University of Trieste: GLOBAL CHANGE ECOLOGY a.a. 2019-2020

Conservation & Management in Marine Protected Areas

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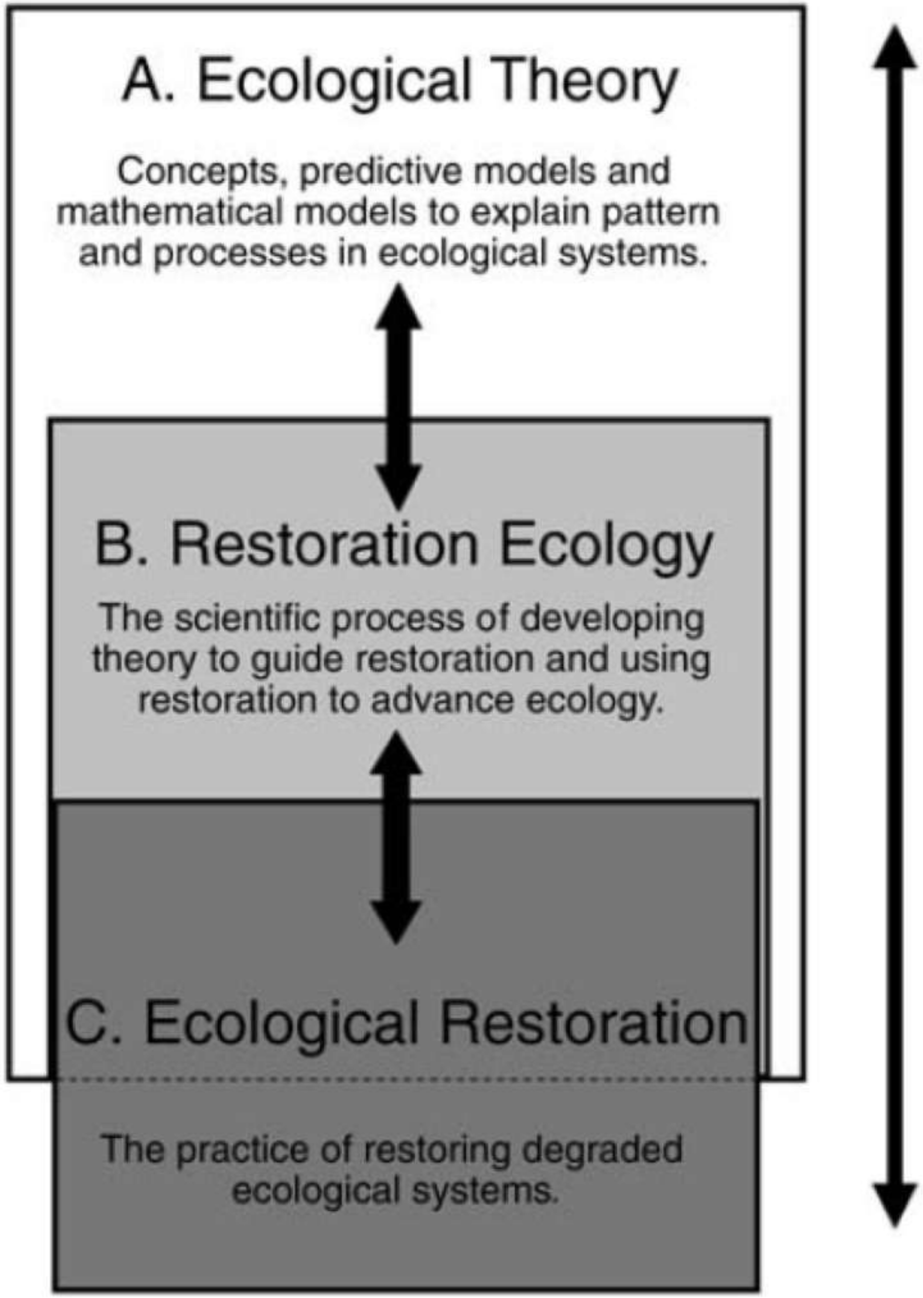
Restoration ecology in marine environments

Restoration ecology and ecological restoration



A. Ecological Theory

Concepts, predictive models and mathematical models to explain pattern and processes in ecological systems.

B. Restoration Ecology

The scientific process of developing theory to guide restoration and using restoration to advance ecology.

C. Ecological Restoration

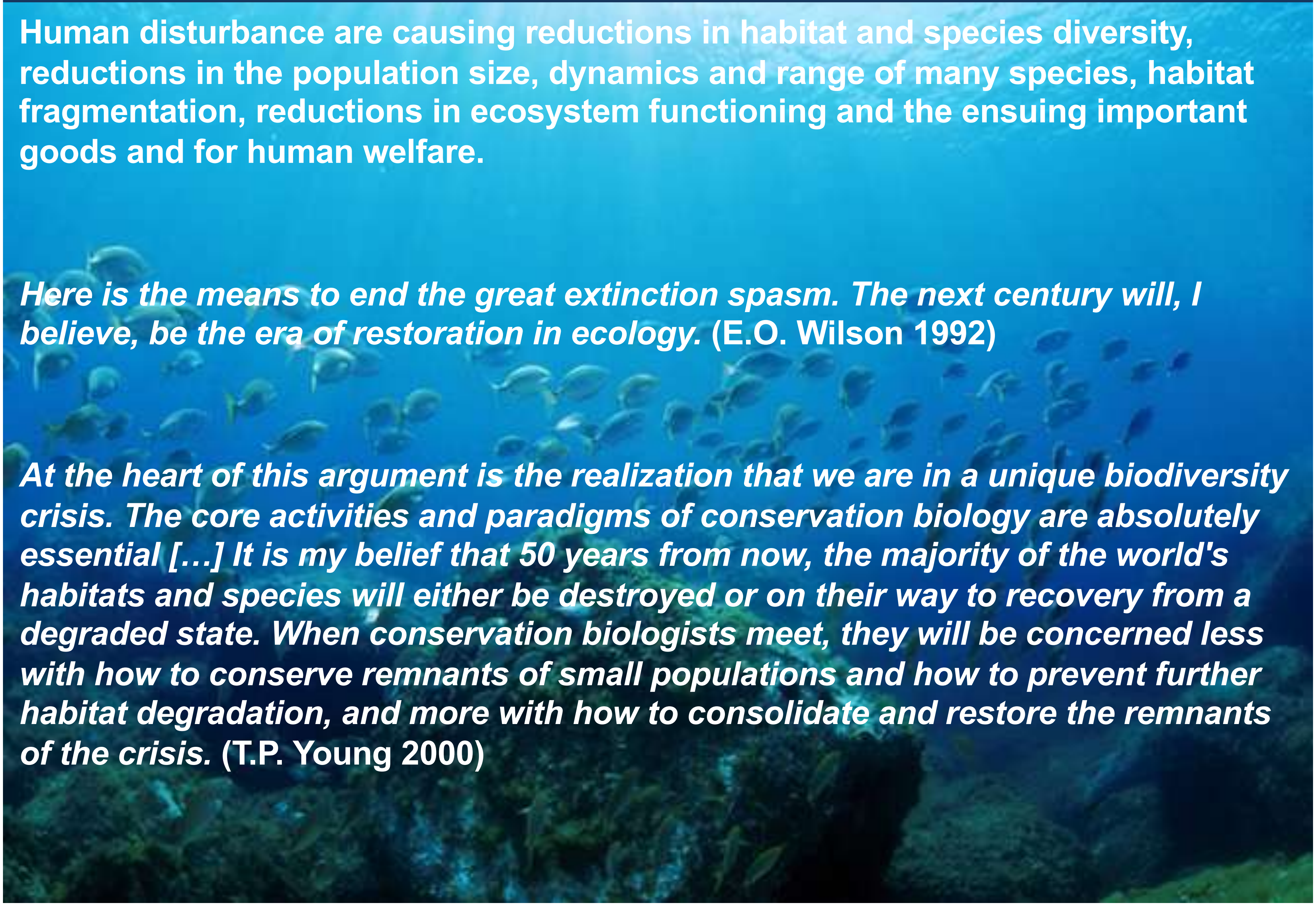
The practice of restoring degraded ecological systems.

Benefits of linkages

- Offers opportunities to study ecosystem elements in a manipulative context
- Offers opportunities to test and expand theories that are central to ecology
- Offers opportunities for ecologists to contribute directly to vital restoration efforts worldwide
- Provides an intellectual framework for restoration
- Clarifies multiple interactions that may operate in even a simple restoration project
- Improves the quality and effectiveness of restoration efforts

Palmer et al 2006

Who need restoration?



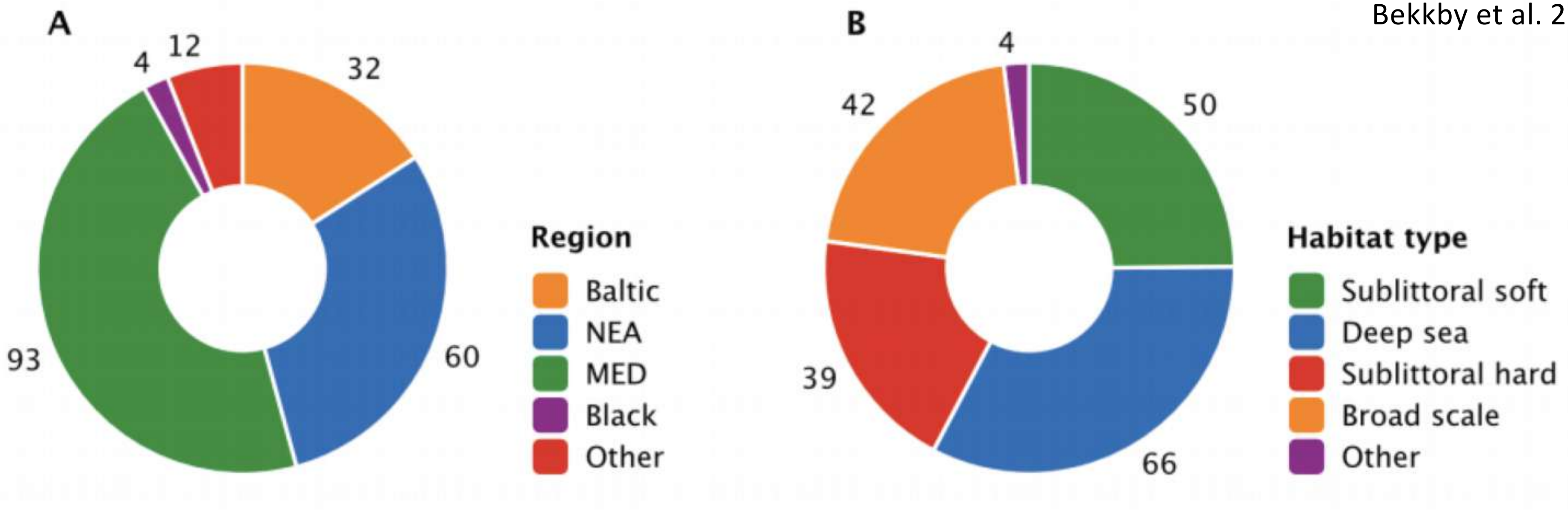
Human disturbance are causing reductions in habitat and species diversity, reductions in the population size, dynamics and range of many species, habitat fragmentation, reductions in ecosystem functioning and the ensuing important goods and for human welfare.

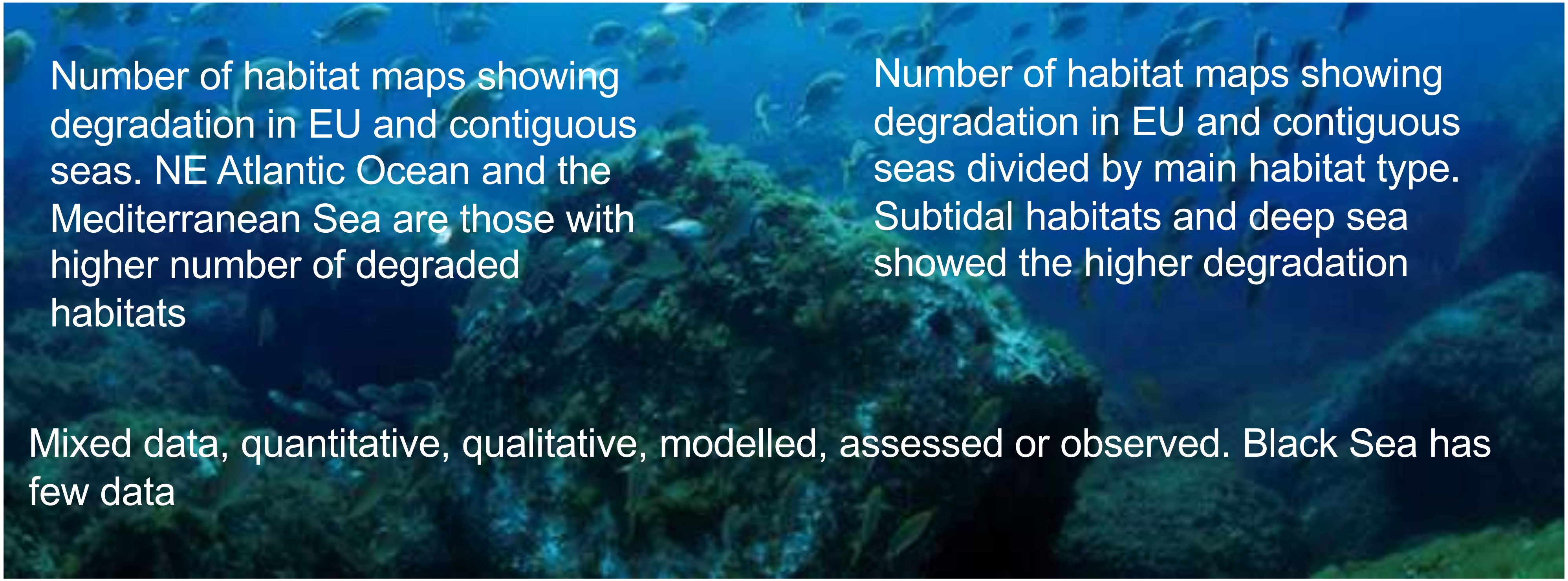
Here is the means to end the great extinction spasm. The next century will, I believe, be the era of restoration in ecology. **(E.O. Wilson 1992)**

