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 (not a separate field or sub discipline; coined ~30 years ago).

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 characterise and **explain 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

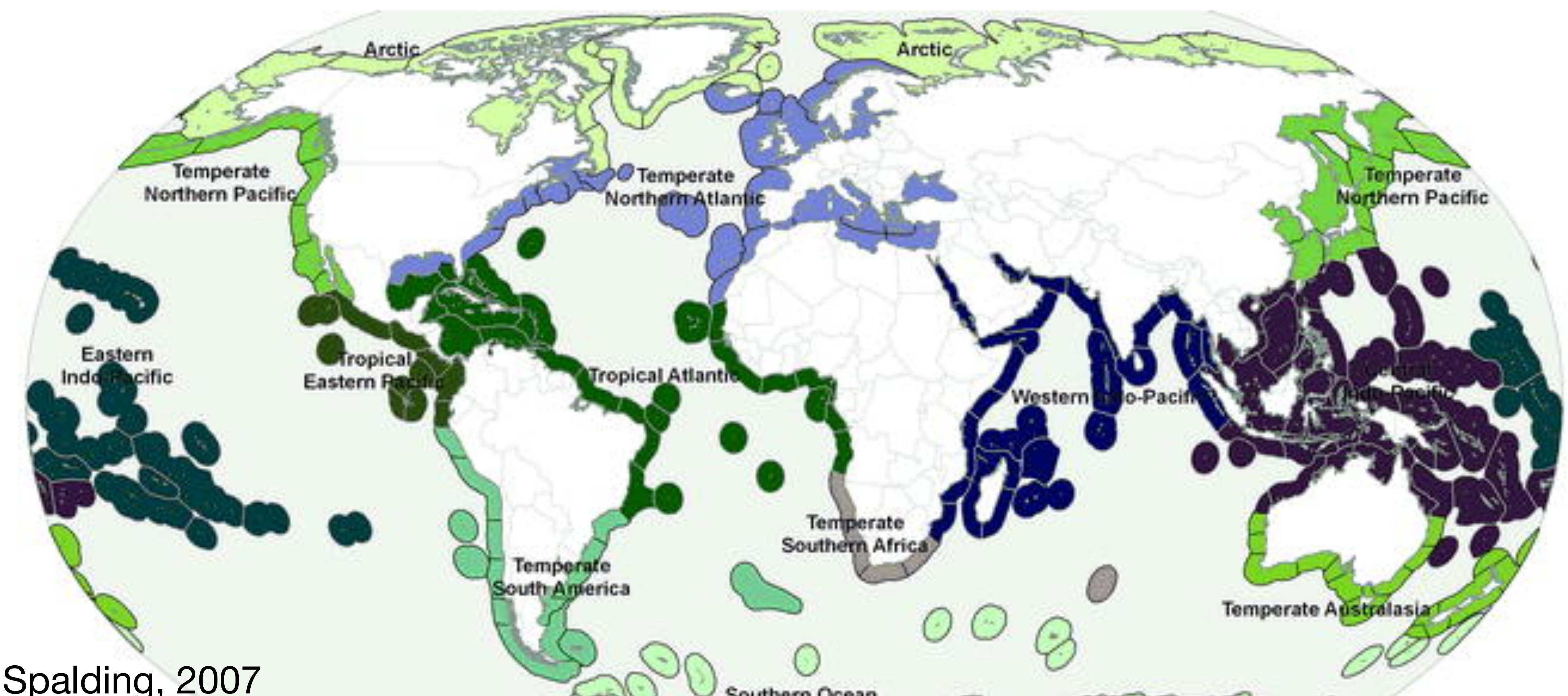
Distribution limits are shaped by constrains on dispersal

(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.**

Well defined biogeographic patterns of diversity and species composition.

