Scienze per l'Ambiente Marino e Costiero
a.a. 2024-2025

GESTIONE E CONSERVAZIONE ECOSISTEMI MARINI - IMPATTI ANTROPICI E CONSERVAZIONE DELLA FAUNA MARINA

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Ecological principles underlying marine conservation

Contribution of ecological theories to marine conservation

Theory of island biogeography

(MPAs can be seen as 'islands' of reduced human influence within a 'sea' subject to several human pressures; the larger the more speciose, high isolation - low diversity)

Supply side ecology

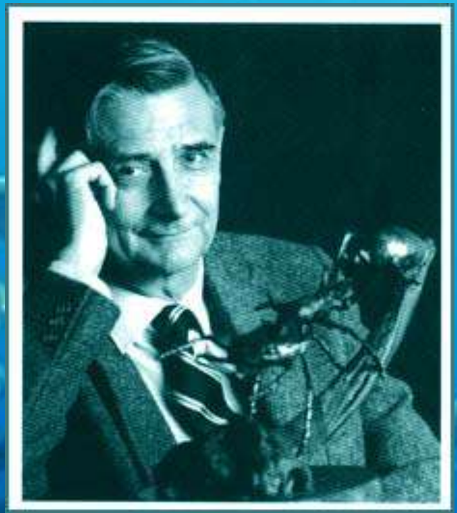
Metapopulation theory

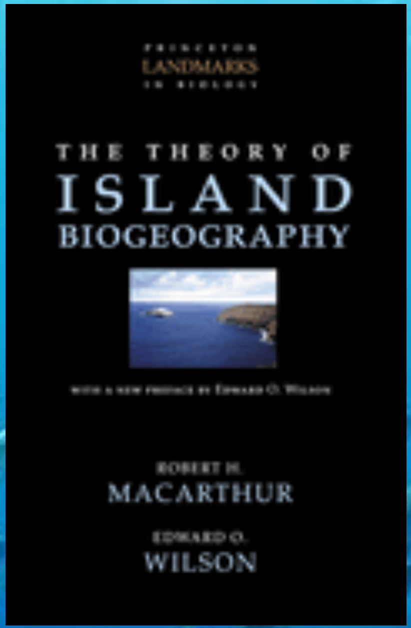
Patch dynamic

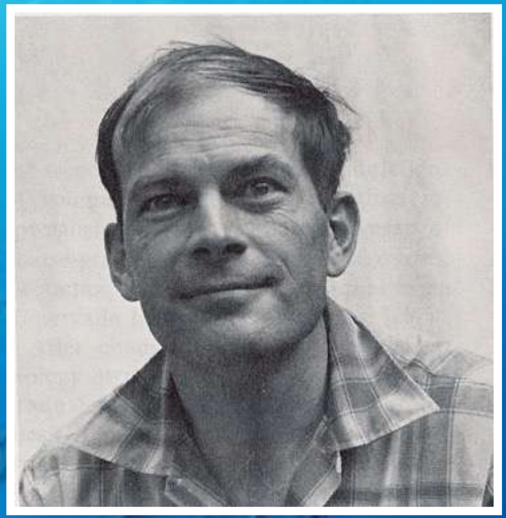
Great contribution of experimental marine biology and ecology

The Theory of Island Biogeography

Robert H. MacArthur and Edward O. Wilson (1967)



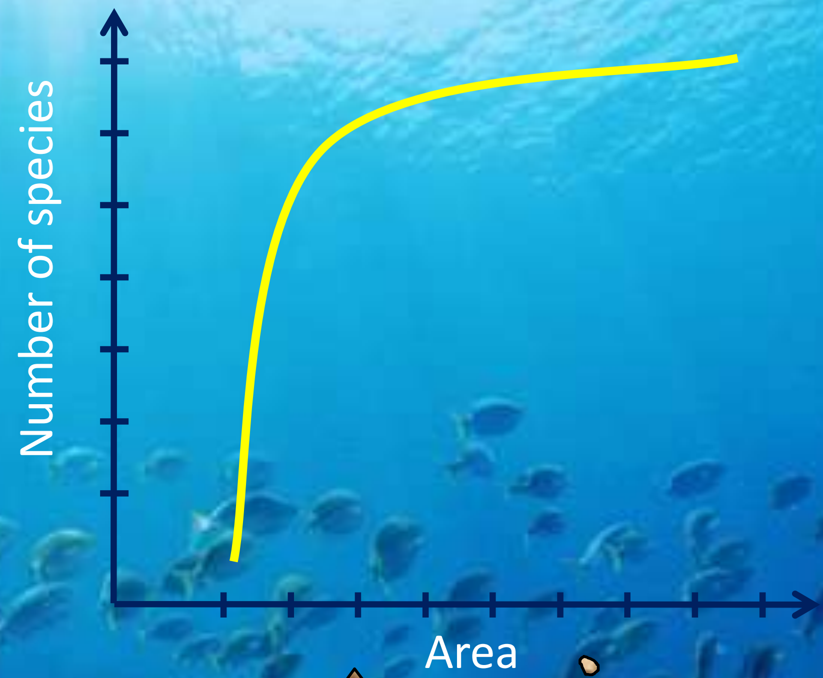




Theory is based on the concept of ‘island’, which true islands (portions of land surrounded by water) are only one representation. Everything ‘isolated’ is an ‘island’. Also, depending on the scale considered, even different portions of continuous environments can be considered as islands.

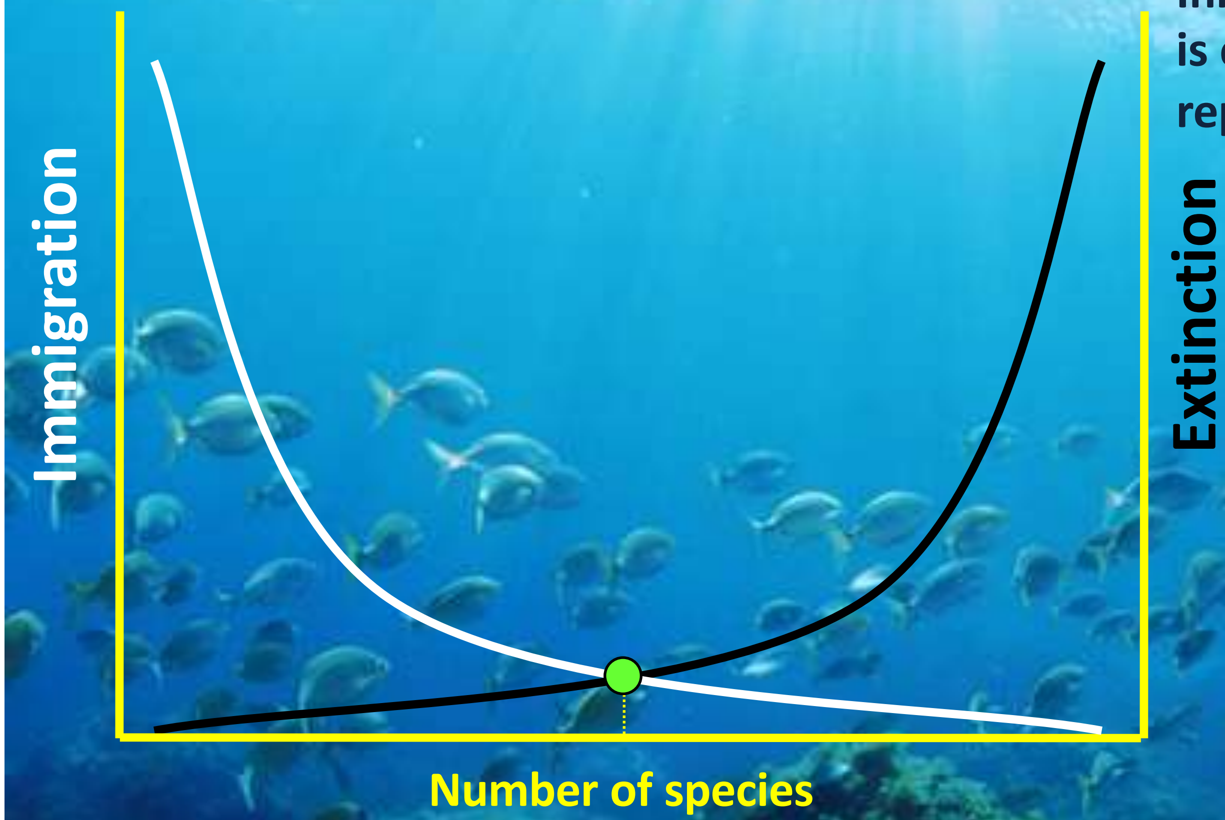
Distance from the “source” and size

The species-area relationship predicts that the number of species increases at increasing sampled surface. Therefore, the number of species in a given island will depend on its size (surface), the larger the islands the higher the number of species.



In TIB, species richness of islands will depend on immigration and extinction rates, and thus also from the distance of the island from mainland.

Immigration and extinction



Initial rate of immigration is high (island is empty and each new arrival likely represent a new species

As species number increase, immigration decrease and tends to 0 as the number of species tends to reach that of the source

Extinction is 0 at the beginning, when no species are on the island, and is low when few species reach the island. Then it rapidly increase

1) The number of species is the result of the balance between immigration and extinction

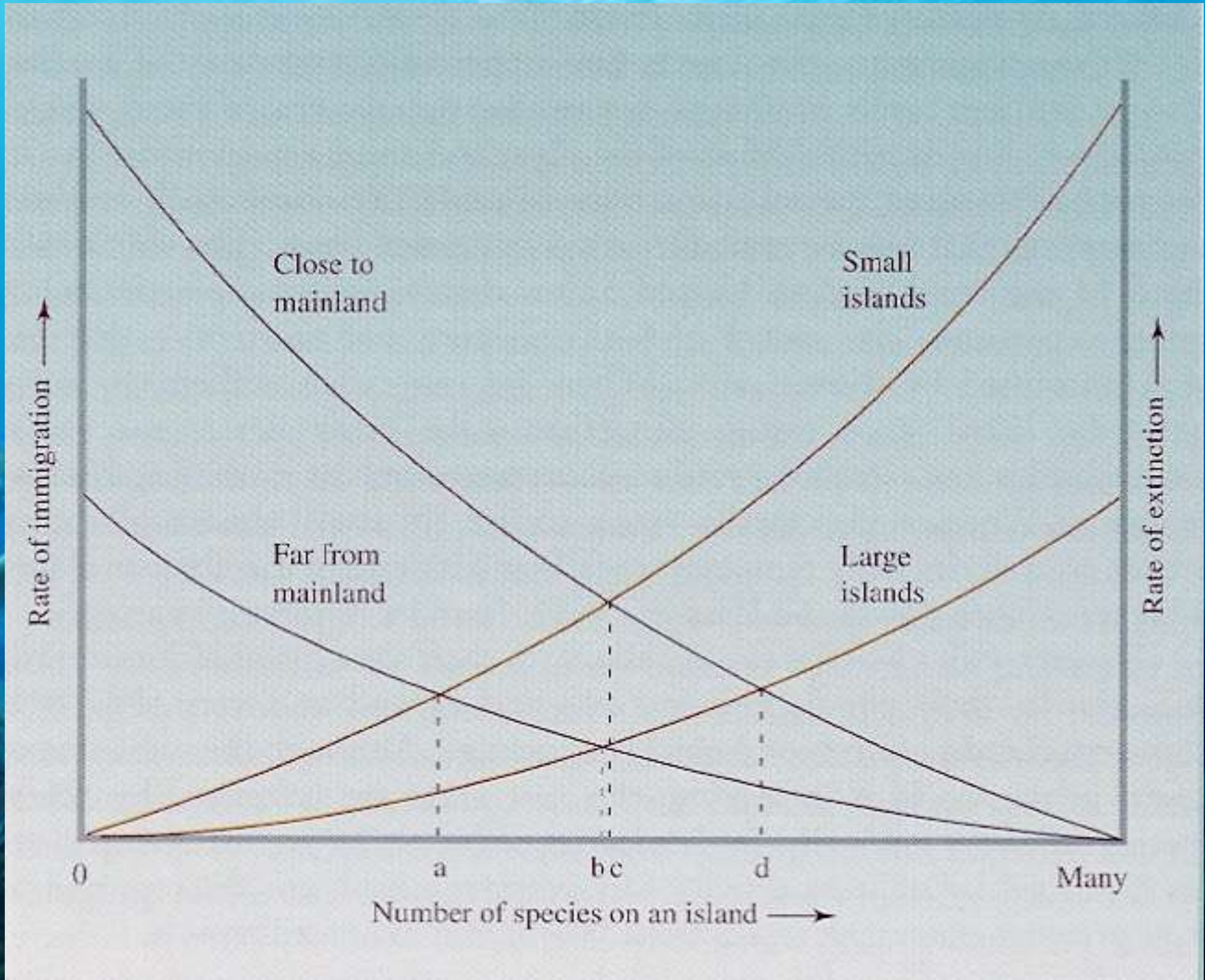
2) This balance is dynamic, because species will go extinct and will be replaced by others continuously

