University of Trieste: GLOBAL CHANGE ECOLOGY a.a. 2020-2021

Conservation & Management in Marine Protected Areas

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Ecological principles underlying marine conservation

Implications for differences in conservation strategies and reserve networks

Feature	Terrestrial ecosystems	Marine ecosystems
Reserve objectives		
Spatial focus for protection	within reserves	within and outside reserves
Emphasis on propagule export	little	great
State of knowledge		
Taxonomic identification	good	poor
Patterns of species distribution and abundance	good	poor to moderate
Geographic patterns of marine ecosystem diversity	good	poor
Design criteria		
Movement (connectivity) corridors		
Importance of connectivity	less	greater
Type	primarily habitat based	primarily current based
Importance of habitat corridors	greater	lower
Human managed	great	little
Constancy/predictability	high	low
Protection of nonreserve populations	less critical	very critical
Reserve size		
Sufficient for local replenishment (single reserve)	smaller	larger
Habitat diversity necessary for resource requirements	smaller	larger
Reserve location		
Sensitivity to biogeographic transitions	less	greater
Importance of import–export processes (i.e., winds, currents)	less	great

(Carr et al., 2003)

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)

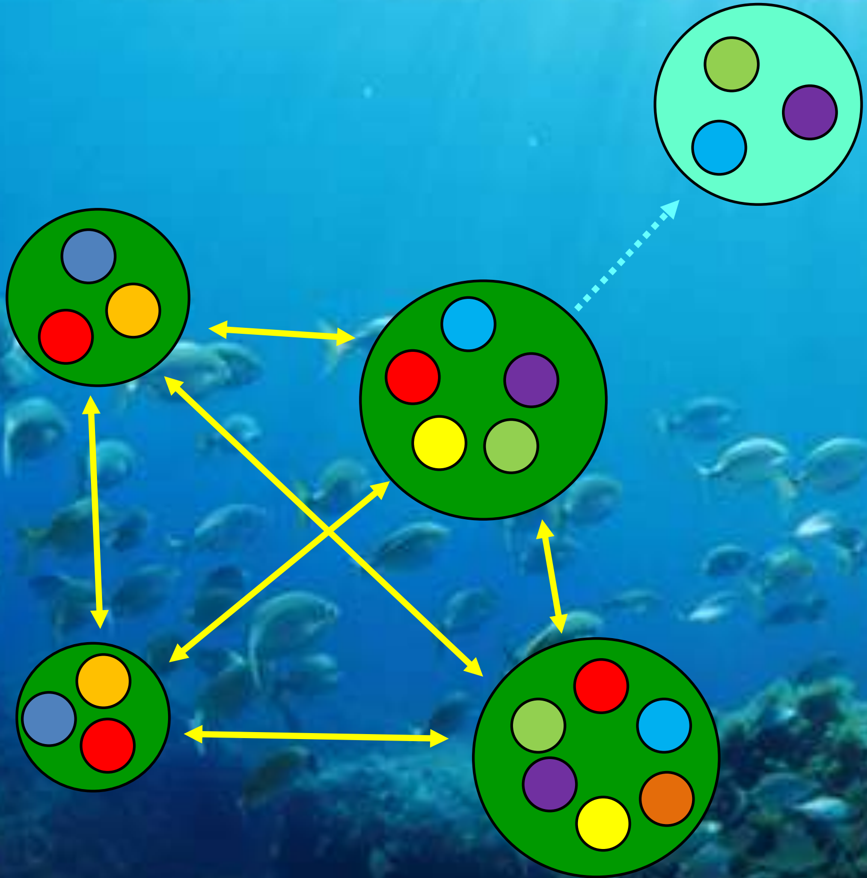
Supply side ecology

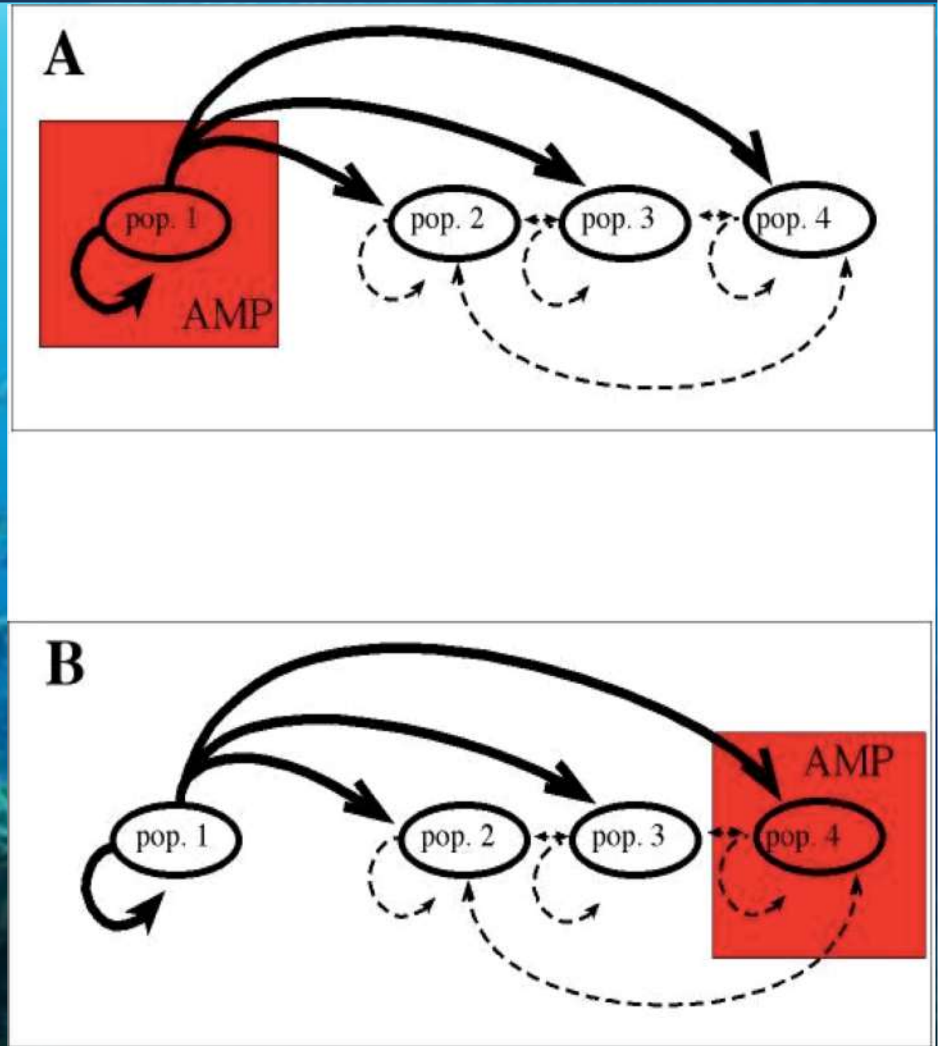
Metapopulation theory

Patch dynamic

Great contribution of experimental marine biology and ecology

Supply side ecology, metapopulations, and metacommunities





Sinks and sources

The importance of life cycles and life histories

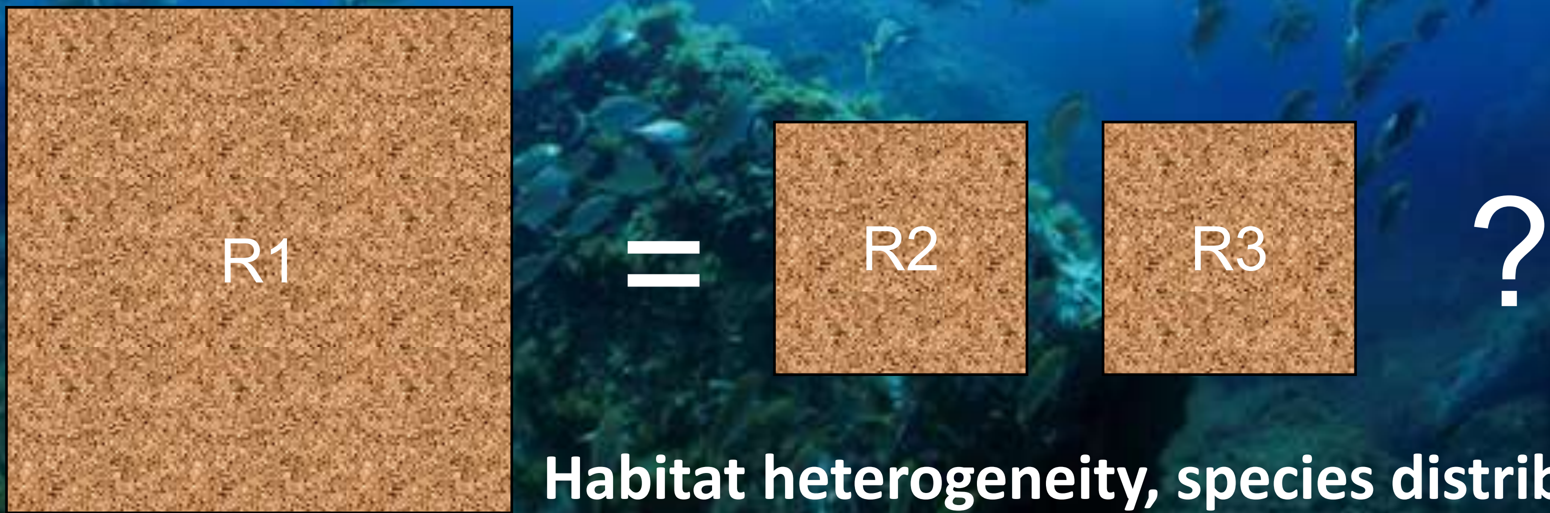
Inter-habitat harmonization

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 expensive in terms of management and enforcement. 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

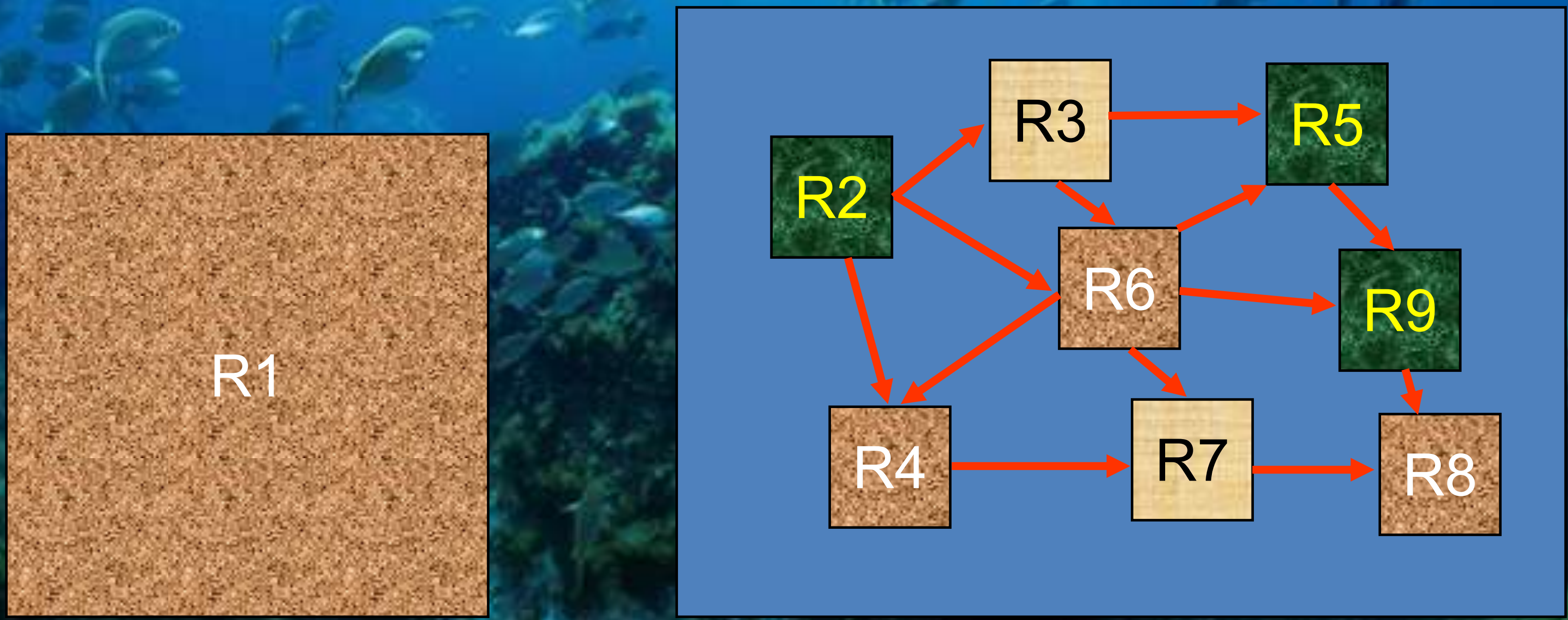
Large reserve for large animals or animals requiring a large surface for movements and foraging