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



Spalding, 2007

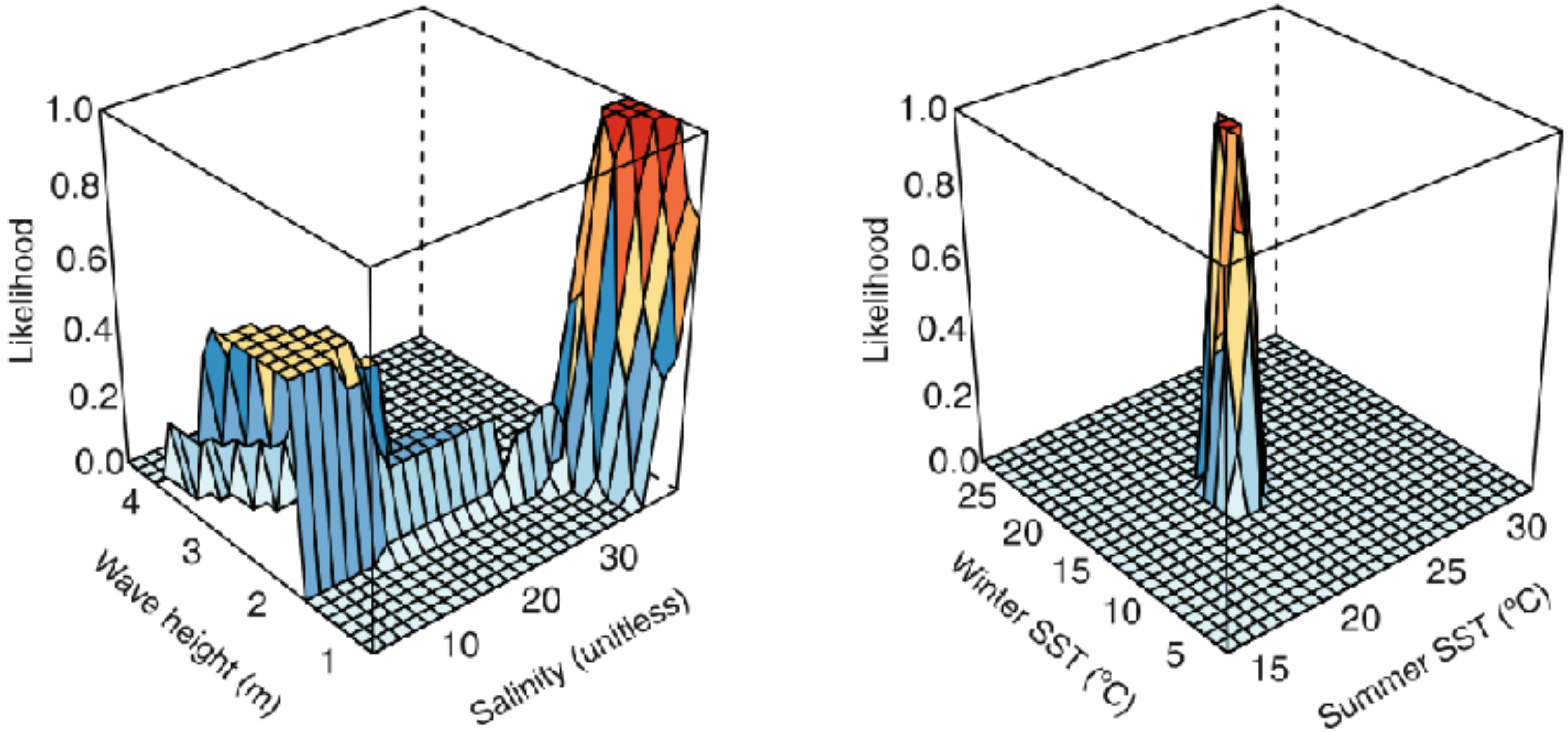
Niche concept is central in Macroecology