3) The immigration rate will mostly depend on the distance form the source

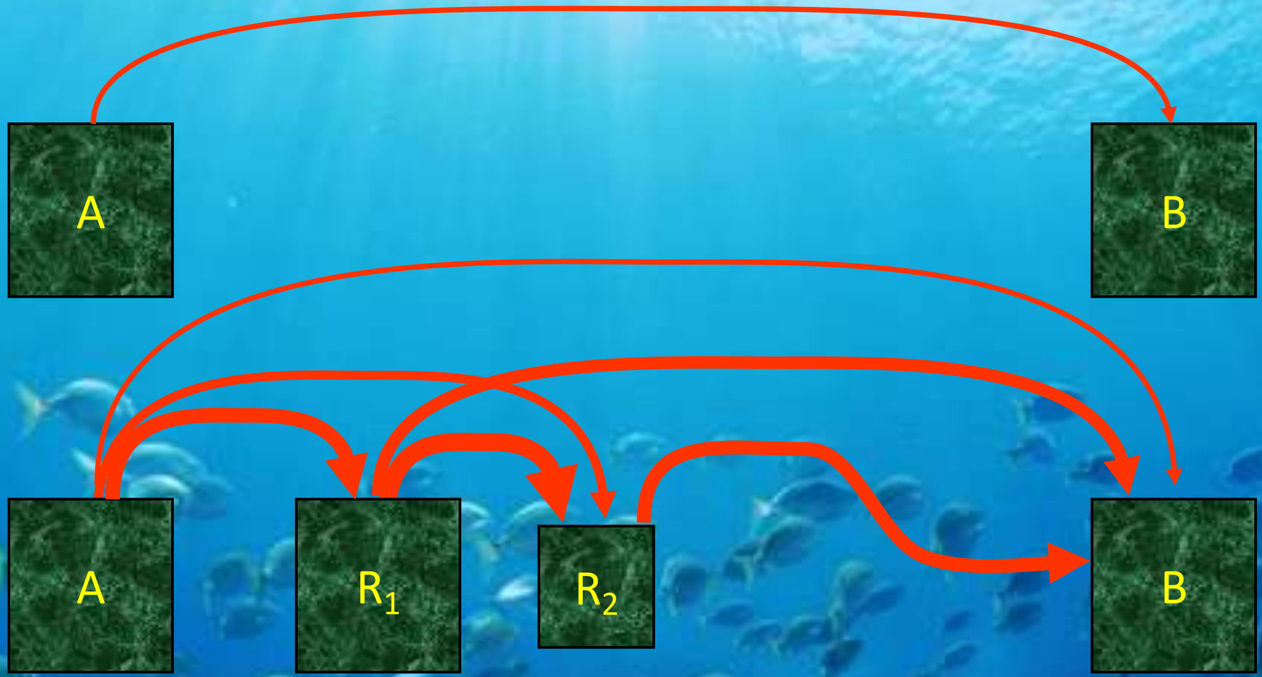
4) The extinction rate will mostly depend on the size of the island

Scenarios

Shape of the immigration curve depends on the distance from the source: the closer the source the higher the immigration rate. The size of island also influence Immigration, because larger islands are more likely to intercept propagules than smaller ones, and offer more habitats. Extinction is strongly influenced by island size, because of reduced resources, habitat availability, and higher probability to compete with other species in smaller islands with respect to larger ones



Stepping stones



Stepping stones are islands (or patches) that may help connection between the source of species and the receiving island (or patch). If too close to the source or too small they do not contribute substantially to connection. The same occurs if they are to far from the receiving islands. They may help weak dispersers to reach the island that is too far from the source to allow a direct colonization of such species.

Stepping stones

Man made fixed structures, ships, litter, could serve as stepping stones for dispersion, or as vectors of invasion

Supply-side ecology

Supply-side ecology relates to the consequence on the structure and dynamics of assemblages due to variations in numbers and timing of offspring arriving into any portion of habitat. (Lewin 1986)

More generally, includes the arrival of individuals from any planktonic stage of the life cycle.

It focuses on the role of larval (and more generally of propagules) supply in shaping the structure of marine assemblages, besides biological interactions that may have a role only *after* colonization (settlement and/or recruitment) of patches.

This because the first step in community formation is that colonizers reach the empty patch. Predators have to reach the area in sufficient number to exert their influence in structuring the community. The same is true for dominant competitors

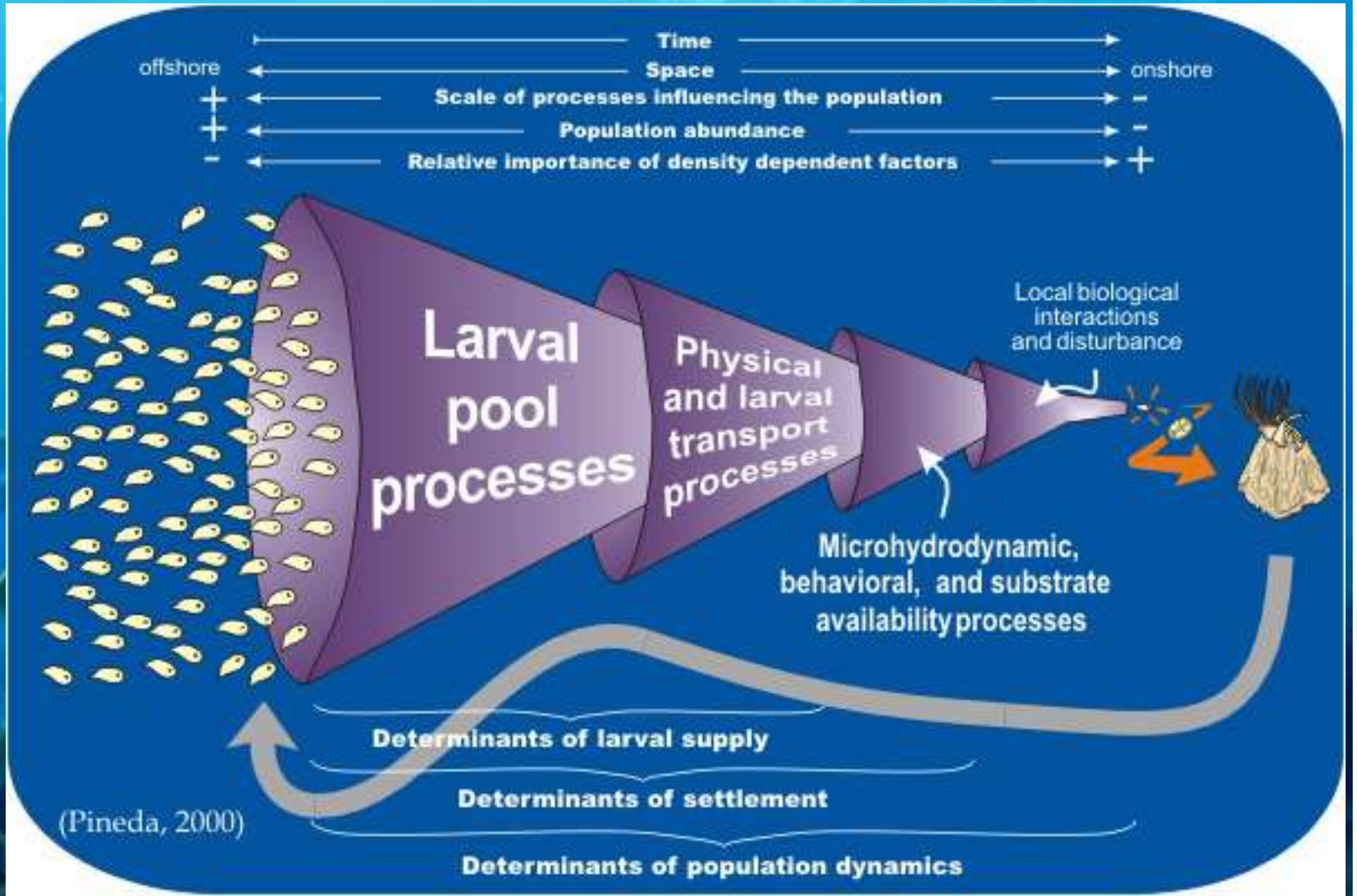
Processes affecting larval supply

Larval production
(life histories – production of eggs, sperms; asexual propagules; fertilization success)

Dispersal ability
(life cycle – planktotrophic, lecithotrophic, adult dispersal; duration of larval stage)