At the heart of this argument is the realization that we are in a unique biodiversity crisis. The core activities and paradigms of conservation biology are absolutely essential […] It is my belief that 50 years from now, the majority of the world's habitats and species will either be destroyed or on their way to recovery from a degraded state. When conservation biologists meet, they will be concerned less with how to conserve remnants of small populations and how to prevent further habitat degradation, and more with how to consolidate and restore the remnants of the crisis. **(T.P. Young 2000)**

Habitat degradation in European Seas

Bekkby et al. 2017





Number of habitat maps showing degradation in EU and contiguous seas. NE Atlantic Ocean and the Mediterranean Sea are those with higher number of degraded habitats

Number of habitat maps showing degradation in EU and contiguous seas divided by main habitat type. Subtidal habitats and deep sea showed the higher degradation

Mixed data, quantitative, qualitative, modelled, assessed or observed. Black Sea has few data

Activities related to degradation

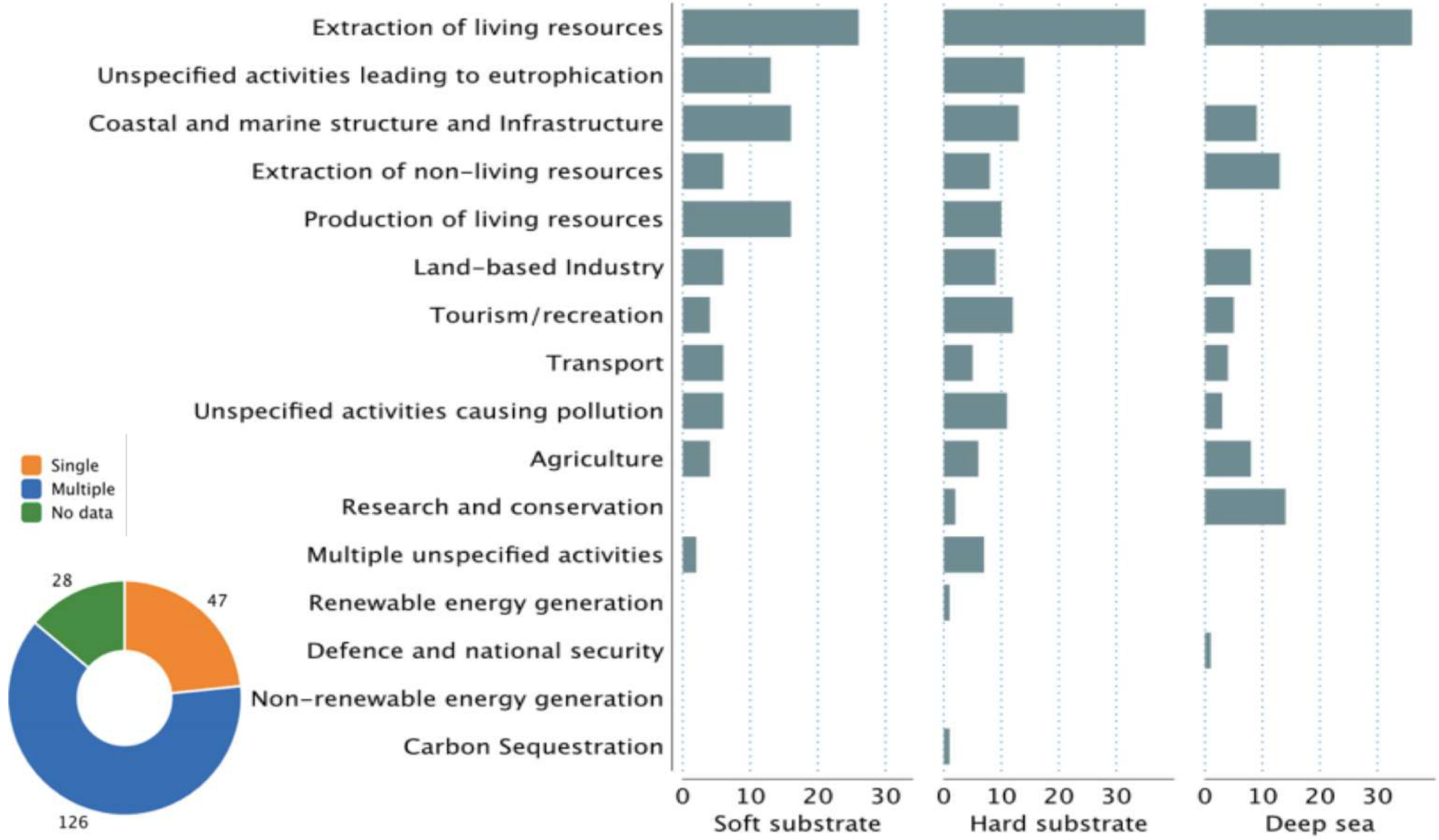
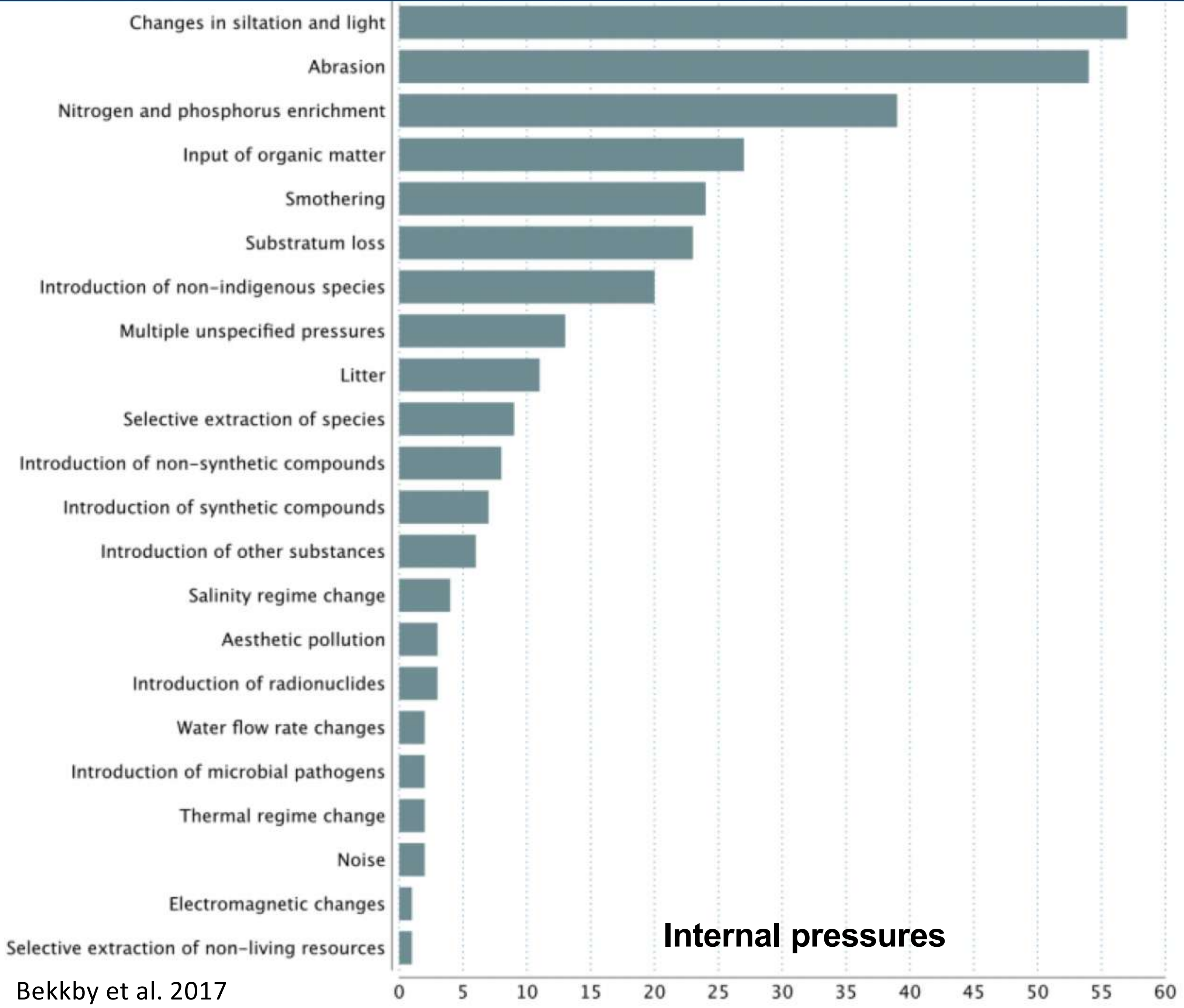


Figure 3.39. Activities entries by major habitat type in the degraded habitat map entries in decre

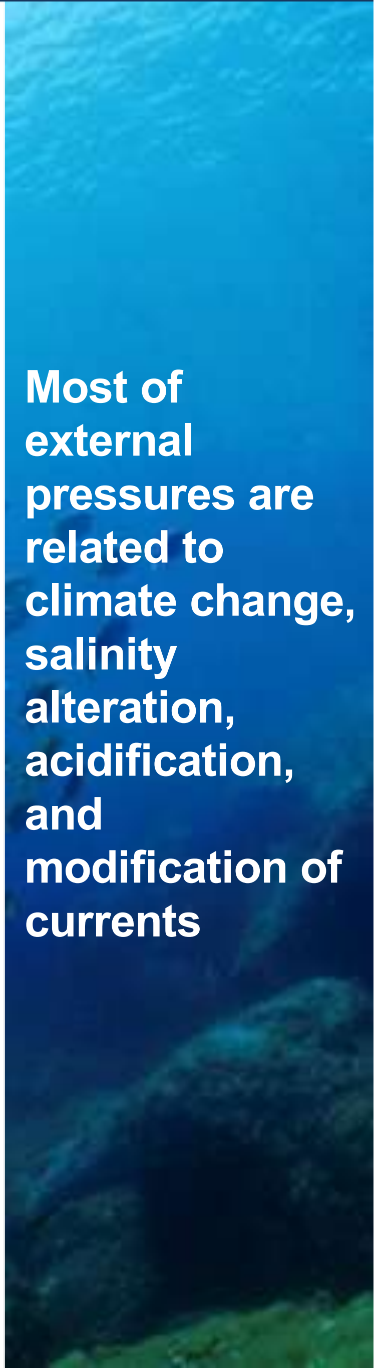
Bekkby et al. 2017

Pressures



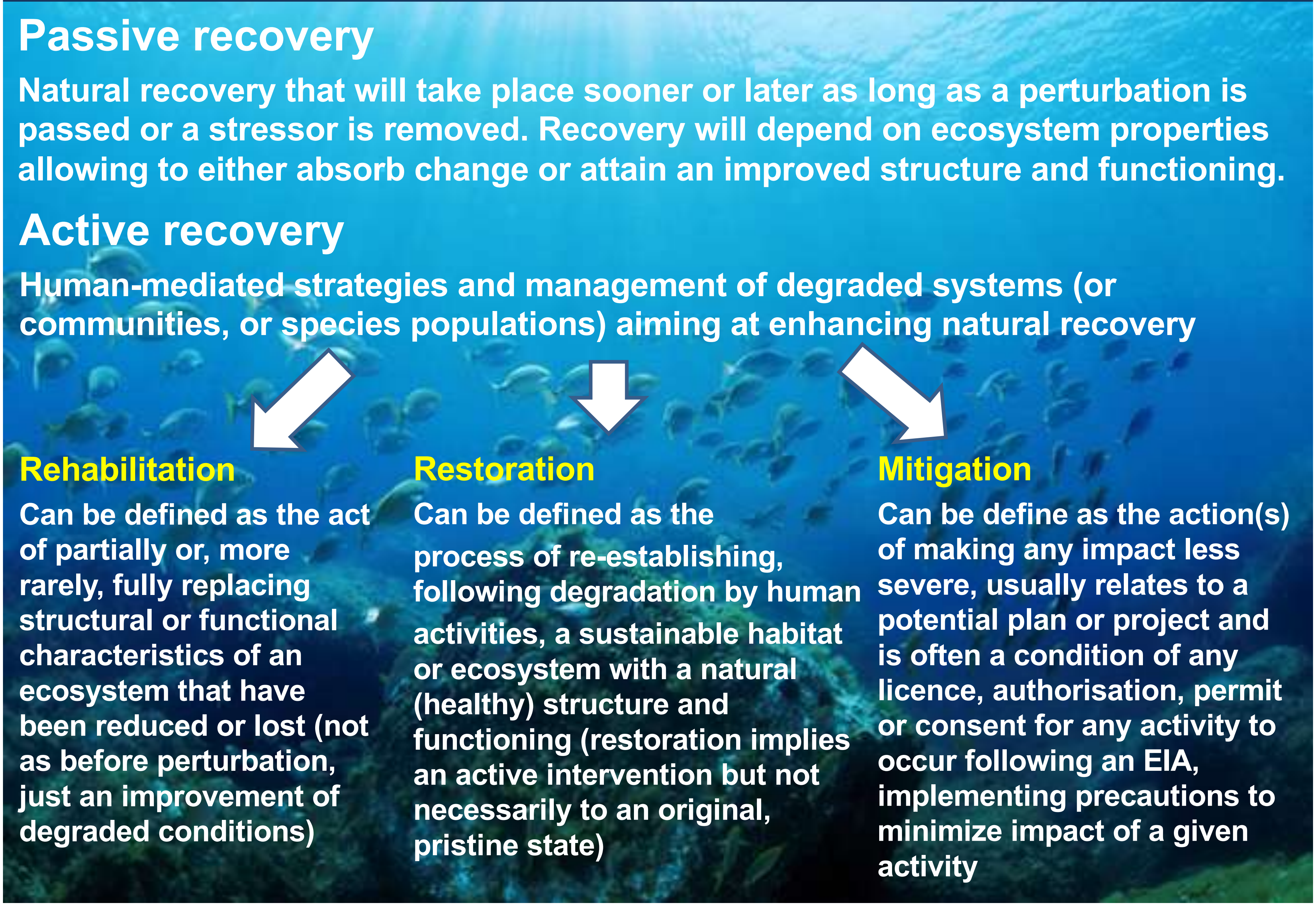
Internal pressures

Bekkby et al. 2017



Most of external pressures are related to climate change, salinity alteration, acidification, and modification of currents

Concepts and definitions



Passive recovery

Natural recovery that will take place sooner or later as long as a perturbation is passed or a stressor is removed. Recovery will depend on ecosystem properties allowing to either absorb change or attain an improved structure and functioning.

