Modelling the distribution of biodiversity and climate change

Ecological niches and geographic distributions

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Macroecology

It’s a big-picture statistical approach to Ecology.

Focuses on **patterns and processes** operating **at large spatial and temporal scales**, ignoring local and fine-scaled details / drivers.

Aims to **explore the relationship between biodiversity and the environment**, and to **explain** and **predict patterns of abundance, distribution and diversity**.

e.g.,

Which environmental drivers explain the distribution of a species?

How global climate change may affect marine biodiversity?

Niche concept is central in Macroecology

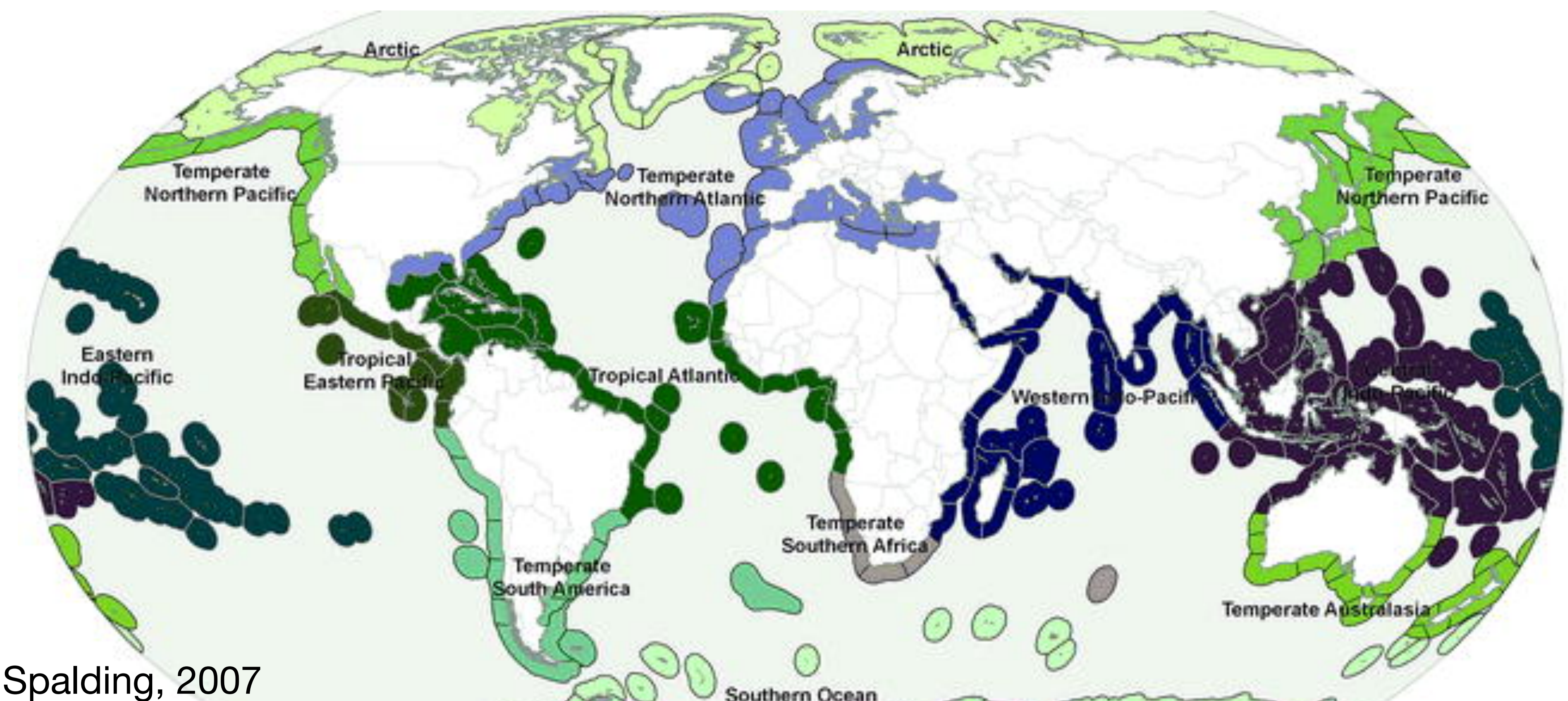
Distribution limits are shaped by constrains on dispersal

(i.e., there are limitations for species to fulfil whole ranges, such like **movement of individuals** and their **successful establishment**);

With no dispersal limits, every species could be everywhere, and **global patterns of diversity would be absent or random**.

There are well-defined biogeographic patterns of diversity.

e.g. **Marine Ecoregions of the World (Spalding et al., 2007)**; shows defined patterns under a nested system of 12 realms, 62 provinces, and 232 ecoregions; e.g., the Tropical Atlantic has different diversity and species composition compared to the Temperate Atlantic.