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;

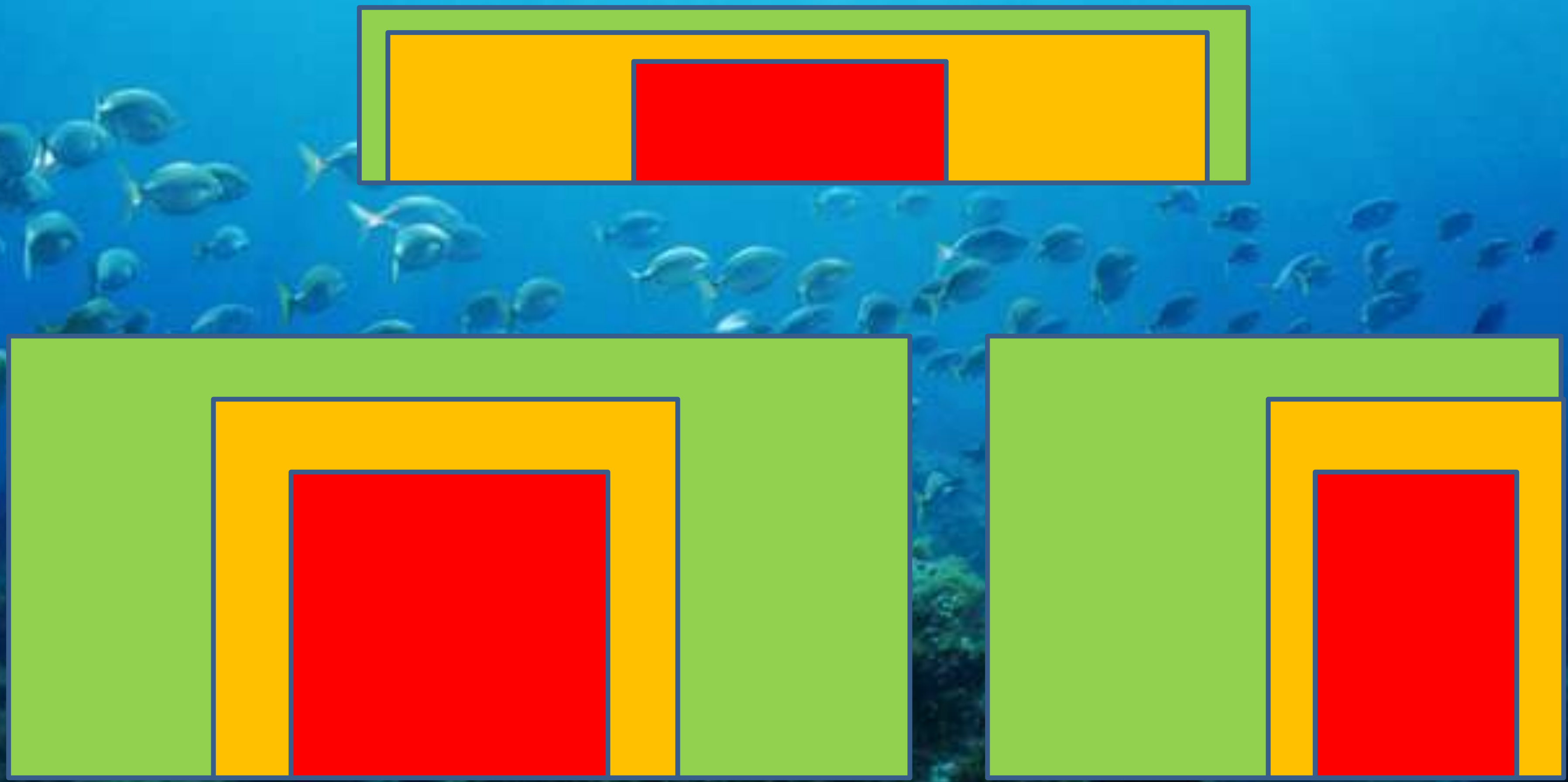
3 – include a larger range of environments to allow persistence of different species populations in the long term;

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

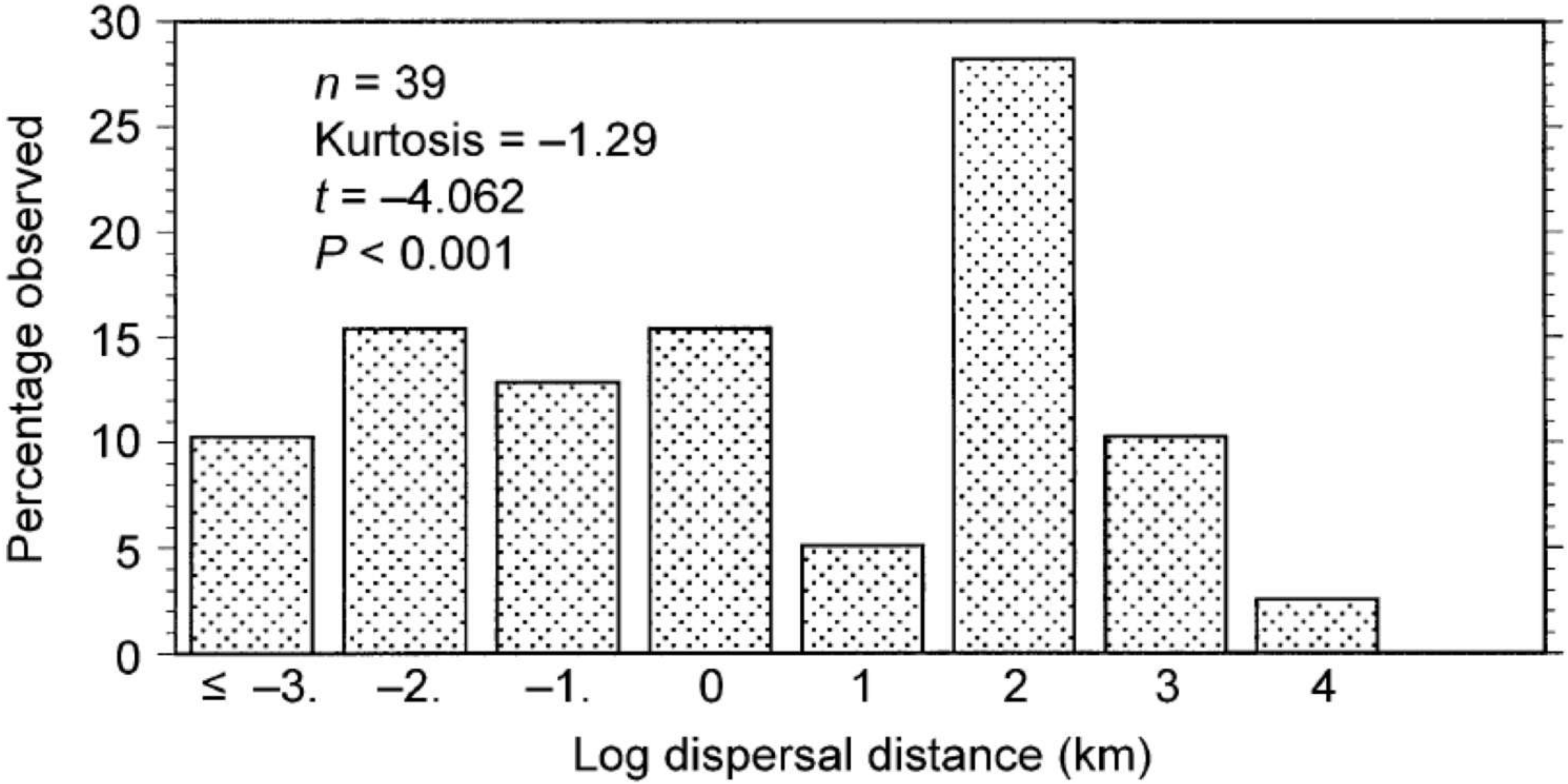
5 – better respond to external disturbace through a buffer effect