Active recovery

Human-mediated strategies and management of degraded systems (or communities, or species populations) aiming at enhancing natural recovery

Rehabilitation

Can be defined as the act of partially or, more rarely, fully replacing structural or functional characteristics of an ecosystem that have been reduced or lost (not as before perturbation, just an improvement of degraded conditions)

Restoration

Can be defined as the process of re-establishing, following degradation by human activities, a sustainable habitat or ecosystem with a natural (healthy) structure and functioning (restoration implies an active intervention but not necessarily to an original, pristine state)

Mitigation

Can be define as the action(s) of making any impact less severe, usually relates to a potential plan or project and is often a condition of any licence, authorisation, permit or consent for any activity to occur following an EIA, implementing precautions to minimize impact of a given activity

Concepts and definitions

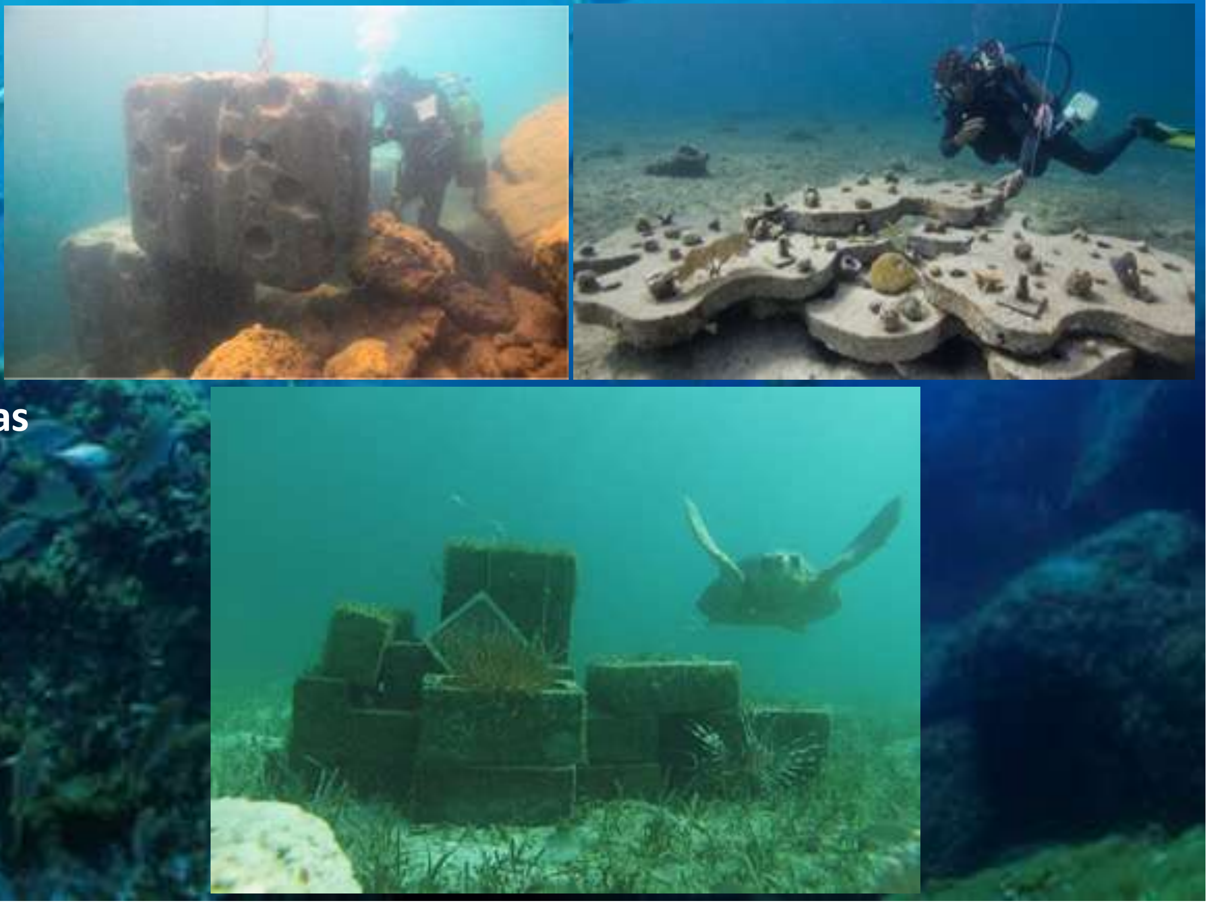
Compensation

Ecological compensation is a positive conservation action that is required to counterbalance ecological values lost in the context of development or resource use, and is an intentional form of trade-off. Trade-offs are determined through EIA, which provides a framework for decision-making in relation to projects with adverse environmental effects.

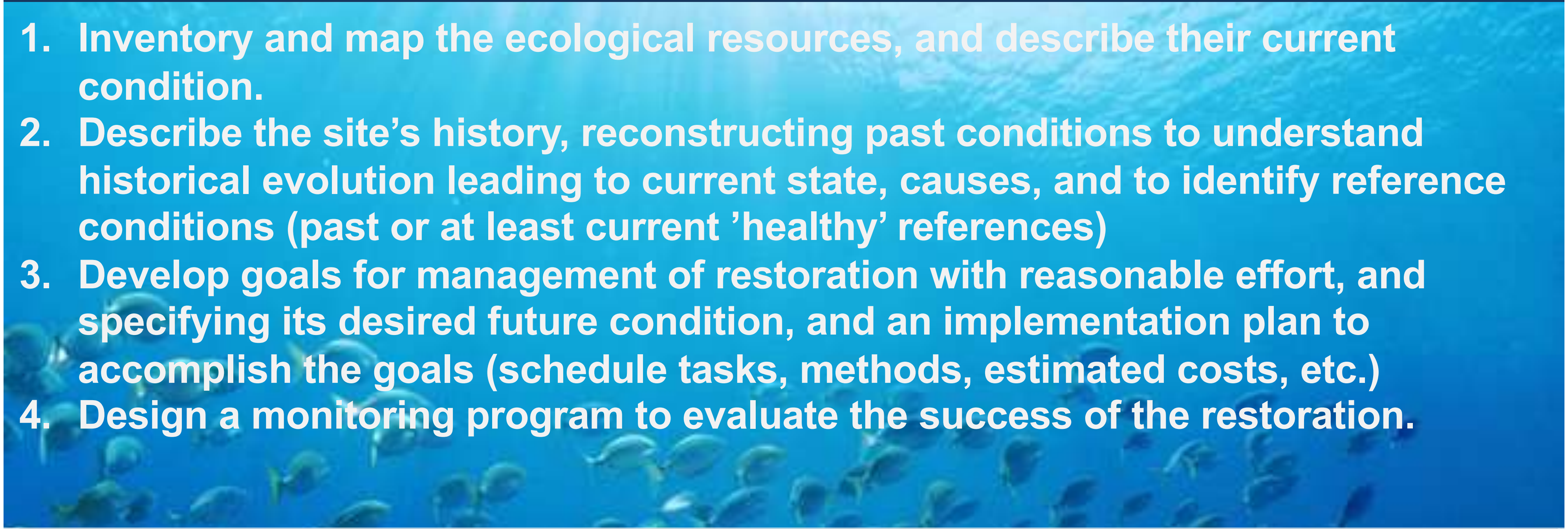
Economic (pay for damage, e.g. firshermen)
Enhancing goods or services in other areas or in the disturbed area, which can be different from those altered
Re-creating destroyed habitat elsewere
Supporting conservation actions, etc.

Habitat enhancement and creation

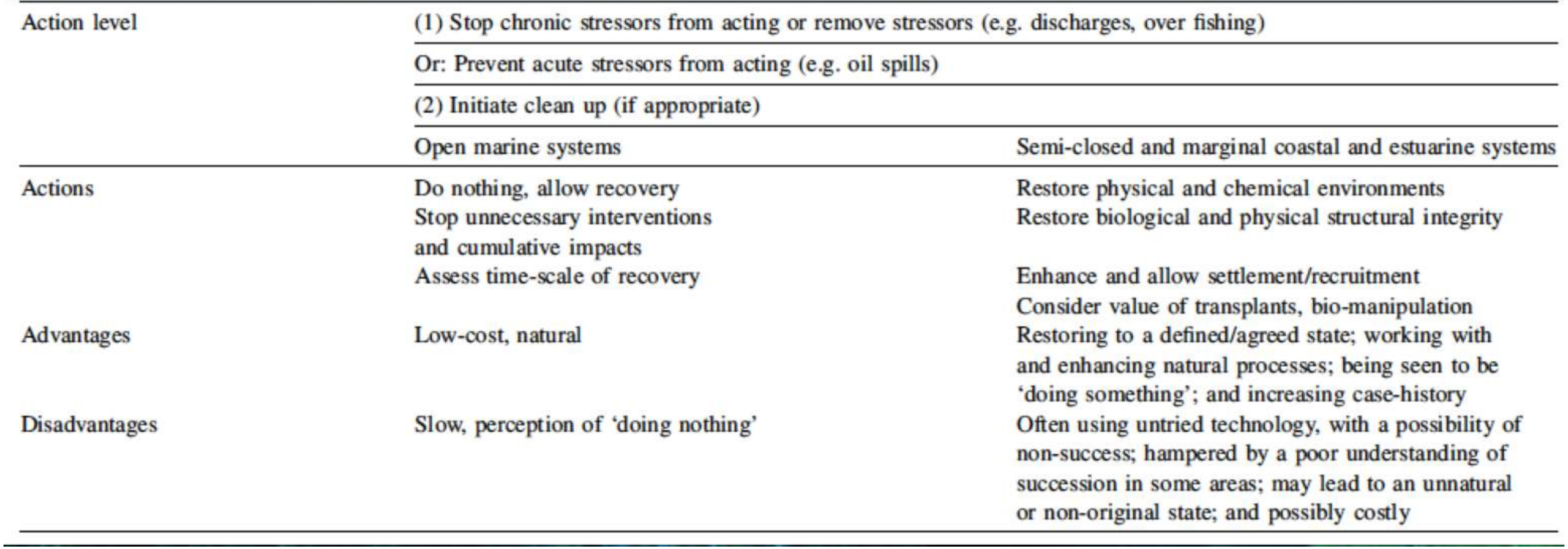
Habitat enhancement can simply be defined as a management approach which directly or indirectly increases the ecological value, goods and services of the habitat.
Marine habitat creation is an anthropogenic intervention which produces a habitat not previously there.