Spalding, 2007

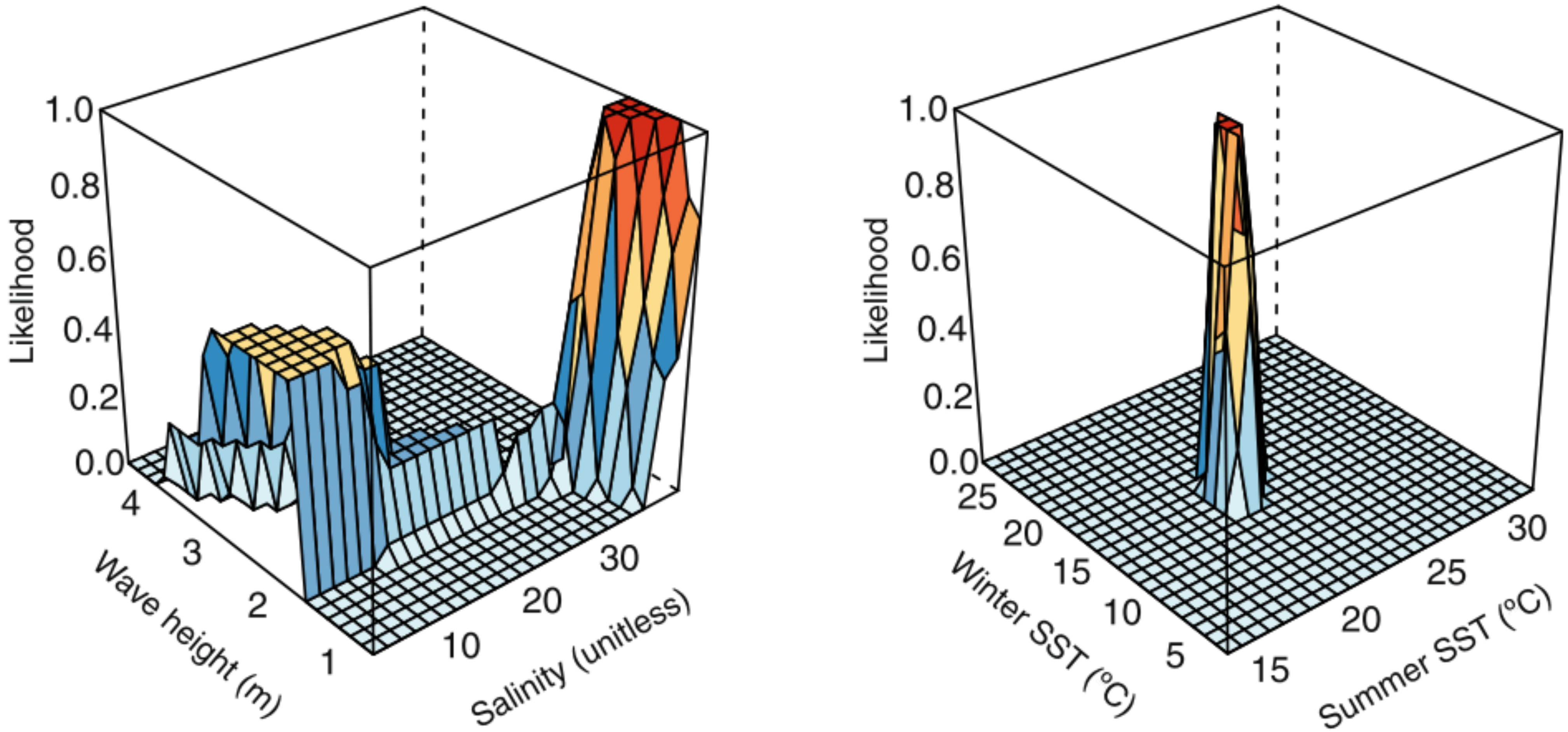
Species occupy well-defined regions.

Hutchinson (1987; the classic reference) defined the **niche as environmental space where a species can survive and reproduce.**

Fundamental niche: the environmental space in the absence of biotic interactions (e.g., competition, predation);

Realized niche: fundamental niche including the effects of biotic interactions.