Shape

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



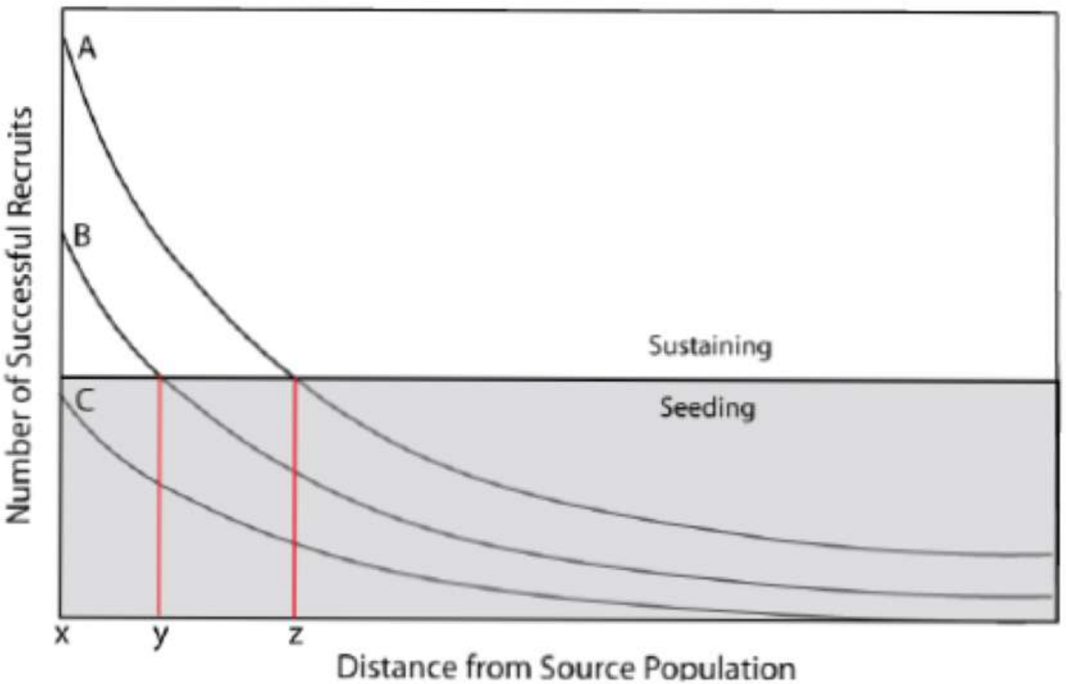
Spacing

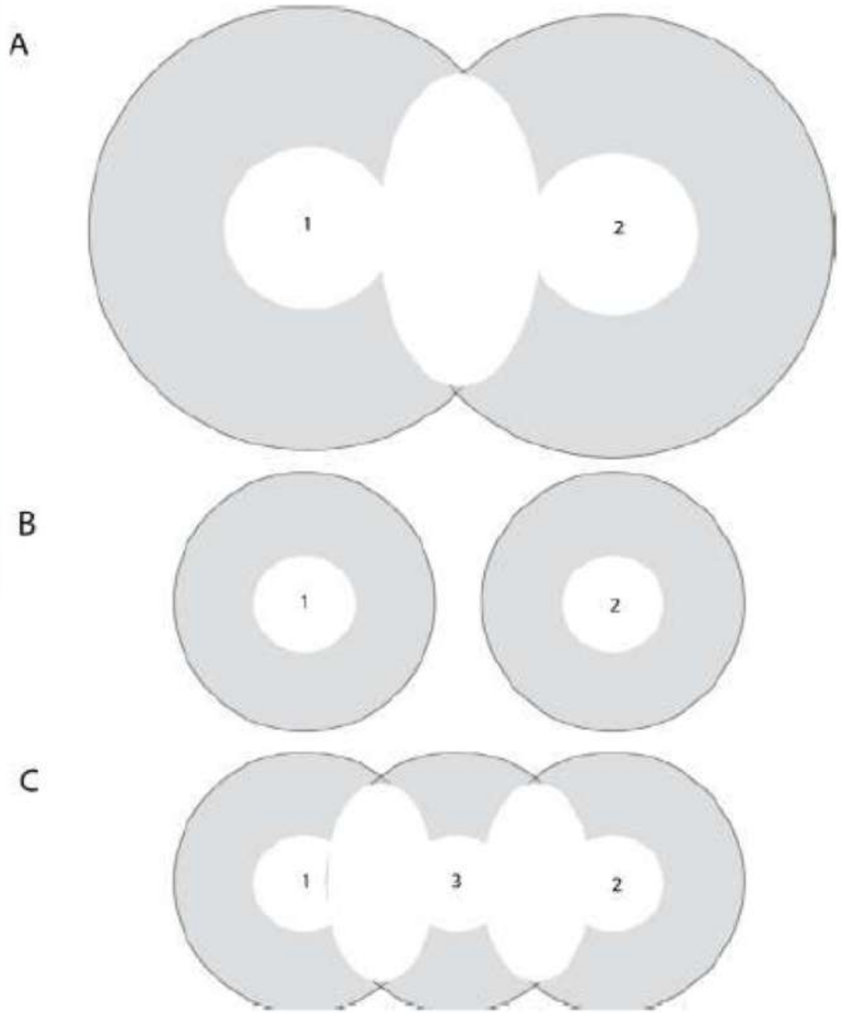


1) Bimodal trend in dispersal strategies, one short distance and long distance.
2) Reserves with diameter of 4-5 km, 10-20 km apart are wide enough to retain propagules of short-distance dispersers and far enough to allow long-distance dispersers to be captured. However, limited range of organisms. Habitat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

Spacing

To understand the effects of dispersal on population replenishment and resilience, it is important to differentiate between (1) “sustaining” dispersal: ecologically/ demographically important in maintaining or increasing a local population and (2) “seeding” dispersal: evolutionarily important in maintaining gene flow and decreasing the long-term probability of local extinction. Sustaining dispersal occurs over small spatial scales whereas seeding dispersal occurs over large spatial scales.

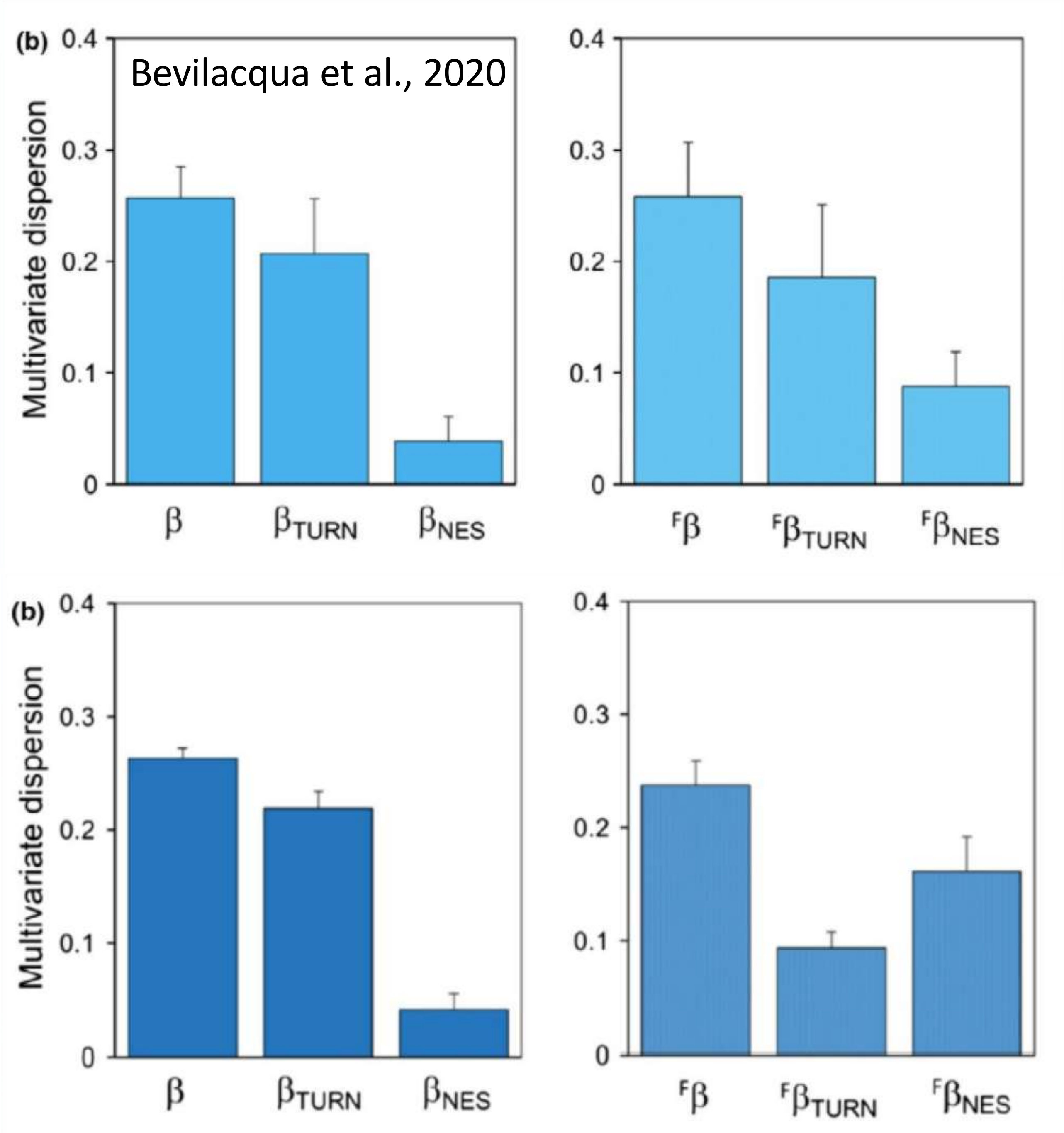




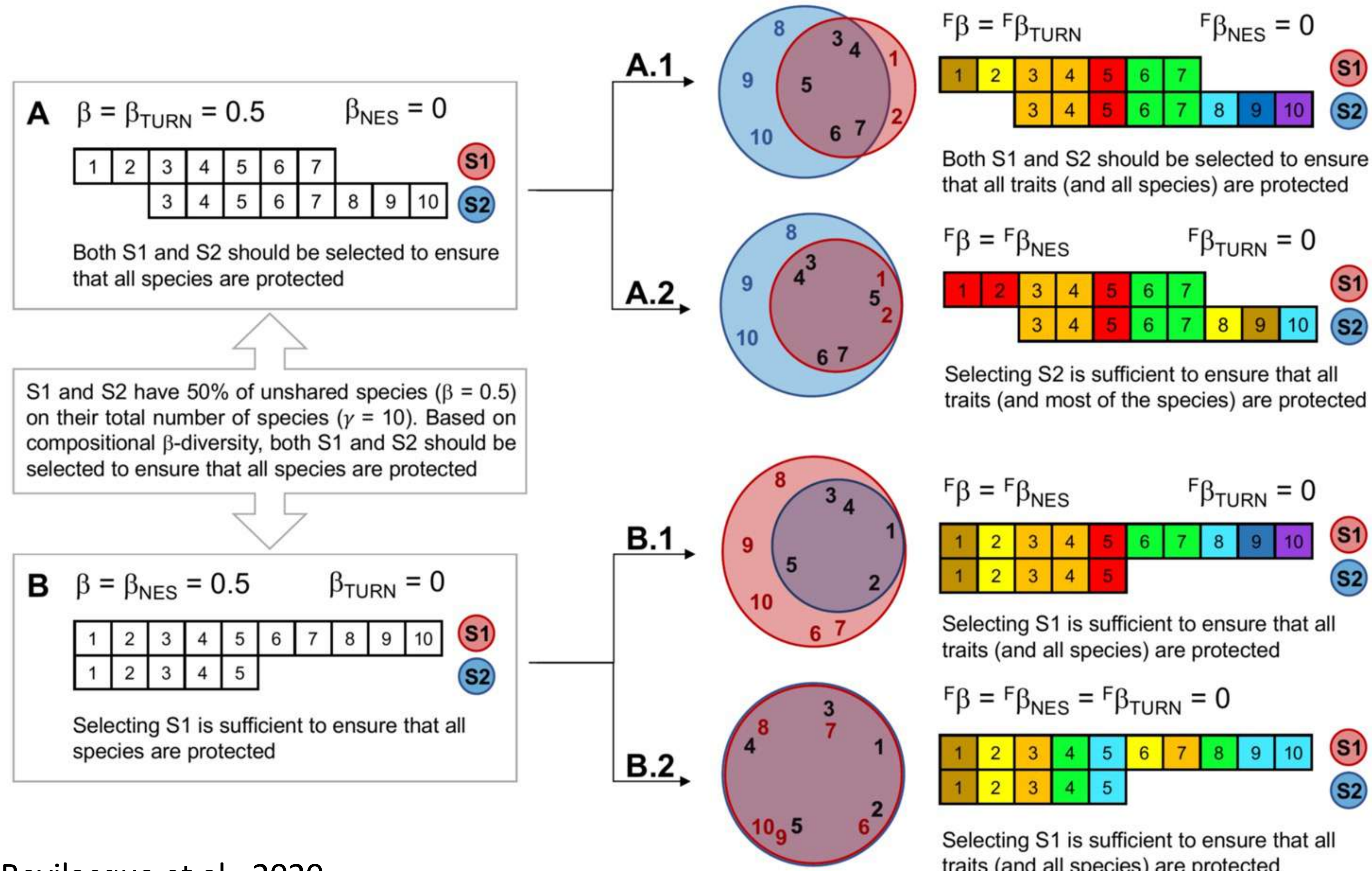
Small populations produce fewer propagules than large populations. Thus, as size decrease distance of seeding and sustaining decrease.

Biological heterogeneity

Siting and spacing are strictly related to connectivity. Current transport of propagules, and heterogeneity in distribution of species are main factors to account for ecologically coherent network. Often, the analysis of beta-diverity patterns focuses on taxoonomic diversity. However, other aspects of diversity should be considered to implement networks that, beyond representative of species diveristy also allow to conserve functional diversity.