Principles and actions

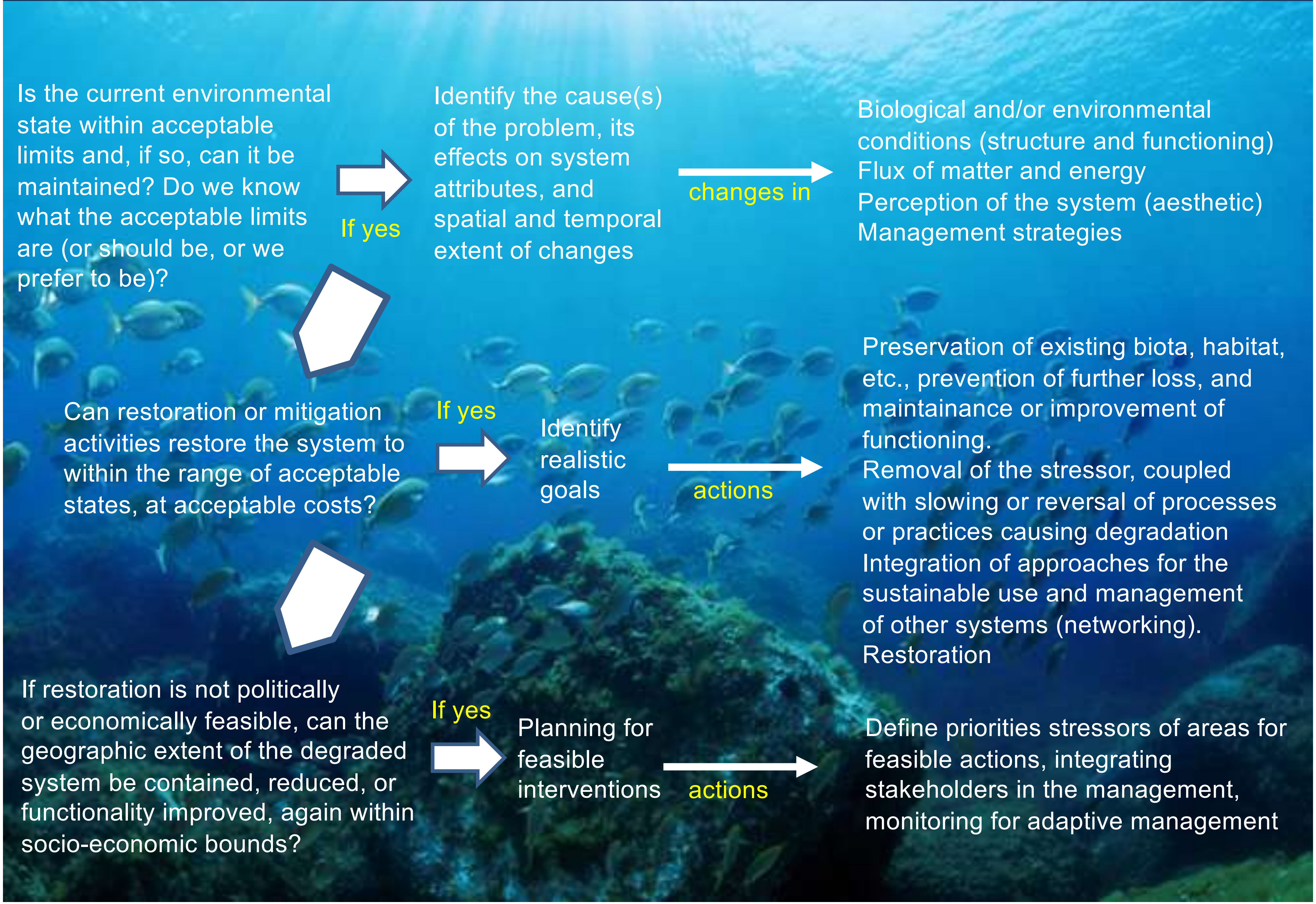


1. Inventory and map the ecological resources, and describe their current condition.
2. Describe the site's history, reconstructing past conditions to understand historical evolution leading to current state, causes, and to identify reference conditions (past or at least current 'healthy' references)
3. Develop goals for management of restoration with reasonable effort, and specifying its desired future condition, and an implementation plan to accomplish the goals (schedule tasks, methods, estimated costs, etc.)
4. Design a monitoring program to evaluate the success of the restoration.



Action level	(1) Stop chronic stressors from acting or remove stressors (e.g. discharges, over fishing)	
	Or: Prevent acute stressors from acting (e.g. oil spills)	
	(2) Initiate clean up (if appropriate)	
	Open marine systems	Semi-closed and marginal coastal and estuarine systems
Actions	Do nothing, allow recovery Stop unnecessary interventions and cumulative impacts Assess time-scale of recovery	Restore physical and chemical environments Restore biological and physical structural integrity Enhance and allow settlement/recruitment Consider value of transplants, bio-manipulation
Advantages	Low-cost, natural	Restoring to a defined/agreed state; working with and enhancing natural processes; being seen to be 'doing something'; and increasing case-history
Disadvantages	Slow, perception of 'doing nothing'	Often using untried technology, with a possibility of non-success; hampered by a poor understanding of succession in some areas; may lead to an unnatural or non-original state; and possibly costly

Framework



Is the current environmental state within acceptable limits and, if so, can it be maintained? Do we know what the acceptable limits are (or should be, or we prefer to be)?

If yes

Identify the cause(s) of the problem, its effects on system attributes, and spatial and temporal extent of changes

changes in

Biological and/or environmental conditions (structure and functioning)
Flux of matter and energy
Perception of the system (aesthetic)
Management strategies

Can restoration or mitigation activities restore the system to within the range of acceptable states, at acceptable costs?

If yes

Identify realistic goals

actions

Preservation of existing biota, habitat, etc., prevention of further loss, and maintainance or improvement of functioning.
Removal of the stressor, coupled with slowing or reversal of processes or practices causing degradation
Integration of approaches for the sustainable use and management of other systems (networking).
Restoration

If restoration is not politically or economically feasible, can the geographic extent of the degraded system be contained, reduced, or functionality improved, again within socio-economic bounds?

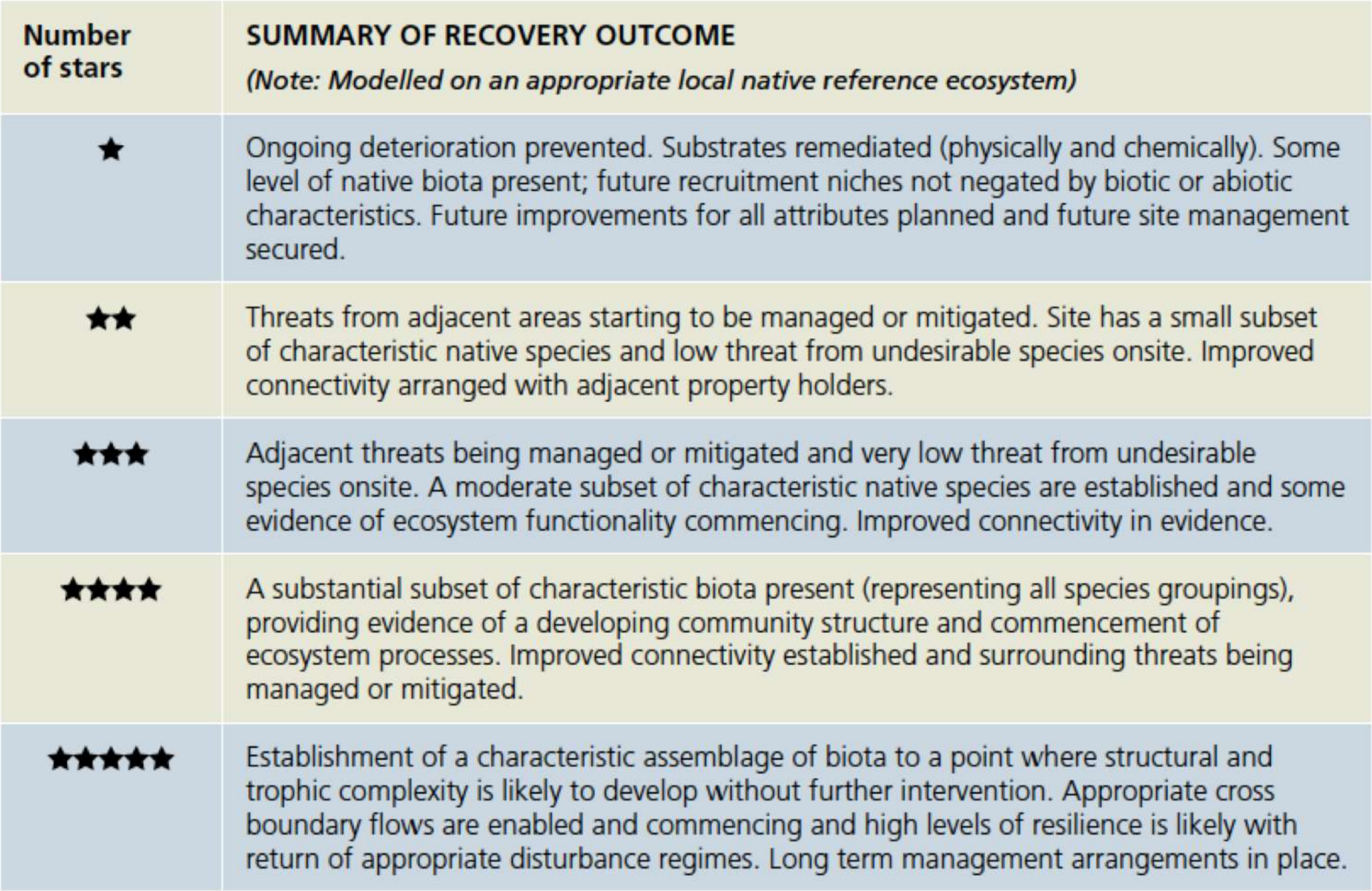
If yes

Planning for feasible interventions

actions

Define priorities stressors of areas for feasible actions, integrating stakeholders in the management, monitoring for adaptive management

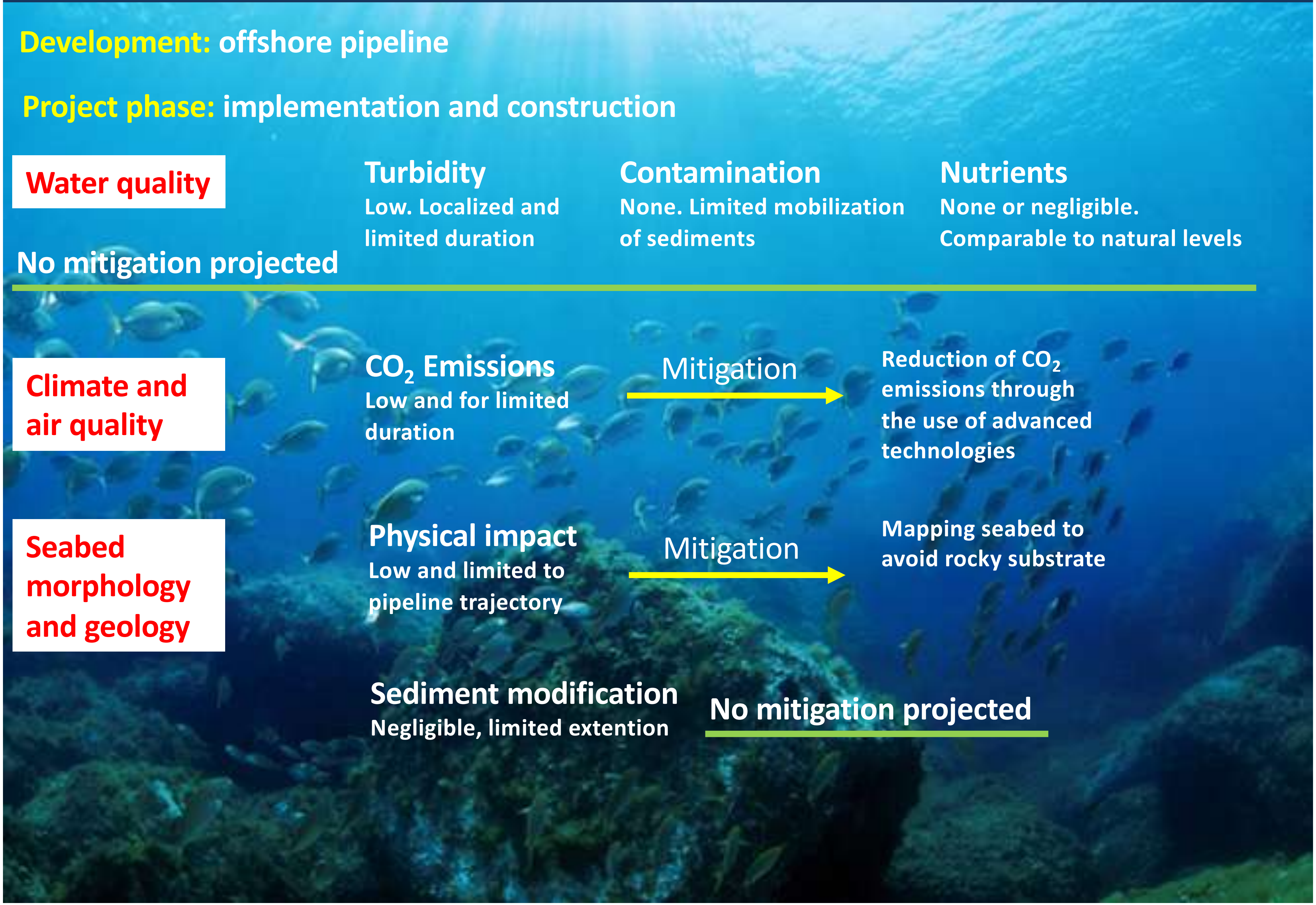
Evaluation



Number of stars	SUMMARY OF RECOVERY OUTCOME *(Note: Modelled on an appropriate local native reference ecosystem)*
★	Ongoing deterioration prevented. Substrates remediated (physically and chemically). Some level of native biota present; future recruitment niches not negated by biotic or abiotic characteristics. Future improvements for all attributes planned and future site management secured.
★★	Threats from adjacent areas starting to be managed or mitigated. Site has a small subset of characteristic native species and low threat from undesirable species onsite. Improved connectivity arranged with adjacent property holders.
★★★	Adjacent threats being managed or mitigated and very low threat from undesirable species onsite. A moderate subset of characteristic native species are established and some evidence of ecosystem functionality commencing. Improved connectivity in evidence.
★★★★	A substantial subset of characteristic biota present (representing all species groupings), providing evidence of a developing community structure and commencement of ecosystem processes. Improved connectivity established and surrounding threats being managed or mitigated.
★★★★★	Establishment of a characteristic assemblage of biota to a point where structural and trophic complexity is likely to develop without further intervention. Appropriate cross boundary flows are enabled and commencing and high levels of resilience is likely with return of appropriate disturbance regimes. Long term management arrangements in place.

