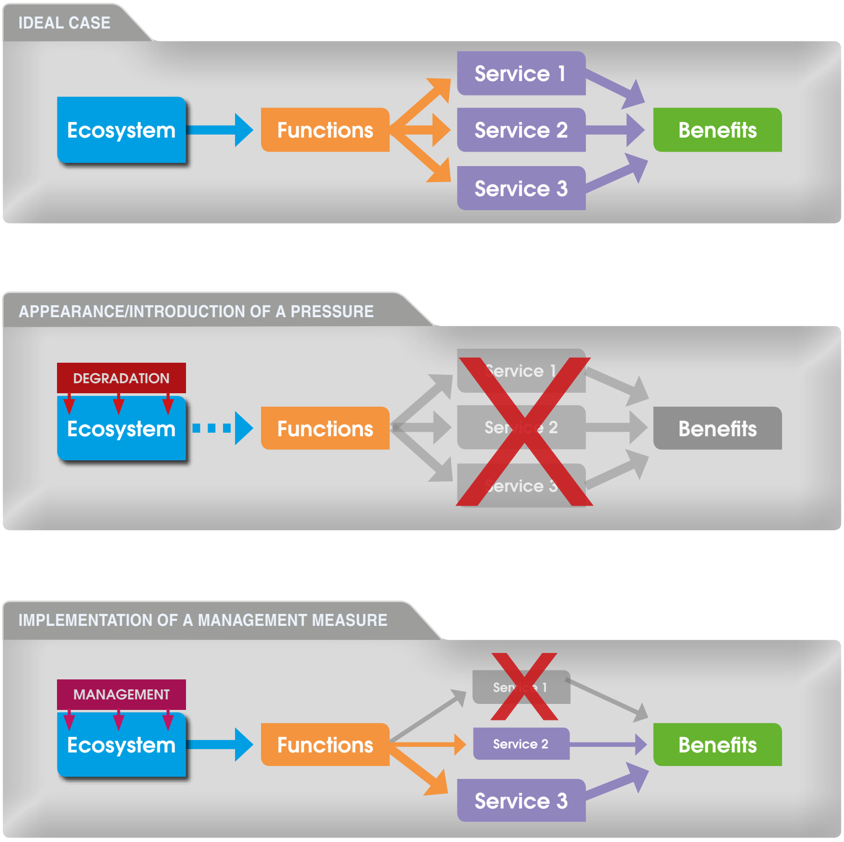


Figure 14
Losses and gains of services according to ecosystem use and regulation. Source: MEEDD/MNHN (2010).

The degradation or unwise use of an ecosystem results in the loss of ecological functions and reduces or may even eliminate one or all **ecosystem** services (Figure 14). In turn, human recipients of these economic, social, and cultural benefits are negatively affected. It should be noted, however, that implementing regulation measures will impact the ecosystem and the services that it provides. For example, in zones where regulations prohibit fishing, the service "production of animals for professional or sport fishing" is eliminated, while other services such as "regulation of functional diversity" are enhanced. It is, therefore, important to take into account that enhancing one service can negatively impact other pre-existing services, as well as the stability of the ecosystem, (Bullock *et al.*, 2011).

Many people are not aware that they receive benefits from ecosystems, making it difficult for them to place a value on the services or to recognize the importance of the ecosystems on which these services depend (de Groot *et al.*, 2010).

2. ES provided by shallow coastal areas

a. ES of the Mediterranean Sea

The ecosystem services produced specifically by the global marine environment are listed in Annex 2 according to the existing literature. This compilation makes it possible to target the services that are specific to shallow coastal areas of the Mediterranean. Table 3 lists the services provided by different habitats, especially those found in shallow coastal zones of the Mediterranean.

Categories of ecosystem services			Habitats: Sandy SA	Gravelly SA	Rocky SA	Organogenic formations	Seagrass	Estuaries Lagoons	Mudflats	Rocky banks	Artificial infrastructures	Ports	
Direct services	Provisioning services	Animal production for professional fishing	●	●	●	●	●	●	●	●	●	● (light blue)	*if the port and the exterior are connected*
		Maintain and support the food culture									●		
		Production of plant for food and functional use					●	●		●	●		
		Production of minerals for extraction	●	●				●	●			● (light blue)	
Indirects services	Regulating services	Regulation of water quality					●	●					
		Regulation of functional diversity	●	●	●	●	●	●	●	●	●	● (light blue)	
		Regulation of interspecific interactions	●	●	●	●	●	●	●	●	●	● (light blue)	
		Erosion protection of coastal zones			●		●				● *Acropods*		
		Protection from storms			●		●				●		
		Preservation of marine species lifecycle	●	●	●	●	●	●	●	●	●	● (light blue)	
		Control of invasive species	●	●	●	●	●	●	●	●	●	● (light blue)	?
		Recycling nutriments (N, P..) and organic material	●	●	●	●	●	●	●	●	●	● (light blue)	
	Socio-cultural services	Support for the tourism industry and leisure outdoor sports	●	●	●	●	● *Diving*	●		●	● *Artificial reefs, wrecks*	● (light blue)	
		Support for aesthetic landscaping	●	●	●	●	●	●	●	●			
		Support for scientific research	●	●	●	●	●	●	●	●	●	● (light blue)	
		Support of the development of educational knowledge		●	●		●				● *Artificial reefs*	● (light blue)	?
		Production of animals for recreational fishing	●	●	●	●	●	●	●	●	●	● (light blue)	
		Production of heritage species	●	●	●	●	●	●	●	●	● ?	● (light blue)	
		Support for health care			● *Algae, sponges*				● *Marine sludges*				

Table 3 . Ecosystem services provided by the different habitats of shallow coastal areas. *Services that are less frequently found in shallow coastal regions of the Mediterranean are listed in italics. Services that could potentially be provided by ports thanks to eco-design and engineering or recovery of certain functions through different restorative actions are shown in light blue* ●.

It should be noted that some habitats provide a great number of services: this is the case for seagrass meadows, lagoons, and even some artificial structures. In-depth assessments of these habitats should be conducted in restoration or mitigation projects.

Other services will only be available from a small number of habitats (e.g., regulation of water quality of lagoons - filtering, auto purification - or coastal protection from storms and erosion). It is also important to take these services into account in restoration projects, if the areas in which the project will be implemented provide these services.

This does not necessarily imply, however, that certain habitats have priority over others, nor that habitats providing fewer services should not be considered. In fact, many services result from a combination of habitats and the interface zones which link them. Such combinations may be complex and should also be taken into careful account.

b. **Values and benefits from ecosystem services**

In the list of ecosystem services provided in Annex 3, the benefits and values associated with ES of shallow coastal areas as well as the socio-economic outcomes of each service are identified. This list provides an overview of how each service, linked to specific habitats, provides benefits to society, whether it be by maintaining an economic activity such as fishing or tourism, or by positively affecting human quality of life in general terms. Biodiversity has many values, including cultural, aesthetic, recreational, educational, spiritual, scientific, social, economic, etc. In an analysis of different research studies on the value of biodiversity, three main types were identified (FRB 2013, Salles 2013):

> **Intrinsic value**: The value of the mere existence of biodiversity in and of itself. Whatever the potential for human use, the diversity of life on earth should be respected and preserved for ethical reasons.

> **Heritage value**: The unique cultural and historical value of biodiversity, which makes some of its elements or processes something to be respected and preserved for present and future generations. Example: protection of a natural landscape or a species, which have symbolic significance, for their cultural importance.

> **Instrumental value**: Biodiversity provides resources as well as useful and essential services for human society. Example: instrumental value linked to the production of food, or the use of open spaces for recreation. **An optional value** could also be considered, a kind of instrumental value that is a potential source of innovation for present and future generations. Example: discovery of new molecules that are important for the pharmaceutical industry.

On the other hand, some scientists emphasize the **ecological value** of an ecosystem for its importance in the functioning and resilience of the larger landscapes or seascapes in which it occurs, and thus to the populations and species that are part of it, and to other ecosystems with which it interacts.

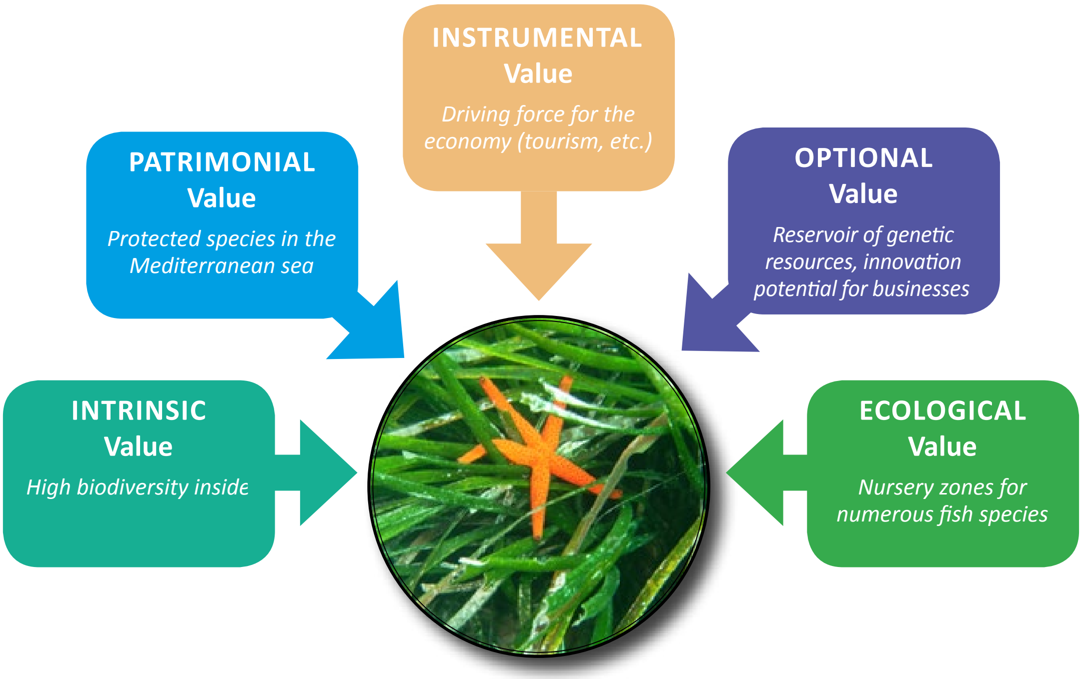


Figure 15
The different values that can be given to an ecosystem by humans. Example of the Posidonia seagrass meadow. Modified from FRB (2013).

As a result of these different approaches, for any given component of biodiversity, the given value will be different according to the actors involved (Figure 15).

In this example, the value attributed to a *Posidonia* seagrass meadow will be different from the point of view of a corporation, a researcher, or a tourist.

c. Example of an evaluation method of ecosystem services – the EFESE approach

According to the French Foundation for Research on Biodiversity (FRB, 2013):

" Economic assessments have become more and more common when evaluating biodiversity and ecosystem services. Such assessments build on several different methods (cost analysis, individual preferences, etc.), each of which has strengths and weaknesses. The notion of a total economic value attributed to biodiversity was developed to encompass all of the values of biodiversity. Based on a typology that distinguishes between the values of use and non-use, the idea of applying this notion to biodiversity is to widen the perspective of its value beyond instrumental values." (Chevassus-au-Louis *et al.*, 2009)

Furthermore, the results of economic assessments are often the subject of debate, which provides an opportunity to present arguments for including biodiversity in political decision-making. Lastly, these evaluations will also allow the development of financial tools (tax incentives, payment for environmental services, etc.), thereby providing economic incentives to preserve biodiversity.

"However, these economic assessments present questions on [biodiversity's] real contribution and its limits, as well as on the model of society that it evokes." (FRB, 2013).

> **EFESE –** French Evaluations of Ecosystems and Ecosystem Services

The project, created through the MEDDE initiative, aims to develop a set of indicators that can be used to provide an estimate of the current loss of services, as well as to determine the potential gains to be had from interventions to restore or partially restore the service or services lost.

The evaluations conducted by French researchers, as compared to most other work elsewhere, were notable for the following features:

> *Inclusion of specific ecosystems (Mediterranean forests, tropical ecosystems in overseas departments and territories, urban ecosystems, etc.) and an in-depth study of the links between biodiversity, ecological functions and ecosystem services.*

> *Integrating interactions between global changes and ecosystem services.*

> *Evaluating the interrelations between services (by bundles of ecosystem services) with regard to a given public policy.*

> *The heritage value (and not an economic value) for ecosystem services which have a spiritual and cultural dimension.*

> *Measuring the benefits of certain provisioning services provided to human societies in terms of the actual goods or revenues associated with them.*

The values targeted within the framework of the EFESE focused mainly on three areas:

> ***Biophysical** : which aims to evaluate the current condition of ecosystems and the principal ecological functions (taking into account their evolutionary tendency).*

> ***Social**: which attempts to measure the links between the services provided by ecosystems and their contribution in terms of employment, health, quality of life, security of assets and people, etc.*

> ***Economic**: which aims to provide monetary values extracted from goods and services (through a cost observation technique).*

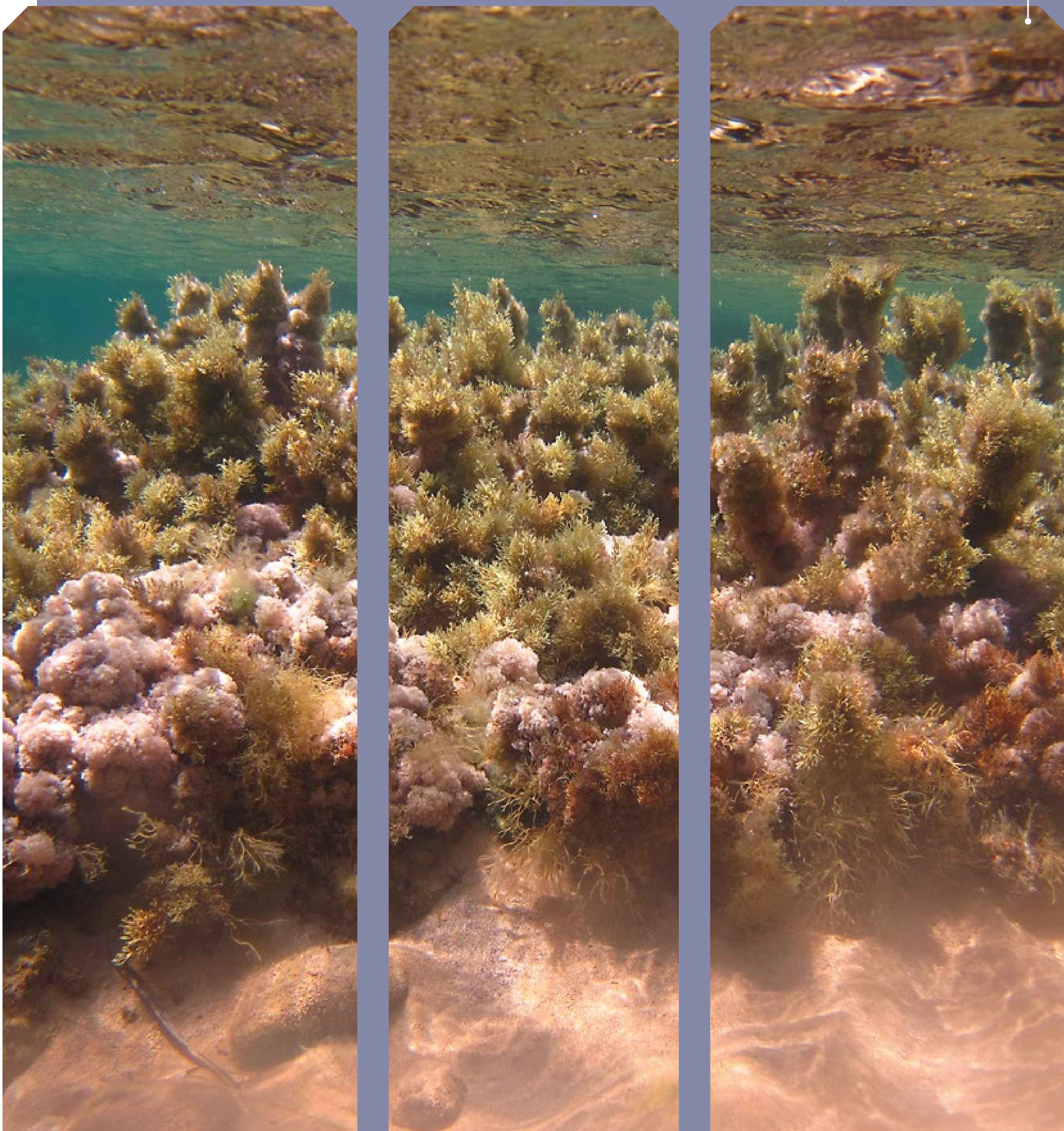
Chapter 2
The Contribution of Shallow Coastal Areas to Human Society: Ecosystem Services

> SUMMARY

The link between ecosystems and society...	*Ecosystems and society are interconnected and the actions within one of these organized systems will logically have an impact, whether positive or negative, on the other. The notion of ecosystem services (ES), defined as the goods and services provided to people by ecosystems, highlights how the natural environment provides benefits to human societies.*
...is made evident through ecosystem services (ES).	*The concept of ES, developed in the 1970s, has greatly evolved. Today, there are several different nomenclatures to define SE and the CICES classification was selected for use in this Guide. The concept defines 3 categories: supply service, regulation service and those with a social dimension.*
Coastal habitats supply ecosystem services...	*The habitats of shallow coastal regions provide services to people. Some of them provide several ES; however, certain services are only provided by a small number of habitats. These facts should be taken into account during development or restoration projects of coastal areas, especially with regard to the habitats present in the affected zone.*
...providing different benefits...	*People enjoy a certain number of benefits from ecosystem services. These benefits can provide an economic and cultural value to the various ES, yet associating those values to specific services may be difficult, even if some economic models have been developed for this purpose.*
...that should be preserved.	*The many services provided by shallow coastal regions depend on maintenance and preservation of the relevant ecosystems and their biodiversity. Human activities obviously affect both the quality and quantity of benefits derived from ecosystem services and the condition of the ecosystems themselves.*

Salses-Leucate lagoon

"Forest" of *Cystoseira* (a brown seaweed)



Chapter 3

Human Actions in Shallow Coastal Zones: **Pressures, Impacts and Issues**

> "Closed and semi-closed seas, such as the Mediterranean, have for a very long time undergone sustained environmental impacts, due to the intensity of human activities in the areas that surround them. This has led to the degradation of coastal and marine ecosystems, as well as an increased risk of more serious damage. Population concentrations (residents and seasonal visitors) and diverse human activities around the Mediterranean basin significantly threaten the coastal and marine ecosystems as well as the abundant resources of the coastal regions. In the coming years, coastal zones in Europe will most likely be confronted with increasing pressures. Habitats and natural resources (land, fresh water, sea water and energy) will be the most affected. The most likely contributing factors are urbanisation, tourism, agriculture, fishing, transportation and industry, due in large part to increasing demands for infrastructures such as ports, marinas, public transport networks, water treatment centers, etc."
>
> (Source: European Environment Agency, 2000).