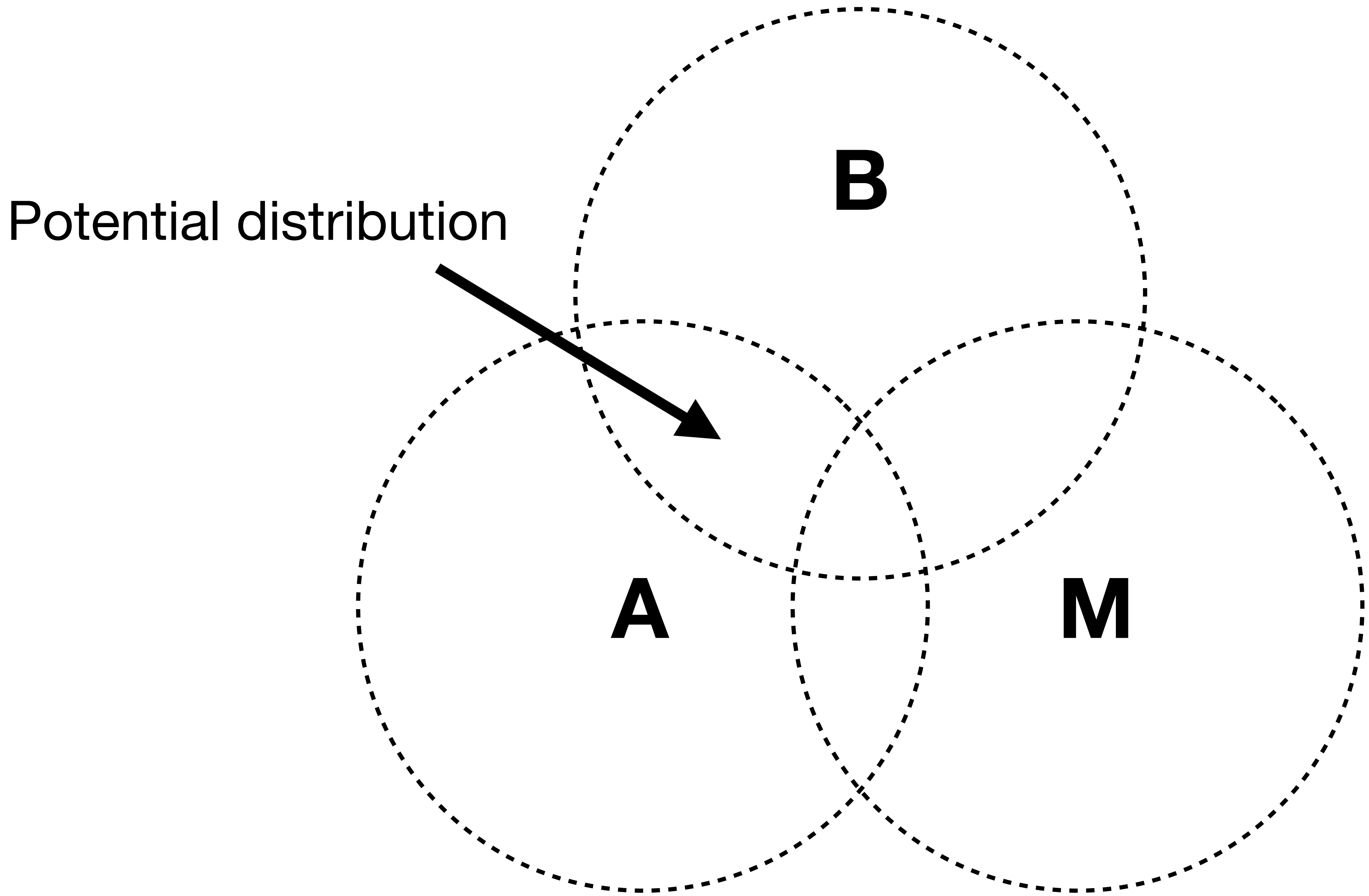
Realised niche is always equal or smaller than the fundamental niche due to negative interspecific interactions.



Fundamental niche of a mediterranean coral. Environmental conditions where species can survive and reproduce.

e.g.,

The **niche is well-defined** by **thermal conditions (15.0ºc to 22.5ºC)**, **wave intensity** and **salinity**.



