Coastal Habitat Conservation

New Perspectives and Sustainable Development of Biodiversity in the Anthropocene

Edited by
Free Espinosa

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Laboratorio de Biología Marina, Departamento de Zoología, Facultad de Biología, Universidad de Sevilla, Sevilla, Spain

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CHAPTER

7

The ecological restoration: A way forward the conservation of marine biodiversity

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1. Introduction

1.1 Background

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 semienclosed 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, in particular, 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."

However, human activities are developing very rapidly along the coastal regions of the Mediterranean, with dire consequences for these shallow 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 have led to the construction of numerous and elaborate ports and marinas. 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 the low-lying coastal regions, from the shoreline to 10 m above sea level in the French Mediterranean coastal area has grown threefold since 1975 (Fig. 7.1), but because of strongest policy, the artificialization rate is now stable since a decade.

Among the vast expanses of marine waters, coastal regions are the most productive. The coastal fringe is home to numerous ecosystem functions such as the so-called nursery zones, which are vital for the renewal of populations of many marine organisms, especially fish but also crustaceans, and mollusks. Indeed, the life cycle of coastal fish is composed of different stages with their own characteristics. Each stage has a natural mortality rate, increased by

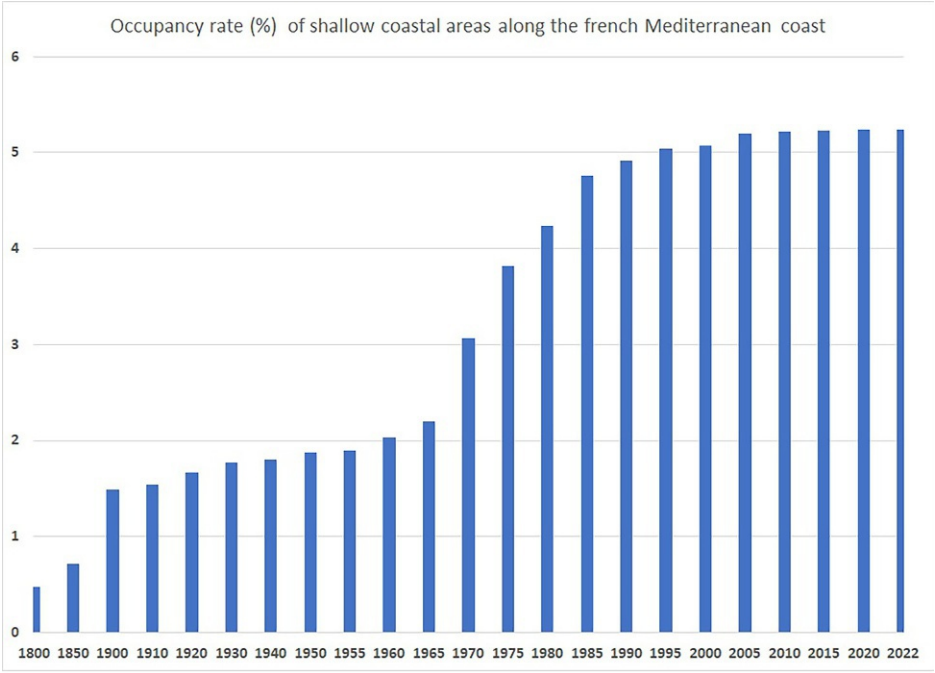

FIG. 7.1 Occupancy rate of shallow coastal areas (% of artificialization) (from 0 to 10 m deep) along of the French Mediterranean coast, from AD 1800 to the present. *Data from MEDAM website (2022); Credit: MEDAM. (2022). Côtes MEDiterrannéennes françaises. Inventaire et impact des AMénagements gagnés sur le domaine marin. http://www.medam.org/index.php/fr/.*

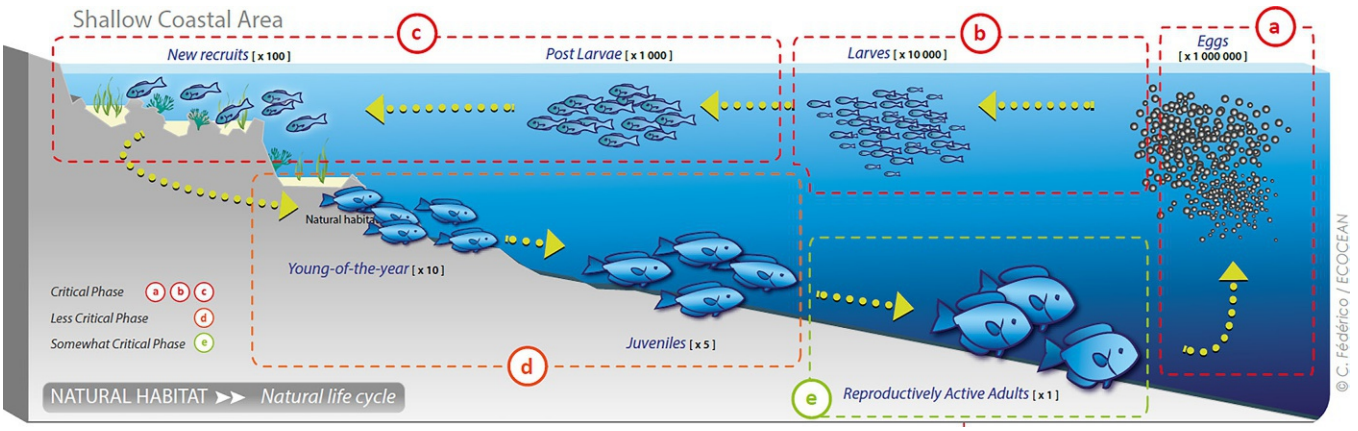

FIG. 7.2 Illustration of the life-cycle of marine coastal fish. *Credit: Lenfant, P., Gudefin, A., Fonbonne, S., Lecaillon, G., Aronson, J., Blin, E., et al. (2015). Restoration écologique des nurseries des petits fonds côtiers de Méditerranée. Orientations et principes. 95 p.*

human activities (direct or not). Consequently, for about one million eggs, only one fish will eventually become a reproductive adult. In this cycle, the early life history stage ("c" phase in Fig. 7.2) is the most critical and very associated to shallow coastal water.

Regarding this context, concerns about the state of our global environment have led scientists, NGOs, and citizens to sound the alarm, particularly for problems relating to climate change and biodiversity massive destruction. 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 high pressures that the Mediterranean area has had to endure: flows from rivers and watersheds, massive tourism, marine traffic, natural resource exploitation, and urbanization and artificialization of the coastal fringe.

For many years, multiple efforts have been made to improve water quality and to reduce pollution in shallow coastal areas of the Mediterranean. At the same time, European conservation regulations—as well as those of individual Mediterranean nations—have evolved and ecosystems are now considered in their entirety. Societal expectations have also evolved: nowadays, acceptable water quality for human seaside activities is not enough; there is a requirement for rich, healthy, and waste-free ecosystems. Awareness of this situation began in the 1970s at both national and European levels, when the first series of measures were taken to reduce pressures and bring the

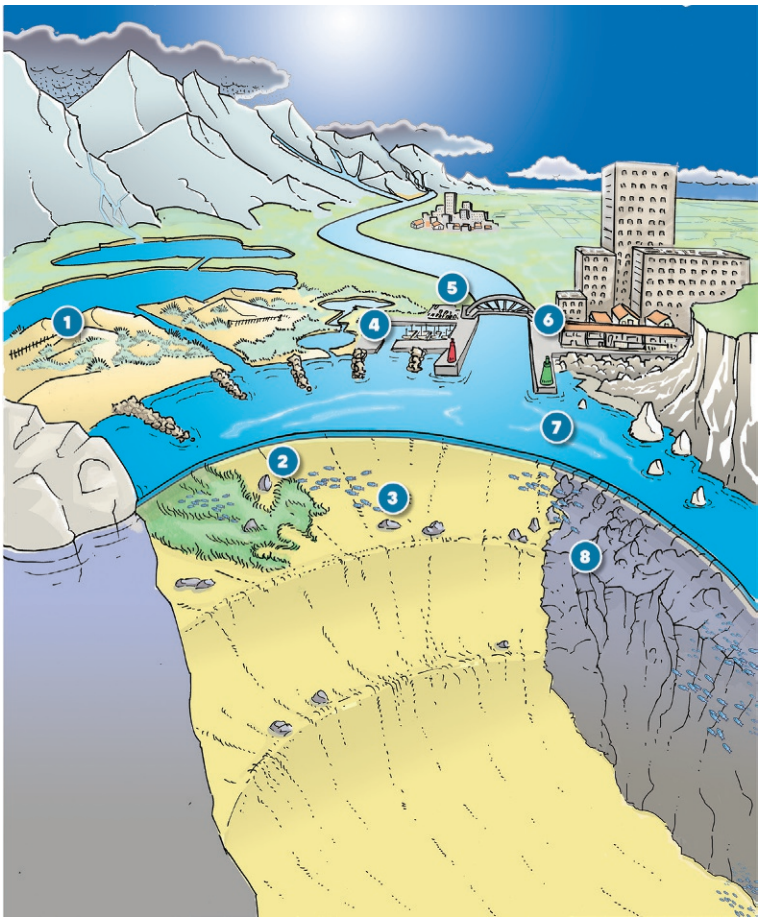

FIG. 7.3 Anthropogenic pressures on the shallow coastal areas: 1. Non indigenous species; Aquaculture—2. Anchorage zone; Macro-waste; Swimming area—3. Sound pollution; Materials extraction; Cleaning out/oil slick—4. Port & marinas—5. Polluted input from rivers; Diffuse input of nutrients and chemical contaminants from catchment basin by flow—6. Urbanization; land reclamation—7. Disposal of waste water and industrial waste; Dragging/port cleaning—8. Professional and recreational fishing; Anchorage zone; Trawler fishing. *Credit: Lenfant, P., Gudefin, A., Fonbonne, S., Lecaillon, G., Aronson, J., Blin, E., et al. (2015). Restoration écologique des nurseries des petits fonds côtiers de Méditerranée. Orientations et principes. 95 p.*

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.