1. The Driving forces, Pressures, State, Impact, Resources (DPSIR) model

Focusing only on human impacts on the environment is not enough. It is equally important to take into account the driving forces and pressures that generate these impacts and consider how to mitigate and manage their consequences. The model that is most commonly used in Europe is called DPSIR (Driving forces, Pressures, State, Impact, Responses), developed by the European Environment Agency (EEA). The DPSIR model is an aid for evaluating factors that appear to have an effect on the environment in a presumed cause and effect relationship. It is organized into 5 key elements:

> **Driving forces**: changes in social, economic, and institutional systems that cause indirect or direct changes to the surrounding environment.

> **Pressures**: occasional or prolonged pressures that cause changes in the state of the environment. This term refers to the direct action of one or more **driving forces** that may result in changes in flows, cycles, or responses of ecosystems.

> **State**: observable changes of an **ecosystem**, which are determined through measureable physical, chemical or biological variables.

> **Impact**: consequences that result from changes in the **state** of the fauna and flora of the ecosystem under pressure. These may be considered losses or gains depending on the effects.

> **Responses**: interventions undertaken to reduce the ecological impact caused by human activities.

This method allows for some flexibility when planning or conducting assessments of ecological degradation. If, for example, the pressures and the effects thereof are not well understood, it is still possible to conduct pertinent evaluations through analysing the driving forces that are at the origin of these effects. Also, in the absence of data on pressures, driving forces data, which are more easily collected than data on pressures, may be used as the basis of evaluations. In situations where it is difficult to evaluate anthropogenic pressures exerted on the environment and all of their effects, the DPSIR model helps to select the most important pressures and effects (Bouchoucha *et al.*, 2010).

In Figure 16, an increase in recreational boating is a driving force in which one of the direct consequences on shallow coastal regions is the increase of pressure related to the excessive number of boats in anchorage zones. Often, this pressure includes unauthorized mooring and the use of anchors that are ill-suited for use in coastal areas. These anchors often have a direct and highly negative impact on seagrass meadows.

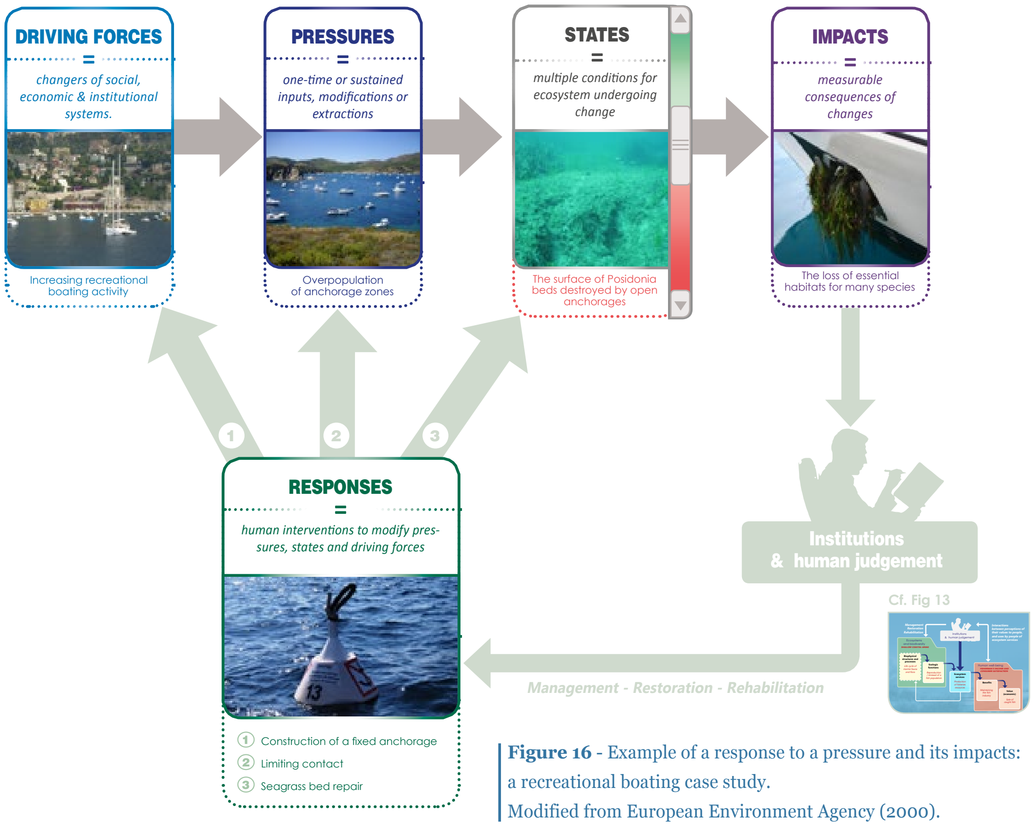


Figure 16 - Example of a response to a pressure and its impacts: a recreational boating case study.
Modified from European Environment Agency (2000).

Different types of interventions can be conducted in parallel in order to respond to a local situation at different levels: limiting the number of recreational boats and the number of visits in certain zones (intervening thereby at the "driving forces" level); decreasing pressure in the zone by creating mooring buoys that are less harmful for *Posidonia* seagrass meadows; educating boaters of the need for conservation (including mooring strategies and anchor types); restoration of seagrass beds that have been damaged or degraded, with the help of "seagrass patch-up" (intervention at the "state" level); improving ground maps of zones that have seagrass meadows - one such map was completed in 2012-2014 and is available as a smartphone application (DONIA project).

> What lies "beneath" the Mediterranean? - DONIA

The DONIA application was developed by Andromede Oceanologie, an innovative French company, with the support of the Rhone-Mediterranean and Corsica Water Agency. This smartphone application is free and is designed to help protect Posidonia seagrass meadows in the Mediterranean. DONIA allows users to visualize the sea floor at a given location and to identify the zones where seagrass beds are located. The goal is to help limit the negative impacts of mooring and anchoring on seagrass beds.

2. The main pressures and their potential impacts on shallow coastal areas

An analysis of the stresses exerted on the coastal zones of the Mediterranean, which include shallow coastal regions, shows a large diversity of direct and indirect pressures (Figure 17). The principal issues related to these **pressures** were identified through the PAMM in the Western Mediterranean (internet source: DIRM Mediterranean). They can be described as follows:

1 - Riverine pollution: inflows from the Rhone River and coastal streams are the principal source of pollutants that can cause contamination of the food chain.

2 - Urban pollution: Inflows from local surrounding agglomerations are also a source of contamination of the marine environment.

3 - Artificialization of coastlines: approximately 20% of the French Mediterranean coastline (excluding Corsica) has been urbanized, causing considerable degradation and destruction of ecosystems found in shallow coastal regions.

4 - Mechanical damage: trawling, dredging and anchoring have also impacted underwater marine **habitats**.

5 - Pressures related to fishing: over recent years, stocks of certain populations of fish have dramatically decreased.

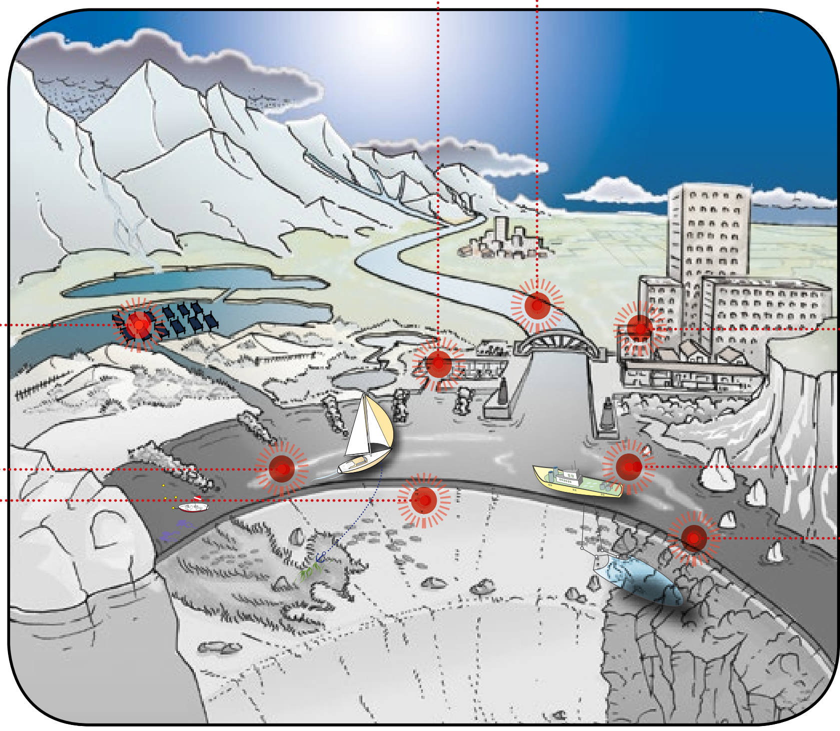


Figure 17
A representation of various anthropogenic pressures on shallow coastal areas.

6 - Solid wastes have strong impacts on marine **habitats** and fauna. There is, however, a lack of knowledge on this subject.

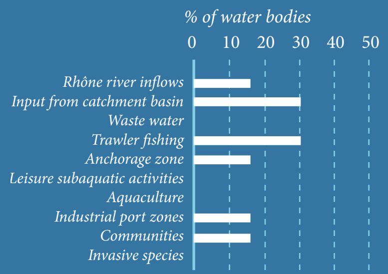
7 - Illegal and accidental discharges from ships: despite strict legislation these still occur, especially off the coast of *Côte d'Azur* and the eastern coastline of Corsica.

8 - Invasive species: accidental and intentional introduction of non-indigenous species can lead to competition or displace indigenous species, thereby causing significant impact on ecosystem functioning and health. Though we have some knowledge of these species and their impacts, there is still a great deal that remains unknown.

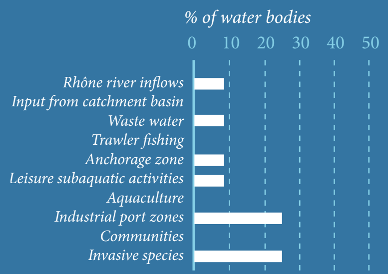
According to the marine water quality atlas provided by the coastal water surveillance network (RMC Water Agency, 2013), chemical and biological analysis, as well as an evaluation of pressures, 21% of near-shore Mediterranean coastal land areas in France have been degraded, along with 19% of near-shore waters within 1 nautical mile of the coast.

> Major pressures identified through work completed within the inventory of the Rhône Mediterranean and Corsica basin set up in 2005 as part of the WFD.

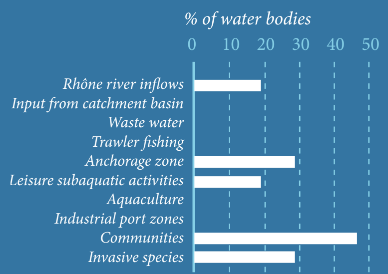
The three sectors experiencing distinct pressures on the Mediterranean Coast are:



The "West Coast" territory (from the Spanish border to the west of Camargue): pressures on this environment come mainly from inflows of small streams and the Rhone river, as well as other uses of the sea, namely trawler fishing (28%), open anchoring (14%) and industrial port zones and large surrounding communities (14%).



The "Activity Zone of Marseille" territory (from the Gulf of Fos to the Bay of Toulon): the two most significant pressures come from the industrial port zones and surrounding agglomerations (which affect 25% of the bodies of water in the area), and invasive species. Other pressures, inflows from the Rhone, discharges from the water treatment plant, open anchoring and nautical activities affect less than 10% of water bodies.



The "Eastern Coastal Zone" (from the Giens Peninsula tombolo to the Italian border): the most significant pressures come from the surrounding urban areas (which affect 45% of bodies of water), open anchoring (27%), subaquatic activities (18%), invasive species (26%) and inflows from coastal streams (18%).

3. The links between pressure, impacts, and risks

Shallow coastal regions are subjected to numerous types of human activities and are at high risk of degradation. The risks are dependent on the probability of the appearance of a pressure and the vulnerability of an ecosystem to this pressure.

> The notion of risk

Risk *is a random event with a certain level of probability of causing damage. This concept is composed of two distinct elements: an event – such as a pollution, a natural catastrophe, etc. – defined by its location and intensity, and second, the populations and parts of the environment that are vulnerable to being affected by the event. The estimation of the likelihood of this event occurring is called probability.*

Figure 18 illustrates the concept of an environmental risk and its consequences using a concrete example: a boat discharging oil close to a shallow coastal zone that has habitats where various populations of fish live during different periods of the year. This causes an increase in hydrocarbons that could affect a post-larvae colonization zone. This type of hazard is not uncommon in certain areas of the Mediterranean basin. Also, for a great majority of coastal fish species, the larvae ***colonization*** *period of the coastal regions occurs mainly between March and September, which means that exposure to this hazard is at its highest in spring and at its lowest in fall and winter. The risk that oil pollution will affect post-larvae is much higher, therefore, in summer then in winter. Thus vulnerability to an event can vary according to the period, the type of event, and the type of habitat affected.*

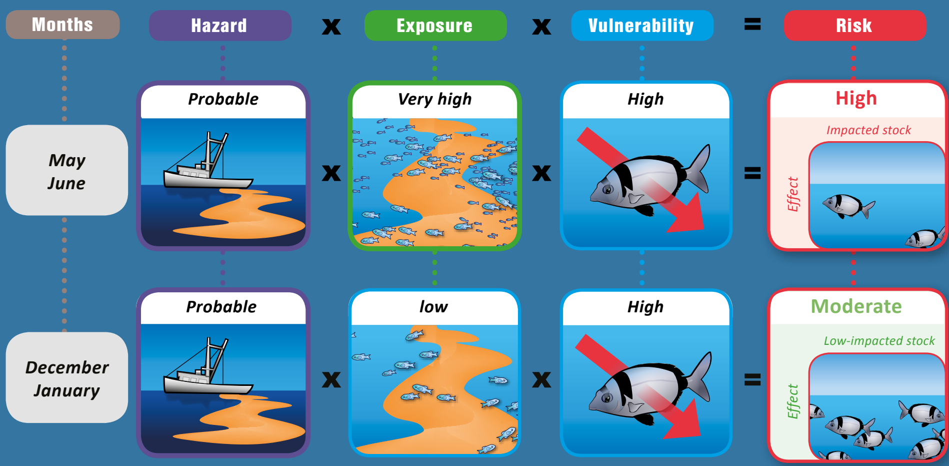


Figure 18 - . An example of the temporal variation of level and significance of risk associated with illegal discharges from tankers on post-larvae populations.

Of the pressures listed in WFD and the MSFD, we focused mainly on those affecting the shallow coastal regions of the Mediterranean. Table 4 provides information on the driving forces affecting, as well as their potential impacts on, the principal types of shallow coastal zones. The main pressures are all linked to increased human population: coastal urbanization (especially construction on land reclaimed from the sea), human activities (agriculture, aquaculture, granulate extraction, fishing, marine transport, nautical leisure activities) and various wastes (waste water, inflows from catchments during rain, industrial discharges, solid wastes, etc.). The impacts generated by these can be physical (habitat destruction, turbidity, etc.), chemical (pesticide pollution and other toxic chemicals, etc.) and/or biological (stress on individuals and populations, selective removal of local species and general reduction of biodiversity which, together with habitat degradation, accelerates the introduction and spread of invasive species). These impacts, detailed in Annex 4, cannot be accurately measured individually.

Therefore, the results shown in the second part of the table 4 are qualitative but can still be used to assess the fragility and vulnerability of certain ecosystem types. For example, unlike sandy bottoms, Posidonia seagrass meadows are particularly vulnerable to anthropogenic pressures. It is also important to note that post larvae are highly vulnerable and at risk due to their fragile metabolism.

Tableau 4 - Pressures, impacts, and driving forces influencing different coastal and near-coastal ecosystem types.

PROBLEMS			HABITATS									
Driving forces		Human-induced pressures	Sandy SA	Gravelly SA	Rocky SA	Organogenic formations	Seagrass	Estuaires/ Lagoons	Mudflats	Rocky banks	Artificial infrastructures	Ports
Increase of human population	at the global level	Fish/shellfish aquaculture					?	●				
		Fisheries using trawling gear	●	●	●	●	●			●		
		Artisanal fisheries	●	●	●	●	●	●	●	●	●	
		Waste water discharge	●	●	●	●	●	●	●	●	●	●
		Global changes	●	●	●	●	●	●	●	●	●	●
	in coastal regions	Landfill constructions	●	●	●	●	●	●	?		Except artificial reefs ●	●
Development of pleasure boating and in freight navigation		Overpopulation of anchorage zones	●	●	●	●	●	●	●	●		
		Port and shipping channel dredging, immersion of the collected sediments										●
Development of seaside tourism		Leisure activities	●	●	●	●	●	●	●	●	●	●
		Recreational fishing and spearfishing	●	●	●	Shore fishing ●		●	●	●	●	●
		Sound and electromagnetic pollution	●	●	●	●	●	●	●	●	●	●
		Solid waste and debris	●	●	●	●	●	●	●	●	●	●
Development of hinterland activities		Input from catchment basin by flow	●	●	●	●	●	●	●	●	●	●
Development of construction industry		Extraction of gravel/minerals, beaches nourishment	●	●			●	?				

Along with the pressures identified and their corresponding impacts, it is also important to detail the ecosystem services that are affected, in order to better inform managers and public policy makers of the issues involved, and the costs of inaction or neglect.

> IMPACT:

modelling the combined pressures linked to human activities on coastal zones and drafting a map indicating vulnerable marine habitats.

Andromede Oceanologie and the Rhone-Mediterranean and Corsica Water Agency developed a mapping tool that provides access to coastal data called MEDTRIX (www.medtrix.fr). The project, called IMPACT (Figure 19), provides information on the principal pressures that affect coastal zones. Zones affected by these pressures are modelled to provide an idea of their cumulative effects. This information, along with biocenosis maps, can provide an initial analysis of the vulnerability of marine habitats.

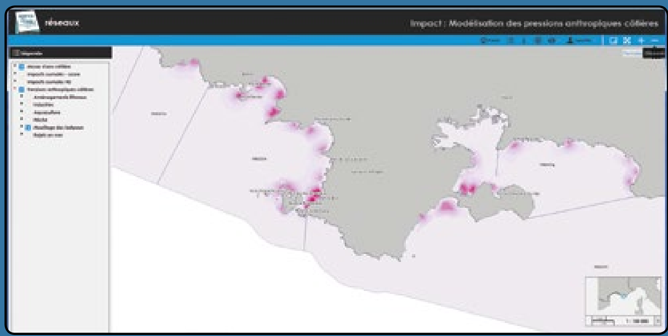


Figure 19
An example of modelling anthropogenic pressures on marine environments near Toulon (Var Department, southern France). Data from MEDTRIX website.