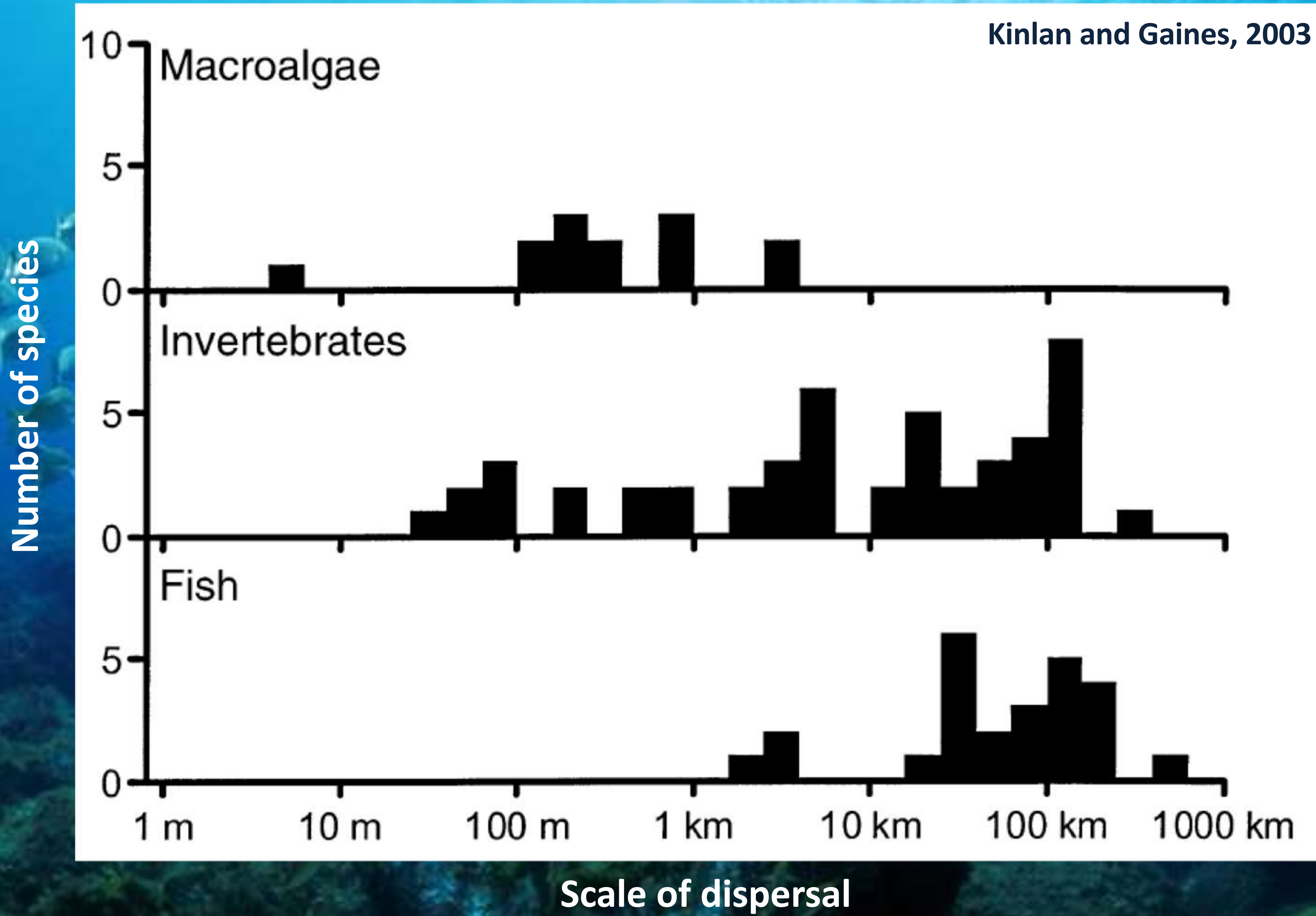
Larval transport
(currents, vectors, isolation)

Larval mortality
(predation in the water column, disturbance, limiting food resources, sinking/advection)



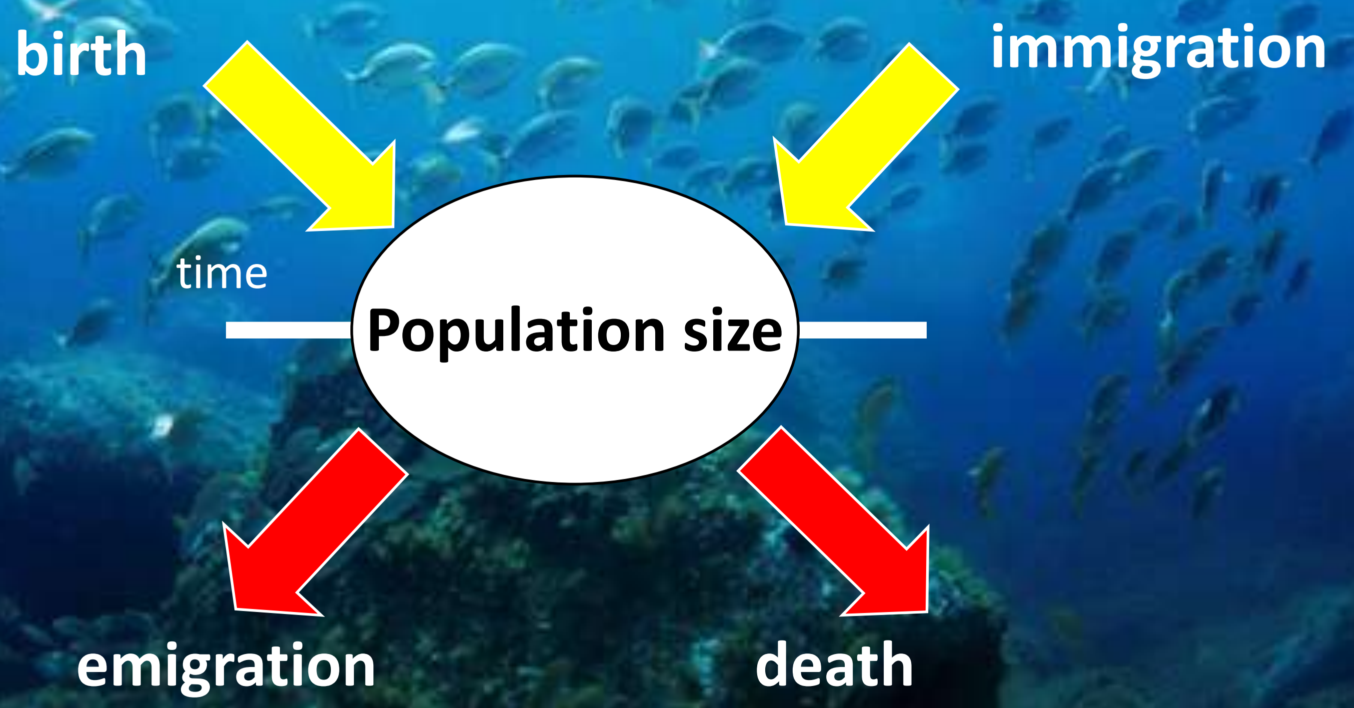
Settlement
Predation, biological disturbance (e.g. whiplash, bulldozing, overgrowth), environmental disturbance.

Dispersal potential in marine species



Populations

A population is a group of individuals of the same species that live in a given area, this group being spatially, genetically or demographically disjointed from other groups.
Populations can be also defined on the basis of research interests, which can fix the limit of population.

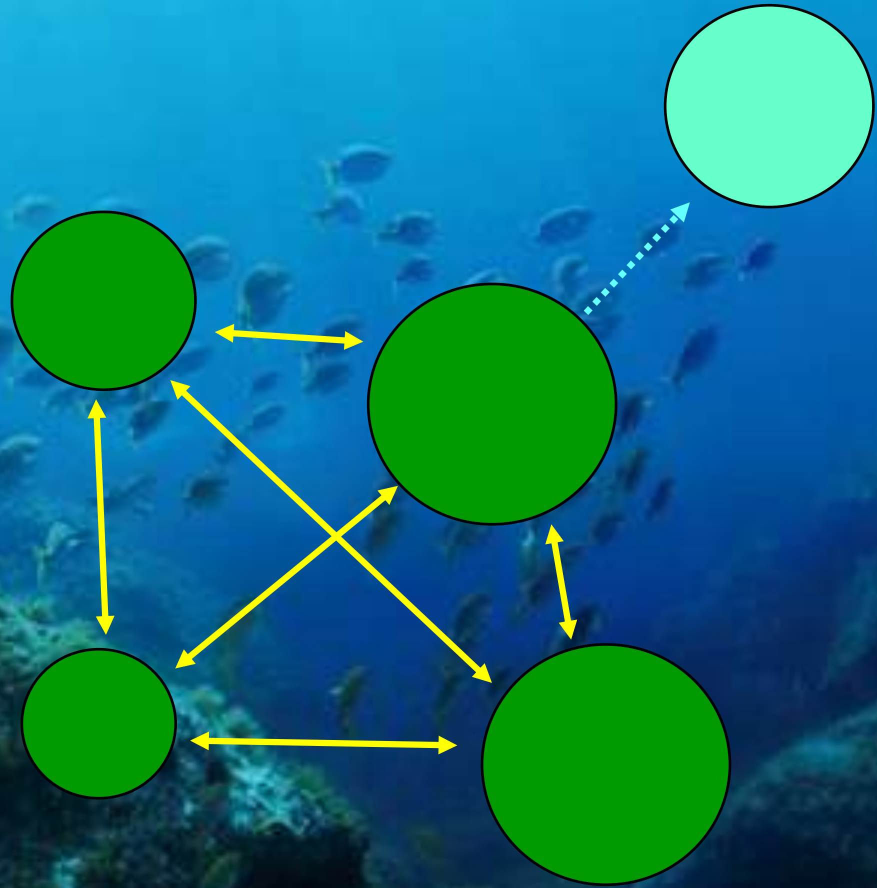


Metapopulations

Metapopulations are groups of populations in which there are one or more core populations stable in time, and satellite populations undergoing temporal fluctuations.

Levins, 1969

The habitat can be modelled as a set of patches. Some of which productive, due to favourable environmental conditions for the species to thrive, and other unproductive. Productive patches produce emigrants that can colonize satellite patches.
This model identifies productive patches as 'sources', and receiving patches as 'sink'. Sinks are unproductive patches where mortality exceed birth, due to unfavourable conditions. Their persistence depend on immigration from sources.

