FishMed-PhD

Teaching week 2023

Ecological engineering: a tool to increase the productivity of the oceans

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INTRODUCTION

- THE CHALLENGES 2050
- MANAGEMENT MEASURES AIMED TO PROTECT STOCKS, ESSENTIAL FISH HABITATS (EFHS) AND BIODIVERSITY
- TOWARDS A NEW APPROACH

ECO-ENGINEERING IN THE CONTEXT OF THE NbS APPROACH

- LIMITING FACTORS AFFECTING THE OCEANS' POTENTIAL
- DEFINITION OF ECO-ENGINEERING
- ROLE OF ECO-ENGINEERING IN NBS
  - Type 2 NbS - solutions that develop/improve sustainable and multi-functional ecosystems
  - Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

The challenges 2050

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Introduction

Moving towards 2050 the main global challenge the society has to face is **to accommodate the need for food, sustainable energy and fresh water** for a world population of almost 10 billion people.

In addition, adaptation to **climate change and mitigation of its negative consequences, reduction of pollution from contaminants and noise, and conservation of biodiversity** rate equally high among societies' grand challenges.

As our planet's surface is for 71% covered with water, unlocking its potential and utilize in a sustainable way the overall resources the oceans can offer through a strategy of Blue Growth is fundamental.

The importance of the use of the marine environment is widely acknowledged within the EU and reflected in agendas as the EU Blue Growth strategy, the Food 2030 agenda and the Food from our Oceans vision.

The challenges 2050

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Introduction

Optimize the use of marine space ⇨

- Coexistence of different activities in a single location (MSP)

Optimize sustainable exploitation of natural biological resources ⇨

- Implement the principle of MSY and the fisheries management plans incorporating the ecosystem approach
- Exploit organisms at lower trophic levels
- Reduce discard (In Med trawl fisheries discard represents 40% of the catch)
- Increase the carrying capacity of the marine environment, e.g., recover degraded Essential Fish Habitats, implement trophic chains, reduce natural mortality

Implement sustainable aquaculture ⇨

- Develop more efficient and sustainable feed for fish farming
- Minimize risks of deseases and parasites while reducing the use of drugs
- Implement farming systems with low environmental impact, e.g. integrated multitrophic aquaculture (IMTA), extensive farming, offshore farming, and develop less polluting techniques and sistems
- Expand the range of farmed species including organisms at lower trophic levels, e.g. seaweeds, olothurians

Optimize the production chain ⇨

- Utilize all by-products of the overall production chain, both in fisheries and aquaculture
- Optimize the use of available technologies and infrastructures, e.g., shared use of vessels and production platforms among different actors

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The challenges 2050

Passive protection of sensible habitats, spawning and nursery areas

UN environment programme

COP15, Montreal 2022, on the UN Convention on Biological Diversity adopted the"**Kunming-Montreal Global Biodiversity Framework" (GBF)**, including four goals and 23 targets for achievement by 2030.

Among the global targets for 2030:

- *Effective conservation and management of* ***at least 30% of the world's lands, inland waters, coastal areas and oceans,*** *with emphasis on areas of particular importance for biodiversity and ecosystem functioning and services……* ***Currently 17% and 10% of the world's terrestrial and marine areas respectively are under protection****.*
- *Have* ***restoration completed or underway on at least 30%*** *of degraded terrestrial, inland waters, and coastal and marine ecosystems*
- ***Reduce to near zero the loss of areas of high biodiversity importance****, including ecosystems of high ecological integrity*
- ***Cut global food waste in half*** *and significantly reduce over consumption and waste generation*
- ***Reduce by half both excess nutrients and the overall risk posed by pesticides and highly hazardous chemicals***
- ***Prevent the introduction of priority invasive alien species****, and* ***reduce by at least half the introduction and establishment of other known or potential invasive alien species****, and eradicate or control invasive alien species on islands and other priority sites*
- *Require large and transnational companies and financial institutions* ***to monitor, assess, and transparently disclose their risks, dependencies and impacts on biodiversity*** *through their operations, supply and value chains and portfolios*

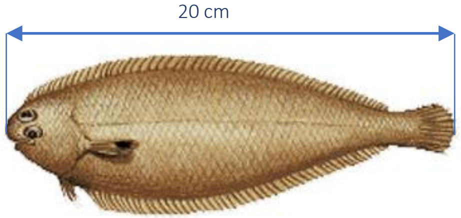
"Without such action, there will be a further acceleration in the global rate of species extinction, which is already at least tens to hundreds of times higher than it has averaged over the past 10 million years."

Management measures aimed to protect stocks, EFHs and biodiversity

Introduction

The Common Fisheries Policy aimed to protect fish stocks and ensure sustainable fisheries has been mostly based on **restrictive** management measures

Mininum landing sizes



Restrictions regarding the typology and use of fishing gears

Minimum dimensions of mesh sizes

Biological fishing stop

Reduction of fishing hours per week

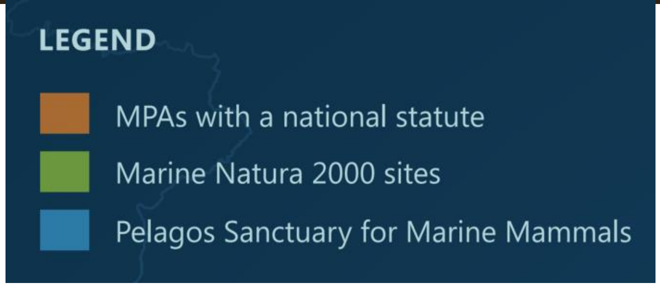
Annual total allowable catch (TAC) for specific stocks

Reduction of fishing fleets

Management measures aimed to protect stocks, EFHs and biodiversity

Introduction

Passive protection of sensible habitats, spawning and nursery areas



Marine Protected Areas (MPAs)

8.33 % *Source 1*

Surface under protection status
209,303 km² / 1,087 officially designated Marine Protected Areas (MPAs) including*:

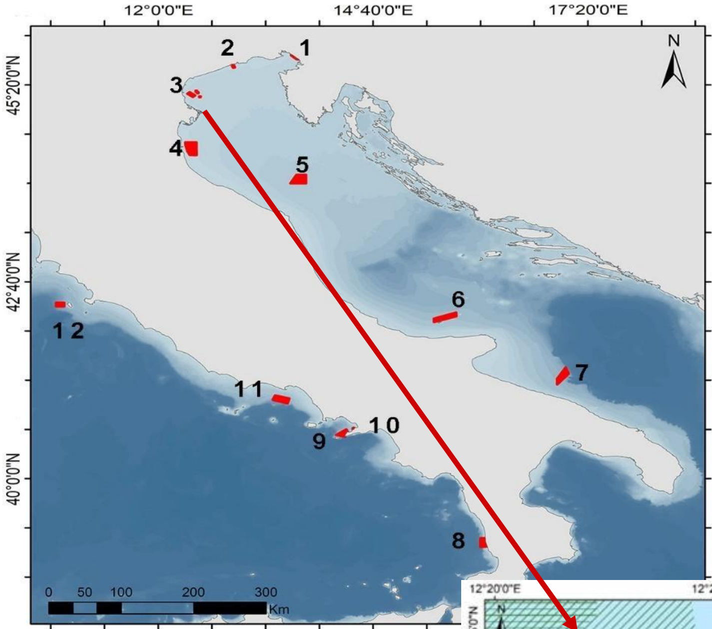
- 257 MPAs with a national statute: 3.18 % (including the Cetaceans Migration Corridor in the Mediterranean - Spain: 1.84 %)
- 829 marine Natura 2000 sites: 3.17 %
- Pelagos Sanctuary for Marine Mammals (France, Italy, Monaco): 3.49 %

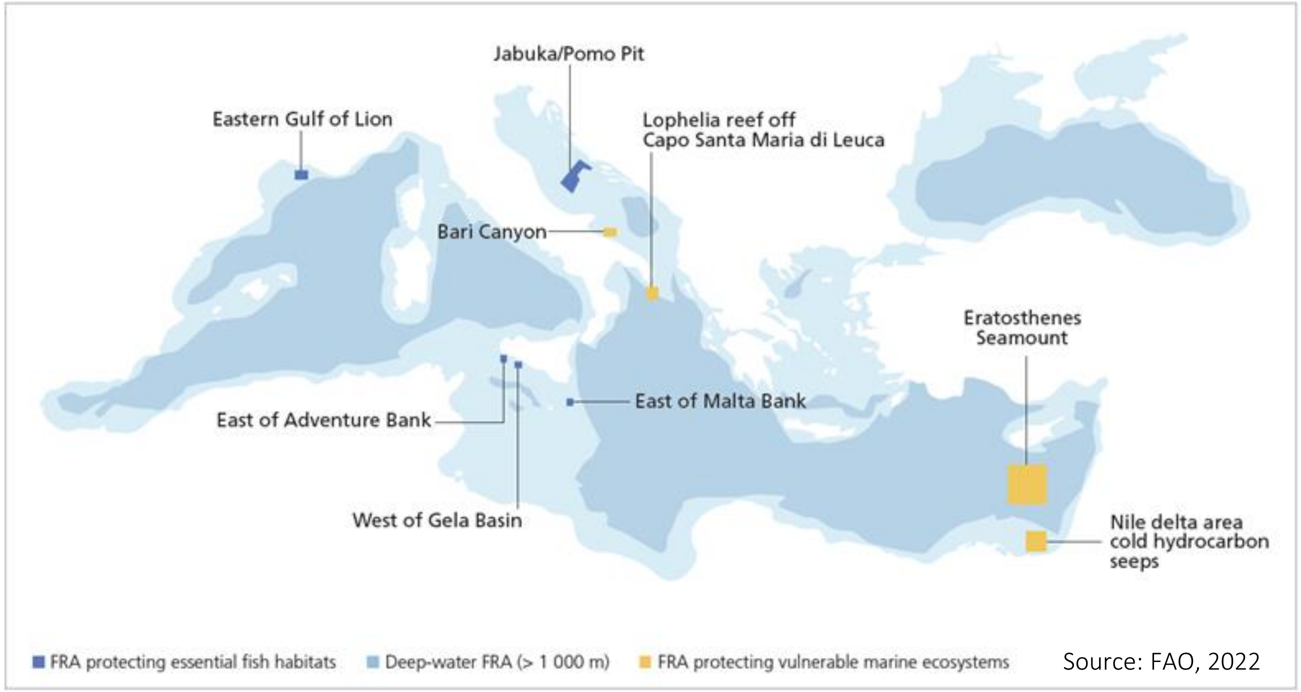
** Some of these MPAs are recognised as Specially Protected Areas of Mediterranean Importance (SPAMIs). The network of SPAMIs covers 138,464 km² (5.51 %) with 39 sites.*

Management measures aimed to protect stocks, EFHs and biodiversity

Passive protection of Essential Fish Habitats

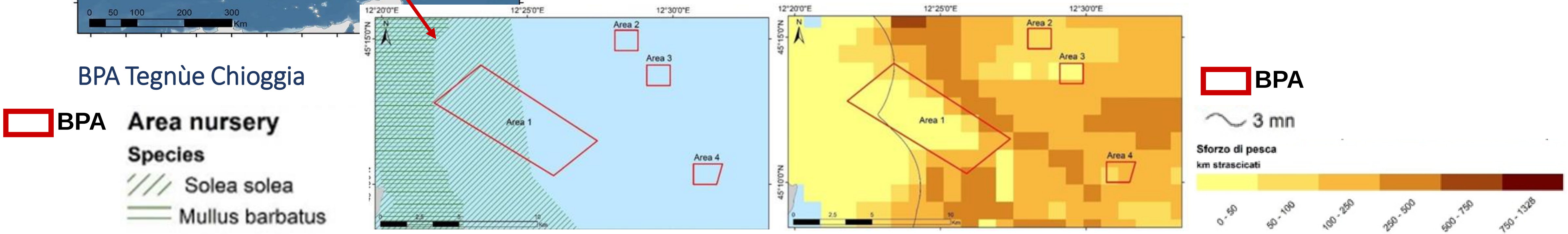
- Coastal trawl ban within 3 mn offshore or less than 50 m depth
- 9 GFCM Fisheries Restricted Areas (FRAs)
- 12 Biological Protection Areas (BPAs)