4. The challenges surrounding human activities

Some human activities create pressures on various **ecosystems** and their **biodiversity**, and as a result, negatively **impact ecosystem** services delivered to people. By cross-referencing the pressures/impact data in Table 4 with the ecosystem services data in Table 3, it is possible to identify the type of impact (positive or negative), the level of reversibility of the impact (if it is negative) from an environmental point of view, and how easily the impact could be managed from a socio-economic point of view. This information allows an evaluation of the issues with regard to a given service (Table 5) in terms of loss (in the case of degradation), as well as from an ecological and socio-economic point of view.

Some of the information in Table 5 should be analysed carefully, particularly where different types of seagrass meadows are clustered together. There are large disparities between types of seagrass. For example, if an activity destroys a *Posidonia* seagrass meadow, the dead mat that remains does not allow the seagrass to regrow. However, if the same situation occurs with eelgrass meadow, the seed bank remaining in the sediment could allow the seagrass to regrow. Among the 5 pressures listed, many have a strong impact on seagrass habitats. This is not, however, always the case, as certain pressures have varying degrees of impact, and in some cases may even have a positive impact on certain ecosystem services.

Table 5

Seagrass meadows provide an example of pressures and impacts influencing different ecosystem services of habitats within shallow coastal areas, the issues corresponding to these pressures and impacts, and the corresponding magnitude of concern for each of these issues: very high ■, low ■, and none ■.

Impact on shallow coastal zones — Global population increase

Services	1. Sea aquaculture: IMPACT (level)	1. REVERSIBILITY (level)	1. MANAGEMENT CAPACITY	1. ISSUES AND CHALLENGES	2. Shell aquaculture: IMPACT (level)	2. REVERSIBILITY (level)	2. MANAGEMENT CAPACITY	2. ISSUES AND CHALLENGES	3. Trawler fishing: IMPACT (level)	3. REVERSIBILITY (level)	3. MANAGEMENT CAPACITY	3. ISSUES AND CHALLENGES
Animal production for professional fishing	Negative medium	Positive low	Positive low	high	Positive medium			no-existent	Negative high	Positive low	Positive low	very high
Regulation of water quality	Negative high	Positive low	Positive low	very high	Negative medium	Positive low	Positive low	no-existent	Negative low	Positive low	Positive low	medium
Regulation of functional diversity	Negative medium	Positive low	Positive low	high	Positive medium			no-existent	Negative high	Positive low	Positive low	very high
Regulation of interspecific interactions	Negative medium	Positive low	Positive low	high	Positive medium			no-existent	Negative high	Positive low	Positive low	very high
Erosion protection of coastal zones	Negative low	Positive low	Positive low	medium	no-existent			no-existent	Negative medium	Positive low	Positive low	high
Protection from storms	Negative low	Positive low	Positive low	medium	no-existent			no-existent	Negative medium	Positive low	Positive low	high
Preservation of marine species lifecycle	Negative low	Positive low	Positive low	medium	Positive medium			no-existent	Negative high	Positive low	Positive low	very high
Control of invasive species	Negative high	Positive low	Positive low	very high	no-existent			no-existent	Negative medium	Positive low	Positive low	high
Recycling nutriments (N, P..) and organic material	Negative high	Positive low	Positive low	very high	Positive medium			no-existent	Negative medium	Positive low	Positive low	high
Support for the tourism industry and leisure outdoor sports	no-existent			no-existent	no-existent			no-existent	Negative low	Positive low	Positive low	medium
Support for aesthetic landscaping	no-existent				Positive medium			no-existent	Negative low	Positive low	Positive low	medium
Support for scientific research	Negative medium	Positive low	Positive low	high	Positive medium			no-existent	Negative medium	Positive low	Positive low	high
Support of the development of educational knowledge	Negative low	Positive low	Positive low	medium	Positive medium			no-existent	Negative medium	Positive low	Positive low	high
Production of animals for recreational fishing	no-existent			no-existent	no-existent			no-existent	Negative high	Positive low	Positive low	very high
Production of heritage species	Negative medium	Positive low	Positive low	high	Positive medium			no-existent	Negative high	Positive low	Positive low	very high
Support for health care	Negative high	Positive low	Positive low	very high	Negative medium	Positive low	Positive low	no-existent	Negative low	Positive low	Positive low	medium

Impact on shallow coastal zones — Global population increase

Services	4. Small-scale industrial fishing: IMPACT (level)	4. REVERSIBILITY (level)	4. MANAGEMENT CAPACITY	4. ISSUES AND CHALLENGES	5. Waste water discharge: IMPACT (level)	5. REVERSIBILITY (level)	5. MANAGEMENT CAPACITY	5. ISSUES AND CHALLENGES
Animal production for professional fishing	Negative high	Positive medium	Positive medium	medium	Negative high	Positive low	Positive medium	high
Regulation of water quality	no-existent			no-existent	Negative high	Positive medium	Positive medium	medium
Regulation of functional diversity	Negative high	Positive medium	Positive medium	medium	Negative high	Positive medium	Positive medium	medium
Regulation of interspecific interactions	Negative high	Positive medium	Positive medium	medium	Negative medium	Positive medium	Positive medium	low
Erosion protection of coastal zones	Negative low	Positive medium	Positive medium	very low	Negative medium	Positive low	Positive medium	medium
Protection from storms	no-existent			no-existent	Negative medium	Positive low	Positive medium	medium
Preservation of marine species lifecycle	Negative high	Positive medium	Positive medium	medium	Negative high	Positive medium	Positive medium	medium
Control of invasive species	Negative low	Positive medium	Positive medium	very low	Negative high	Positive medium	Positive medium	medium
Recycling nutriments (N, P..) and organic material	no-existent			no-existent	Negative high	Positive low	Positive medium	high
Support for the tourism industry and leisure outdoor sports	no-existent			no-existent	Negative high	Positive medium	Positive medium	medium
Support for aesthetic landscaping	Positive medium			no-existent	Negative medium	Positive medium	Positive medium	low
Support for scientific research	Positive medium			no-existent	Positive medium			no-existent
Support of the development of educational knowledge	Positive medium			no-existent	Positive medium			no-existent
Production of animals for recreational fishing	Negative high	Positive medium	Positive medium	medium	Negative high	Positive low	Positive medium	high
Production of heritage species	Negative low	Positive medium	Positive medium	very low	Negative high	Positive medium	Positive medium	medium
Support for health care	no-existent			no-existent	Negative high	Positive medium	Positive medium	medium

challenge: no-existent; very low; low; medium; high; very high

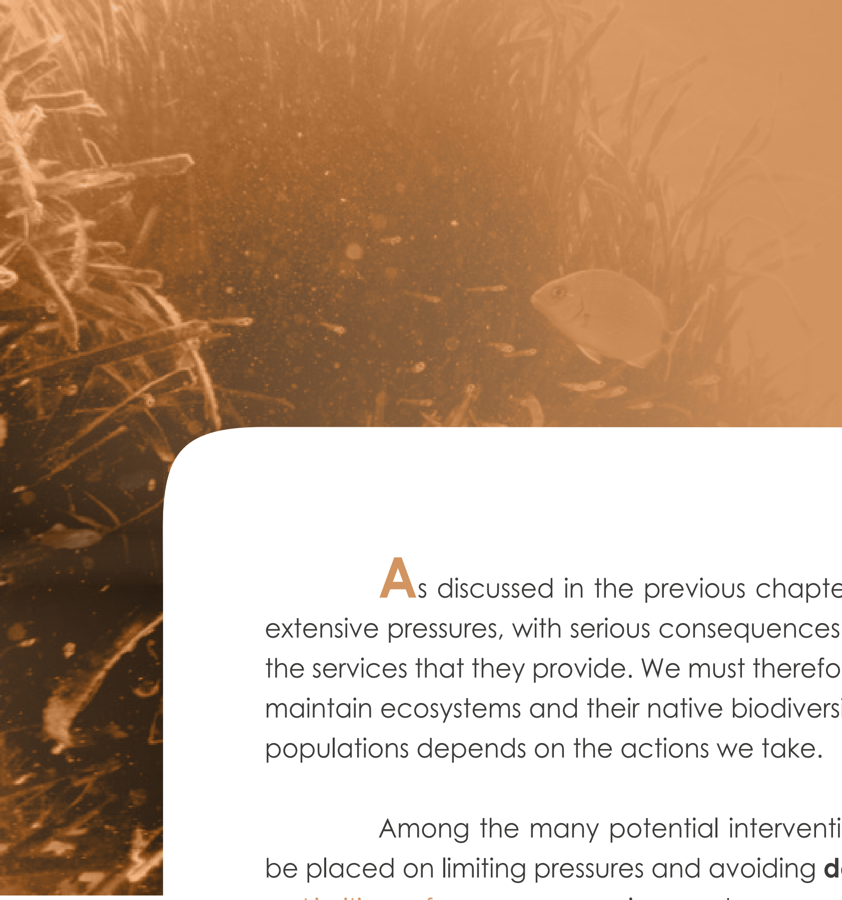
Positive: high; medium; low
no-existent
Negative: low; medium; high

Chapter 3
Human Actions in Shallow Coastal Zones: Pressures, Impacts and Issues

> SUMMARY

Taking into account pressures and their corresponding impacts…	*To evaluate human related impacts, it is necessary to identify the different causes and the driving forces of these impacts, as well as their consequences. The DPSIR (Driving Forces, Pressures, State, Impact, Responses) is a methodological approach to analyse the factors and relationships that have an effect on the environment.*
…as well as the resulting risks…	*In order to define the notion of risk, it is necessary to take into account two criteria: an event (pollution, natural catastrophe, etc.), defined by its location and intensity, as well as the components of the environment that are exposed to this risk and which are vulnerable thereto (fish populations, habitats, etc.). The probability that this could occur is called hazard.*
…to shallow coastal regions…	*Shallow coastal regions ensure an interface between land and sea, are vulnerable to pressures originating from either of these two environments and are subjected to a number of degradation risks. The origin of these impacts may be local or distant and they may be caused by single or multiple factors. Management of these impacts becomes complex when the impacts are caused by multiple factors and the consequences are difficult to evaluate, especially since the impacts of the corresponding pressures accumulate.*
…makes it possible to determine the issues that affect each habitat.	*Cross-referencing the pressure and impact data with ecosystem services data enables management staff to identify the issues, their relative importance, and whether or not they are reversible. Each habitat has a particular level of vulnerability as a function of the types of pressure that it is subjected to and their intensity. Also, certain pressures are specific to certain habitats.*


BM



Chapter 4

Ecological Restoration: A Way Forward

As discussed in the previous chapters, coastal ecosystems have been subjected to extensive pressures, with serious consequences in light of their ecological importance as well as the services that they provide. We must therefore act, either directly or indirectly, to protect and maintain ecosystems and their native biodiversity. The survival and well-being of coastal human populations depends on the actions we take.

Among the many potential interventions and management measures, priority should be placed on limiting pressures and avoiding **degradation**.

> Limiting of pressures requires upstream policy efforts to reduce harmful impacts on the environment, primarily legislation to promote reasonable and sustainable use of natural resources and reduction or elimination of all forms of pollution.

> Avoiding degradation entails taking a series of actions, such as: conserving sensitive sites and zones with environmental and heritage importance; controlling human activities through promoting awareness and enforcement of laws and rules; and creating effective nature reserves and marine protected areas.

However, putting preventive measures into place is not enough for ecosystems that have been severely impacted over decades or centuries. Direct action is necessary. This direct action is called ecological restoration. This term, often used in a vague fashion, is best defined as "the process of assisting the recovery and regeneration of ecosystems that have been damaged, degraded or destroyed" (SER, 2004).

Sound ecological and biological knowledge is needed to achieve successful results in restoration projects. In general, these projects can only be envisaged after steps have been taken to limit pressures, and when the methods of application and management have been evaluated. Otherwise, all restoration efforts will be in vain. In other words, it is necessary to identify the causes of degradation, and when possible to treat these causes and not just the symptoms.

1. An ecosystem trajectory

a. **Ecosystem dynamic under natural and man-made influences**

All **ecosystems** have a certain degree of variability (Figure 20) and the **trajectory** that an ecosystem follows (blue curve) is constantly modified by **natural disturbances** (in dark blue). An ecosystem's level of **resistance** determines the level of negative impact or disruption, and an ecosystem's **resilience** will determine how well it can re-establish itself as well as the time required to do so. Currently, few ecosystems are impacted solely by natural disturbances. Pressures linked to human activities (in orange) add to natural pressures and increasingly contribute to the negative impacts on ecosystems and their natural disturbance regimes. As pressures accumulate, and persist over an extended period of time, each ecosystem risks losing its capacity to **auto regenerate** and to adapt to changing environmental conditions (red curve). Over and above a certain **threshold** (grey zone), even if the pressures are removed, the ecosystem will not be able to go back to its previous trajectory (see figure 21 page 59). When the alteration has negative consequences for humans and for the resilience of a system, this is an example of ecosystem degradation.

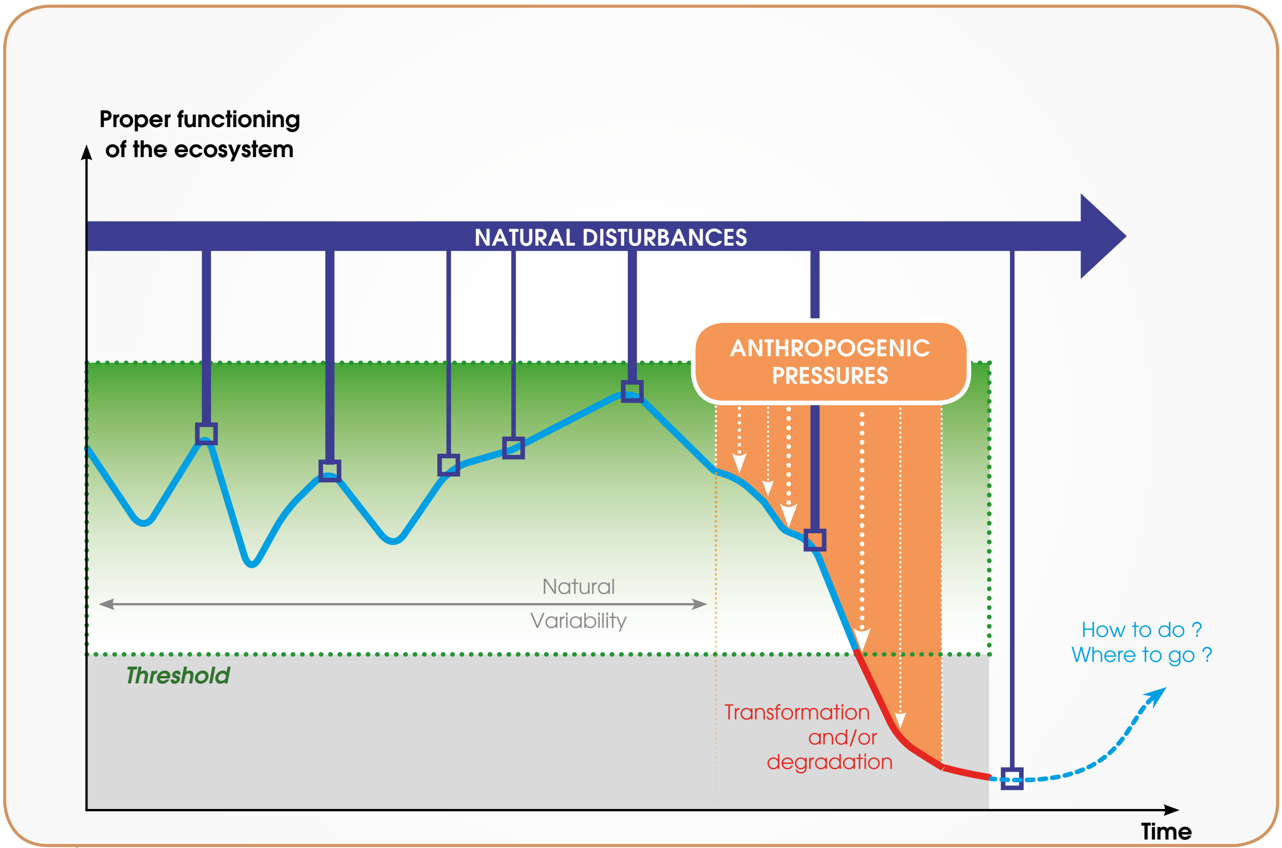


Figure 20
The dynamics of an ecosystem subjected to natural disturbances and anthropogenic pressures on an intermittent or regular basis.

Consequently, direct action is necessary to bring the degraded ecosystem back to an acceptable trajectory (dotted blue line). As previously mentioned, if management and protection measures are not sufficient, it may be necessary to act directly on the ecosystem in order to assist recovery to an acceptable state. It is, of course, important to know the desired state and trajectory. Before beginning any intervention, it is essential to choose or to construct (from information drawn from one or various sources) an ecosystem that can be used as a **reference** in order to guide the restoration work (see below).

b. **Reference ecosystem**

The reference **ecosystem** concept was defined by Aronson *et al.* (1993 a, b), Le Floc'h *et al.* (1995) and SER (2004) as an approximation of the desired state, a chosen norm among several possible alternative states, each of which may be characterized as occurring along an ecosystem trajectory including degradation, transformation and recovery. The reference ecosystem is not the final objective of a restoration project but rather a model we can use to evaluate progress in the restoration project. Our aim is to help the target ecosystem to return to a state and a trajectory which come close to those of the reference we have selected or constructed.

Please note the difference between: the ***reference ecosystem****, as the term is used in restoration ecology, is a model selected or constructed for a particular ecosystem that has been defined as degraded, damaged, or destroyed and is now targeted for restoration. In contrast, the* ***reference status for a body of water****, as defined within the Water Framework Directive, is linked to chemical or quantitative criteria of "a* ***good ecological status****" for which the norm is generally fixed according to an ecosystem type. "Good ecological status" is attained when the biological state or the chemical state corresponds to threshold parameters defined for this type of body of water.*

How to choose or construct a reference ecosystem?

A reference system for ecological restoration can be difficult to determine, because there are many possible options (Clewell & Aronson, 2013). The choice of a reference is therefore imperfect and partially subjective, but nonetheless essential for a scientifically rigorous ecological restoration project. Clearly, this reference needs to be carefully defined or constructed and needs to be adapted to the project. To determine the reference, it is possible to use different sources of information (White & Walker, 1997) that vary both in space and time.