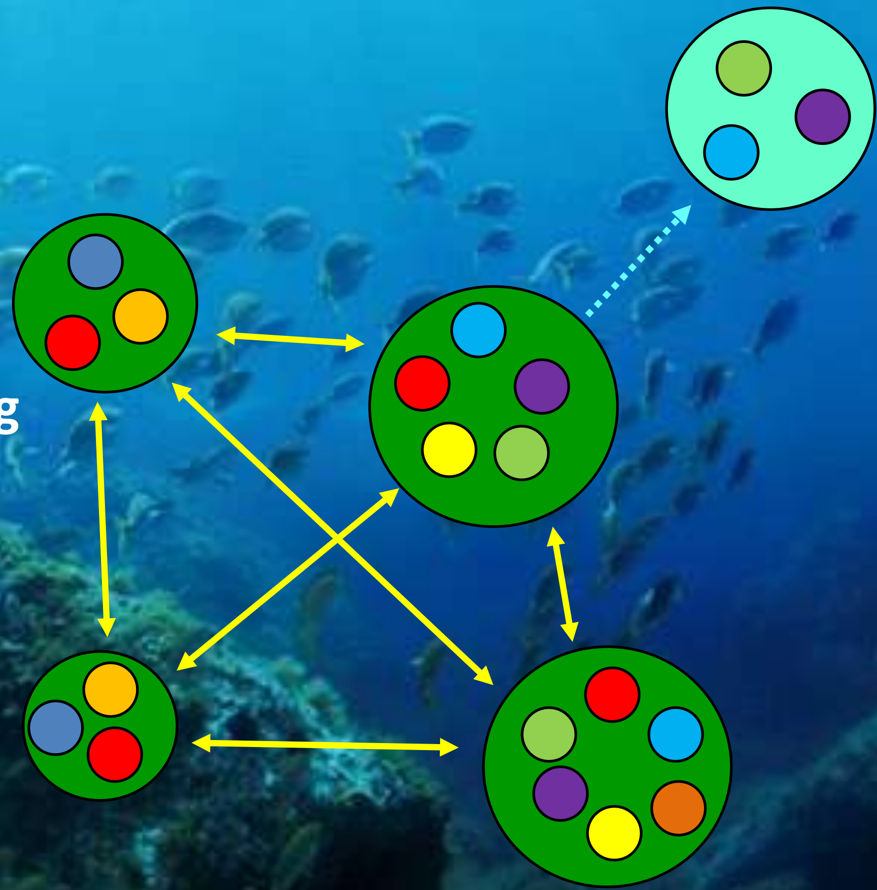


Sinks may experience extinction and subsequent recolonization

Metacommunities

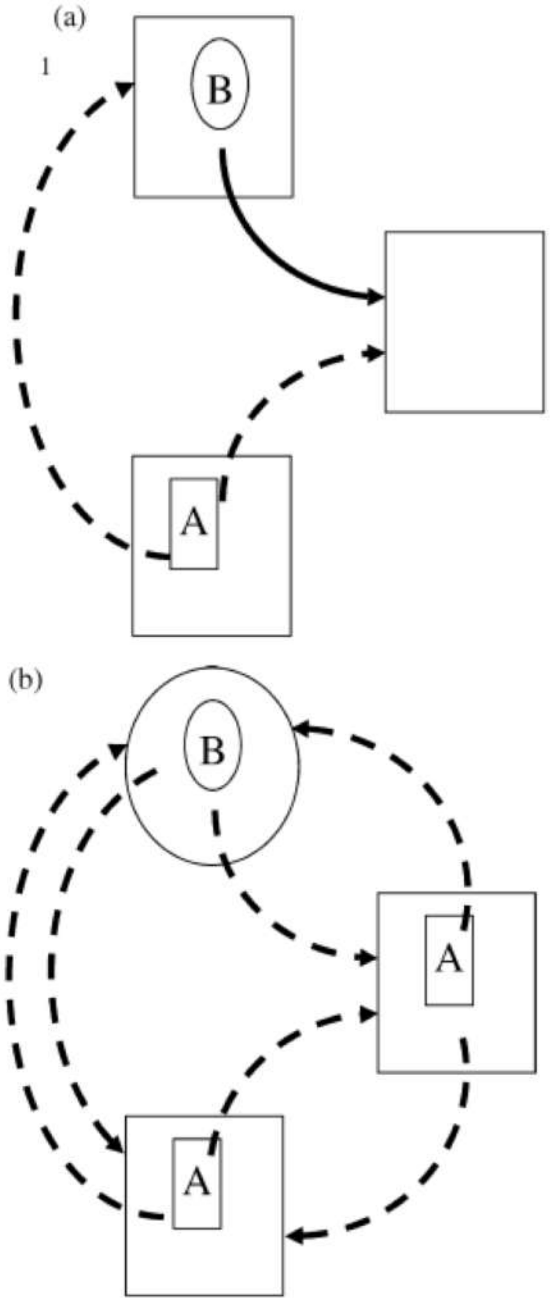
Metacommunities are sets of communities interconnected by dispersal, immigration and/or emigration of multiple (interacting or potentially interacting) species

(Gilpin and Hansky, 1991)



Sink-source
Species sorting (environmental filtering and biotic interactions)
Patch dynamic
Stochasticity (neutral theory)

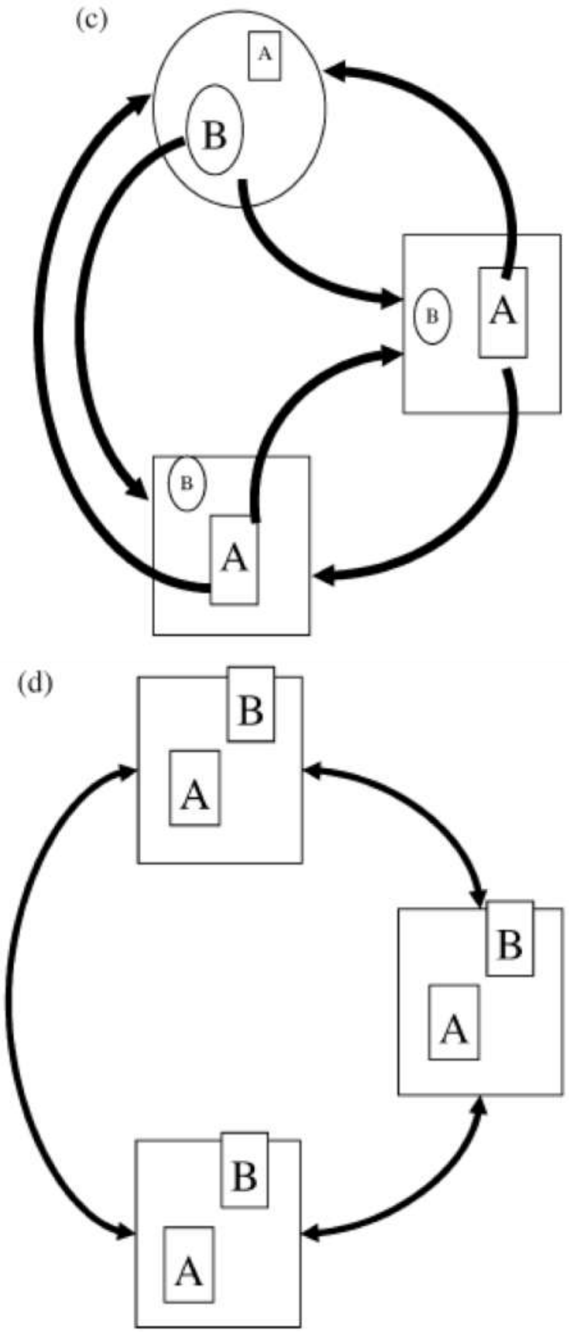
Perspectives in meta-communities



Patch dynamics: competitive model of coexistence in a homogeneous habitat. The habitat is composed by equal patches, which could be empty or occupied. Species coexistence is mediated by competition for resources and dispersal abilities. Local dynamics are not important. There are strong competitors and good dispersers, and trade-offs between these abilities determine the distribution of species in the habitat.

Species sorting: model of coexistence in a heterogeneous habitat. The habitat is composed by unequal patches, because of differences in conditions and resources. Species coexistence is mediated by local conditions. Depending on niche width, species can occupy several patches, or only those where local conditions allow survival. Dispersal is not so important, since good dispersers could reach more patches than poor dispersers, but colonization is mediated by the environment.

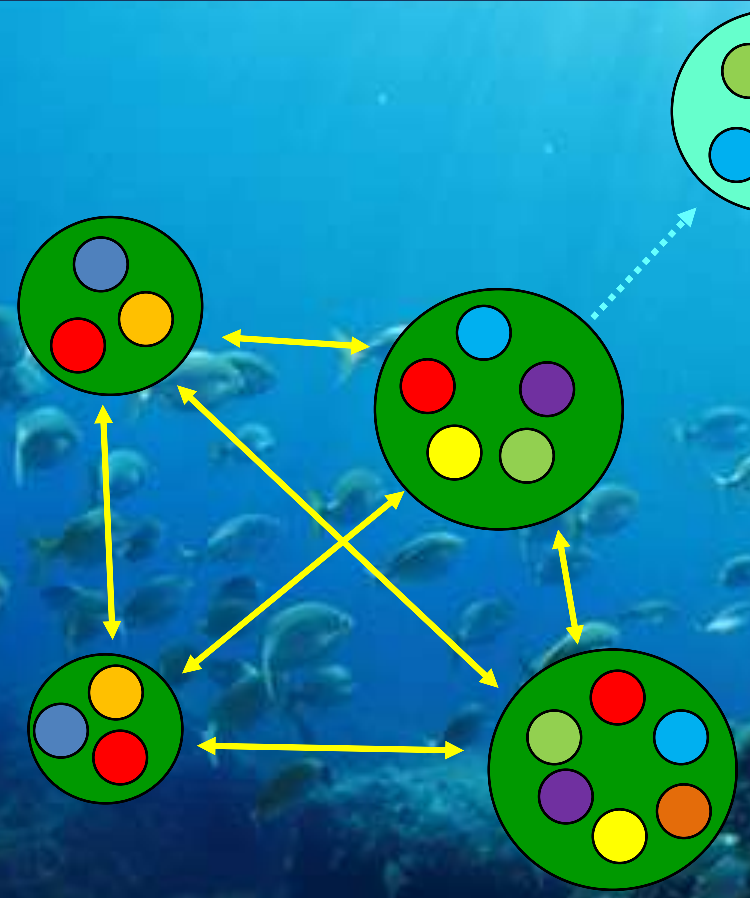
Perspectives in meta-communities

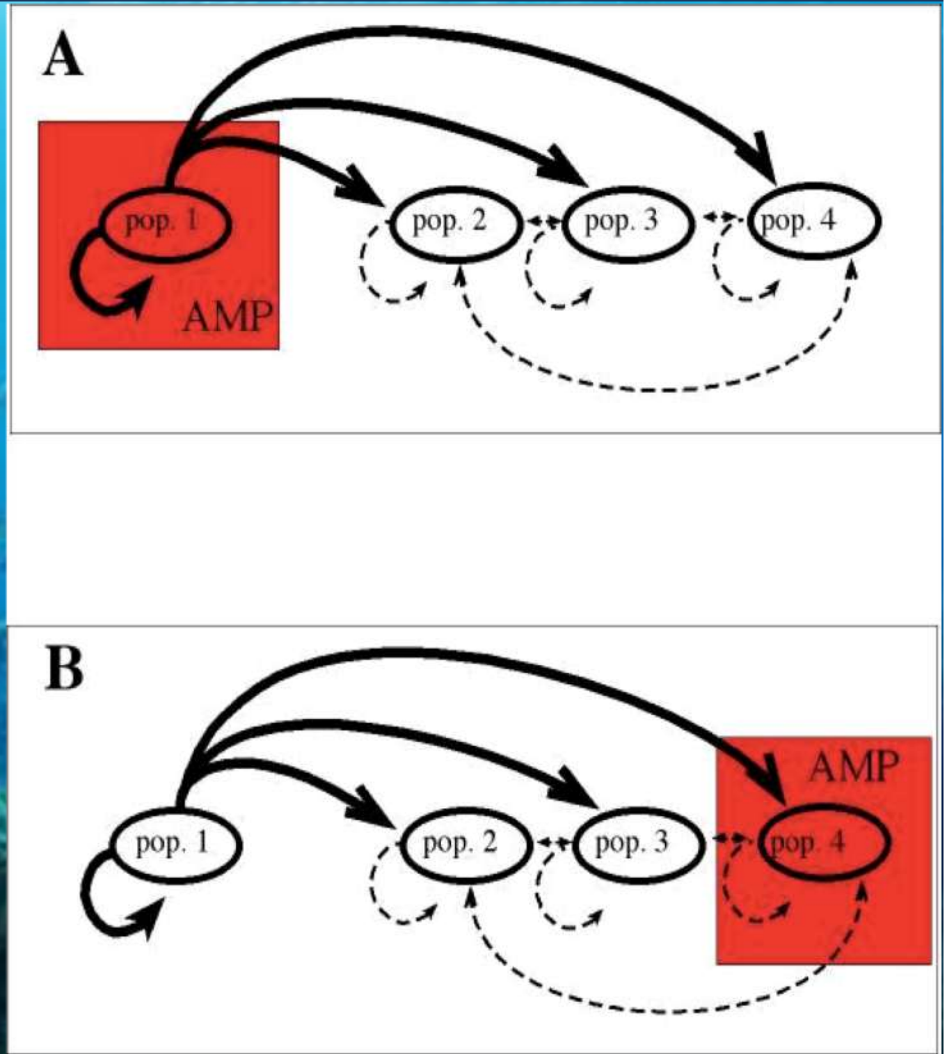


Sink-source (or mass effect): Species coexistence is mediated by immigration and emigration. Local competitive exclusion in patches where species are bad competitors are compensated by immigration from communities where they are good competitors. There are productive patches (sources) and receiving patches (sink), connected by dispersal.

Species are equal in terms of competitive abilities, dispersal and fitness. Community composition depends on stochastic factors related to speciation-immigration and extinction-emigration.