BAM diagram

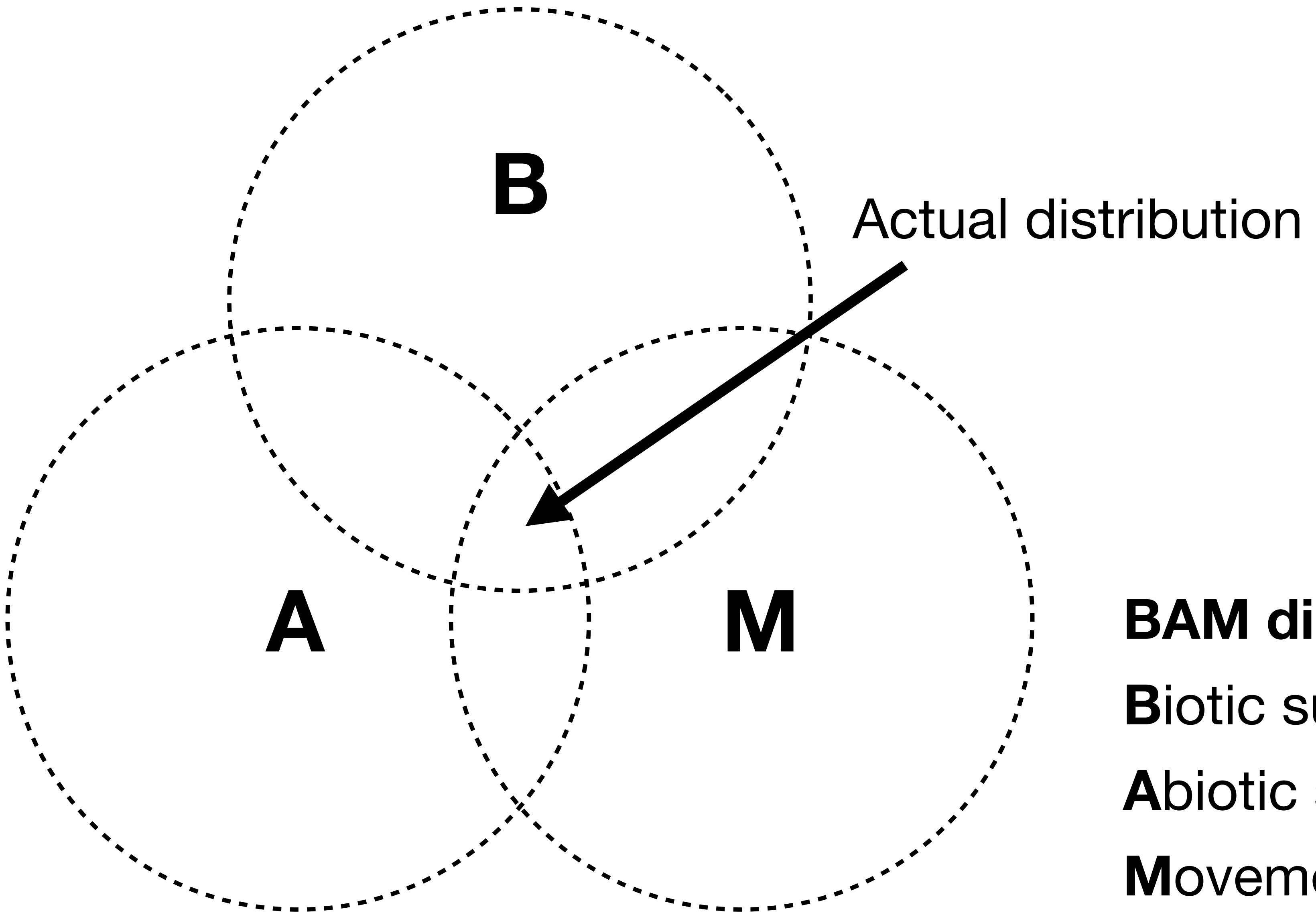
Biotic suitability

Abiotic suitability

Movement

BAM (biotic-abiotic-movement) diagrams depicts the complex interplay of factors that limit species distributions.

Abiotic conditions and **B**iotic interactions define where species can survive with positive population growth.