Despite all these conservation efforts, human coastal activities and population pressure are always increasing, with dire consequences for the coastal region and the shallow coastal areas. The anthropogenic pressures on shallow coastal areas are briefly listed in Fig. 7.3.

The anthropogenic pressures on shallow coastal areas have 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 fundings—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. Therefore, action needs to be taken with the utmost urgency, especially as scientific knowledge and current conditions favor the development of ecologic restoration projects.

1.2 Chapter objectives

This chapter is providing key information needed to develop and implement shallow coastal water **restoration** projects. It provides a short review of what current ecological restoration is, within a restoration project in the 2020 coming decade. 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.

Today, ecological restoration is not only possible but also advisable in highly human-impacted areas. It is an additional tool to support the marine environment, complementing and reinforcing protection and conservation tools.

However, the aim of ecological restoration has to be consistent with the ecological reality: to completely restore the original ecosystem—to its pristine state before degradation—is technically impossible in most cases. Nowadays, ecological restoration is used to improve or return to a satisfactory ecological state by enhancing or reinstating essential functions of the ecosystem, while supporting associated economic activities. In order to do that, innovative technical solutions derived from recent advances in **ecological engineering** are very useful. Depending on the ecological status obtained through restoration, a certain level of management may be necessary for a limited period to maintain the proper functioning of the ecosystem.

2. Ecological restoration: A way forward

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, primary 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, and unfortunately, putting preventive measures into place is not enough for ecosystems that have been severely impacted over decades or centuries. Direct action is necessary in the form of what 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" (Society of Ecological Restoration, Ruiz-Jaen & Aide, 2005).

Sound ecological and biological knowledge is needed to achieve successful results in restoration projects. In general, these projects can only be envisaged after measures have been taken to limit pressures, and once methods of application and management have been evaluated. It is therefore necessary to first identify the causes of degradation, and when possible, to treat these causes. Otherwise, any restoration efforts are likely doomed to failure.

2.1 Ecosystem trajectory under natural and man-made influences

All ecosystems have a certain degree of variability (Fig. 7.4), and the trajectory that an ecosystem follows (Fig. 7.4, blue curve) is constantly modified by natural disturbances (in dark blue). As a definition, the level of resistance of the

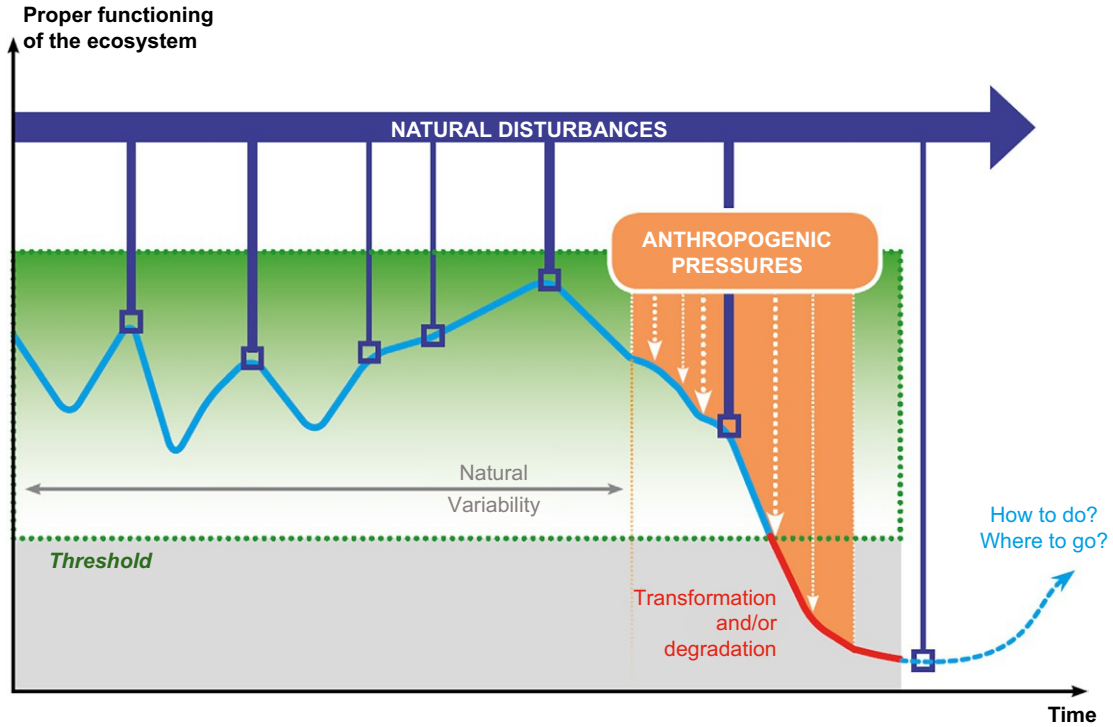

FIG. 7.4 The dynamics of an ecosystem subjected to natural disturbances and anthropogenic pressures on an intermittent or regular basis. *Credit: Lenfant, P., Gudefin, A., Fonbonne, S., Lecaillon, G., Aronson, J., Blin, E., et al. (2015). Restoration écologique des nurseries des petits fonds côtiers de Méditerranée. Orientations et principes. 95 p.*

ecosystem determines the level of negative impact or disruption that can be absorbed without any critical damage to this ecosystem, and the ecosystem 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 (Fig. 7.4, in orange) add up 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, the ecosystem risks losing its capacity to recover and to adapt to changing environmental conditions (Fig. 7.4, red curve). Below a certain threshold (Fig. 7.4, gray zone), even if the pressures are removed, the ecosystem will not be able to go back to its previous trajectory. When the alteration has negative consequences for humans and for the resilience of a system, this is an example of ecosystem degradation.

Consequently, direct action is necessary to bring the degraded ecosystem back to an acceptable trajectory (Fig. 7.4, 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. Before any intervention it is important (i) to identify in advance the desired state and expected trajectory and (ii) to choose or to construct (from information drawn from one or various sources) an ecosystem that can be used as a reference/control in order to guide the restoration work.

2.2 The possible actions to place a site or an ecosystem onto desirable trajectory

In theory, three types of possible actions could be envisaged on a damaged site. They are reported in Fig. 7.5.

