

MODELLING THE RESPONSE OF THE DISTRIBUTION OF BENTHIC MARINE SPECIES TO CLIMATE CHANGE

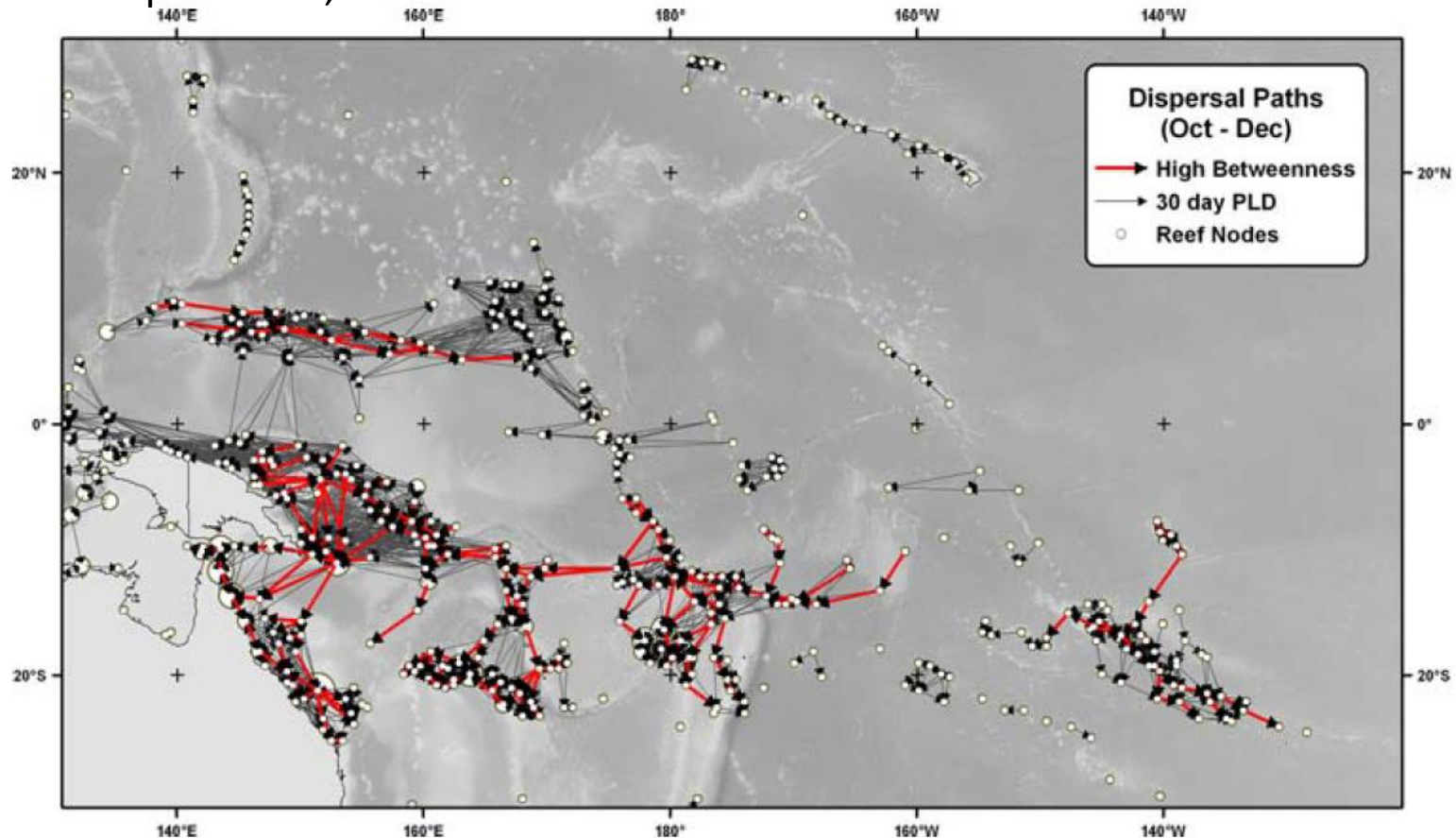
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Species biogeography / landscape ecology

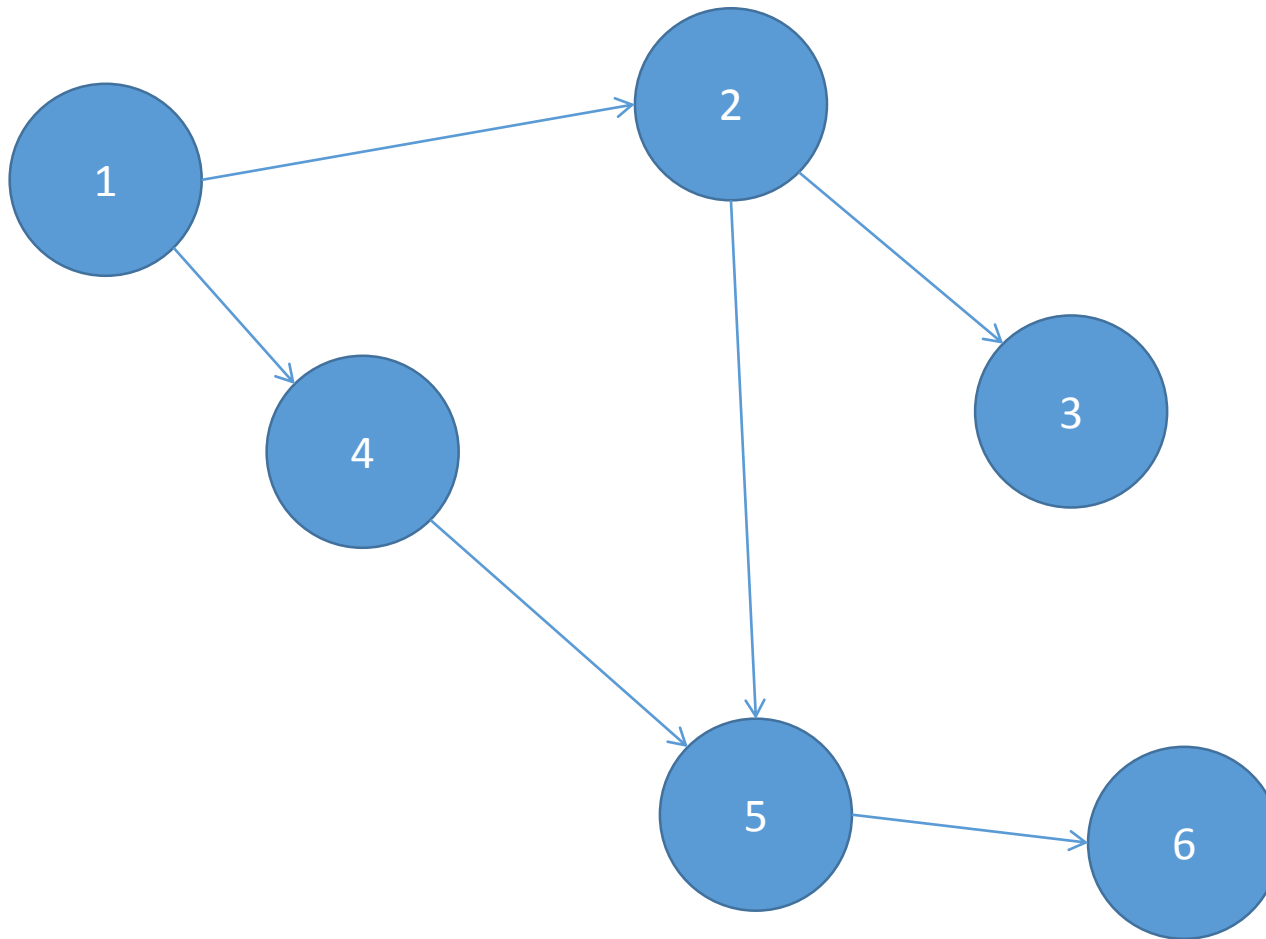
“To better manage marine systems, we must understand how the scale of connectivity and the temporal and spatial scales of disturbance (and resulting landscape fragmentation) interact as a framework for predicting the implications of more complex variability in colonization potential » - Lundquist et al., 2010



Dispersal pathways, Treml et al., 2008 - Modeling population connectivity by ocean currents, a graph-theoretic approach for marine conservation