Practitioners must ask:

> *Will we use an existing nearby site or ecosystem, or rather another ecosystem, ex situ, as a reference?*

> *Will we use some relevant ecosystem in its current state, or rather in a state that existed at some stage in the past?*

> *Under what conditions will we combine information from various sources, past and present, near and far, and how will this information be combined?*

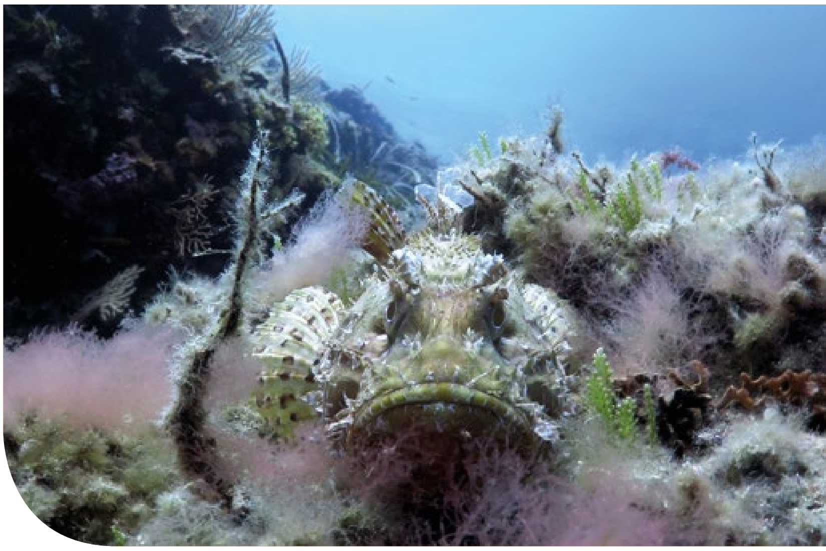
Building on these fundamental questions, it is possible to choose or develop a reference ecosystem (the reference). Often, this reference will not be a single site, but rather a mixture of information from several relevant sites. If there is no existing healthy reference ecosystem close to the target ecosystem, neither choice would be better than the other. As long as the reference corresponds to the objective (which should also be realistic), an historical choice or the creation of a composite reference (even if it is a subjective choice) can be equally appropriate (Aronson *et al.*, 1995).

However, it should be noted that restoring a damaged ecosystem so that it is identical or even approximately identical to the reference ecosystem is generally impossible to achieve. In addition, any attempt to return the damaged ecosystem to its previous state is pointless if the harmful pressures and impacts that altered the ecosystem are still present.Thus the reference ecosystem is used to help in planning project work that aims to achieve a significant and sustainable improvement in terms of the biodiversity, resilience and functioning of the target ecosystem. It also should be used for comparison during monitoring and evaluation of the target ecosystem's responses to attempted restoration.

Criteria to take into account

To answer the questions listed above, the first criteria that need to be taken into account are the complexity of the reference ecosystem under consideration and the quality and quantity of the resources and services provided. However, it is also important to focus on a realistic choice from ecological (some transformed states are quite acceptable), economic and social points of view. Management, cost and level of technical difficulty, as well as acceptance by local community (residents and stakeholders), must also be taken into account when selecting or constructing a **reference ecosystem**.

Red scorpionfish (*Scorpanea scrofa*)



In all cases, the chosen characteristics of the reference ecosystem need to be quantifiable (SER, 2004) in order to allow monitoring and evaluation, not only in terms of whether the objectives were reached, but also how quickly and effectively they were achieved.

Evolution of a reference

A reference is unique for each project. Also, the reference is not necessarily static but rather can evolve over time, particularly if the objective of the project is modified or if it becomes clear that the initial choice was not ideal. It is also possible to choose intermediate references between the actual state and the final desired reference. This method, called sequential referencing (Aronson *et al.*, 2012; Clewell & Aronson, 2013), allows realistic objectives to be set, over an acceptable period of time, and enables detailed recording and evaluation of the development as well as the results of the restoration project. The attempted recovery of "historical continuity" (Clewell & Aronson, 2013) will in theory help the target ecosystem to better adapt to changing conditions in the future. Decades rather than years will generally be required to fully gauge the success of a restoration project.

2. The various possible actions to place a site or an ecosystem onto a desirable trajectory

> The Mitigation Hierarchy

Projects that could have an impact on biodiversity should be based on the mitigation hierarchy – Avoid, Reduce, Mitigate, *adopted in France in 1976 by the Law for the Protection of Nature, and later supported by the State doctrine (source: MEDDE).*

A compensatory measure is an ecological action that aims to restore or recreate a natural ecosystem in order to offset environmental damage or biodiversity loss caused by a project or anticipated in a future project.

If a project leader wishes to implement an intervention that will benefit the environment, he or she may also put into place ecological restoration actions, or support measures to strengthen ecological functions (rehabilitation, artificial habitats, etc.)

a. **Ecological restoration and rehabilitation**

Before commencing a restoration or rehabilitation project, it is important to clearly define the project objectives. The steps to be taken will vary according to the aim of the project, the available resources, and the obstacles and pressures on-site. The choice of the reference ecosystem will also vary accordingly. There are two tasks that should be completed before beginning a project:

1 - select or construct the reference ecosystem, which should have ecological and socio-economic attributes that match, insofar as possible, what the project is intended to achieve.

2 - decide if the project will aim for ecological restoration, i.e., to assist the target ecosystem to regenerate to a pre-disturbance historical state, or rather if the objective will be to recover the ecological functions that correspond to current socio-economic, demographic and cultural realities (ecological rehabilitation).

Apart from these tasks, the preliminary phase of the project should also take into account the specific characteristics of each site, as well as the priorities and constraints of each stakeholder. This will ensure that the project will progress more effectively (Figure 21).

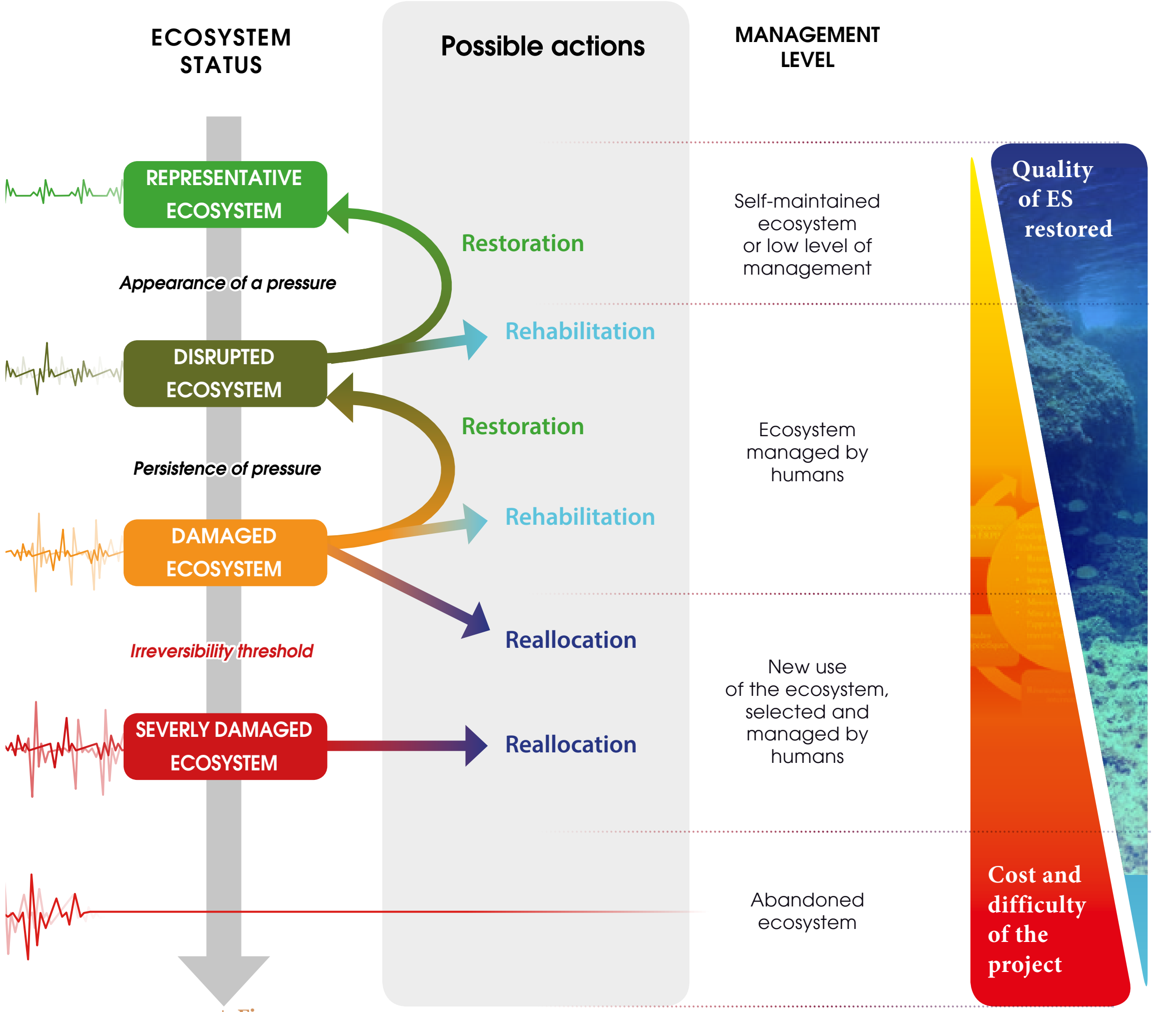


Figure 21
The three types of possible responses/actions after the degradation of one or several marine and coastal ecosystems.
The notion of a threshold of irreversibility is theoretical and difficult to measure in the field.
Modified from Aronson *et al.* (2007).

Shallow rocky areas

Ecological restoration and rehabilitation projects are typically only undertaken if the ecosystem in question has crossed one or more "thresholds", which means they are unlikely to recover without human intervention. There are two main options to consider in this case:

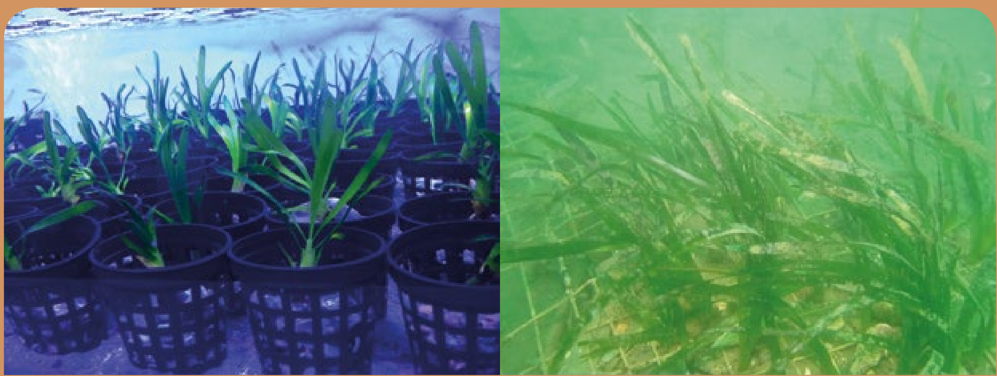
> **Ecological restoration** considers the target **ecosystem** holistically and in the long term. The objective of this option is to "repair" the structure, composition and functioning of the target ecosystem and thereby recover all of the **functions** it performed and the **ecosystem services** it provided before it was damaged. Therefore, in addition to restoring the ecosystem's pre-disturbance fauna and flora, ecological restoration also aims to recover as many of the physical, chemical, hydrologic, and geomorphologic aspects as possible. This approach is the most ambitious and its hoped-for outcome is the ideal. In other words, when our restoration target is the whole ecosystem, the aim is to help it recover to the point at which it resembles as closely as possible the historically-based reference ecosystem. This type of intervention is also the most difficult to achieve since it entails taking into account a significant number of attributes, some of which are not well understood or readily subject to intervention (e.g., those linked to fundamental processes of the ecosystem). However, there are many long-term benefits that could be obtained using this option, since the goal is to restore the diversity and quality of ecosystem services and eliminate the need for costly management after restoration is achieved (assuming all harmful pressures are removed).

Graines de mer
Sowing for the Mediterranean

> **Seeds of the Sea –** *Sowing for the Mediterranean*

Seeds of the Sea is an ecological restoration pilot project that aims to develop innovative techniques and transplanting procedures for ecosystem-essential flowering plants such as Posidonia *seagrass in the sea and* Zostera *eelgrass in the lagoons. From 2011 to 2014, SM² Solutions Marine gathered seeds of these essential plants on beaches, cultivated them in a marine nursery, and then transplanted the seedlings and monitored their development at the Languedoc Natura 2000 site "*Posidonia *seagrass on the coast of Palavas".*

Figure 22 - Photos of transplants from a *Posidonia* seagrass meadow.

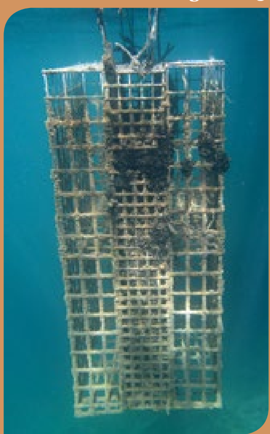


Project financed by the RMC Water Agency and the City of La Grande Motte

> Rehabilitation also relies on the reference ecosystem, but only targets a certain number of attributes and services, such as those that can help ensure habitat and population reinforcement for plants or animal species. In other cases, the objective may be to recuperate the productivity of the ecosystem. In general, ecological rehabilitation efforts are more explicitly anthropocentric then ecological restoration, and may not require the complete removal of existing pressures nor elimination of all the consequences of past change and degradation. Rehabilitation may be a good compromise between ecological restoration and inaction, especially when a site or ecosystem has been highly disturbed or degraded, and when it is too complicated and costly to envision holistic ecological restoration. However, a rehabilitated ecosystem generally requires more management and maintenance than a restored ecosystem. Rehabilitation is also often wrongly thought to be restoration. Though they are distinct from one another, a rehabilitation effort can well be considered a preliminary or intermediate stage on the trajectory of long-term restoration.

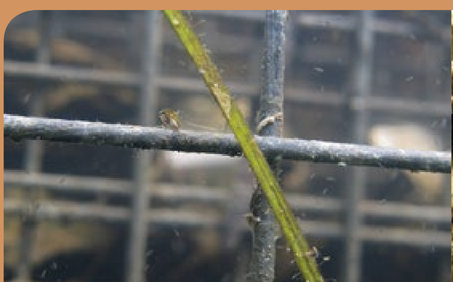
> The NAPPEX project
Artificial Nurseries for Exemplary Ports

Figures 23



a - A Biohut® installed on a pontoon

This project aimed to counter the disappearance of coastal nurseries in harbor zones through the creation of artificial habitats (such as Biohut® dock or pontoon). This procedure is able to mimic the ecological function of a nursery by protecting post-larvae as well as the juveniles from predation, allowing them to grow sheltered from predators and providing them with necessary nutriments thanks to the abundant fixed fauna and flora. This procedure is an innovative solution for ports and aims to contribute to the ***good ecological status*** *of the environment as well as to the natural biodiversity. Six ports in the south of France were included in the NAPPEX project: Port-Vendres and le Barcarès (Pyrénées-Orientales department), Vendres, Agde, and Mèze (Hérault department) and Six-Fours (Var department). The results published in Bouchoucha* et al. *(2016) are encouraging and available at the following website: www.nappex.fr.*



b - a young Blenny recruit on the Biohut® (10 mm)

c - a juvenile Grouper (70mm, newly arrived in the area)

The project is supported by Ecocean, in partnership with CREM (Center of Research on Marine Ecosystem, from the CEFREM Laboratory – UMR 5110 CNRS/UPVD). The project was initiated through a Call for Proposals launched in 2011 by the French Ministry of Ecology, Sustainable Development, Transport and Housing within the framework of the National Strategy for Biodiversity (NSB) 2011-2020. The Nappex project is funded under the "Development of innovative ecological restoration techniques for coastal marine environments" component of the "Call for innovative projects within the ecological engineering domain". It was approved by the Pôle Mer Mediterranée and was co- financed by the Rhone-Mediterranean and Corsica Water Agency, the Hérault Departmental Council and the French Ministry of Ecology.

b. **Other interventions**

When an ecosystem is heavily degraded, it is sometimes impossible for it to return to an acceptable trajectory without massive investment. Ecological restoration is thus not a realistic option. Two types of alternative measures should then be considered:

> **Re-allocation**. This kind of intervention is not undertaken with a reference ecosystem in mind, but rather addresses a local or societal need from a landscape or urban planning perspective. In this type of scenario, when the degradation of an ecosystem is severe, it may make sense to modify it in order to make it useful for purposes completely different from the services that it historically provided. This is generally easier to put into place and is less costly than rehabilitation or restoration, but the quality and diversity of services provided is usually much lower. Considerably more management may also be required to maintain these types of modified ecosystems so that they remain in good working order. In some cases, reallocation may be considered as an intermediate stage on an ecological restoration trajectory.

> **Abandoning an Ecosystem**. When an ecosystem has been so severely degraded that it appears to have crossed a threshold of irreversibility, the ecosystem may be considered to be destroyed.

> Example of a re-allocation project:
sewage basins in the coastal lagoon of Nador, an ancient Mediterranean coastal city in northeastern Morocco.

Figure 24 - Coastal lagoon of Nador, northern Morocco.

The basins, which were constructed directly in a natural lagoon (Figure 24a), were used for many years to treat sewage water. After a water purification plant was constructed in 2011, the artificial basins were completely abandoned. Technical problems, including removal and sanitary treatment of sludge residues and debris, the high costs of rehabilitation, the social demand within the framework of tourism development of the zone, and other factors led local authorities to transform this site into a nature park with special emphasis on bird watching. This reallocation cost relatively little, but did entail backfilling the basins and then re-planting them with ecologically appropriate native plants (Figure 24b).

To summarize, no matter what the objective and the reference ecosystem may be, it is also important to take technological difficulties and ecological aspects into account, as well the costs and the resources available to restore or rehabilitate a degraded ecosystem and then maintain it afterwards in its desired state.

3. Resources and costs to take into consideration

a. Resources

Methods and tools within the domain of **ecological engineering** are often used to implement restoration and rehabilitation projects and reallocations (Figure 25). As used in France, the term ecological engineering represents the full spectrum of techniques and skills relevant to any actions or interventions that aim to re-establish the **good ecological status** of a site or ecosystem. Ecological engineering combines all of the scientific and technical knowledge that informs and guides ecosystem recovery and regeneration. It also provides the means and know-how to carry out each kind of intervention required to reach the objectives of a specific restoration project. Note that in other countries, ecological engineering and ecological restoration are considered complementary rather than indivisible fields of both science and technology (SER, 2004; Aronson *et al.*, 2016).