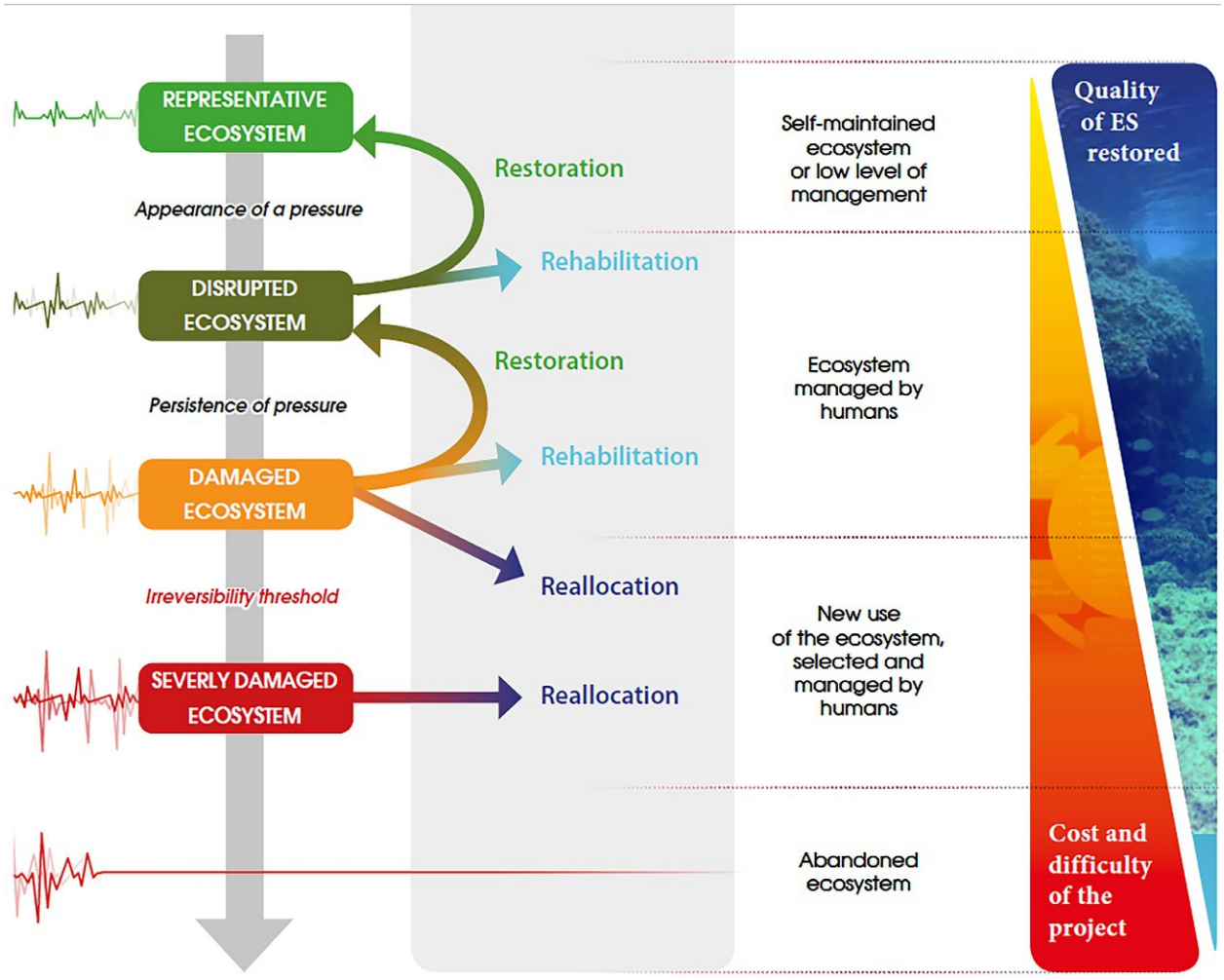

FIG. 7.5 The three types of possible responses/actions after the degradation of one or several marine and coastal ecosystems. The notion of a threshold of irreversibility is theoretical and difficult to measure in the field. *Modified from Aronson, J., Milton, S. J., & Blignaut, J. N. (Eds.). (2007). Restoring natural capital: Science, business and practice. Washington, DC: Island Press. Credit: Lenfant, P., Gudefin, A., Fonbonne, S., Lecaillon, G., Aronson, J., Blin, E., et al. (2015). Restoration écologique des nurseries des petits fonds côtiers de Méditerranée. Orientations et principes. 95 p.*

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 predisturbance 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).

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 than ecological restoration and may not require the complete removal of existing pressures or 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.

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 are 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, re-allocation may be considered as an intermediate stage on an ecological restoration trajectory.

A fourth, but as an inaction process, could also be a response. 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 (**abandoned** ecosystem).

2.3 Why can we conduct restoration work now?

2.3.1 Current regulations and emerging attitude

The regulatory context of the marine environment has evolved over the past 40 years at both European (WFD—Water Framework Directive, MSFD—Marine Strategy Framework Directive), etc.) and French (Water Acts, PAMM—Plan d'Action Milieu Marin) 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.

Lenfant et al. (2015) explain in a very detailed way the current regulations. Fig. 7.6 is resuming the evolution of legal regulations for the whole environment, the marine environment in general but with a focus on shallow coastal areas.

2.3.2 Existing solutions

The implementation of an active and operational ecological restoration action requires the five following prerequisites:

➢ Availability of proven technical solutions that address a particular problem.
➢ A commitment to restore degraded environments and to use existing technical solutions.
➢ An adequate financial resource to implement all aspects of the project.

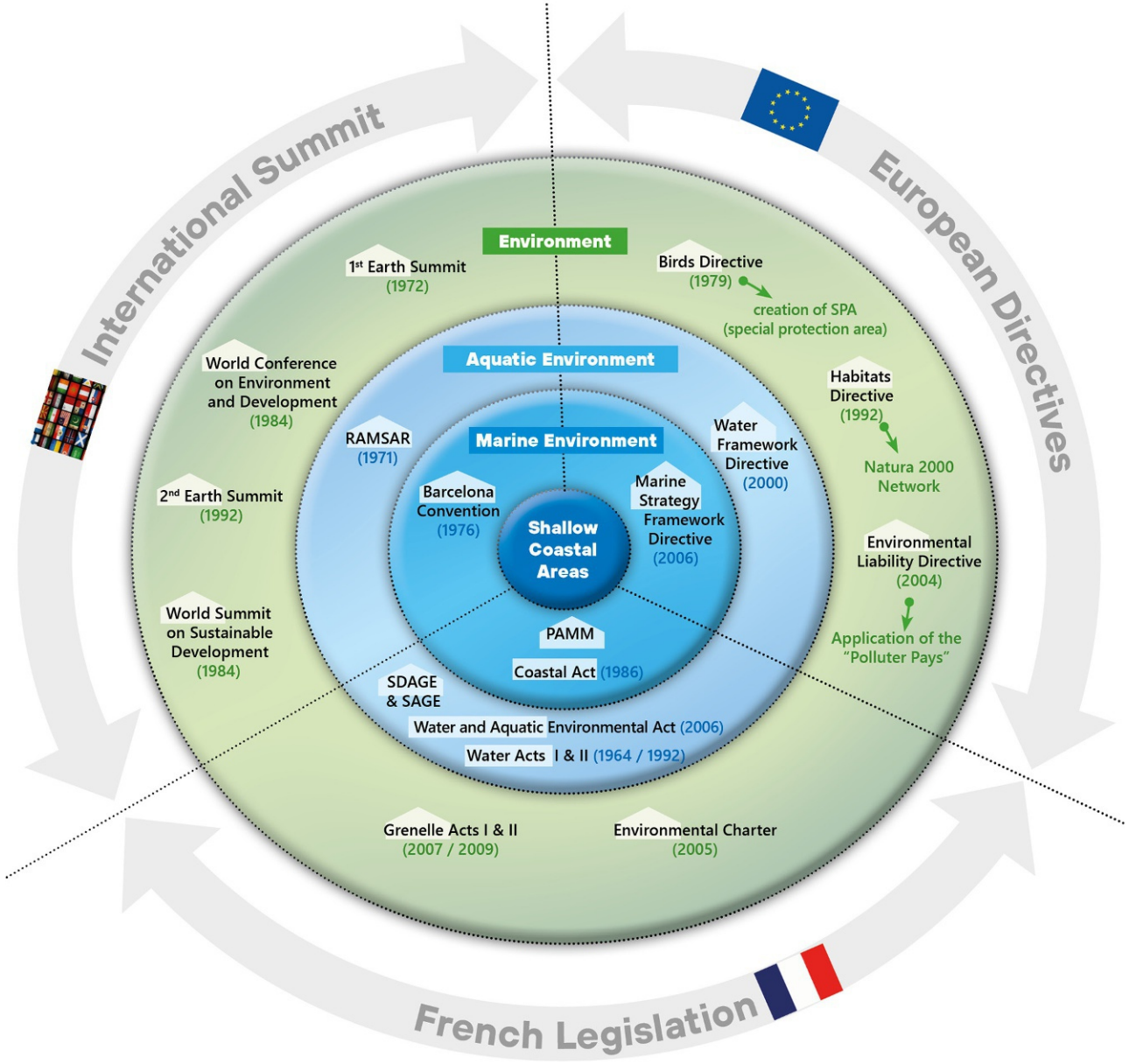

FIG. 7.6 The evolution of legal regulations for the environment, the marine environment in general, and shallow coastal areas in particular in France. *Credit: Lenfant, P., Gudefin, A., Fonbonne, S., Lecaillon, G., Aronson, J., Blin, E., et al. (2015). Restoration écologique des nurseries des petits fonds côtiers de Méditerranée. Orientations et principes. 95 p.*

➢ An administrative and regulatory authority to implement the project backed by good and transparent governance.
➢ Robust monitoring to enable a comprehensive evaluation of the restoration project.

Various projects and studies conducted over the past decade have permitted innovation and the development of effective restoration methods. Some of these resulting techniques may still 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. Fig. 7.7 below provides a summary regarding technical readiness level for existing solutions.

Ecological restoration is by definition a response to site degradation, so the first 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.

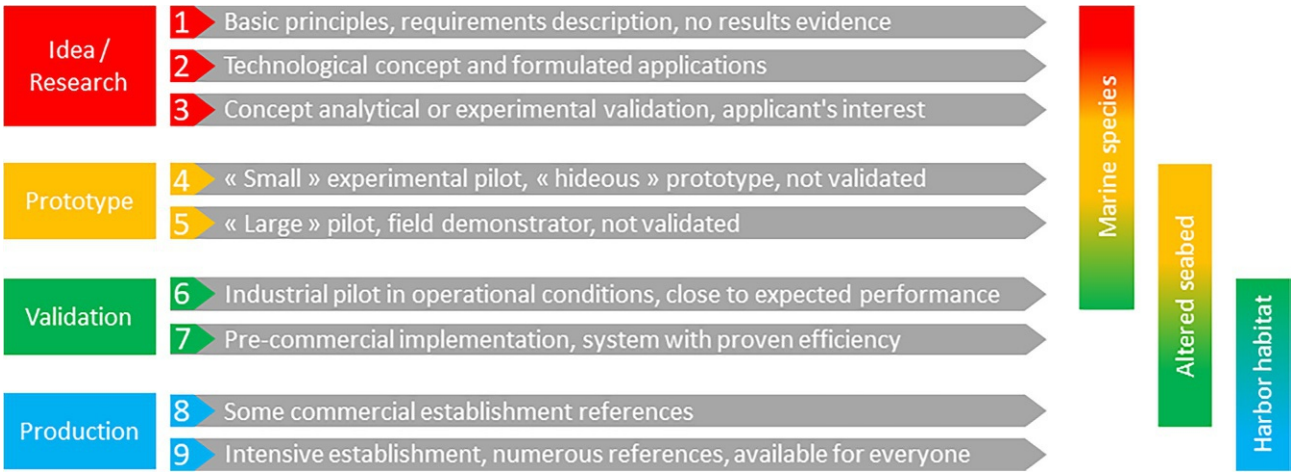

FIG. 7.7 Presentation of the TRL scale (Technology Readiness Level: measurement system used to assess the level of maturity of a technology) for technical solutions in the context of the ecological restoration of coastal shallows: marine species, altered seabed, harbor habitat. *Credit: Lenfant, P., Gudefin, A., Fonbonne, S., Lecaillon, G., Aronson, J., Blin, E., et al. (2015). Restoration écologique des nurseries des petits fonds côtiers de Méditerranée. Orientations et principes. 95 p.*

Moreover, 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.