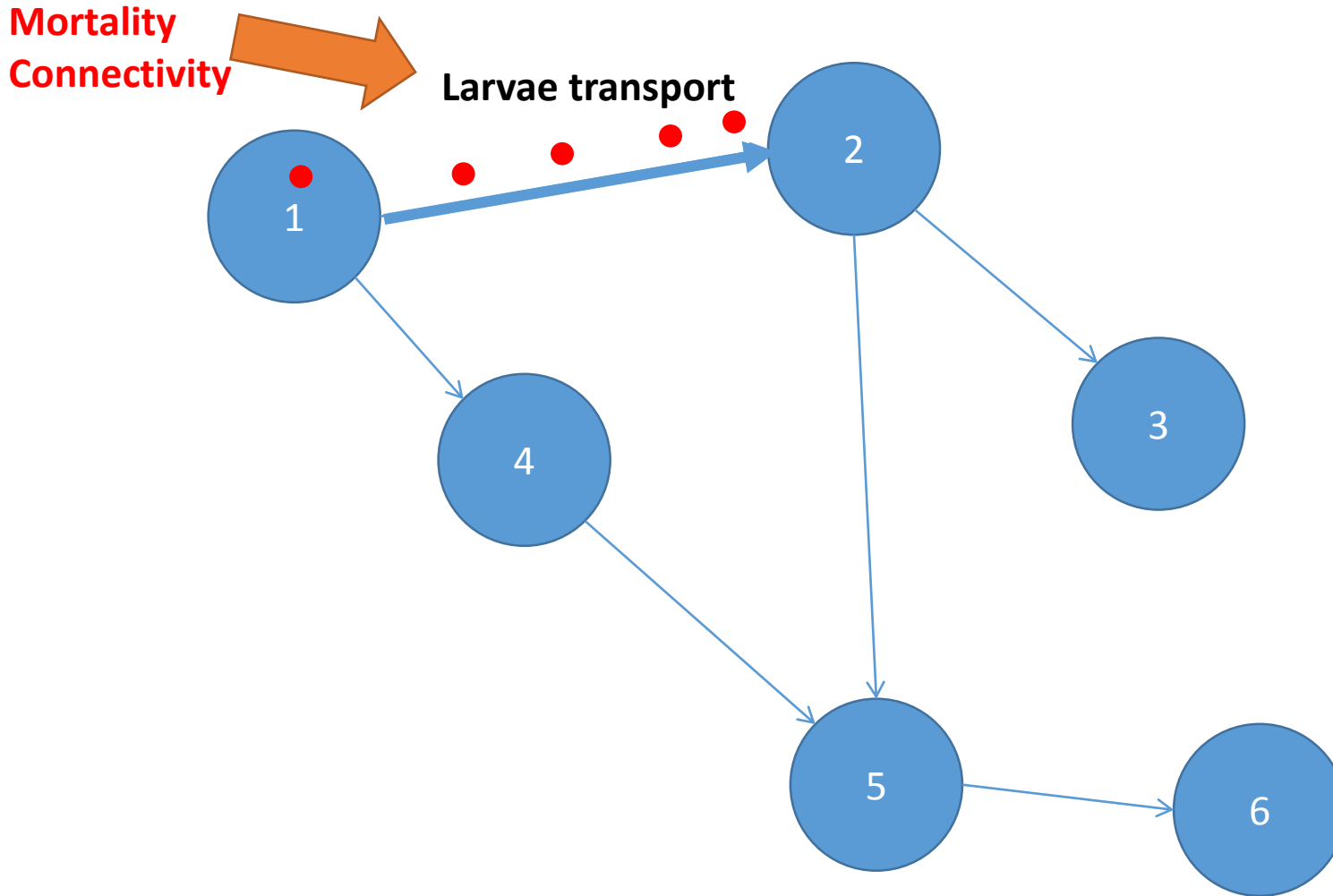
Spatial dynamics, processes and drivers

Habitat patches and migration pathways

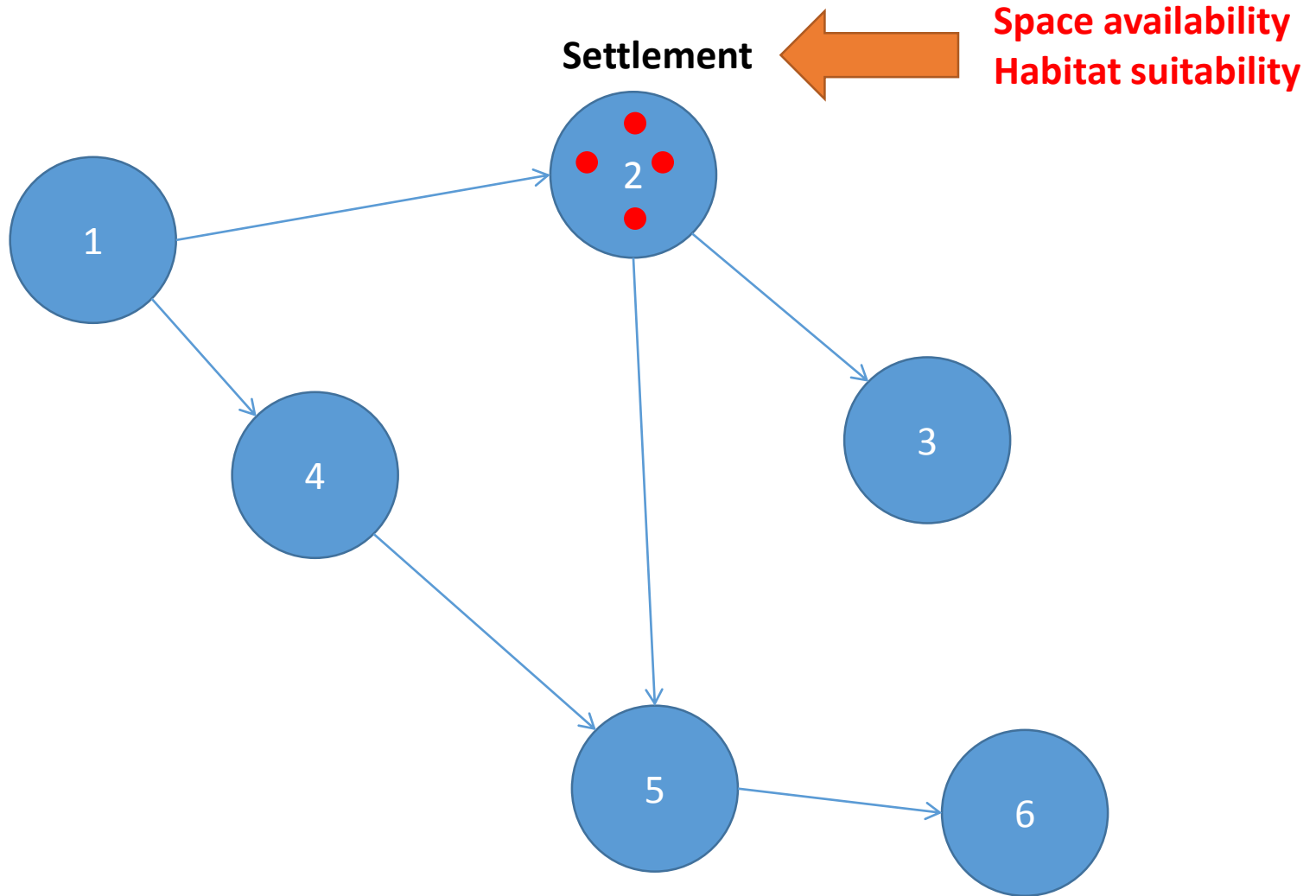


Spatial dynamics, processes and drivers

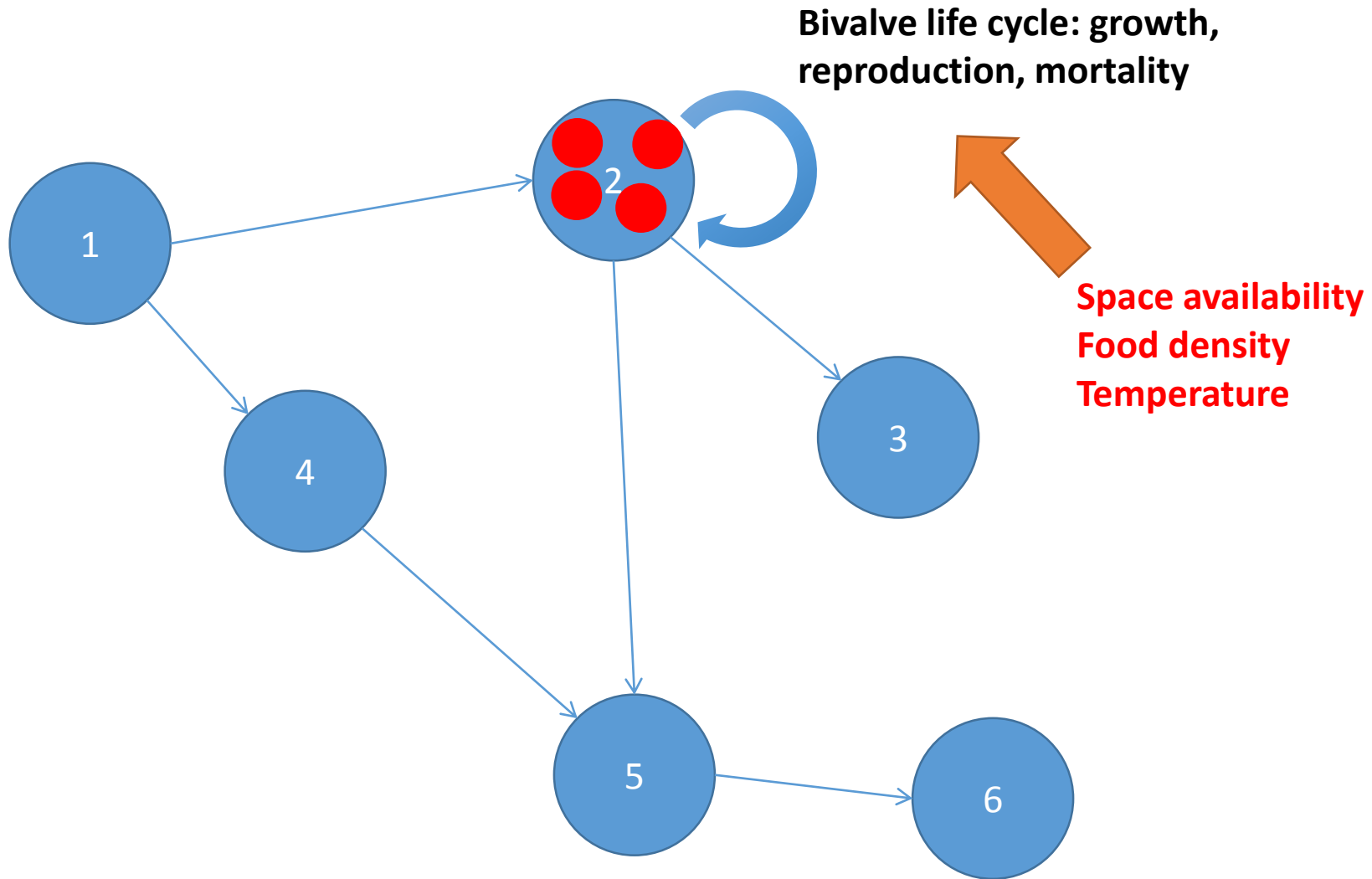
Network of habitat patches



Spatial dynamics, processes and drivers

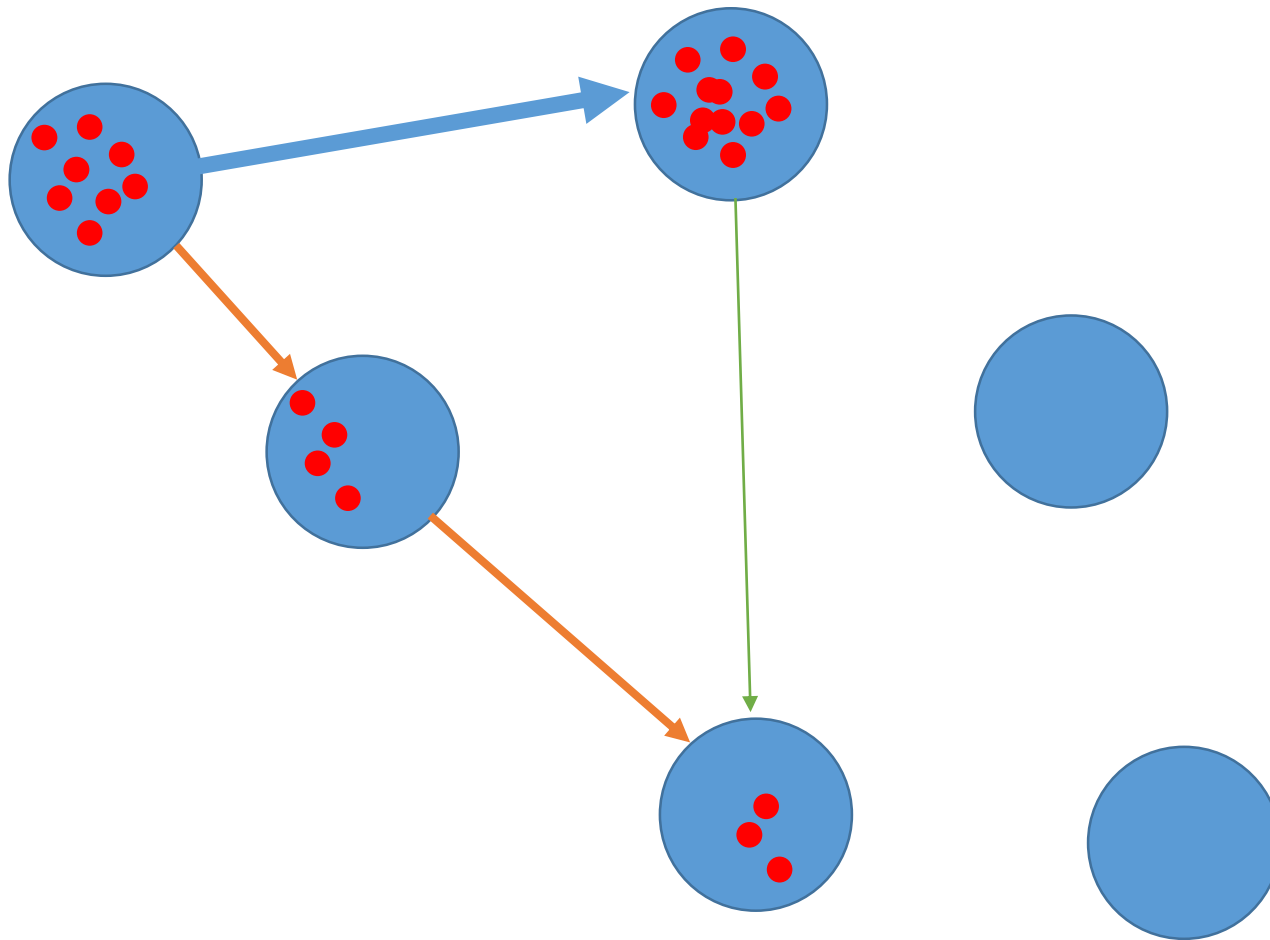


Spatial dynamics, processes and drivers

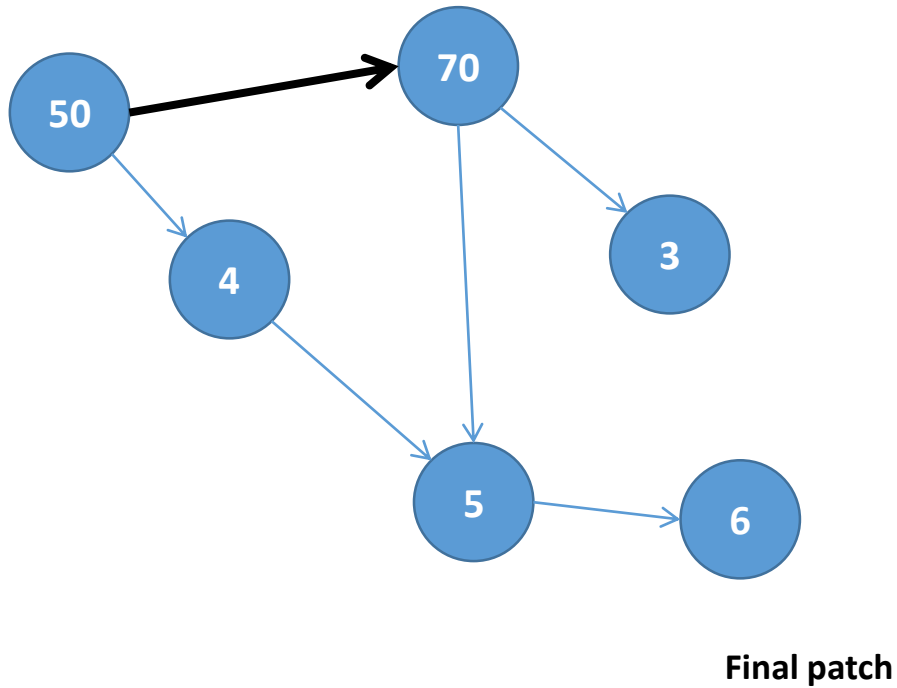


Spatial dynamics, processes and drivers