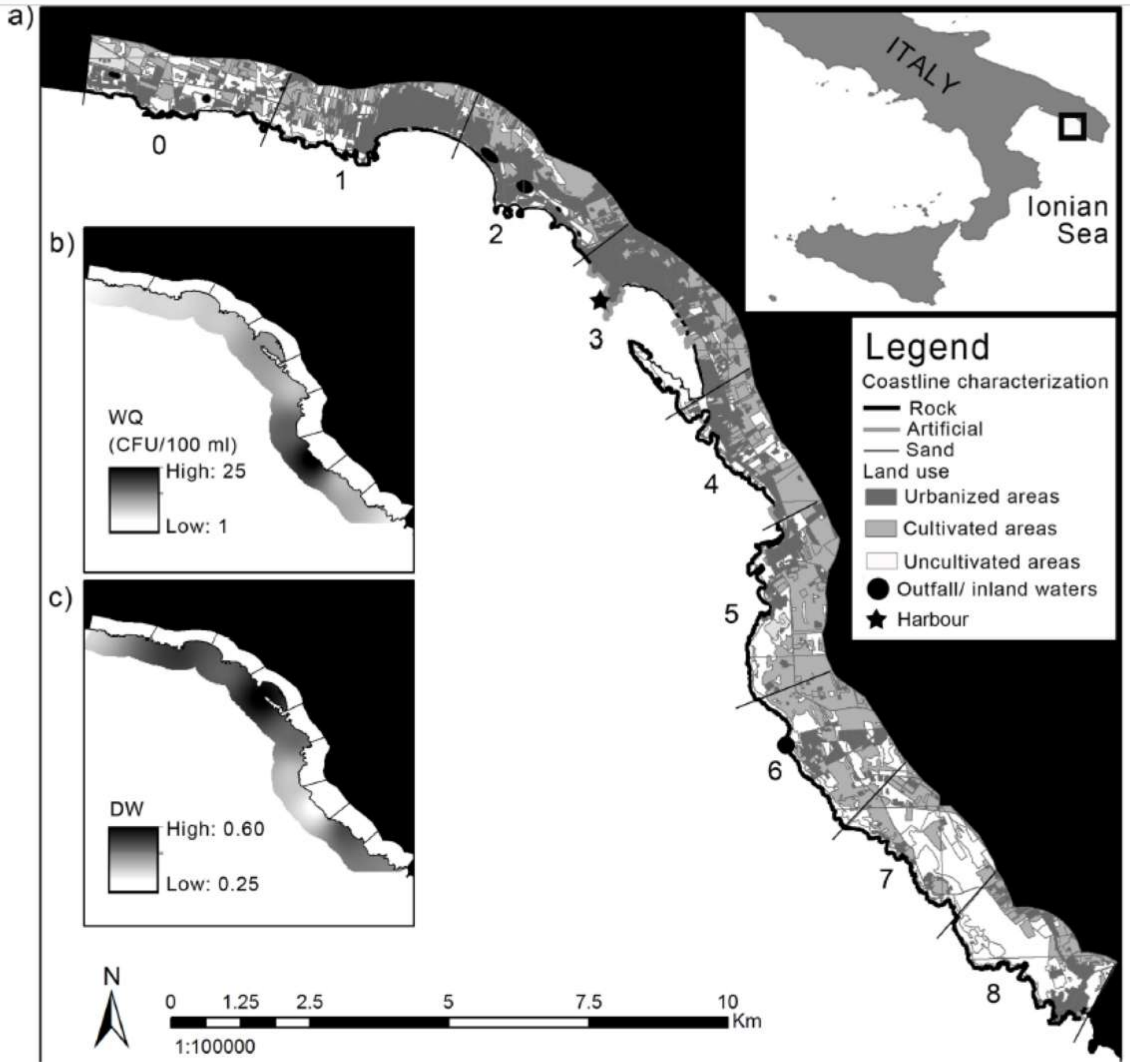


Implication for siting and spacing



Bevilacqua et al., 2020

Environmental context: human threats

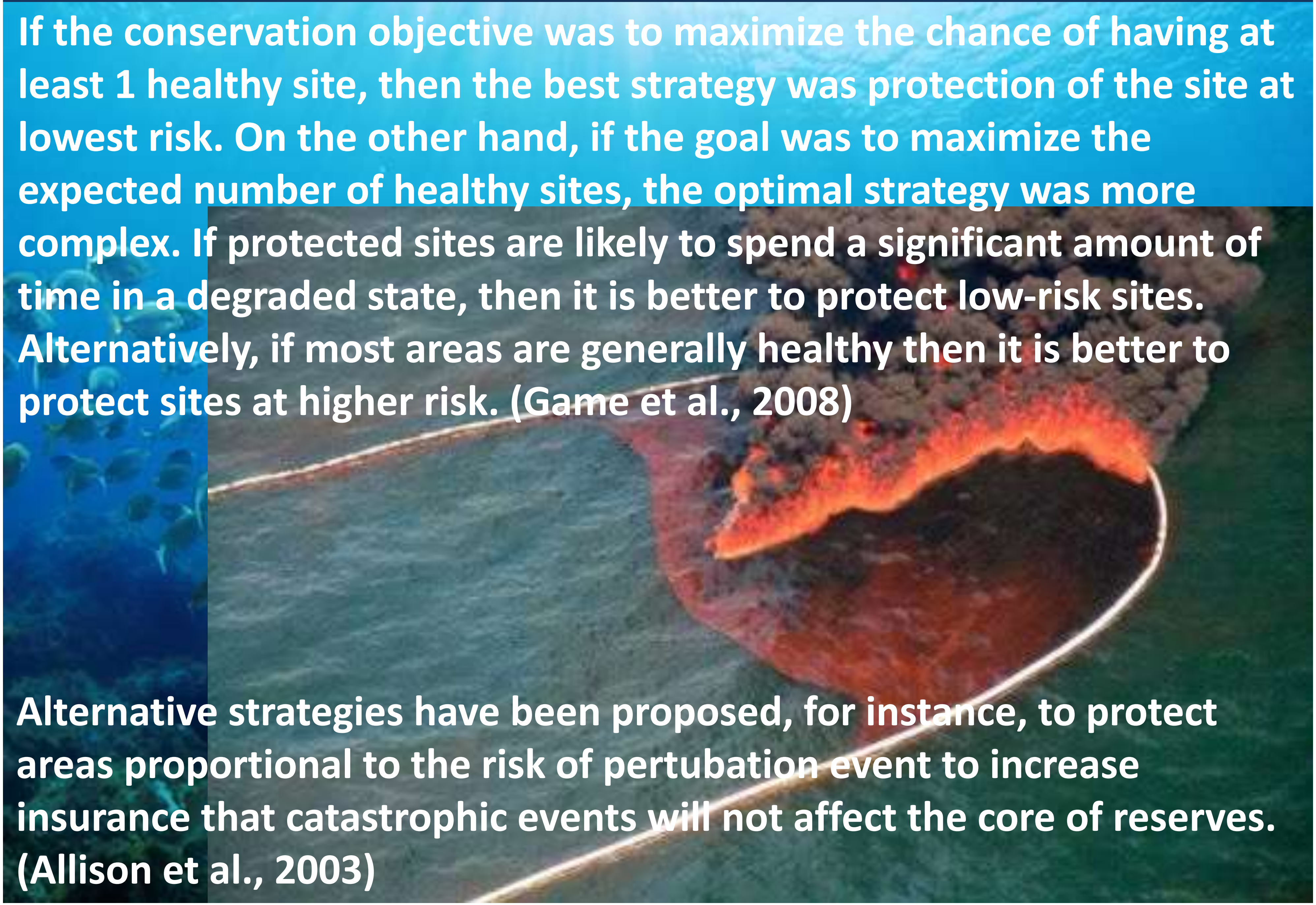


Guarnieri et al., 2016

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

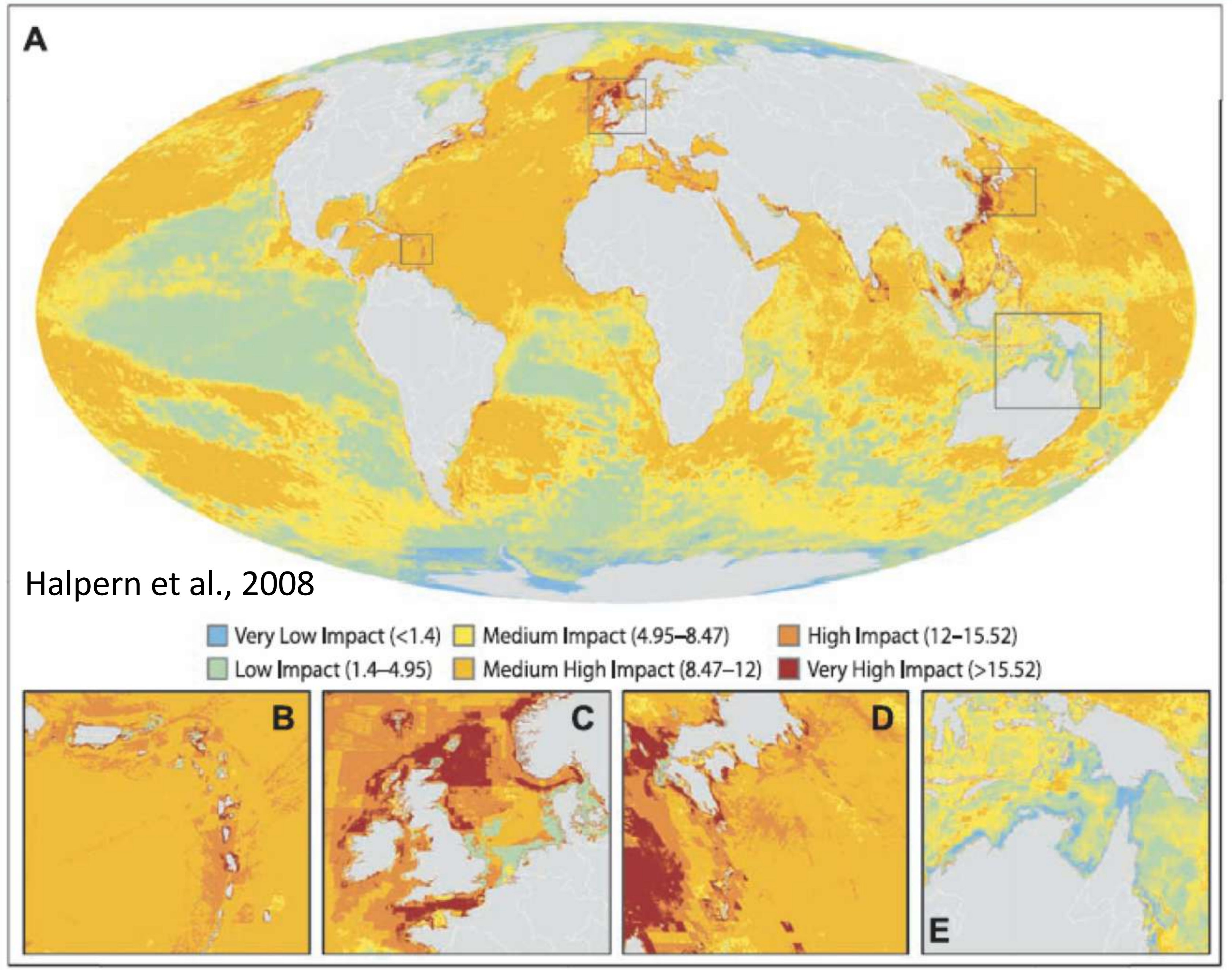
Should We Protect the Strong or the Weak?

If the conservation objective was to maximize the chance of having at least 1 healthy site, then the best strategy was protection of the site at lowest risk. On the other hand, if the goal was to maximize the expected number of healthy sites, the optimal strategy was more complex. If protected sites are likely to spend a significant amount of time in a degraded state, then it is better to protect low-risk sites. Alternatively, if most areas are generally healthy then it is better to protect sites at higher risk. (Game et al., 2008)



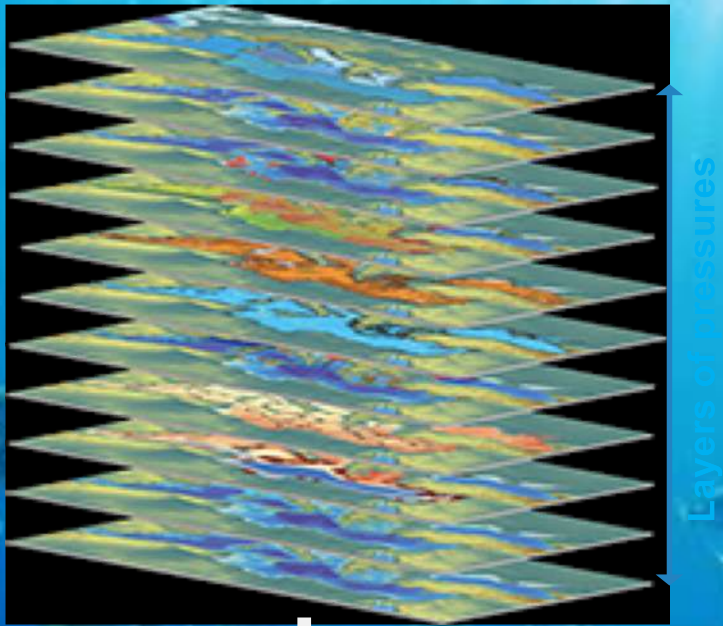
Alternative strategies have been proposed, for instance, to protect areas proportional to the risk of pertubation event to increase insurance that catastrophic events will not affect the core of reserves. (Allison et al., 2003)

