Living with global environmental changes

University of Trieste

Seminar Marine Biology course

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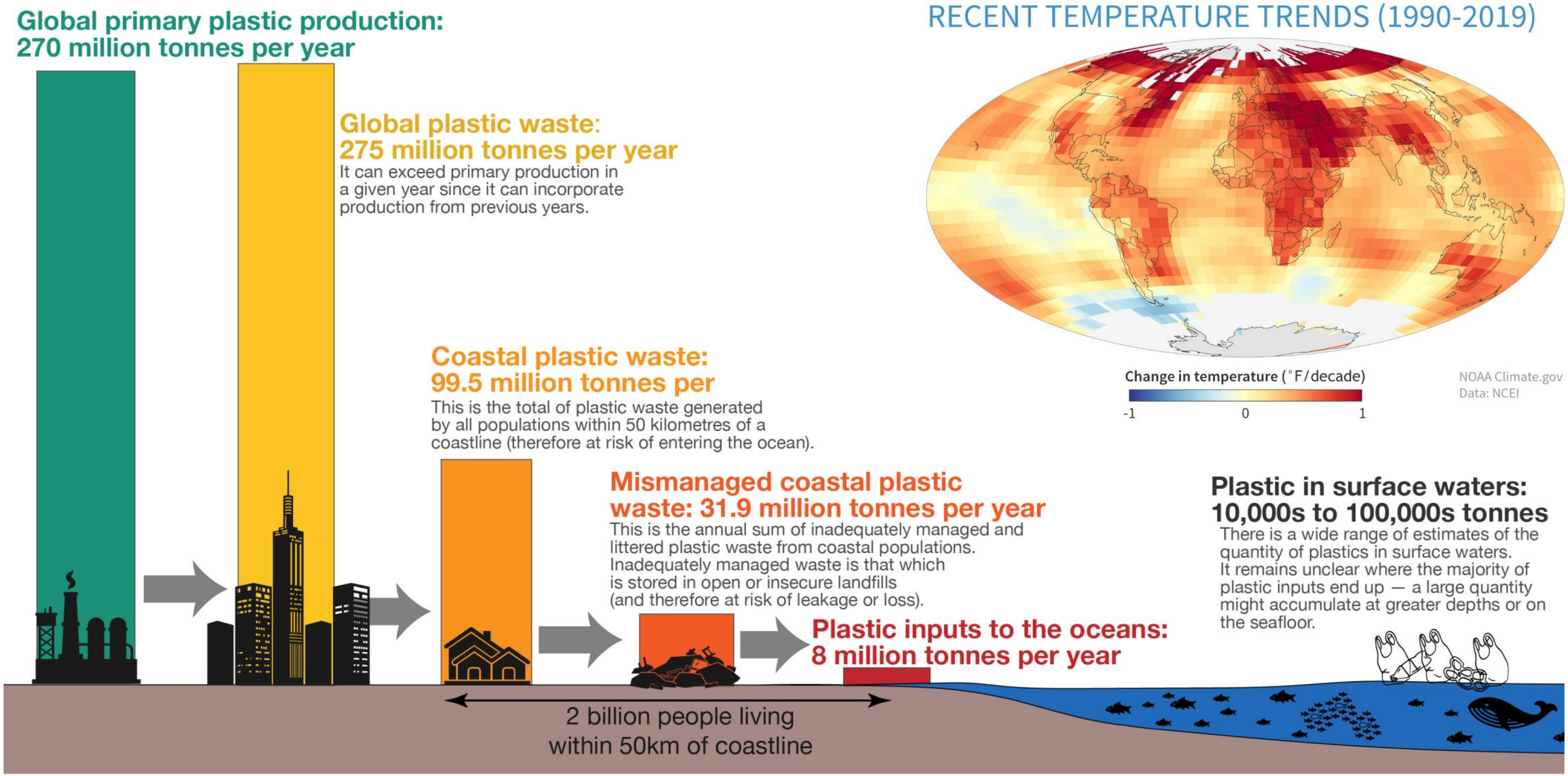
Ph. D student **Jessica Pazzaglia** (UNITS – SZN)

UNIVERSITÀ DEGLI STUDI DI TRIESTE

Stazione Zoologica Anton Dohrn Napoli

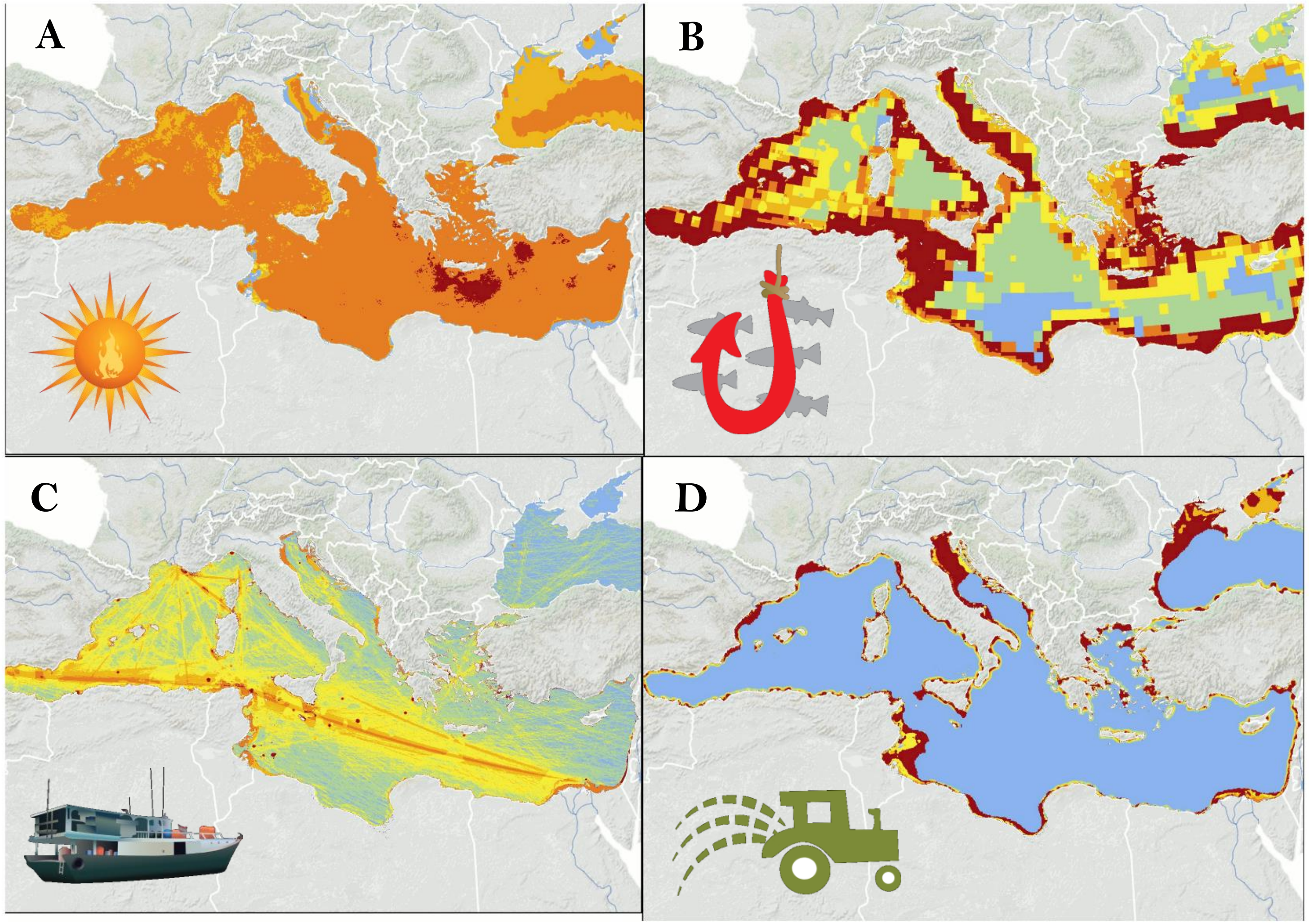
The pathway by which plastic enters the world's oceans

Estimates of global plastics entering the oceans from land-based sources in 2010 based on the pathway from primary production through to marine plastic inputs.



Source: based on Jambeck et al. (2015) and Eriksen et al. (2014). Icon graphics from Noun Project.
Data is based on global estimates from Jambeck et al. (2015) based on plastic waste generation rates, coastal population sizes, and waste management practices by country

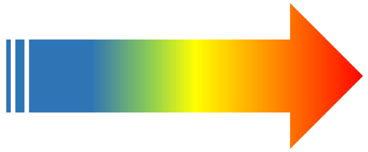
The Mediterranean Sea is a hotspot of environmental changes



Micheli et al., 2013

Driver categories are: climate (i.e. the combined cumulative impact of temperature and UV increase, and acidification; **A**), fishing (all fishing types combined; **B**), sea-based drivers (commercial shipping, invasive species, oil spills and oil rigs; **C**) and land-based drivers (nutrient input, organic pollution, urban runoff, risk of hypoxia and coastal population density; **D**).