Combination of drivers and processes result in multiple pathways,
population growth and expansion

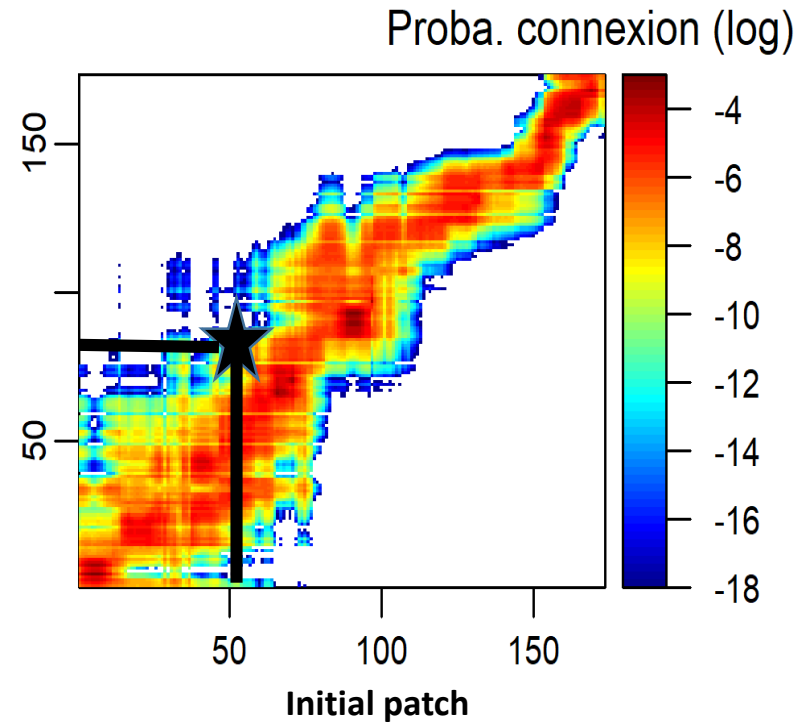


From network to connectivity matrix



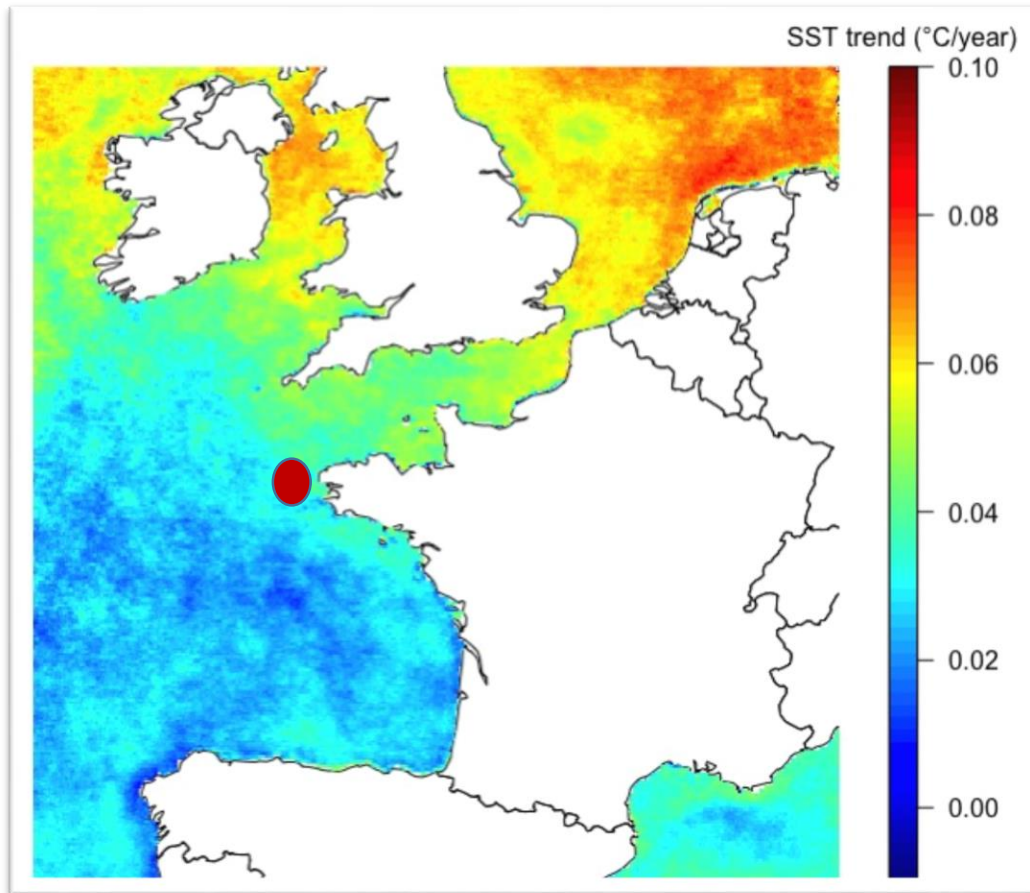
Arrow = flux, probability, link

Circle = habitat patch



Issues: Evidence of temperature change

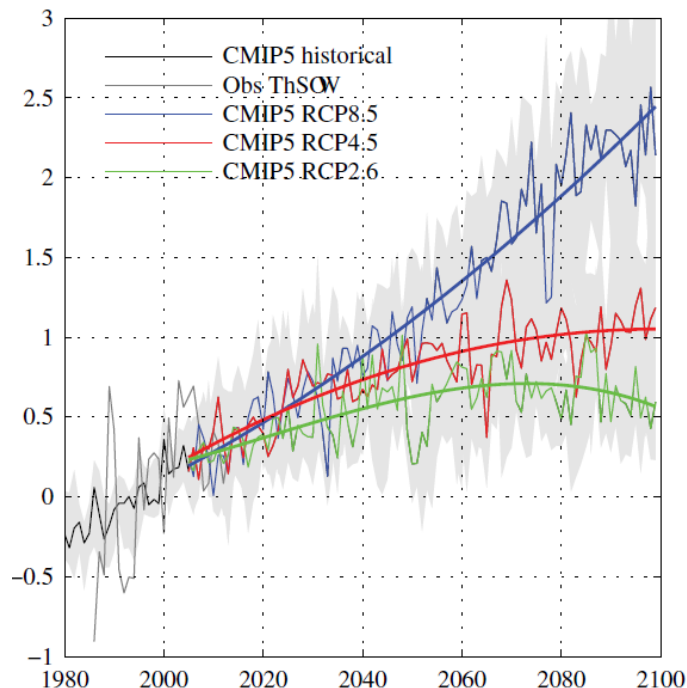
- **Observed temperature trend (1986 – 2006) in North East Atlantic revealed by satellite data (Saulquin and Gohin, 2010)**
 - ✓ **Spatial gradient**
 - ✓ **0.2-0.8 °C/decade**