Estimating cumulative impacts



Halpern et al., 2008

The additive formula



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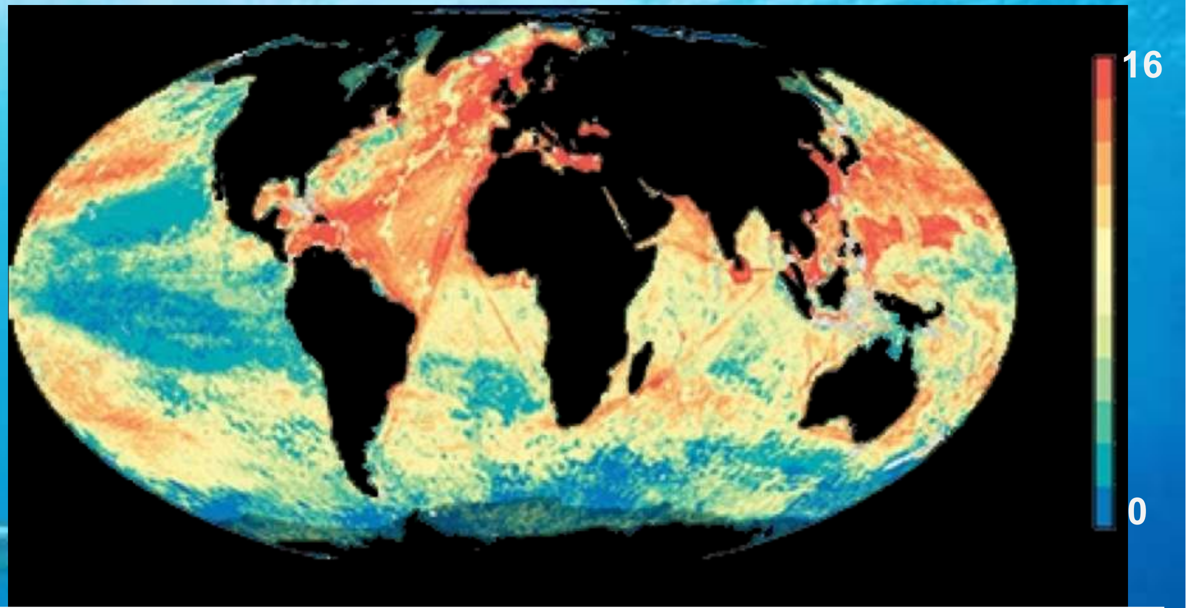
Sensitivity weights by expert opinion

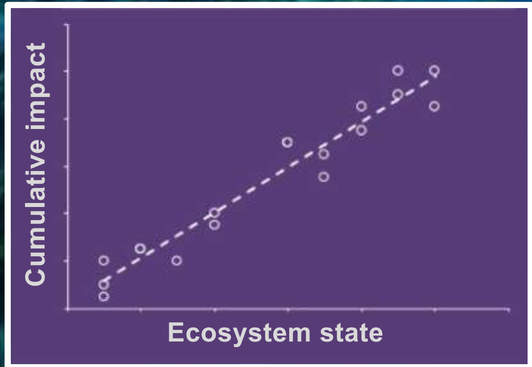
Computing geo-referred impact score

$$I_c = \sum P_i w_i E_j$$



Map of cumulative impact

Cumulative impact score versus ecosystem state



Linear response to pressure

Additivity of impacts

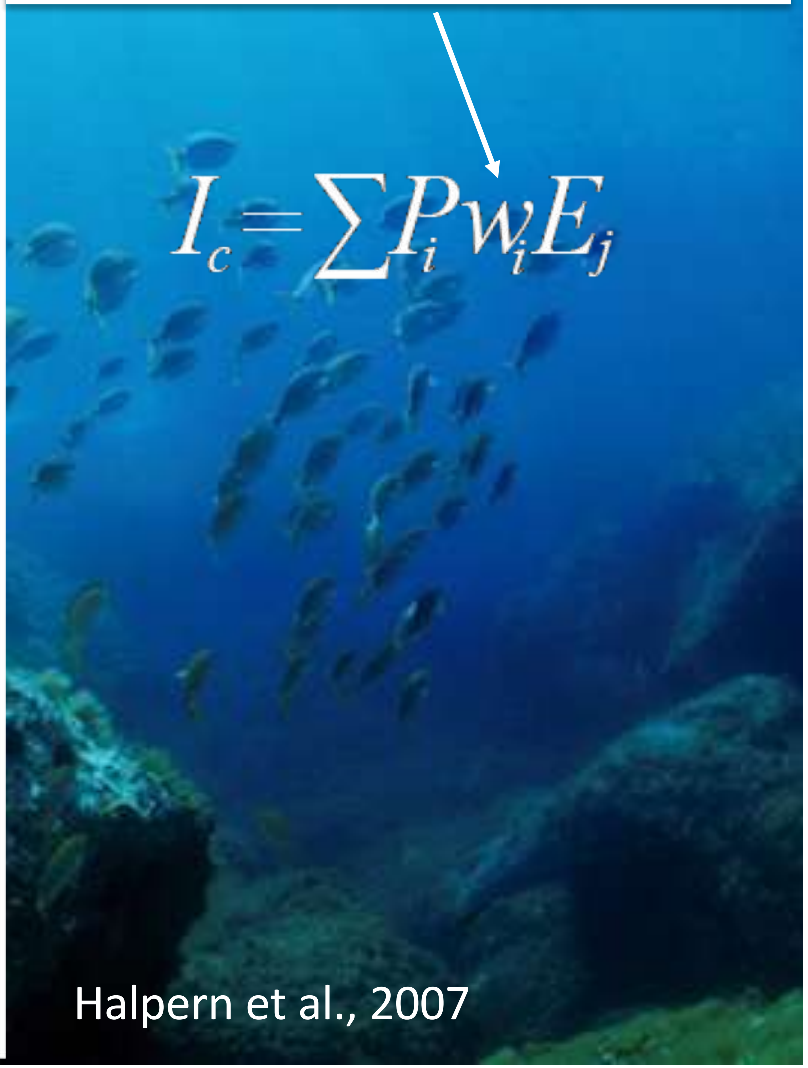
Expert-based sensitivity

Resolution and downscaling

Scores

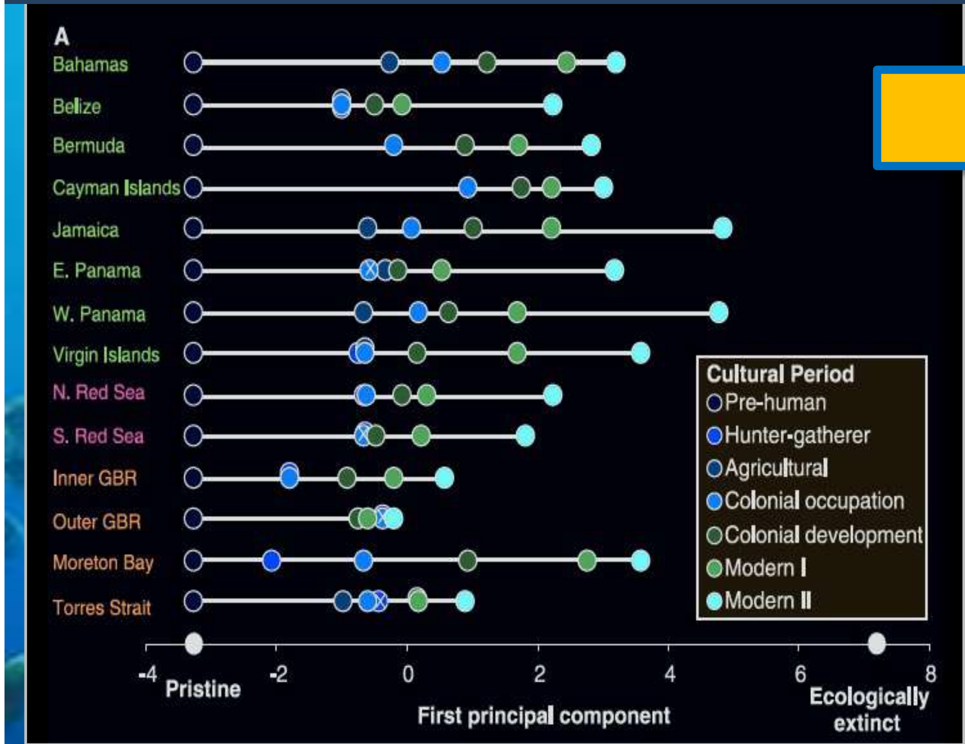
	Intertidal					*Coastal*				
	Rocky intertidal	*Intertidal mud*	*Beach*	*Mangrove*	*Salt marsh*	*Coral reef*	*Seagrass*	*Kelp forest*	*Rocky reef*	*Suspension-feeder reef*[c]
Threat[b]	13	5	7	7	14	24	6	7	9	5
Freshwater input										
increase	1.6	1.3	0.3	1.8	1.9	1.5	1.6	0.0	1.5	1.7
decrease	1.1	1.1	0.0	2.6	1.9	0.4	1.4	0.0	0.6	1.2
Sediment input										
increase	2.4	2.0	1.1	2.2	2.2	2.8	2.9	1.2	2.0	2.2
decrease	0.6	1.6	0.7	1.3	1.7	0.4	0.5	0.0	0.0	1.5
Nutrient input[d]										
into oligotrophic water	1.8	1.1	0.2	1.4	1.4	2.4	2.1	0.0	1.7	0.0
into eutrophic water	1.3	2.1	0.6	2.1	2.3	1.1	2.0	0.8	1.5	2.8
Pollutant input										
atmospheric	0.8	0.7	0.0	0.9	1.6	0.9	0.6	0.0	0.5	1.8
point, organic	2.4	2.1	1.9	2.0	1.5	2.2	1.9	0.8	2.1	2.4
point, nonorganic	2.2	1.7	0.8	1.1	2.0	1.9	0.4	0.2	1.6	2.4
nonpoint, organic	2.1	2.8	0.1	1.4	1.7	1.2	1.0	1.0	2.2	2.8
nonpoint, nonorganic	2.1	1.6	0.6	0.5	2.0	0.7	0.8	0.0	2.2	2.7
Coastal engineering	2.7	2.1	2.8	3.1	2.3	2.3	2.4	0.0	1.9	3.0
Coastal development	2.7	2.9	3.2	3.4	2.8	2.9	3.3	1.2	2.5	3.2
Direct human	2.8	2.2	2.7	3.3	1.6	2.3	2.5	1.6	2.5	3.0
Aquaculture	2.0	2.0	0.1	3.1	1.7	1.8	2.1	0.0	1.9	1.5
Fishing										
demersal, destructive	1.2	1.4	0.2	0.0	1.0	1.2	0.2	1.5	2.7	3.1
demersal, nondestructive	0.8	1.9	0.9	0.9	1.0	1.6	1.1	2.1	2.9	0.7
pelagic, high bycatch	0.9	0.0	0.1	0.0	0.5	0.5	0.0	0.0	2.6	0.0
pelagic, low bycatch	0.0	0.0	0.0	0.0	0.4	0.7	0.0	0.0	2.6	0.0
aquarium	1.4	0.0	0.0	0.7	0.5	1.6	0.4	0.0	1.8	0.0
illegal/unregulated/unreported	1.2	0.0	0.7	0.0	0.4	1.0	0.6	0.0	1.2	0.0
artisanal, destructive	1.1	0.5	0.8	1.2	0.5	2.0	0.0	1.5	2.3	1.2
artisanal, nondestructive	1.4	0.3	0.5	2.2	0.6	2.5	0.6	0.0	2.1	0.7
recreational	2.0	1.7	0.4	2.1	0.5	2.1	2.2	2.3	2.6	1.3
Climate change										
sea level	2.5	1.9	2.1	3.0	3.1	2.4	2.6	1.6	1.5	1.8
sea temperature	2.8	1.4	0.6	2.4	1.4	2.8	2.1	2.0	1.9	0.8
ocean acidification	0.9	1.0	0.0	1.2	1.3	1.1	1.4	0.0	1.1	0.7
ozone/UV	0.9	1.3	0.0	0.2	1.1	0.8	0.5	0.1	0.7	0.0
Species invasion	2.8	2.9	0.9	1.0	2.8	1.5	1.2	1.3	2.5	2.6
Disease	1.3	1.8	0.0	1.7	1.1	2.2	1.0	0.7	1.8	2.1
Harmful algal blooms	1.9	2.2	0.9	1.6	2.0	1.8	2.3	0.4	1.7	2.5
Hypoxia	1.2	2.1	0.6	0.6	1.9	0.8	1.3	1.0	1.6	2.9
Ocean-based pollution	1.3	0.8	0.5	1.2	1.2	1.2	0.5	0.1	1.7	0.0
Commercial activity	0.3	1.9	1.9	2.0	1.4	1.5	1.9	0.0	1.4	0.0
Ocean mining	0.9	0.0	0.3	0.0	1.1	0.8	0.4	0.0	1.3	0.0
Offshore development	0.7	0.0	0.4	0.0	0.7	0.2	0.0	0.5	0.7	0.0
Benthic structures	1.0	0.9	0.8	1.3	0.9	0.5	1.6	0.0	1.7	0.4
Ecotourism	1.6	0.0	1.0	2.3	1.3	1.8	1.5	0.8	1.7	0.3
Summed threat	58.9	51.4	28.4	55.7	54.9	57.2	48.9	22.4	66.6	53.2
Average threat	1.5	1.4	0.7	1.5	1.4	1.5	1.3	0.6	1.8	1.4