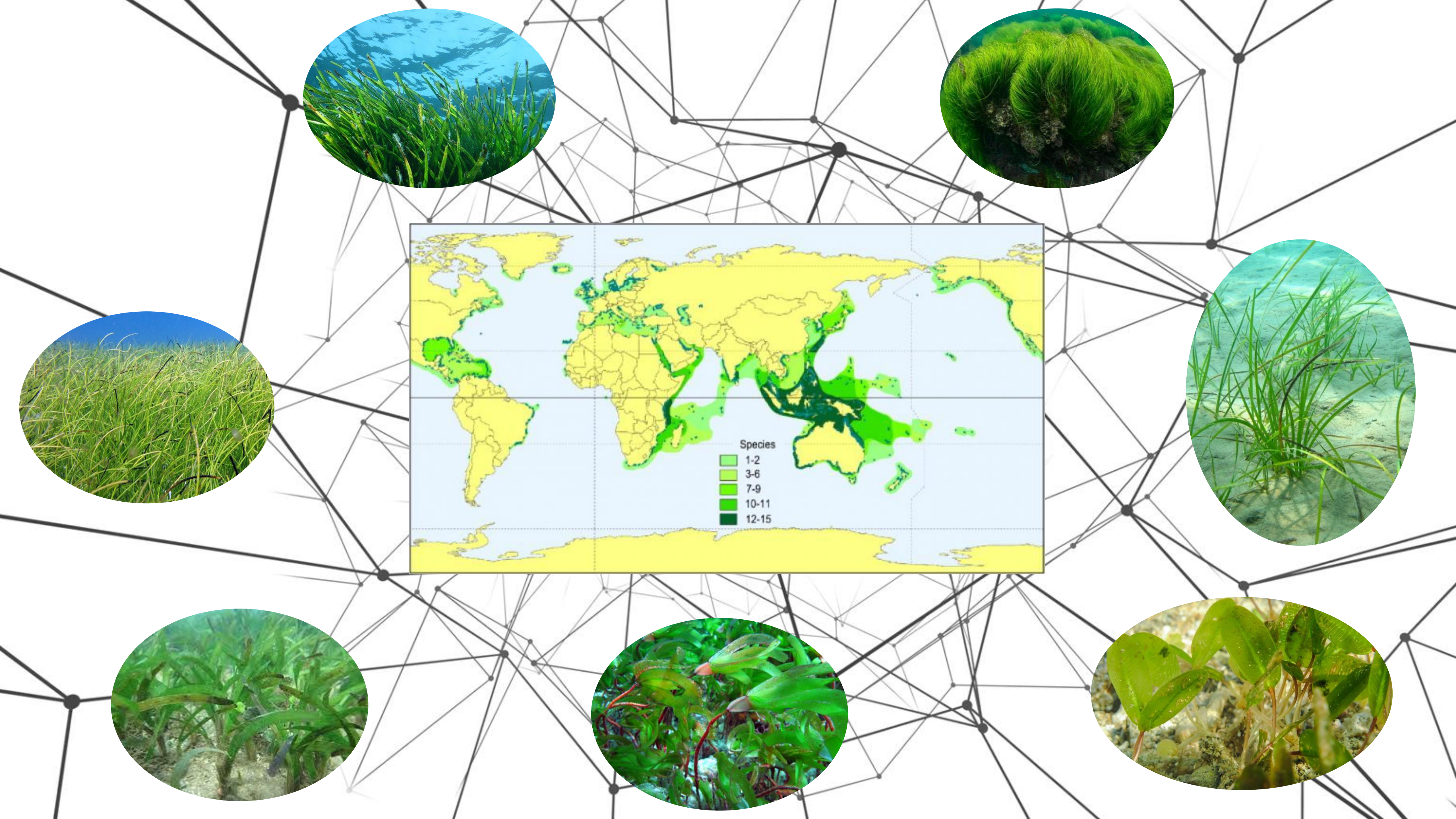
LOW-IMPACTS



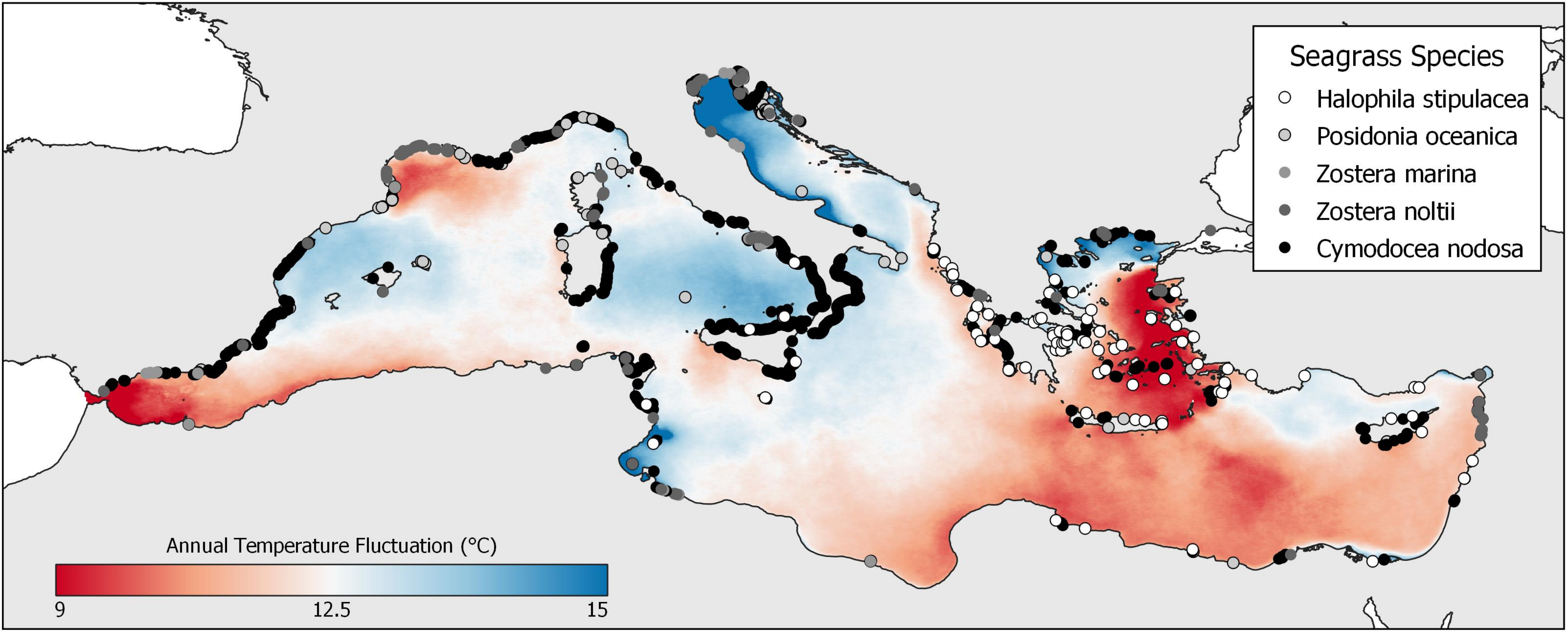
HIGH-IMPACTS

Seagrasses: an ancient giant

- ‘Ecosystem engineers’
- ‘Lungs of the Sea’ (1m2 = 1L O2)
- ‘Nursery habitats’ (40 000 fish – 50milion invertebrate species)
- Foundation of Coastal Food Webs
- Regulators of biophysical processes (nutrients, sediments, coast erosion)
- Blue carbon (1 acre = 83g C per year = 80milion of tons per year)
- Prevention of coast erosion


Species
1-2
3-6
7-9
10-11
12-15

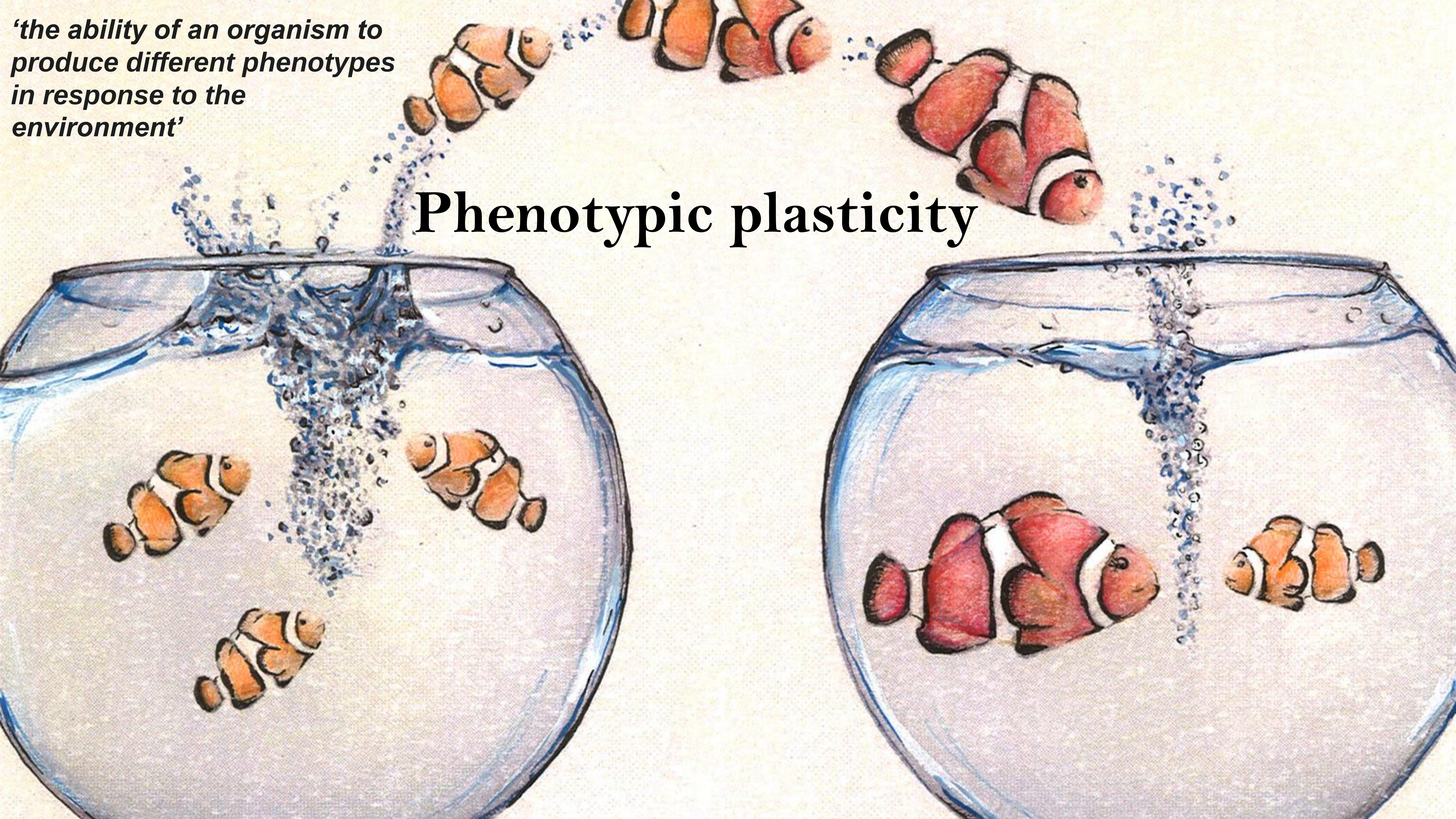
Distributed across different environments



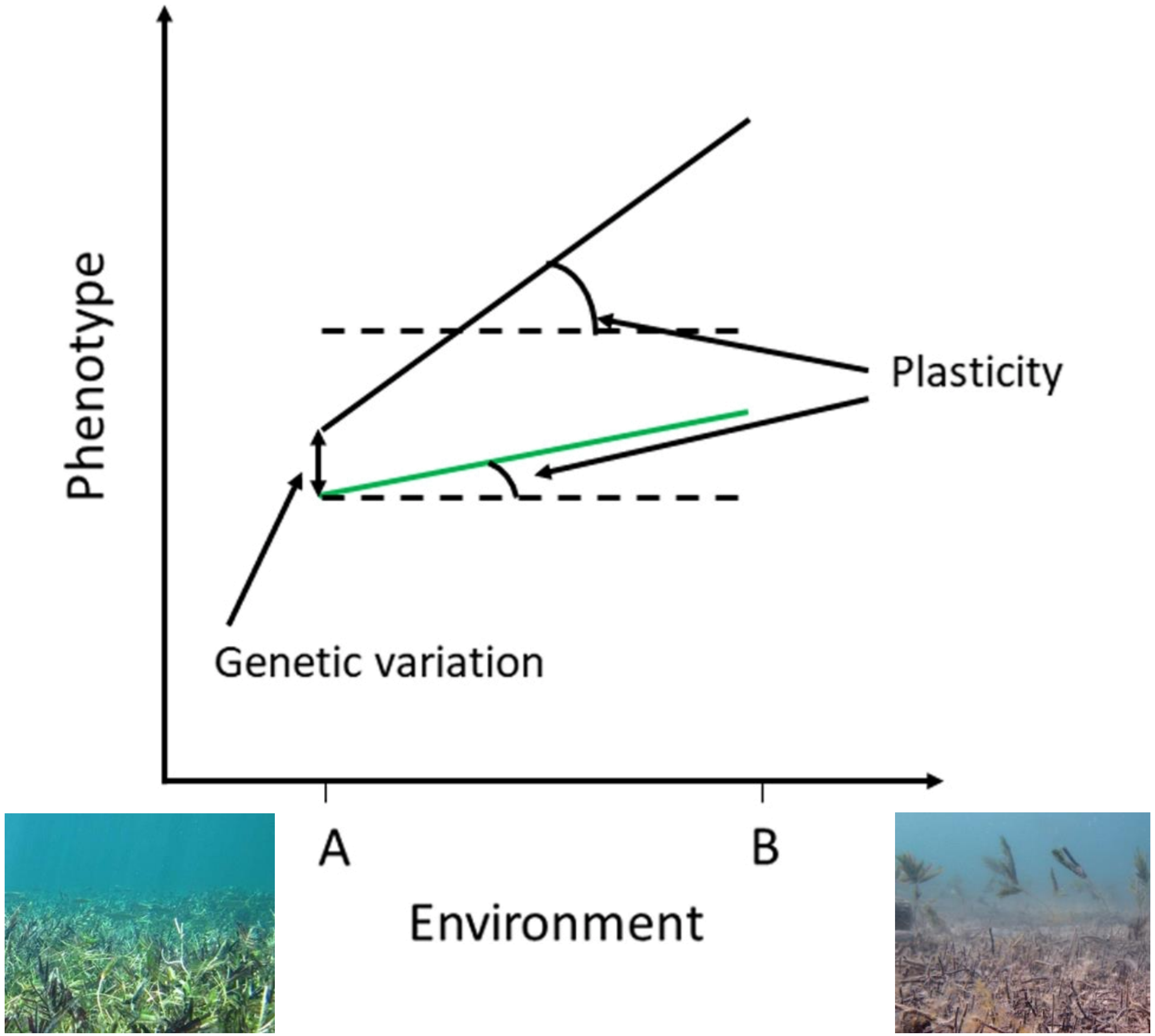
Short et al., 2007

Phenotypic plasticity

‘the ability of an organism to produce different phenotypes in response to the environment’



How to be plastic?