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 (more precisely ecological rehabilitation) than managers of other aquatic environments. In 2022, only for France, almost 40 marinas are engaged with artificial fish nursery equipment. In Europe, Denmark is following the train lead by France with 8 marinas equipped. Belgium, the Netherlands, and recently Spain started to implement ecological restoration projects. In the south of the Mediterranean Sea, Moroccans are leading the process with one marina equipped (Atalayoun) and in a short time, another one should get involved.

2.3.3 Resources and costs

The cost of an ecological restoration operation may greatly vary depending on the focus of the work.

For the restoration of nursery functions in a port area, the average budget committed to operations carried out for the French Mediterranean coast is in the order of € 60,000. In addition to the cost of installation and equipment, should be added the cost of the ecological monitoring of the action, which is around €30,000 for 3 to 4 years.

The cost operation regarding restoration of ecological functions in a degraded marine site using artificial reefs may vary widely. It must integrate preliminary definition studies, impact assessment, equipment and installation monitoring and scientific studies, and, often, awareness-raising and communication actions. As part of the PRADO Project 2006 operation in Marseille (France), which is the largest artificial reef operation in Europe, the budget was set to 6.5 M €, but the total expenditure over a period of 20 years exceeds 20 M €. It is, therefore, necessary to bear in mind the expenditure linked to the investment, in general, the work itself, and the charges linked to surveillance, maintenance, awareness-raising actions, and in general terms operations necessary for the management of the developed site.

In all operations and as a well-integrated project into the territory, local jobs will be set up for all actions previously mentioned.

3. Restoration for tomorrow's society?

In a context marked by strong pressure on shallow coastal waters, the conservation alone of these ecosystems and their associated ecological functions are no longer sufficient. Ecological restoration could therefore constitute an essential complement to the conservative approach. Some ecological engineering solutions already exist and others continue to be developed.

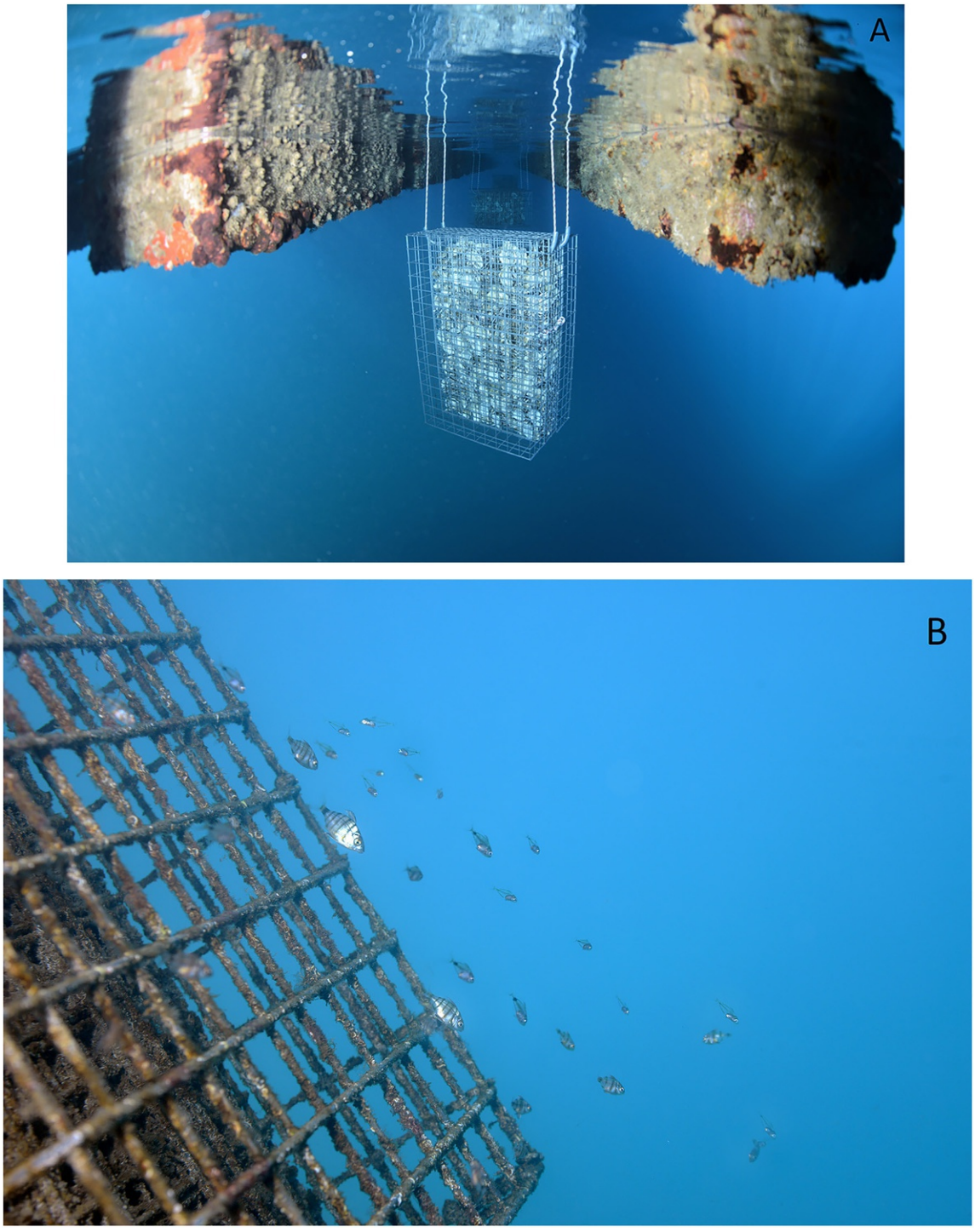

FIG. 7.8 A Biohut artificial fish nursery, the most common solution (A) and illustration of biodiversity found on Biohut habitat (B). *Credit: Rémy DUBAS—Ecocean.*

3.1 Results of a successful ecological restoration initiatives

3.1.1 Nursery habitats in harbor

This initiative aimed to counter the disappearance of coastal nurseries in harbor zones through the creation of artificial habitats (e.g., Biohut dock or Biohut pontoon) (Fig. 7.8). This solution 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 (Fig. 7.9). This

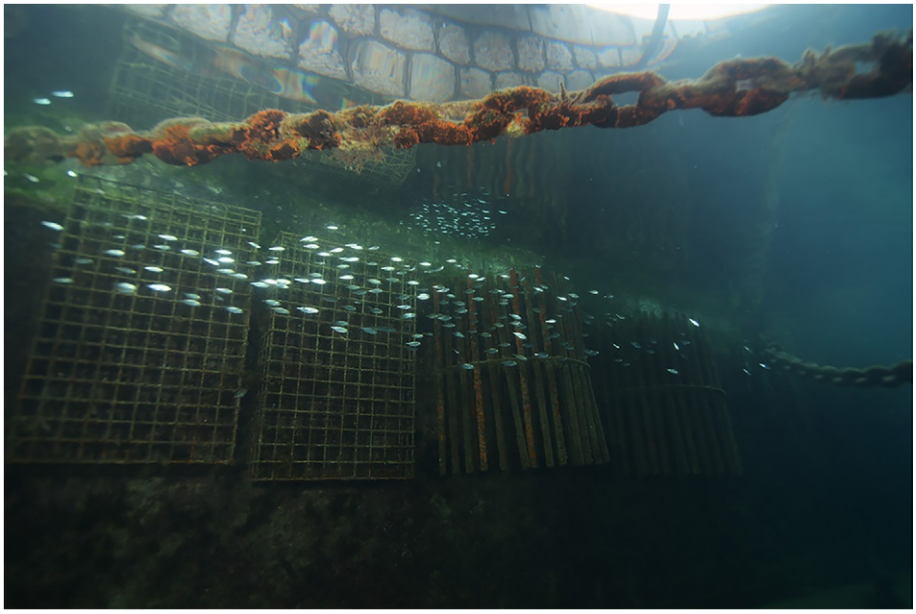

FIG. 7.9 Different existing artificial habitat used in fish nursery restoration. *Credit: Rémy DUBAS—Ecocean.*

is an innovative solution for ports that aims to contribute to the good ecological status of the environment as well as to the natural biodiversity. After a 3 years research and development process in 6 ports in the south of France, the results published in Bouchoucha et al. (2016) are encouraging. Mercader et al. (2017) have also demonstrated interest in those solutions within commercial harbors.

In June 2014, and with a view to the ecological recovery of the Marchica lagoon (Morocco), the Atalayoun marina was equipped with 50 pontoon-type Biohut to allow juvenile fish to find a refuge suitable for the postlarva stage and juvenile, a high critical stage in the life cycle of fish. The effectiveness of these microhabitats in terms of ecological restoration was a fundamental question of this pilot project.