Score from expert opinion. For each ecosystem and each threat a sensitivity score has been assigned

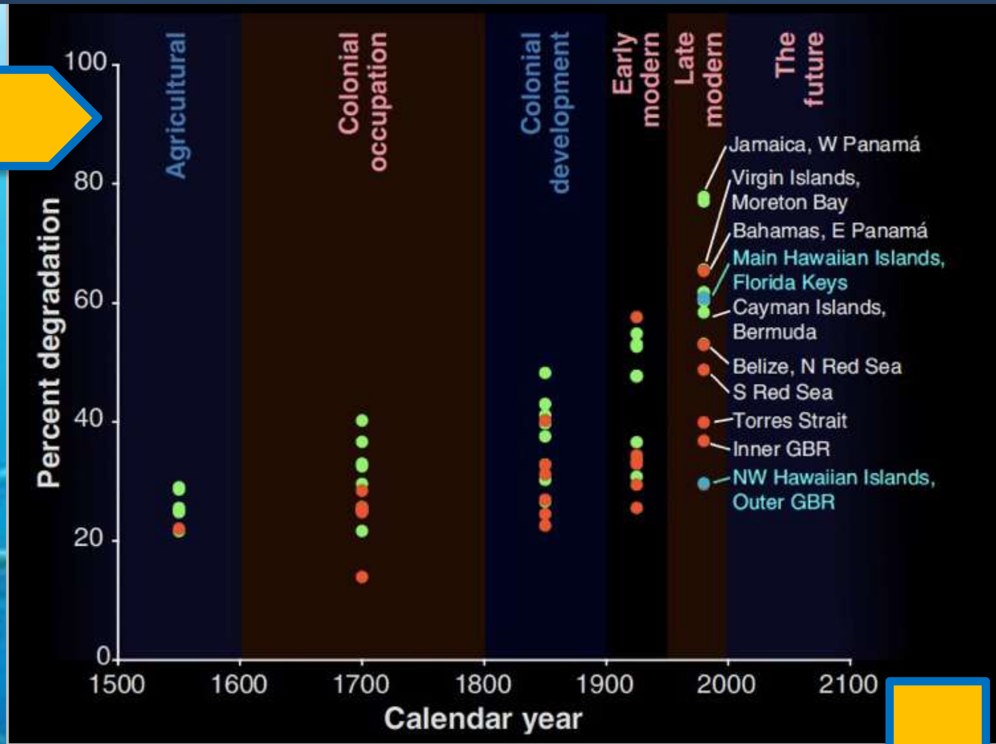


$$I_c = \sum P_i w_i E_j$$

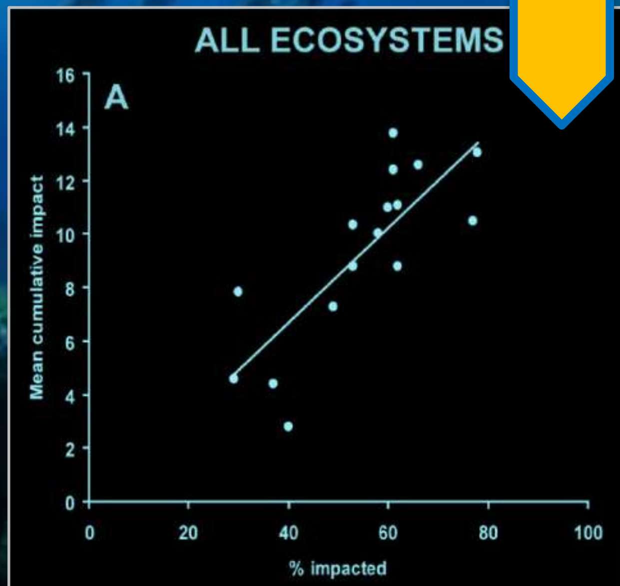
Pressure response relationship



Pandolfi et al., 2003. Science



Pandolfi et al., 2005. Science

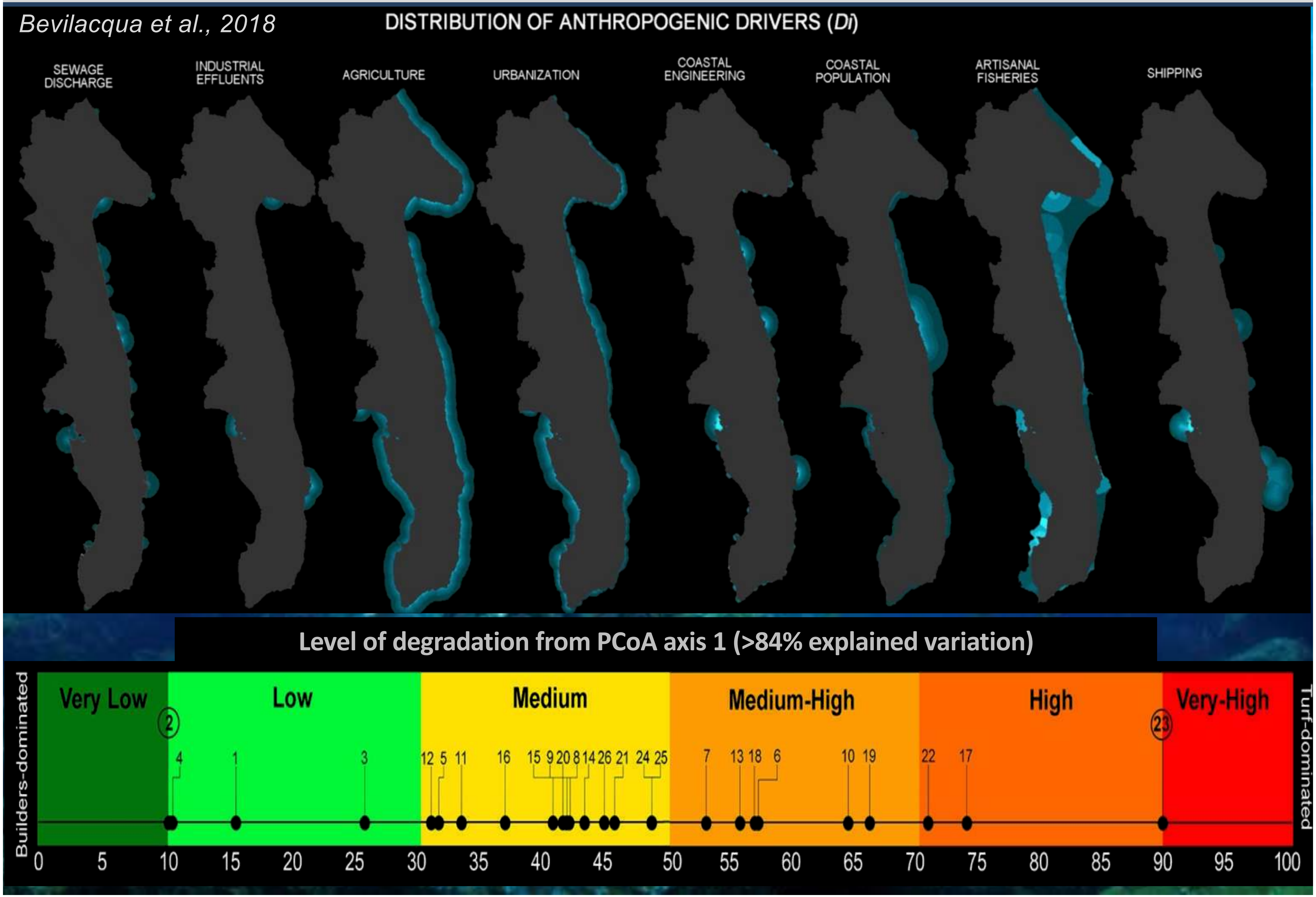


I_c = 0.1762 × [level of system degradation] – 0.3381

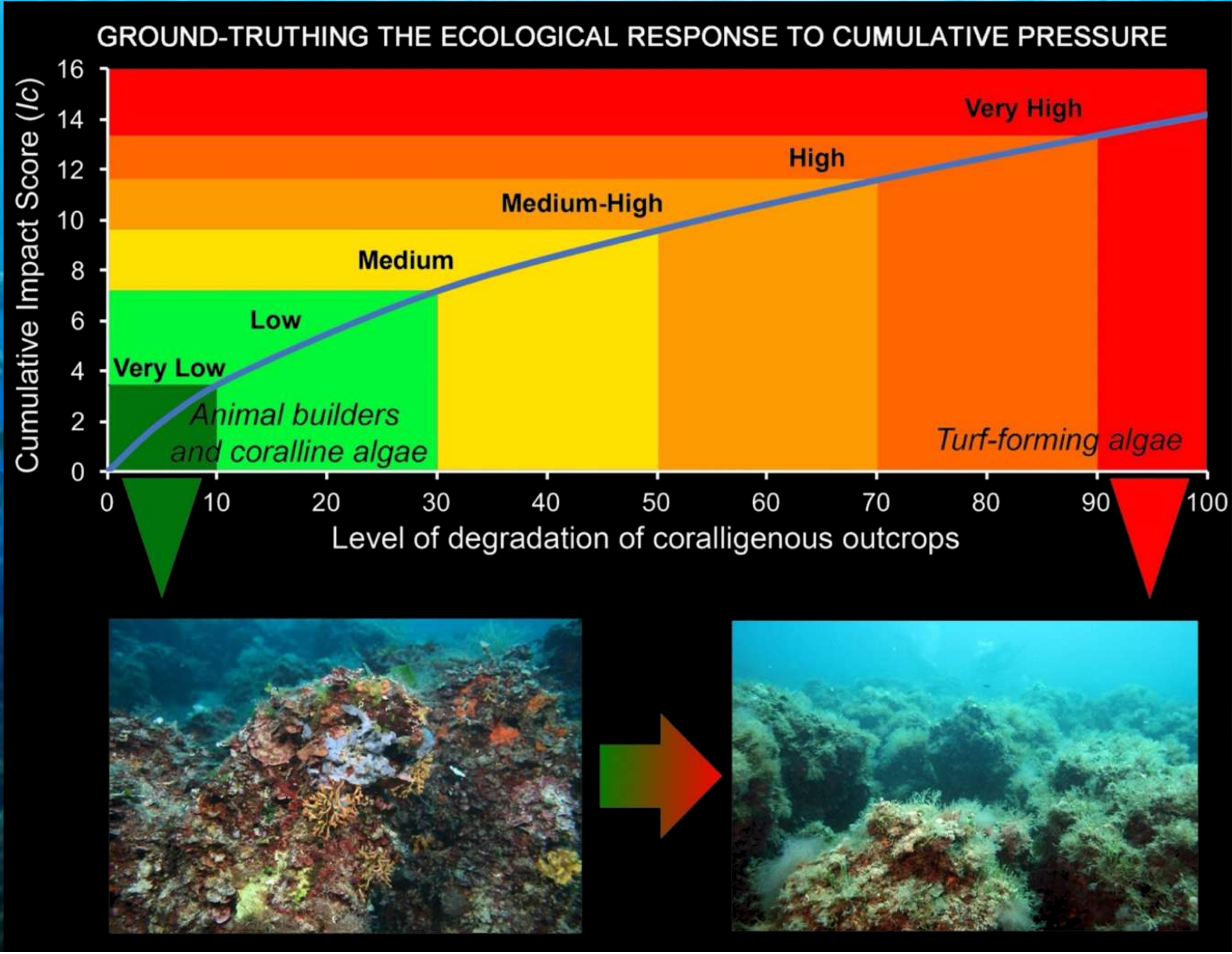
Halpern et al., 2008. Science

<10%	very low	(<1.4)
10-30%	low	(1.45-4.95)
30-50%	medium	(4.95-8.47)
50-70%	medium-high	(8.47-12)
70-90%	high	(12-15.52)
>90%	very high	(>15.52)