<u>Genotype :</u> *The genetic makeup (i.e. complete genome) of a single organism*

↓

Environment

↓

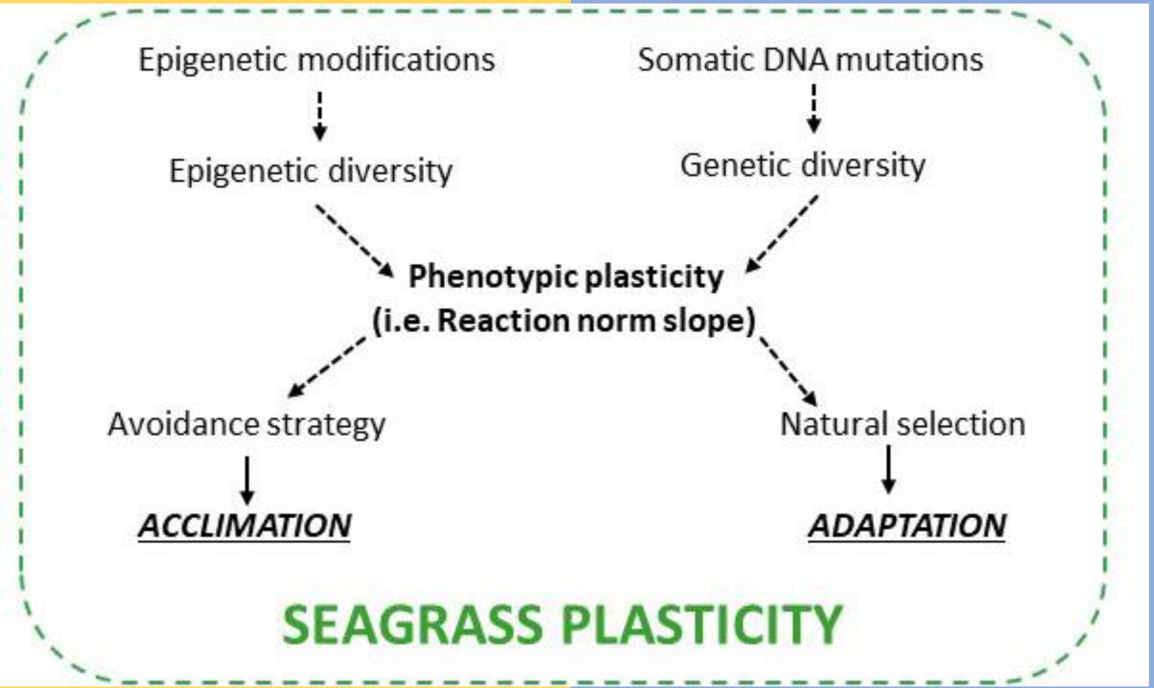
<u>Phenotype :</u> *The expression of a trait as a result of both genetic and environmental changes*

↓

<u>Reaction norm</u> *is the function which describes a curve that relates the environment to a phenotype. Different shapes of this function describe the degree of plasticity of a single genotype across the environment*

Epigenetics

Genetics



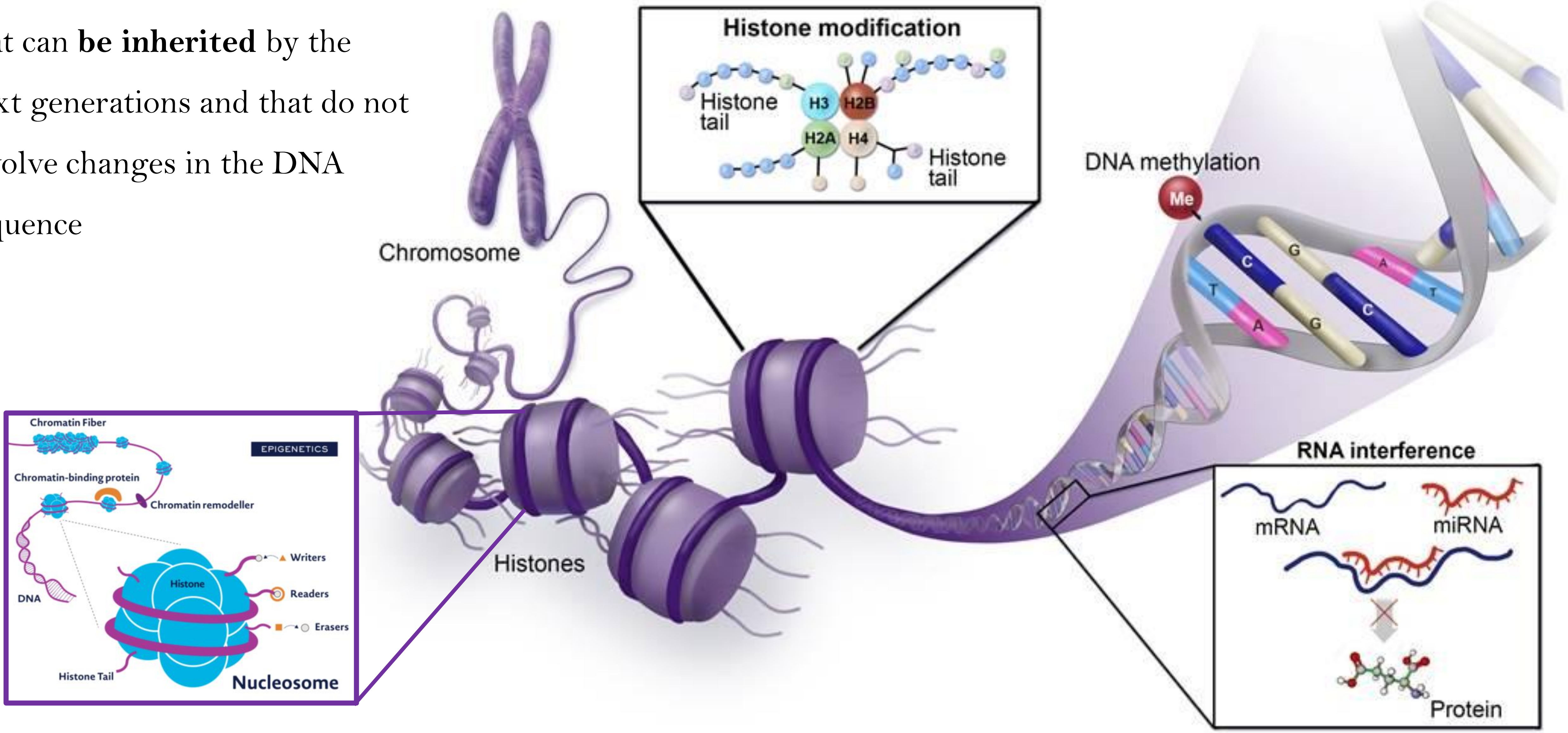
Acclimation : The most relevant short-term response which allows organisms to adjust to rapidly changing environments extending their tolerance ranges

Adaptation: process resulting from the natural selection of better-suited genotypes across generations, changing the genetic composition of populations

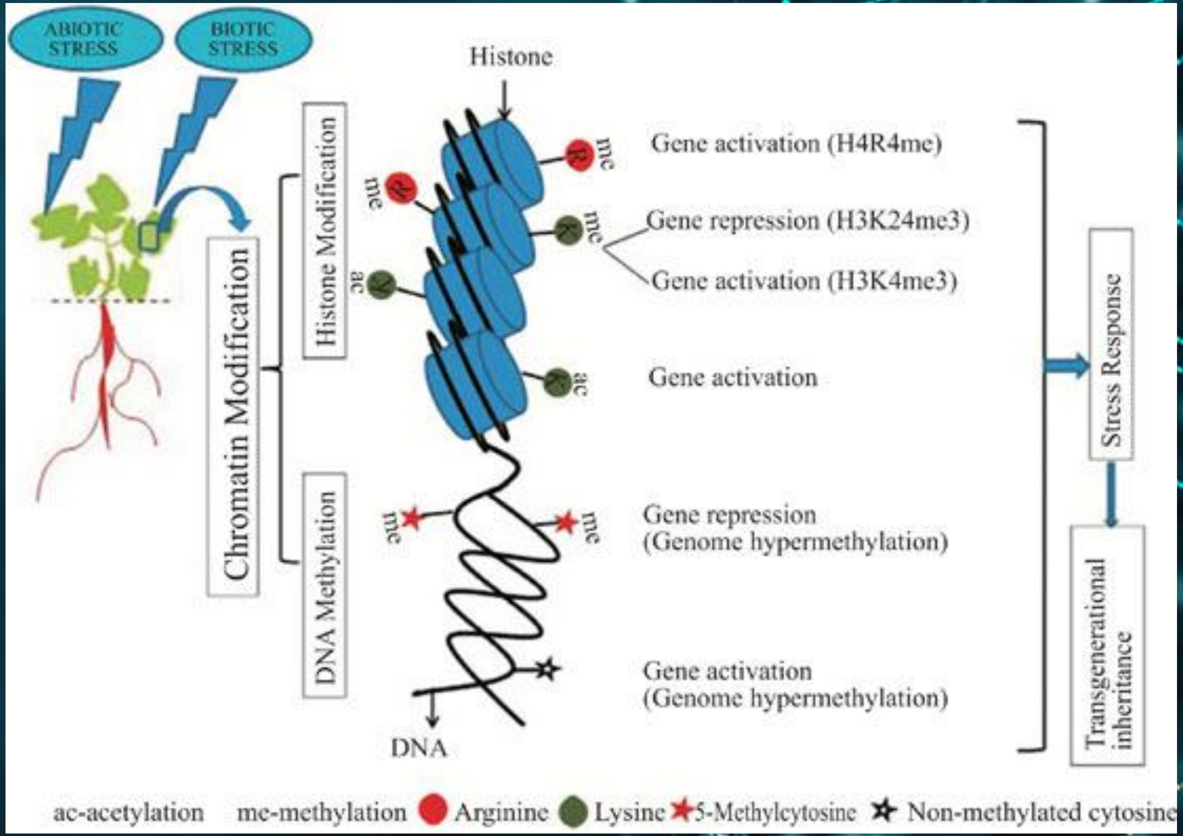
Pazzaglia et al., 2021

What is epigenetics?