Source: FAO, 2022

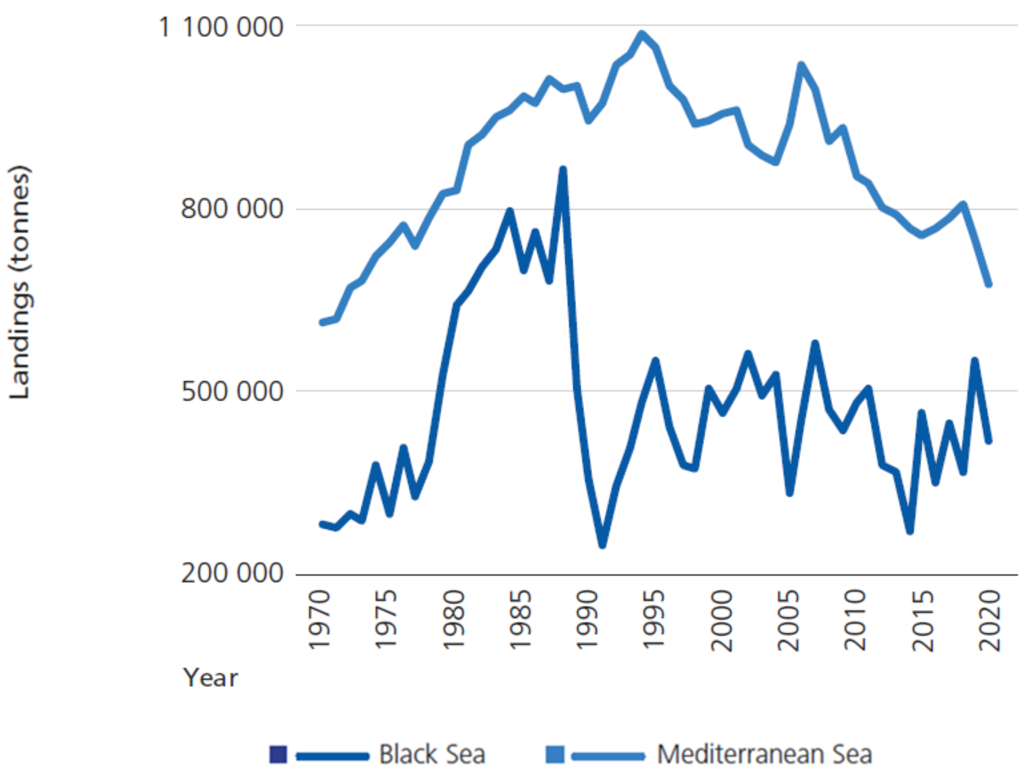
BPA Tegnùe Chioggia



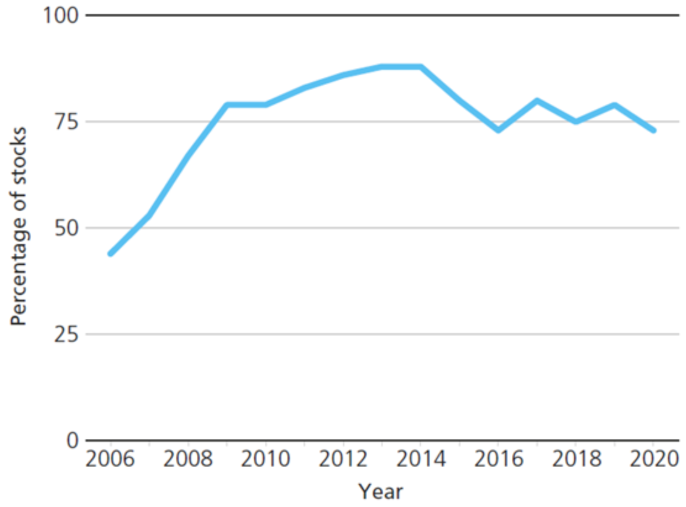
Source: Tassetti *et al.*, 2019

Management measures aimed to protect stocks, EFHs and biodiversity

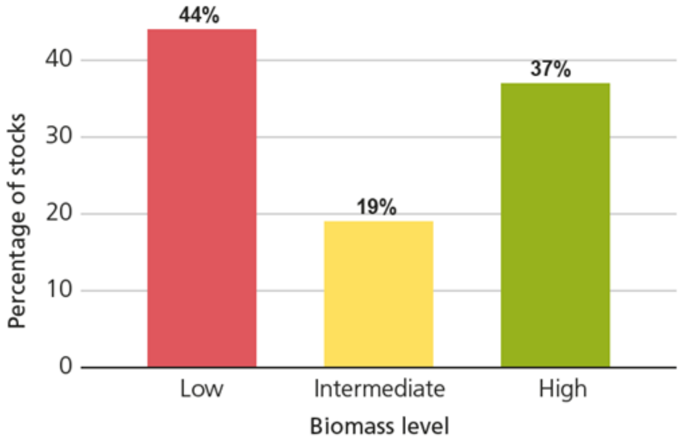
Introduction



Total landings in the Mediterranean and the Black Sea per year, 1970–2020 (FAO, 2022)



Percentage of stocks in overexploitation in the GFCM area, 2006–2020 (FAO, 2022)



63% of stocks overexploited

Percentage of Mediterranean stocks at low, intermediate and high relative biomass levels (FAO, 2022)

Towards a new approach

What is changing?

- In the last years, at global level it is seeking to address the societies' major challenges from a **new perspective** based on a 'transitions' from a resource-intensive growth model towards a more resource-efficient, inclusive and sustainable growth model.
- It is believed that such transition may be possible through the implementation of **Nature based Solutions (NbS)** as innovation opportunities that optimise the synergies between nature, society and economy.
- The recent 2022 resolution by the United Nations Environment Assembly highlights NbS' role in addressing climate change and providing sustainable social and economic development, while protecting or restoring the planet's biodiversity and ecosystem services (UNEA-UNEP, 2022).
- This is what the EU is also doing with its Research & Innovation (R&I) policy - NbS are explicitly mentioned in several areas of the Biodiversity Strategy and Horizon Europe programme.

Towards a new approach

Introduction

Nature based Solutions

What are the NbS?

Nature-Based Solutions, or NbS, are solutions that incorporate natural features or processes into design, management and engineering practices to solve societal problems. They base on a holistic concept integrating human, engineering, and natural sciences (Riisager-Simonsen et al., 2022).

They *"are actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits"* (UNEA-UNEP, 2022)

The concept is not new, and it has surfaced in the past in many shapes and forms such as ***eco-engineering, bio-mimicry*** or ***building with nature***.

There are many examples of Nature based Solutions, yet **in the marine domain there appears to be few experiences with developing NbS practices.**

Towards a new approach

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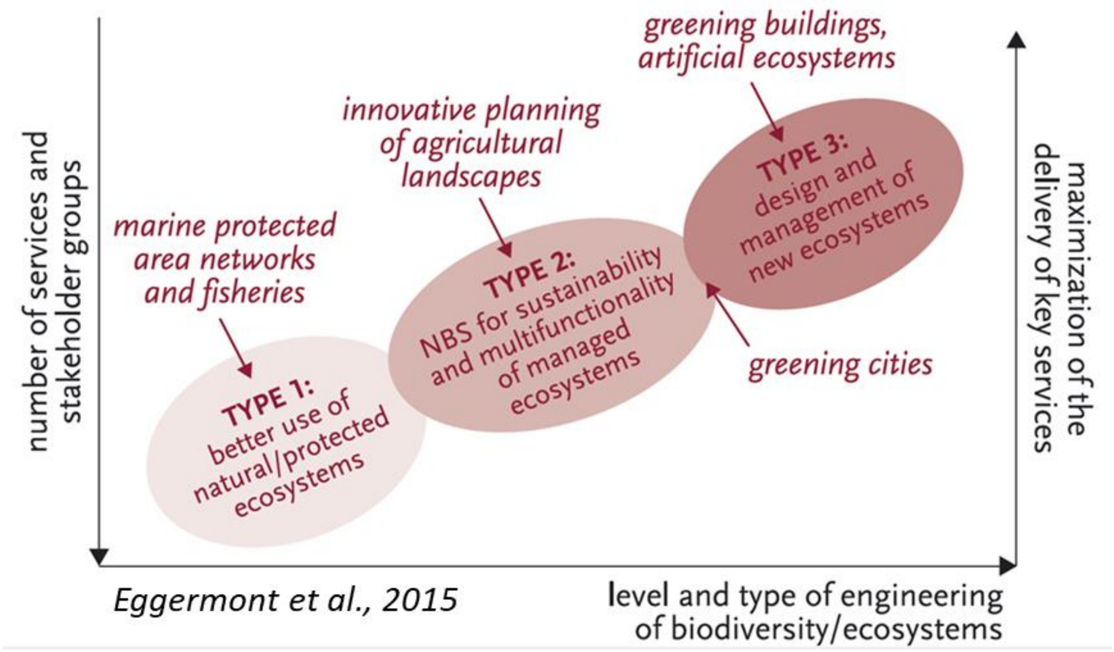
Introduction

Nature based Solutions



Type 1: no or minimal intervention in ecosystems, with the objectives of maintaining or improving the delivery of a range of ES both inside and outside of the preserved ecosystems.

Type 2: management approaches that develop sustainable and multi-functional ecosystems (extensively or intensively managed) and improve the delivery of selected ES compared to what would be obtained with a more conventional intervention.

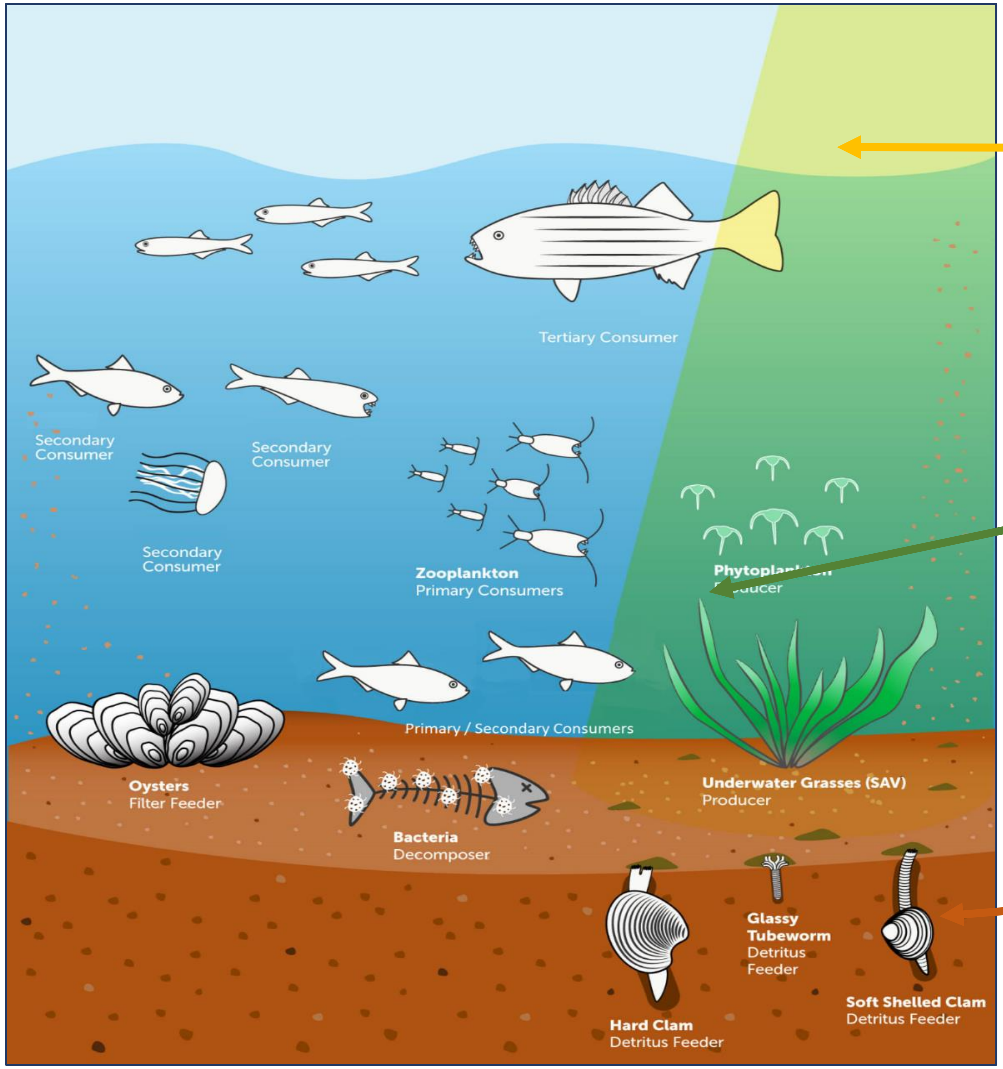
Type 3: managing ecosystems in very intrusive ways or even creating new ecosystems (e.g., artificial ecosystems with new assemblages of organisms).

Protecting highly productive sensitive habitats

Overcoming the bottlenecks which impede the full utilization of the energy (i.e. nutrients, larvae) naturally occurring in the marine environment by unlocking a few essential limiting factors **mimicking some features of the natural habitats**

Increase the carrying capacity and productivity of the marine environment to address one or more IUCN major societal challenges and produce multiple ecosystem services

Limiting factors affecting the oceans' potential



Light

Food availability

Space

Limiting factors affecting the oceans’ productivity

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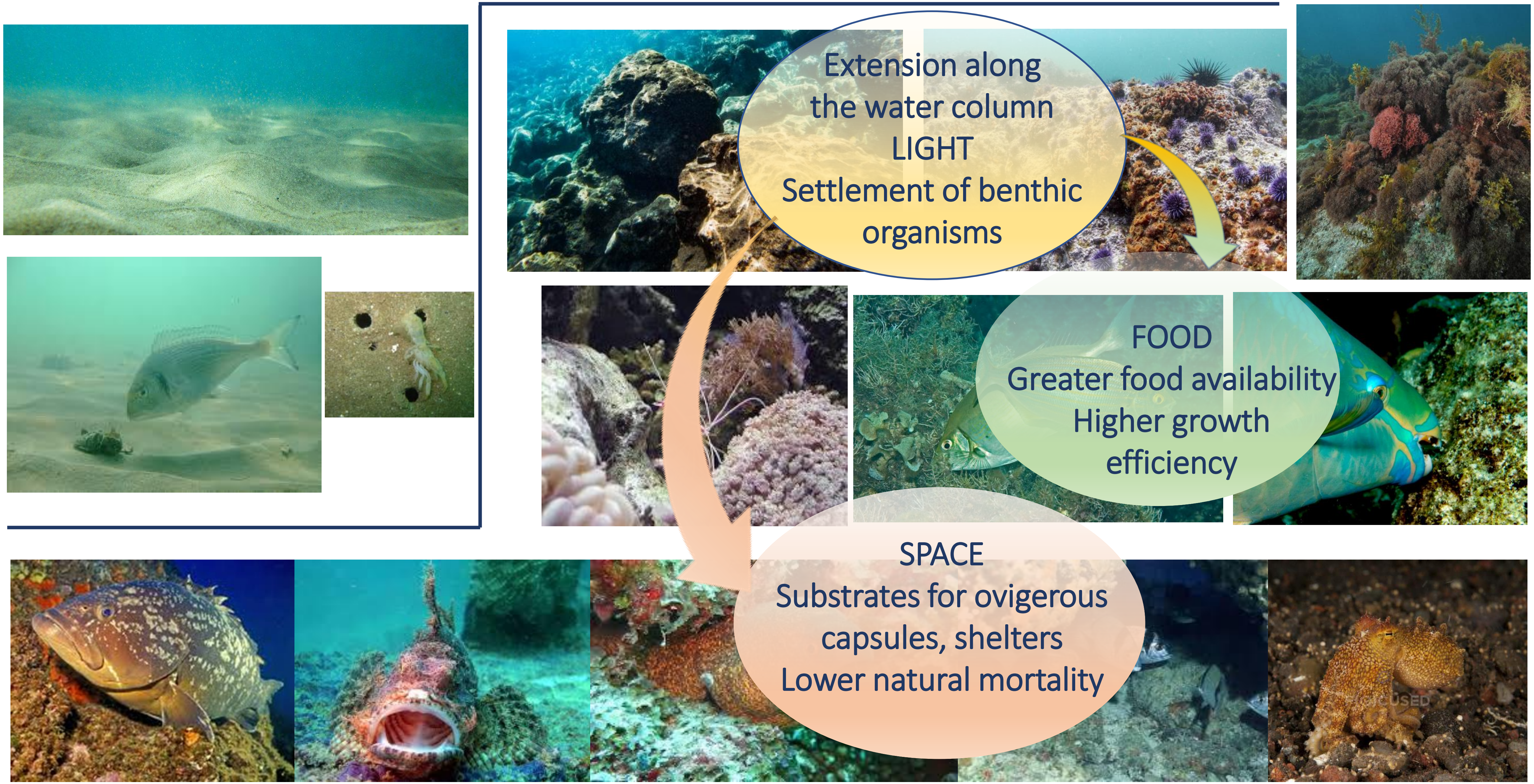
3-dimensional spatial heterogeneity contributes to increase oceans’ productivity