SER 2016

Mitigation: an hypothetic example



Development: offshore pipeline

Project phase: implementation and construction

Water quality

Turbidity
Low. Localized and limited duration

Contamination
None. Limited mobilization of sediments

Nutrients
None or negligible. Comparable to natural levels

No mitigation projected

Climate and air quality

CO_2 Emissions
Low and for limited duration

Mitigation →

Reduction of CO_2 emissions through the use of advanced technologies

Seabed morphology and geology

Physical impact
Low and limited to pipeline trajectory

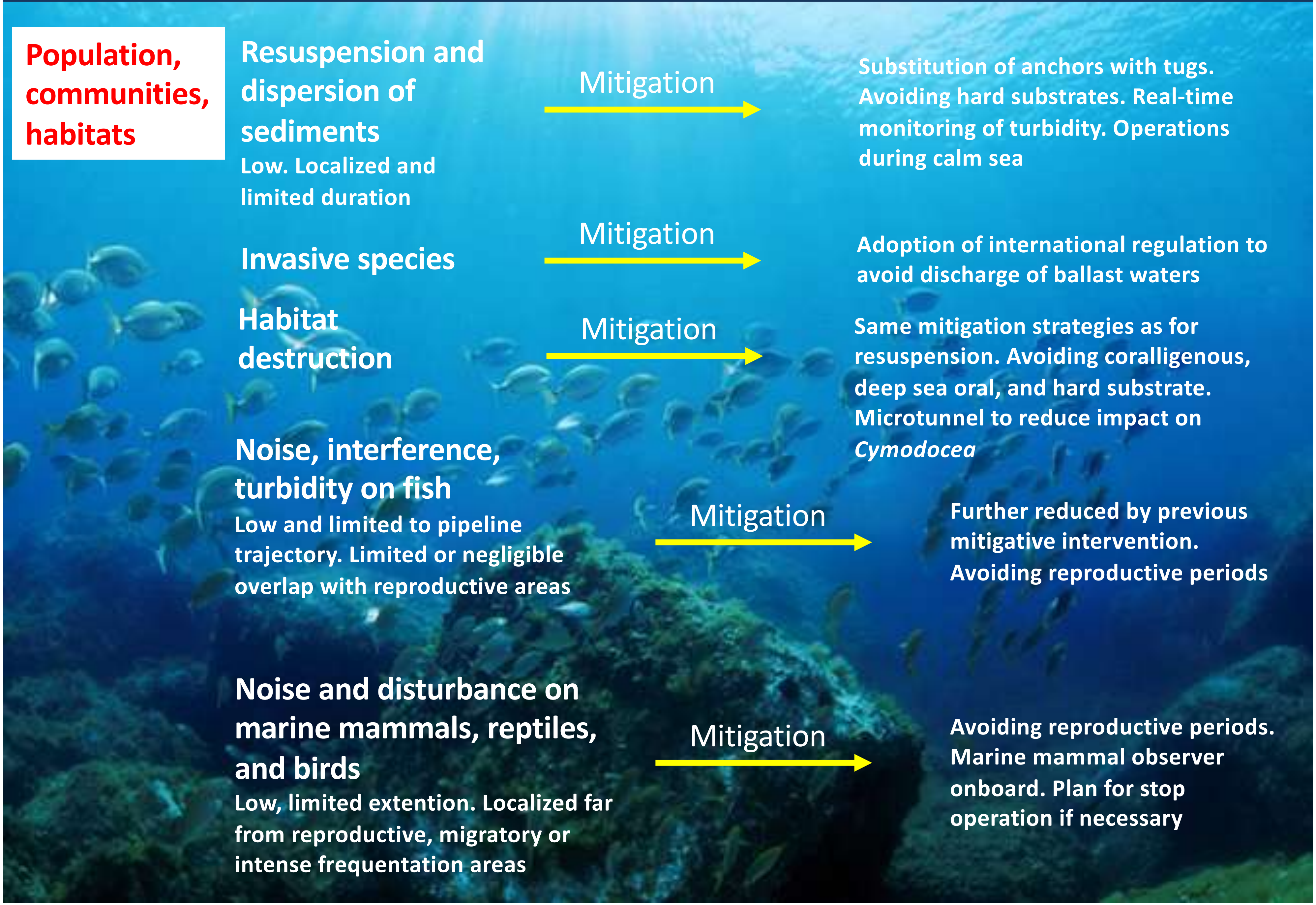
Mitigation →

Mapping seabed to avoid rocky substrate

Sediment modification
Negligible, limited extention

No mitigation projected

Mitigation: an hypothetic example



Population, communities, habitats

Resuspension and dispersion of sediments

Low. Localized and limited duration

Mitigation →

Substitution of anchors with tugs. Avoiding hard substrates. Real-time monitoring of turbidity. Operations during calm sea

Invasive species

Mitigation →

Adoption of international regulation to avoid discharge of ballast waters

Habitat destruction

Mitigation →

Same mitigation strategies as for resuspension. Avoiding coralligenous, deep sea oral, and hard substrate. Microtunnel to reduce impact on *Cymodocea*

Noise, interference, turbidity on fish

Low and limited to pipeline trajectory. Limited or negligible overlap with reproductive areas

Mitigation →

Further reduced by previous mitigative intervention. Avoiding reproductive periods

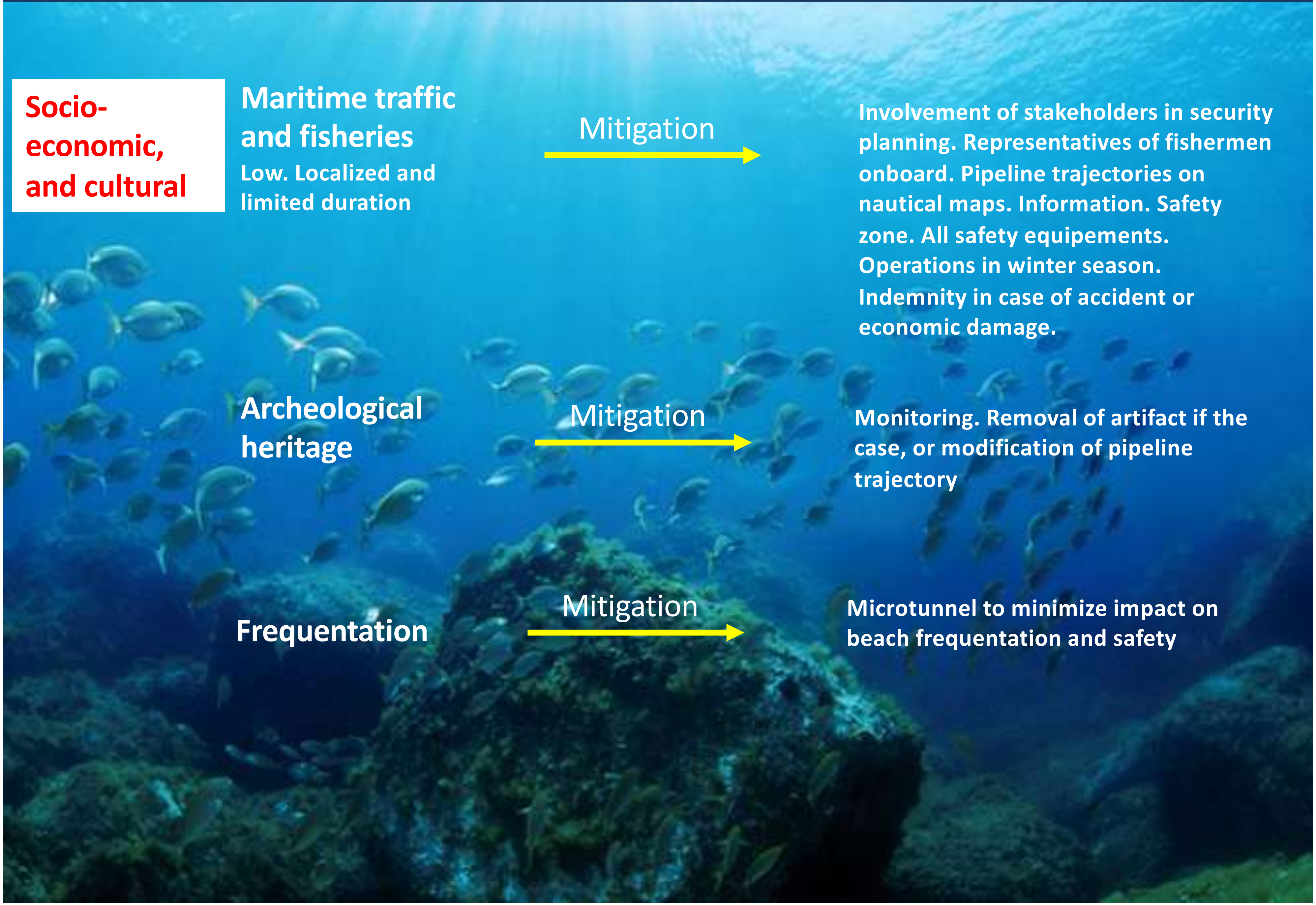
Noise and disturbance on marine mammals, reptiles, and birds

Low, limited extention. Localized far from reproductive, migratory or intense frequentation areas

Mitigation →

Avoiding reproductive periods. Marine mammal observer onboard. Plan for stop operation if necessary

Mitigation: an hypothetic example



Socio-economic, and cultural

Maritime traffic and fisheries

Low. Localized and limited duration

Mitigation →

Involvement of stakeholders in security planning. Representatives of fishermen onboard. Pipeline trajectories on nautical maps. Information. Safety zone. All safety equipements. Operations in winter season. Indemnity in case of accident or economic damage.

Archeological heritage

Mitigation →

Monitoring. Removal of artifact if the case, or modification of pipeline trajectory