DNA and **chromatin changes** that can **be inherited** by the next generations and that do not involve changes in the DNA sequence



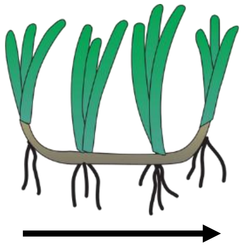
Epigenetics modulates gene expression



In seagrasses:

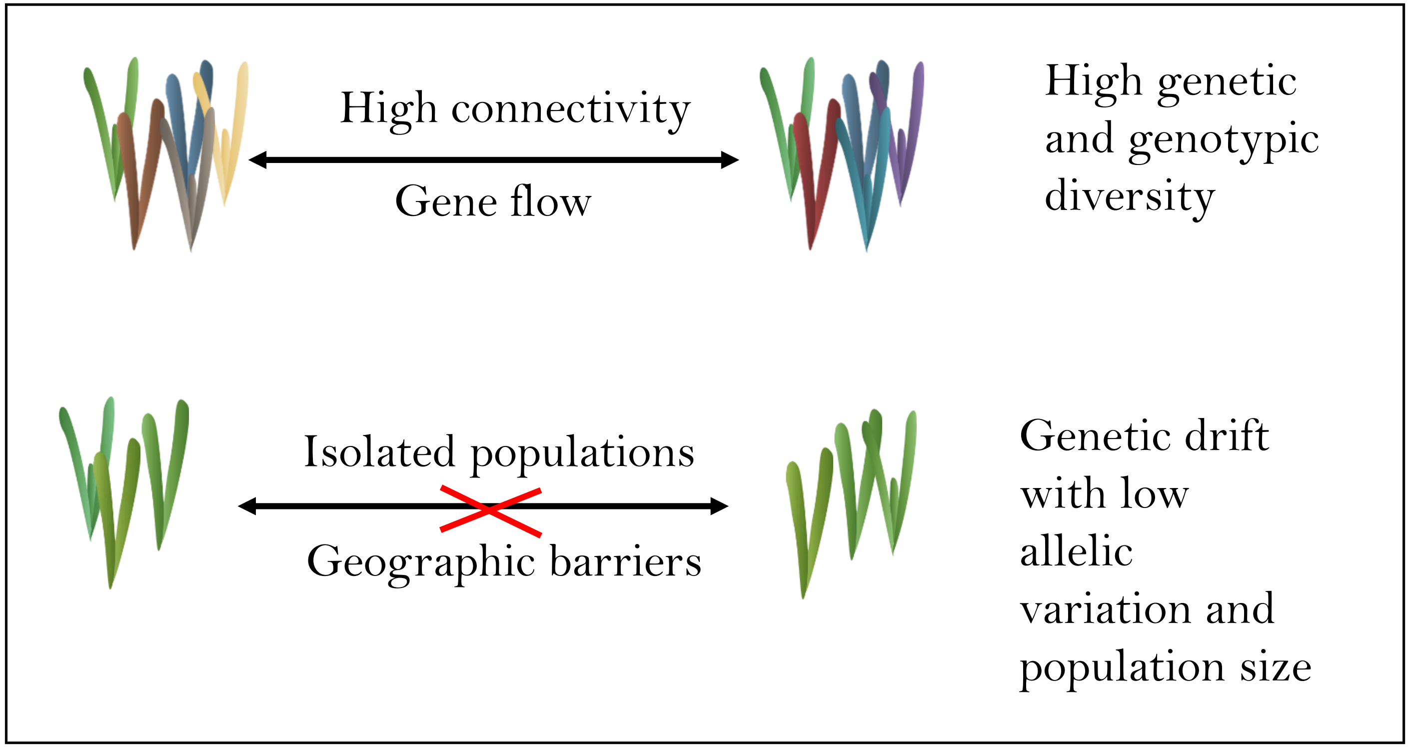
- Cadmium exposure affects DNA methylation in *P. oceanica* plants modifying the expression of methyl-transferases (*Greco et al., 2012*)
- Methylation affects functional genes in *Z. marina* under thermal stress (*Jueterbock et al., 2020*)

Genetic diversity and connectivity in seagrasses



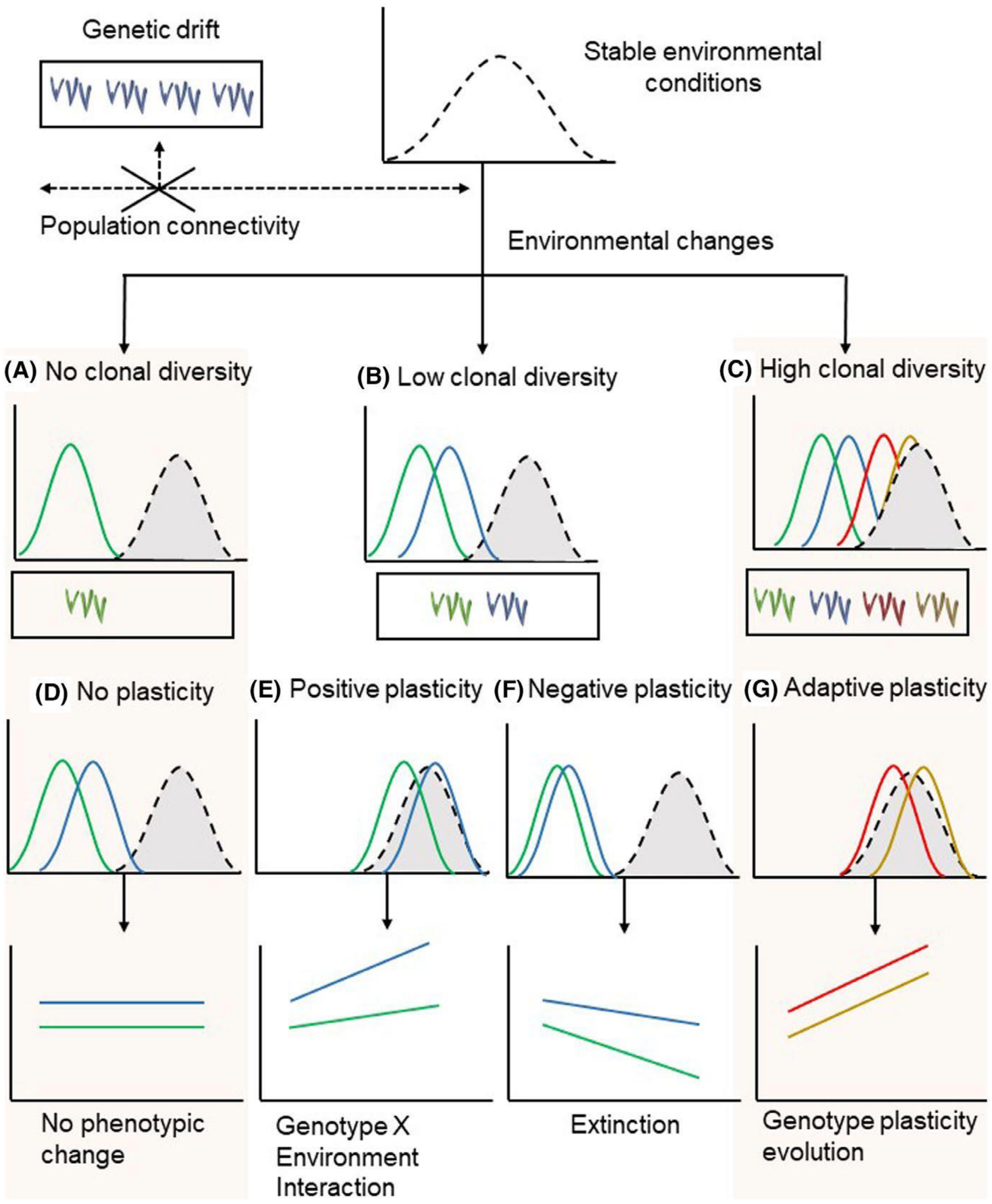
Clonal propagation (source of genetic variation are somatic DNA mutations)

Sexual reproduction by seeds dispersion



The connectivity among populations depends on the existence of geographic or oceanographic barriers and the different features of dispersal vectors (sexual or clonal propagules)

Connectivity among populations affects genetic diversity and the potential to survive under environmental changes



The **genetic component** of **phenotypic plasticity**: the case of seagrasses

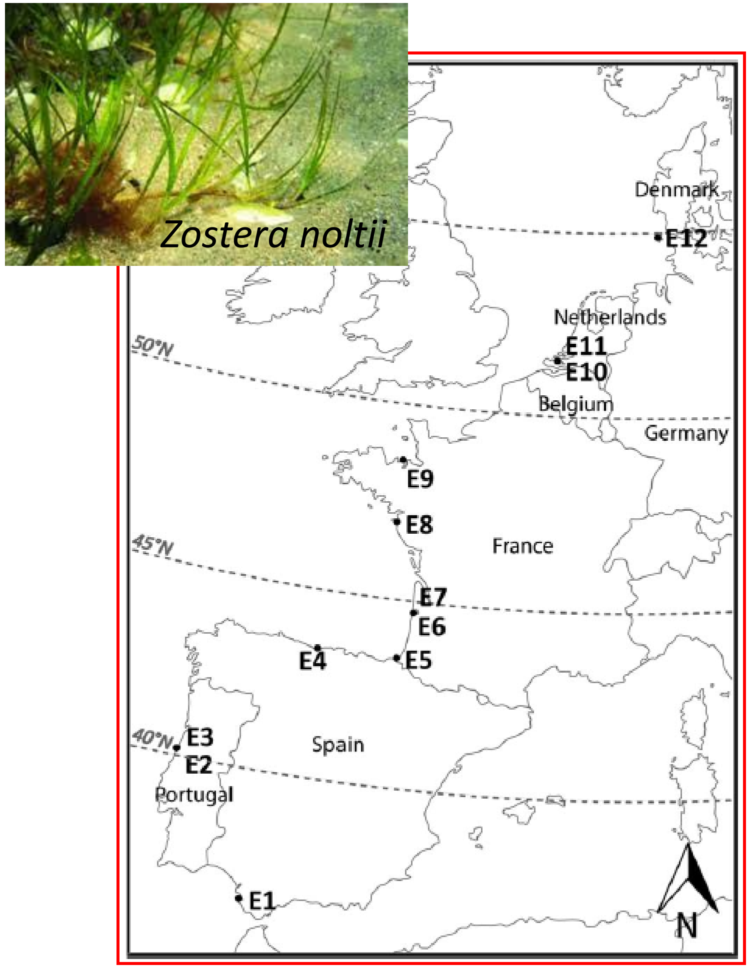
The amount of phenotypic
variation across the environment describes the degree of genotype plasticity (**genotypes by environment interactions –GxE**)

Pazzaglia et al., 2021

How to approch phenotypic plasticity in seagrasses?

Approaches	Pros	Cons
Field observations	Inform about factors that potentially promote the evolution of phenotypic variation and how plasticity can contribute to evolutionary differentiation within species	Limited to observations
Field experiments	Quantify the degree of plastic responses, analyzing phenotypic changes in relation to the environment	Natural environmental variation leads to misleading interpretations
Mesocosm experiments	Simulate the effect of the stress factor of interest for analyzing intraspecific and interspecific responses and the genetic basis of phenotypic plasticity	Require sophisticated systems. Results cannot be automatically transferred to natural conditions
Reciprocal transplant experiments	Identify the genetic component of plastic responses	Sensitive to environmental forces and regional stressors
Common garden experiments	Allow discriminating the contribution of genetic and plastic effects comparing genetically distinct families or populations	Require long acclimation phases and an accurate experimental design