Supply side ecology, metapopulations, and metacommunities

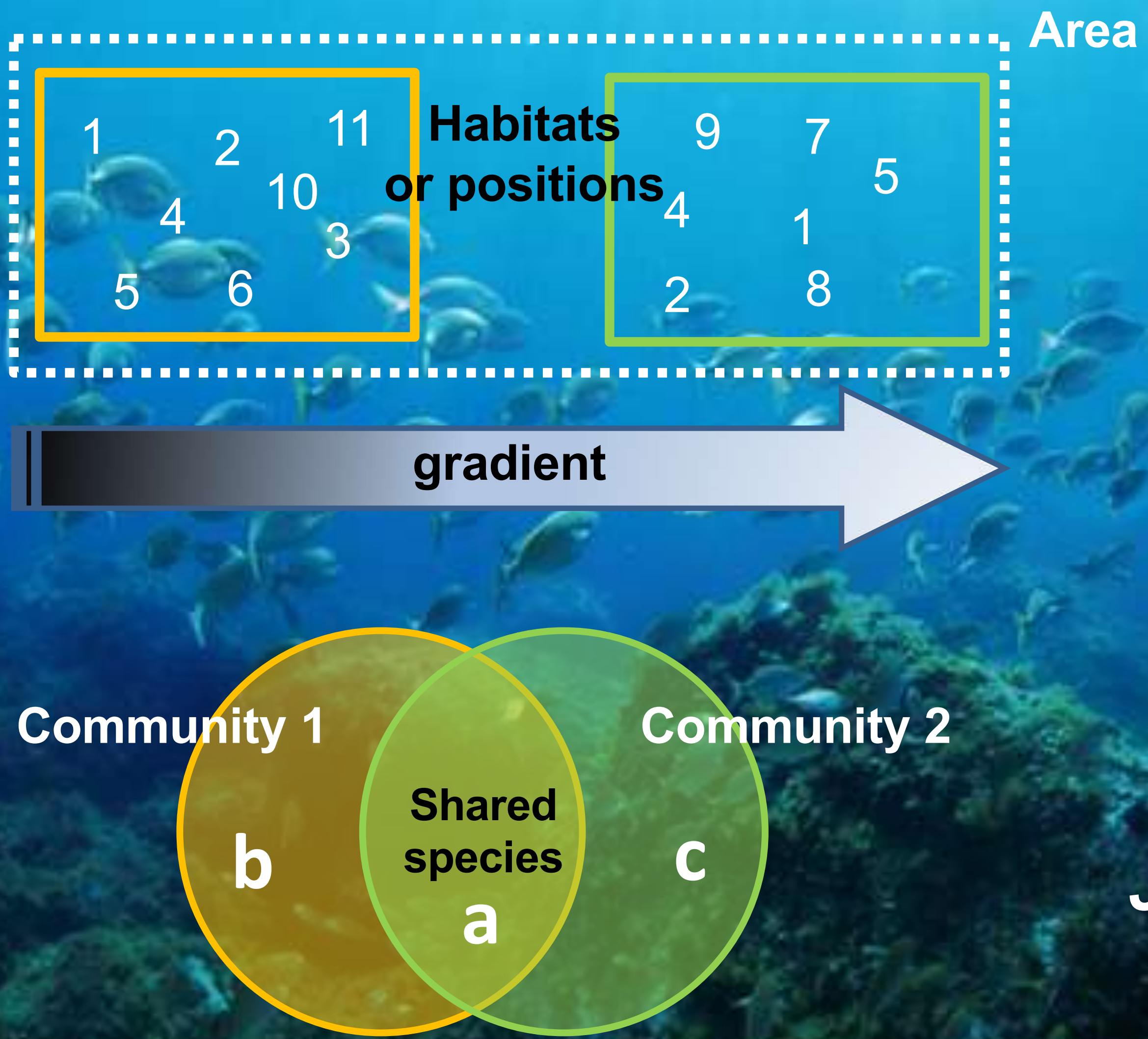




Sinks and sources
The importance of life cycles and life histories
Inter-habitat harmonization

β-diversity: basic concepts

The extent of change in community composition, or degree of community differentiation, in relation to a complex gradient of the environment, or a pattern of the environment (Whittaker 1960).



γ-diversity

the total diversity in the landscape

α-diversity

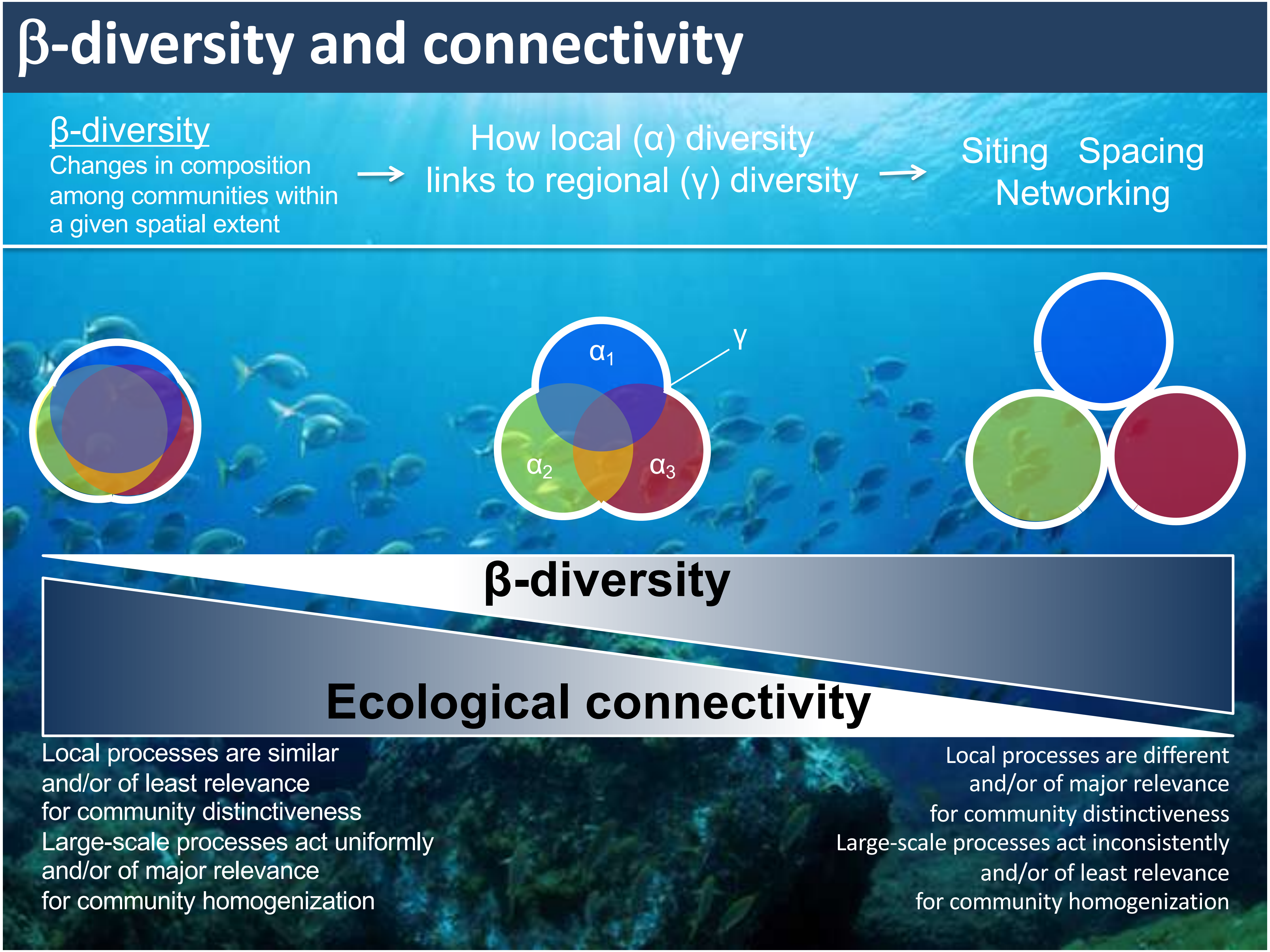
the local (site or habitat) diversity

β-diversity

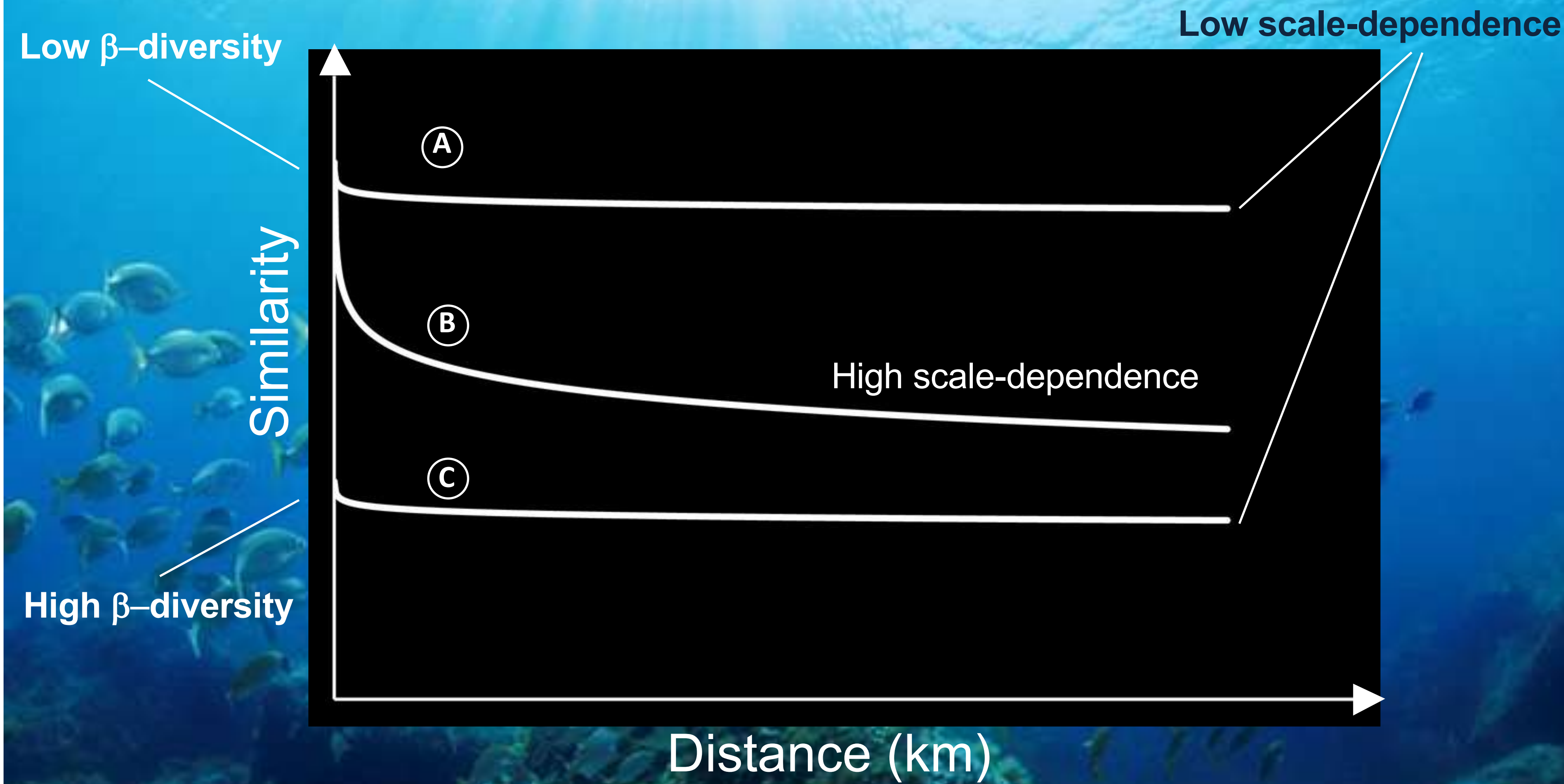
the differention diversity between sites or positions

$$\beta = \frac{b+c}{a+b+c}$$

Jaccard distance


β-diversity and connectivity
β-diversity
Changes in composition among communities within a given spatial extent
→
How local (α) diversity links to regional (γ) diversity
→
Siting Spacing Networking
α1
α2
α3
γ
β-diversity
Ecological connectivity
Local processes are similar and/or of least relevance for community distinctiveness
Large-scale processes act uniformly and/or of major relevance for community homogenization
Local processes are different and/or of major relevance for community distinctiveness
Large-scale processes act inconsistently and/or of least relevance for community homogenization