Saulquin and Gohin, 2010

Issues: Evidence of temperature change

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 - ✓ Spatial gradient
 - ✓ 0.2-0.8 °C/decade
- **Predicted temperature indices in Brittany (L'Heveder et al., 2017)**
 - **RCP2.6 (green): scenario designed to meet the 2 °C global average warming target compared to pre-industrial conditions by 2100**
 - **RCP8.5 (blue): assuming a high rate of radiative forcing increase, peaking at 8.5Wm⁻² in year 2100**



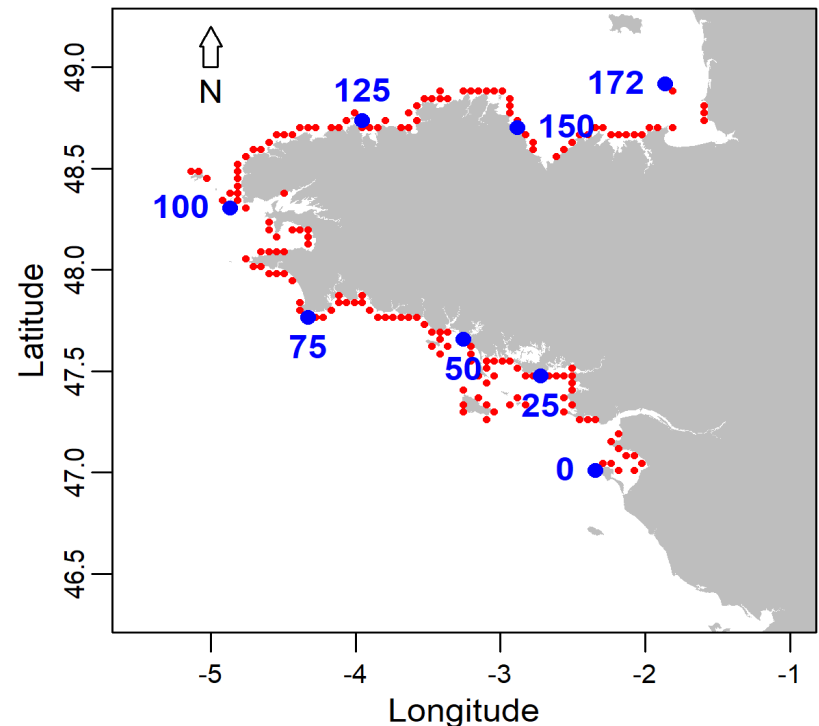
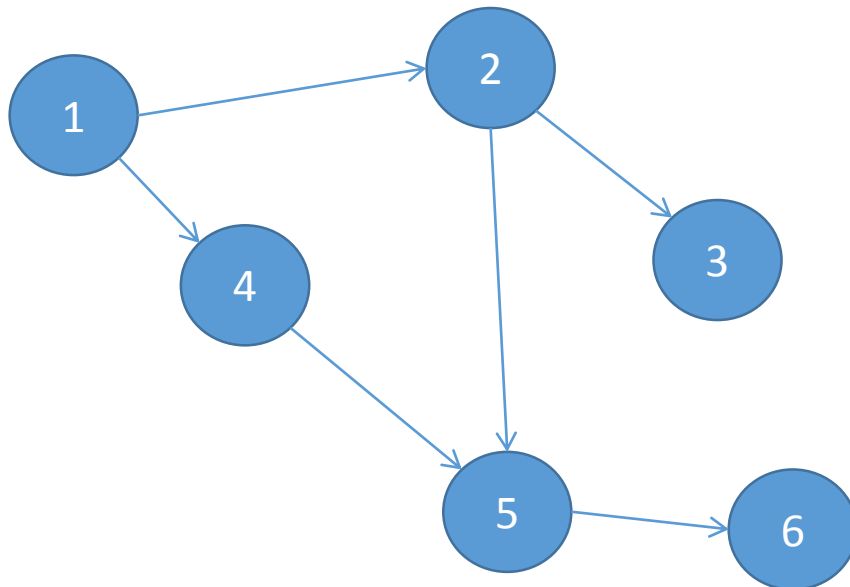
L'Heveder et al., 2017

Issues: Evidence of temperature change

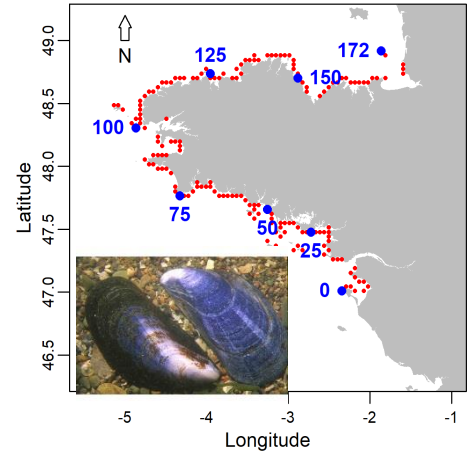
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- **Rationale: Expected impacts depend on species thermal niche**
 - **Temperature affects biological rates and phenology at the individual scale**
 - **Food concentration drives the population growth rates locally**
 - **Habitat availability controls the maximum number of individuals – density dependence**
 - **Habitat connectivity drives the colonization speed – here larval phase**
 - **Population response involves multiple spatial and temporal scales: individual responses, connectivity between habitat patches, settlement and competition for space**
 - **Simulation models help deciphering the role of each process**

Objectives

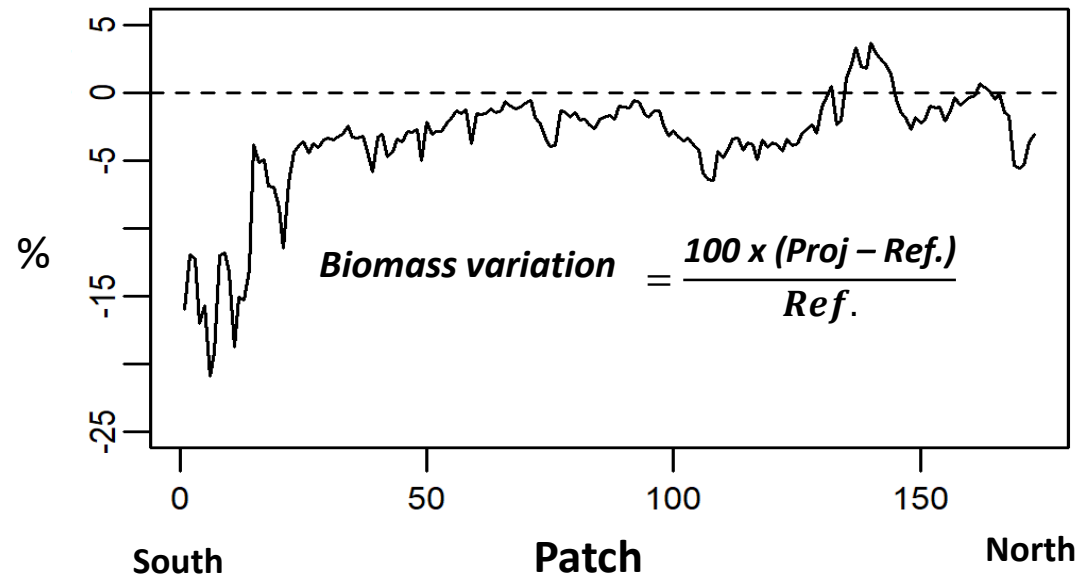
- To build a process-based model and simulate the spatial and temporal dynamics of bentho-pelagic marine species
- To apply to *Mytilus edulis* along the Brittany coast: spatial distribution, colonisation time, steady state density and biomass
- To assess sensitivity to climate change, using RCP8.5 simulated temperature

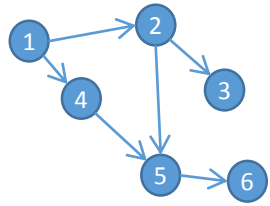


The model predicts
a decrease of
biomass due to
temperature
increase



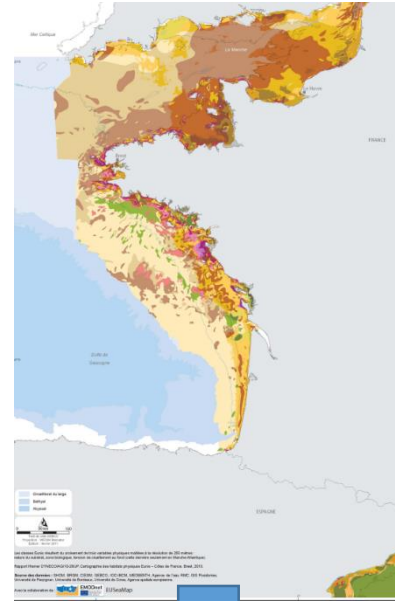
- Average of simulated biomass over 15 years in each patch
- Biomass decreases ca. 5%
- South/North gradient





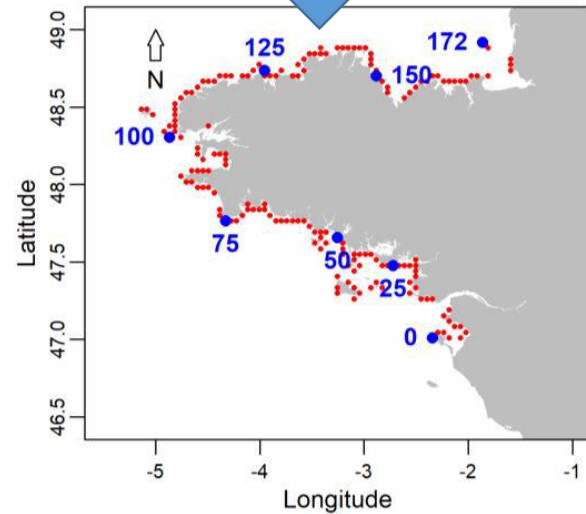
Model Building

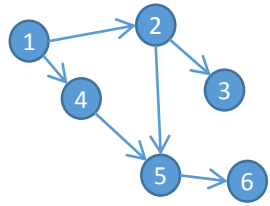
Habitat mapping (EUNIS)
Species preference