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

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

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

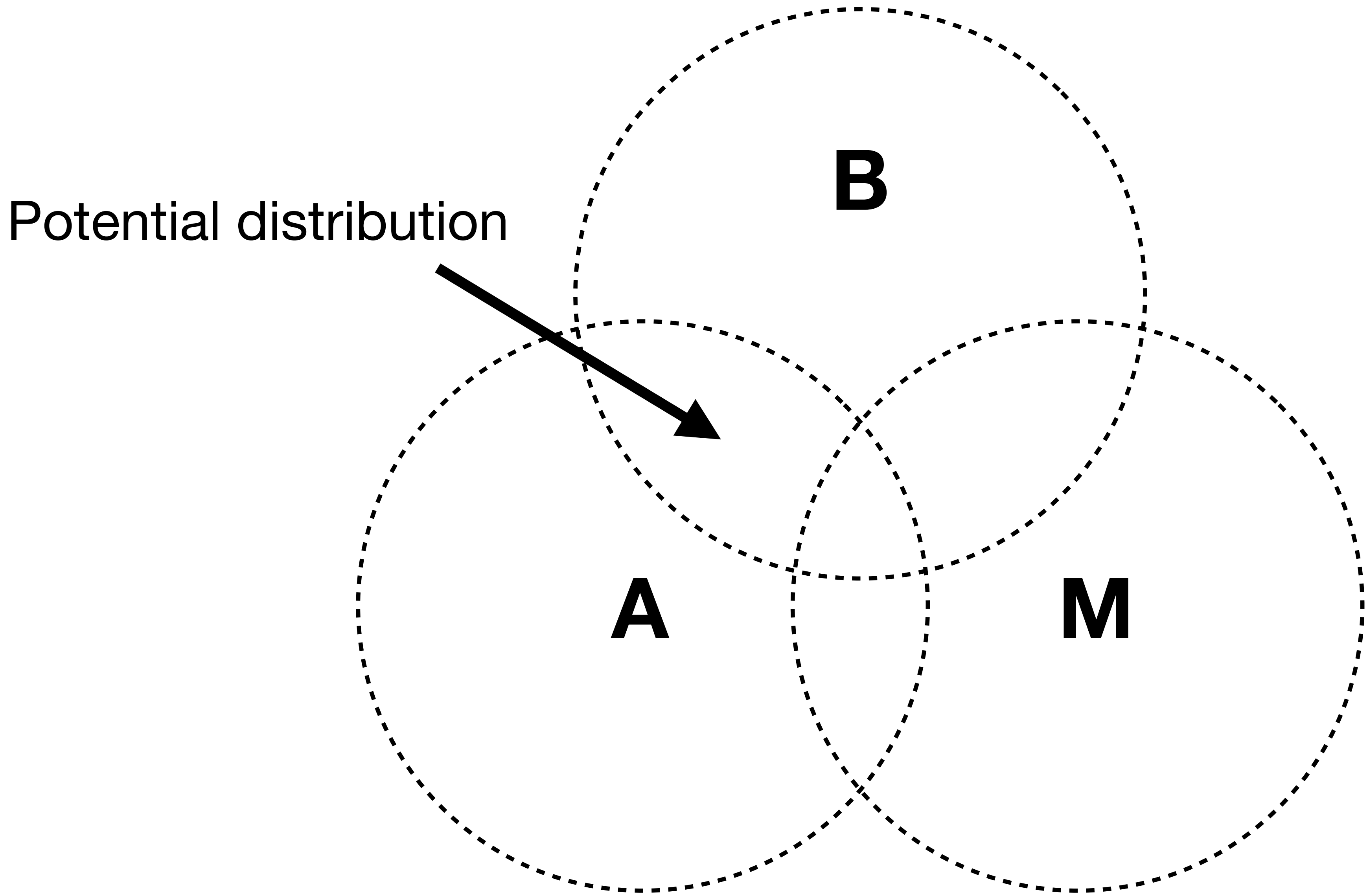
Realised niche is always equal or smaller than the fundamental niche due to negative interspecific interactions.



Environmental conditions where species can survive and reproduce (fundamental niche).

e.g.,

A **Mediterranean cora**l with the **niche defined** by **thermal conditions (15.0ºc to 22.5ºC)**, **wave intensity** and **salinity**.