General patterns of distance-decay



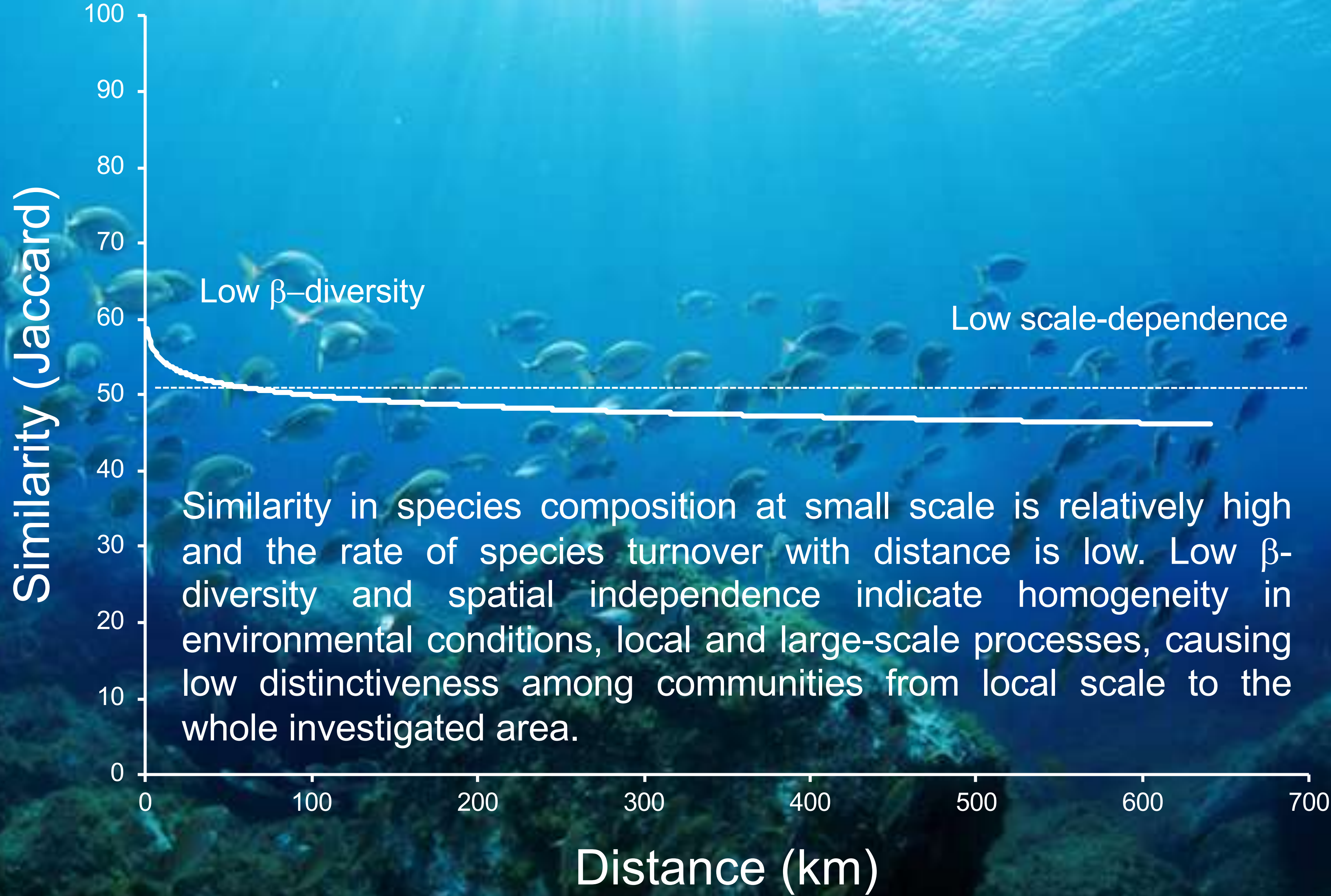
A
Homogeneity from local to large scale: high connectivity across the region

B
Homogeneity decrease with scale: high connectivity at local scale that decrease over large scale

C
Heterogeneity at local scale, llow connectivity across the region

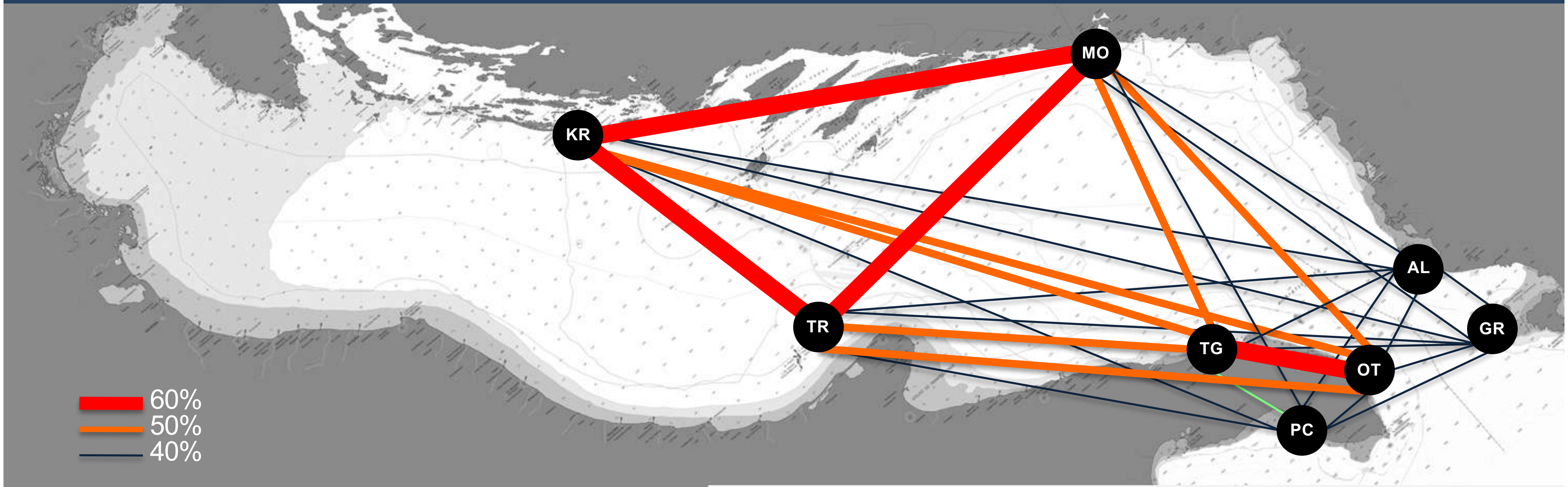
Modified from Soininen et al, 2007

Distance-decay sessile assemblages: Adriatic Sea



Similarity in species composition at small scale is relatively high and the rate of species turnover with distance is low. Low β-diversity and spatial independence indicate homogeneity in environmental conditions, local and large-scale processes, causing low distinctiveness among communities from local scale to the whole investigated area.

Similarity in composition in the Adriatic



Higher similarity among locations in the central (KR-TR-MO) and southern Adriatic (TG-OT)

Intermediate similarity between these two groups

Discontinuity with locations AL, GR, PC

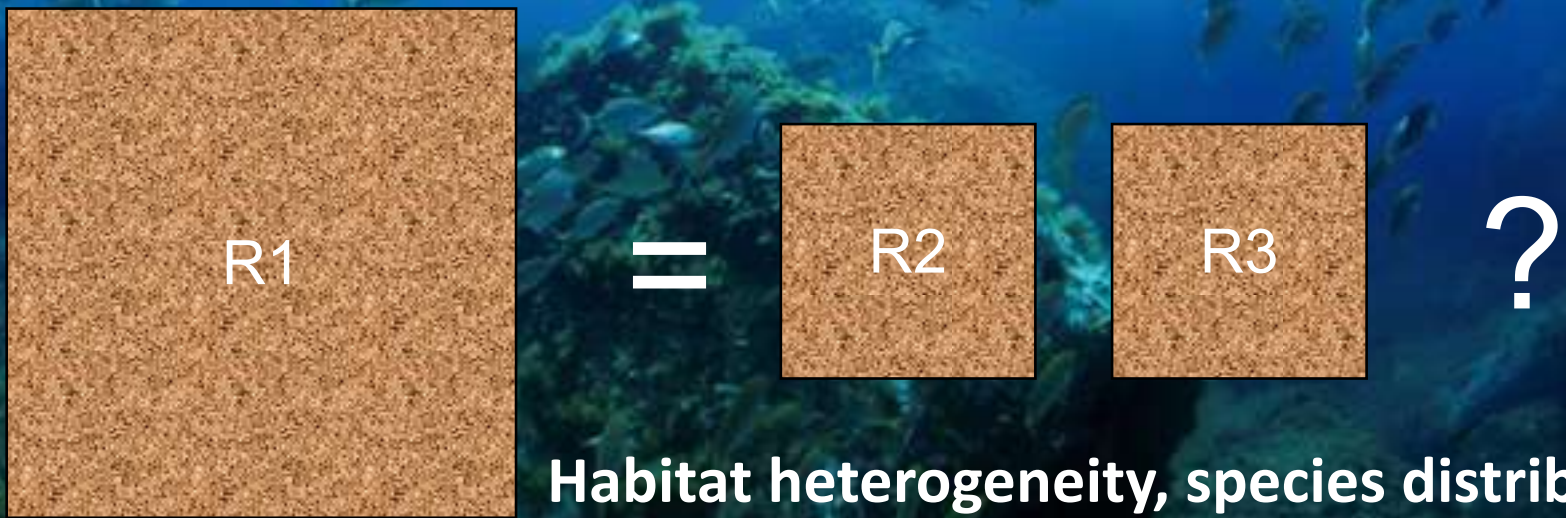
Sessile assemblages on subtidal rocky reefs

SLOSS controversy

IBT raised concerns about the opportunity to implement single large or several small reserves

Large areas allow protecting more species than smaller ones.
However…Large areas are more difficult to manage and control.
They are politically difficult to propose and sustain.
Large areas have higher probability to create social and economic conflicts. They are also more difficult to monitor
Uncertainty on the result of conservation in terms of amount of species protected…

$S_{R1} \leq (S_{R2}+S_{R3})$



Habitat heterogeneity, species distribution

A question of size

Pelagos Sanctuary (SPAMI)
Year of institution: 1999
Surface: about 90,000 km^2
Countries: Italy, France, Monaco