Scientific monitoring by visual counting has shown that the presence of Biohut has a positive effect on the ichthyic fauna in the Atalayoun marina, with a higher average diversity on the equipped area than the rest of the lagoon. The attractiveness effect induced by the structures of the marina and amplified by the introduction of artificial microhabitats (Biohut) was significant.

The Biohut process also seems to have a positive influence on the preferences of certain species, in particular seabreams and groupers. In this case, of the 29 individuals of the Sharpsnout seabream (*Diplodus puntazzo*) identified in the Atalayoun marina, 25 were observed on the Biohut, 14 of which were less than 100 mm in size, and only 4 on the artificial dike. This is perfectly consistent with the specificity of Biohut-type microhabitats as preferential juvenile habitats of the pointed-snouted seabream.

This positive behavior toward microhabitats also concerns groupers. Compared to the natural habitats and the dike, the Biohut sheltered the highest densities of juvenile groupers, whether it be the brown grouper or the king grouper. They can thus be considered as reservoirs for young groupers, including the emblematic species of the Mediterranean, the brown grouper. These artificial microhabitats are also useful in reinforcing the role of the lagoon as an ichthyic nursery. In addition, Biohut can also serve as a support for the creation of small marine reserves, which can promote the long-term recovery of certain endangered species (Mercader et al., 2017; Selfati et al., 2018).

3.1.2 Artificial reef

Artificial reefs are solutions initiated by humans for several centuries to exploit the marine environment, but their large-scale use dates back to the 1950s with significant development in Japan (Thierry, 1988). Depending on the region of the globe, the contexts and objectives may vary. In the Mediterranean, the coastal strip is the site of many economic activities, such as tourism, recreational (diving, boating, recreational fishing, etc.), or linked to the exploitation of natural resources (fishing, marine cultures, etc.). In this highly coveted space, both productive and very fragile, the ecological functions essential to the life of the marine organisms that are concentrated there (breeding area, nursery area, etc.) are under great pressure. Historically, fishing has dominated, sometimes with significant and sometimes

illegal overfishing when the activity is too close to the coast (trawling). The artificialization due to the extension of marinas and coastal towns leads to strong erosion of marine biodiversity. In addition, there are many contributions from coastal rivers (terrigenous pollution, microplastics, etc.). To compensate for this loss of natural habitats and associated functionalities, it may be necessary to resort to artificial habitat solutions.

Artificial reefs are indeed real tools that can be used for fishing, recreation, restoration, or even ecological compensation to compensate for the loss of biodiversity or the disappearance of natural habitats in the face of these anthropogenic pressures (Seaman, 2007). Associated with adequate management, they allow the development of marine flora and fauna to support sustainable uses. Artificial reefs are very complementary tools to marine protected areas (MPAs). They thus find their place in the European public policies of the Marine Strategy Framework Directive (MSFD) or the Mediterranean protocols governed by the Barcelona Convention. Several definitions have been proposed in the scientific literature, we have retained the one proposed by Ifremer: "Artificial reefs represent structures voluntarily submerged with the aim of creating, protecting or restoring a rich and diverse ecosystem. These structures can induce in animal's responses of attraction, concentration, protection and in some cases an increase in the biomass of certain species."

The basic elements are manufactured specifically or from the public works industry. The reefs can come from the recovery of obsolete objects previously decontaminated.

The immersion of reefs meets various objectives: (i) ecological to support populations of marine species and associated habitats (refuge, breeding area, etc.) (Koenig, Coleman, & Kingon, 2011), (ii) fish production (Leitao, Santos, Erzini, & Monteiro, 2009), (iii) physical protection, mainly against illegal trawling (Relini, Relini, Palandri, Merello, & Beccornia, 2007), (iv) tourism such as diving (Polak & Shashar, 2012), or even (v) cultural as status immersion or other works of art. The given function of artificial reef conditions the chosen reef complex and therefore the type of submerged modules, its architecture, the materials used, the volumes, and the elevation (Sherman, Gilliam, & Spieler, 2002). To support fishery resources, a reef will present roughness, heterogeneity, and above all complexity (crevices, holes of variable size, etc.) that are much greater than for an antitrawling reef which must be mainly resistant to it. Overall, the results show the presence of numerous species due to the creation of a new hard substrate-type habitat on a soft bottom (e.g. Charbonnel, Serre, Ruitton, Harmelin, & Jensen, 2002; Hackradt, Félix-Hackradt, & García-Charton, 2011). This also creates transition zones or ecotones particularly sought after by predators. In addition to being rich in species, artificial reefs also show densities much higher than what can be observed in natural rocky environments. This is due to a concentrator effect due to reduced habitat availability, such as an oasis effect in the desert. However, numerous studies have also shown that artificial reefs can become production areas, either by using this habitat for food or for reproduction. Studies using acoustic telemetry show that individuals are more or less sedentary in these artificial areas (Abecasis, Bentes, Lino, Santos, & Erzini, 2013; D'anna, Giacalone, Pipitone, & Badalamenti, 2011; Koeck et al., 2013; Özgül, Lök, Tanrıkul, & Alós, 2019). Beyond increasing fish populations, monitoring of fishing landings shows that artificial reefs can also help maintain coastal artisanal fishing activities with catches similar to those obtained in natural areas (e.g. Leitao et al., 2009; Recasens, Lombarte, & Sánchez, 2006; Santos & Monteiro, 1998). This makes it possible to open up natural areas while offering fishing sites closer to home ports, thus helping to reduce operating costs and carbon footprint of fishing vessels (Leeworthy, Maher, & Stone, 2006).

Taken together, these results show that artificial reefs play a significant ecological and economic role within the ecosystems in which they are deployed. Beyond the role of artificial habitat in the service of coastal management, reefs are also tools for dialogue that facilitate the establishment of synergies between stakeholders. Indeed, artificial reefs catalyze energies, make it possible to federate, raise awareness, coordinate, and therefore manage uses in order to limit their pressure on the marine environment. The prospects for artificial reefs are directly linked to the development of 3D printing, which will make it possible to control the parameters important to their efficiency (roughness, complexity, etc.) (Mohammed, 2016). This is in line with growing demand from recreational divers who seek esthetic forms such as what is sought with wrecks (Morgan, Massey, & Huth, 2009). Ultimately, this strategy may make it possible, as with artisanal or recreational fishing, to reduce the pressure on natural sites (Polak & Shashar, 2012; Tynyakov et al., 2017).

3.1.3 Seagrass transplant

The restoration of marine seagrass has been the subject of years of experimentation. Very few of them were successful. If the principle remains simple, namely to take healthy cuttings from a site and transplanted them to the site to be restored, it is clear that these operations have too often been the subject of a reduced experimental surface and followed up on a short time. In fact, the conditions for their success have rarely been met.

However, at least four promising operations should be presented.

a. The first operation concerns the restoration of the *Cymodocea nodosa* seagrass in the Brusc lagoon (SAR-LAB program 2017–23, Institut Océanographique Paul Ricard, Six-Fours-Les-Plages, Var, France). After a trial period of few months on a small-scale area, a restoration operation was initiated on a larger surface to help recovering the lost seagrass meadow of *Cymodocea* within the marine lagoon. The particularity of this action is that it is also coupled with actions to restore the nursery functions of shallow coastal waters using artificial habitats of the Biohut type and an action to restore a coastal neglected wetland. After 3 years, *Cymodocea* are spreading outside the transplant complexes and the early protection of the transplant avoided the herbivore fish pressure (Couvray et al., 2021).

b. The second operation concerns the transplantation of a *Posidonia* herbarium threatened by maritime works in Monaco. For the first time, a large area of seagrass bed (500 m^2) has been moved and transplanted. The transplants were taken with its clod of sediment so as not to break the plant-soil bond. After nearly 2 years of transplantation, it is doing well and even bloomed during the year 2020 showing all its vitality.

c. The third operation took place in Villasimius, Sardinia (Italy) where *Posidonia* herbarium transplants have been transplanted into areas altered by the anchors of pleasure craft in order to fill the "bleeding" thus created. The operation is still ongoing but the first results are interesting.

d. Finally, the last example concerns the REPIC operation in Antibes (Alpes Maritimes, France). This operation aims to transplant in shallow water the pieces of *Posidonia* herbarium torn by the anchors of the ships during the summer season, pieces doomed to die. After 2 years of studies, the survival of transplants exceeds 80%, which suggests certain operational prospects.

However, it should be taking into account that if scientific work suggests interesting prospects for the restoration of seagrass beds, it must be recognized that up to date the best restoration policy is not to have to restore seagrasses. Their nondegradation remains the main policy in this domain and definitely much cheaper than initiating seagrass restoration programs.

3.1.4 PCC-R-based fish enhancement

Typically, fishery enhancement programs breed and release farmed seed as juveniles, but the release of these hatchery-produced animals remains controversial (Bell, Bartley, Lorenzen, & Loneragan, 2006; Taylor et al., 2017). Despite significant advances in aquaculture techniques, social and economic assessments, ecological modeling, and genetic testing concerns remain about the potential impacts on wild populations, homogenization, and the spread of disease (Bell et al., 2006; Lorenzen, Leber, & Blankenship, 2010). An alternative but understudied approach to the release of farmed juveniles is the harvesting and rearing of wild pelagic postlarvae for re-release as juveniles (Postlarval Capture, Culture, and Release; PCC-R), sometimes termed *capture-based enhancement* (Bell et al., 2006; Bell, Clua, Hair, Galzin, & Doherty, 2009; Hair, Bell, & Doherty, 2002). By catching and keeping wild postlarvae until they have reached a size refuge from predation, PCC-R-based enhancement aims to mitigate concerns over the negative genetic impacts of releasing cultured hatchery-seed and offers a potentially lower cost, and more genetically diverse source of juveniles better adapted to natural conditions (Bartley & Bell, 2008; Hair et al., 2002).