BAM diagram

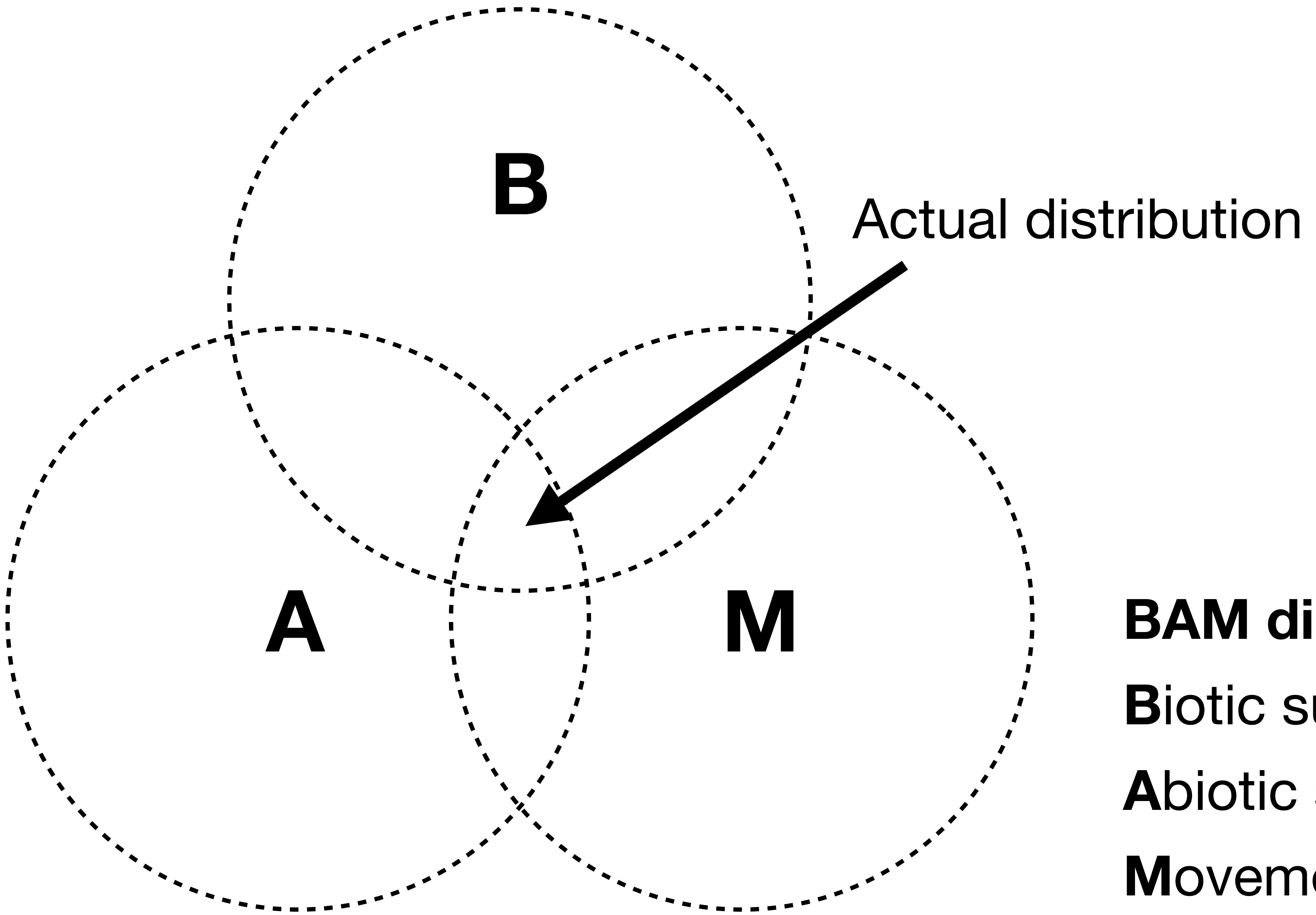
Biotic suitability

Abiotic suitability

Movement

BAM (biotic-abiotic-movement) diagrams shows the main factors that limit species distributions.

Abiotic conditions (e.g., environment) and **B**iotic conditions (e.g., competition) define the potential distribution - where species can survive and growth.