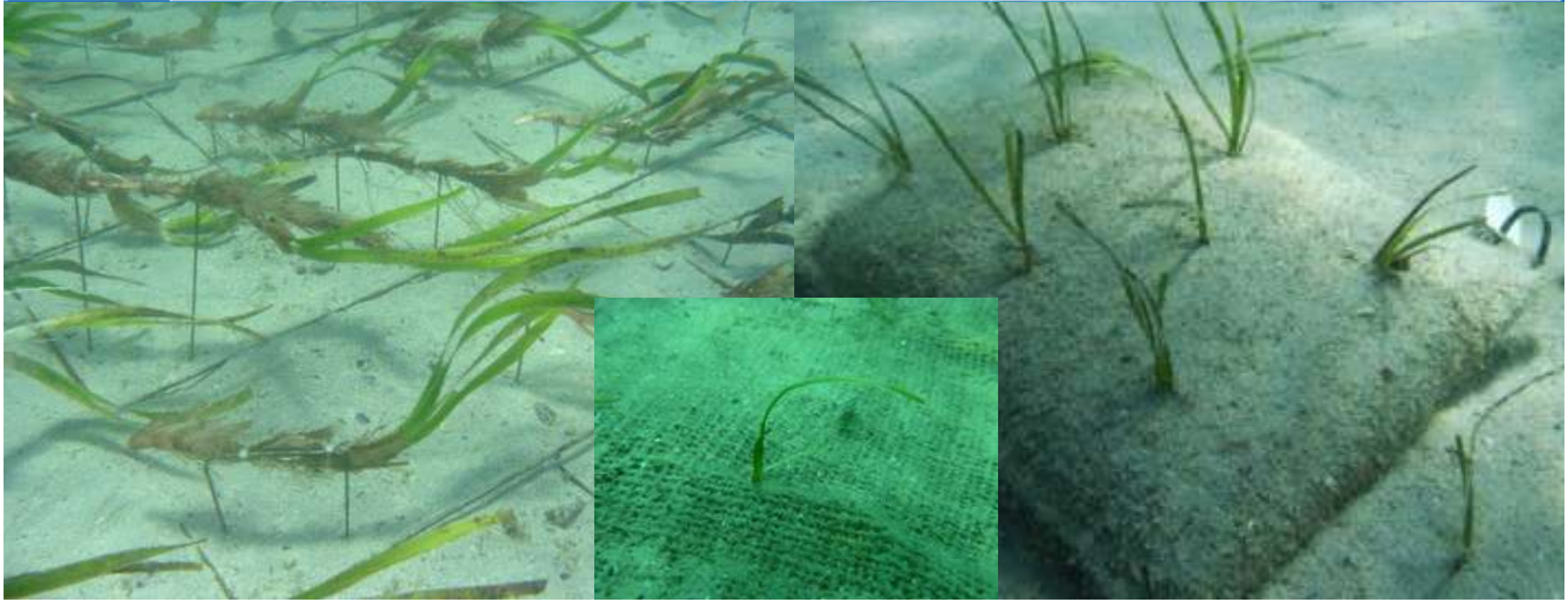
Frequentation

Mitigation →

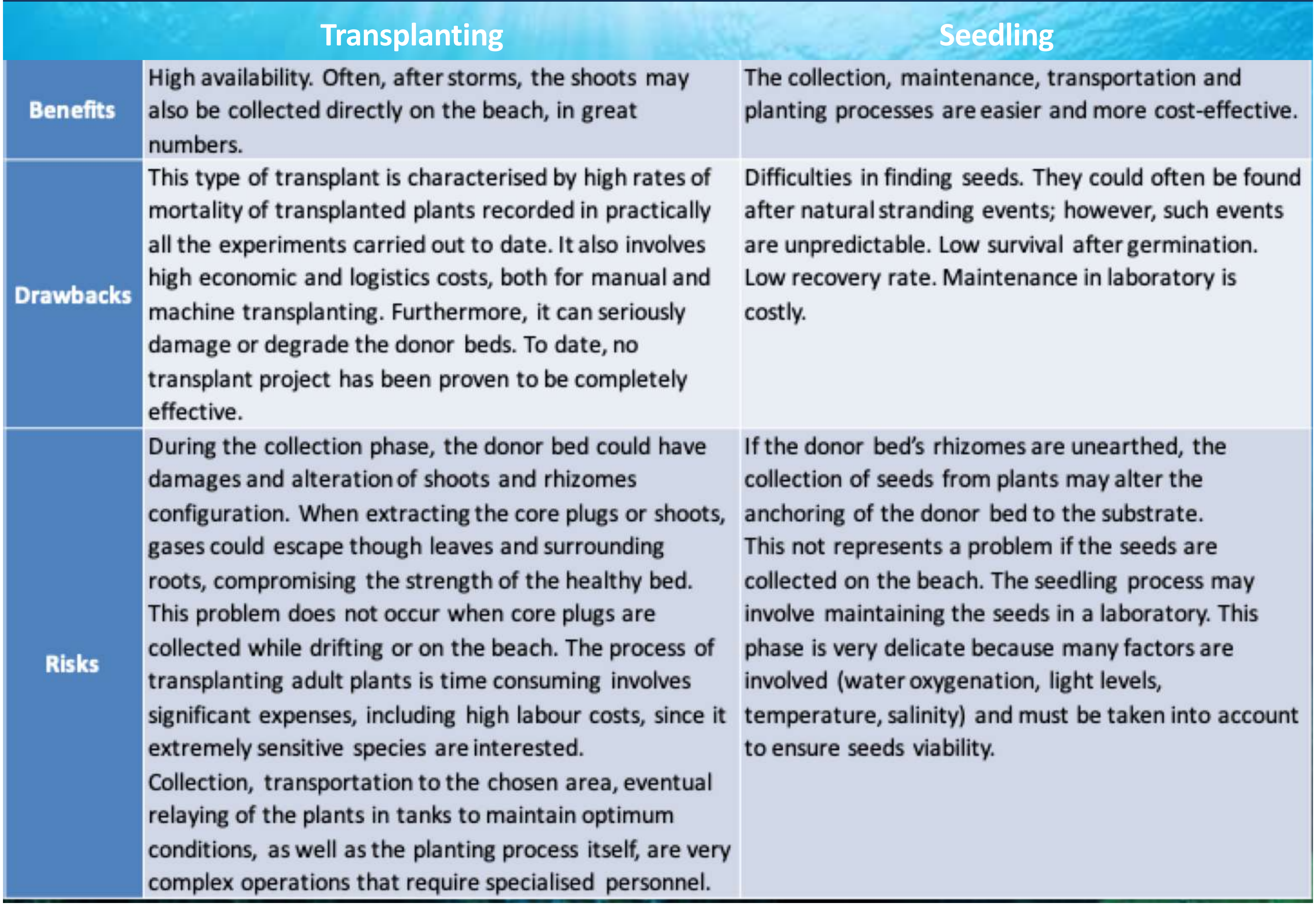
Microtunnel to minimize impact on beach frequentation and safety

Seagrass restoration techniques

	Technique	
	Transplanting	Seedling
Description	Traditionally, this is the most widely used method, probably because habitats are immediately re-established. This technique focuses on collecting core plugs, or adult plants, from healthy beds, mature plants with rhizomes and adhered substrate, or shoots without adhered substrate, for subsequent transplant into degraded areas. The core plugs are either inserted directly into the substrate or planted by means of a biodegradable support. The shoots may be weaved on to grids or frames, preferably made of a biodegradable material, or attached directly to the substrate.	Once the seeds have been collected directly on the bed, they may be planted directly in the area to be restored or maintained and treated in a laboratory to promote or even induce germination (by means of temperature and salinity variations) before being taken to sea. Eventually, large quantities of seeds may reach the beach, where they may be collected. However, this type of collection cannot be predicted.



Seagrass restoration techniques



	Transplanting	Seedling
Benefits	High availability. Often, after storms, the shoots may also be collected directly on the beach, in great numbers.	The collection, maintenance, transportation and planting processes are easier and more cost-effective.
Drawbacks	This type of transplant is characterised by high rates of mortality of transplanted plants recorded in practically all the experiments carried out to date. It also involves high economic and logistics costs, both for manual and machine transplanting. Furthermore, it can seriously damage or degrade the donor beds. To date, no transplant project has been proven to be completely effective.	Difficulties in finding seeds. They could often be found after natural stranding events; however, such events are unpredictable. Low survival after germination. Low recovery rate. Maintenance in laboratory is costly.
Risks	During the collection phase, the donor bed could have damages and alteration of shoots and rhizomes configuration. When extracting the core plugs or shoots, gases could escape though leaves and surrounding roots, compromising the strength of the healthy bed. This problem does not occur when core plugs are collected while drifting or on the beach. The process of transplanting adult plants is time consuming involves significant expenses, including high labour costs, since it extremely sensitive species are interested. Collection, transportation to the chosen area, eventual relaying of the plants in tanks to maintain optimum conditions, as well as the planting process itself, are very complex operations that require specialised personnel.	If the donor bed's rhizomes are unearthed, the collection of seeds from plants may alter the anchoring of the donor bed to the substrate. This not represents a problem if the seeds are collected on the beach. The seedling process may involve maintaining the seeds in a laboratory. This phase is very delicate because many factors are involved (water oxygenation, light levels, temperature, salinity) and must be taken into account to ensure seeds viability.

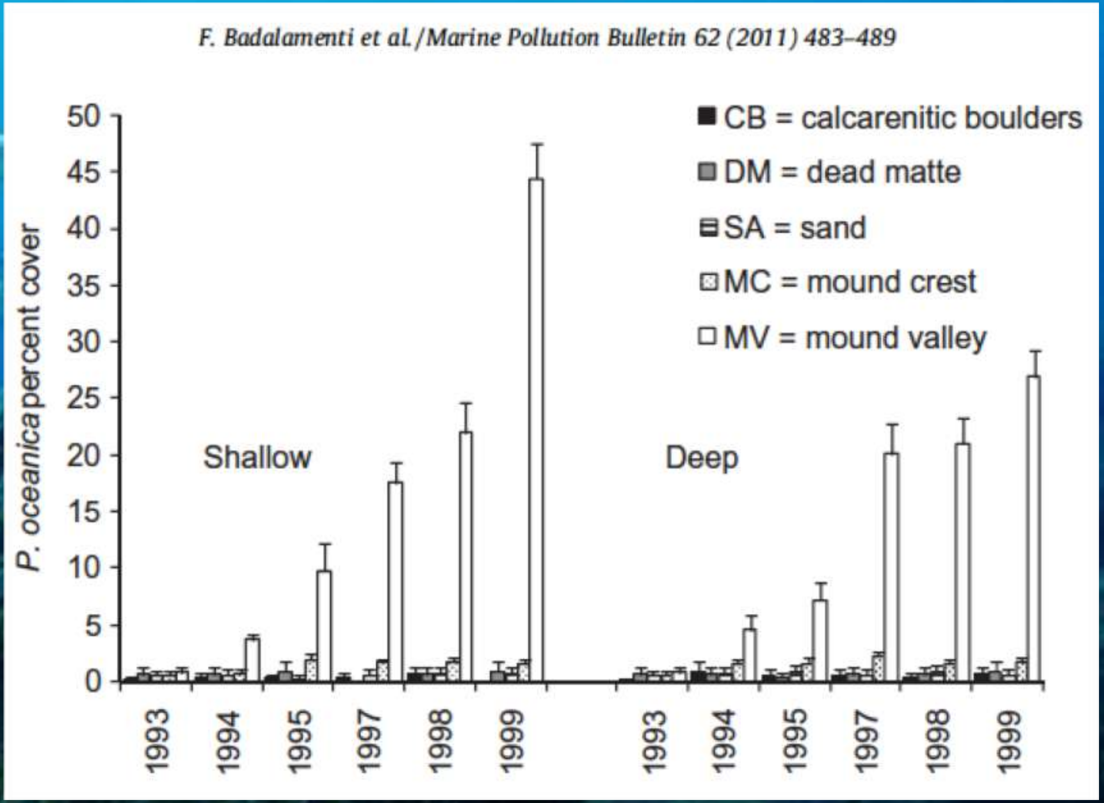
Summary for seagrass

Seagrass restoration currently remains a costly somewhat developmental process. Although innovative techniques have been developed, and improvements to the success of restoring some seagrass species have been made.

Seagrass restoration techniques have still only been documented to successfully replace small areas of seagrasses and the restoration of several hundred hectares of seagrass is still to be realised. Seagrass transplanting and other restoration techniques have still not been developed to the extent that particular methods could be recommended for different species in different habitats

Use of growth hormones (auxins) to enable *Posidonia* seedlings and cuttings to establish more quickly. But evidence are contrasting among species. (Glasby et al. 2014)

Fertilization seems to help success of transplantation by increasing number of shoots (Balestri and Lardicci (2013)



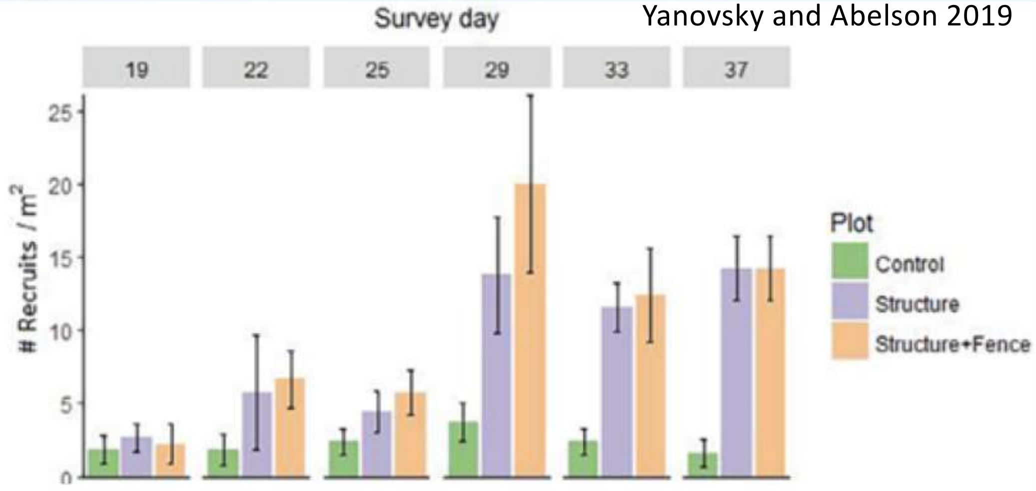
F. Badalamenti et al./Marine Pollution Bulletin 62 (2011) 483–489

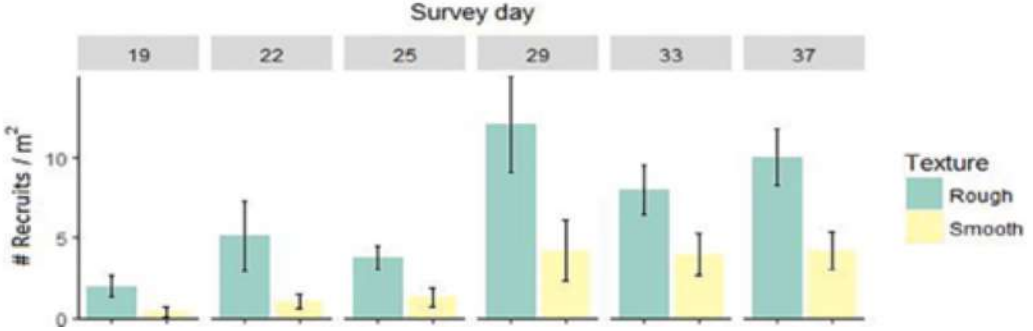
Use of different material could further improve restoration success

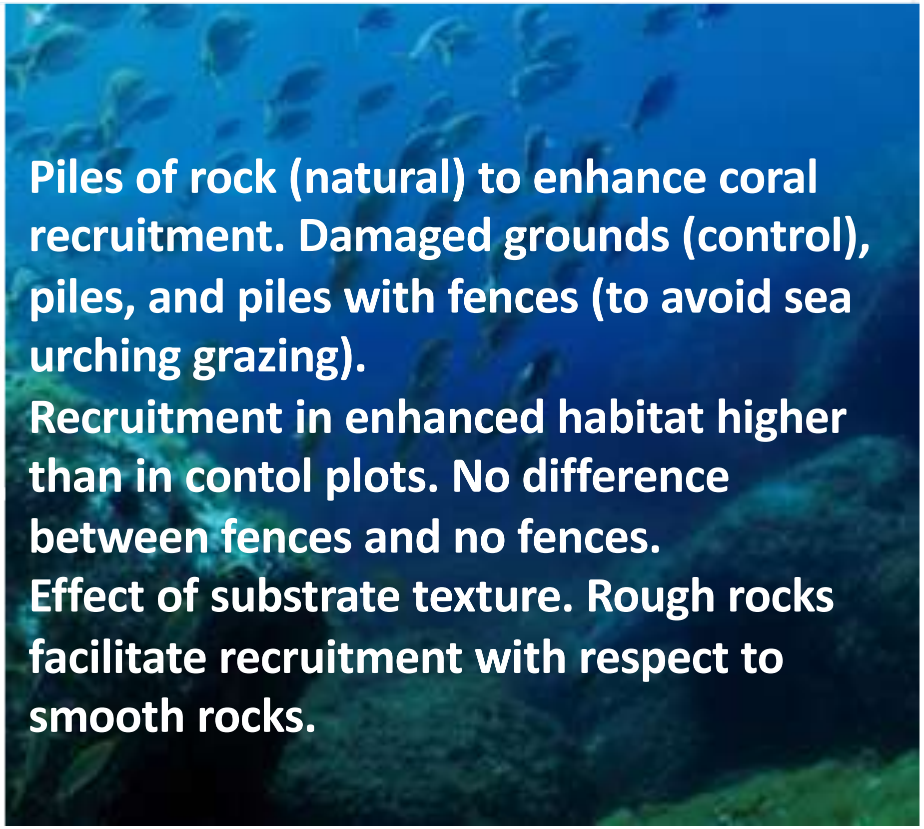
Coral reefs: habitat enhancement

The three different plot treatments on a degraded reef ("the Edge site"): (a) control plot, (b) structure only plot, (c) structure enclosed by a fence