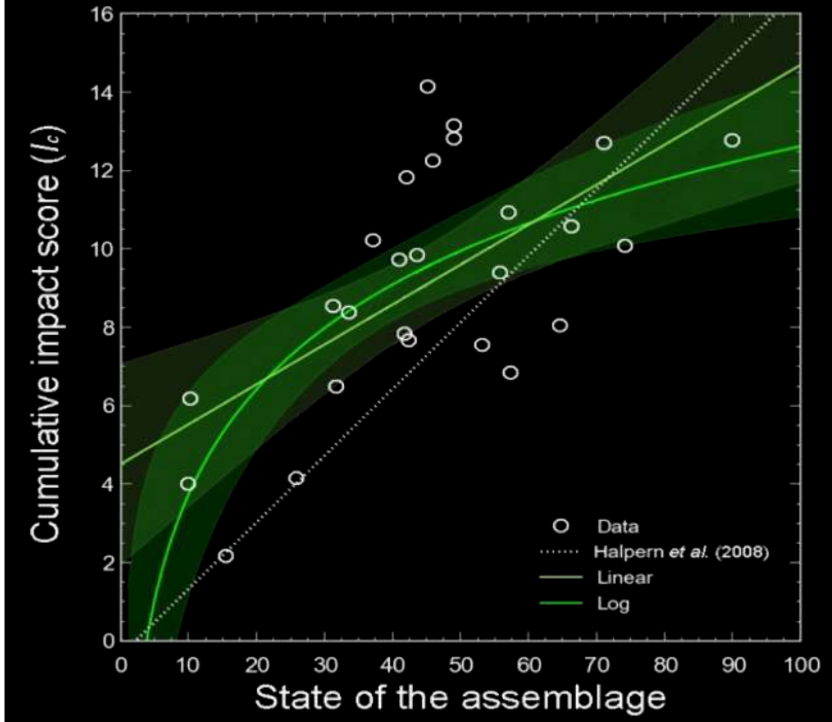
A case study on coralligenous outcrops



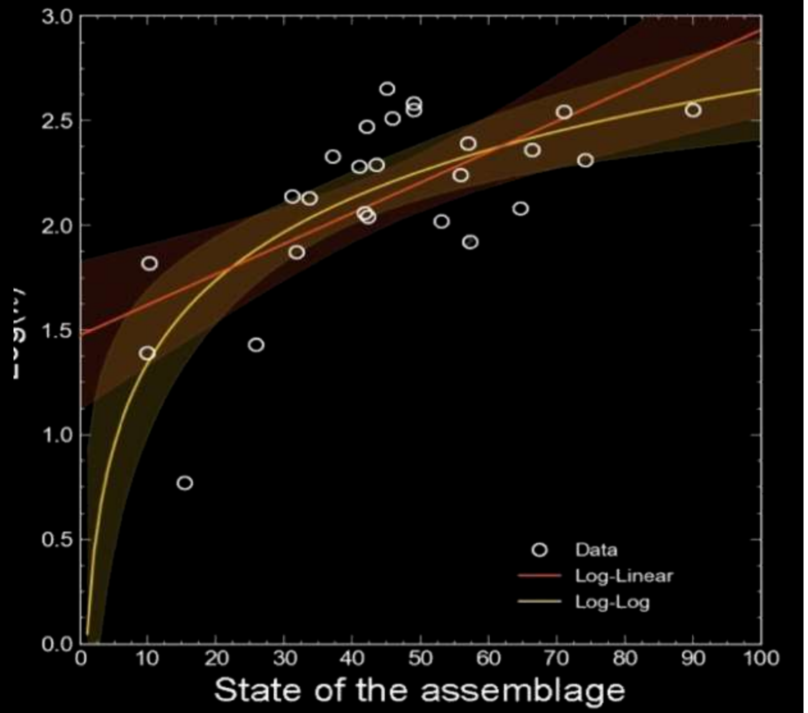
Status of coralligenous



Pressure-response relationship

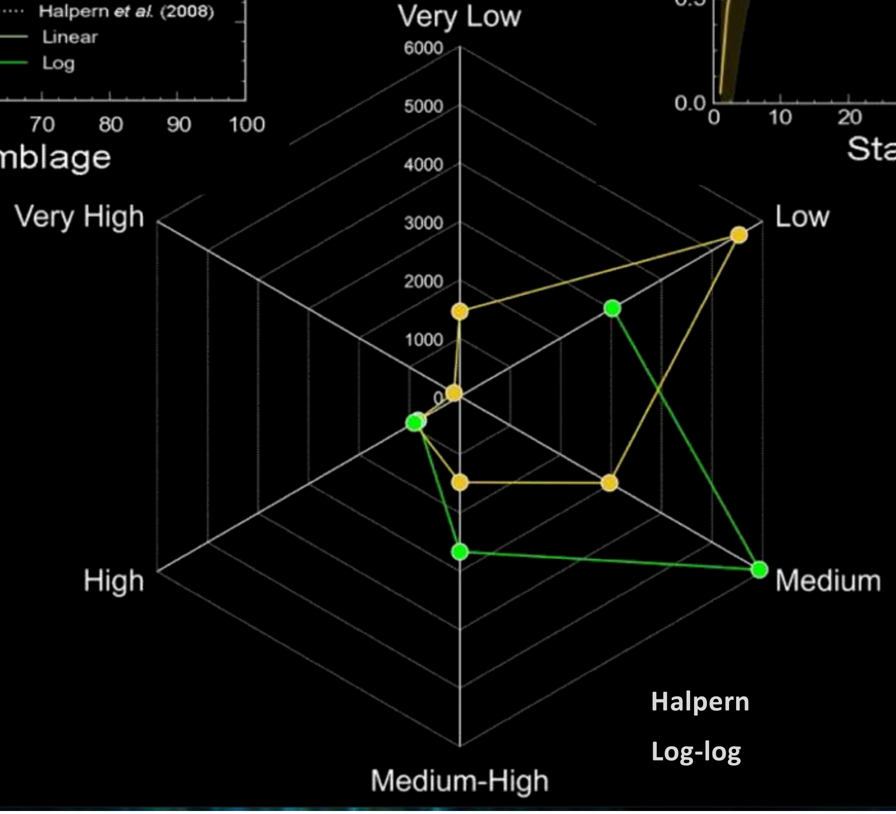


A log-log model best fitted the pressure-response relationship
Halpern's linear model was unlikely



Thresholds from Halpern's linear model

- very low (<1.4)
- low (1.45-4.95)
- medium (4.95-8.47)
- medium-high (8.47-12)
- high (12-15.52)
- very high (>15.52)



Thresholds from log-log model

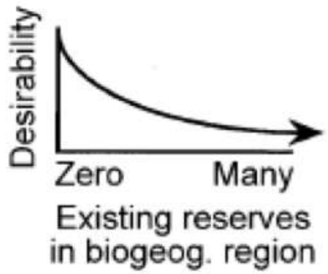
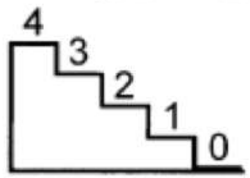
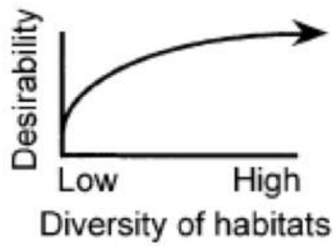
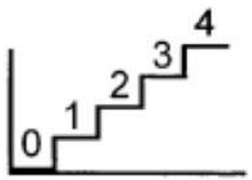
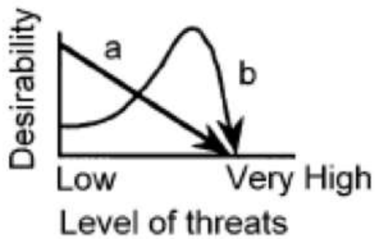
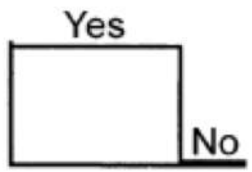
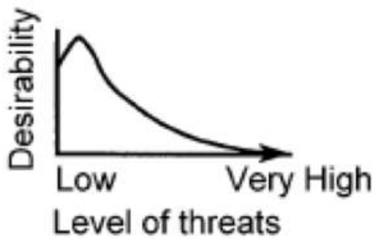
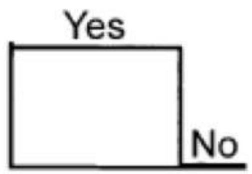
- very low (<3.86)
- low (3.86-7.19)
- medium (7.19-9.59)
- medium-high (9.59-11.6)
- high (11.6-13.37)
- very high (>13.37)

Network of MPAs: general criteria

Roberts et al., 2003

1) Define the goals of the network.
2) Define area of interest.
3) Divide it into possible reserve units. These may be defined in many ways, for example through grids of uniform sized blocks (e.g., 10 km^2), stretches of coastline, habitat classification schemes, or other means.
4) Select criteria for the evaluation of those units that are appropriate to the goals.
5) Decide how to quantify the information needed for determining the level achieved for each criterion.
6) Assemble information on those units (e.g., species or habitats present, levels of threat, etc.).
7) The evaluation process
    a) Characterize or "score" sites based on the following characteristics:
        i) Define biogeographic regions, scoring sites based on what region they occur in. At this stage, sites could be stratified according to region, with site selection decisions made separately for each region. The latter approach would be most useful where a large geographic area is being considered and there are many potential sites from which to choose.
        ii) Define habitats within each biogeographic region for representation.
        iii) Exclude sites subject to excessive levels of threat from human or natural sources.
        iv) Include sites that are already reserves.
        v) Score potential reserves on the basis of habitat heterogeneity and representation criteria, ensuring that reserve units will be sufficiently large to include viable populations.
        vi) Rank or score sites within each habitat type according to other modifying criteria.
    b) Set conservation targets for each of the above criteria (e.g., decide what proportion of the region and of each habitat to protect, what level of replication is required, levels of connectivity desired, etc.).
    c) Select among sites for inclusion in the network (this can be done with an algorithm, by ranking or scoring, or by delphic methods). Criteria may be given different weightings at this stage in order to meet specific network objectives. Map the various possible biologically adequate reserve networks.
    d) Ensure that the networks resulting from the above selection process are sufficiently connected.
8) Use information on alternative, biologically adequate reserve networks to inform final network selection according to socioeconomic criteria.