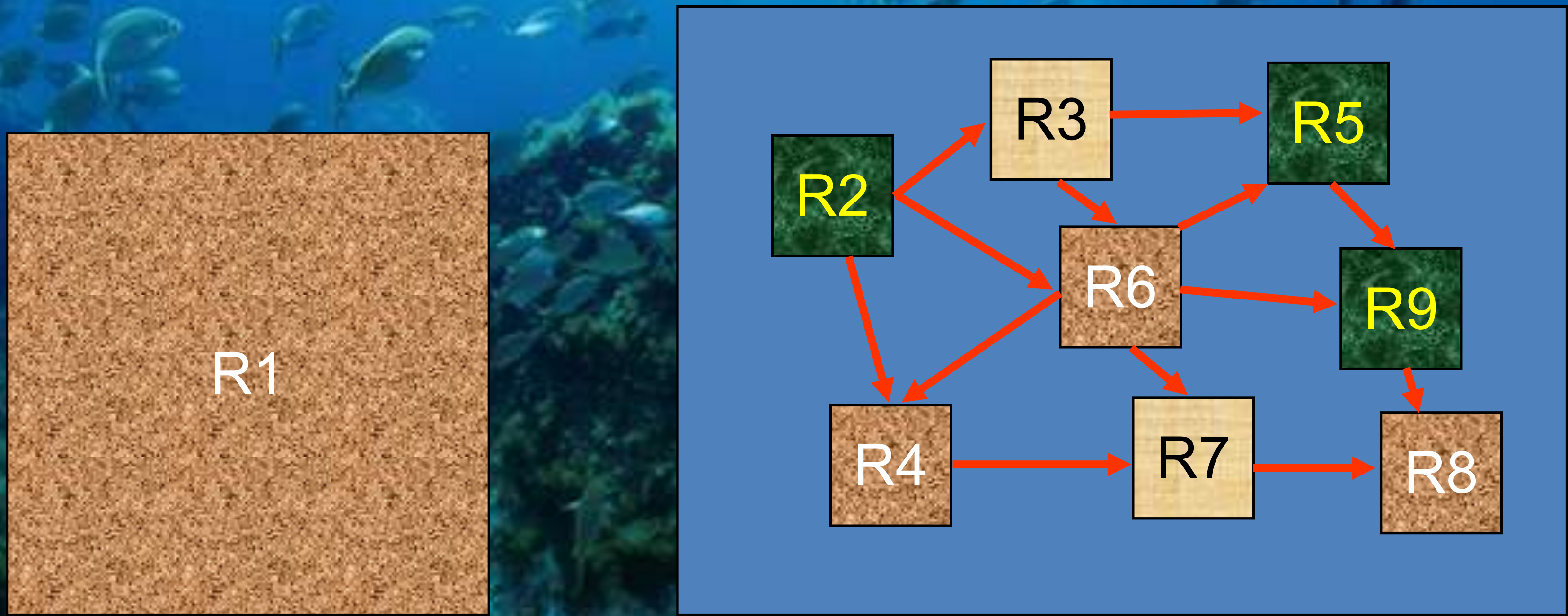
Large reserve for large animals or animals requiring a large surface for movements and foraging

A question of size: distribution

The largest marine park in the Mediterranean Sea is the National Marine Park of Sporadi, in the Aegean Sea. Created in 1992, it is devoted to protection of *Monachus monachus*, the Mediterranean monk seal

Small reserves could increase chance in the face of perturbations

Several small interspersed reserves could provide insurance against perturbations (e.g., catastrophic disturbance or demographic events), with recolonization provided by undisturbed sites, or including higher habitat diversification with respect to larger ones and therefore more species



Notwithstanding, large reserves…

Should….

1 – decrease competition and predation pressure from neighbouring species, with border populations more exposed than those in the centre of the reserve;

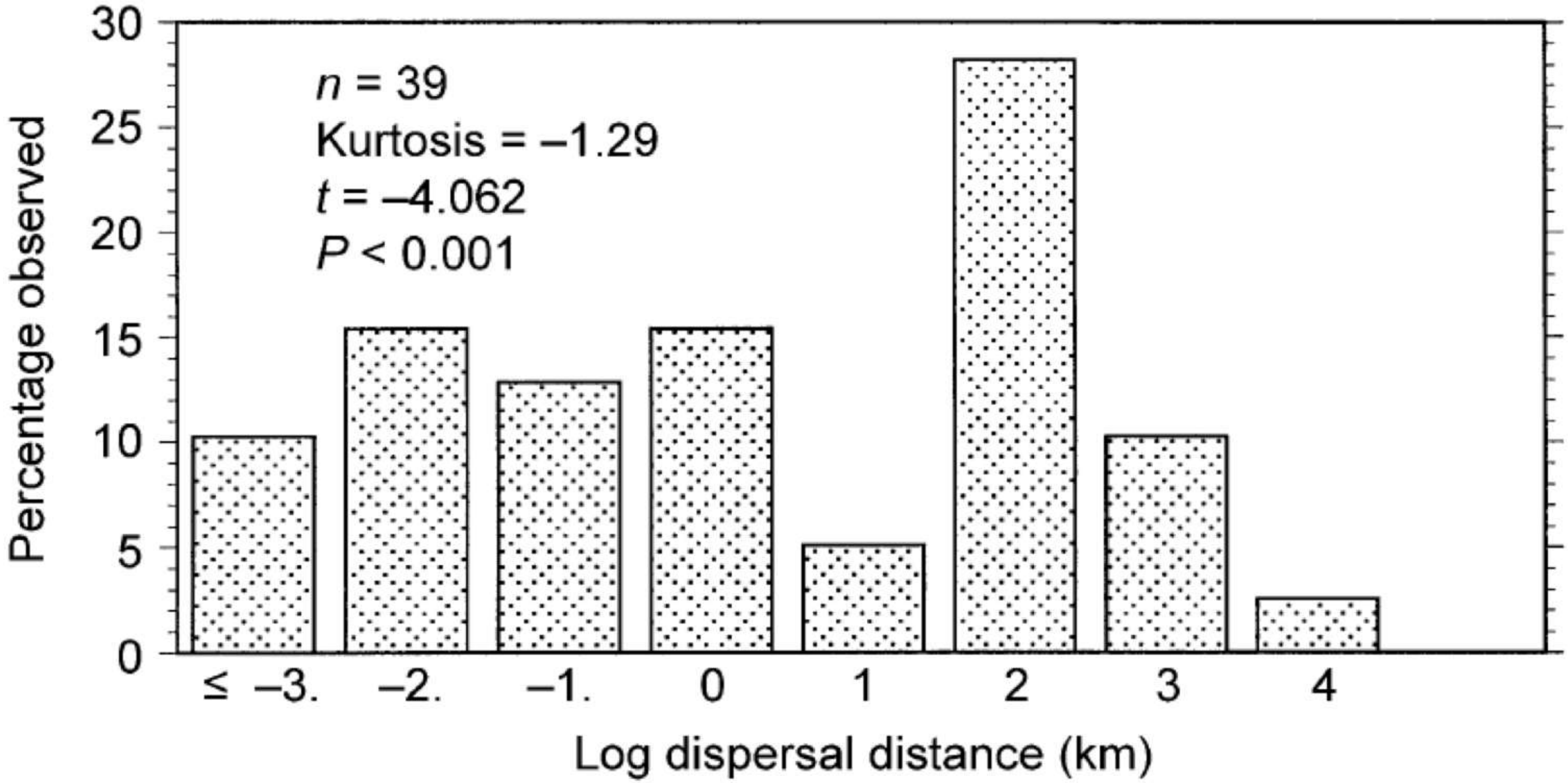
2 – provide a better spatial match with the *home-range* of large carnivorous species;

3 – include a larger range of environments to allow persistence of different species populations in the long term;

4 – include different subpopulations and, as a consequence, higher intra-specific genetic diversity;