Patch definition

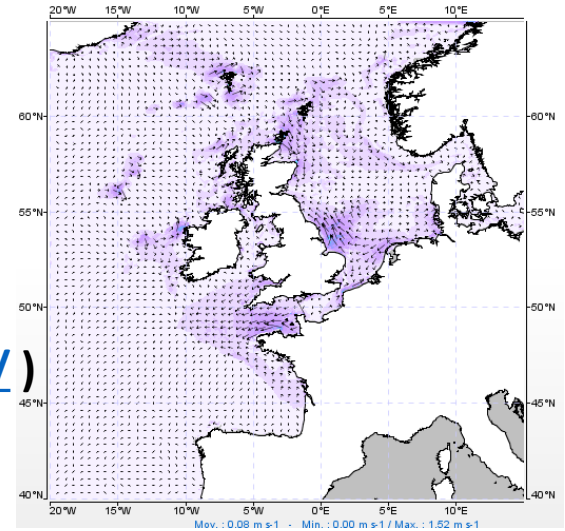
Set of 173 patches





Model Building

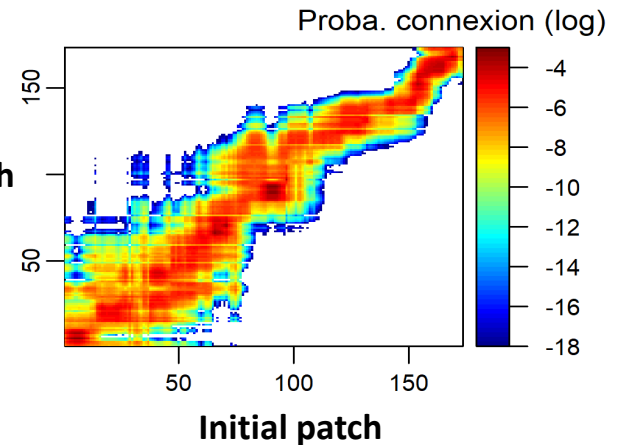
Hydrodynamic modelling
 Lagrangian transport modelling
 (Ifremer, <https://marc.ifremer.fr/>)

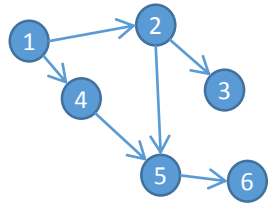


**Connectivity
 between habitat
 patches**

Connectivity matrix

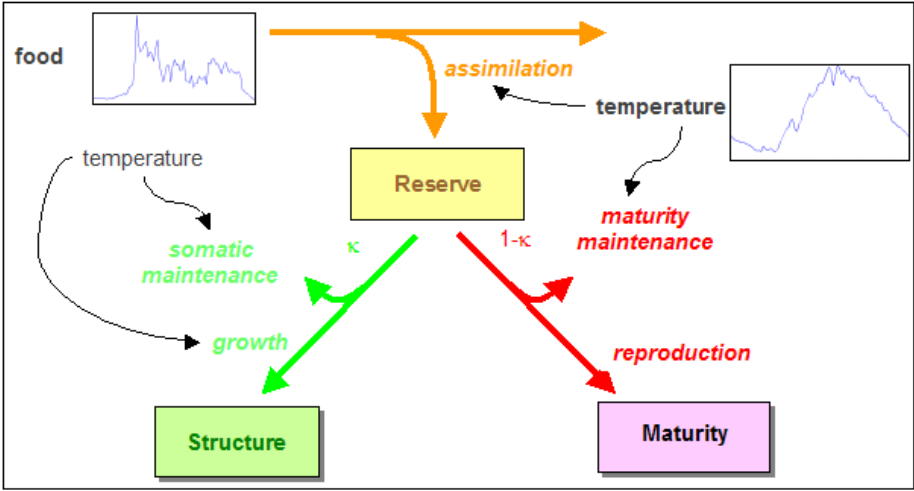
Final patch





Model Building

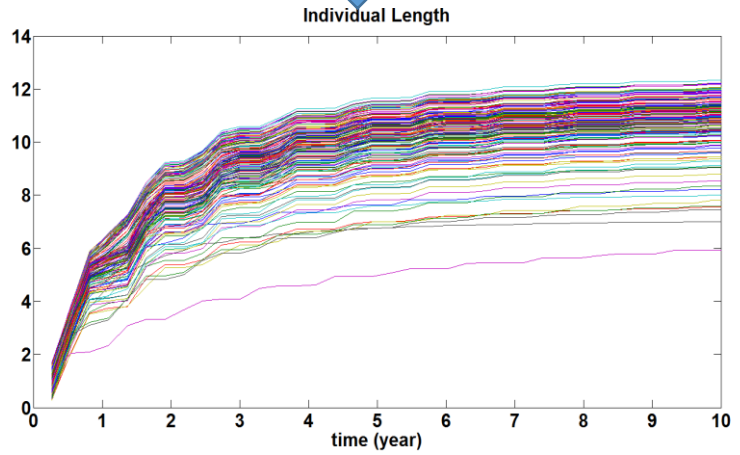
Dynamic Energy Budget theory

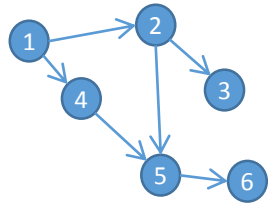


Life history traits

Output Variables

- Physical length
- Individual mass
- Fecundity
- Gametes





Model Building

Individual based model

Interactions rules within each patch
 (competition for space)
 Food and temperature in each patch
 Connectivity between patches

Population dynamics



NETLOGO simulation platform

AGENTS

Patches

Turtles

Command Center

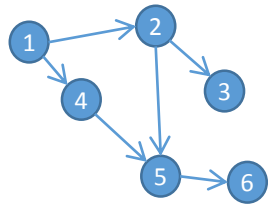
observer>

Bouton

Plot

Monitoring

COMMANDS

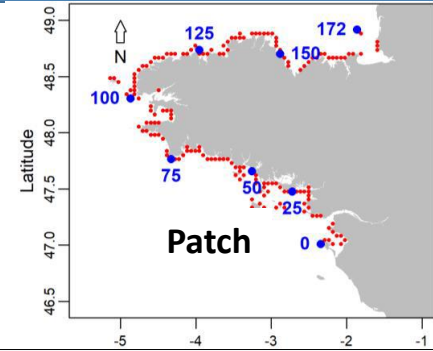


Model Building

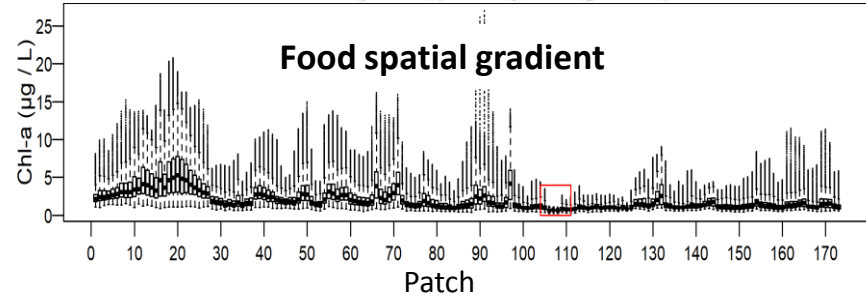
Simulation setup

Spatial and temporal scales

- ✓ Time step : 1 day
- ✓ Duration of simulation : 30 years
- ✓ Patch size: 4 × 4 km

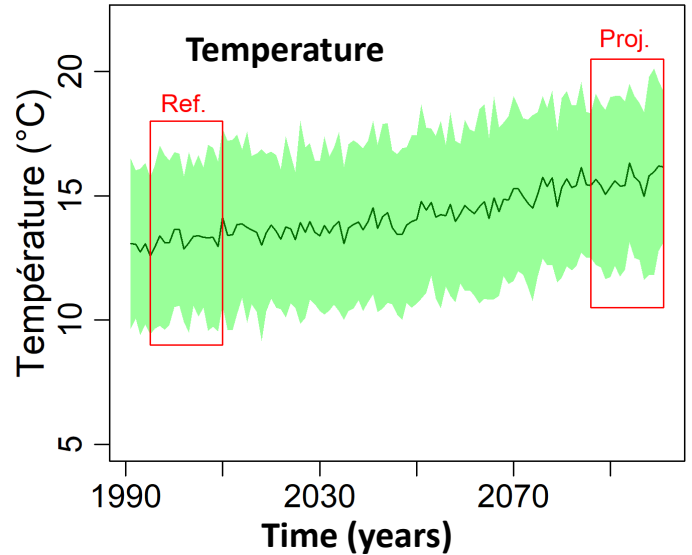


Reference temperature scenario



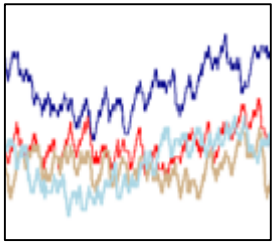
Projection temperature scenario

- ✓ RCP 8.5
- ✓ CNRM-CM5



Model outputs

- ✓ Colonisation speed
- ✓ Number of cohorts
- ✓ Biomass in each patch
- ✓ Total biomass



Simulation Results

Colonisation – Reference scenario

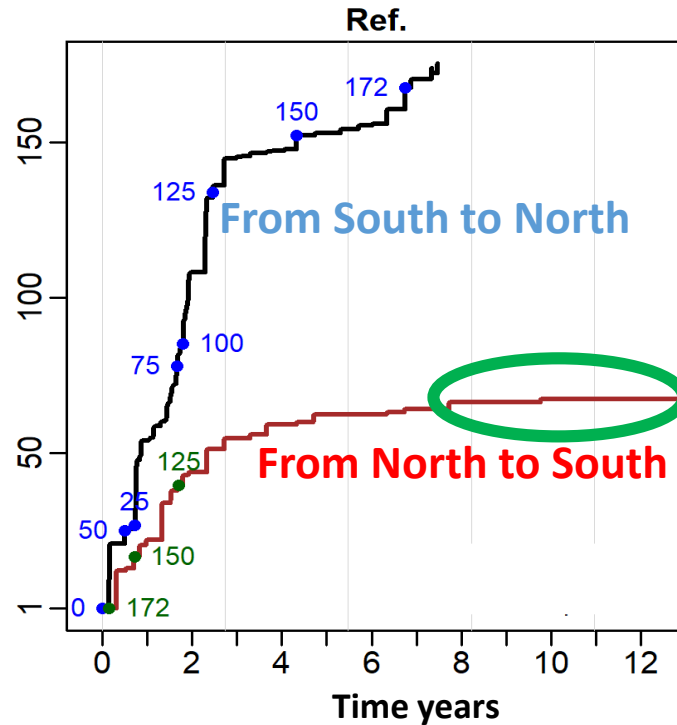
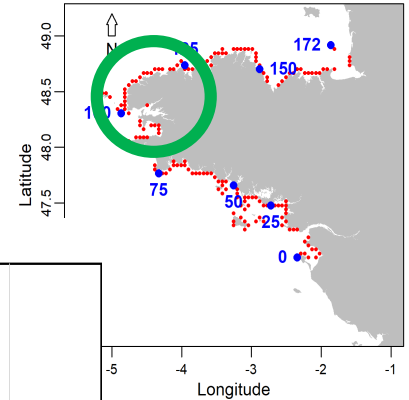
➤ Initialisation