PCC-R fisheries enhancement is best-suited to coastal species that start life as pelagic larvae before settling to shallow inshore habitats, where they remain site attached as juveniles and adults, creating self-replenishing populations. However, engagement with stakeholders also provides social and financial benefits, including international EU funding to support national research and fisheries, and collaboration with a local artisanal fishermen.

The method PCC-R has benefited from scientific validation within the framework of the European Life + SUBLIMO project coordinated by the University of Perpignan. Based on an elastomeric type marking of individuals released after rearing, the scientists followed the evolution of numbers (evaluation of survival) and individual sizes (evaluation of growth) over a period of 1 month with visual monitoring in diving. With a daily follow-up frequency in the first 5 days and then every 5 days thereafter, the results show a promising survival rate of around 50%.

The CasCioMar project, carried by the company Ecocean and supported by the program Nature 2050 by CDC Biodiversity, aims to rehabilitate coastal fish populations with the release of juveniles and so restore the ecological functions lost in the Marseille basin due to urban sprawl. This PCC-R project is ongoing in Marseille-La Ciotat-Cassis cities in France since 2015. A total of 26,000 individuals from 75 different species have been captured and raised over the project. From larval capture to the release of juveniles, an average of 16% of mortality occurred within the process, contrasting with more than 90% of mortality in a natural healthy environment (could reach 100% within a degraded shoreline).

Wild postlarvae can be successfully captured and cultured. Hatchery-based enhancement programs show that some organisms can be reared and released cost-effectively and at large scales, supporting the likely viability of PCC-R-based enhancement that combines such approaches (Bell et al., 2006; Hair et al., 2002). Where PCC-R can provide incomes for local coastal communities, it may provide additional socioeconomic benefits and promote active stewardship of local marine resources. Indeed, PCC-R initiatives could form part of a larger funded initiative designed to restore natural coastal resources and support coastal fishing in a region.

A cost-benefit analysis of the CasCioMar initiative indicated that while long-term impacts are not yet quantifiable, there are net-positive short-term impacts on the fishery, fishers, those directly employed in the supply chain, and regional economic development.

3.1.5 Endangered species translocation: The example of the Patella ferruginea limpet and corals

Ecological restoration practices are being increasingly considered in order to assist in the recovery of damaged ecosystems. However, in the marine environment, the success in restoration activities has been achieved at small spatial scales (Abelson et al., 2020) because the lack of knowledge about the underlying drivers to attain good outcomes (Montero-Serra et al., 2018). Moreover, there is not a relationship between success and associated costs in marine restoration (Bayraktarov et al., 2016), due to the variety of methods applied. One of these practices are focused on translocation of species either endangered or ecologically relevant. Even though translocations have been traditionally used to improve the conservation status of the target species, there is an increasing international interest as a tool to restore ecological processes, specifically when the translocated species are "ecosystem engineers" (IUCN/SSC, 2013; Palmer, Valentine, Page, & Hobbs, 2020). Nevertheless, even when translocation projects have been implementing from a long time ago and they seem to be straightforward to deal with the current biodiversity crisis and to manage for reducing extinction risk in threatened species, there is a debate about their utility and/or feasibility (Pérez et al., 2012). These authors proposed that translocation procedures should only be undertaken when three main levels were attended (accordingly with IUCN guidelines for translocations): (1) the necessity of the translocation; (2) a risk evaluation; and (3) technical and logistical suitability. One of the most relevant issues is that the causes of population decline had been removed within the area where the translocation will be done (Meffe, 1992), guaranteeing the success of such initiatives.

Apart from the feasibility of translocation initiatives, focusing on the marine system, the efforts must be done on species that act as a keystone species or ecosystems engineers (Geist & Hawkins, 2016). In this sense, limpets and corals, respectively, are good examples.

Limpets are considered keystone species in coastal areas because they maintain patches free of algae, allowing the coexistence of many species and boosting the biodiversity (Branch, 1981; Raffaelli & Hawkins, 1996). In this sense, giant limpets are both keystone species in their habitats, and it is like for them to be endangered because of the use as a food resource or bait by people being one of the most endangered species the so called ferruginean limpet, *Patella ferruginea* Gmelin, 1791 (Espinosa & Rivera-Ingraham, 2017). This species is endemic of the Western Mediterranean where has been almost extirpated from the European shores and only remnant populations can be found sparsely distributed through the Western Mediterranean (Espinosa et al., 2014). In fact, the species is considered as one of the most endangered marine invertebrate in the Mediterranean Sea (Ramos, 1998). In this sense, translocation procedures have been attempted to try repopulation programmes or avoid the impact of coastal development. First, the species was translocated lifting up the specimens from the substrate and placing them into a new one (Espinosa et al., 2008). However, high mortality rates (50% after transplant) were observed during the first time when the specimens were translocated due to their noneffective attaching onto the new topography of the receiving substrate (see Espinosa et al., 2008). Second, the use of cages to avoid desiccation and predation had been proposed by Espinosa, Guerra-García, Fa, and García-Gómez (2006), although was not tested until later, when cages proved to reduce mortality after translocation procedures (Zarrouk, Romdhane, & Espinosa, 2018). Nevertheless, detaching specimens from the substrata has been showed being harmful anyway. However, the most successful methodology until now has been based on the translocation of the limpets attached to their original substrate when very high survival rates (87% after 10 mo.) have been reported (Fa, Finlayson, Sempere-Valverde, & García-Gómez, 2018). To do it, great boulders of a breakwater were moved to a new position with the assistance of cranes. Despite showing good results, this procedure is quite expensive and difficult to perform in case of facing the translocation of many specimens (hundreds to thousands). In this regard, recruitment plates (40 × 20 cm) made using 3D printing technology to mimic the topography of the substrate have been developed which allow the recruitment on their surfaces under the LIFE program of the EU (www.liferemopaf.org). These plates called AIMS (artificial inert mobile substrates) have been designed to be easily extracted and allocated into a different place, in order to carry out the translocation of this species from dense and

healthy populations to sites where the species becomes extinct, or its populations have decreased. These techniques could be used in other endangered species of limpets such as *Patella candei, Lottia gigantea,* or *Scutellastra mexicana*.

On the other hand, among the most studied species regarding with translocation experiences in the marine realm are corals (Montero-Serra et al., 2018) since they are "ecosystem engineers" or habitat-forming species (Montero-Serra et al., 2018). Overall, transplanting corals to degraded reefs have been shown to increase coral cover and structural complexity, even though the influence on recruitment, coral richness, and healthy of coral populations have not been widely proved (see Hein et al., 2020). Besides, coral restoration has shown a lack of standardized monitoring to evaluate the outcomes as well as short timeframes (around 1 year as a mean), in order to assess the appropriateness of restoration as a tool for management and conservation (Boström-Einarsson et al., 2020). In addition, geographical constraints on different approaches to coral restoration have made difficult a comprehensive comparison. In this regard, in the Caribbean, the focus has been set up on two endangered species of *Acropora,* whereas in the Indo-Pacific, the focus has been oriented toward restoring reef structure and resilience against global phenomena such as bleaching (Hein et al., 2020).

Coral reef restoration methods have been much diverse than other coral restoration initiatives focused on temperate or deep coral species. A major concern after an impact caused by storms, ship grounding, anchoring, or dynamite fishing on coral bottoms has been the stabilization of the unconsolidated reef substrate formed by rubble coral (Ceccarelli et al., 2020). In this sense, rubble prevents recruitment and growth of coral colonies by physical action when they roll and impact through the bottom (Cameron, Pausch, & Miller, 2016). Stabilization of rubble has been done in a several ways: direct rubble removal, using metal mesh to stabilize rubble, installing metal stakes, injecting chemicals like cement, allocating 3D frames like MARRS Reef Stars, deploying BioRock, SECORE tetrapods, or concrete Reef Balls, or using baskets and reef bags (see Ceccarelli et al., 2020 and references therein). Nevertheless, many coral translocations have not taken into consideration substrate stabilization prior to restoration.

Furthermore, coral reef translocations have also been conducted differently (see Table 7.1 and examples in Kotb, Hanafy, and Monir (2018) or Hein et al. (2020) for a detailed and photographical description), and it is out of the scope of this chapter to make a precise review in this regard (see Boström-Einarsson et al., 2020 for a comprehensive review), except provides a general framework. For example, in the Red Sea, Kotb et al. (2018) undertook a coral reef restoration using 20 different genera detaching healthy colonies that were subsequently attached with marine cement but also using coral nubbins from broken branched corals maintained in a table nursery. In fact, one of the most promising emerging approaches is the so called "gardening concept" in which two steps are sequentially done: (1) in situ nursery phase with coral nubbins farmed and (2) transplantation of such nubbins to a degraded reef area (Rinkevich, 2015).

TABLE 7.1 Coral species in which translocation procedures have been implemented.