Field observations: G x E

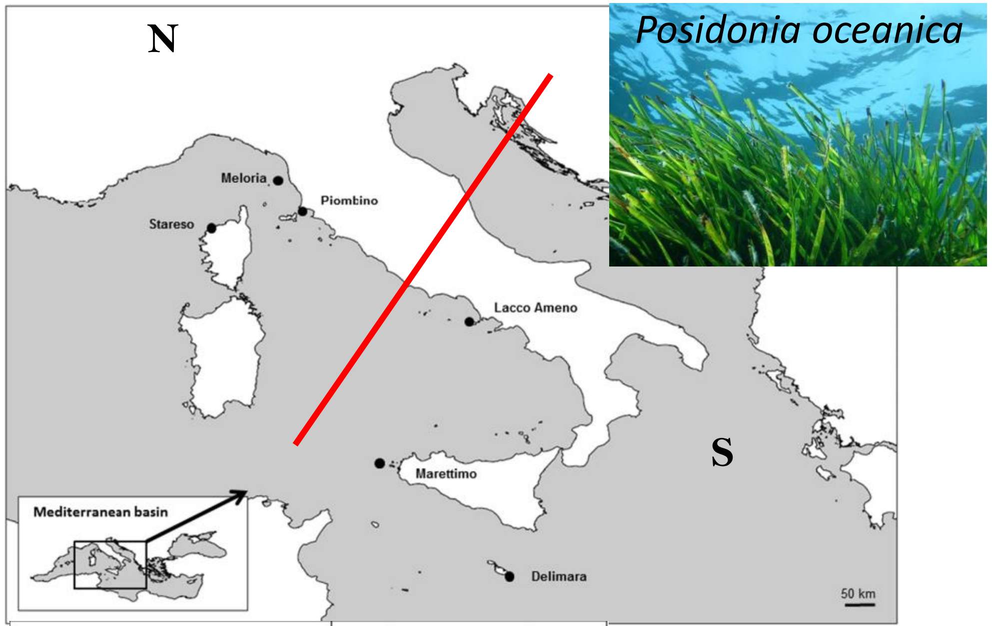


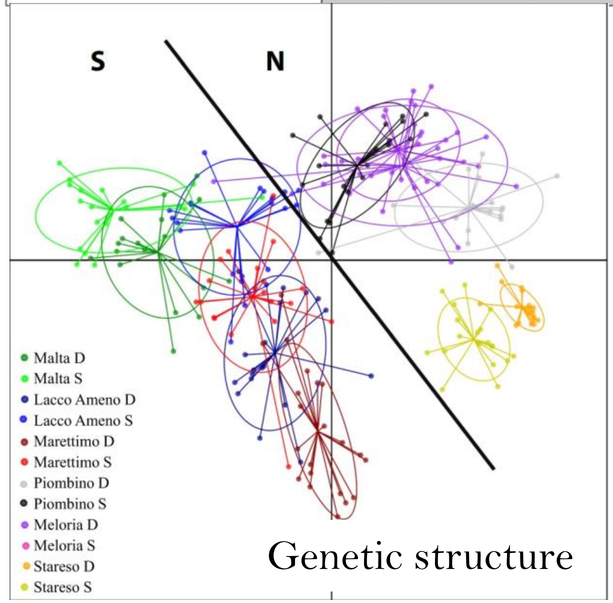
Soissons et al., 2017

Weaker and thinner

Local environmental status

Stronger and stiffer

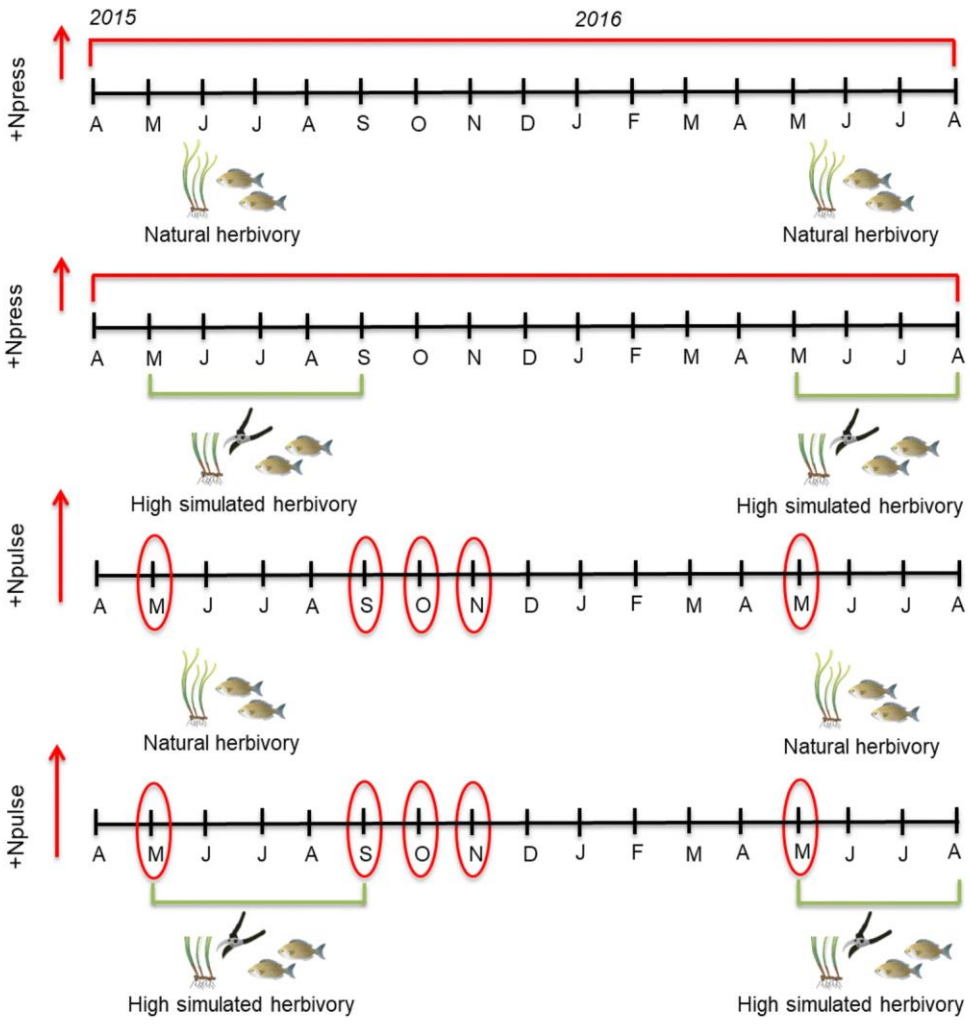


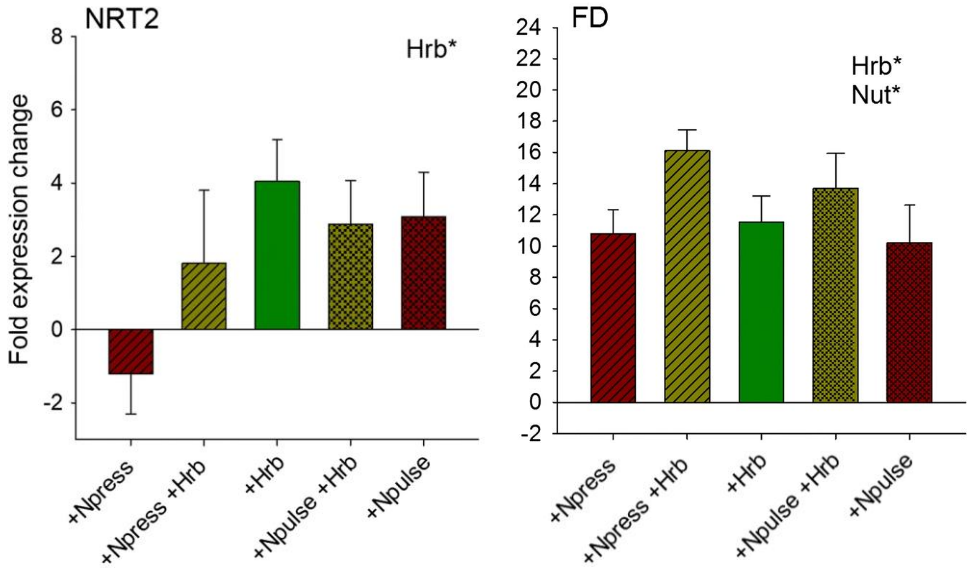


Jahnke et al., 2019

- Northern and a southern population cluster
- Independent populations stands of the same populations sampled at different depths (5m vs 20-25m)

Field experiments: degree of plasticity to selected factors

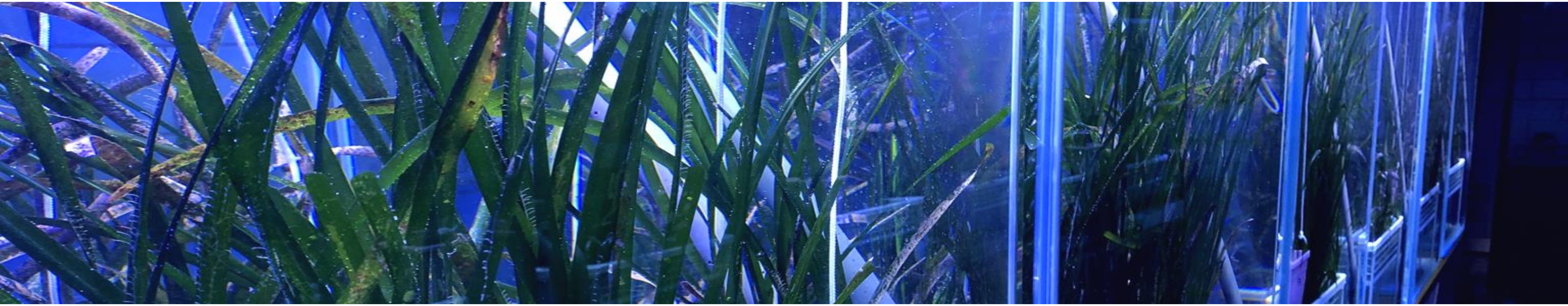


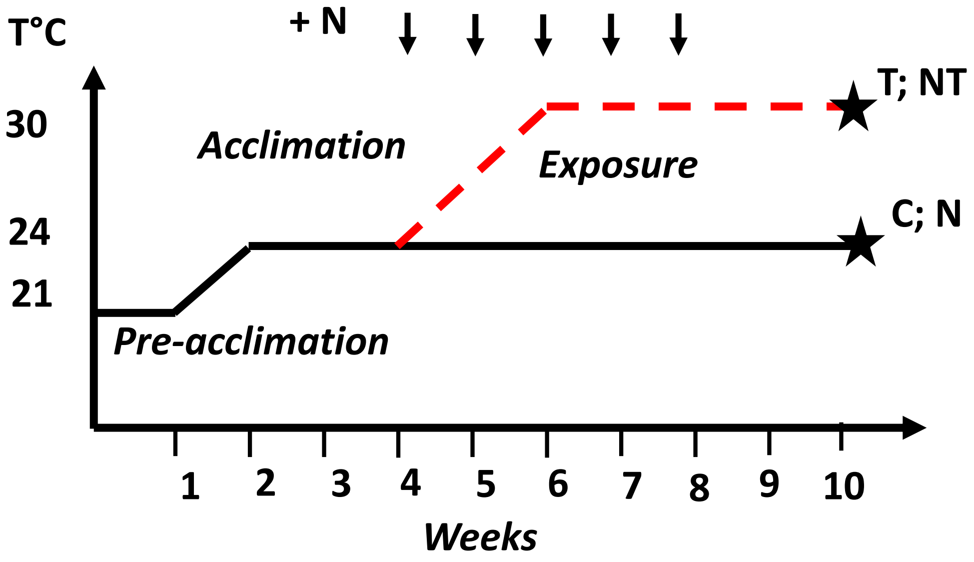


Increased herbivore pressure affected the molecular response more dramatically than did nutrient enrichment

Ruocco et al., 2018

Mesocosm experiments: isolating the effect of single factors

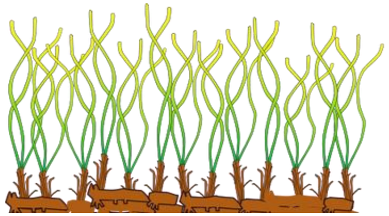


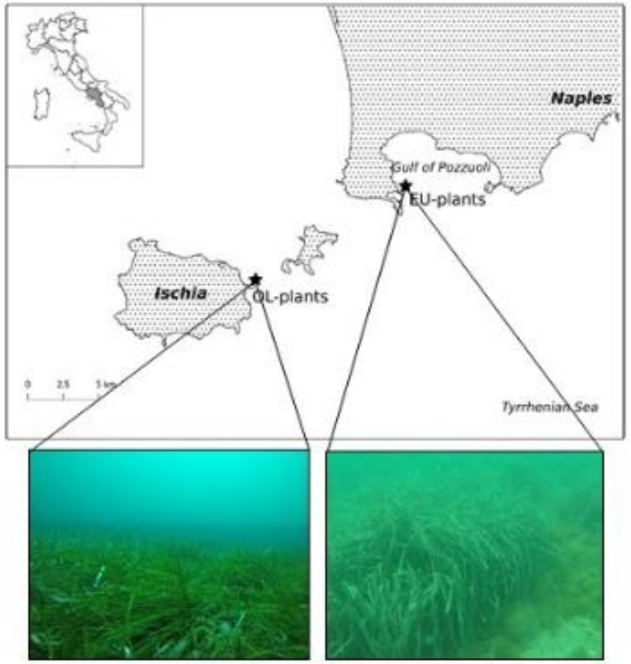


- Multi-factorial controlled experiments
- Test for local adaptation
- Evaluate the degree of phenotypic plasticity in the form of a genetically determined reaction norm

Common-garden experiment: local influence

Ol plants
(oligotrophic environment, Ischia Island)