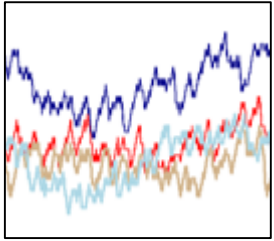
1. **South: initial density in patch 1**
2. **North: initial density in patch 173**

➤ Results

Faster colonisation from South to North

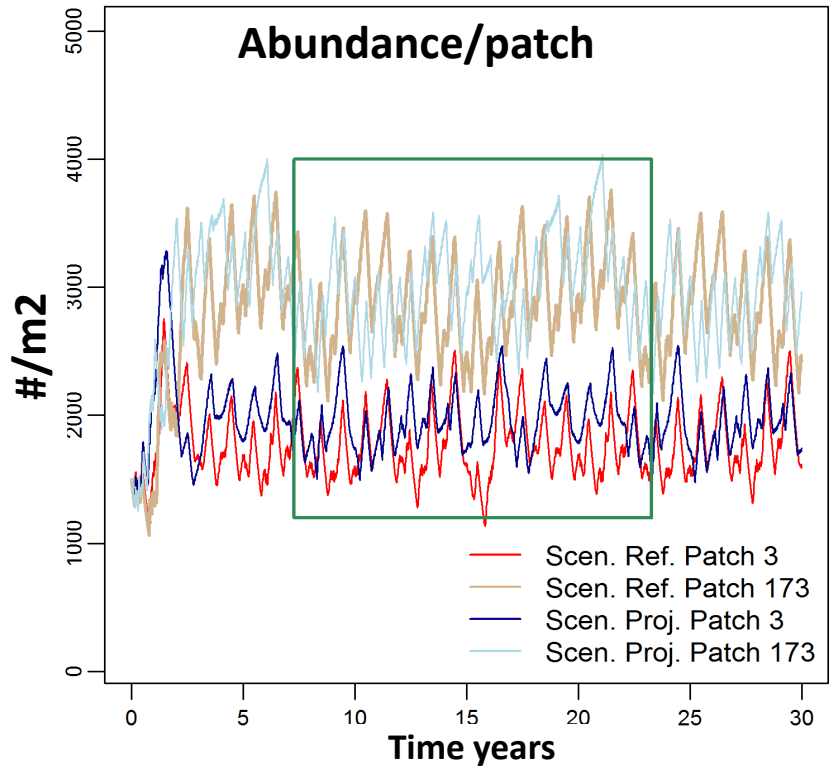
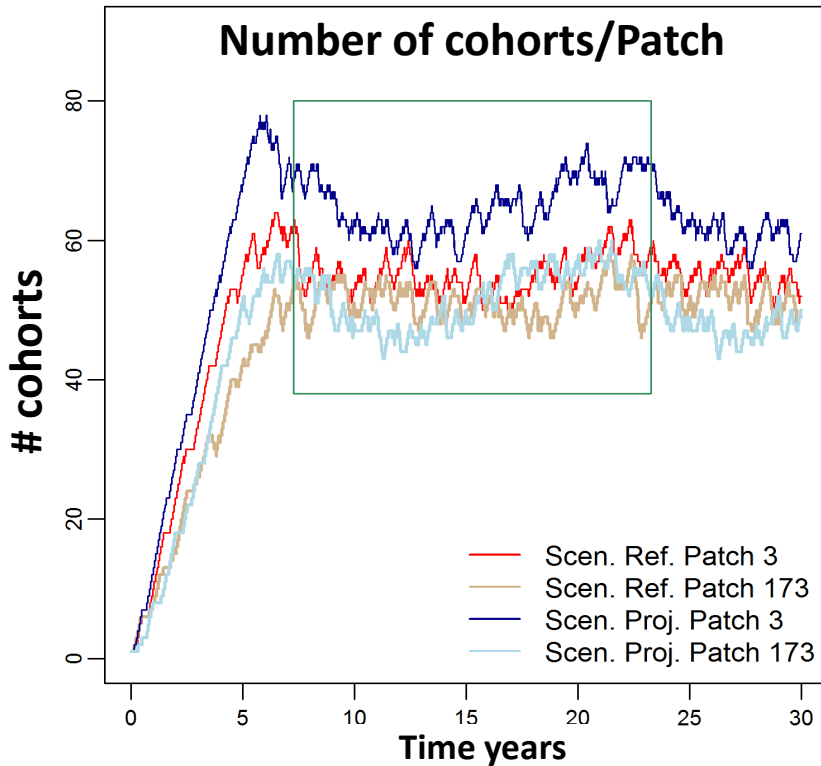
Biological barrier: local trophic factors



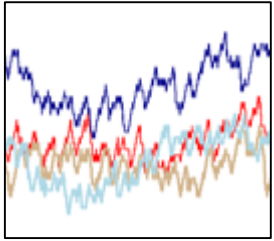


Simulation Results

Effects of global warming on population structure



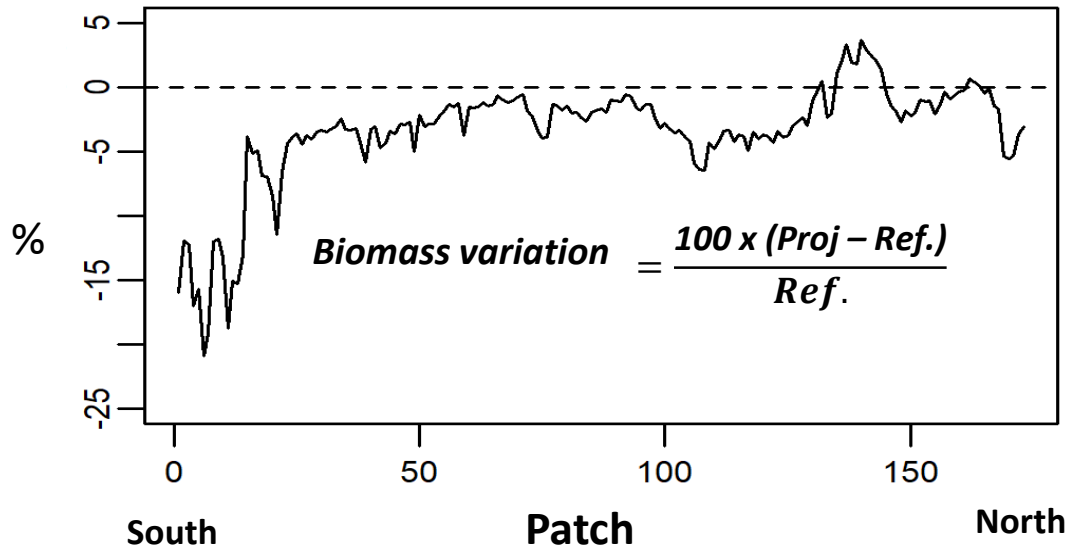
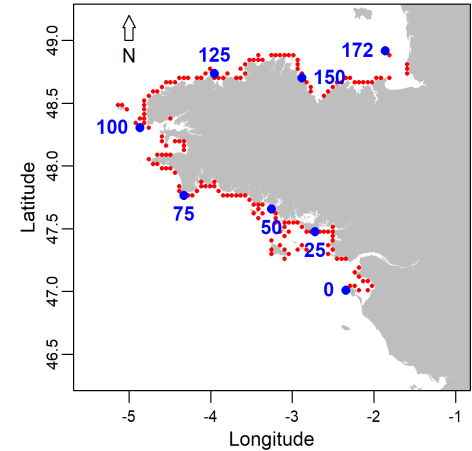
- **Steady state: local control due to competition for space**
- **Inter-annual fluctuations: environmental forcing/biological traits**
- **Spatial differences**
- **Differences between temperature scenarios**



Simulation Results

Effects of global warming on Biomass

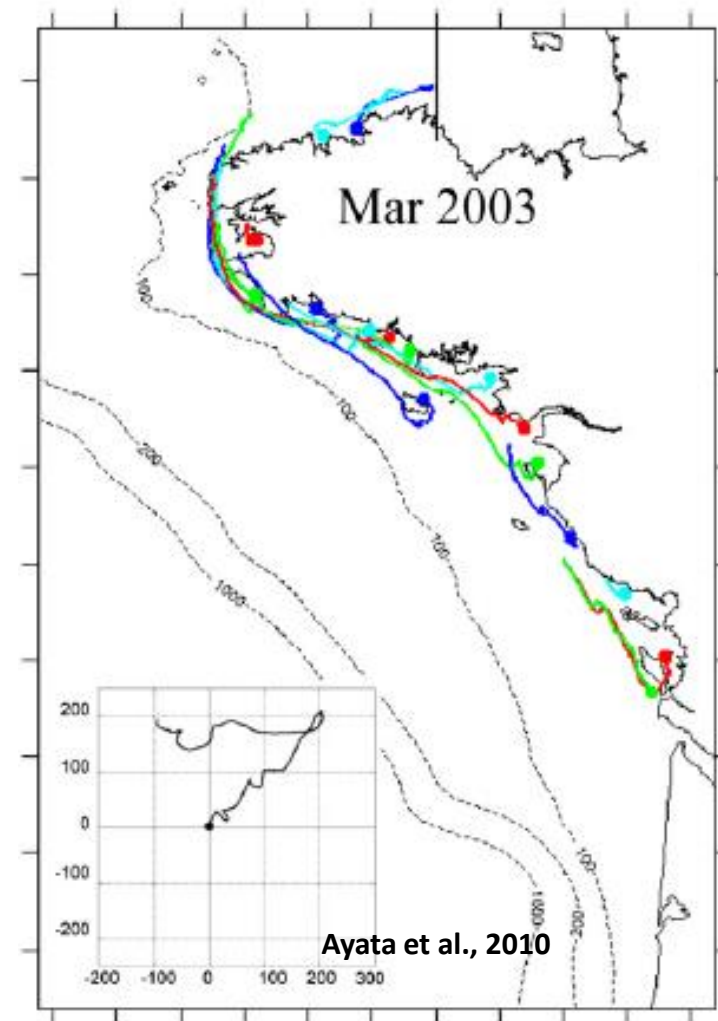
- Averaged biomass over 15 years in each patch
- Rate of variation between the 2 climate scenarios
- Main results
 - ✓ Biomass decrease
 - ✓ South/North gradient



Main findings

➤ Spatial process

- Fast colonisation ca., 10 years – see connectivity
- Colonisation for South to North : main ocean circulation (Ayata et al., 2010)
- Biological frontiers : variability of food+ temperature conditions affect individual history traits