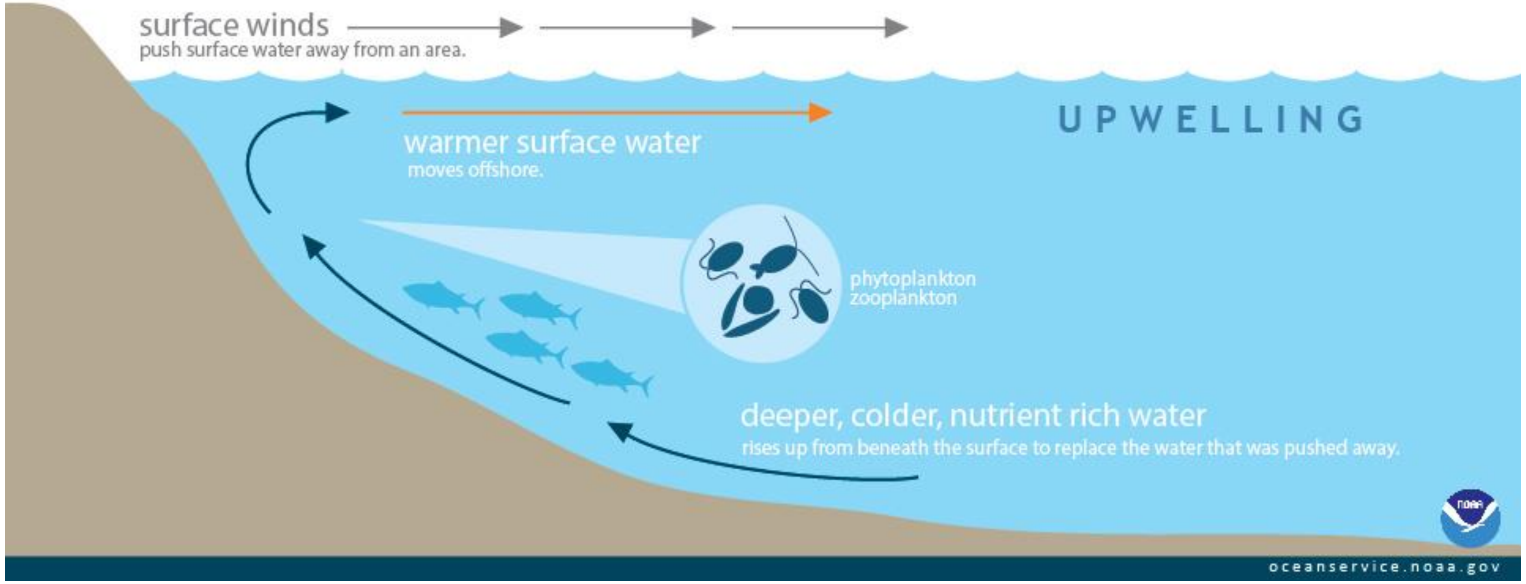
Eco-engineering within NbS approach



Limiting factors affecting the oceans' potential

Mobilization of deep water nutrients

Eco-engineering within NbS approach



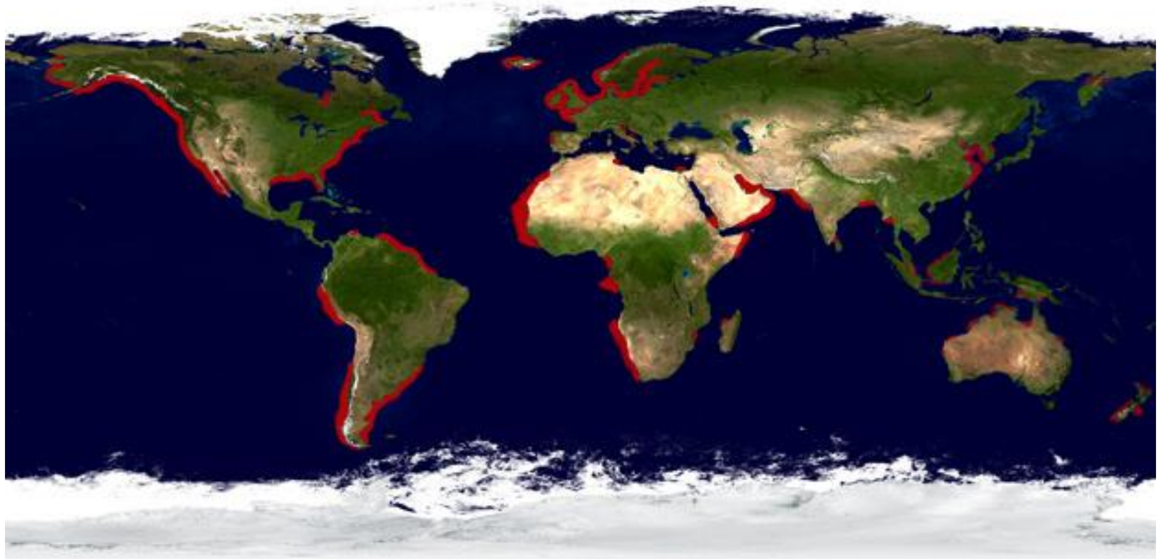
Upwelling

↓

Nutrients'mobilization

↓

Implementation of mesopelagic and pelagic trophic chains



Definition of eco-engineering

Eco-engineering within NbS approach

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Ecological engineering (Barot et al., 2012): a branch of ecology and engineering aimed to develop more sustainable practices informed by ecological knowledge with the goals of:

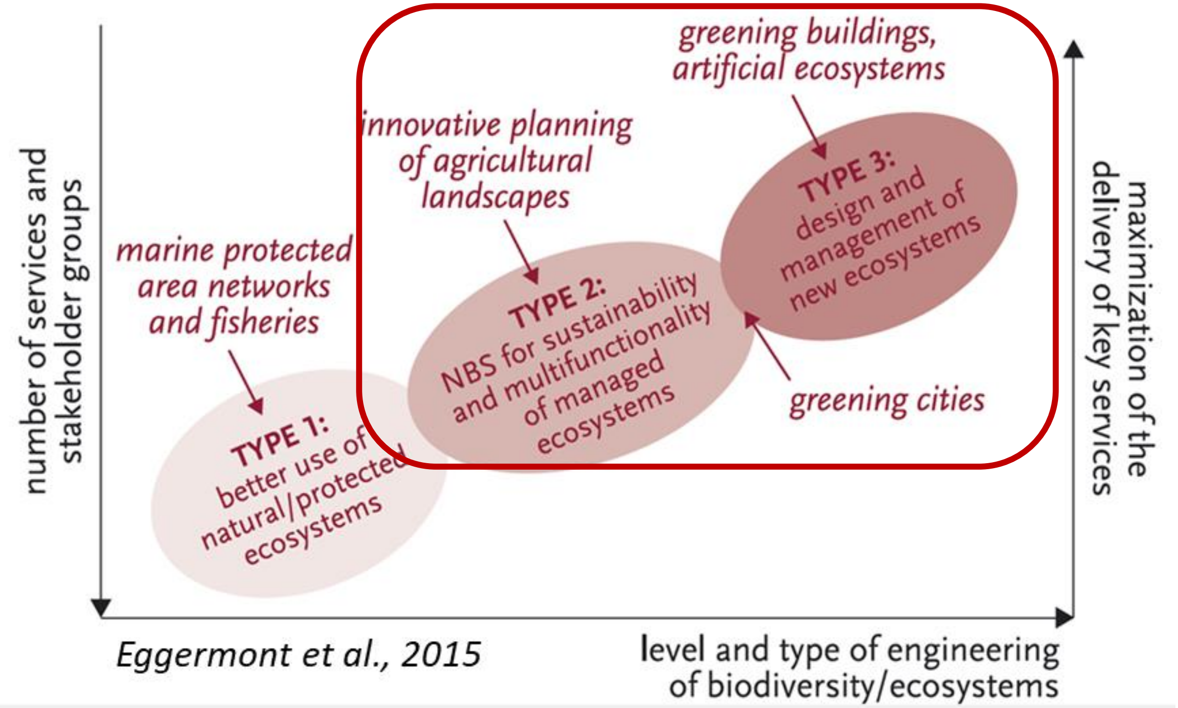
- Protecting and restoring ecosystems
- Modifying ecosystems to increase the quantity, quality and sustainability of particular services they provide
- Building new ecosystems which provide services that would otherwise not be provided through conventional engineering based on non-renewable resources

NbS approaches (IUCN, 2016)
Ecological restoration ~~Ecological engineering~~ Forest landscape restoration
Ecosystem-based management Ecosystem-based adaptation Ecosystem-based mitigation Climate adaptation services Ecosystem-based disaster risk reduction
Natural infrastructure Green infrastructure
Integrated coastal zone management Integrated water resources management
Area-based conservation approaches including protected area management

Ecological engineering

Role of eco-engineering in NbS

Eco-engineering within NbS approach



Type 2: management approaches that develop sustainable and multi-functional ecosystems (extensively or intensively managed) and improve the delivery of selected ES compared to what would be obtained with a more conventional intervention.

Type 3: managing ecosystems in very intrusive ways or even creating new ecosystems (e.g., artificial ecosystems with new assemblages of organisms).

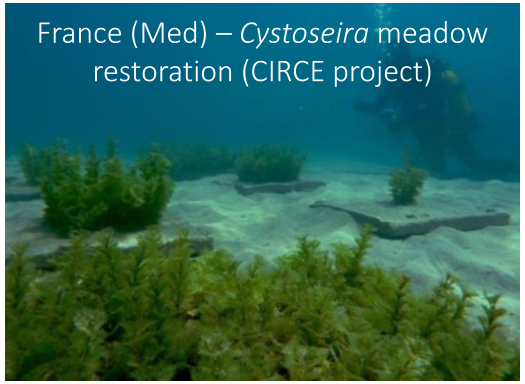
IUCN Major Societal Challenges (Cohen-Shacham et al., 2016)

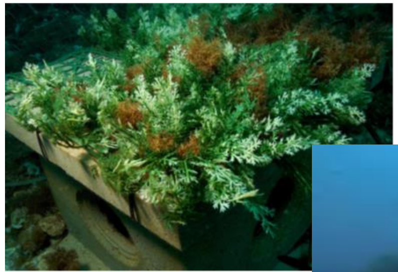
Type 2 NbS - solutions that develop/improve sustainable and multi-functional ecosystems

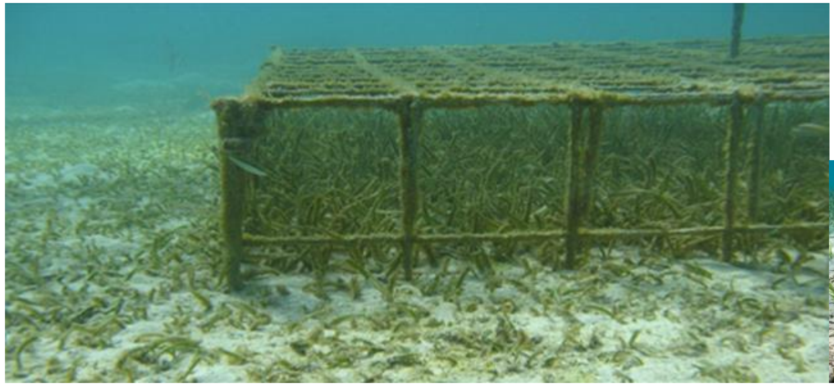
Ecological **active** restoration has accelerated in recent years in response to a growing awareness of the degradation of marine habitats around the world and to an increased ability to quantify the economic value of habitat benefits

Societal challenges: 1) Climate change mitigation and adaptation; 2) Disaster risk reduction; 3) Economic and social development; 5) Food security; 7) Environmental degradation and biodiversity loss

➢ Seagrass and seaweed restoration


France (Med) – *Cystoseira* meadow restoration (CIRCE project)





Bermuda – Turtlegrass (*Thalassia testudinum*) meadow restoration

- **Carbon sequestration** - in Chesapeake Bay (FL) mean carbon sequestration under restored Zostera marina beds was 38.7 — 13.1 MgCorg·ha^{-1} against 25.7 — 6.7 MgCorg·ha^{-1} of natural seagrass meadows (Thorhaug et al., 2020)
- **Reversal of environmental degradation and biodiversity loss**
- Spawning and nursery areas
- Protection of coastline against erosion

Type 2 NbS - solutions that develop/improve sustainable and multi-functional ecosystems

Role of eco-engineering in NbS

- Restoration of subtidal boulder reefs/beds

Denmark - cavernous boulder reefs restoration

- **Reversal of environmental degradation and biodiversity loss**
- **Habitats for associated fish and crustaceans (EFH)** - After the reef habitat restoration, economically valuable fish species spent more time within the habitat than outside, and had greater abundances than before the intervention
- Carbon sequestration

- Shellfish reef/bed restoration

Oyster reef restoration (e.g., Australia, U.S.)