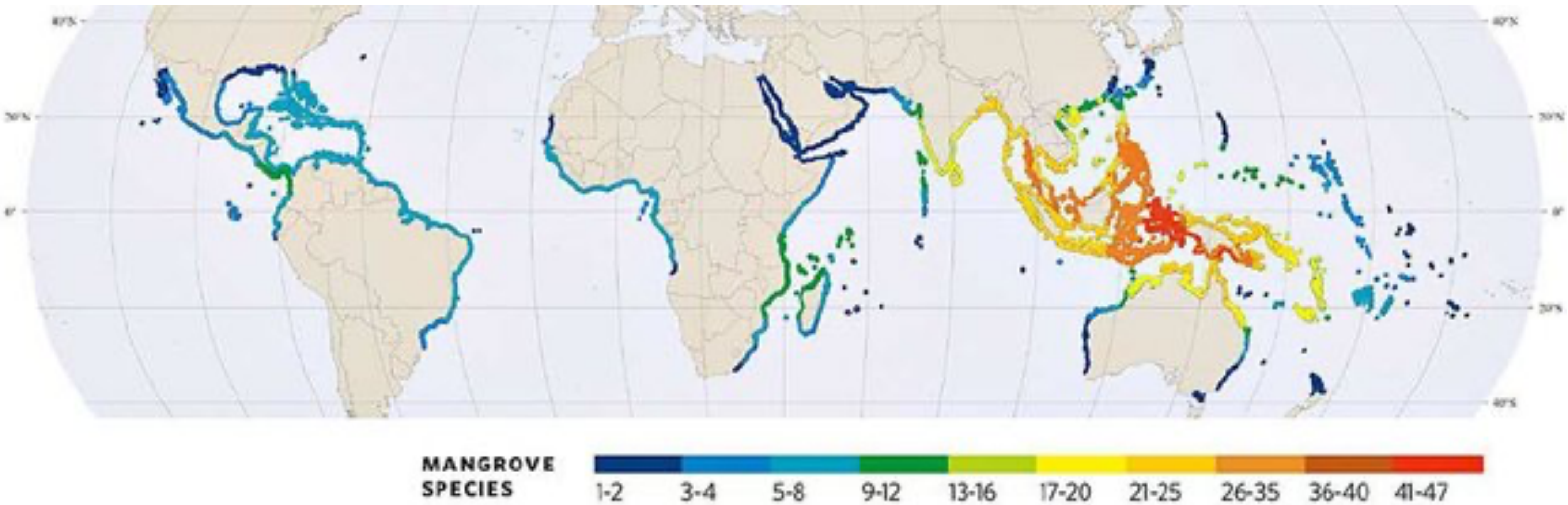
BAM diagram

Biotic suitability

Abiotic suitability

Movement

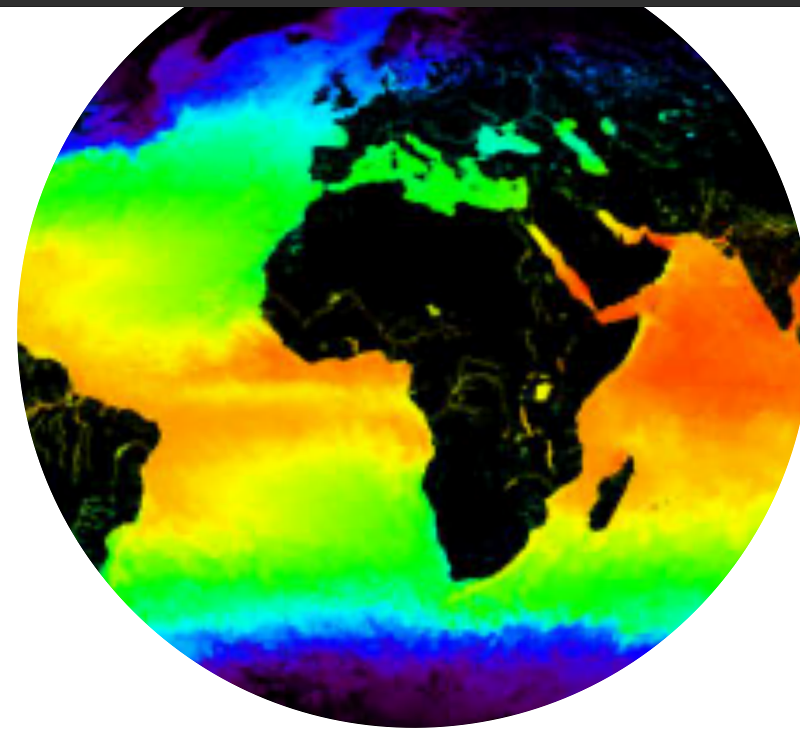
BA + Movement determines whether a species is present in suitable habitats: **a species can be absent from a suitable habitat due to dispersal limitations**. When populations go locally extinct, dispersal determines how fast the empty suitable habitats will be recolonised.



Movement

Younger species (evolutionary speaking) **occupy less of their potential distribution** than older species.

Migratory fish and mammals tend to have broad distributions, while low dispersive species (e.g., corals and kelp forests) **occupy less of their potential distribution.**



Which factors set range limits?

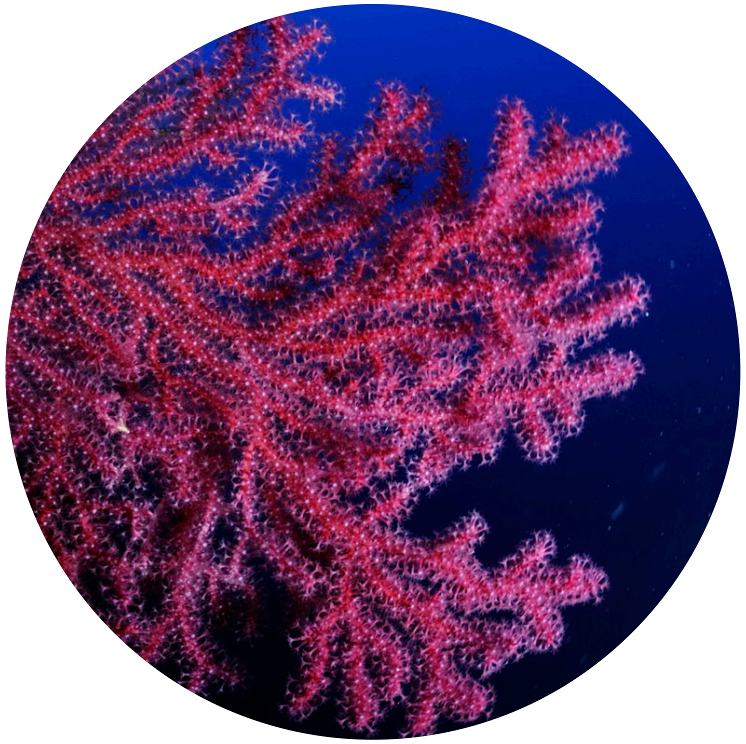
Multiple environmental factors may set the distribution of species, creating biogeographic patterns (macroecological scales).

These factors **may act on the whole / part of species' ranges.**

e.g.,

Poleward limits set by tolerance to ice scouring and extreme minimum air temperatures;

Low latitude limits set by maximum temperatures and limiting nutrient conditions.