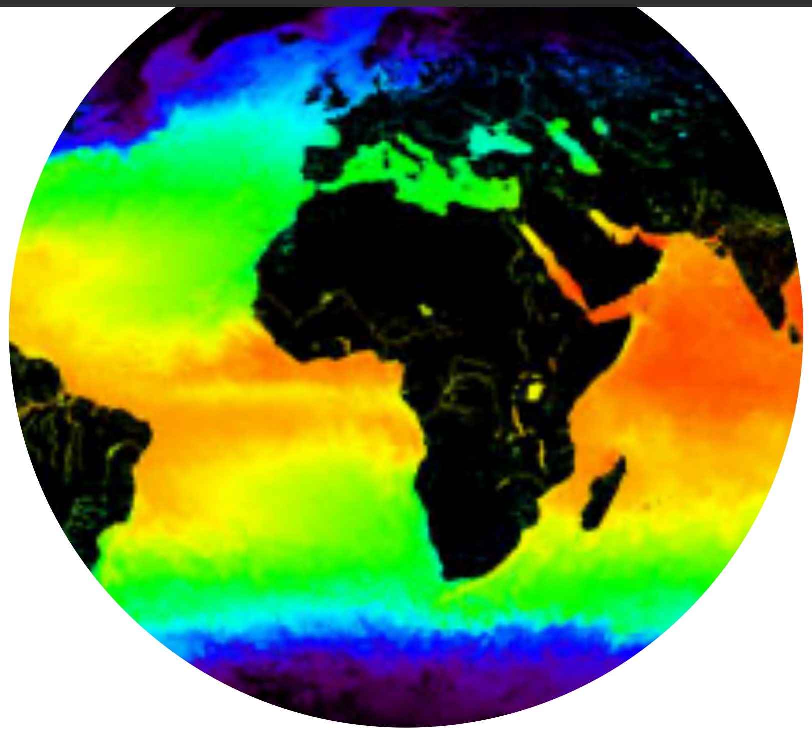
BAM diagram

Biotic suitability

Abiotic suitability

Movement

BA + Movement determines whether a species is present in a given place: **a species can be absent from a suitable habitats due to dispersal limitations** (i.e., it cannot get there).



Which abiotic factors set range limits?

Multiple abiotic factors may set the range limits of species to create biogeographic patterns (macroecological scales)**.** These **may act on the whole / part of species' ranges** being considered.

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.

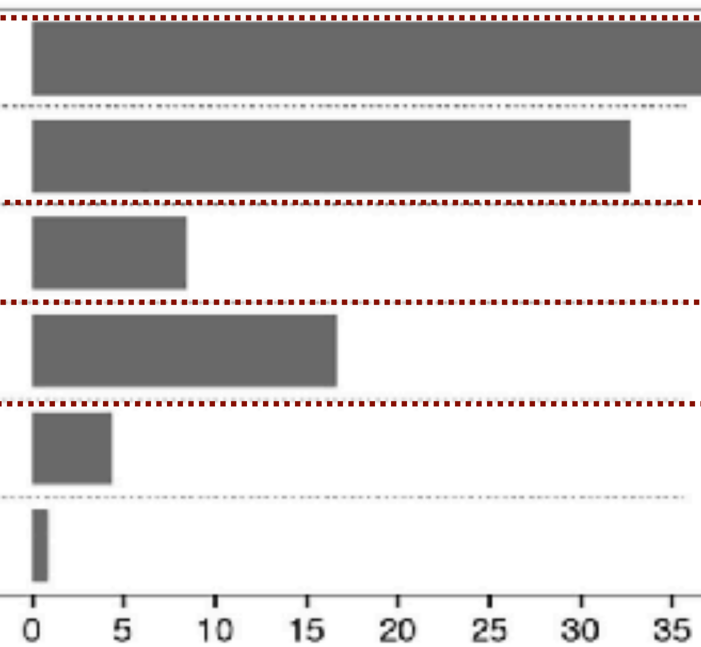
Mediterranean coral

Predictor (unit)	Oc. range	LP model	LP literature	Relative contribution(%)
Temperature min. (°C)	11.4 - 16.0	<11.5	<12.0[1,2]	
Temperature max. (°C)	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)