- **Reversal of environmental degradation and biodiversity loss** – Bivalves also contribute to water purification from contaminant
- **Provision of economically valuable shellfish -** At restored *C. virginica* beds in U.S. mean oyster recruitment was ~12 times higher than in natural reefs and potential larval output was estimated to be 6 times larger than at natural reefs
- **Reef habitats for associated fish and crustaceans (EFH)**
- Protection of coastline against erosion
- Carbon sequestration - In Pacific oyster Carbon contributes 12g for every 100g of shell, or 12% of overall shell mass

Type 2 NbS - solutions that develop/improve sustainable and multi-functional ecosystems

- Coral reef restoration – due to the diversity of life, coral reefs are often called the "*rainforests of the sea.*" About 25% of the ocean's fish depends on healthy coral reefs

Dinamited area restoration

Biorock process for coral restoration (Maldives, Bali, Papua Nuova Guinea, Seychelles, Japan, Caribbean)

Antigua: Maiden Island total reef restoration

Mexico: Cozumel Coral Reef Restoration Program

- **Reversal of environmental degradation and biodiversity loss**
- **Reef habitats for associated fish and crustaceans (EFH)**
- **Tourism**
- **Protection of coastline against erosion**
- Carbon sequestration

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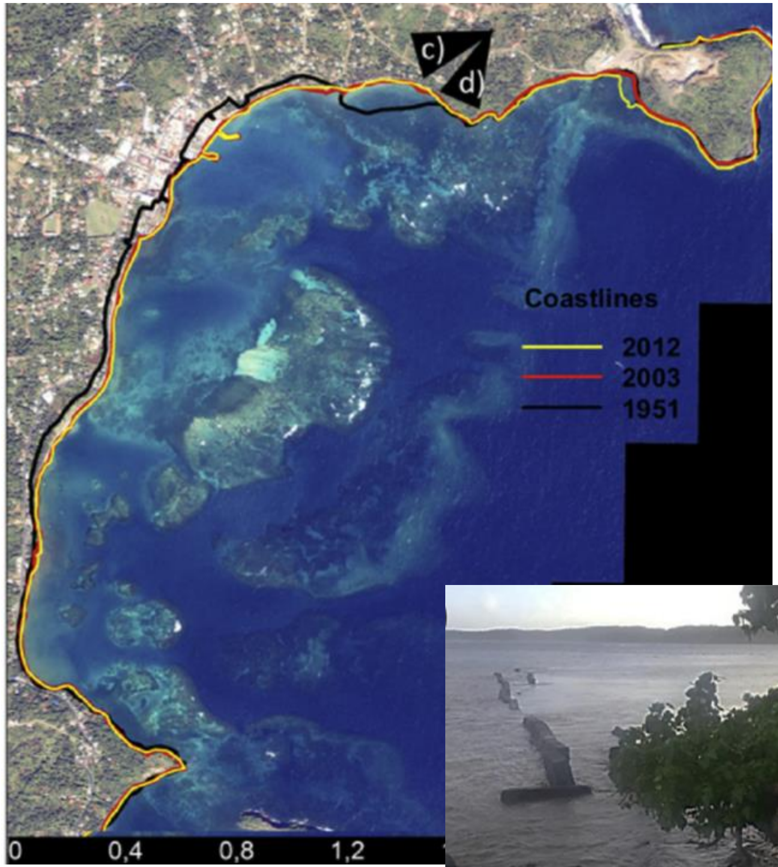
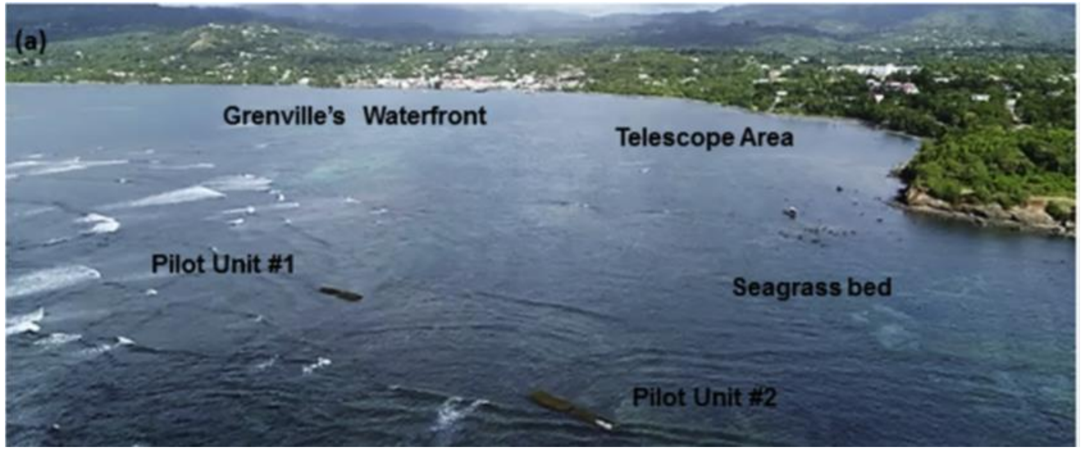
Type 2 NbS - solutions that develop/improve sustainable and multi-functional ecosystems

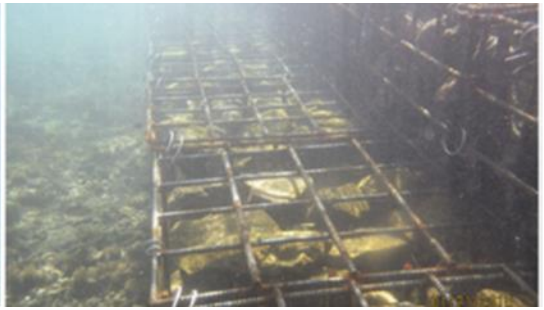
Role of eco-engineering in NbS

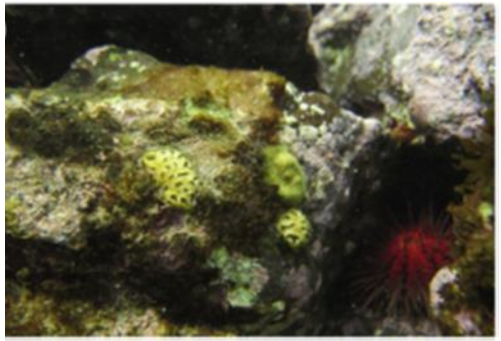
Coral reef restoration for coastal protection

Grenville Bay, Grenada Isle (Caribbean Sea)







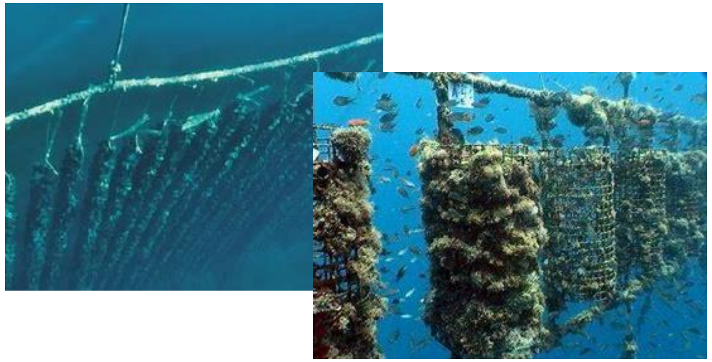


Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

Role of eco-engineering in NbS

submerged (or partly exposed to tides) structures deliberately placed on the seabed to mimic some functions of natural reefs, such as protecting, regenerating, enhancing and/or managing populations of living marine resources

Artificial reefs

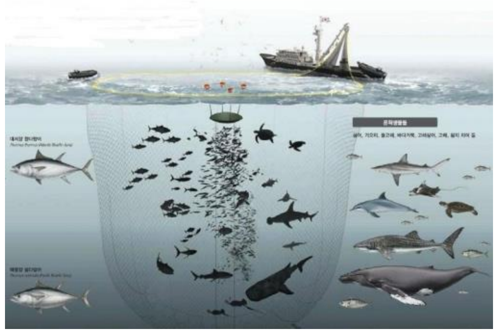


ARTIFICIAL HABITATS

FADs

Other anthropic structures

Wrecks



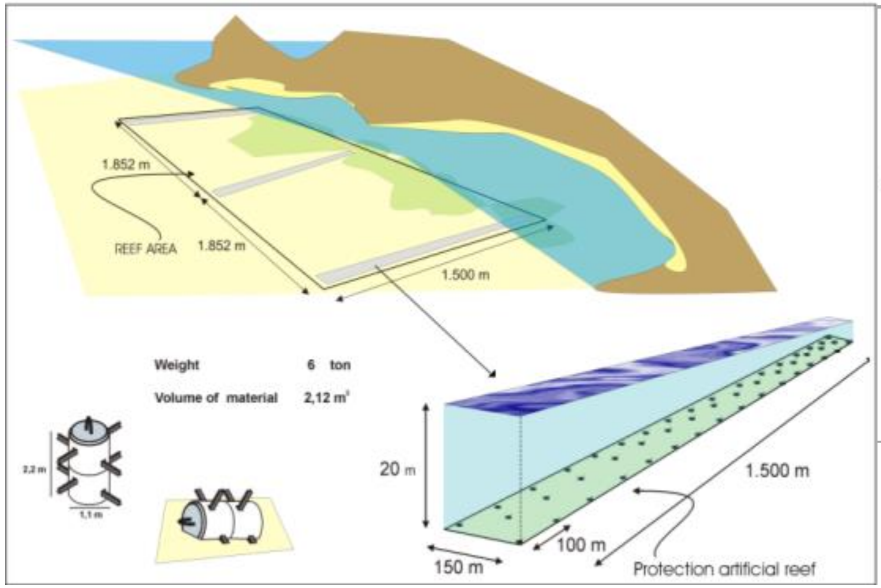
surficial or midwater floating structures employed in fishing techniques to aggregate fish

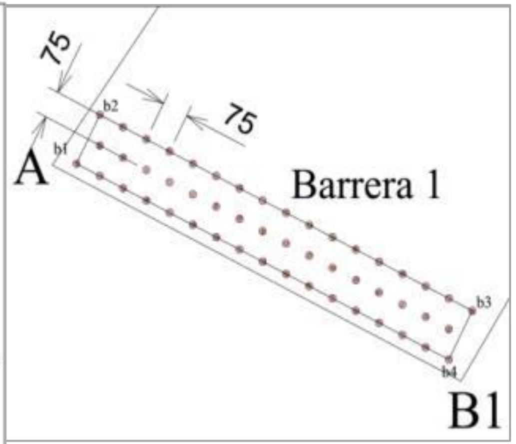
constructed in the marine environment for different primary purposes but that also have, as secondary effect, some functions of artificial reefs or of FADs

Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

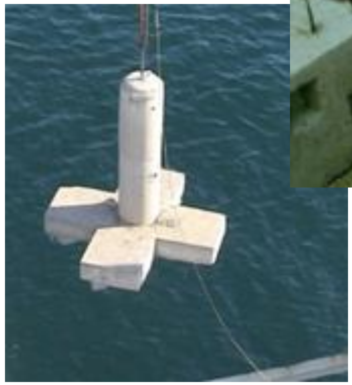
Role of eco-engineering in NbS

➢ Artificial reefs to protect spawning and nursery grounds against illegal trawling





- **Reversal of environmental degradation and biodiversity loss**
- **Spawning and nursery areas**
- Carbon sequestration



Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

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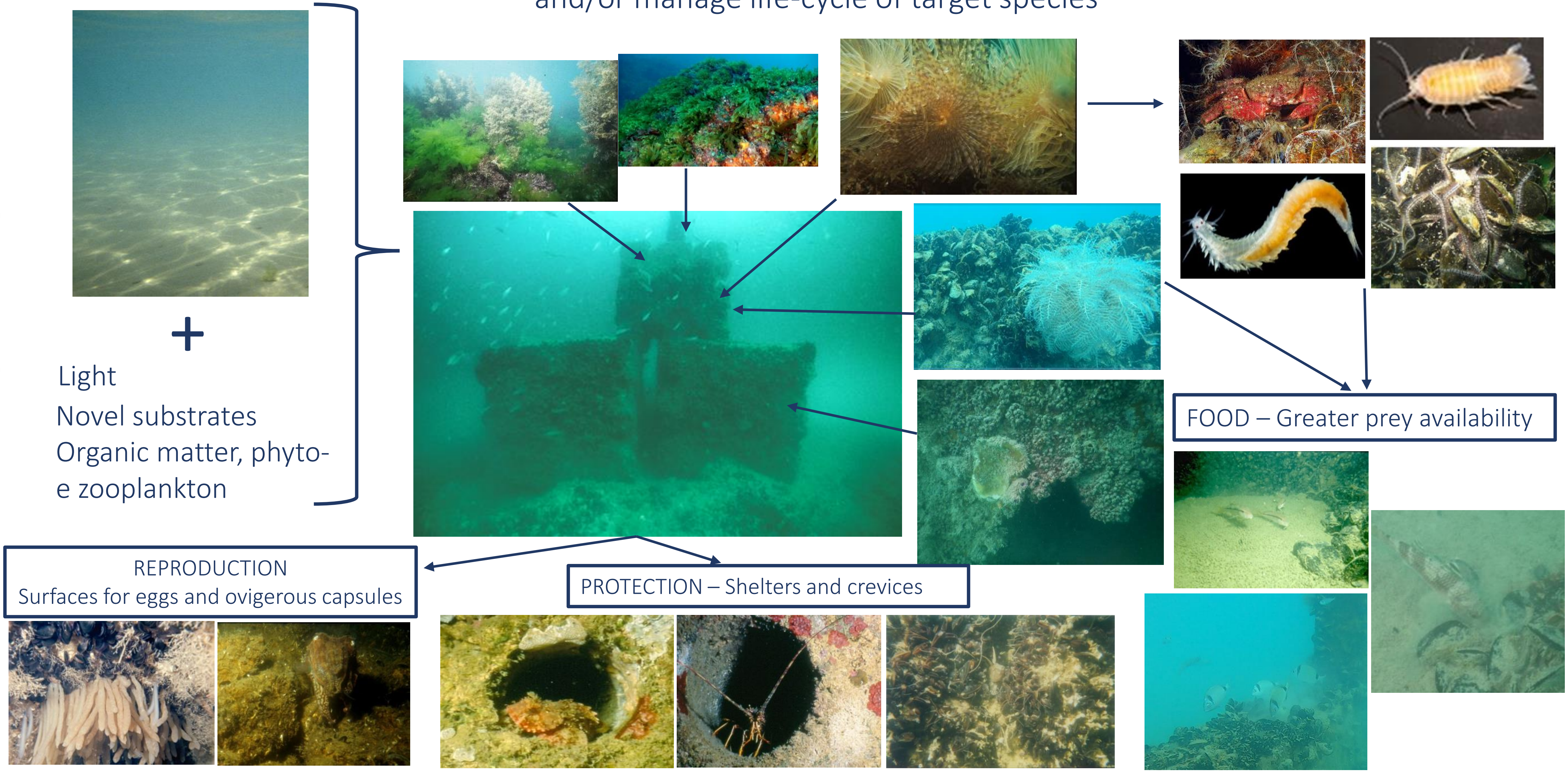
- Creation of novel functional habitats to protect coastal areas, provide habitats to aquatic organisms, and/or manage life-cycle of target species