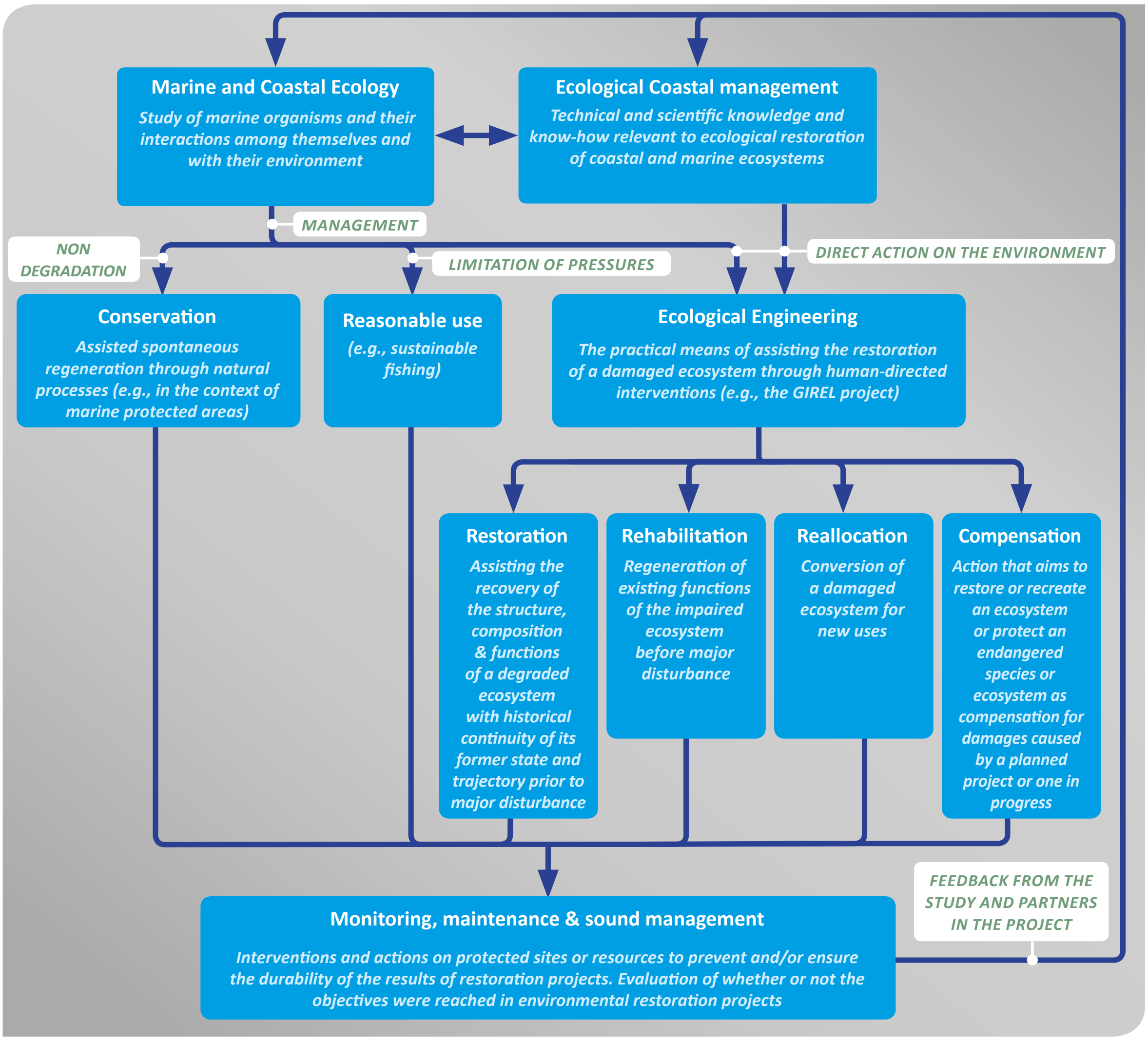


Figure 25 - Logic diagram to plan and coordinate four main types of ameliorative interventions in coastal environments.

In an ecological restoration project, the first step is to identify the causes of **degradation** and eliminate or reduce them. Next, before undertaking further interventions, the project manager should assess the following factors that will help indicate how project objectives can be best achieved.

1 - The zone targeted for restoration needs to be well-defined and the restoration interventions need to be achievable with realistically available restoration tools and methods (For example, it is technically very difficult, time consuming, and excessively costly to restore several hectares of seagrass meadows or coralligenous formations even if it can be done on a small-scale, i.e., for a square meter patch).

2 - The level and duration of past **degradation** of the **ecosystem** should be rigorously assessed, since it will determine the type of actions that need to be developed and provide the means to monitor the success of the interventions.

3 - The quality and diversity of **services** provided by the ecosystem prior to degradation and which services could realistically be recovered will also influence decisions on how much effort and resources to devote to the project.

4 - External socio-economic issues, drivers, and difficulties that may affect the results of the restoration project should also be taken into account.

5 - The potential beneficiaries and all stakeholders affected by restoration actions should be identified, contacted and included in discussions from the outset.

6 - Likewise, a financial plan needs to be developed and finalized: will funding be 100% government, 100% private, or mixed public-private? This question should be answered for restoration, rehabilitation, and re-allocation interventions, as well as for the design and development of projects or other long-term management actions.

b. **The costs**

The costs of a project are as important as the resources available. If costs turn out to be much higher than the expected benefits provided by the restored ecosystems, then stakeholders may argue it is not worth the effort and investment (although different stakeholders may use different criteria to evaluate the benefits). Discussion and compromise should be expected, as no precise cost-benefit calculations can be made for any restoration work in marine environments at this early stage of research and development. Moreover, the cost of inaction should also be taken into account, and better enforcement of existing laws will incur risks of penalties for polluters and developers who avoid restoration and compensation.

In addition to stakeholders' varying positions, the level of technical difficulty and the upfront and expected costs will determine or at least influence the type of project to be conducted, as well as its intensity and the investments made.

Example 1: construction of a parking lot that encroaches upon a marine environment

In this example (Figure 26), we compare different types of construction designs for a parking lot with varying environmental consequences and costs:

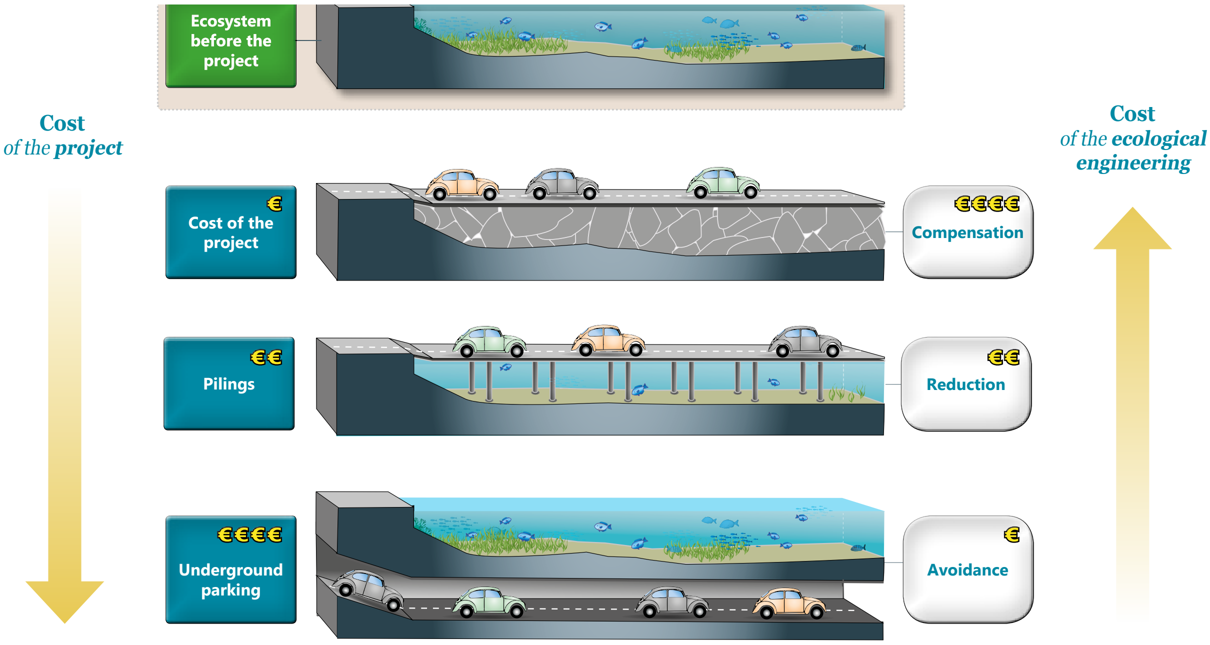


Figure 26 - Different possible measures that can be taken in a development project that encroaches, or may encroach on, marine environments.

> *Backfilling:* inexpensive in financial terms, but environmentally destructive. This type of project does not respect the notion of avoidance – the first step in the mitigation hierarchy. Any degradation that results from this type of construction will require mitigation, which generally means high supplementary costs, ultimately making this option less attractive compared to others.

> *Construction on iron, steel or reinforced concrete stilts:* more expensive, but with significantly fewer negative environmental impacts and therefore much greater conservation value.

> *An underground parking area:* very expensive but provides a means to conserve the marine ecosystem insofar as possible intact, and therefore greatly reduces mitigation costs. Full life-cycle analysis of each such project is required (e.g., cost and impact of excavating and removing large volumes of material.)

Example 2: Restoration of a seagrass meadow

The pressures leading to seagrass meadow degradation may occur over a long period of time, or as a single event. Single events that can cause degradation fall into three major categories:

> *accidental mechanical destruction:* uprooting by anchors (from recreational and professional fishing boats),

> *increase of turbidity* (e.g., sand pumping for refilling dune ridges)

> *construction of a seawall* that destroys a certain area of seagrass meadow.

A restoration project on a seagrass meadow having suffered from any of the above-mentioned damages requires:

> a preliminary study on the biological communities, the grain size of the sediment, the hydrodynamics of the area, the times of year best suited for different phases of restoration, a map of the site, etc.
> authorization to collect the seeds and propagules of legally protected species.
> propagules and seeds of protected species must then be gathered, transported, stored in a seed bank or nursery, cultivated in tanks or basins,
> then transplanted in the natural environment and monitored.

The costs of this type of restoration project are still unclear as very little R&D has yet been carried out. However, the small-scale restoration of *Posidonia* seagrass meadows damaged by boat anchors in French Mediterranean waters required the cultivation of patches of seagrass at a current cost of approximately €1000 per m², excluding monitoring costs.

In order to illustrate how the notions developed in Part 1 of this Guide are connected, several analogies that compare these notions to those used in medicine are proposed in the schematic diagram shown in Fig. 27.

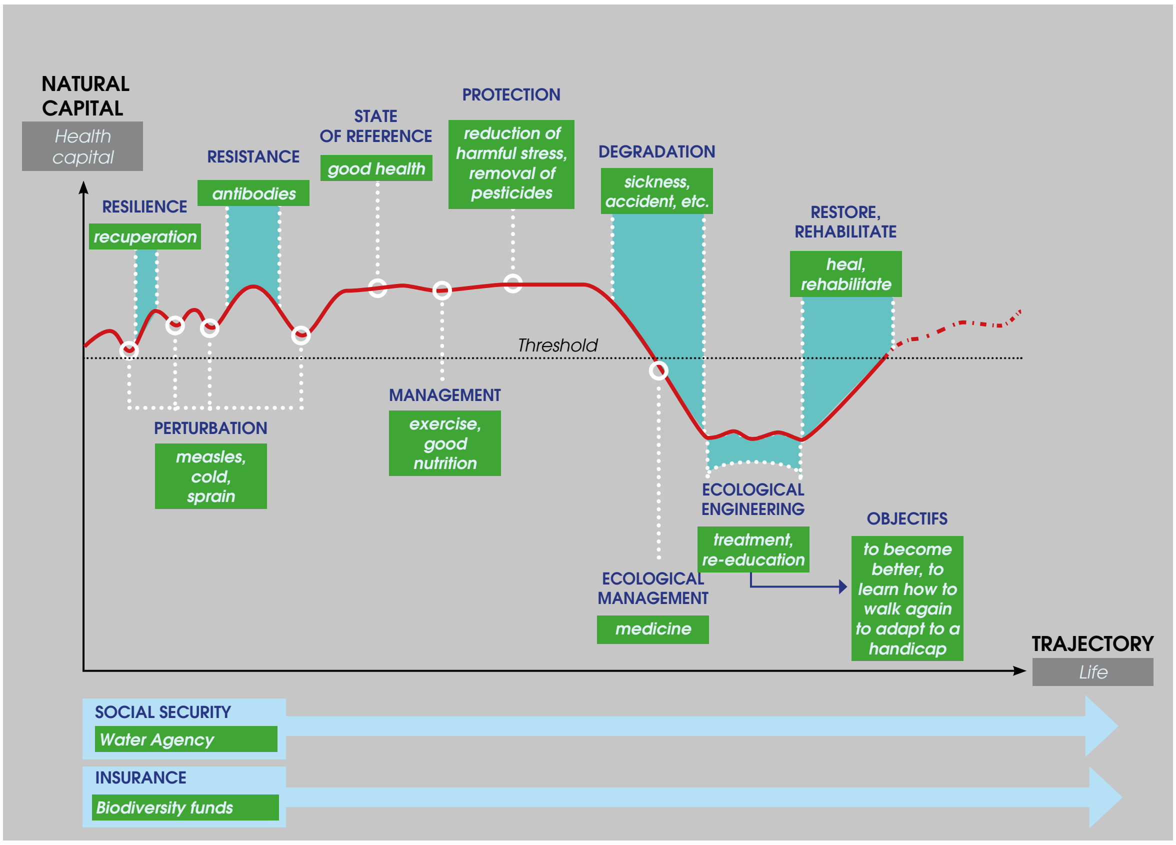


Figure 27 - Elements of comparison between an ecosystem trajectory over time and the life of a person.
The attributes and events that affect the maintenance and the restoration of natural capital inherent in ecosystems are represented in dark blue; the corresponding phenomena needed to maintain or restore health of an individual person are in green. In restoration ecology the concept refers to a degree of degradation causing an ecosystem to enter into a new phase, or begin a new trajectory. In medicine, the term could be applied to a patient who has undergone a major trauma or is suffering from a chronic illness.

Chapter 4
Ecological Restoration: A Way Forward

> SUMMARY

The ever-growing human footprint…	*Each ecosystem is subjected to natural disturbance regimes to which anthropic pressures are often added. When humans add pressures that alter the disturbance regime and damage becomes severe, the natural trajectory of the ecosystem is changed, often profoundly.*
… makes human interventions necessary…	*In certain cases, especially when protection or revised management are insufficient, people can act to restore the ecosystem by reorienting it towards an acceptable or desired trajectory. Depending on the objectives of the project (and especially the reference ecosystem targeted in the case of restoration or rehabilitation projects), different options are possible.*
…through the use of restoration actions…	*Ecological restoration takes into account the entire ecosystem. The objective is to restore, insofar as possible, all of the components as well as the structure and functions of the historical ecosystem, and consequently all of the services formerly provided by the ecosystem.*
…of rehabilitation actions…	*In contrast, ecological rehabilitation projects seek primarily to recover the functional attributes of the disturbed ecosystem, using an historically-based reference system as a guide. The short-term objective is often to recover a certain productivity or type of ecosystem service. Rehabilitation is also sometimes confused with restoration; indeed, the two have much in common as compared to other ameliorative actions.*
…or re-allocation actions…	*Re-allocation to new uses may be the best option when a site or ecosystem has been so severely transformed or degraded that its recovery to an historical trajectory seems impossible or exceedingly expensive to achieve. In this case, an option is to transform the area for other uses.*
…that all have different technical and financial difficulties.	*Whether the objective of a project is restoration, rehabilitation, or re-allocation, it is critical to take into consideration the technical and ecological difficulties, as well as the costs, labour, and resources needed to set-up, follow through and execute the project as well as maintain the site and carry out monitoring and evaluation.*

Part 2

Restoration for Tomorrow's Society?

1. Why should we conduct restoration work now?

Efforts that have been made over the last 20 years in the battle against domestic and industrial pollution have significantly improved the quality of Mediterranean coastal waters. At the same time, the demand for healthy marine environments and the obligations imposed by European and National regulation have slowly evolved from " simple protection " of water bodies to a more holistic view, in which the entire ecosystem is taken into account.

Today, it is no longer sufficient to focus only on good quality water that is safe for swimming. It is also important to have fish that reproduce, seaweed, healthy *Posidonia* seagrass meadows and… no waste material.

The situation on the Mediterranean coast, however, is heterogeneous. There are steep rock faces, large sandbanks, urban zones, large agglomerations, harbor zones, and very few areas that have little or no artificial structures. Coastal activities, as well as population pressures, have continued to grow and the resulting damage to these fragile ecosystems has also increased, often with increasing complexity and obstacles to recovery.

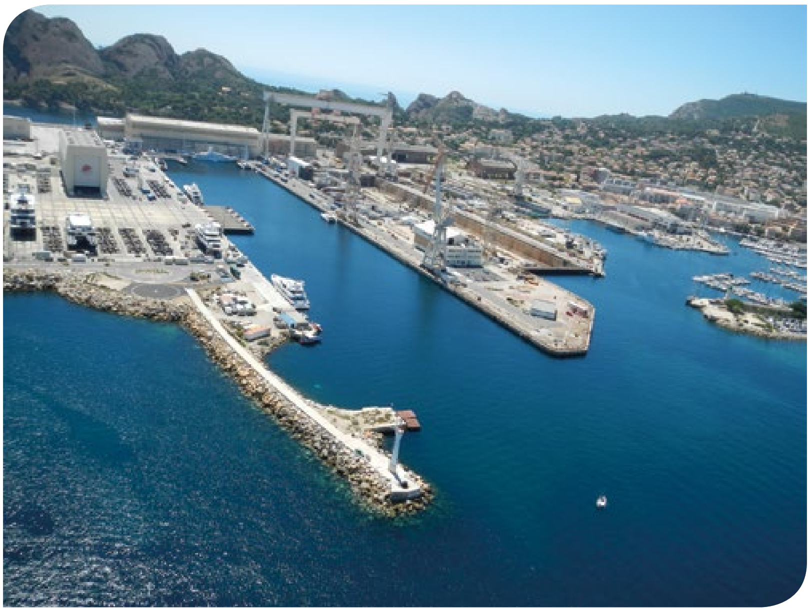


Figure 28 - La Ciotat Harbor

La Ciotat Harbor, southern France. Harbors and ports are geographical sectors of coastal zones in which the quality of the natural environment has often been altered.

These alterations have also contributed to the destruction of shallow coastal regions which collectively play a vital role in global ecological fluxes and cycles.

Regulation and local policy interventions should provide the means to anticipate and manage these ecological challenges, while decreasing pollution of all kinds at the source. Nevertheless, rehabilitation of areas that have already been degraded, as well as managing emerging pressures (water-related activities such as fishing, deep-sea diving, recreational boating, etc.) are more recent concerns for which new methodologies and strategies are needed.

a. **Current regulations promoting the protection of the sea**

Over the past few decades, public policy efforts have focused on reducing pollution. The latest European directives (Water Framework Directive and the Marine Strategy Framework Directive), however, have proposed that we re-evaluate our working methods. It is no longer sufficient to enhance our administrative, technical or financial capabilities in respect of the marine environment. It is now time to act and achieve a far more ambitious objective: the good ecological status of coastal and offshore marine waters. This concept is not yet fully operational, however, although it obligates us to produce results for 2021.