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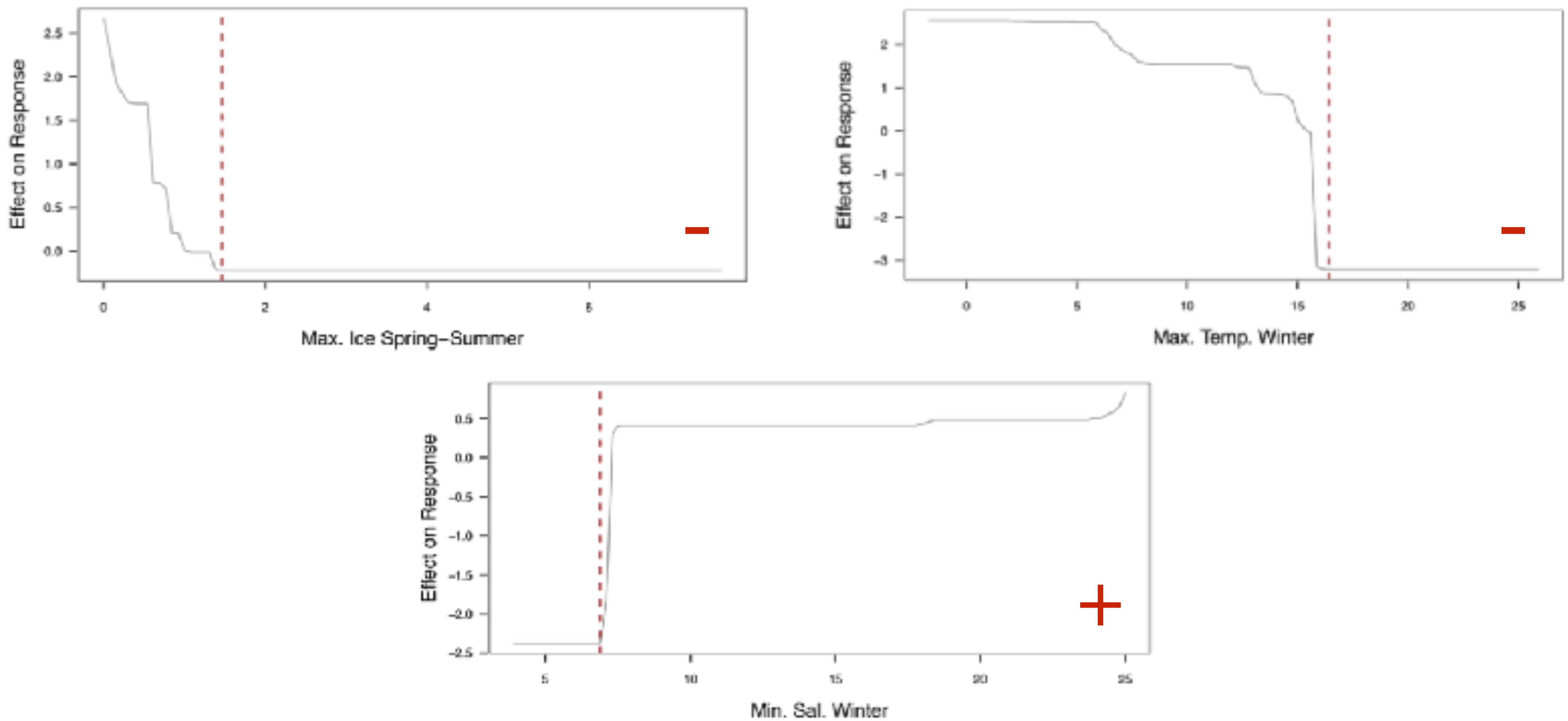

Species response functions

Unimodal responses are the most common, typically, **positive or negative**.

Skewed response curves are expected (physiological stress limiting occurrence at the "harsh").

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

Modelling with abiotic conditions

Ecophysiological knowledge should guide the modeller in process of choosing which factors may determine the distribution of species.

My main questions

Which environmental variables drive the distribution of my model species?

Which response I expect for each environmental variable?

My main hypotheses must be based on ecophysiological knowledge

(…)