Main findings

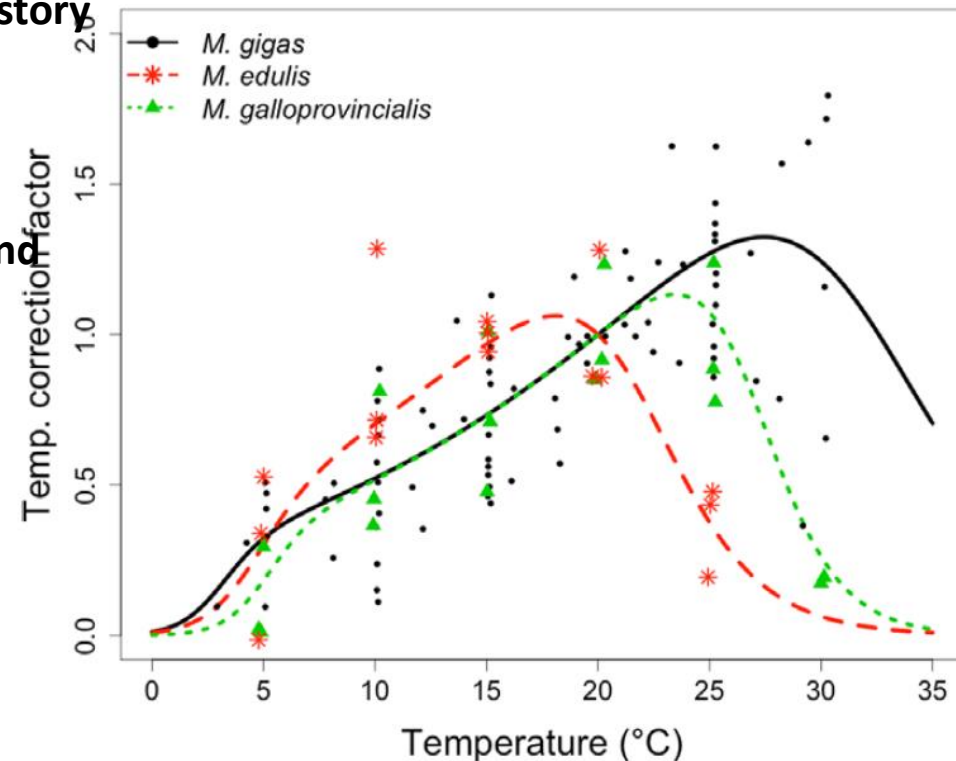
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➤ Effect of warming (RCP8.5)

- Metabolic fluxes: thermal niche (Thomas and Bacher, 2018)
- Phenology : spawning window and reproduction effort
- Earlier recruitment on average
- Longer no-recruitment period in summer
- Biomass variation ~ [-20 %, +5 %]

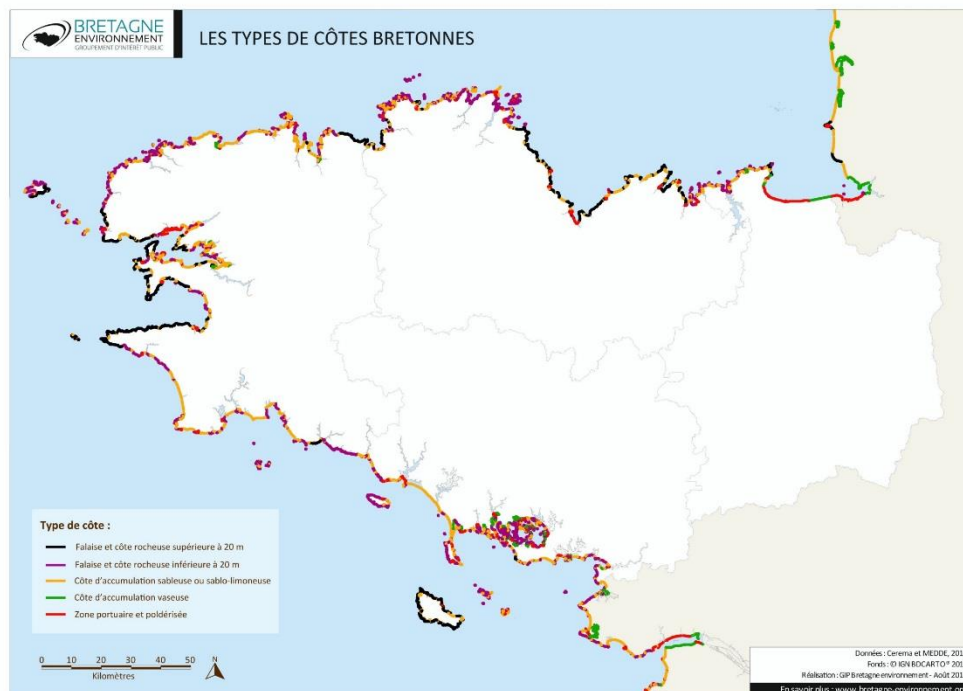
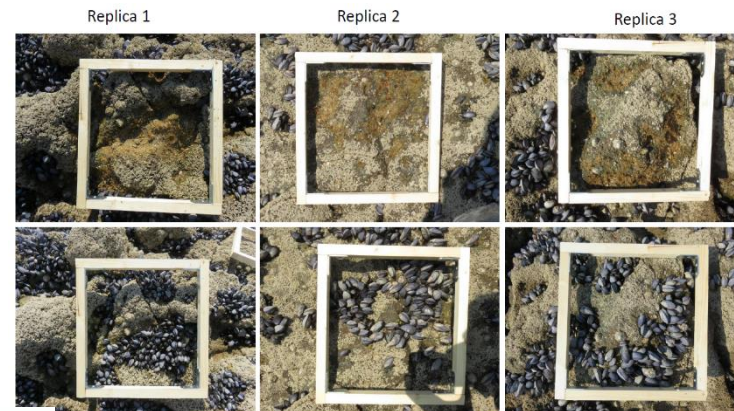
➤ Winner/loser species



Future plans

➤ **Validation, variability, competition for space, suitable habitat**

See poster - Romina Barbosa thesis (2018-2021)



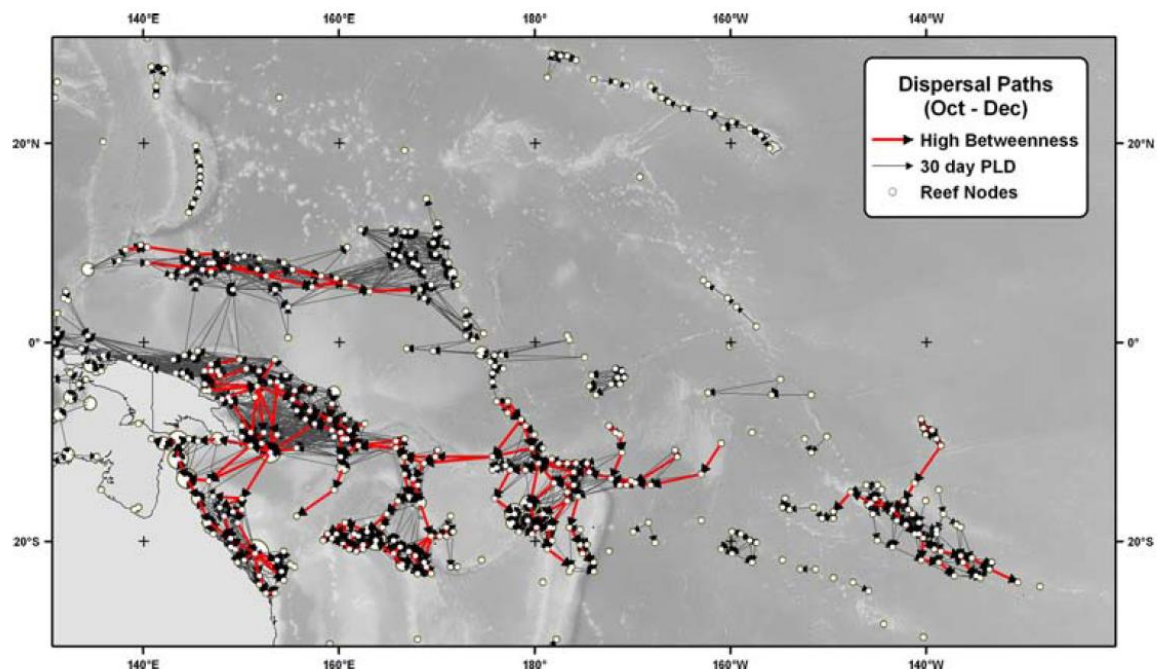
Future plans

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See poster - Romina Barbosa thesis (2018-2021)

- **Colonisation and key patches and connections**

Graph theory (Fortunato, 2010)

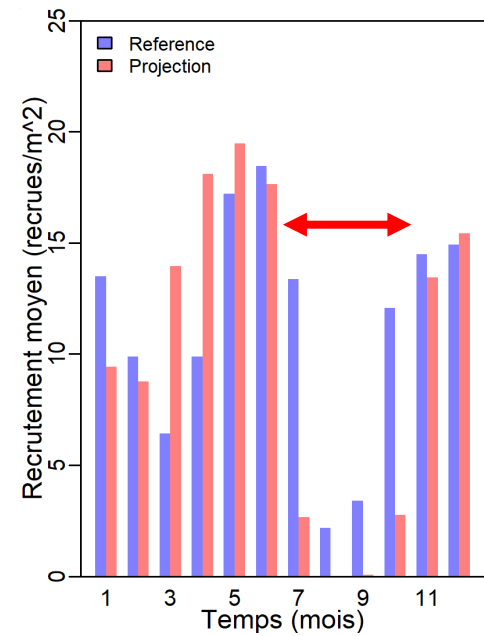
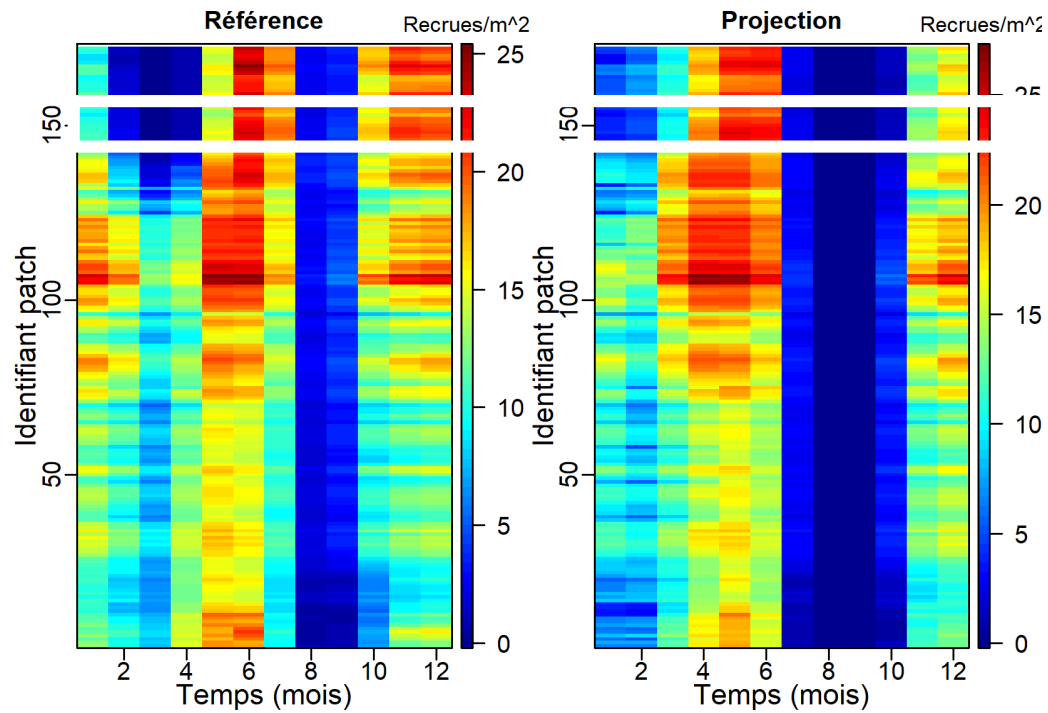