However, we should not forget that the two other European policy guidelines for promoting marine conservation (Natura 2000 and Spatial Marine Planning) require that each country develop an adequate policy and put it into action. This policy relies on 3 complementary actions:

> **Combating Pollution**: this remains a crucial element despite recent efforts, especially upgrading of water treatment plants. Potential exists for improved management of coastal water courses and their inflows during periods of high rainfall.

> **Avoiding Degradation**: this is particularly important - If the natural environment is not damaged, there is no need to restore it. This notion is really important for marine habitats since we are still lacking the science and technology to enable restoring these ecosystems, especially on a large scale.

> **Ecological Restoration**: is a relatively new approach, and thus the technical, administrative, and financial frameworks are still under development.

b. **How is “ecological restoration” defined?**

The first part of this guide provided a glimpse into the complexity of the notion of restoration. For marine coastal managers, the concepts of re-allocation, rehabilitation, restoration or compensation may be confusing and difficult to understand. This may be the reason why a rigorous scientific approach is not generally taken into account by local decision makers. For a local stakeholder, two notions merit careful attention: ecological restoration and compensation.

The need for ecological restoration occurs when environmental degradation is observed and subsequent evaluation of the affected ecosystem precludes spontaneous recovery following other management measures. The issues that need to be addressed are those affecting the fauna, flora and habitats on the one hand – structure and composition, as well as underlying processes and functions that assure water quality, which is of course an essential component of a **good ecological status**.

Because the area to be restored was subjected to pressures that caused its **degradation**, it is also important to remember that the second prerequisite is the management or the elimination of these pressures. These two points demonstrate how ecological restoration extends to an action that aims to improve or recover a satisfactory ecological status.

Restoration is the suite of actions that consists of restoring a degraded or damaged ecosystem as closely as possible to a previous and preferable ecological status as reflected in the **reference ecosystem** that is selected or constructed for the project.

Mitigation aims to counterbalance the negative effects of an activity on the environment by implementing restoration, management, or enhanced protection work simultaneously. This implies that the ongoing or proposed activity causes either irreversible or reversible damage to the environment, but that this is considered acceptable because these damages are mitigated for by other actions that are beneficial to the environment, and hence to society. Within the context of our broad objectives - to improve water quality, avoid degradation and recover a healthy natural environment - compensation cannot be considered as a solution, in and of itself, especially within the framework of the European directives mentioned previously.

Within the context of this guide, and with the objective of facilitating the adoption of this new notion for decision-makers, we propose to define ecological restoration as ***"an action undertaken with respect to marine habitats, and their fauna and flora, which will improve their condition within coastal zones where the quality of water is good and where the pressures that are the cause of degradation have disappeared or have been controlled".***

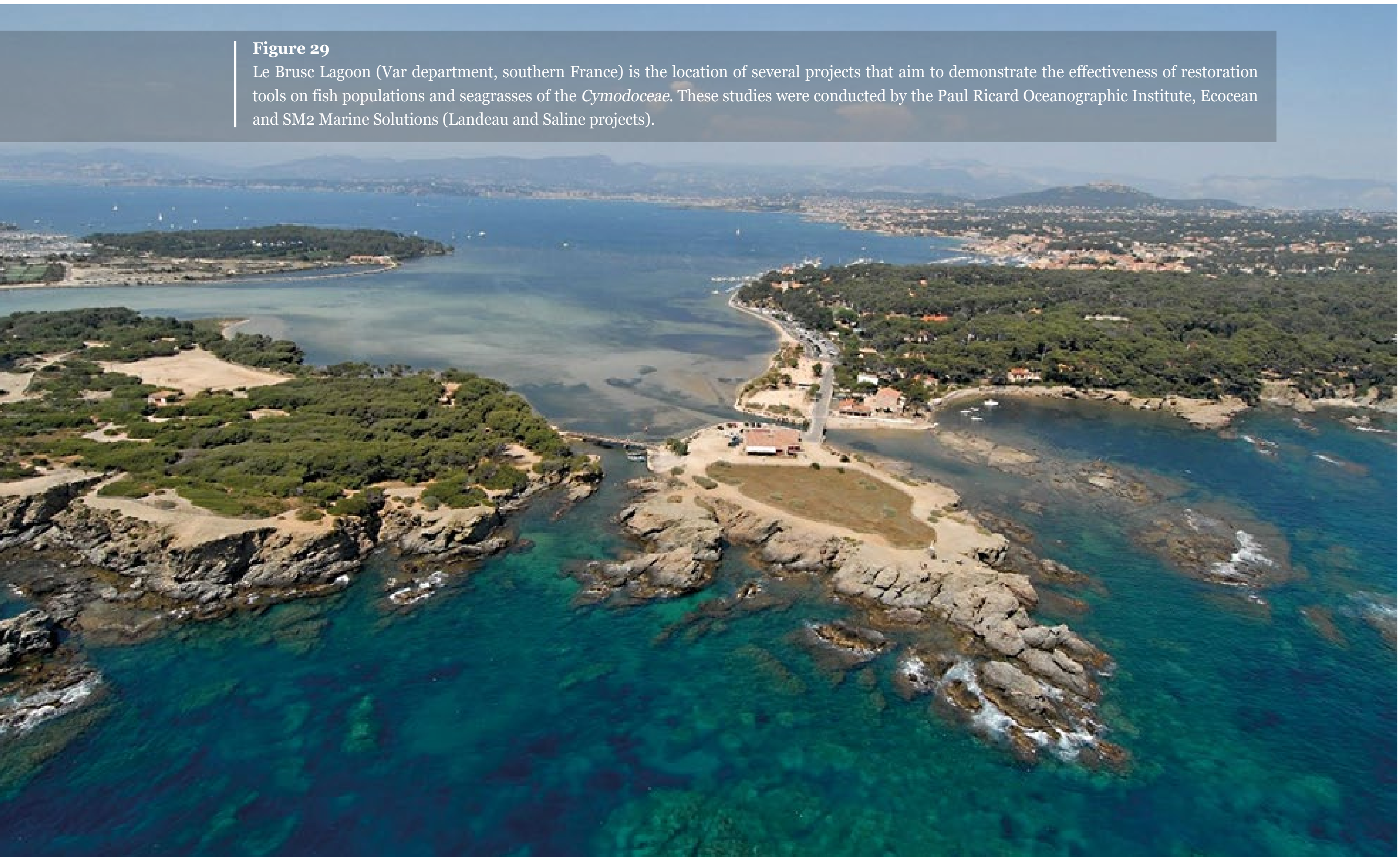


Figure 29
Le Brusc Lagoon (Var department, southern France) is the location of several projects that aim to demonstrate the effectiveness of restoration tools on fish populations and seagrasses of the *Cymodoceae*. These studies were conducted by the Paul Ricard Oceanographic Institute, Ecocean and SM2 Marine Solutions (Landeau and Saline projects).

c. **When can we consider ecological restoration to be an operational policy?**

The implementation of an active and operational ecological restoration policy requires the following:

> Availability of proven technology that address a particular problem,
> A commitment to restore degraded environments and to use existing technical solutions,
> Adequate financial means to implement the project,
> Administrative and regulatory authorization to implement the project backed by good and transparent governance.

Various projects and studies conducted over the past few years have permitted innovation and the development of effective restoration methods. Some of these resulting techniques may require further testing and enhancement of their operational impacts. However, it is already possible to conduct a preliminary evaluation of the tools that can be used to restore shallow coastal nurseries. The table below provides a summary:

Operational restoration tools
> Artificial reefs
> Dock and pontoon habitats
> Transplantation of macroalgae

Figure 30 - a transplant of *Cystoseira* (wrack, a brown seaweed)

d. **Ecosystem managers: current and emerging attitudes to ecological restoration**

Port authorities have in recent years demonstrated greater commitment to act and to lead ecological restoration projects, and have shown a greater openness to ecological restoration, than managers of other aquatic environments. The NAPPEX and GIREL projects have reinforced the reputation of ports for applying innovative and effective tools.

It should also be highlighted that these actions are entirely voluntary. The technical and financial incentives - as much as the efforts made in terms of information, communication and awareness - are beginning to show their effectiveness, despite economic setbacks. The main driving force of action remains, however, the commitment to act. Therefore, it is essential to highlight, support, and incentivize this attitude shift among marine site and resource managers. However, where environmental matters are concerned, regulation remains the most important tool for achieving action. Perhaps in the future, legislators will require the restoration of degraded environments to be given the same priority as the protection of near-pristine and intact areas.

e. **Cost constraints: real or imagined**

Funding is often a limiting factor. However, if we compare the cost of ecological restoration to the cost of pressures or implementing solutions to combat these pressures, funding appears less of an issue. For example, the cost of the PRADO reef intervention implemented in Marseille was estimated to be less than 1% of the cost incurred by local governments to reduce the influx of pollutants into the sea. We find this same type of ratio between the costs of installation of artificial nurseries for juveniles compared to the investments made in harbor constructions that are the cause of habitat **degradation**.

> **The PRADO operation**, the first full-scale restoration action, initiated in 1996

This pioneering artificial reef immersion project in Marseille Harbour took almost 10 years to complete, covering a surface area of 110 hectares and creating around 30,000 cubic metres of artificial reefs favourable to marine life. The PRADO project had 3 objectives:

1 - recreate a zone of biological productivity using an ecosystem-based approach,
2 - sustain and develop the economic activity of the coastal zone, especially artisanal fisheries,
3 - ensure ecological continuity between close natural rocky areas and the immersion site.

The total cost was approximately €10 million, spread between preliminary studies, immersion of reefs, colonization monitoring, management and communication. The project won the French Grand Prix for Ecological Engineering in 2014.

Figure 32 - Artificial Reefs created near the fringe of natural *Posidonia* seagrass meadows in the southern part of the Marseille port

f. **Creating a coherent legal framework for ecological engineering**

Regulations covering the protection of the coastal and marine environments, Publicly-owned Coastal Land and underwater engineering and construction are vast in extent, variable and sometimes contradictory from one issue to the next, and almost always extremely complex. Therefore, administrative procedures are often difficult to wade through and hinder initiatives. Currently, deliberations regarding this issue are being conducted at national level in France, with the aim of developing a conducive legal framework for the new professional domain of ecological marine engineering (cf. p78). An analysis of current regulations and of possible propositions is also currently underway. However, it is important to remember that the aim is not to encourage a reformation of existing regulations so that they provide less protection for the marine environment, but rather to explore to what extent a new combination of different sector-based regulations could be developed and enforced to encourage the research and development of truly effective restoration and rehabilitation projects, and to assure their implementation, monitoring and on-going refinement and integration in large-scale planning and management efforts.

g. **A working example of a successful ecological engineering project.**

Ideally, the restoration of a nursery function that has been lost during the construction of harbour zones could resemble the following:

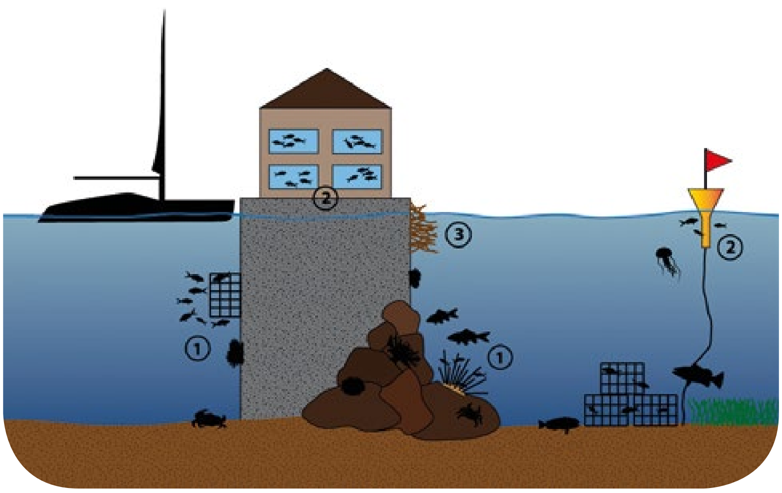


Figure 32
An example of the development of a harbor zone (Boissery, 2014) :

① installation of artificial habitats in the port and surrounding areas,

② management of larvae populations,

③ the restoration of microalgae belts.

2. Developing an ecological restoration project

Once the decision has been made to implement an ecological restoration project, the next step is to clearly define, before work begins, the following points:

First, the geographical perimeter targeted for ecological restoration needs to be identified. This will also serve as a platform for dialogue. It is important to have a good vision as well as a global understanding of the zone to be restored (perspective of operating forces, better analysis of pressures and threats, local actions, etc.).

The second stage is to define "the ecological target". It is necessary to understand the situation from the very beginning and, therefore, the extent of the degradation of the area to be restored. For this, it is necessary to evaluate the type of site (natural, artificial, etc.), its configuration (an open natural environment, a closed or open urban environment, in a bay, next to the mouth of a river or waste discharge, etc.), the habitats and species present (whether they are protected or not, invasive species etc.), the biological, chemical and hydromorphological quality of the environment, the pressures and threats, and current management measures that exist on the site.

Recovering the site fully to its pre-disturbance, non-degraded state is unrealistic. This should first and foremost be explained, understood and acknowledged. However, the intervention must also provide a way to improve the ecological condition of the site. When intervening in shallow coastal regions and on their nursery function, the aim should be based on the notion of "more young fish at short term for more adult fish at middle-to-long terms".

Coordinating efforts through partnerships is also essential for success. Stakeholder ownership and engagement is done through providing information as soon as possible before work begins, but also through the involvement of various actors in decision-making, including institutions (decentralized state services, local authorities, chambers of commerce, etc.) and users and professionals (fishermen, divers, beach establishments, yachtsmen, NGOs, etc.). Success depends on project ownership by all stakeholders. Organizing public meetings could contribute to facilitating stakeholder project ownership.

The feasibility of the project also depends on its funding and legal authorization.

Regulation of coastal and marine zones is quite complex. Numerous texts govern the protection of the fauna and the flora, construction, uses, the quality of water, the activity of the Publicly-owned Coastal Land and the immersion of material, etc. As such, it is important to involve all of the departments in charge (in France, this includes DIRM, DDTM-DML, DREAL and PREMAR) well ahead of time. To aid in understanding the complex French regulatory system, a study entitled RESTAUREG is currently underway. The study aims to summarize all of the related regulation texts and administrative procedures, as well as to conduct a critical analysis of several case studies and design simple flowcharts that show the correct procedures required for each restoration intervention. Operational recommendations for implementation will also be provided.

As in all projects, sourcing funding is necessary, but at times difficult to achieve. Ecological restoration is a new approach and very few organizations have included measures dedicated to ecological restoration in their general policies. One of the few exceptions is the Rhone-Mediterranean and Corsica Water Agency, through its intervention program "Save the Waters". This program provides funding, under certain conditions, for restoration projects that target coastal zones (www.eaurmc.fr). The Var Department Council is also able to provide support to municipalities wishing to develop restoration projects in coastal areas (www.cg83.fr).

Successful and measurable achievement of the project's interventions is an important objective. Therefore, the evaluation strategy for the project's ecological effectiveness must be prepared and agreed upon at the outset. The tools used for evaluation and the various practical aspects should be precisely defined: which indicators, frequency of data collection, type of interpretation grid, etc.

The distribution of information and promotional material should be conducted regularly throughout the project, and where necessary targeted at particular stakeholders according to their needs and concerns. Socio-economic actors such as fishermen should also be given special attention. For example: fishermen will be pleased to hear about recovery and restoration of fish nurseries; tourism businesses will welcome improved water quality or a new eco-attraction; local media will require information on local impacts, while national and international media will want to know how these benefits can be achieved elsewhere.

In summary, a project leader or coordinator of restoration work should develop and implement a realistic strategy which includes the following:

> a plan of action that details different phases of the project and the role of each phase,

> specific written guidelines and monitoring scheme,

> a realistic timetable to reach the fixed objectives,

> committed technical and human resources,

> a joint financial plan validated by committed funding partners,

> a stakeholder engagement plan with detailed strategies for achieving buy-in and contingency measures for addressing objections.

> strategic and relevant coordination,

> plans for on-going monitoring and evaluation of the progress made in achieving objectives that, if applicable, would make it possible to identify any additional considerations that need to be taken into account (adaptive management).

> Should particular sectors/areas be prioritized for restoration?

Ecological restoration is by definition a response to site degradation, so the question should be "what and where the degraded areas of the Mediterranean coast are?" Identifying areas of concern on a map is not always easy, so the following areas should always be considered.

Port zones usually have degraded habitats, with ecological functions such as nurseries and spawning grounds generally compromised. They also lend themselves more easily to ecological restoration. Therefore, port areas, including commercial harbors and marinas, should be considered high-priority.
Zones with urban discharges or with high-frequency anchoring also have good potential for effective restoration - even if their contribution to the nursery function is less important – and thus they should also be prioritized.

3. Towards a new economic sector

The notion of ecological restoration as an economic sector, and its subsequent development, evolved over the past few years in France through the coordinated efforts of three major stakeholders:

The *Pôle Mer Méditerranée* identified a crucial strategic challenge as part of its policy brief: the restoration, rehabilitation and re-allocation of ecosystems interconnected to the marine environment, as well as the sustainable development of coastal zones. This strategic challenge has been addressed over a medium-to-long term perspective, and its strategic focus has become known as "coastal ecological engineering".

The Rhone-Mediterranean and Corsica Water Agency, increasingly concerned for the marine environment, has mobilized the technical and financial resources necessary to develop and apply new methods. The agency's intervention program "Save the Waters" prioritizes ecological restoration of shallow coastal regions. The agency has become the leading public-sector partner for restoration projects in the French Mediterranean region (Boissery 2014).

The French Ministry of Ecology, Sustainable Development and Energy (MEDDE) has developed a "National Strategy for Biodiversity" and has approved and awarded funding to projects that promote "innovative methods in ecological restoration and development of the coastal and marine environment". The Ministry also supports GECMEDD, a project which aims to develop the Coastal Ecological Engineering sector on the Mediterranean using a sustainable development approach. The project, coordinated by Pole Mer Méditerranée, in partnership with Pole EAU and the Éa Éco-Entreprises association, involves a range of coastal and marine stakeholders. It is expected to contribute significantly to the development of coastal ecological engineering as a distinct professional field (GECMEDD, 2015).

Ecological Engineering Practitioners on the French Mediterranean coast

Roughly 50 organizations are involved in ecological engineering on the French Mediterranean coast, including research laboratories, small and medium businesses, major groups and associations. They are listed in the GECMEDD directory according to their capabilities: research, training, socio-economic studies, environmental studies, environmental surveillance, suppliers, contractors and communication specialists. They form a coherent group from a technological and economic point of view as well as from the products and services offered.

Within this grouping, there are young and dynamic small and medium businesses (including ECOCEAN, SM2, and others), which bring drive and innovation to the field. They are juxtaposed with biodiversity units that have been recently established within the major groups (EGIS, Suez Environment, Bouygues, etc.), which provide commercial and scientific depth and credibility.