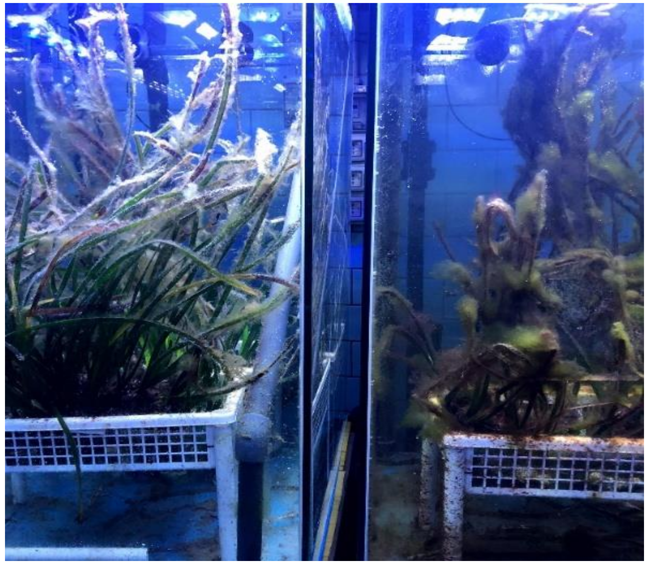


Eu plants
(eutrophic environment, Gulf of Pozzuoli)

Nutrients (N)

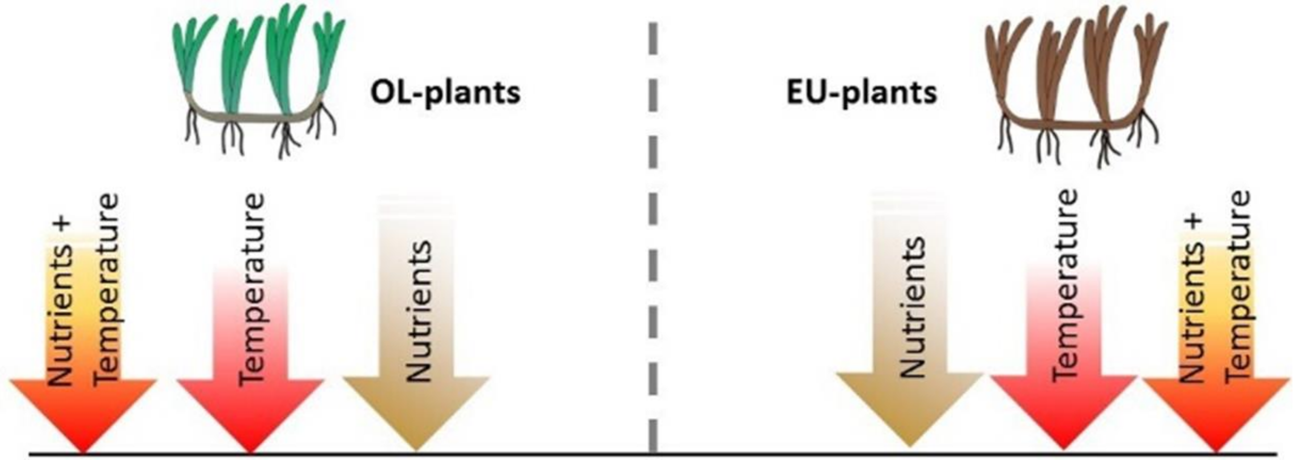
Temperature (T)

Nutrients + Temperature (NT)



Multiple stressors

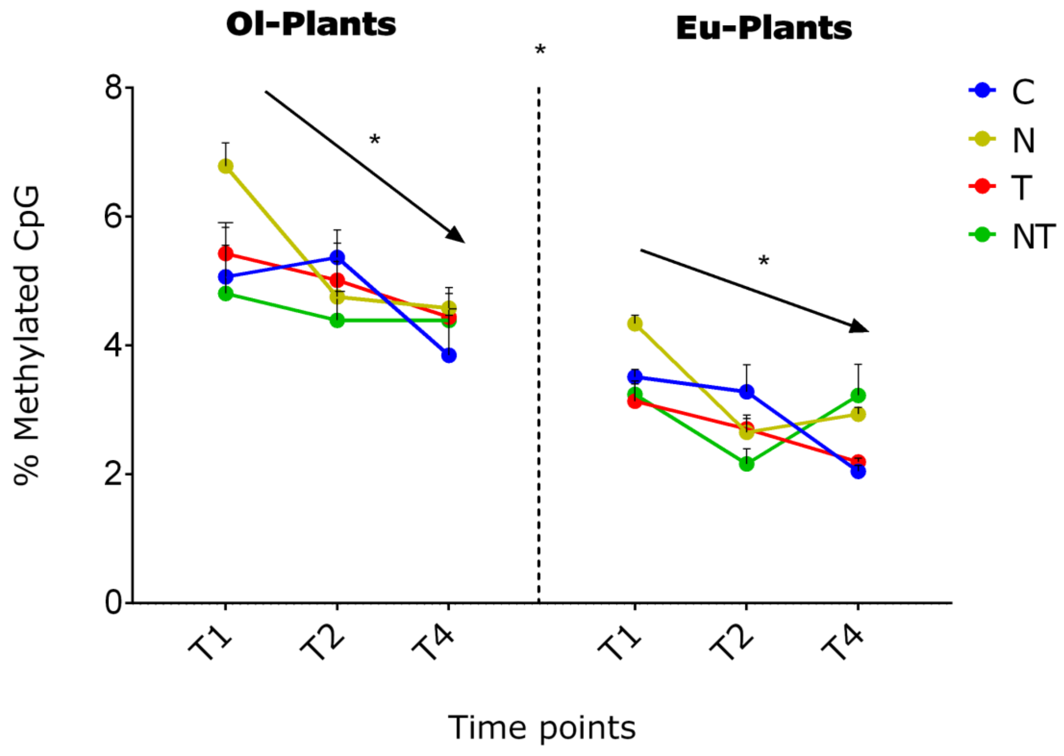
Physiological and transcriptomic responses to multiple stresses



OL: Nutrients + Temperature	OL: Temperature	OL: Nutrients		EU: Nutrients	EU: Temperature	EU: Nutrients + Temperature
+	=	+	%N	+	=	+
-	=	-	C:N	-	-	-
=	=	=	Pigments content	+	=	=
-	=	-	ETRmax	-	=	-
-	=	-	Photosynthetic surface	-	=	=
+	-	+	%Necrosis	+	=	+
-	=	-	TNC Leaf	-	-	-
=	=	=	TNC Rhizome	-	-	=
=	-	-	Relative growth rate	-	-	=
-	-	-	Net shoot change	-	-	-

- Different patterns among leaf and rhizome
- Different strategies among plants in terms of nutrients assimilation, energy consumption and photosynthetic performances

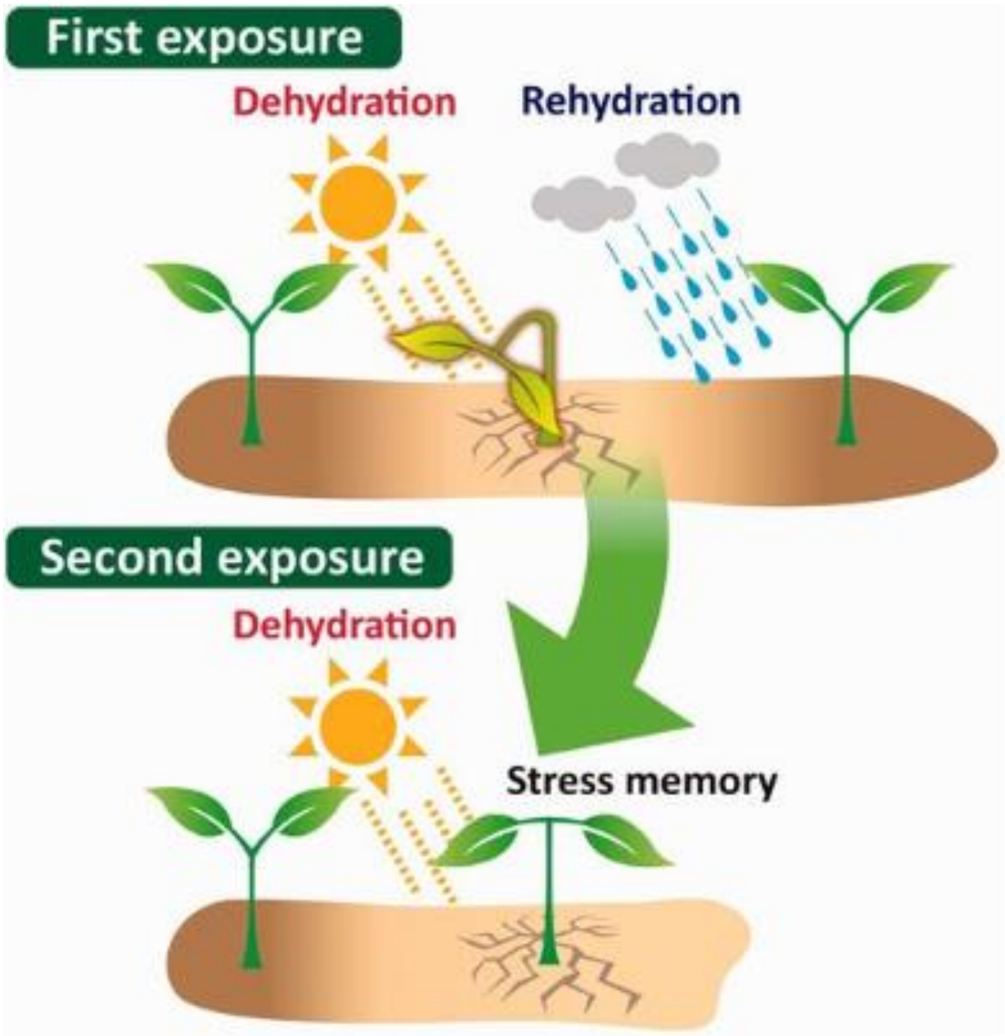
Pazzaglia et al., 2020



Is epigenetics involved in the memory of the native environment in seagrasses?

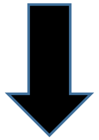
Ongoing..