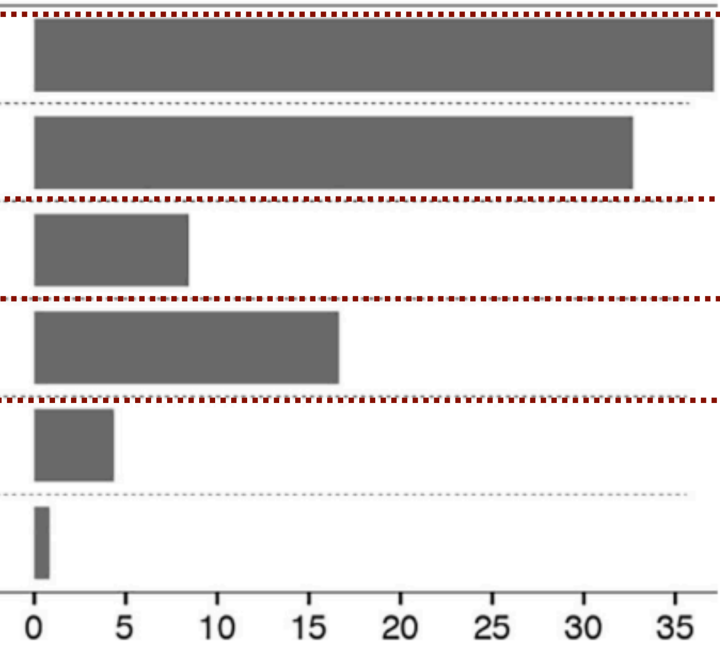
Mediterranean coral

Predictor (unit)	Oc. range	LP model	LP literature	Relative contribution(%)
Temperature min. (ºC)	11.4 - 16.0	<11.5	<12.0 [1,2]	
Temperature max. (ºC)	14.1 - 24.4	>25.5	>25.0 [1,3,4]	
Slope (degree)	$3.2e^{-2}$ - 22.2	<0.1	steep [1]	
Silicate max. (µmol/L)	1.6 - 19.9	>20.1		
Productivity min. (gC/m³/day)	$7.5e^{-6}$ - $3.3e^{-3}$	$<4.0e^{-6}$		
Phosphate min. (µmol/L)	$1.6e^{-4}$ - 0.5	$<2.2e^{-5}$	< 0.08 [5]	
Phosphate max. (µmol/L)	$2.4e^{-2}$ - 0.77	>0.6		
Nitrate min. (µmol/L)	$1.0e^{-6}$ - 5.2	$<7.2e^{-7}$	< 2.0 [5]	
Nitrate max. (µmol/L)	$2.5e^{-3}$ - 10.9	>5.4		

Boavida et al., 2016

Agressive invasive macroalgae

Environmental predictor	Unit	Tipping points	Relative importance (%)
Long-term min. Light at bottom	$E \cdot m^{-2} \cdot yr^{-1}$	4.04	
Long-term max. Ocean Temperature	°C	26.55	
Long-term min. Ocean Temperature	°C	2.20	
Long-term min. Ocean Salinity	PSS	31.05	
Long-term min. Nitrate concentration	$mmol \cdot m^{-3}$	0.42	
Long-term min. Phosphate concentration	$mmol \cdot m^{-3}$	0.06	



Koerich et al., 2019

Layer
Temperature
Salinity
Sea ice concentration
Sea ice thickness
Current velocity
Nitrate
Phosphate
Silicate
Dissolved molecular oxygen
Dissolved iron
Chlorophyll
Phytoplankton
Primary productivity
Light at the bottom

Abiotic factors setting range limits?

Non-estuarine cold-temperate fish (N Atlantic)

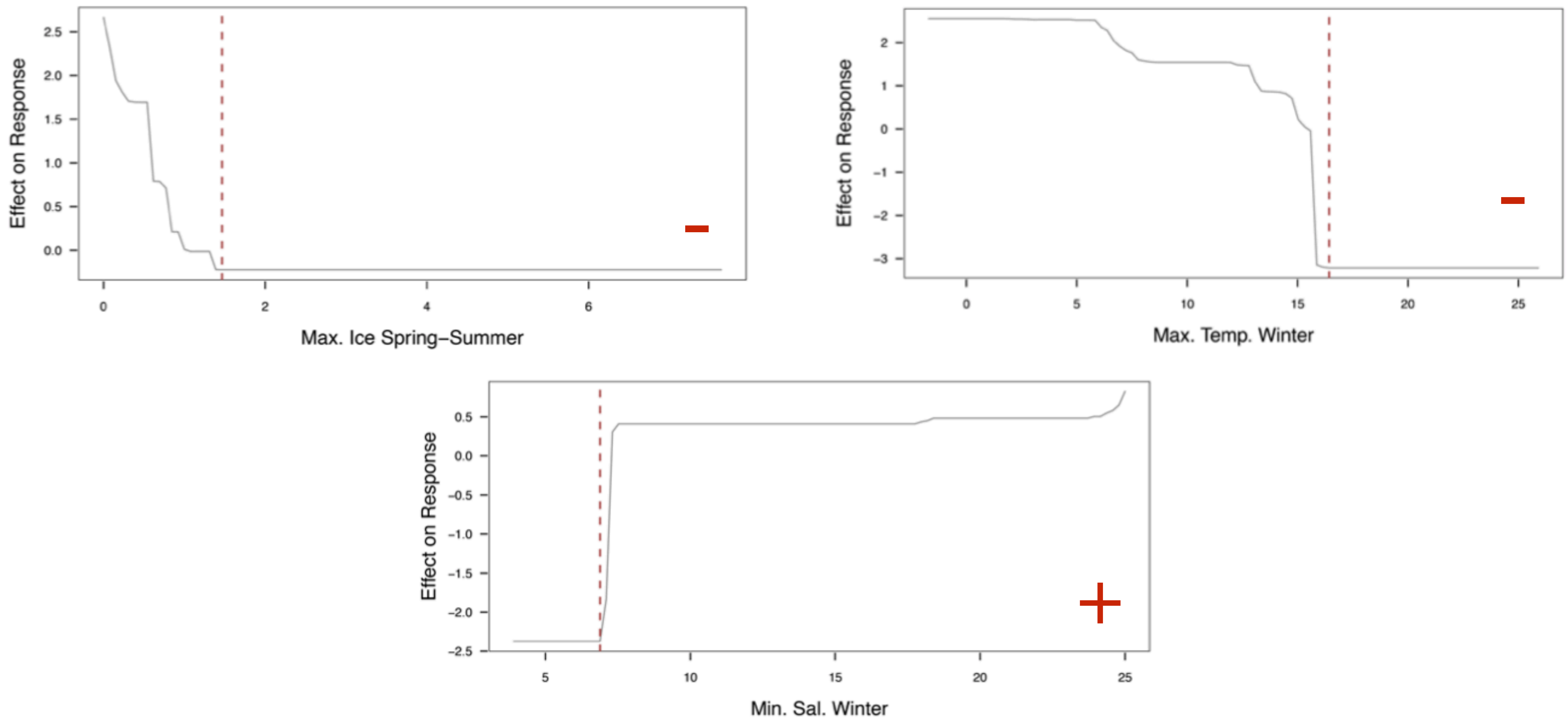
Non-estuarine tropical fish (Equator)