5 – better respond to external disturbace through a buffer effect

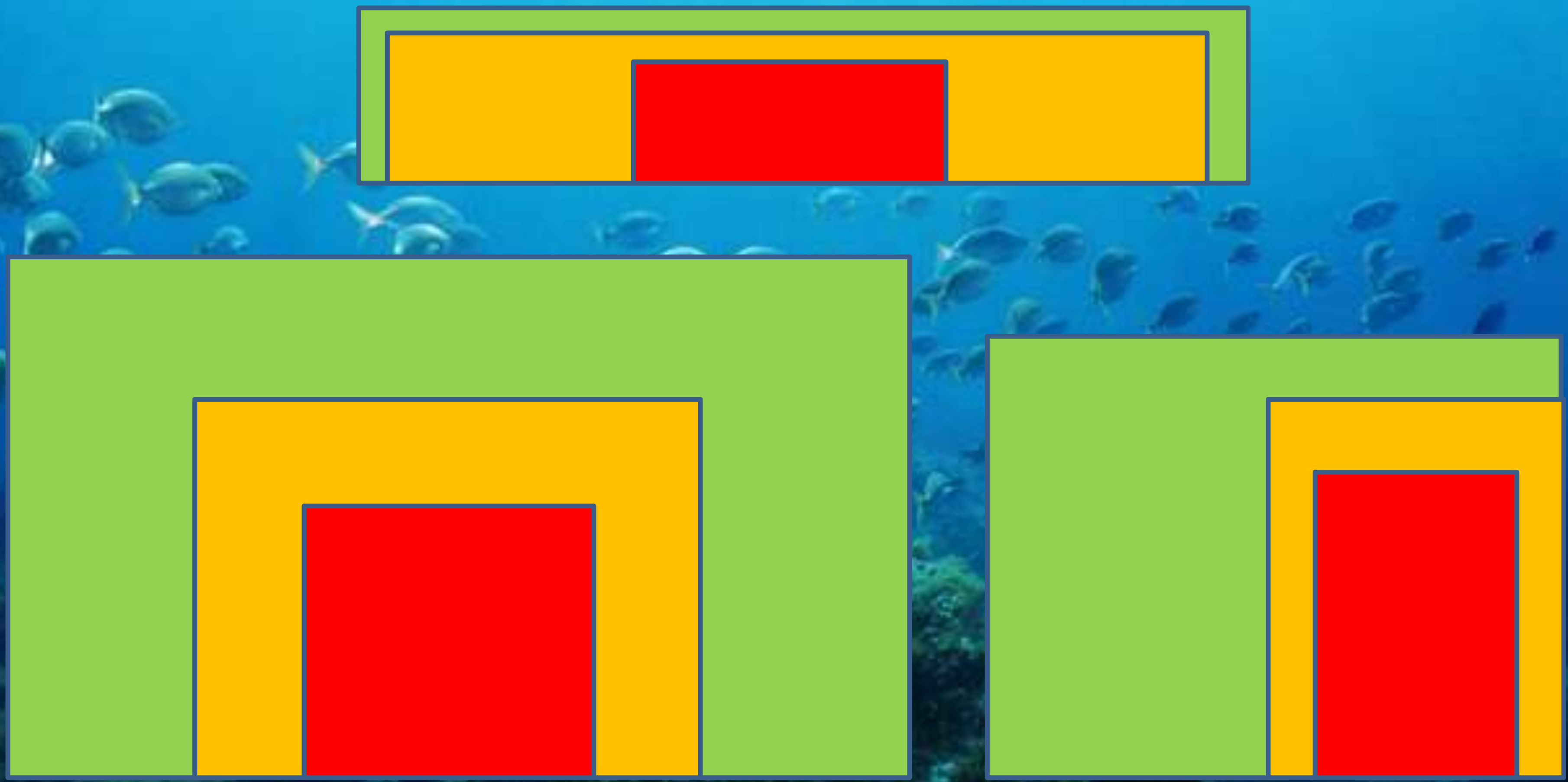
Spacing



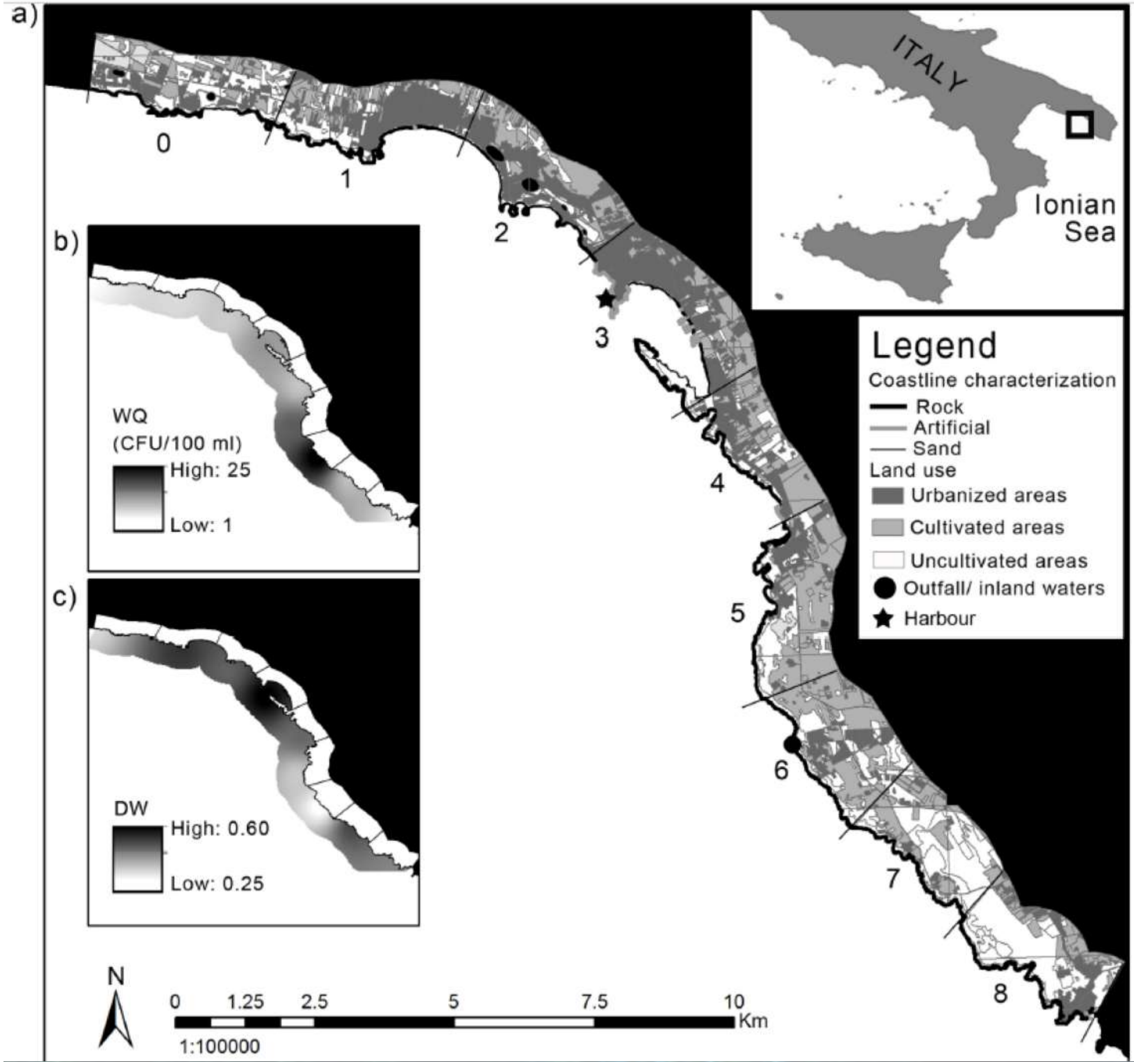
1) Bimodal trend in dispersal strategies, one short distance and long distance.
2) Reserves with diameter of 4-5 km, 10-20 km apart are wide enough to retain propagules of short-distance dispersers and far enough to allow long-distance dispersers to be captured. However, limited range of organisms.
Shank et al., 2003

Shape

Low area/perimeter ratio could increase exposure of central populations to external influence



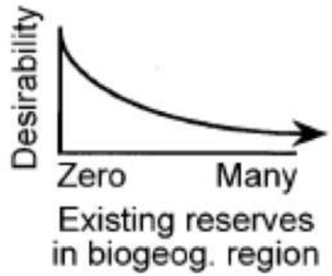
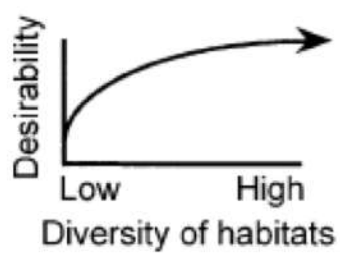
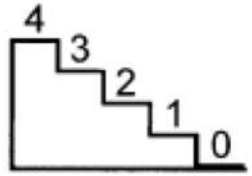
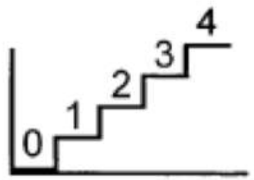
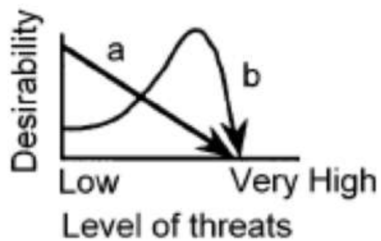
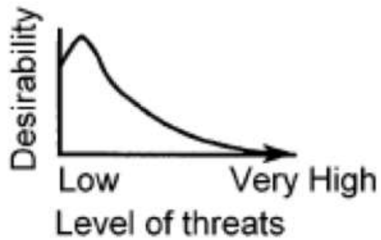
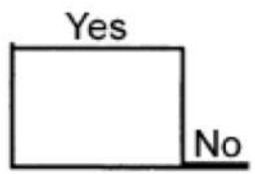
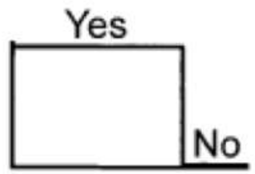
Environmental context: human threats



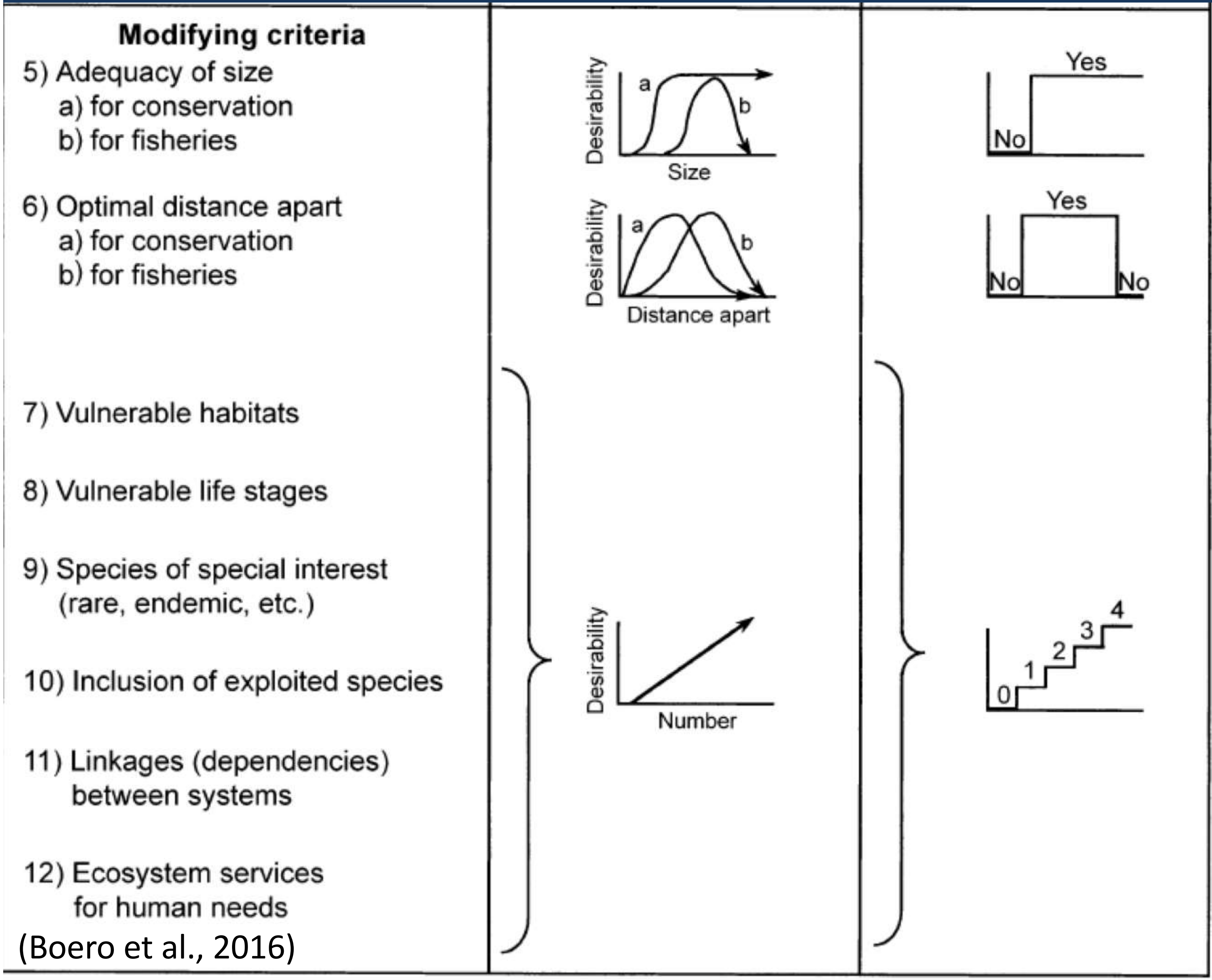
Guarnieri et al., 2016

High level of anthropization could increase exposure of protected populations and communities to human pressures or impacts

Network of MPAs: general criteria

Criteria	Relationship	Possible ranking
Prerequisite criteria 1) Biogeography 2) Habitats a) Diversity b) Diversity *not* protected elsewhere	 	 
Excluding criteria 3) Human threats a) Non-mitigatable b) Mitigatable 4) Natural threats (Boero et al., 2016)	 	 

Network of MPAs: general criteria



(Boero et al., 2016)

Issues

Effective protection require three main points:

1) as first, MPAs should be sited to fulfil well-defined conservation purposes. This in turn will guide positioning and subsequent conservation strategies. The aims of MPAs should take into account connectivity, population dynamics, diversity distribution and, last but not least, the context to reduce socio-economic conflicts and external human pressures.

2) effective protection cannot fall outside considerations of geopolitical and large scale governance constraints, resources availability to maintain governance of reserves, and therefore enforcement, to avoid creation of 'paper reserves'

3) adaptive management is unavoidable; habitats distribution could change, zonation could require refinements, and monitoring is mandatory to detect changes and implement actions, modifying strategies, or simple to insure that conservation target are being achieved

(Airamè et al., 2003)

Necessary but not sufficient…

Research is demonstrating that marine reserves are powerful management and conservation tools, but they are not a panacea;

They cannot alleviate all problems, such as pollution, climate change, or overfishing, that originate outside reserve boundaries. Marine reserves are thus emerging as a powerful tool, but one that should be complemented by other approaches.

The answer to the question, ''how much is enough'' is the holy grail of conservation in both marine and terrestrial ecosystems. The goal of marine reserves is to ensure the persistence of the full range of marine biodiversity—from gene pools to populations, to species and whole ecosystems—and the full functioning of the ecosystem in providing goods and services for present and future generations. Because there will always be opportunity costs to conservation, there is a limit to how much we can conserve.

(Lubchenco, 2003)