	Translocation procedure				
Species	**Extraction**	**Allocation**	**% Survival**	**Depth (m)**	**References**
Tropical corals					
Acropora cervicornis *Acropora palmata* (Florida Keys, Virgin Is.)	Fragment of opportunity collected and placed in coral PVC tree nurseries	Directly with epoxy cement	35% after 1 year 44% after 1 year	8	Montero-Serra et al. (2018) Hein et al. (2020)
Montipora sp. *Porites lobata* *Pocillopora meandrina* (Hawai)	Fragments of dislodged corals by storm or ship runs aground were gathered into a basket underwater to the restoration site	Removing of the layer with coral rubble using a vacuum hose attached to a boat and cement to attach corals to the seafloor	–	10	NOAA (2014)
Acropora hemprichii *Pocillopora damicornis* *Stylophora pistillata*	Nubbins taken from broken branched corals	Inserted into a slot made in plastic tubes that were allocated to a table nursery	88% after 2 years 90% after 2 years 87% after 2 years	5	Kotb (2016)
20 coral genera (Gulf of Aqaba, Red Sea)	Detached healthy colonies using a hammer and chisel	Marine cement with liquid hardener	87.3% after 2 years		

TABLE 7.1 Coral species in which translocation procedures have been implemented—cont'd

Species	Translocation procedure		% Survival	Depth (m)	References
	Extraction	Allocation			
Temperate corals					
Astroides calycularis (Southern Spain)	Extracted using scuba diving	Substratum cleaned with a steel comb and colonies attached using epoxy resin	64.3%–81.2% after 1 year	8	Terrón-Sigler, León-Muez, Peñalver-Duque, and Espinosa-Torre (2016)
Corallium rubrum (NE Spain)	Decomised from illegal harvesting	Epoxy putty	99.1% after 4 years	15–17	Montero-Serra et al. (2018)
Eunicella cavolinii (NE Spain)	Collected from trammel nets fishing of artisanal fishers	Directly with epoxy putty to natural cobble supports or artificial made with concrete	100% after 3 months	5–30	Montseny et al. (2020)
Paramuricea clavata (NE Spain)	Fragments of surviving colonies found at the bottom of walls	"Stick procedure" (PVC stick 5 cm long fixing the fragment using a plastic bridle and adhering to the bottom with an epoxy putty)	70% after 1 year/16% after 3 years (vs 52% after 3 years in natural population)	15–20	Linares et al. (2008)
Eunicella cavolinii *Eunicella singularis* *Eunicella verrucosa* *Paramuricea clavate* (Liguria, Italy)	Terminal branches cut by blades	Branches were glued by silicone to 1.5 mL plastic tubes and mounted on 1-m side frames	30% after 1 year 35% after 1 year 30% after 1 year 2.5% after 1 year	25	Fava, Bavestrello, Valisano, and Cerrano (2010)
Deep corals					
Eunicella cavolinii (NE Spain)	From artisanal fishers's bycatch	On stainless structures (2 m diameter) with a base grid (10 × 10 cm^2) surrounded by four concrete plots and a central 1 m vertical axis holding an acoustic reflector (30 cm diameter) supported by four stainless steel bars	87.5% after 1 year	85	Linares et al. (2020)
Lophelia pertusa (Gulf of Mexico)	Submersible	On a concrete base (6 cm diameter) with four PVC union fitting where each fragment was placed	91% after 13.5 months	460–503	Brooke and Young (2009)
Corallium sp. *Isidella tentaculum* *Keratoisis* sp. *Paragorgia arborea* *Sibogagorgia cauliflora* *Swiftia kofoidi* (California, United States)	Using ROVs from colonies visually healthy and cut into fragments	On coral pots made of PVC and attached at the potbase with Sakrete© fast setting cement	100% after 1 year 0%–50% after 1 year 30% after 1 year 0%–40% after 1 year 40/0% after 1 year and 2 years 100% after 2 years	800–1300	Boch et al. (2019)
Oculina varicosa (Florida, United States)	Deep diving (64–90 m)	On concrete reefballs (81x81x71 cm) with attached coral fragments using cable ties and quick-setting cement On concrete reefdiscs (30 cm diameter) with vertical PVC post (40 cm) in which a coral fragment was attached using cable ties	25% after 1 year 50%–60% after 1 year	50–183	Brooke, Koenig, and Shepard (2006)

Shaded and white indicate that the information about these species has been obtained from the same reference.

Several examples can be arised, in the island of Koh Tao (Tailand), the *New Heaven Reef Conservation Program* started in 2007 using a wide variety of approaches collecting fragments from the bottom for further coral transplantation. These fragments were attached to mid-water ropes and table nurseries for a few months and then directly transplanted into natural holes and crevices or attached to artificial structures such as electrified steel frame, non-electrified steel frame, concrete reef balls, and glass bottles in concrete. Attachment methods were also varied: epoxy cement, nylon thread, cable ties, or fine metal wire depending on the structure. On the other hand, within Landaa Giraavaru islet in Maldives coral restoration has been led by *Reefscapers* group using sand-coated steel structures ranging from 110 × 40 cm to 200 × 110 cm (width × height), where coral fragments were attached by cable ties on land and subsequently deployed on the reef. A similar approach has been used by Williams, Sur, Janetski, and Hollarsmith (2019) to restore a coral reef in Indonesia after blast fishing using modular open structures called "spiders" for stabilizing rubble and attach coral fragments. Moreover, in the Florida Keys (United States) the *Coral Restoration Foundation* has promoted since 2007 the restoration of *Acropora* species (*A. cervicornis* and *A. palmata*), which are both catalogued as "critically endangered" by the IUCN. In the same way, *The Nature Conservancy* also started coral conservation of such species in 2009 in the Virgin Islands, United States (Schrack, Beck, Brumbaugh, Crisley, & Hancock, 2012). To achieve this aim, coral fragments from remnant colonies were collected and allocated in coral tree nurseries made by PVC and suspended in the water column. Once fragments are sufficiently large, they were directly affixed to the reef substrata using epoxy cement. Although the assessment of the success highly depends on geographical and species-specific constraints, it seems that a restoration design that includes a mix of direct transplantation and a variety of artificial structures led to the greatest complexity, coral diversity, coral recruitment, and improving coral health (Hein et al., 2020).

Shallow temperate corals have also been the target of several translocation experiences. Even though they do not form reefs in a comparable way to the tropical ones, temperate corals act as an ecosystem engineers in coastal areas, providing shelter and food for many species and creating 3D underwater forests (Montseny et al., 2020). Many different approaches have been used in temperate corals in restoration efforts. Extraction has been based on collecting colonies directly from the bottom, from artisanal fisher's bycatch, cutting branches of healthy donor colonies or directly detaching whole colonies, whereas allocation has varied from attaching the colonies directly onto the substrate with epoxy putty, the use of sticks to guarantee the fixation of the transplants or attach them to an experimental frame that was subsequently fixed to the bottom. More sophisticated devices have also been performed such as a stainless structure with grids where the branches were already fixed (see Table 7.1).

Restoration initiatives` in the deep sea could be useful to ameliorate the consequences of the three major activities that have been highlighted to affect the deep sea: trawling, mining, and oil and gas exploitation, with affected areas from several 100s km^2 for oil and gas extraction to 1000s km^2 for mining and trawling and ranging in depth from 200 to 4000 m (Da Ros et al., 2019). Although the evidence indicates that deep habitats have been mostly destroyed by trawling fisheries (Van Dover et al., 2014), natural phenomena are not able to be discarded such as protracted upwelling, benthic storms, or disease (see Brooke et al., 2006). In this way, restoration of deeper benthic ecosystems where deep corals can be found, and which some are reef forming species such as *Oculina varicosa* or *Lophelia pertusa* are extremely uncommon (Boch et al., 2019; Brooke et al., 2006; Brooke & Young, 2009; Da Ros et al., 2019) in spite of their importance as fish habitat (Brooke et al., 2006; Costello et al., 2003).

Logistical constraints have been the main limit to the restoration initiatives in deep areas, considering that some of them have been implemented in the range 800–1300 m depth (Boch et al., 2019). Nevertheless, the recovery of such deep-sea coral communities is a new frontier for restoration science (Boch et al., 2019) in spite of the cost of restoration may be two or three orders of magnitude greater per hectare than those in shallow marine areas, accounting to up 4.8 million $ per 600 m^2 (Van Dover et al., 2014). The successes of these translocations have been driven by the different sensitivity of the species to transplanting methods, several authors pointed out that repopulation efforts accelerate the recovery of damaged coral communities (Boch et al., 2019). Moreover, some attempts have been conducted also with the gorgonian *Eunicella cavolini* on the Mediterranean continental shelf at 90 m depth (Montseny et al., 2019).

Restoration actions must be implemented in connection with protection measures that avoid the pressures that could be going on in such areas. In this sense, for deep coral assemblages the closure of fishing activities should be mandatory before any restoration procedures start and at least until a specific threshold either in size/biomass of coral species or area covered was achieved (Linares et al., 2020).

The translocation procedures used with deep corals have in common the use of ROVs (remote operational vehicles) that collect short fragments of coral tips from a donor healthy population, whereas others took fragments or complete colonies from artisanal fishers's bycatch (Linares et al., 2020). Nevertheless, submersibles have been sometimes used to collect coral fragments (Brooke & Young, 2009). Afterward, they are attached to a variety of artificial structures such as concrete modules (with or without PVC pieces), racks, or stainless steel structures (provided with

a grid to attach the corals) and using epoxy putty such as Corafix Superfast (GROTECH©), Sakrete© fast setting cement or similar to affix the fragments (Boch et al., 2019; Linares et al., 2020) (see Table 7.1). The structures where the corals were attached must be later deployed from boats using lines and pulleys. Moreover, some authors have tested new methods being low-cost and large-scale feasible consisting in attaching corals to cobbles (natural or concrete made) with epoxy putty and throwing directly from a boat in a free landing procedure named "badminton method" (Montseny et al., 2020).