Role of eco-engineering in NbS



Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

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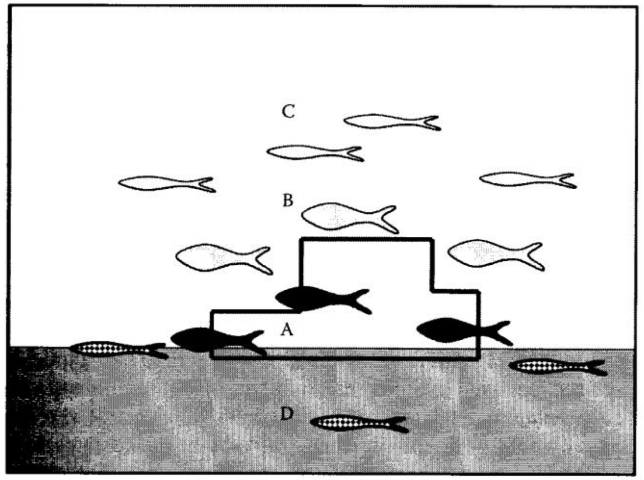
Role of eco-engineering in NbS

- Creation of novel functional habitats to protect coastal areas, provide habitats to aquatic organisms, and/or manage life-cycle of target species

Ethology of target species



Bortone, 2011

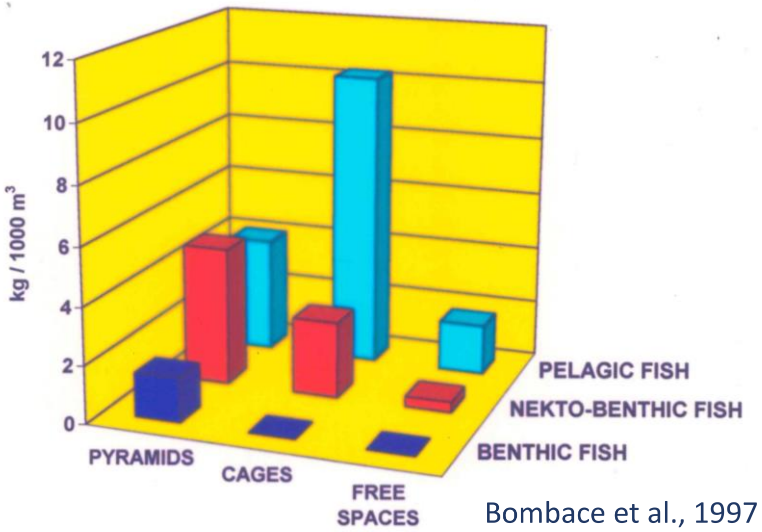
Type A: species living at strict contact with the reef, on the structures or inside them (benthic and nekto-benthic species)

Type B: species living close to the reef but which do not have any strict contact with it (nekto-benthic species)

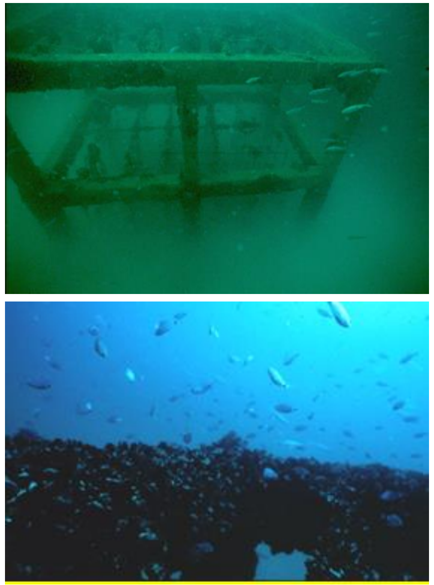
Type C: species swimming above the reef (pelagic species)

Type D: species living in the natural substrate around the reef and which have no contact with it (benthic and nekto-benthic species)

Shape and dimensions of modules



Bombace et al., 1997



Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

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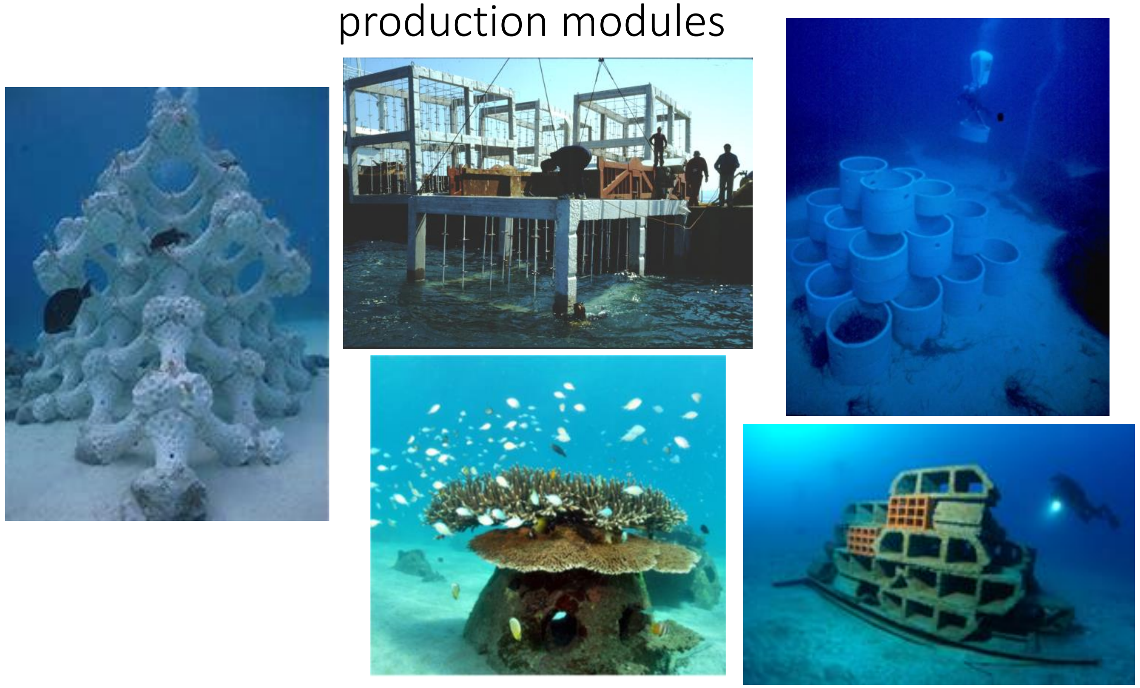
Role of eco-engineering in NbS

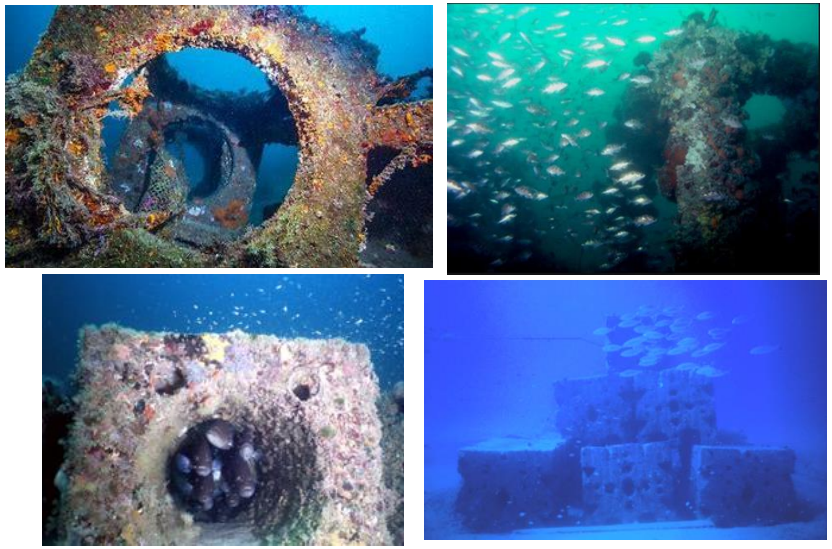
- Creation of novel functional habitats to protect coastal areas, provide habitats to aquatic organisms, and/or manage life-cycle of target species

production modules



- Reef habitats for target fish and crustaceans (EFH)
- Tourism
- Reversal of environmental degradation and biodiversity loss
- Carbon sequestration

mixed modules (protection + production)

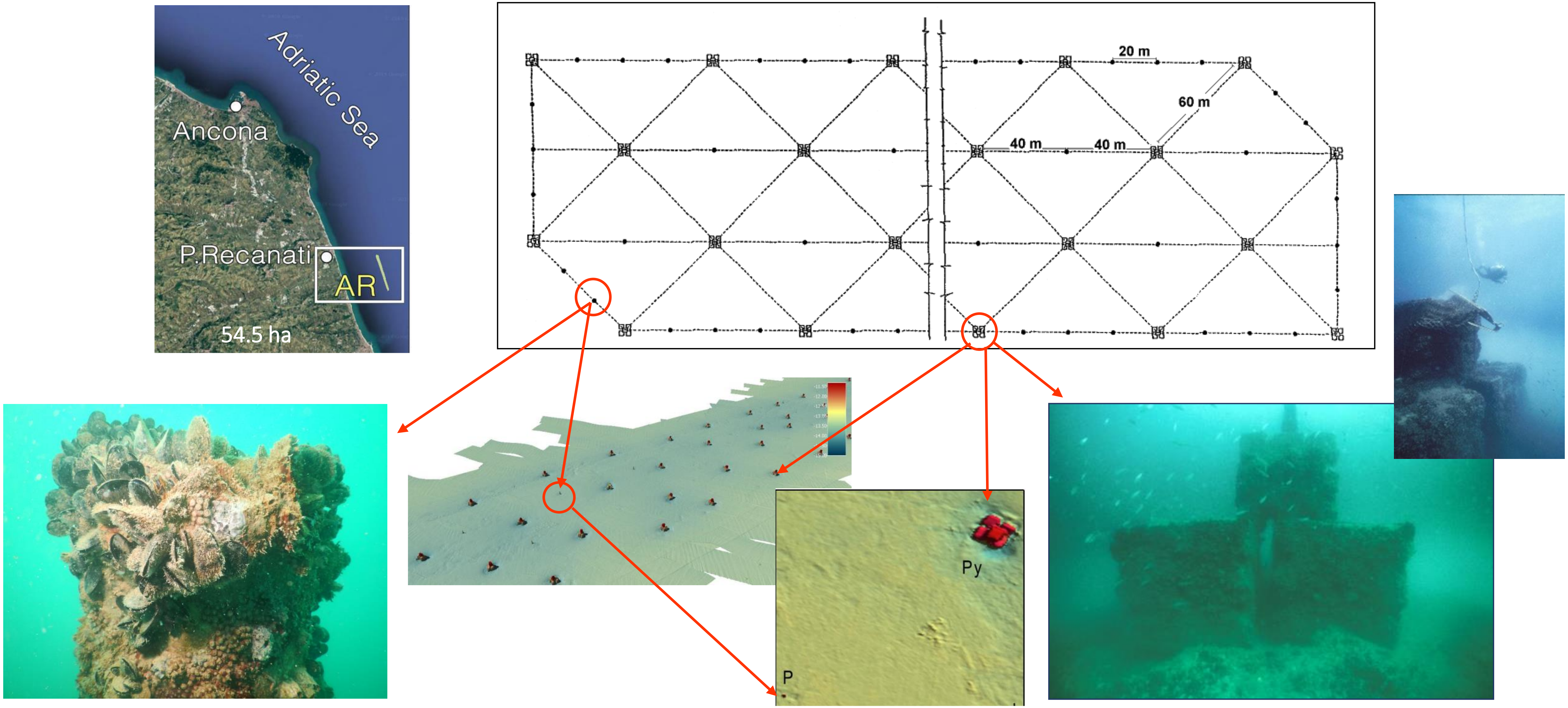


- Reversal of environmental degradation and biodiversity loss
- Spawning and nursery areas
- Reef habitats for associated fish and crustaceans (EFH)
- Tourism
- Carbon sequestration

Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

Protection of coastal spawning and nursery ground + creation of areas for reef dwelling species

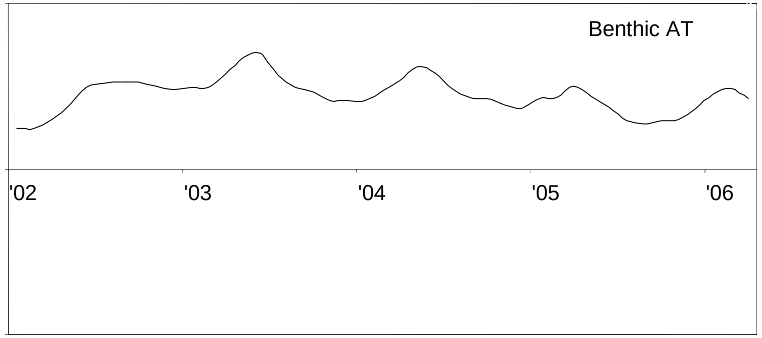
Role of eco-engineering in NbS

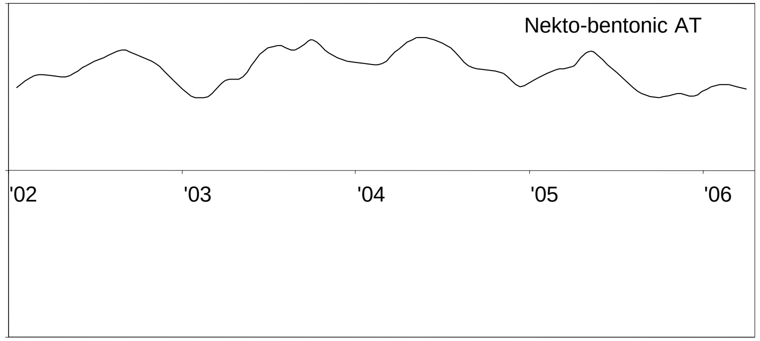


Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

Role of eco-engineering in NbS

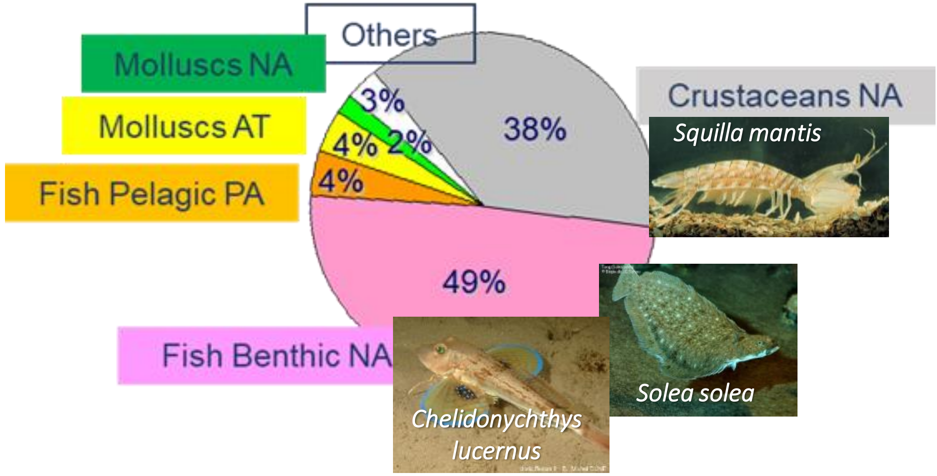
Protection of coastal spawning and nursery ground + creation of areas for reef dwelling species