Yanovsky and Abelson 2019





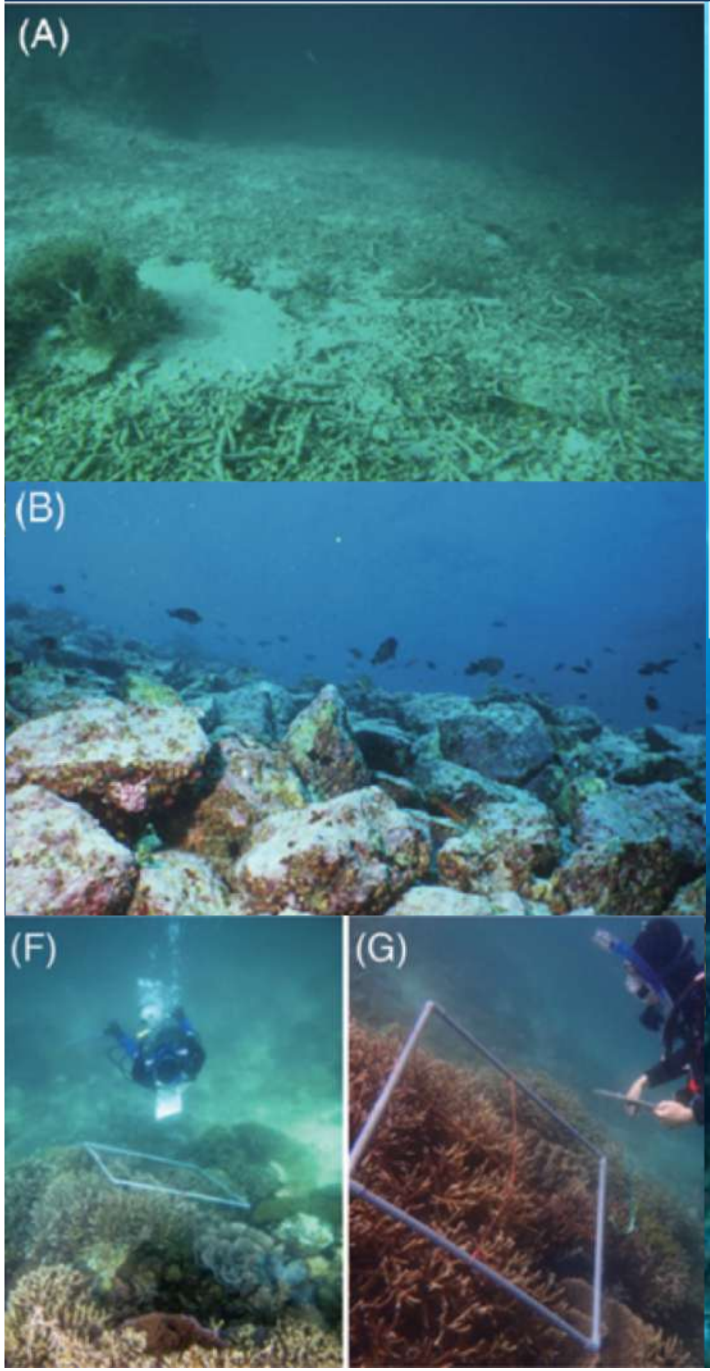


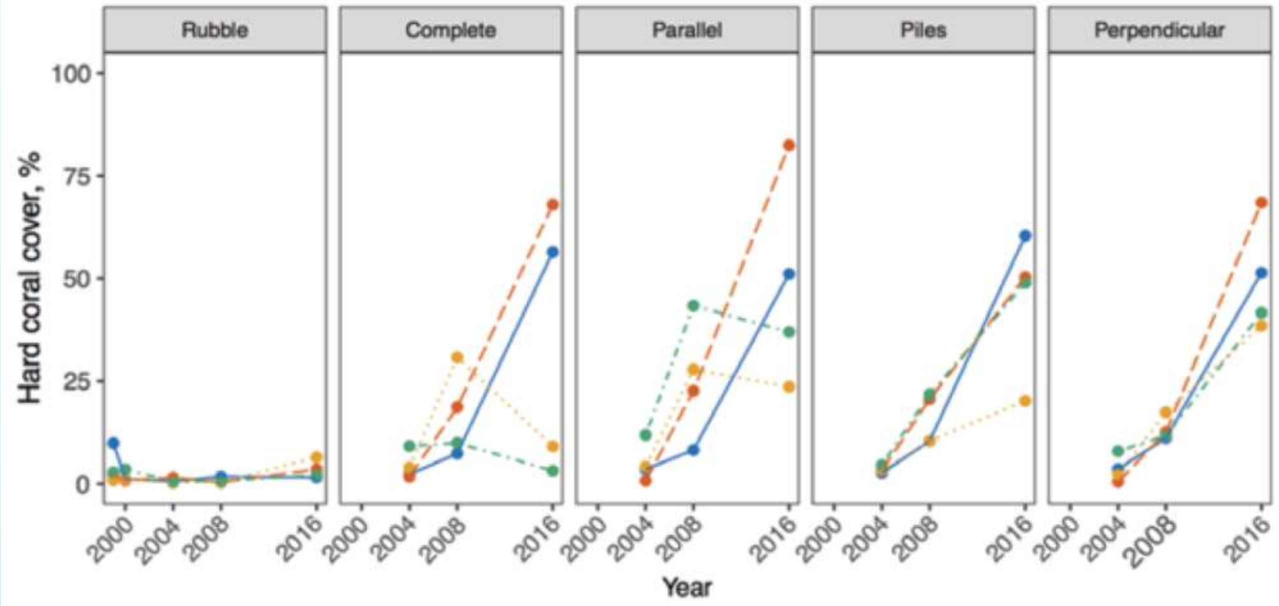
Piles of rock (natural) to enhance coral recruitment. Damaged grounds (control), piles, and piles with fences (to avoid sea urching grazing).

Recruitment in enhanced habitat higher than in contol plots. No difference between fences and no fences.

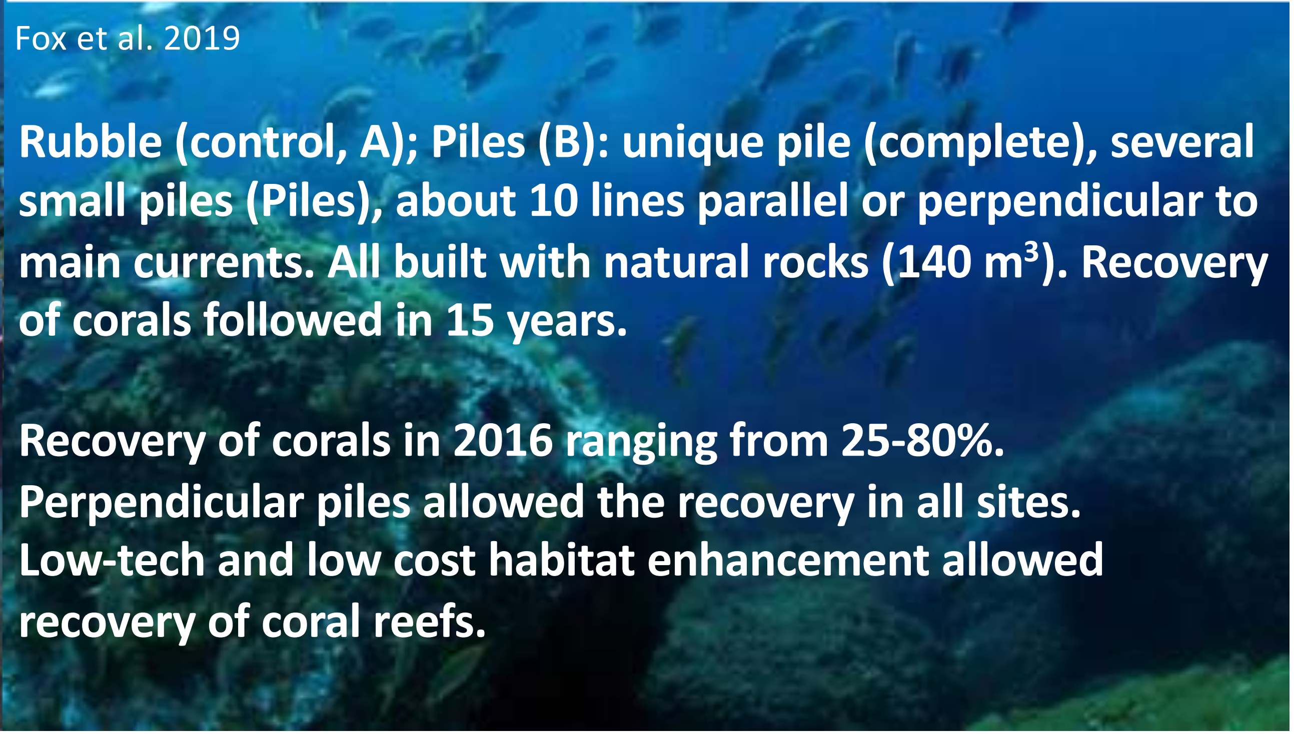
Effect of substrate texture. Rough rocks facilitate recruitment with respect to smooth rocks.

Coral reefs: successful restoration





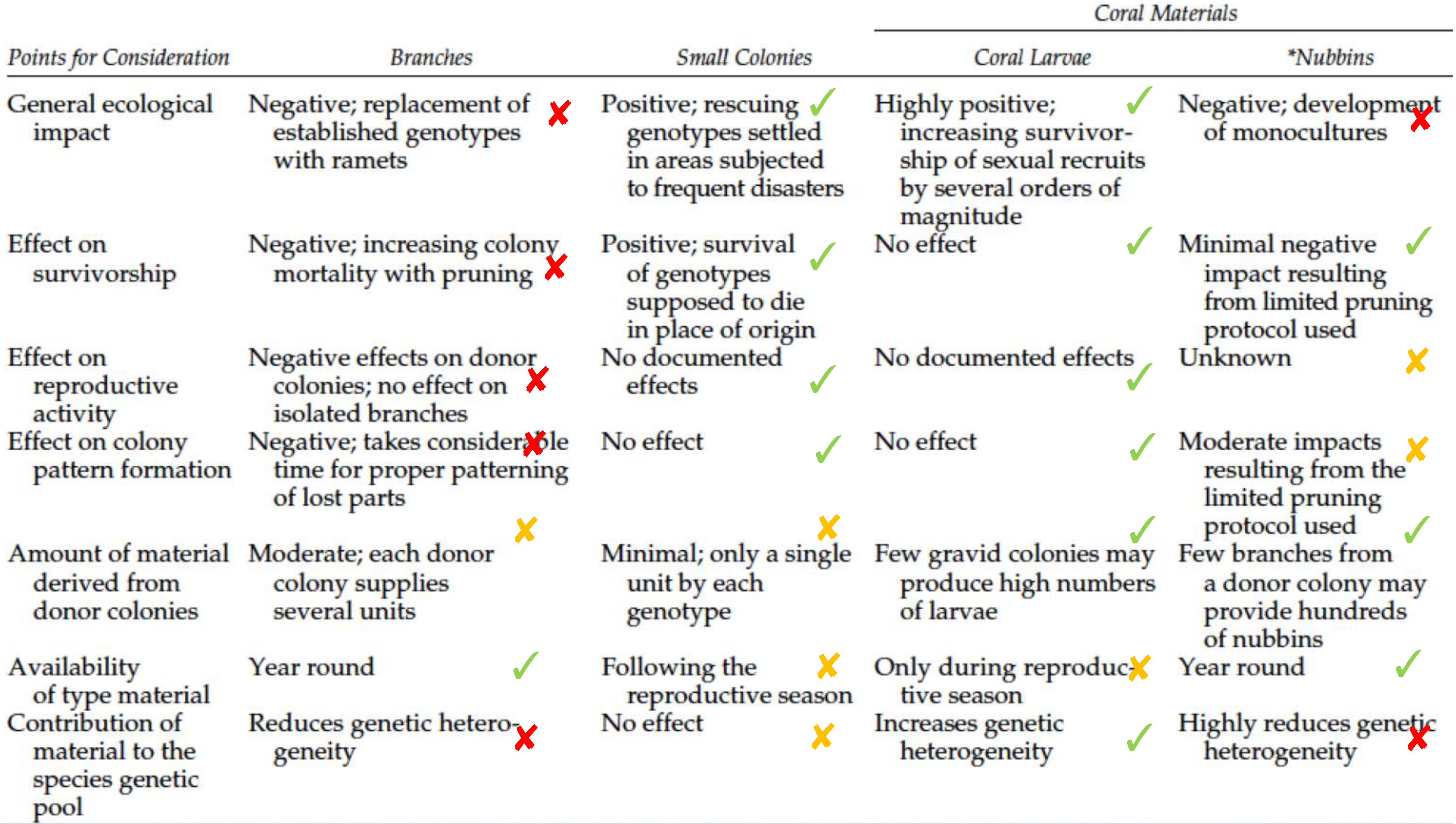
Fox et al. 2019



Rubble (control, A); Piles (B): unique pile (complete), several small piles (Piles), about 10 lines parallel or perpendicular to main currents. All built with natural rocks (140 m^3). Recovery of corals followed in 15 years.