How plants remember the past

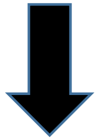


Kinoshita et al., 2014

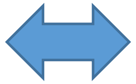
Environmental stress



Epigenetic modifications



Hardening/ Priming



Stress-memory

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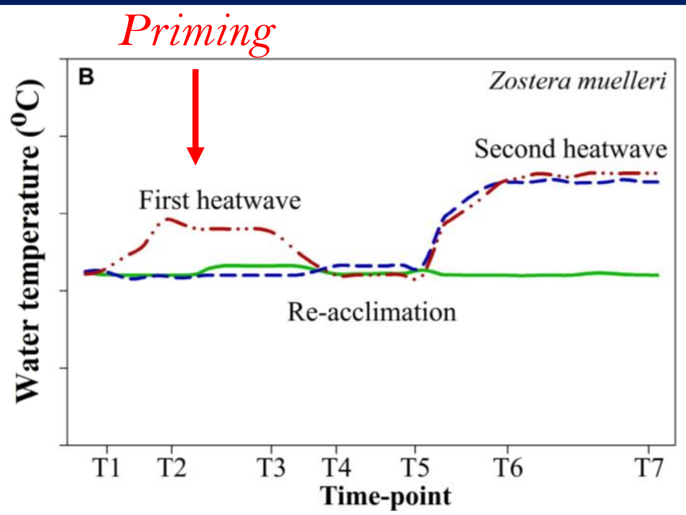
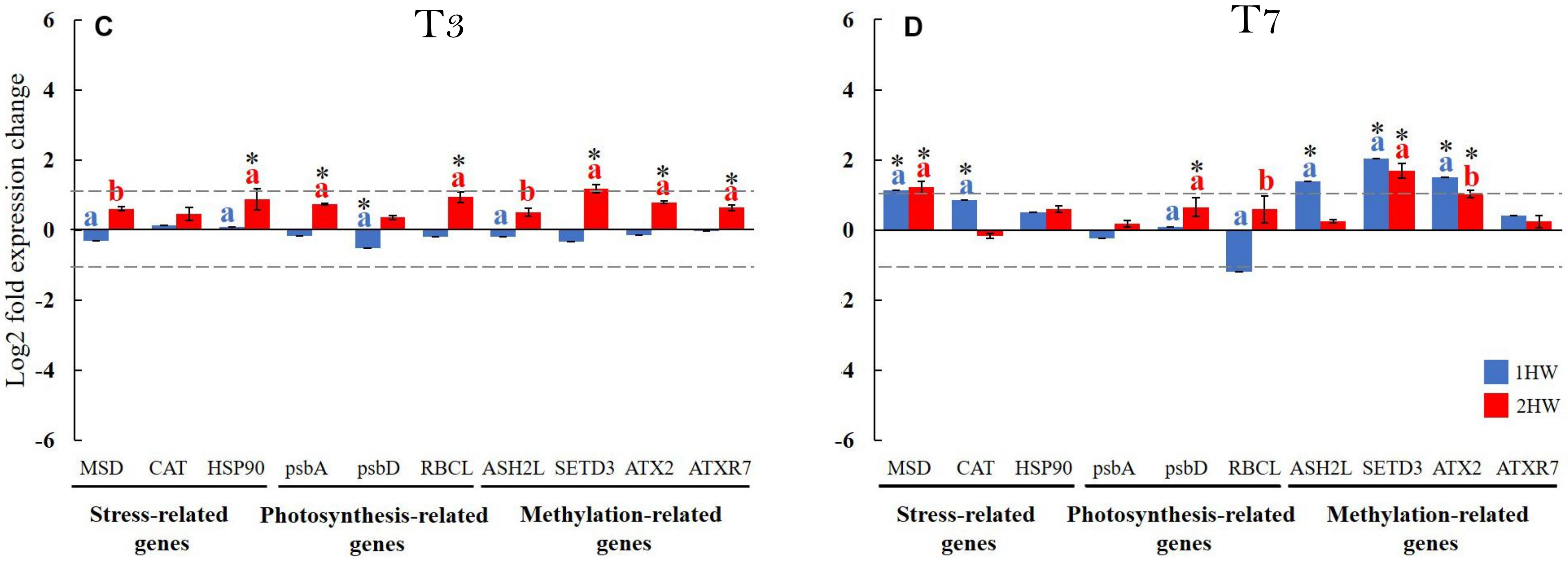
Stress memory in marine plants

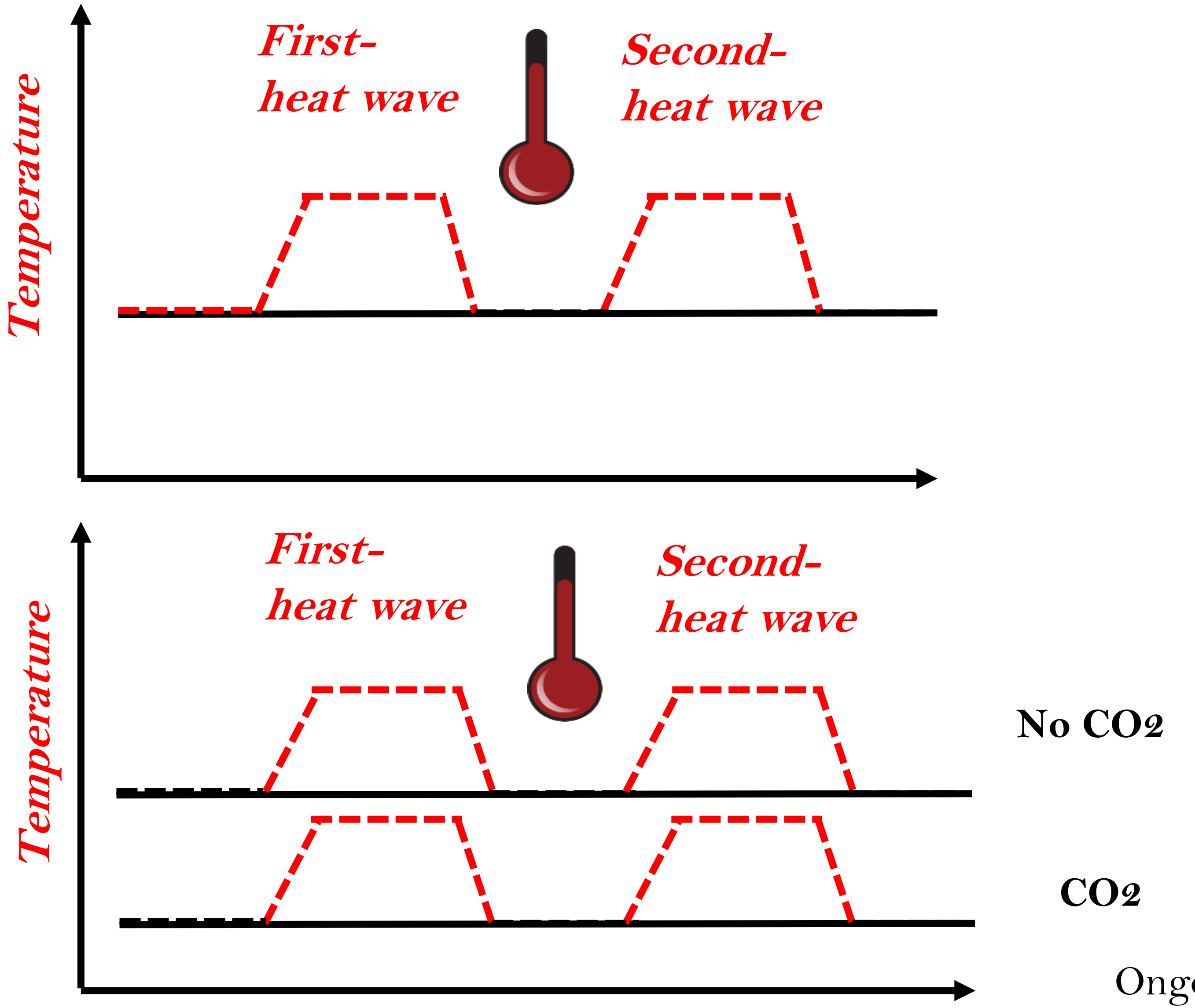


- Pre-heated plants performed better during the more extreme second heatwave
- Key role of methylation-related genes



Nguyen et al., 2020

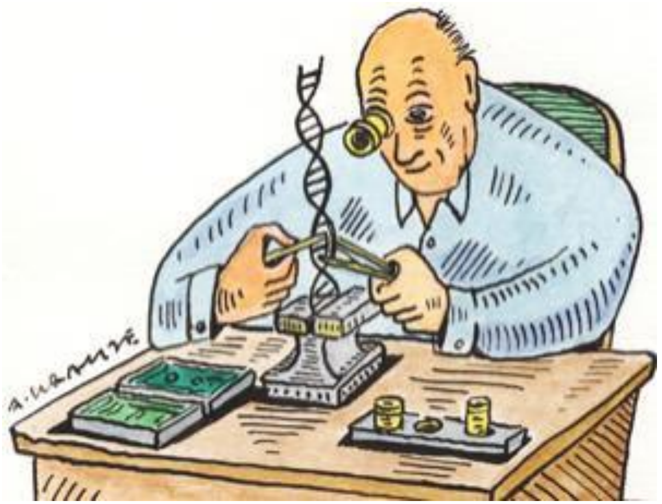
Stress memory in marine plants using seedlings



Ongoing…

Assisted evolution

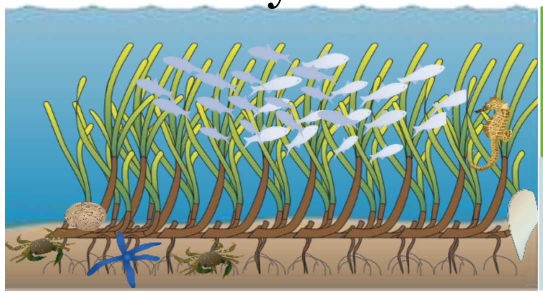
*'**Conservation strategy** adopted for vulnerable species and based on human intervention, which aims to **accelerate the rate of natural evolutionary processes** enhancing population resilience and the **rapid adaptation to environmental changes**'*



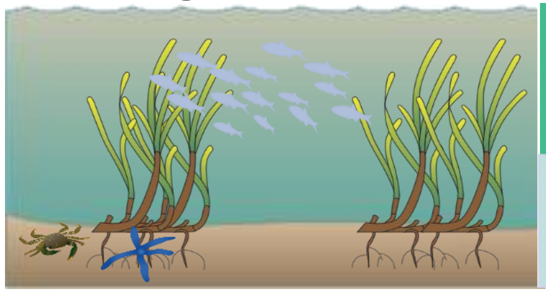
- Selection of resistant genotypes through manipulative selection experiments and by identifying local adaptation (i.e., selection) in natural populations
- Genome editing
- Priming / hardening methods

Applications in seagrass restoration management

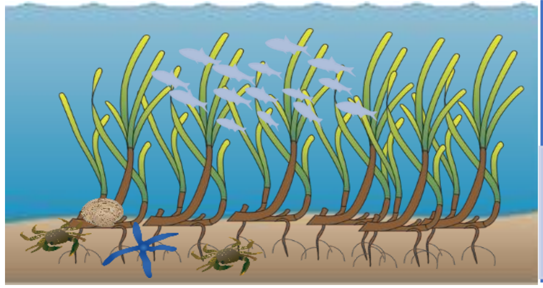
Healthy habitat



Degraded habitat



Restored habitat



A priori knowledge

- Assessment of genetic diversity in donor and receiving sites
- Assessment of local adaptation in donor and receiving sites
- Potential, realized connectivity and distribution maps
- Evaluation of local environmental factors and distrubances

Decision-making for restoration

Replicate or Reinforce

Legal and ethical issues

- Selection of donor site
- Selection of plant material
- Selection of transplantation method

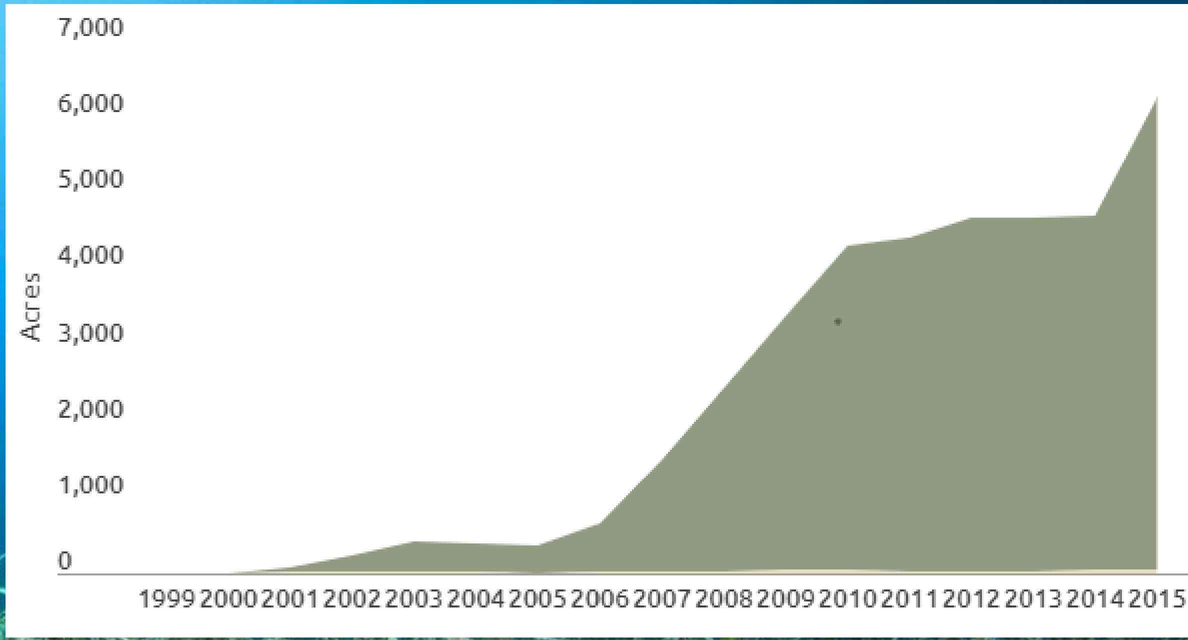
Monitoring

- Genetic assessment of restored populations
- Performances over time
- Assessment of realized connectivity over time