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

Modifying criteria

5) Adequacy of size
   a) for conservation
   b) for fisheries

6) Optimal distance apart
   a) for conservation
   b) for fisheries

7) Vulnerable habitats

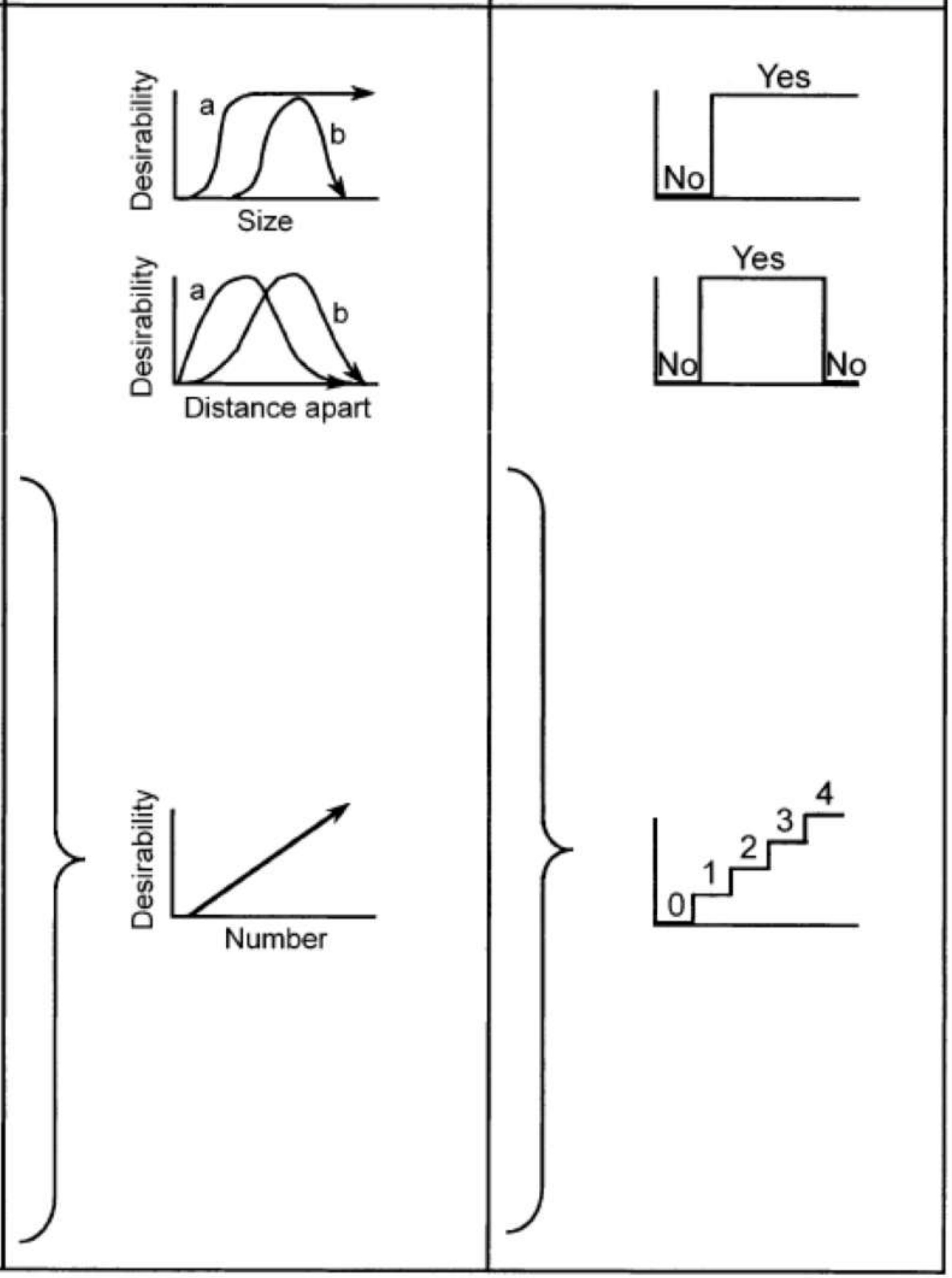
8) Vulnerable life stages

9) Species of special interest (rare, endemic, etc.)

10) Inclusion of exploited species

11) Linkages (dependencies) between systems

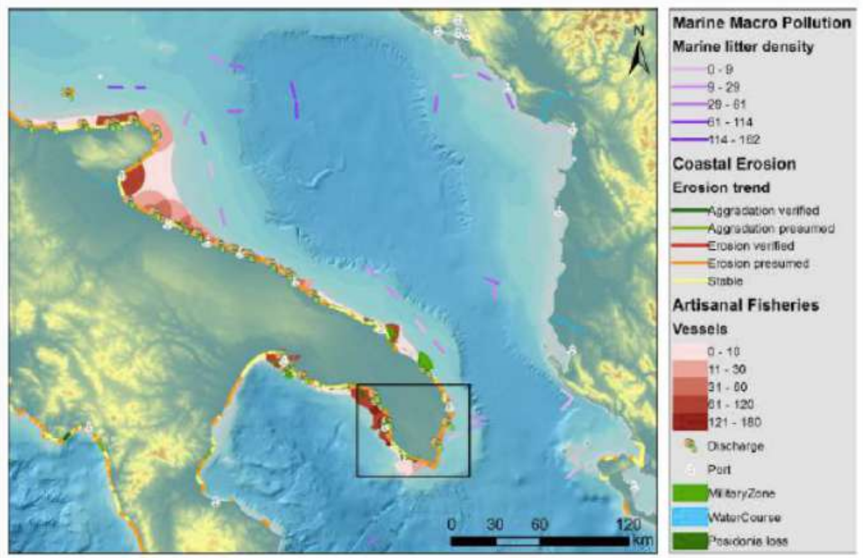
12) Ecosystem services for human needs

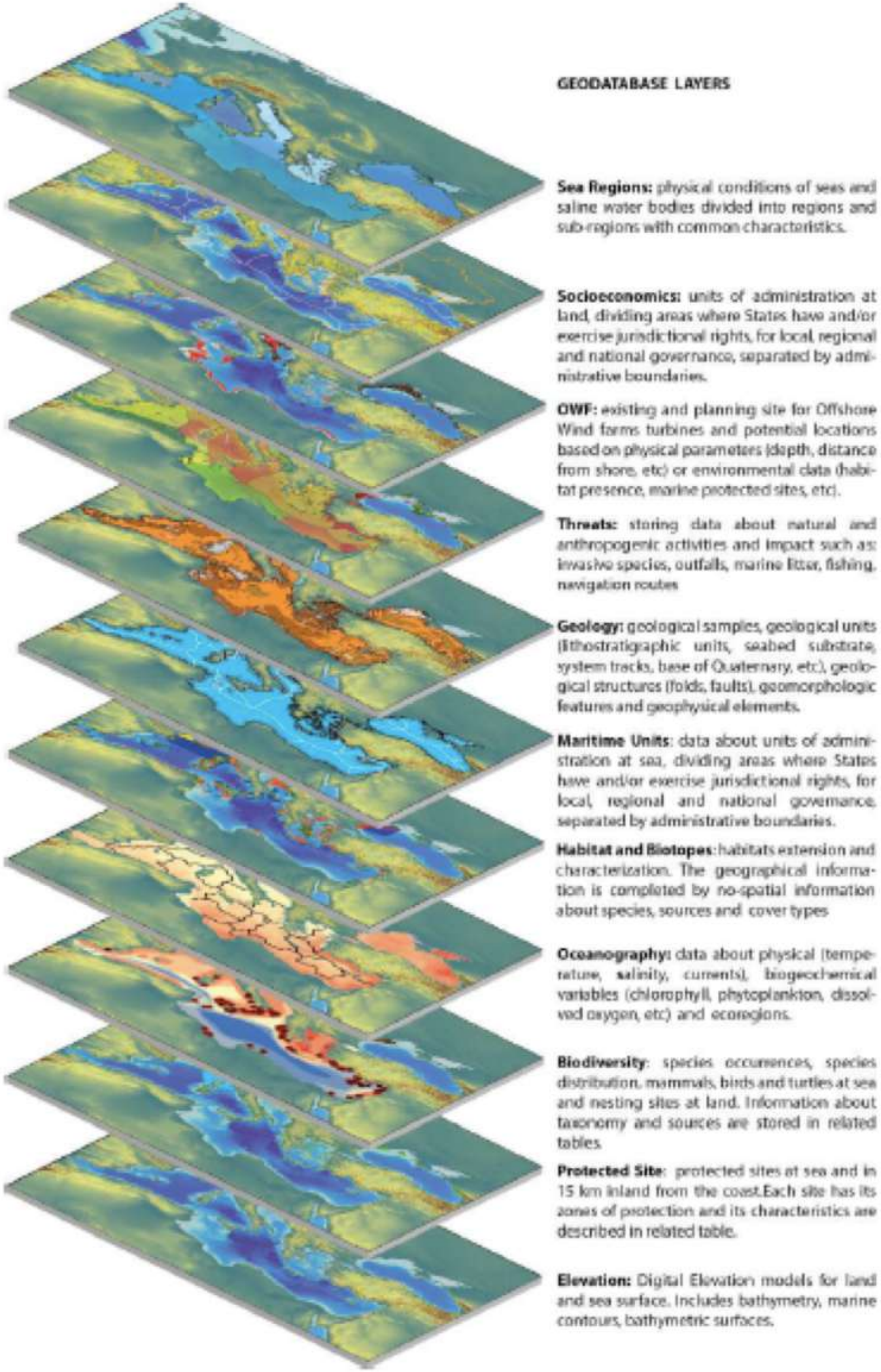


(Boero et al., 2016)

Mapping

Habitat mapping is fundamental for the identification of hot spots of habitat diversity. Maps permit detection of changes in habitat cover, and allow boundary demarcation of multipleuse zoning schemes. Large-scale maps visualise the spatial distribution of habitats, thus aiding the planning of networks of MPAs and allowing to monitor the degree of habitat fragmentation. Geomorphological, oceanographic, biogeographic, biological and anthropogenic features are as well.





Criteria for selection of MPAs

MPA Selection Factor	Attributes
Knowledge	This covers not only information about the present situation (best available scientific knowledge) but also its historical ecology (how the current situation came about). Unfortunately, it is rare to have such knowledge as there is a general lack of long time series data in the marine environment, but it may be possible to undertake comparative studies to help distinguish features which are artefacts of human influence from those which arise naturally.
Scientific justification	This refers to how well the site accords with accepted ecological criteria (CBD, Habitats Directive), as well as the network contribution e.g. replication and resilience.
Risk assessment	The location of the site should be assessed in relation to shipping lanes, actual or potential industrial development including renewable energy, possible accidental pollution events, attraction of tourists/poachers, colonisation by invasive species, aquaculture or other possible impacts. The potential for mitigating such impacts should be elaborated, for example possible contingency measures to respond to incidents where there is major vessel traffic through the area (Lisovsky *et al.*, 2015).
Political feasibility	Surveys and consultations are needed to confirm stakeholder agreement, from government to civil society at all levels. In particular, any conflict and/or lack of cooperation between environmental and fisheries management agencies will inhibit progress in establishing MPAs.
Legislation applicable and/or available	An audit of the existing local, state and supranational legislation should be undertaken, as well as resource ownership and access, freedom of navigation rights etc. For designation purposes, a check is needed on which littoral states are parties to specific international agreements and how they interpret them in national legislation.
Governance model	The potential governance model (Table 6) should be determined as part of the stakeholder consultation process, and whether and how the site will form part of a network at the international level under the regional agreements.

Criteria for selection of MPAs

Management integrity	The site management plan has to be prepared in full collaboration with the relevant stakeholders. The recruitment of suitable staff, planning competence, effectiveness, monitoring and adaptability are other issues to be taken into account.
Economic sustainability	The need and potential for self-financing of the site administration has to be considered. Sustainable financing needs to be put in place in from the beginning, employing appropriate economic instruments based on assessments, valuations and MCDA.
Communication and outreach	The potential role of the site to provide research, education and public awareness opportunities (forming a part of collaborative networks, Table 1) should be considered.
Secular trends	Natural and political worlds operate as complex systems with characteristics which ensure that they will function unpredictably over time. Therefore, the potential for the site and its management to adopt objectives and policies that are adaptable over short, medium, and long-term timescales is an important factor.

The governance system proposed for a new MPA, or MPA network, is crucial in terms of delivering the benefits expected by the stakeholders during the formation phase. It is important to distinguish between “governance” (which is the strategic,decision making and monitoring process) and “management” (which is the executive role of those responsible for implementing the management plan).

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 governace 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)