Ecological restoration of coastal environments is an essential part of the ecological engineering field. It provides innovations – e.g., artificial habitat design and implementation, seagrass and/or seaweed belt restoration, restocking of populations – which can be integrated or added to coastal projects and interventions. Coastal stakeholders are gradually assuming ownership of this approach, as seen at the local level with recent projects that targeted sites on the Golden Islands and areas bordering the bays of Toulon and Marseille (South of France). These projects integrated ecosystem preservation and restoration together with the reduction of pollution.

The scientific community is also becoming more aware of the role of coastal ecological restoration in the process of adaptation to global change. Coastal ecological restoration also integrates well into strategic marine research and development initiatives, such as "a blue growth research and innovation initiative for the Mediterranean", launched by the European Commission.

As noted already, the science, technology, business, politics and law of ecological restoration in marine environments are still in their infancy. As a result, it is not easy to evaluate the economic value or the role of potential markets. However, we are able to evaluate the potential short-term benefits by examining economic studies and ecological restoration projects that have been conducted over the past few years. According to the Boston Consulting Group in 2012[1], the land and marine biodiversity restoration markets in France represent 2 billion euros and included the involvement of 150 to 200 small and medium businesses. This figure is expected to increase to 3 billion between now and 2020. It is also estimated that in France, the ecological engineering sector has 22,000 employees (which is expected to increase to 40,000 in 2020)[2].

At the coastal level, the market study component of the Nappex project indicated that of the 140 marinas in the French Mediterranean, more than 75% are planning for expansion and internal redevelopment. Marina managers generally take the environment into account when building or modifying marine infrastructure, as they are very often divers, yachtsmen and/or fishermen – i.e. people who are fond of the sea – and seem willing to invest in positive biodiversity actions. This has been the case in Marseillan and Agde (Herault department), where an initiative to install artificial nurseries in ports is currently under way. These installations are also used to raise awareness among clients who use these ports and also as an education platform for local schools.

Ownership through active involvement in the design of this approach is already occurring in certain coastal development projects and will more than likely experience a strong growth:

> Port extensions (Calais 2015, Marseille and Guadalupe Maritime ports, etc),
> Construction of coastal viaducts (Reunion Island),
> Implementation of voluntary coastal ecological engineering solutions by managers of ports and coastal communities (Marseille, Monaco, Nador, etc.).

Internationally, European countries that have the same regulatory **constraint** to France are also potential markets. Mediterranean states (Turkey, Morocco, Tunisia), the Near East (Oman, Qatar, UAE) and in the USA, Canada, Brazil, Australia and Japan already have such regulations in place. For example, the first significant document about Ecological Restoration has recently appeared in Australia[3]. Countries that do not yet have appropriate regulations in place will also require the expertise of ecological restorers to help them draw up suitable laws and guidelines in order to comply with international accords.

1 *Les Echos magazine, 27/05/2014*

2 *Estimations of the Ministry of Ecology in its convention of technical support in the formation of a Biodiversity and ecological services domain dated 2011.*

3 *The National Standards for the Practice of Ecological Restoration in Australia (http://www.seraustralasia.com/standards/contents.html).*

The implementation of the RESTORE Act in the USA provides opportunities in an important market, as can be demonstrated in the British Petroleum and Deepwater Horizon incident. The estimated cost for the restoration of damage caused by the accident is more than 20 billion dollars.

Brazil is also planning to construct 100 ports in response to the Panama Canal Expansion Project, which will double the canal's current capacity. This is an important potential market for which certain French companies are already well positioned. Looking forward, global investments in biodiversity could reach between 2,000 and 6,000 billion dollars by 2050.

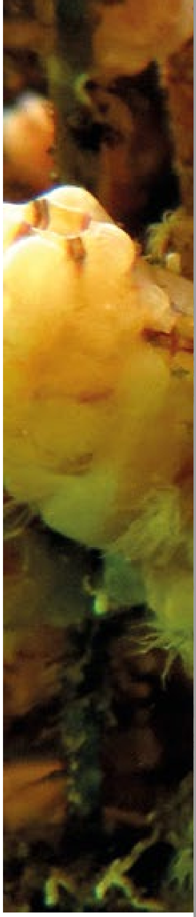
Coastal ecological engineering has grown rapidly over the past few years, due in large part to changes in perspectives of affected communities, which are reflected in policies whose objectives are to improve the quality of ecosystems. In Europe, governmental directives and policies are also moving in this direction. Terrestrial ecological engineering, which is much older and which has conducted more projects, is also growing. Marine ecological restoration is still in its initial experimental phase, but certain tools are beginning to become fully operational.

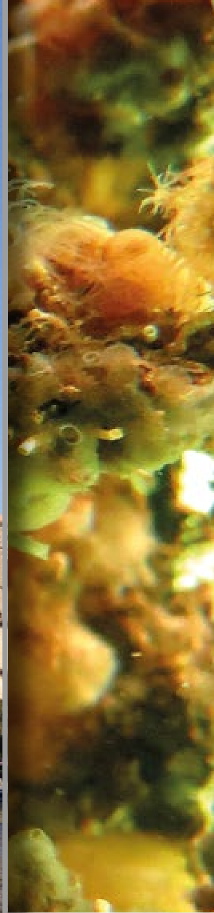
Several indicators demonstrate that there is potential for rapid economic growth:

> Expanding ownership and buy-in through active design of projects.
> Growth of innovative small and medium businesses.
> Creation of specialized groupings or clusters in emerging ecological engineering fields.
> Development of research centres specializing in marine ecosystems.
> Development of university curriculums that incorporate coastal ecological engineering.
> Global leadership - France is one of the international leaders in this field and has experienced researchers, showcase projects and the commitment to act.

Ecological restoration is a new challenge that requires innovation, commitment and financial resources. It also requires new or at least updated regulation. However, such regulation should not only encourage or even enforce coastal ecological restoration, where appropriate; it should also be based on the highest professional and ethical standards of companies, organizations and individual involved in the field.

Figure 33 - School of Damselfish *(Chromis chromis)*






Conclusion

France and the EU have made strenuous efforts over many years to reduce pressures, prevent pollution, and build public awareness of the importance of clean water. Thanks largely to these efforts, the **good ecological status** of water bodies has become a desirable and attainable public good. As a result, ecological restoration of shallow coastal regions of the Mediterranean is now an important topic for discussion on the public policy agenda.

Recent advances in scientific knowledge on the functioning of coastal and marine ecosystems (and the ecosystem services they provide for people) have enabled a number of preliminary experimental interventions, and more in-depth projects have also been launched. A new economic sector is also emerging – one that focuses on ecological restoration, ecological engineering and eco-design – and is being supported by the *Pôle Mer Méditerranée*.

Although there are currently few tools available for ecological restoration of degraded Mediterranean marine ecosystems, those that exist have already demonstrated their effectiveness after just 4 years of testing. Even though knowledge of certain ecosystem functions is still far from complete, it is still possible to act to restore - or improve - certain ecological functions. There are two objectives to keep in mind: to recover healthy ecosystems for present and future generations, while also respecting and – insofar as possible - supporting all sustainable economic activities in the coastal and near-shore areas. No restoration or rehabilitation project, or any other "repair" action, can have a long-lasting effect unless the pressures that cause the **degradation** are also reduced and - wherever possible - eliminated. This requires a carefully designed environmental action plan that is carried out according to clear and measurable goals.

This Guide provides a means to develop and improve upon current scientific knowledge and indicate how to adapt relevant concepts and methods of ecosystem restoration, rehabilitation, reallocation, and creation to shallow coastal regions of the Mediterranean. It also highlights the importance of the coastal zones for people and from an ecological point of view, especially for the life cycle of fish.

Of course this Guide is limited by the current knowledge base, which is far from complete, but it provides a basis for discussion and an overview of the knowledge and methods available today, both of which are indispensable for the emerging economic sector mentioned above. In the future, it will be important to periodically update the Guide based on current knowledge and feedback from the various projects now in progress.

Annex 1

Different classifications of ecosystem services.

14 PROVISIONING SERVICE (production og goods)	
	Support for crops
	Support for energy crops
	Support for aquaculture
	Animal production for professional fishing
	Plants and mushrooms production for picking
	Providing minerals for extraction (aggregates)
	Support for the production of fibers and other materials
	Support for wood production
Freshwater storage, groundwater recharge	Supplying water for domestic use
Freshwater storage, groundwater recharge	Supplying bottled water (mineral and spring)
Freshwater storage, groundwater recharge	Supplying water for agriculture
Freshwater storage, groundwater recharge	Supplying water for industrial use (including energy production)
	Life reservoir
	Maritime waterway transport

15 REGULATION SERVICES (production of services)	
Water cycle regulation	Flood prevention
Water cycle regulation	Drought impact mitigation
Water cycle regulation	Rivers geomorphological disorders prevention
Water cycle regulation	Water purification
Soil quality regulation	Mudslides & erosion regulation
Soil quality regulation	Avalanches limitation
Chemical elements cycle regulation	Soil quality preservation
Chemical elements cycle regulation	Organic matter recycling
Animal and plant population dynamic regulation	Regulating the dynamics of pathogens and parasites
Animal and plant population dynamic regulation	Regulation of pest and invasive species dynamics
	Pollination preservation
Climate regulation	Purification and preservation of air quality
Climate regulation	Local climate regulation
Climate regulation	Global climate regulation
	Biodiversity and ecosystem functioning, mutual preservation

13 SOCIAL SERVICES (production of services)
Quality of the landscape (aesthetics)
Quality of the olfactory environment
Quality of the sound environment
Intrinsic and patrimonial value of biodiversity (protected species, etc.)
Specific human communities, source of artistic inspiration
Production of animals for hunting
Production of animals for fishing
Support for outdoor sports
Support for tourism and outdoor leisures
Support for hydrotherapy and thalassotherapy
Support for the development of educational knowledge

Annexe 1a - CICES classification

4 TYPES OF ECOSYSTEM SERVICES (de Groot *et al.* 2010)			
PROVISIONING	REGULATING	HABITAT/SUPPORTING	CULTURAL (provide opportunities for:)
1 - Food	7 - Air quality regulation	16 - Nursery service	18 - Aesthetic enjoyment
2 - Water	8 - Climate regulation (incl. C-sequestration)	17 - Genepool protection	19 - Recreation & tourism
3 - Raw Materials	9 - Moderation of extreme events		20 - Inspiration for culture, art & design
4 - Genetic resources	10 - Regulation of flooding		21 - Spiritual experience
5 - Medicinal resources	11 - Waste treatment		22 - Cognitice development
6 - Ornamental resources	12 - Erosion prevention		
	13 - Maintenance of soil fertility		
	14 - Pollination		
	15 - Biological control		

Annexe 1b - 4 types of Ecosystem Services (de Groot *et al.*, 2010)

Annex 2

The different ecosystem services provided by the marine environment.

	Level	SERVICE CATEGORIES	CHARACTERIZATION
Provisionning services	HIGH	Animal production for professional fishing	fish, shellfish etc...
	NO-EXISTENT	Gene production	
	HIGH	Substrate for food culture	fish/shellfish aquaculture
	NO-EXISTENT	Energy production	offshore wind / tidal energy / geothermal
	MEDIUM	Production of plants for food & functional food	green algae, omega 3, seaweed for human consumption
	LOW	Maritime transport	ferries and cargo ships
	MEDIUM	Production of minerals for extraction	raw materials (sand, pebble, salt)
	LOW	Agrofuel production	micro algae
	LOW	Production of water for domestic and agricultural use	desalinating sea water, underwater springs
	LOW	Production of medicinal and pharmaceutical products	biotechnology, cosmetic
Regulating services	HIGH	Regulation of water quality	decontamination, waste dilution, degradation, uptake, O2
	LOW	Regulation of air quality	solubilization of air pollutants
	NO-EXISTENT	Climate regulation	CO2 sequestration, T °
	HIGH	Regulation of interspecific interactions	herbivores, carnivores ...
	HIGH	Regulation of species interactions	predator/prey, symbiosis, parasitism
	HIGH	Erosion protection of coastal zones	coastline (land) preservation, soil/sediment fixation
	HIGH	Protection from storm	beachcomber / human risk / swell damping
	HIGH	Preservation of marine species lifecycle	crucial stage of the cycle
	HIGH	Control of invasive species	habitat competition, good ecological status of the ecosystem
	MEDIUM	Recycling nutriments (N, P..) and organic material	sedimentation, detritivores
	LOW	Local climate regulation	maritime inputs / T° / humidity
Socio-cultural services	HIGH	Support for the tourism industry and leisure outdoor sports	sailing, water sports, jetski, cruises, diving
	HIGH	Support for aesthetic landscaping	soothing landscape
	LOW	Support for artistic inspiration	marine arts (esp. painting and photography)
	LOW	Support for local traditions	cultural, historical and heritage value
	LOW	Spiritual support	
	MEDIUM	Support for health care	thalassotherapy (mud, sea water, seaweed)
	HIGH	Support for scientific research	SUBLIMO program
	HIGH	Support for the development of educational knowledge	educational facilities & visits
	HIGH	Production of animals for recreational fishing	angling
	HIGH	Production of heritage species	grouper, brown meagre, seahorse

HIGH
MEDIUM
LOW
NO-EXISTENT

Annex 3

Ecosystem services of the marine environment in the western Mediterranean Basin.

	Different Categories of Ecosystem Services	Examples of services	Associated functions
Provisioning services	Animal production for professional fishing	Fish, shellfish etc...	Renewal of animal populations, biomass accumulation, reservoir for species richness
	Maintain and support the food culture	Fish/shellfish aquaculture	*Nutrition*
	Production of plant for food and functional use	*Green algae, omega 3, seaweed*	*Renewal of plant populations, biomass accumulation*
	Production of minerals for extraction	*Raw materials (sand, pebble, salt)*	*Reservoir*
Regulation services	Regulation of water quality	Decontamination, waste dilution, degradation, uptake, O2	Water purification
	Regulation of functional diversity	Herbivores, carnivores...	Renewal of animal populations, biomass accumulation, reservoir for species richness
	Regulation of interspecific interactions	Predator / prey, symbiosis, parasitism	Renewal of animal populations, biomass accumulation, reservoir for species richness
	Erosion protection of coastal zones	Coastline (land) preservation, soil/sediment fixation	Soil stabilization by plants, sedimentary transport/deposit
	Protection from storms	Vague deferlante/risque humain amortissement de houle	Swell decrease
	Preservation of marine species lifecycle	Crucial stage of the cycle	Nutrition, reproduction, nursery function
	Control of invasive species	Habitat competition, good ecological status of the ecosystem	Species competition
	Recycling nutriments (N, P..) and organic material	*Sedimentation, detritivores*	*Decomposition and transformation, provision*
Socio-cultural services	Support for the tourism industry and leisure outdoor sports	Water sports, sailing, cruises, diving	Ecosystem Integrity
	Support for aesthetic landscaping	Soothing landscape	Ecosystem Integrity
	Support for scientific research	SUBLIMO program	Ecosystem Integrity
	Support of the development of educational knowledge	Educational facilities & visits	Ecosystem Integrity
	Production of animals for recreational fishing	Angling	Renewal of animal populations, biomass accumulation, reservoir for species richness
	Production of heritage species	Grouper, brown meagre, seahorse	Ecosystem Integrity
	Support for health care	Thalassotherapy (mud, sea water, seaweed)	Active principle

Annexe 3: Ecosystem services of the marine environment in the western Mediterranean basin

Direct and indirects benefits	Direct and indirect associated values	Reasons for conserving this service
Proteins	Revenue from fishing sales (fish, shellfish etc...) and industry services	Maintenance of the fishing activities and its industry
Proteins	Revenue from fishing sales (mussels, oysters, fish ...) and industry services	Maintien des activités d'aquaculture et de la filière pêche
Proteins, molecules, pharmaceutical & neutraceutical feedstock	*Revenues froms sales*	*Maintenance of seaweed farming activities and its industry*
Raw material for the construction industry and beache replenishment, salt	*Revenues froms sales (roads, buildings...)*	*Support to construction activities, maintenance of tourist activities and quality of life*
Health preservation	Welfare	Maintenance of tourist activities and quality of life
Ecosystem integrity, biodiversity	Welfare	Maintenance of tourist activities and quality of life
Ecosystem integrity, biodiversity	Welfare	Maintenance of tourist activities and quality of life
Protection of people and property, maintenance of economic activities and landscapes	Revenue from economic activities, real estate, saving from adjustement works	Maintenance of tourist activities and quality of life
Protection of people and property, maintenance of economic activities and landscapes	Revenue from economic activities, real estate, saving from adjustement works	Maintenance of tourist activities and quality of life
Ecosystem integrity, biodiversity	Revenue from fishing sales, industry services, tourism activities (catering, leisure)	Maintenance of the fishing industry, tourism activities and quality of life
Ecosystem integrity, biodiversity	Welfare	Maintenance of tourist activities and quality of life
Proper functioning of food webs	*Revenue from fishing sales and industry services*	*Maintenance of fishing activities*
Personal or individual satisfaction	Welfare	Maintenance of tourism activities
Personal or individual satisfaction	Welfare	Maintenance of tourism and artistic activities
Knowledge improvement and transfer	Number of programs, number and rank of publications, patents, innovative projects	Maintainance of scientific research at the cutting edge, change in mentaly
Development of nature awareness	Better environmental footprint	Change in mentality
Protein, personal satisfaction	Welfare	Maintenance of tourist activities related to angling
Ecosystem integrity, biodiversity, personal satisfaction, sense of belonging	Welfare	Maintenance of tourism activities, outreach, quality of life
Improved quality of life	Care and drugs	Improved quality of life

Annex 4

Pressures and impacts on shallow coastal areas of the Mediterranean Sea.