3.2 The crucial role of science/knowledge

Public policies should be based as much as possible on precise and factual elements. In this respect, scientific expertise is a structuring element of decision making. Scientists should make available to the decision maker the elements in their possession but also identify gaps and uncertainties. However, in the end, only the decision maker should assume the final choices. To improve public decision making, we therefore must agree to support scientific research. The decision-making process has to be part of a logic of co-construction over the medium long term and respect for the prerogatives of the various stakeholders. It is also necessary to accept to make operational decisions without having all the answers to the questions. From this perspective, the importance of feedback and sharing of the results acquired is crucial.

The DRIVER Project exchange (https://www.restauration-ecologique.com/) days on the ecological restoration of shallow coastal waters were created in this vision. Bringing together all the actors, State services, National agencies, private sector companies, associations, and scientists, to share feedback as well as proposed research programs and rigorous methods for evaluating restoration actions was the initial objective. These days of meeting and discussions have made it possible to move forward the economic sector of restoration while stimulating scientific research through several research programs and Thesis carried out between 2015 and 2019. Currently, decision makers are working on ecological restoration plans at the scale of the French Mediterranean.

3.3 Toward a new economic sector

About 15 years ago, subjects related to ecological restoration in the marine environment did not exist in international congresses dedicated to ecological restoration, and companies in this sector were rare. Today, several dozens of companies closely (e.g., solution providers) or remotely (e.g., design office provider) linked to ecological restoration have been listed in France. International congresses as SER2021 today have dedicated sessions about ecological marine restoration. Finally, the first university degree is to be set up in 2022 jointly by the universities of Montpellier and Perpignan in close collaboration with those of Morocco. This is the only one in France.

Indeed, mindsets toward ecological restoration are moving ahead quickly, and this new market is growing simultaneously. Yet, companies in this line of business are rather small, often innovative (start-up type), but large industrial groups are also interested, which shows that the subject is now taken seriously.

Sustainable environmental solutions and nature restoration projects should also be considered in terms of socioeconomic benefits. As an example, the CasCioMar PCC-R-based restocking project and for an average of € 1 million achieved by the contractor, a turnover of € 2.3 million, an added value of € 1 million and 15.4 jobs are generated. In total, by considering the direct, indirect, and induced impacts linked to the expenses of the CasCioMar project plus its catalytic impacts on the coastal fishing sector, we can estimate that on average, 1 M € generated by a company in ecological marine restoration doing fish restocking action, should generate annually on the local economy, a turnover between € 2.9 million and € 3.2 million, an added value between € 1.3 million and € 1.5 million and between 20 and 22.2 jobs (CDC Biodiversite, 2019).

Ecological engineering projects could therefore strongly contribute to the economic development of a territory, often with jobs that cannot be relocated.

4. Challenges and opportunities in using ecological restoration to address global biodiversity targets

- ➢ Ecological restoration is a complementary tool to actions to combat pollution and nondegradation of aquatic environments.
- ➢ Engaging in ecological restoration action is often a way to continue and strengthen its mobilization on pollution control actions by mobilizing again to protect the aquatic environment.
- ➢ Ecological restoration is a great opportunity to improve and implement scientific knowledge.

- ➢ Ecological restoration can bring science and biodiversity into urban territories.
- ➢ Ecological restoration can help raise awareness with a positive perspective. In this sense, boat parking is not anymore, a dirty and garbage place, is this considered as an "artificial ecosystem," close to cities, and where kids and citizens can see and touch biodiversity.
- ➢ Innovation has always pushed civilization and economy ahead, this innovative sector will put forward entrepreneurs to innovate into circular economy material, biomimetic to target new ecological functions.
- ➢ Ecological restoration is complementary to marine protected areas and can be applied to larger areas to relay the different effects of integral reserves.
- ➢ The challenge of ecological restoration is to be able to deploy large-scale solutions in order to benefit from a sufficient critical mass in terms of the effect on species and ecological functions to halt the loss of biodiversity.
- ➢ Ecological restoration is a tool that must be fully used in large-scale public policies (e.g., at the European level).

5. Conclusions and recommendations

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, defined as the goods and services provided to people by ecosystems, highlights how the natural environment provides benefits to human societies. The many services provided by shallow coastal regions depend on the 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.

Shallow coastal regions ensure an interface between land and sea, they are vulnerable to pressures originating from either of these two environments and are subject 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 cumulate. 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.

Ecological restoration practices are being increasingly considered in order to assist in the recovery of damaged ecosystems. However, in the marine environment, success in restoration activities has been achieved at small spatial scales. We should not forget that it is necessary to identify the different causes and the driving forces of human impacts, as well as their consequences in a DPSIR (Driving Forces, Pressures, State, Impact, Responses) methodological approach to analyze the factors and relationships that have an effect on the environment. Ecological restoration is not an easy science but operational solutions do exist and have shown promising results.

In addition to actions to combat pollution and to avoid degradation of coastal habitats, ecological restoration makes it possible to support the reconquest of aquatic environments by restoring ecological functions altered or destroyed by human actions. In this sense, it is new hope for improving the status of the seas and oceans.

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This chapter, particularly the "Introduction" and "A way forward" subchapter is based on Lenfant et al. (2015). Ecological restoration of nurseries in shallow coastal areas of the Mediterranean. Guidelines and Principles. 93 p. This document was made as a deliverable from a 2-years project named DRIVER led by CEFREM labs, ECOCEAN Company, and Agence de l'Eau Rhône Méditerranée Corse. Some parts of this document are summed up in this chapter and could show similarities with the original and exhaustive document. Authors agreed on that and recommend more details regarding some notion to look at the 93 pages document translated in French and English.

Glossary

Ecological engineering An intervention process used to assist in the regeneration of an ecosystem damaged through human impacts. This may include the introduction and use of living organisms or other biological materials—even water and earth—to solve socio-economic and environmental problems. As for any engineering activity, special attention is paid to the effectiveness of the work in economic terms.

Shallow coastal Those areas extend from 0 to 20 m in-depth and have a multitude of habitats including seagrass meadows, sandy and rocky areas, and artificial habitats (like seawalls or port infrastructure). Thanks to this diversity, a lot of marine species at different stages of development (from new recruits to adults) take shelter in these habitats. Some habitats have crucial importance for the development of young fish (postlarvae and juveniles) and are called "nurseries." They present specific characteristics such as providing adapted food to the needs of fish and protecting them from predators. Coastal nurseries potentially include all coastal habitats, depending on the species and the time of year.

Ecosystem services Ecosystems, by their different functions, provide multiple high-value goods and services to humankind. These are named ecosystem services. The quantity and quality of goods and services are in inverse proportion to the degradation status of these ecosystems. Examples of certain services and their potential benefits are listed below.

Ecosystem services	Examples	Potential benefits
Provisioning	Food provisioning (fish, shellfish)	Protein, preservation of economic activities
Regulation	Protection from erosion, storm damage, etc.	Protections of people and goods
Socio-cultural	tourism, recreational activities and sport (diving, sailing)	Well-being
	Development of knowledge (centers, school visits)	Sensibilization

Restoration versus mitigation These are two distinct actions: restoration is used to improve ecosystem status, by reinstating some functions once pressures are under control, at the same location where degradation occurred. Mitigation is used to offset current or future degradation through positive actions on the concerned environment or in another location. Mitigation accepts or at least implies that the environment in question is to be degraded. However, its main principle is that, whenever possible, it is better to not degrade in order to not have to restore aquatic ecosystems.

Ecological functions Ecological functions are defined as the biological processes that enable the functioning and maintenance of ecosystems (ecological vision). They are often associated with habitats that can be qualified as essential habitats when the function is essential to completing the life cycle of a species.

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Coastal Habitat Conservation

New Perspectives and Sustainable Development of Biodiversity in the Anthropocene

Edited by Free Espinosa

Coastal Habitat Conservation: New Perspectives and Sustainable Development of Biodiversity in the Anthropocene offers the latest research and approaches to biodiversity conservation in coastal areas. It synthesizes the background of foundational conservation views and provides new perspectives and recent strategies within a sustainable development context for coastal species and organic life.

Written by a team of international authors with expertise in wide-ranging issues of biodiversity conservation, this book analyzes the challenges of conserving marine habitats and species that humanity faces in the Anthropocene era. It explores emerging and unforeseen impacts within a changing world, specifically, the marine-based conservation in the context of global change, coastal urbanization, and mitigation of its environmental impacts, aquaculture, marine bioinvasions, conservation strategies for of out-of-sight communities such as caves, habitat restoration, and the citizen science and its challenging role in monitoring and conservation.

This book is an important resource for researchers, ecologists, and conservationists who wish to understand the environmental impacts in a changing world and the challenges that they represent and the tools to face them.

Key Features

- Discusses different strategies to deal with various biological and ecological impacts on coastal marine species and habitats
- Offers new insights into the practices of marine conservation in the Anthropocene era
- Led by editors whose expertise includes marine biodiversity, marine ecology, and marine habitat conservation

About the Editor

Prof. Free Espinosa currently teaches in the Zoology Department at the University of Seville. He received his PhD in conservation biology of marine invertebrates from the University of Seville. His research expertise includes marine conservation, marine benthic invertebrates on rocky shores, intertidal ecology, marine protected areas, marine environmental monitoring, and marine endangered invertebrate and limpet biology.

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