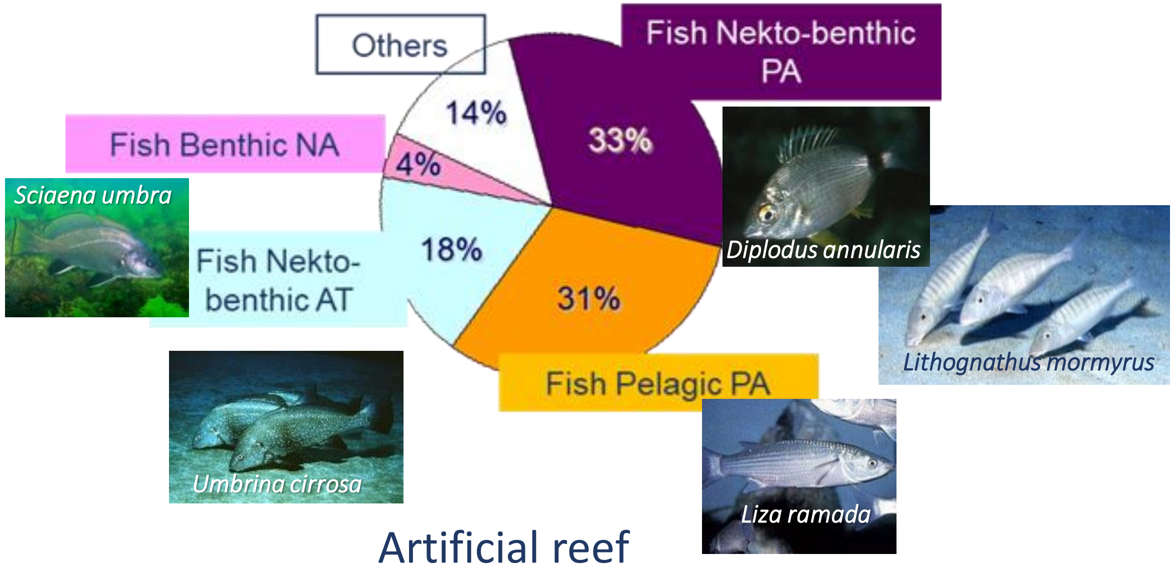


Catch ratio AR / Control site

Shifting the fishing effort from overexploited species of the natural sandy-mud habitat to other valuable reef-dwelling species



Natural habitat



Artificial reef

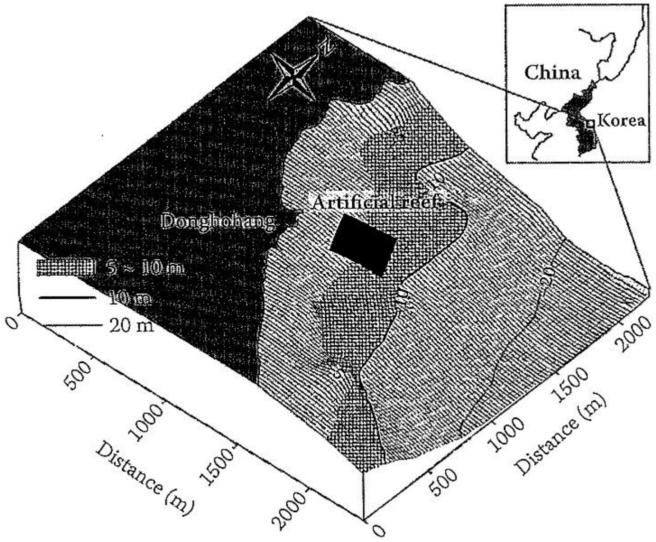
Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

FishMed-PhD

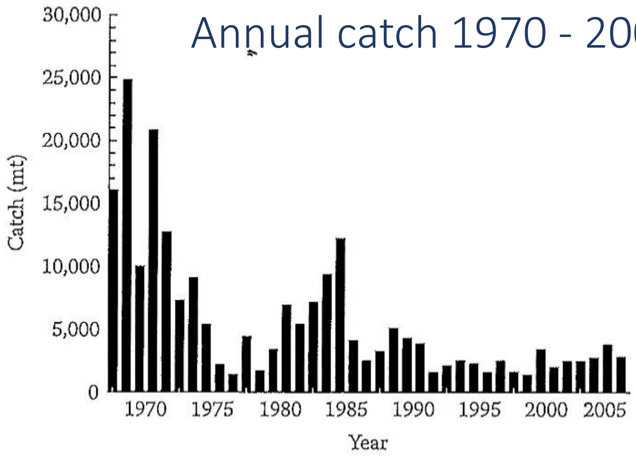
Implementation of spawning and nursery grounds: recovery of the Japanese sandfish stock (Korea)

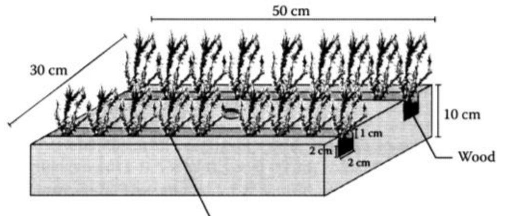
Role of eco-engineering in NbS

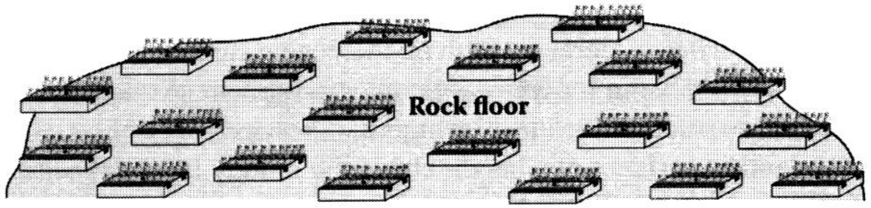
Japanese sandfish (*Arctoscopus japonicus*)



Annual catch 1970 - 2008







- Reduction of fishing effort
- Creation of fishing areas through the deployment of Ars and release of juveniles of different fish species
- Creation of spawning areas

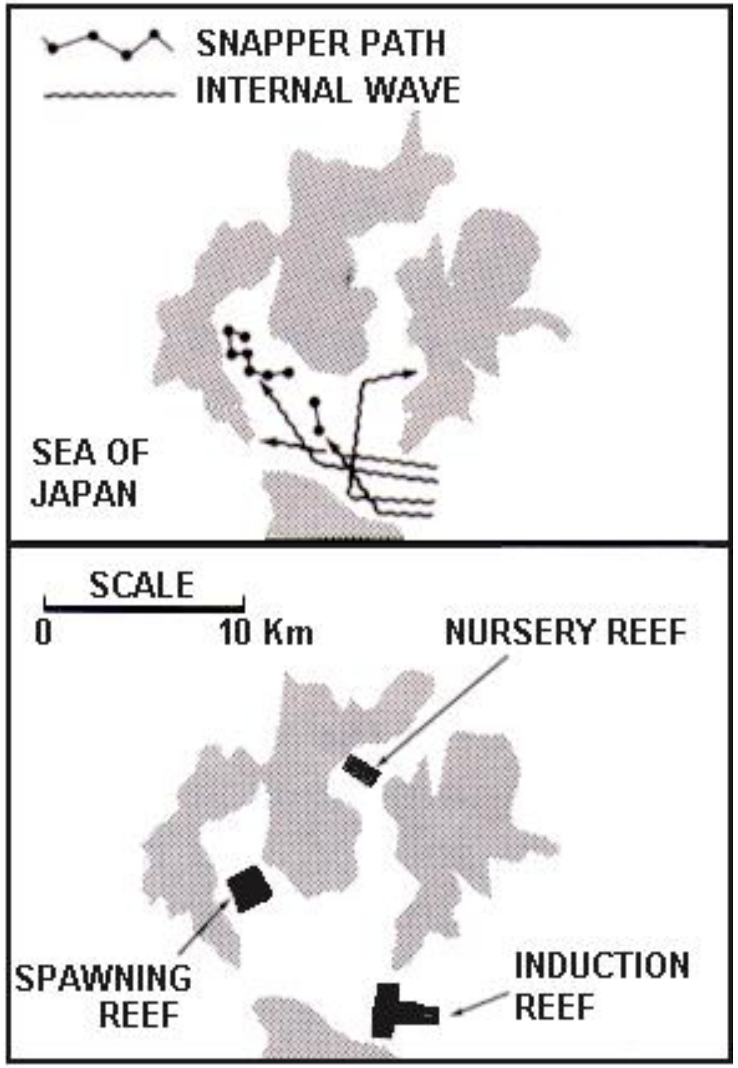
Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

New habitats to manage the life-cycle of fish species: managing life–cycle of snapper in the Iki Islands (Sea of Japan)

Baseline: Schools of snapper were observed to follow a migratory route coinciding with the propagation of waves inside a bay

Strategy: to place an induction reef at the entrance of the bay, a spawning reef where the waves converged and a nursery reef to improve the survival of juveniles

Results: this allowed to confine the life-cycle of snapper into the bay, to considerably improve their survival, and their catches to be sustainably managed by the local fishing communities (Nakamura, 1985).



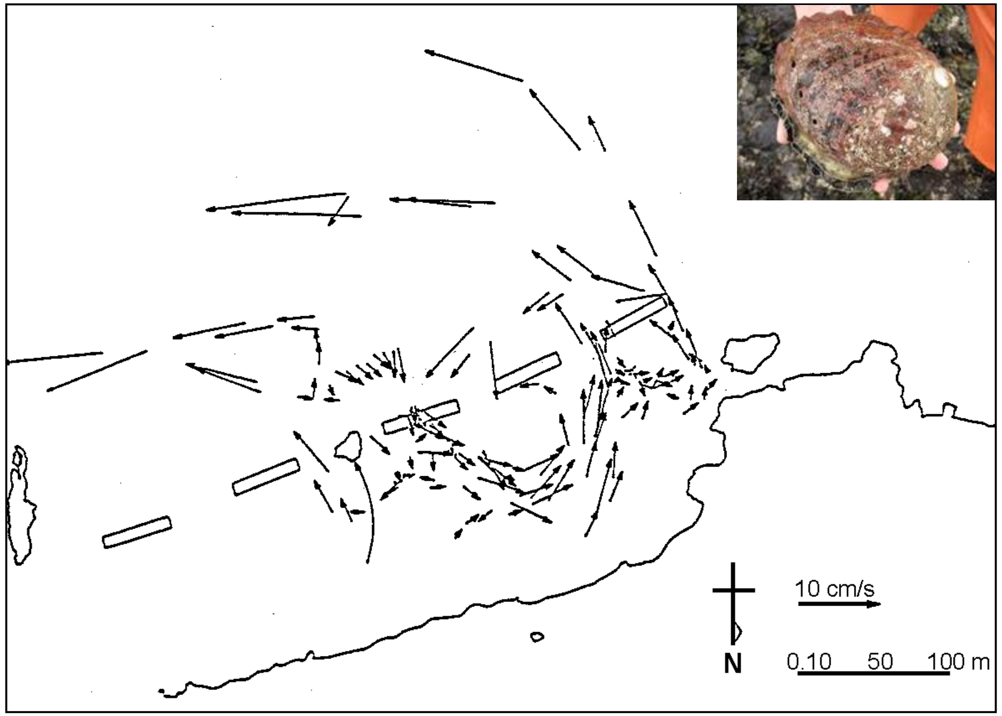
Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

Low trophic aquaculture: creation of settlement areas for abalone (*Haliotis discus* hannai), township of Taro, Japan

Goal: prevent the dispersal of floating eggs, larvae, kelp spores and drifting seaweed by longshore currents

Strategy: installation of circulation-inducing facilities which consisted of a combination of breakwaters and submerged reefs to cause stagnation and local accumulation of drifting larvae and eggs, thereby preventing attrition and dispersal of juveniles and thus enhancing their settling opportunity on local grounds

Results: After reef construction, the area inshore of the subsurface dikes developed a seaweed (*Undaria* sp) and kelp (*Laminaria* sp) community which was inhabited by fast-growing abalone and sea-urchins whose average weight was four times higher that recorded prior to reef deployment (Toda, 1991).



- **Spawning and nursery areas**
- Reef habitats for associated fish and crustaceans (EFH)
- Carbon sequestration

Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

FishMed-PhD

Role of eco-engineering in NbS

Low trophic aquaculture: creation of settlement areas for Mediterranean mussel *(Mytilus galloprovincialis* Lamarck), north-central Adriatic sea, Italy

Goal: reduce larval mortality due to scarcity of suitable substrates

Strategy: deployment of artificial structures which extend along the water column

Results: mussel biomass of 20 - 55 kg m^2/yearagainst 10 - 40 kg m-2/year of natural reefs

- **Production of economically valuable shellfish**
- Reversal of environmental degradation and biodiversity loss
- Reef habitats for associated fish and crustaceans (EFH)
- Carbon sequestration

FishMed-PhD

Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

Low trophic aquaculture: creation of settlement areas for filtering organisms to reduce contaminants and eutrophication, Black sea

Goal: reducing contaminant load and eutrophication both in the water and in the sediments, while recovering the abundance of marine life depleted by illegal trawling

Strategy: deploy artificial subtidal bottom reefs and floating structures for the settlement and development of wild mussel populations, the reefs simultaneously protecting the coastal areas against illegal fishing

Results: substantial improvement of environmental conditions, increase of fish abundance at the reefs and in the coastal areas, and re-establishment of economic and societal services

- Reversal of environmental degradation and biodiversity loss
- Production of economically valuable shellfish
- Reef habitats for associated fish and crustaceans (EFH)
- Tourism
- Carbon sequestration

Tzvetkov and Todorov, 2015

Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

Role of eco-engineering in NbS

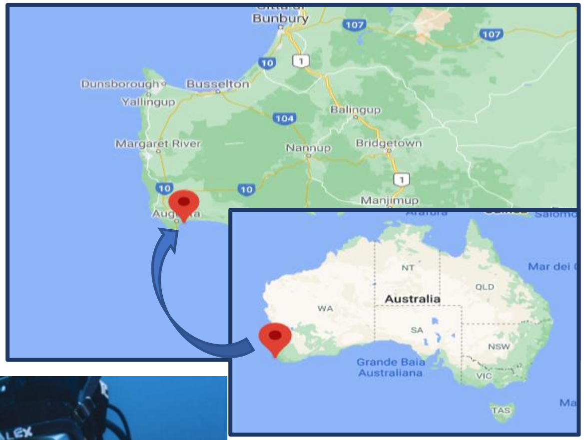
Low trophic aquaculture: Sea-ranching of greenlip abalone (*Haliotis laevigata*), Flinders Bay, Western Australia