Cold-temperate macroalgae (N Atlantic)

Warm-temperate seagrass (Mediterranean)

Cold-temperate coral (Mediterranean)

(…)



Species response functions

Typically unimodal responses, positive or negative.

Skewed response curves are expected (physiological stress limiting individual fittings and there the occurrence of species).

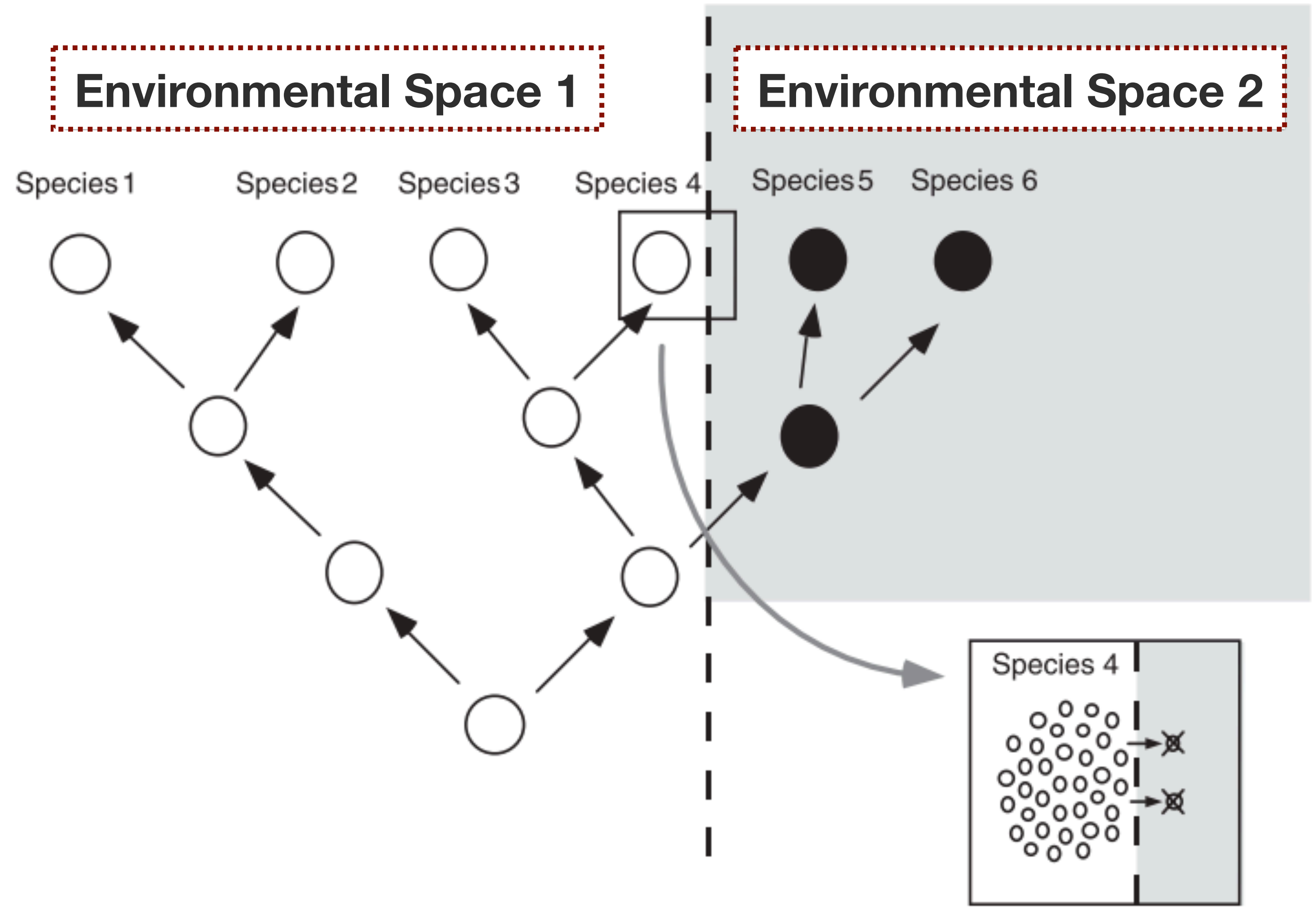
Liebig's law states that **the response of species to one factor can only be detected when all other factors are non-limiting.**

Niche conservatism

Distributional limits are not simply set by the BAM conditions, but also by **the failure of organisms to adapt to new conditions.**

Niche conservatism is the **tendency of species to retain ancestral physiological tolerance limits**;

(i.e., the idea that **species tolerances remaining stable over time**).