Recovery of corals in 2016 ranging from 25-80%. Perpendicular piles allowed the recovery in all sites. Low-tech and low cost habitat enhancement allowed recovery of coral reefs.

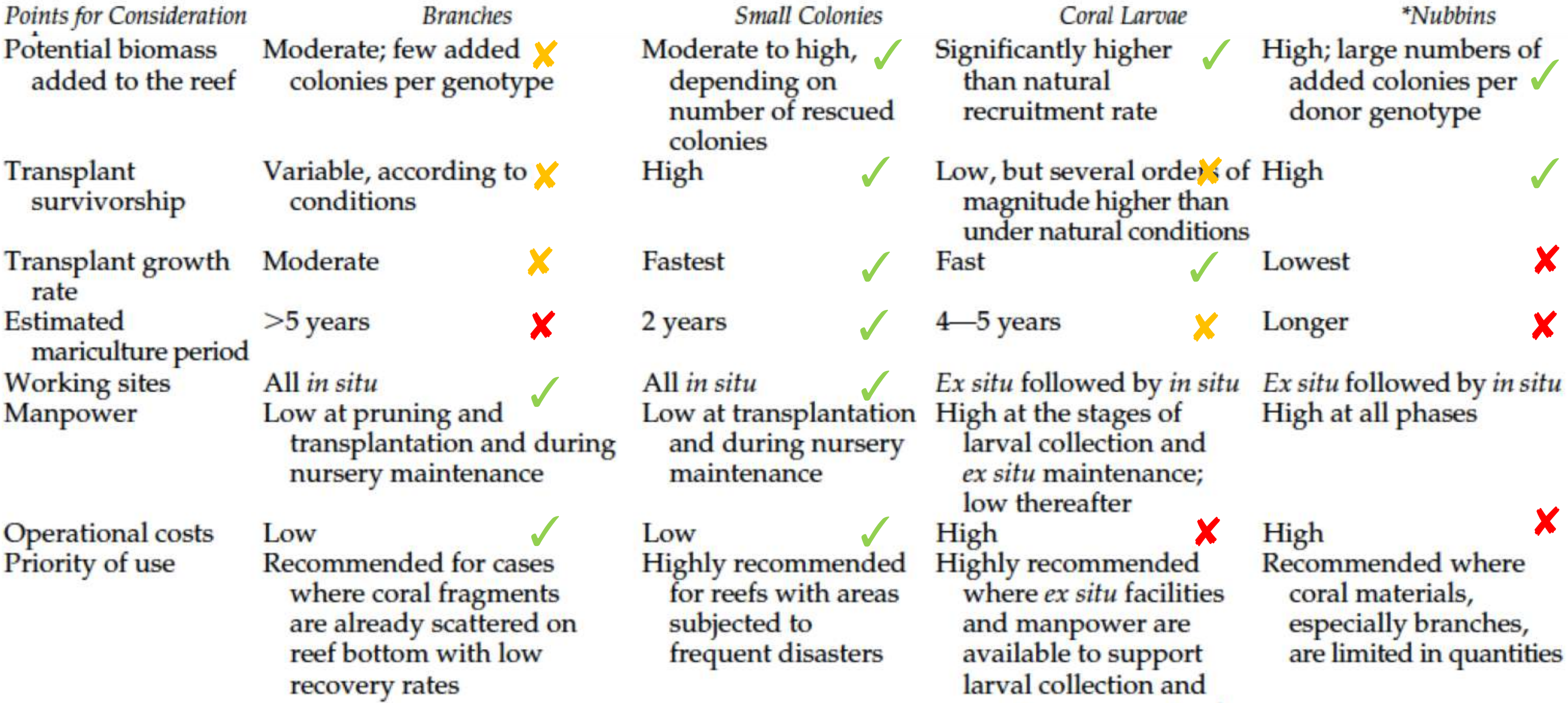
Coral reefs: transplanting and seedling



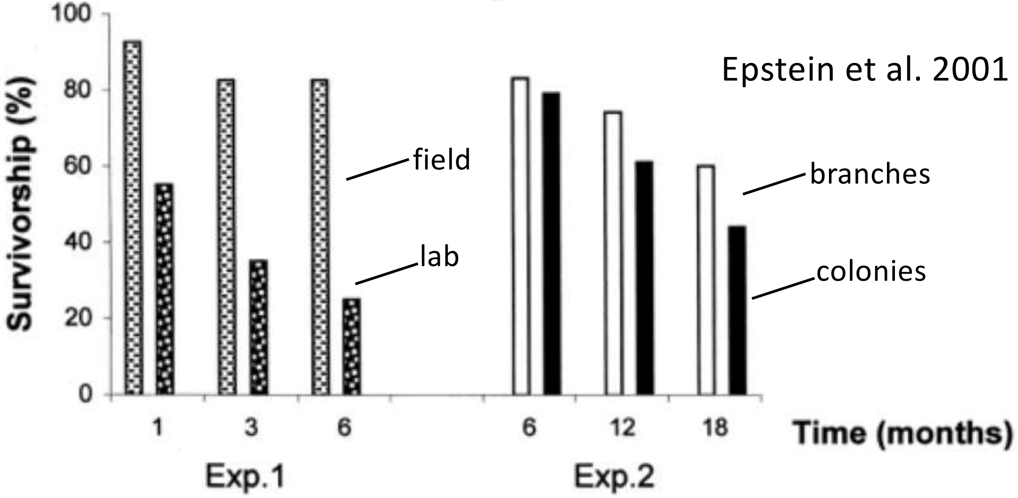
			Coral Materials	
Points for Consideration	*Branches*	*Small Colonies*	*Coral Larvae*	**Nubbins*
General ecological impact	Negative; replacement of established genotypes with ramets ✗	Positive; rescuing genotypes settled in areas subjected to frequent disasters ✓	Highly positive; increasing survivorship of sexual recruits by several orders of magnitude ✓	Negative; development of monocultures ✗
Effect on survivorship	Negative; increasing colony mortality with pruning ✗	Positive; survival of genotypes supposed to die in place of origin ✓	No effect ✓	Minimal negative impact resulting from limited pruning protocol used ✓
Effect on reproductive activity	Negative effects on donor colonies; no effect on isolated branches ✗	No documented effects ✓	No documented effects ✓	Unknown ✗
Effect on colony pattern formation	Negative; takes considerable time for proper patterning of lost parts ✗	No effect ✓	No effect ✓	Moderate impacts resulting from the limited pruning protocol used ✗
Amount of material derived from donor colonies	✗ Moderate; each donor colony supplies several units	✗ Minimal; only a single unit by each genotype	✓ Few gravid colonies may produce high numbers of larvae	✓ Few branches from a donor colony may provide hundreds of nubbins
Availability of type material	Year round ✓	Following the reproductive season ✗	Only during reproductive season ✗	Year round ✓
Contribution of material to the species genetic pool	Reduces genetic heterogeneity ✗	No effect ✗	Increases genetic heterogeneity ✓	Highly reduces genetic heterogeneity ✗

The use of small colonies and larvae has little consequence on donor colonies. The use of nubbins also has reduced effects. The use of branches has the higheste negative effects on donors. Both branches and nubbins may have strong consequences on genetic homogeneization of natural and implanted populations

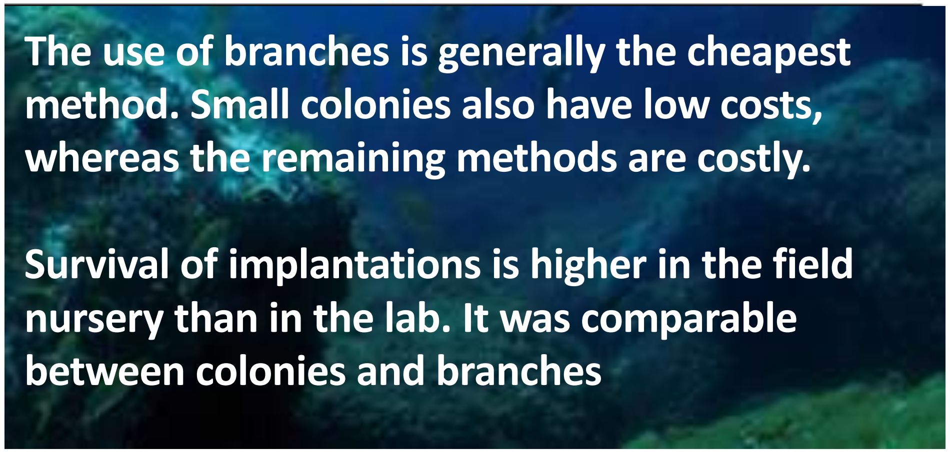
Coral reefs: recruit type



Points for Consideration	*Branches*	*Small Colonies*	*Coral Larvae*	**Nubbins*
Potential biomass added to the reef	Moderate; few added colonies per genotype ✗	Moderate to high, depending on number of rescued colonies ✓	Significantly higher than natural recruitment rate ✓	High; large numbers of added colonies per donor genotype ✓
Transplant survivorship	Variable, according to conditions ✗	High ✓	Low, but several orders of magnitude higher than under natural conditions ✗	High ✓
Transplant growth rate	Moderate ✗	Fastest ✓	Fast ✓	Lowest ✗
Estimated mariculture period	>5 years ✗	2 years ✓	4—5 years ✗	Longer ✗
Working sites	All *in situ* ✓	All *in situ* ✓	*Ex situ* followed by *in situ*	*Ex situ* followed by *in situ*
Manpower	Low at pruning and transplantation and during nursery maintenance	Low at transplantation and during nursery maintenance	High at the stages of larval collection and *ex situ* maintenance; low thereafter	High at all phases
Operational costs	Low ✓	Low ✓	High ✗	High ✗
Priority of use	Recommended for cases where coral fragments are already scattered on reef bottom with low recovery rates	Highly recommended for reefs with areas subjected to frequent disasters	Highly recommended where *ex situ* facilities and manpower are available to support larval collection and maintenance protocols	Recommended where coral materials, especially branches, are limited in quantities



Epstein et al. 2001

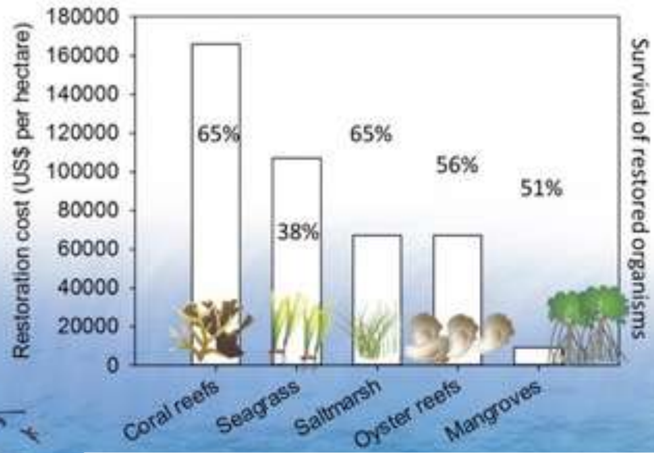


The use of branches is generally the cheapest method. Small colonies also have low costs, whereas the remaining methods are costly.

Survival of implantations is higher in the field nursery than in the lab. It was comparable between colonies and branches

Costs of restoration

Bayraktarov et al. 2016



The median cost of coastal marine restoration is about US$80,000 per hectare but some projects are incredibly expensive, costing many millions of dollars.

Symbols – Integration and Application Network, University of Maryland Center for Environmental Science

Average cost is 1.6 millions (2010) USD (half projects cost 80000 USD or less, but the remaining 50% have higher, sometimes extremely higher costs). When including all costs (capital and operating costs), median cost is 150000-400000 USD per ha per year. In developing countries costs can be 10-200 times lower. Median duration of project is 1-2 years.

Summary

- Most marine and coastal restoration projects have focused on developed countries. Data from developing countries are urgently needed, given that large numbers of people rely directly on the goods and services from marine ecosystems in these countries.
- Projects in developing countries will result in the greatest area of restored habitats given the lower restoration costs.
- The majority of studies reported item-based success in terms of survival and lacked clearly defined and measurable success. Rarely restoration success is focused on the recovery of ecosystem function or services, which should be the ultimate aim of ecological restoration.
- Survival rates of restored organisms varied considerably and complete failures were common. Often inadequate site selection caused project failure. Literature is likely to be biased towards successes rather than failures and many of the lessons learned have been undocumented.
- Project duration was generally limited to only one to two years, which is not sufficient to allow for evaluation of full recovery. Projects should be longer (15–20 years).
- The largest restoration project areas were observed for mangroves, while coral reef and seagrass restoration projects were focused only on small-scale. Restoration projects will need to be conducted and to succeed over larger spatial scales to match the scale of anthropogenic degradation of ecosystems (>10 ha).
- There was no clear relationship between the costs spent and success of marine coastal restoration projects. Careful consideration of site selection and restoration technique are likely to be the most important factors determining success, rather than investment.