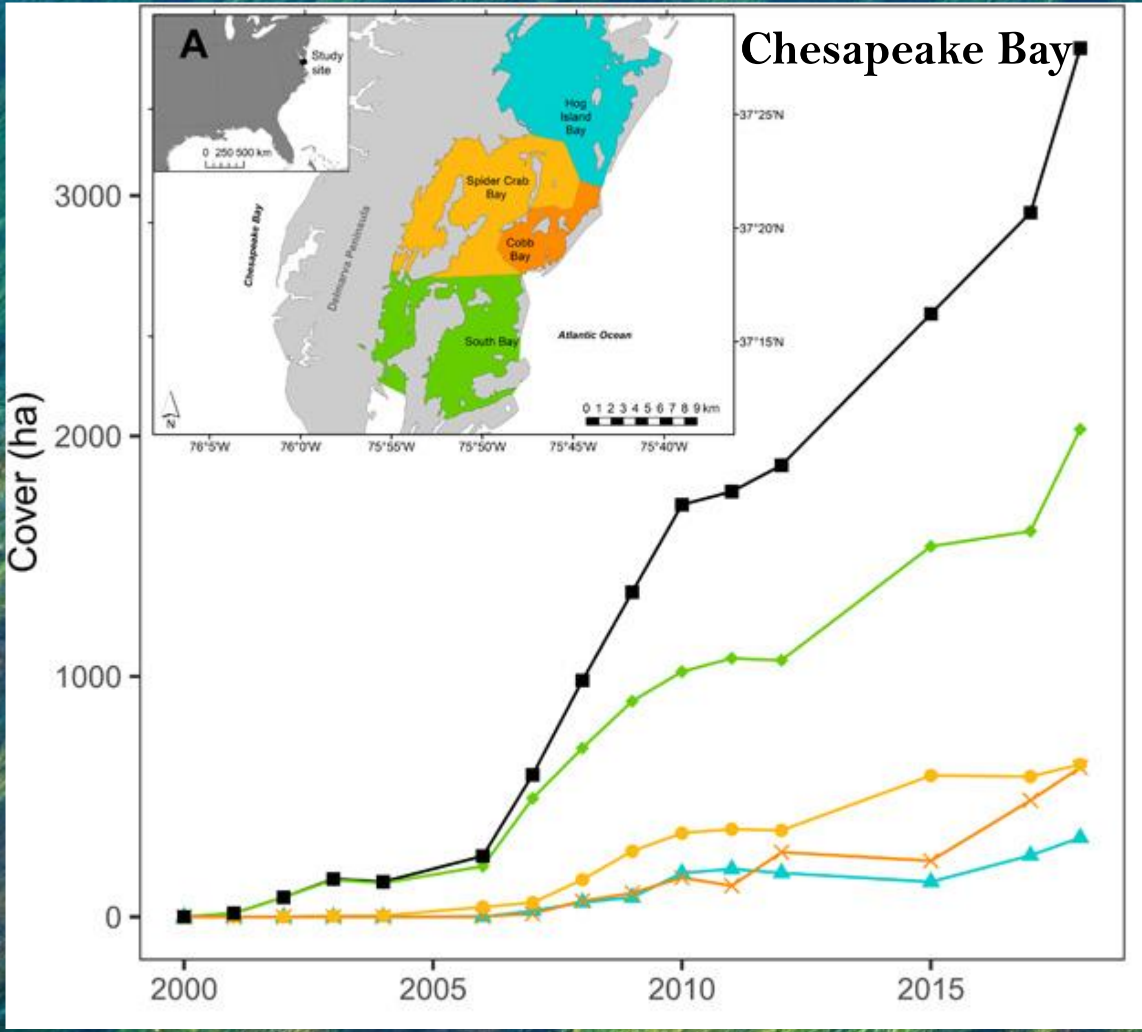
Pazzaglia et al., 2021

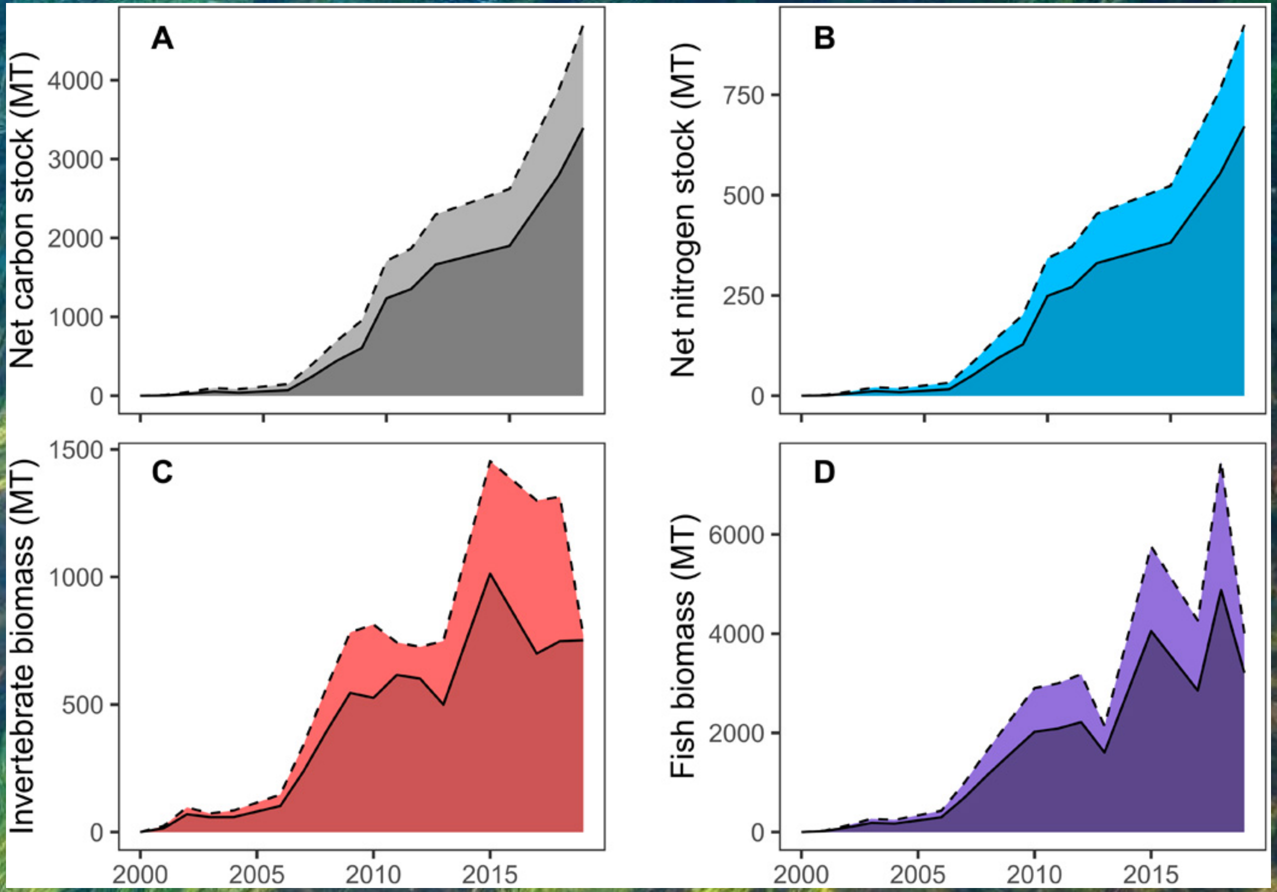
Large-scale restoration in seagrasses

70 million seeds of eelgrass (*Zostera marina*) on a 200-hectare plot



Restoring seagrasses for restoring ecosystem functions

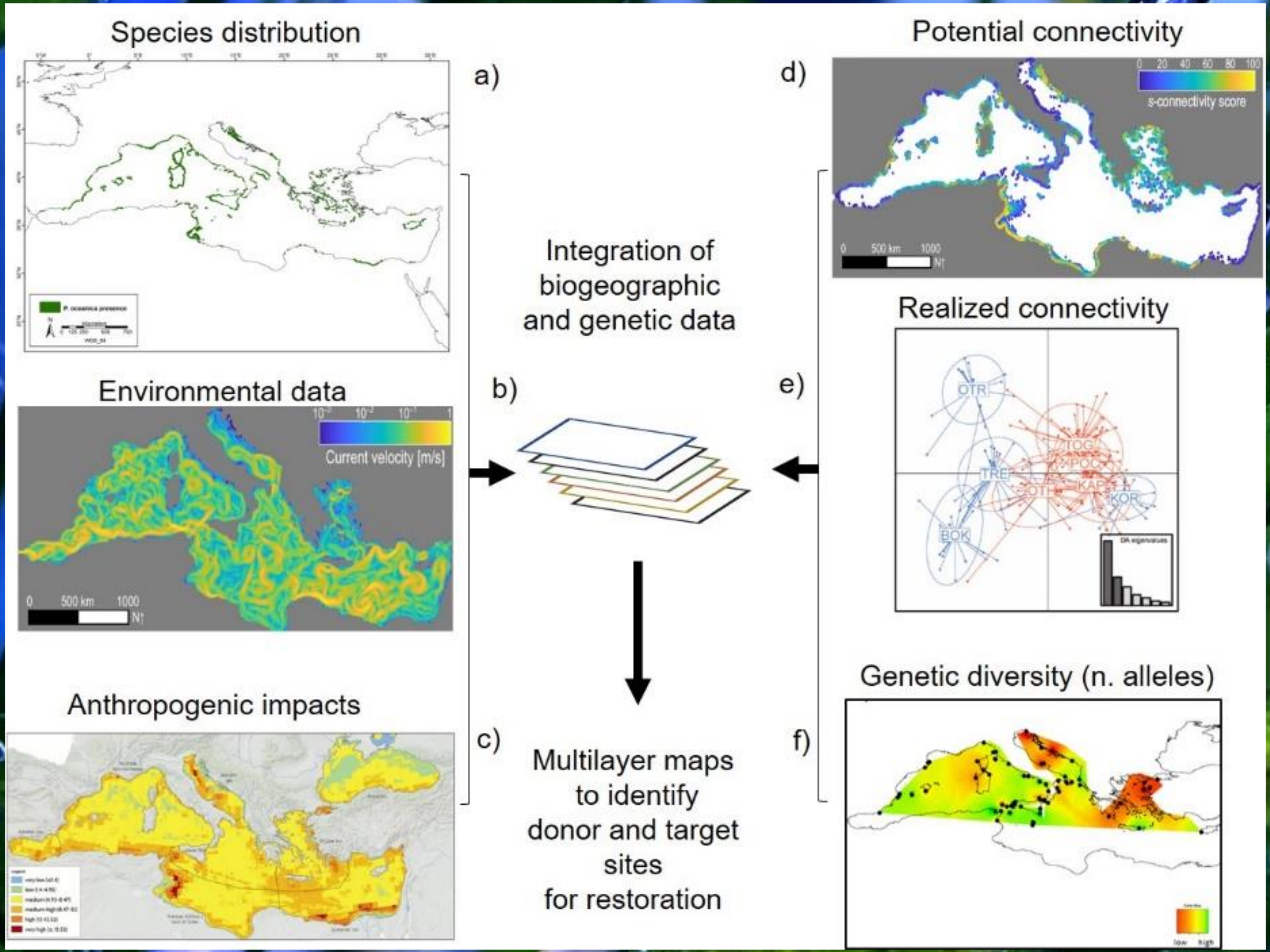




Orth et al., 2020

Future Directions in Seagrass Restoration

Comprphensive multilayer maps



Epigenetic studies

Assisted evolution approaches

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