Goal: to increase local production of greenlip abalone

Strategy:
1° step – Deployment of suitable artificial concrete habitats that provide shelter for juvenile abalone and have sufficient surface area for colonisation by macroalgae

2° step – Seeding of juvenile abalones from hatchery

3° step – Collection of adults basing on the market request



- **Production of economically valuable shellfish**
- Reef habitats for associated fish and crustaceans (EFH)
- Carbon sequestration

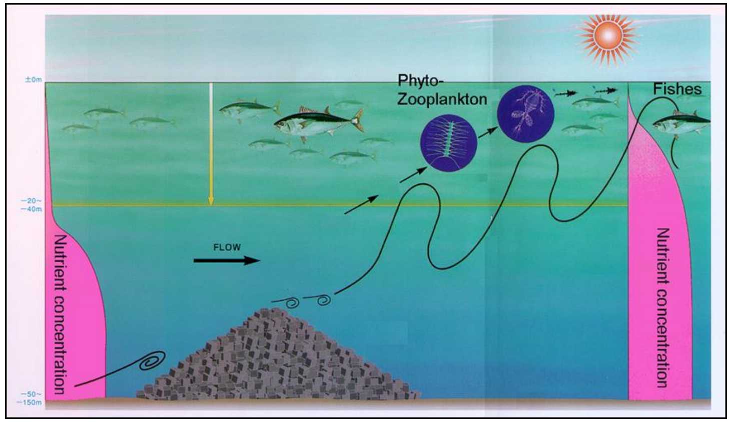
Melville-Smith et al., 2017

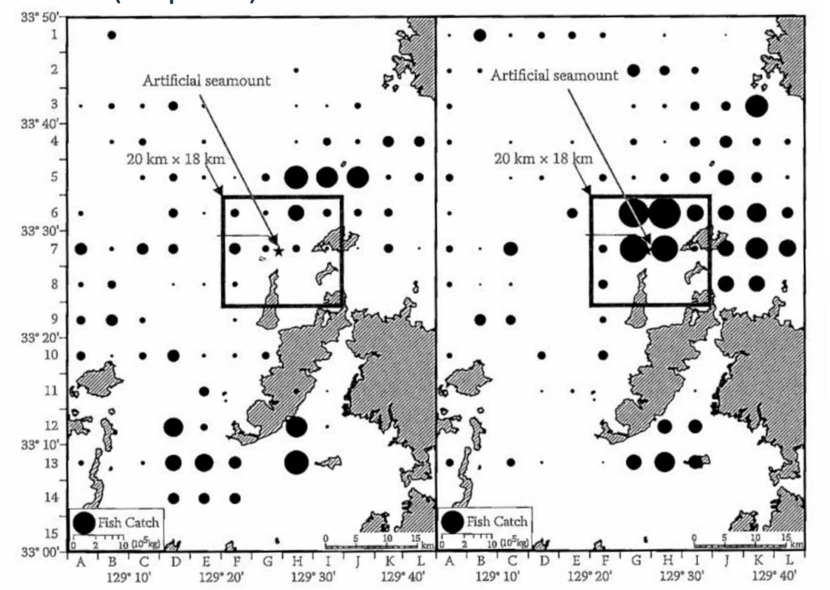
Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

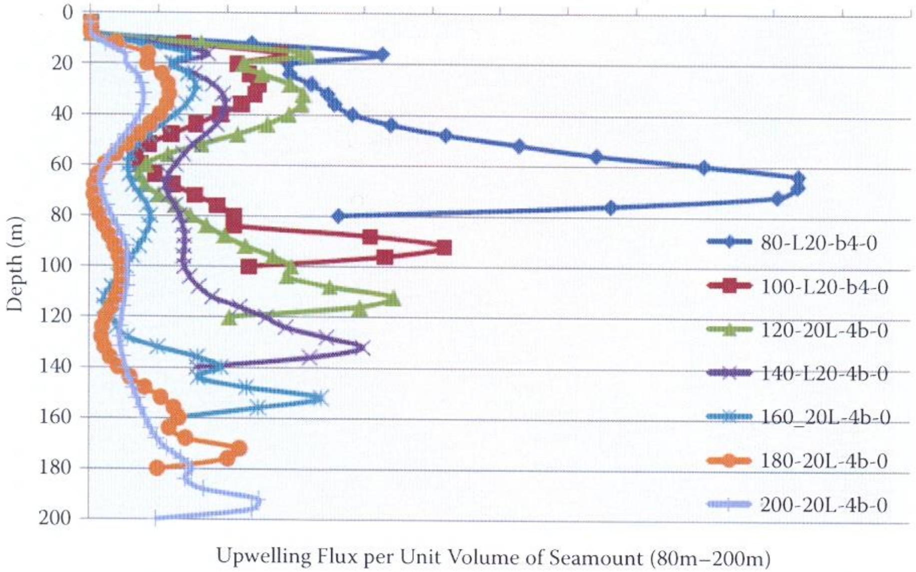
FishMed-PhD

Role of eco-engineering in NbS

Enhancing primary production and pelagic trophic chains on the continental shelf by artificial seamounts, Ikitsuki Island, Nagasaki Prefecture (Japan)







Catch increase of 6 times in the area surrounding the sea mountain (18x20 km) with the structure completed at 70%

- **Increase primary production to enhance fish populations**
- Carbon sequestration

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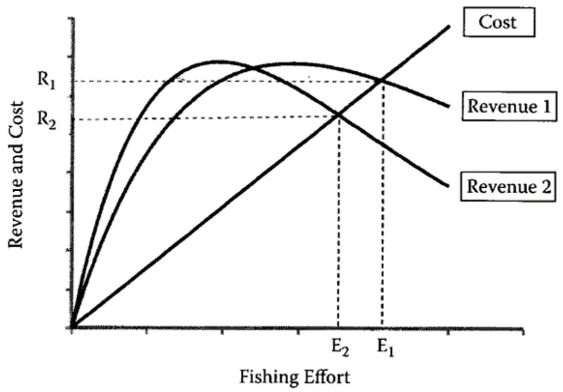
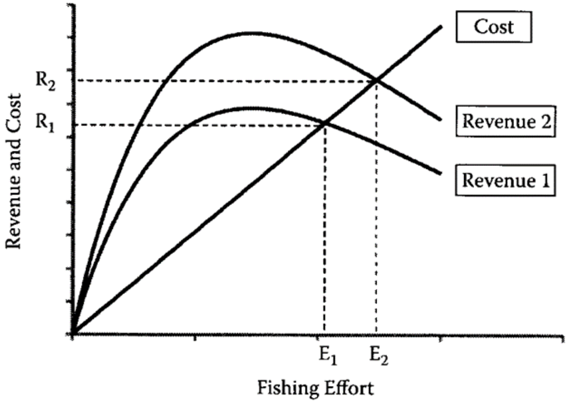
Role of eco-engineering in NbS

Dilemma: aggregation or production?

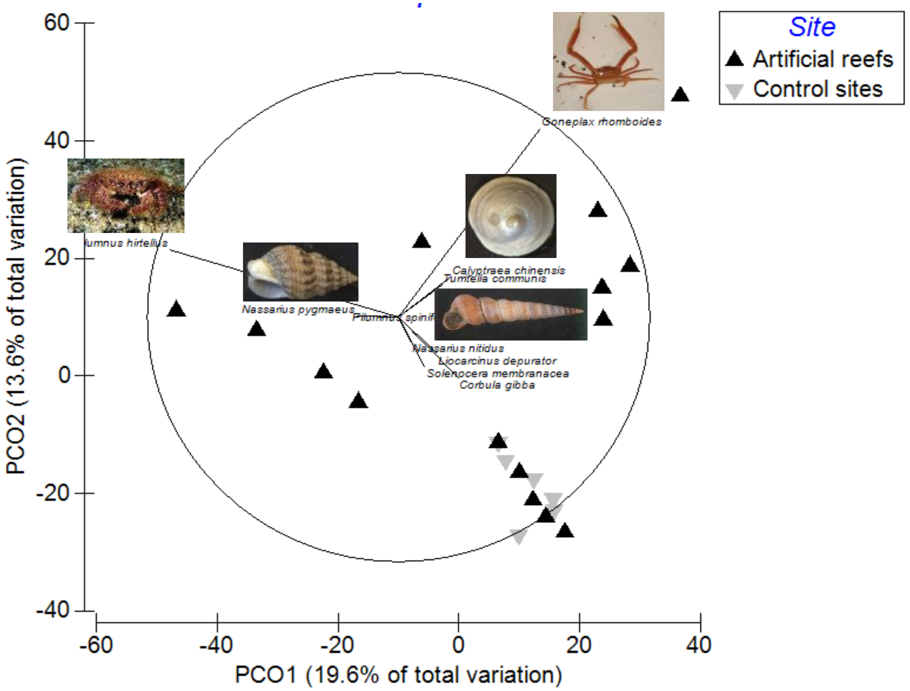


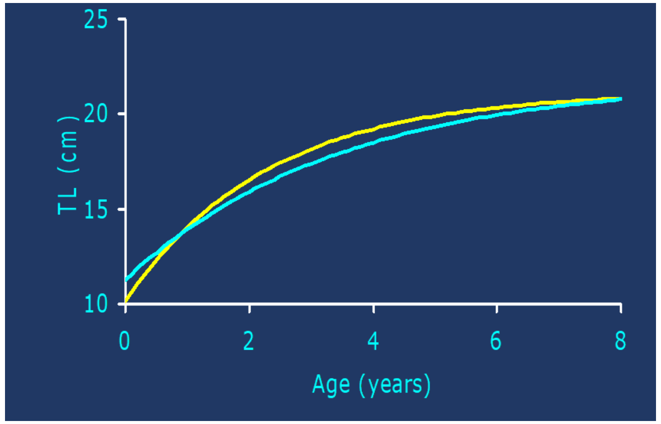
Effects on a commercial fishery of an increase in the efficiency of capture (aggregation scenario). The effect of an aggregation reef is to shift the revenue curve to the left, altering the open-access equilibrium such that effort falls to E2 and revenue to R2.



Effects on a commercial fishery of an increase in the environmental carrying capacity of the stock (enhancement scenario). Here, the starting equilibrium is the same as in Figure 2.2 (aggregation scenario), but the effect of an enhancement reef is to shift the revenue curve outward, and as a result effort and revenue increase.

Scorpaena porcus





Scorpaena porcus	Artificial structures	Natural reefs
L_∞ (cm)	21.16	21.80
k (year $^{-1}$)	0.43	0.29
t_0 (year)	-1.51	-2.51
Φ'	2.29	2.14
n	255	138

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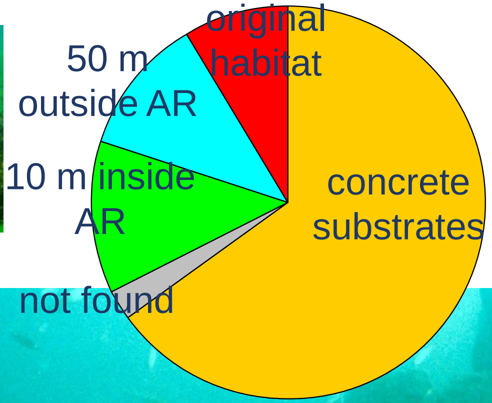
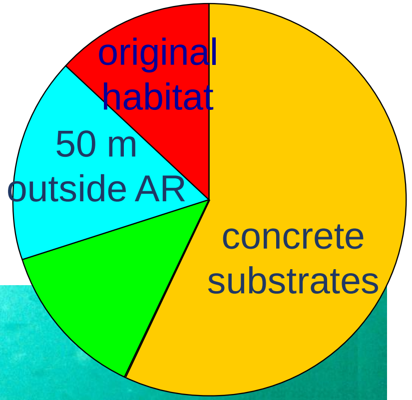
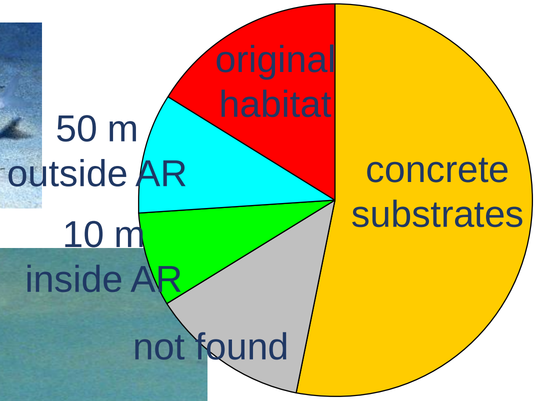
Role of eco-engineering in NbS





Lithognathus mormyrus



Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

Dilemma: aggregation or production?

Production and aggregation are not mutually exclusive and can represent the opposite extremes of a gradient.

Their relative importance can vary according to the ecology of the different species and it is very likely that most of fish are placed between the two extremes.

Aggregation may prevail just after reef deployment but, with the establishment of a benthic community and of a resident fish population, production likely occurs for some habitat-limited species.

Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

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Role of eco-engineering in NbS

- Novel habitats formed by boulders or oyster shells, alone or associated with artificial reefs, for coastal defence as alternative approach to conventional armoured structures



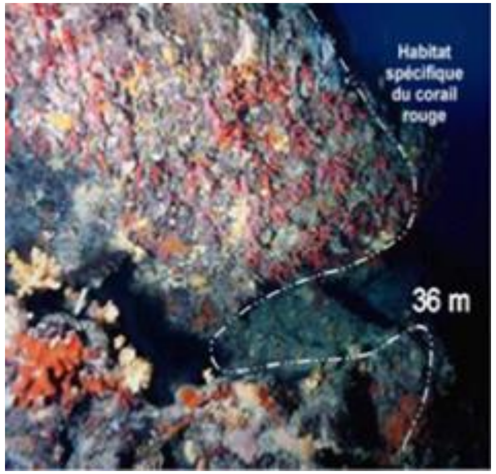
- **Protection of coastline against erosion**
- **Reversal of environmental degradation and biodiversity loss**
- Spawning and nursery areas
- Carbon sequestration

FishMed-PhD

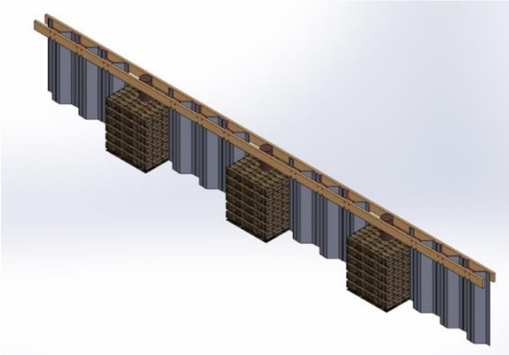
Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

Role of eco-engineering in NbS

➢ "Greening of grey hard infrastructure" where coastal and offshore infrastructures are shaped to facilitate attachment of benthic organisms and offer shelter from predation to juvenile fish



- Reversal of environmental degradation and biodiversity loss
- Spawning and nursery areas
- Carbon sequestration



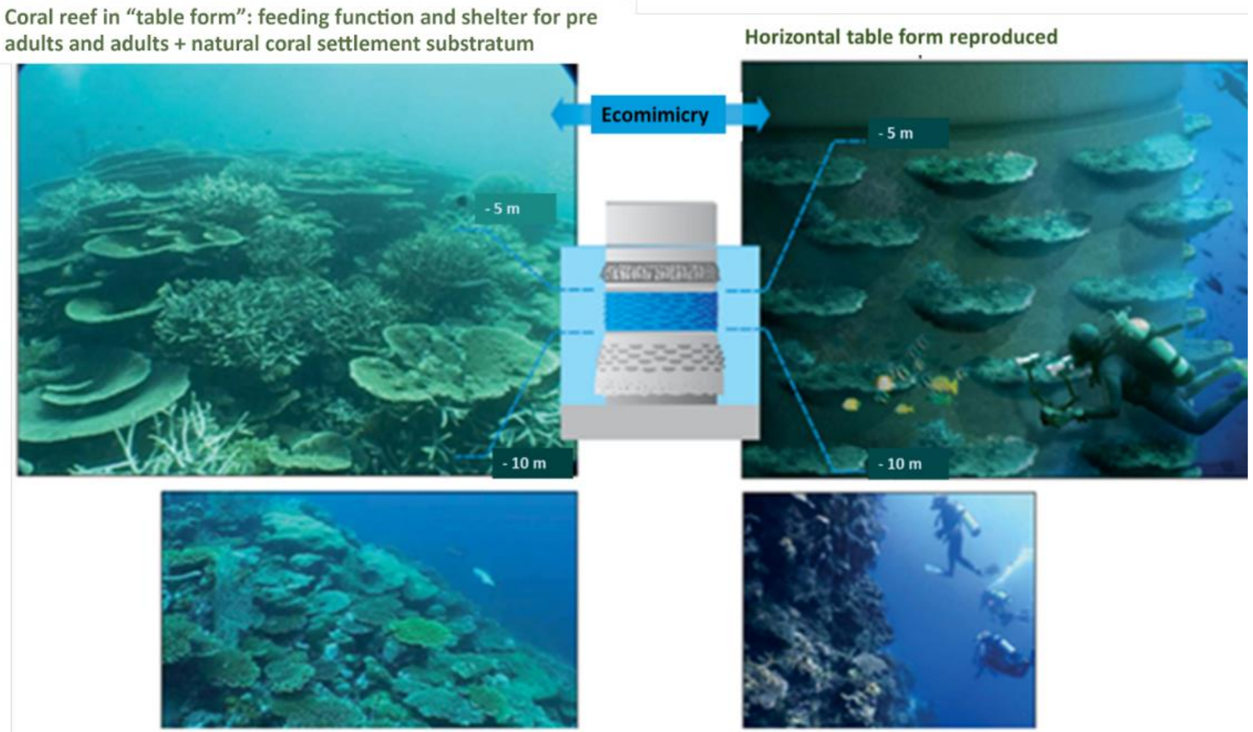
Pioch and Souce, 2021

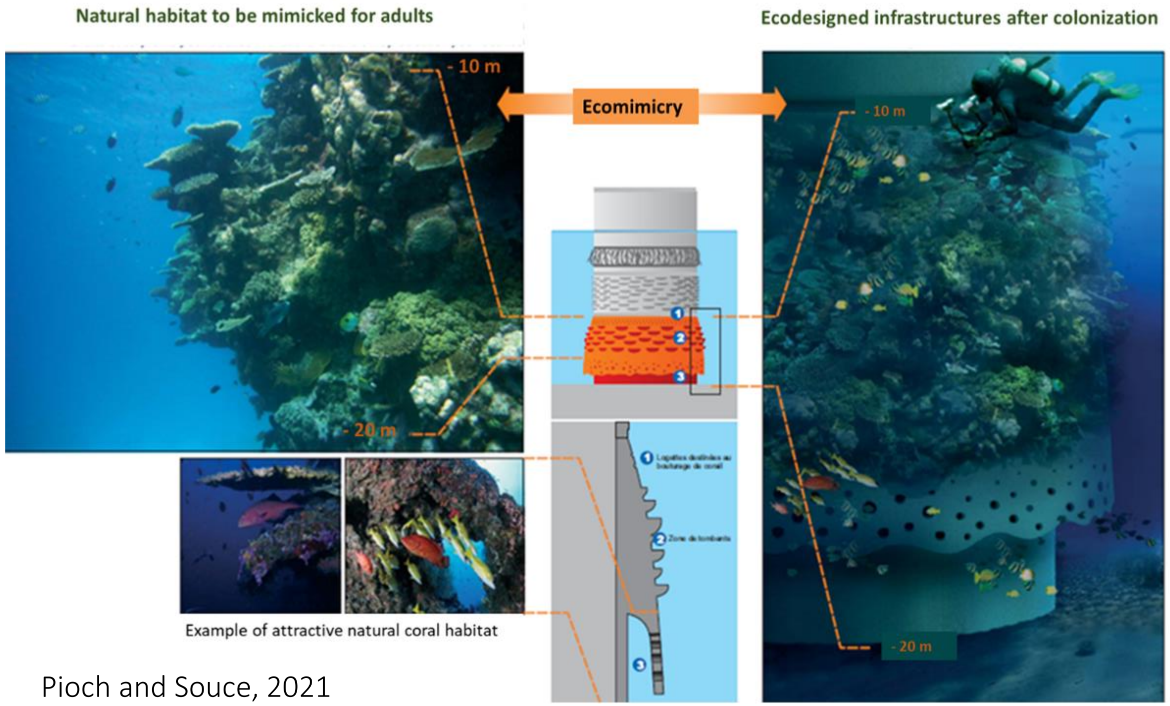
Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

Role of eco-engineering in NbS

- “Greening of grey hard infrastructure” where coastal and offshore infrastructures are shaped to facilitate attachment of benthic organisms and offer shelter from predation to juvenile fish

Reunion Island (Indian Ocean)





Pioch and Souce, 2021

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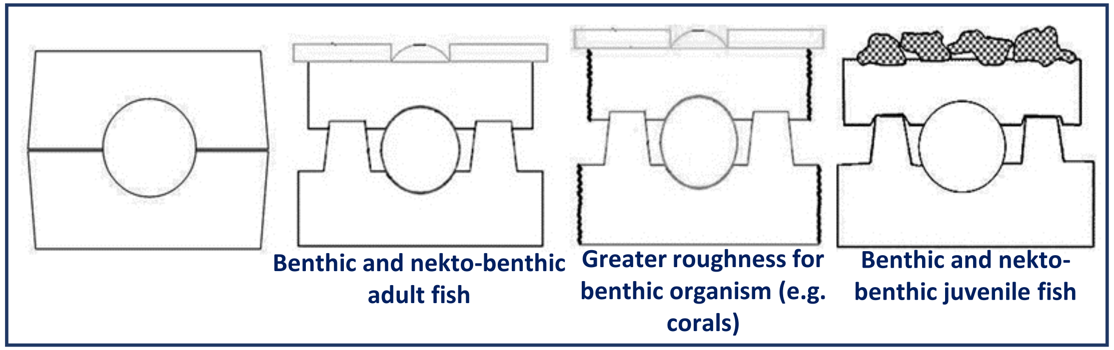
Role of eco-engineering in NbS

➢ "Greening of grey hard infrastructure" where coastal and offshore infrastructures are shaped to facilitate attachment of benthic organisms and offer shelter from predation to juvenile fish

Mayotte Island (Indian Ocean)



- Reversal of environmental degradation and biodiversity loss
- Spawning and nursery areas
- Carbon sequestration

Pioch and Souce, 2021

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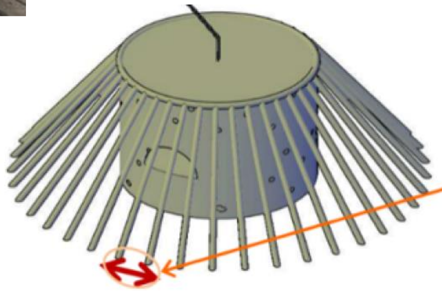
Type 3 NbS – solutions which provide novel, restored or deliberately designed artificial marine ecosystems

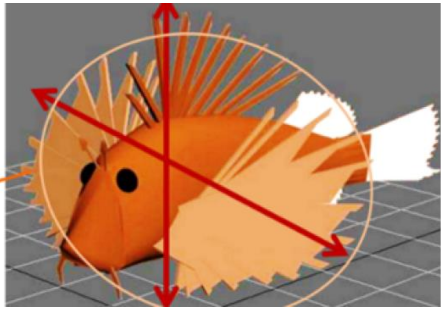
Role of eco-engineering in NbS

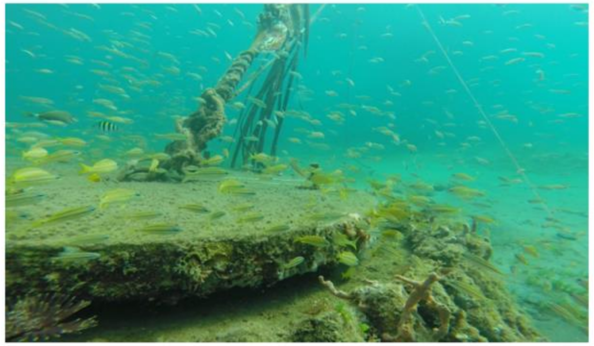
- “Greening of grey hard infrastructure” where coastal and offshore infrastructures are shaped to facilitate attachment of benthic organisms and offer shelter from predation to juvenile fish

Ajaccio, Corsica (Mediterranean sea)

Guadeloupe (Caribbean sea)







Pioch and Souce, 2021

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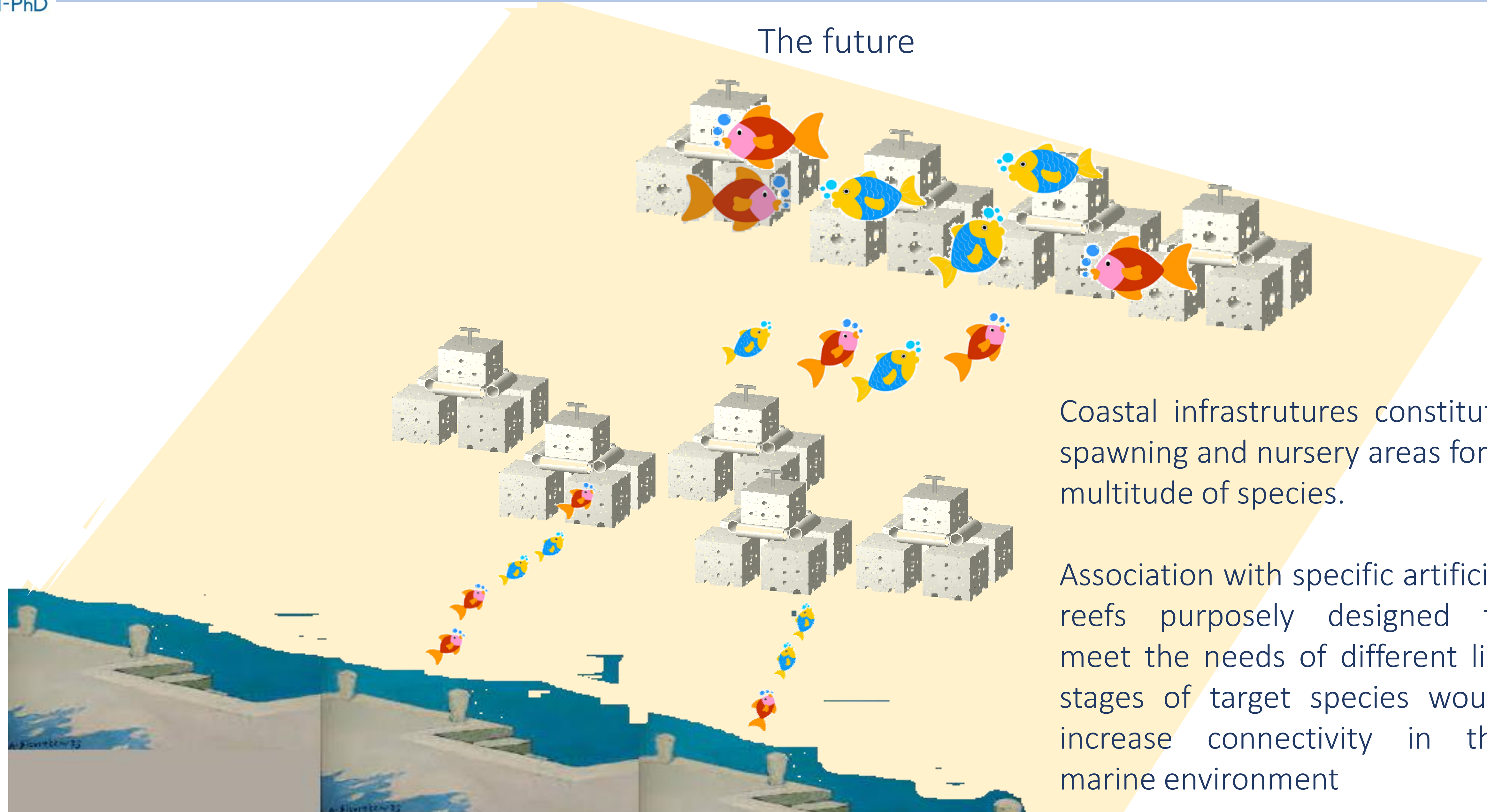
Role of eco-engineering in NbS

The future



Coastal infrastrutures constitute spawning and nursery areas for a multitude of species.

Association with specific artificial reefs purposely designed to meet the needs of different life stages of target species would increase connectivity in the marine environment

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