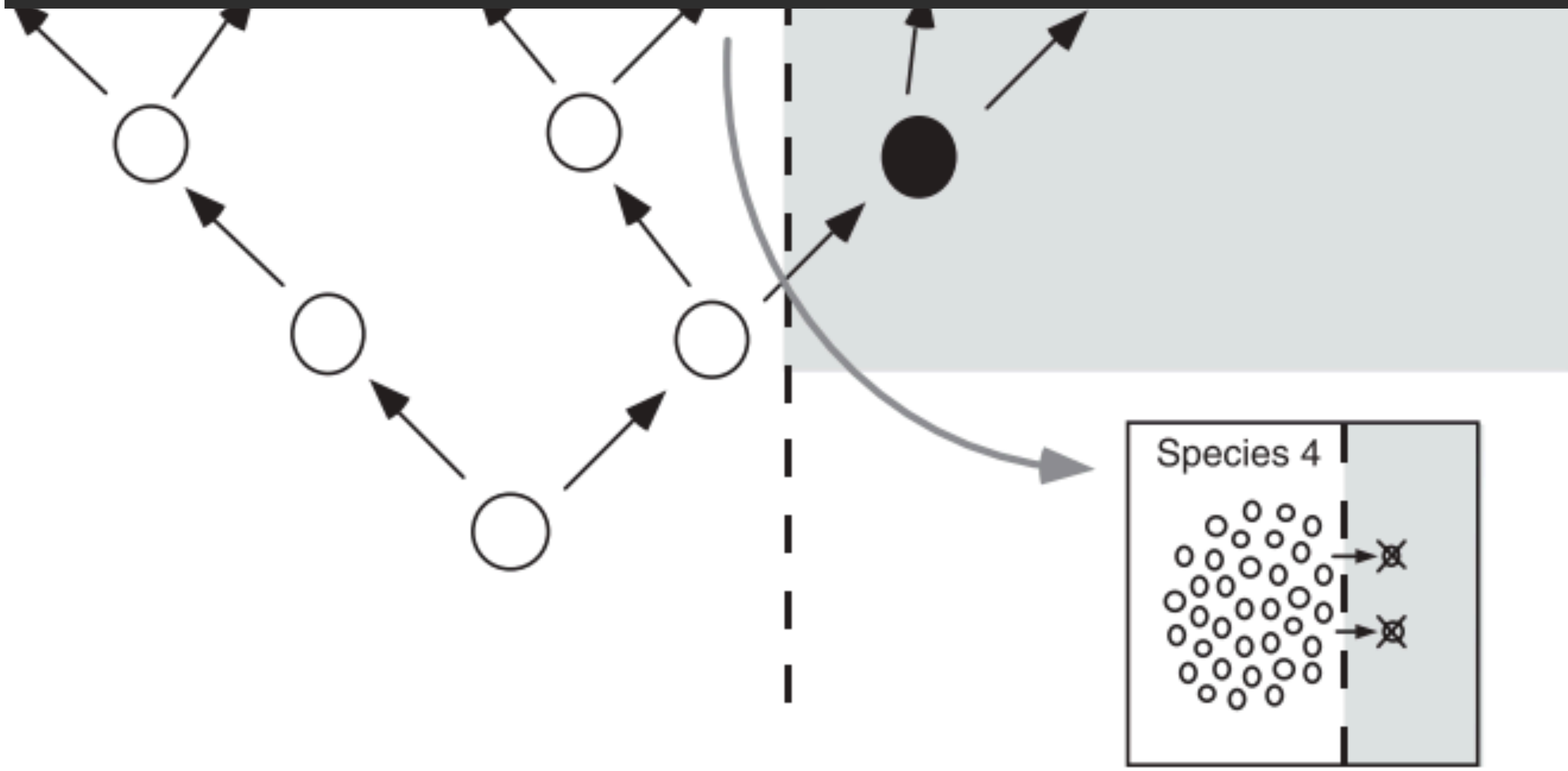


Niche conservatism

e.g., for a given environmental space, the clade originates as a **single ancestral species. In time, there is an evolutionary niche shift** to use a different environment.

Currently, there are 4 species using the ES 1 and 2 species using ES 2. Niche conservatism in species 1-4 limits the individuals of using ES 2.

Wiens et al., 2010



Niche conservatism

Species may adapt to new conditions over time, but biogeographic patterns show that this process to be uncommon.

Species have **well defined physiological tolerances.** Without such limits, every species could be everywhere, and again biogeographic patterns would be random or absent.

Wiens et al., 2010

Niche conservatism

A clear evidence for niche conservatism is how warming is shifting the distribution of species globally, particularly at low latitude warm range edges.

Without niche conservatism, species would persist locally while climate conditions shift.