Treml et al., 2008

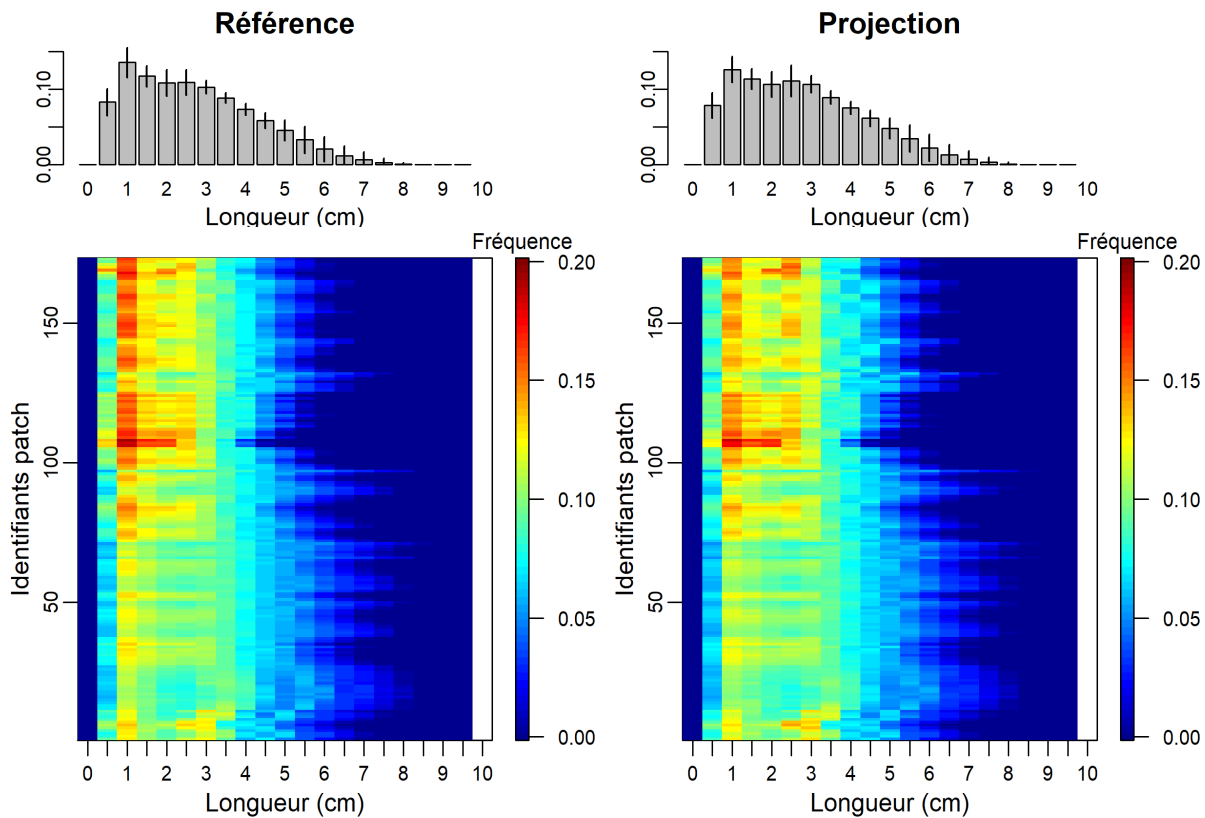


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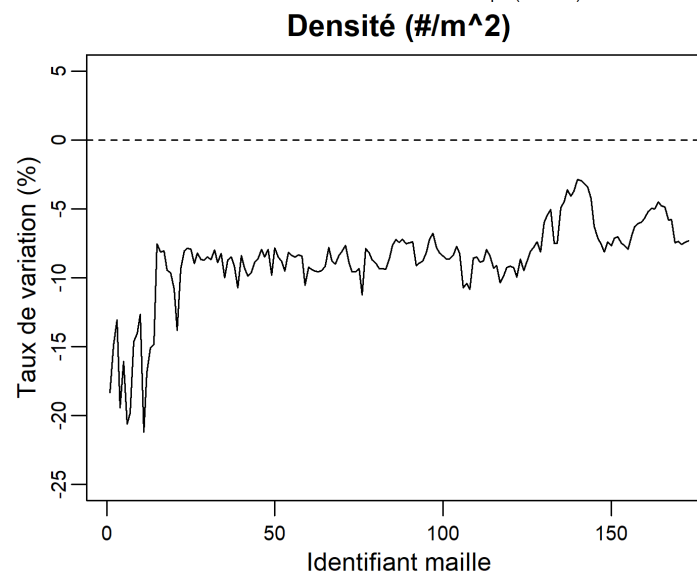
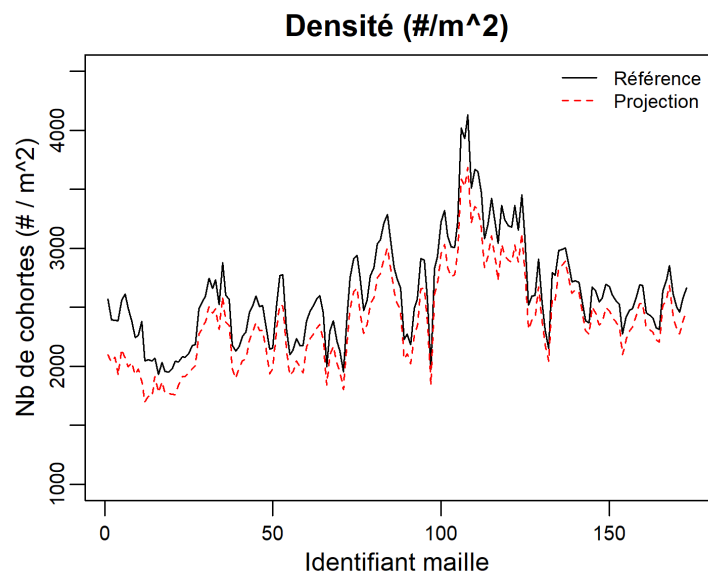
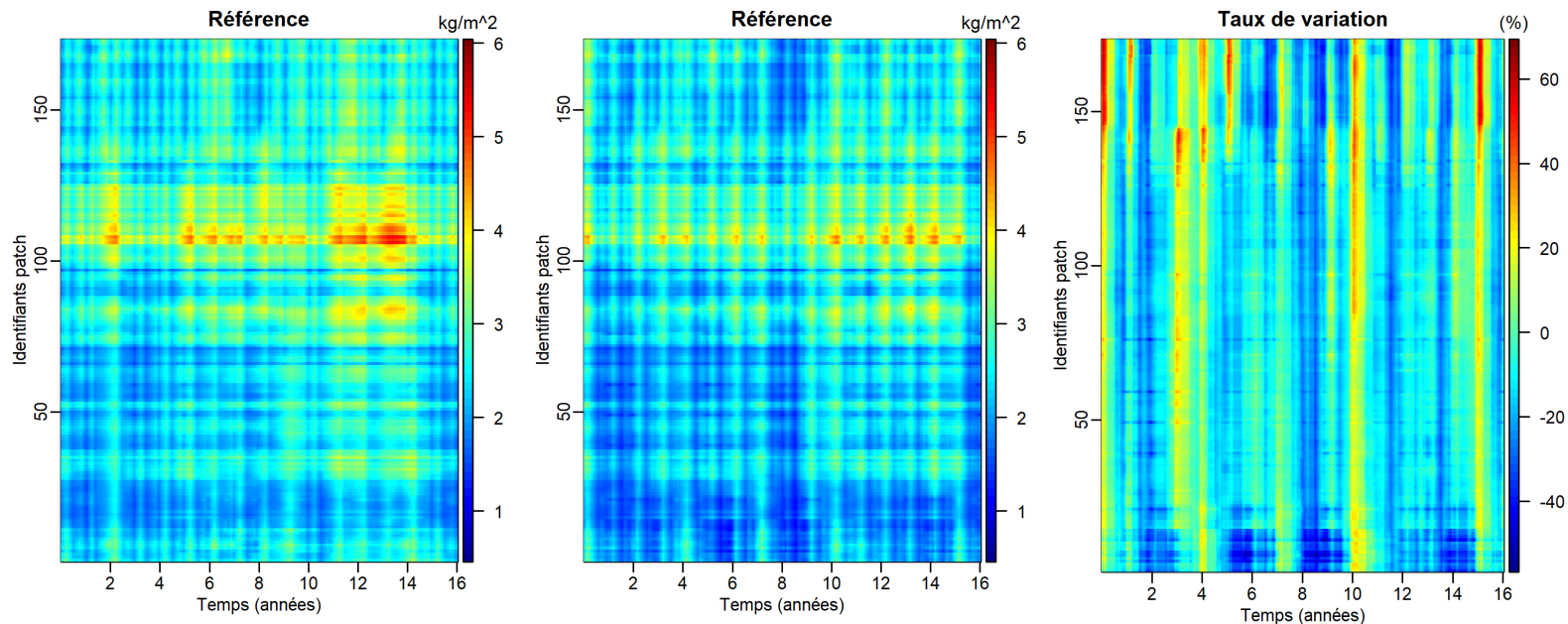
Effect of warming on recruitment



Effect of warming on size



Effect of warming on density



Effect of warming on biomass