Problems					Impacts on shallow coastal areas		
Driving forces		Anthropogenic pressures	Examples	Case type	Physical	Chemical	Biological
Increase of human population	At the global level	fish/shellfish aquaculture	Thau lagoon , Salses-Leucate lagoon (in the south of France)	unique	suffocation - sedimentary modification - OM accumulation	discharges of organic materials, toxic substance (antibiotics, formalin, ...)	introduction of non-native species - destruction of species - decrease in the amount of phytoplankton
		fisheries using trawling gear	trawling	unique	abrasion - strong deterioration / habitat destruction	concentration of contaminants (hydrocarbons, oils ...)	non-selective extraction of individuals - reduced biomass - degradation of the life cycle - population destruction - trophic chain modification
		artisanal fisheries	all practices of the artisanal fisheries	unique	habitat degradation - macrowaste discharges	concentration of contaminants (hydrocarbons, oils ...)	extraction of individuals - reduced biomass - lifecycle weakening
		waste water discharge	outfalls	multiple	increased turbidity - substrate change - temperature modification	permanent input of contaminants and bacteries	life cycle disruption - destruction of populations - changes in spatial distribution of seagrasses meadows - changes in communities
		global change	change in temperature, and in wind strength, direction, number of days	multiple	currents change	biochemical kinetic change	disruption of the life cycle (recruitment)
	In coastal regions	landfill constructions	port facilities (dams, quay)	unique	clogging - suffocation - modification of sediment grain size and transit - increased turbidity - habitats destruction (nurseries) - temperature	/	disruption of the life cycle - changes in connectivity and biodiversity - destruction of populations
			polderization				
Development of pleasure boating and in freight navigation		overpopulation of anchorage zones	mooring, open anchorages, anchors, household waste and oil rejection	unique	abrasion, habitat degradation - macrowaste discharges	concentration of contaminants (hydrocarbons, OM, anti-fouling paints ...), sunscreen	destruction of populations
			dredging	unique	suffocation - abrasion - sedimentary change - increased turbidity - habitat destruction	resuspension of toxic contaminants	destruction of populations
Development of seaside tourism		leisure activities	water sports, swimming, diving, board sports	multiple	abrasion - habitat degradation (trampling of shallow coastal areas, tearing, sampling)	sunscreen	behavior modification - stress
		recreational fishing & spearfishing	shore fishing, boat fishing, spear fishing competition	multiple	habitat degradation	concentration of contaminants (hydrocarbons, oils ...)	extraction of individuals - reduced biomass - weakening of the life cycle - change in population dynamics
		sound and electromagnetic pollution	jet skiing, boat rentals	multiple	barrier effect	/	stress - behavior modification - changes in lifecycle - greater vulnerability to predators - population selection
		solid waste and debris	beach litter	multiple	suffocation - habitat modification - light decrease	release of contaminants and particles	disruption of the life cycle - destruction of populations
Develop-ment of hinterland activities			pesticides due to agriculture, marine debris transported by rivers	multiple	increased turbidity, particle sizes and substrate change - temperature change	reduction or supply of fresh water, contaminant transport, marine debris, eutrophication, oxidizable material - bacteriological contributions	disruption of the life cycle - destruction of populations - changes in spatial distribution of seagrasses meadows - changes in communities
Develop-ment of construction industry		extraction of gravel/ minerals, beaches nourishment	gravel pit	unique	clogging - suffocation - increased turbidity - destruction of habitats (nurseries)	concentration of contaminants (hydrocarbons, oils ...)	disruption of the life cycle - destruction of populations

Glossary

Alternative Steady State: Alternative combinations of **ecosystem** steady states and environmental conditions that may persist at particular spatial and temporal scales. In theory, any **self-generating** ecosystem can shift between two or more states, due to positive feedback mechanisms that operate when a system crosses a **threshold** (Van Andel & Aronson, 2012).

Anthropogenic pressures: Pressures provoked directly or indirectly by human actions.

Benefits: An increase in the well-being of people through the satisfaction of a need or a desire. In this Guide, it corresponds to what people receive from **Ecosystem Goods and Services** and which satisfy their needs and desires.

Benthic: Refers to marine or freshwater organisms that live near the bottom of seas and oceans, lakes, and streams (as opposed to **pelagic**).

Biocenosis: Living beings that co-exist within a given space, as well as their organization and their specific complexity.

Biodiversity: Diversity of life at all levels of organization (gene, individual, population, community, ecosystem, etc.) and the taxonomic classification (e.g., species, genus, family) within a given site or region, or the biosphere as a whole.

CICES – Common International Classification of Ecosystem Services: An environmental accounting project conducted by the European Environmental Agency. The agency contributes to the ongoing revision of the Economic and Environmental Compatibility System managed by the Statistical Division of the United Nations.

Coastal fish: Fish who spend at least a part of their life-cycle in coastal ecosystems.

Coastline: Marks the limit where marine waters can enter on land, in other words the farthest limit on land that waves or marine waters can reach during the highest possible tides.

Colonization: Phase during which larvae return to the coast to continue their development.

Connectivity : In an ecological context, connectivity is defined as the transfer of materials by wind, water, humans, and animals between locations; indicates the degree of movement possible and interactions among individuals or propagules of species populations that occupy different portions or units within a broad landscape or seascape. Also depends on the capacity of the species populations to disperse and migrate (Van Andel & Aronson, 2012).

Coralligenous: Underwater ecosystem characterized by an abundance of calcareous algae, also called coralligenous algae, capable of forming, through encrustations or accumulation of deposits, reefs comparable to coral reefs; hence the name "coralligenous", which means "producer of coral". Diverse animal species with calcareous skeletons: sponges, sea fans, etc., which are also related to biogenic formations.

Decapods: Order of crustaceans that have 5 pairs of large thoracic legs such as crayfish, shrimp, crabs, hermit crabs, as well as the cephalopod mollusks that have 5 pairs of tentacles, of which one pair is longer than the others (cuttlefish, squid, and the now-extinct belemnites.

Degradation: An action that severely damages an ecosystem, or the process through which an ecosystem is so seriously damaged that its biodiversity plummets and its capacity to provide goods and services is altered or diminished.

Driving force: The social, economic and/or institutional forces in a system or region that cause direct or indirect changes of state or trajectory of an ecosystem or the environment (modified after European Environment Agency, 2000).

Ecological corridor: A linear element of a landscape that connects habitats – patches- and allows a flow between habitats, within a larger and more or less unfavorable environment, sometimes called the matrix (Beier & Noss, 1998).

Ecological engineering: Technical know-how and scientific knowledge useful for assisting in the regeneration of an ecosystem (**ecological restoration**, or **ecological rehabilitation**), or in the design and **creation** of an ecosystem with a specific purpose. Unlike civil engineering, which uses inanimate objects, this field applies the use of live organisms and other biological materials to address and resolve environmental and socio-economic problems. As in all engineering activities, special attention is given to cost-effectiveness and the reduction of the unpredictability of outcomes.

Ecological processes: Fundamental phenomena of one or several ecosystems, such as the transfer of energy, water and nutrients, the primary production, in which the dynamic is directly linked to the biophysical structure (habitats, communities, and interactions - competition, parasitism, etc.) of ecosystems.

Ecological rehabilitation: Process of helping a damaged, degraded or destroyed ecosystem to recover its functions. Less concerned with **ecosystem structure** and composition (inventory of indigenous species) than **ecological restoration** but similar in that it entails selecting or establishing a reference model upon which to base the planning, execution, monitoring and evaluation of the project. The objective is generally to recover the productivity or more generally, the capacity of the ecosystem to provide one or several services, which the historical ecosystem provided (Clewell & Aronson, 2013).

Ecological restoration: Process of assisting the recovery or regeneration of an ecosystem that have been damaged, degraded or destroyed (SER, 2004).

Ecological threshold: The limit, 'tipping point', or level of disturbance beyond which an ecosystem shifts – temporarily or permanently - to an alternative state and begins a new **trajectory**. See also **Alternative steady states**.

Ecosystem: The system of relationships and interactions among living organisms (plants, animals, and microorganisms), and their abiotic environment at a specific location. Ecosystems occur at different spatial scales, from seagrass meadow, for example, to estuary or tidal zone. In principle, the biosphere can also be considered as a single ecosystem.

Ecosystem function: The rate of **ecosystem processes** such as primary production, decomposition, nutrient cycling and transpiration and emergent properties resulting from species interactions such as competition, seed dispersal carried out by animals, and mutualistic relationships. Not to be confused with ecosystem services. Functions, or functionality, depend on underlying **ecosystem structure** and ecosystem processes and represent the potential of ecosystems to deliver **goods and services** to humans (Van Andel & Aronson, 2012).

Ecosystem Services (ES) or Ecosystem Goods and Services (EGS): Materials and products (= goods or resources) that benefit people and provide an economic or cultural value (e.g., food, fibre, as well as direct and indirect services with an economic or cultural value (fish available for economical gain, landscape heritage management, etc.) that an ecosystem provides to humans, all of which have no direct production or maintenance costs. Measured in terms of flow as opposed to "stocks", as is the case in natural capital. It is also important to evaluate the long-term capacity and potential of an ecosystem to provide ES (Schroter *et al*, 2014).

Ecosystem Structure: The individuals and communities of plants, animals and microorganisms of which an ecosystem is composed, their age and spatial distribution and the abiotic resources present at a certain point in time ((Van Andel & Aronson, 2012).

Ecotone: Ecological transitional zone between two or more ecosystems. Also called frontier zone.

Emersion: Emergence of a portion of the near-coastal sea-floor due to sinking water levels or a receding sea.

Environment: A part of a territory where populations live and the characteristics are a result of natural or human factors and their interactions. Often confused with **landscape** and, in non-scientific language, with **ecosystem** and **habitat**.

Essential habitat: Particular type of aquatic and substrate area necessary for fish and other organisms to feed and grow until they reach maturity and are able to reproduce (Benaka, 1999).

Euphotic or **photic**: Surface zone of the oceans where light penetrates the water and allows photosynthesis to occur in algae and other photosynthetic plants and organisms.

Food chain: The feeding relationships established between types of organisms at a locality or in a region. Includes producers (e.g., algae), primary consumers (e.g., herbivores), secondary consumers (e.g., carnivores) and decomposers (e.g., bacteria, fungi, nematodes). The pollutants which are not or not much degraded like heavy metal are concentrated at the top of the food chain, in the predators.

Foreshore: Part of the shore that is alternately covered and uncovered by the sea.

Good ecological status: Defined for marine environments in the Marine Strategy Framework Directive as "the ecological status of marine environments in which ecological diversity is conserved and the oceans and seas are clean, in good sanitary condition, and productive within the framework of their own natural and intrinsic state; and that the use of these marine environments is sustainable in such a way as to safeguard the potential of these areas for specific uses and activities for the benefit of current and future generations to come". See also **optimization**.

Habitat: The vital space of an organism or population of a species, recognizable by physical-chemical and geographical characteristics of the environment or specific place in question.

High tide mark: A place that accumulates natural debris deposited by the highest limit of inflows.

Impact: The consequence of a change of state in the fauna and the flora of an ecosystem: a loss or gain according to the effects (modified after European Environment Agency, 2000).

Inland waters: A legal term meaning waters on the landward side of the **marine baseline**.

Installation: The immediate transition of the pelagic larvae stage and the **benthic** juvenile stage (Andrews & Anderson, 2004).

Intra-specific predation: Predation within its own species.

Juvenile: An individual that is not yet able to reproduce.

Landscape: In ecological science, an assemblage of ecosystems that exchange organisms and materials, and produce spatial patterns that are recognizable and recurrent (Forman & Godron 1986). In the social sciences and art history, the term refers to a natural or human-transformed area that has a certain visual and functional identity.

Larval phase: First stage of the life-cycle of fish. The larvae cannot yet independently move from one place to another, but rather live in open water and are carried with the currents.

Macrophytes: Aquatic plants that are visible to the naked eye.

Marine baseline: The limit from which the territorial sea limit is calculated. The normal baseline is the low tide mark, "as shown on large scale marine maps that are officially recognized by the coastal State" (In France, these maps are drawn up by the Hydrographic and Oceanic Marine Service or SHOM). For coastlines deeply indented or lined with islands, deltas, and deep bays, artificially straight baselines are drawn, following the general direction of the coastline. This results in a significant increase of the surface area of the legal **inland waters** (internet source: SHOM).

Maximization: An action that supports something else (e.g. the functioning of a system) at its maximum and at the highest degree possible. Not to be confused with **optimization**.

MEA - **Millennium Ecosystem Assessment**: International program involving nearly 1400 scientists that provided the first summary of the environmental state of the planet (MEA, 2005). The consequences of **degradation** on ecosystems were evaluated in relation to the well-being of people, and four different possible scenarios were proposed as alternative ways for society to cope with these worrying changes and trends.

Natural capital: An economic term for the world's limited stocks of natural assets, which include physical and biological resources. From this capital, people derive a wide range of services, often called ecosystem services. There are 4 main categories of **natural capital**: renewable (functioning ecosystems and their living components, a.k.a., biodiversity), non-renewable (petroleum, carbon, diamonds, etc.), replenishable (clean air and water, fertile soils, etc.), and cultivated (crops, domestic livestock, agro-ecological knowhow, etc.) (Rees, 1995; MEA, 2005; Aronson *et al.*, 2007).

Necto benthic/demersal: Refers to a species that lives close to or at the seafloor.

Nursery: A nursery habitat has a number of specific characteristics appropriate for use by fish species with certain behavior and morphology; it provides for the species' needs in early life stages: (1) adequate nutrition, (2) an ideal habitat for the installation of post-larvae, which protects them from predators or other pressures from the juvenile stage to attainment of **refuge size**, (3) an environment in which juveniles grow much more rapidly and have a better rate of survival then in other types of habitats, (4) a site or area from which movement is convenient from habitats used during the juvenile stage and those preferred during the adult stage (Beck *et al.*, 2001).

Objectives: Results that we propose to achieve. An objective is generally characterized by its expected finality, method and means. A definition of the conditions to fulfill or to create in response to a problem without taking available funding into consideration (Ducrotoy, 2010).

Occupation rate of shallow coastal regions: Relationship between the surface gained on the sea and the initial surface of shallow coastal areas. Provides a way to evaluate the ecological impact of covering resulting from coastal constructions and the destruction of underwater coastal habitats.

Optimization: An approach that seeks high-level functioning of an ecosystem without sacrificing sustainability. Not to be confused with **maximization**.

Organogenic: GEO. Sediments formed from animal or vegetable debris; usually calcareous, less often siliceous (Pérès, 1966).

Pelagic: Aquatic organisms that occupy the upper water column, from the seafloor to the surface.

Phanerogams: Vascular plants that have discrete reproductive organs in cones or flower and reproduce through seed dispersal.

Photophilous algae: Algae that need or tolerate high levels of light.

Post-larvae (or **competente larvae**) : Last stage of the larvae. Stage when the fish returns towards the coast.

Pressure: A single or prolonged event that induces a change in the state or condition of an ecosystem. A direct action of some **driving force** (modified after European Environment Agency, 2000).

Reallocation: Converting an ecosystem to a new type of economic use; an alternative response to degradation that differs from **ecological restoration** and **ecological rehabilitation** in that it disregards historical continuity (Clewell & Aronson, 2013).

Recruitment: In ecology, the integration of juvenile fish into adult populations. This term is different from the notion of fisheries: individuals that have been captured and integrated into the fisheries resources.

Reference ecosystem (or reference model): One or more natural or semi-natural **ecosystems**, ecological descriptions thereof, or, if these are unavailable, assemblages of characteristics of presumed natural or historic semi-natural ecosystems which are chosen to serve as models, benchmarks or targets for planning in **ecological restoration** and **rehabilitation** projects (White & Walker 1997; SER 2004).

Refuge size: Refers to the size of a fish just larger than the mouth opening of a predator that is positioned directly above it on the **food chain**.

Resilience: The capacity of an ecosystem to cope with a single or recurring disturbance and to recover without human intervention, thereby keeping roughly the same functions, structure, identity and regulation processes within one **state** or a series of **alternative steady states** (Walker *et al.*, 2004; Walker & Pearson, 2007; Bouvron *et al.*, 2010).

Resistance: Capacity of an ecosystem to maintain itself (see **self-regeneration**) in the face of disturbances within an historical disturbance regime (Clewell & Aronson, 2013).

Response: The measure implemented by society to decrease the ecological impact of their own activity (modified after European Environment Agency, 2000). For example, the creation of anchorage areas in bays that have been impacted by improper or inappropriate use of anchors.

Risk: Random or unpredictable events that may cause damage to an ecosystem.

Self-regeneration: Ability of an ecosystem characterized by **resistance** and **resilience** to change and adaptability to changing conditions except if heavily disturbed and "pushed" over a **threshold of irreversibility**. Such an ecosystem self-transforms in response to its internal dynamic, environmental flows, and long-term changes to internal and external environmental conditions (Clewell & Aronson, 2013).

Sponges: Aquatic animals from the phylum Porifera (metazoans), most of which are sessile. They have a wall that surrounds a central digestive cavity lined with choanocytes, cells with whip-like flagella. Food and waste enter through many pores and there are also a small number of pores for excretion.

State: Appearance, expression or manifestation of an ecosystem or a landscape, which is defined by its specific composition, the life forms present, the size of the individuals and the structure of the community (Clewell & Aronson, 2013).

TEEB – **The Economics of Ecosystems and Biodiversity**: A five-year global study initiated by the G8 and the United Nations, which focused on "benefits to global human economy of biological diversity, and the costs of the loss of biodiversity and of failure to take protective measures against this loss compared to the costs of effective conservation projects". TEEB promotes the integration of economic values of biodiversity and the services provided by ecosystems into the political and business decision-making processes.

Territorial sea: The sovereignty of a coastal state extends beyond its own territory and **internal waters** (for an archipelagic state, its archipelagic waters) to include a zone of an adjacent sea known as territorial sea. The breadth of this zone is fixed by the coastal state but the breadth of the territorial sea in France, and the majority of countries, is fixed at 12 nautical miles (subject to agreement between neighboring states in which the coasts are within a distance of at least 24 miles) (SHOM). States may also exercise more limited sovereignty in contiguous zones, exclusive economic zones and continental shelves, which may extend to 200 miles or more.

Threshold of irreversibility: The limit or level of disturbance beyond which an ecosystem shifts to an alternative state or **trajectory**. In such cases, **ecological restoration** may not be successful in assisting the ecosystem to return to a former **state**. See also **Resistance** and **Resilience**.

Trajectory: Sequence of historical biotic expressions of an ecosystem, from which future expressions can be predicted (SER, 2004; Clewell & Aronson, 2013). The probable evolution of an ecosystem or social-ecosystem (Ducrotoy, 2010).

Transformation: The shift from one form or type of ecosystem to another, often carried out intentionally to introduce a new use. Example: draining a wet zone to create a new agricultural area.

Upwelling: An oceanographic phenomena produced during strong winds on oceans and seas (usually seasonal surface winds) that displaces surface ocean waters and creates a space where water from the sea bottom can rise and carry with it significant amounts of nutrients.

Values : Measures and indicators used to evaluate the relative importance of **benefits** provided by ES as perceived by people. They can be monetary or non-monetary. They are key to planning societal responses such as restoration, rehabilitation or re-allocation of degraded ecosystems or management modification.

YOY (**Young Of the Year**): Juveniles of the year (age below 12 months).

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Shallow coastal zones are areas that are highly sensitive from both ecological and socio-economic points of view.

The multiple habitats in these zones (rocky and sandy shallow areas, seagrass meadows, etc.), are often subject to severe pressures from human activities both on land and in near-shore marine areas.

Nevertheless, this interface zone is vital in the life cycle of the vast majority of Mediterranean fish species by providing nursery zones, while also providing a great number of ecosystem services for people.

These areas have been impacted for centuries by various kinds of human activities; nowadays we need to work together to better manage our collective 'footprint' in these vital environments and, where needed, restore damaged areas.

With political backing as well as support from a developing economic sector, the necessary science and technology are being expanded and refined.

In this Guide, we have tried to provide a brief overview of the key concepts, methods and proven techniques to increase the scientific knowledge base, and the socio-economic and cultural understanding of the importance of ecological restoration in coastal environments. Ongoing projects in the French Mediterranean region and elsewhere are showing the way forward.