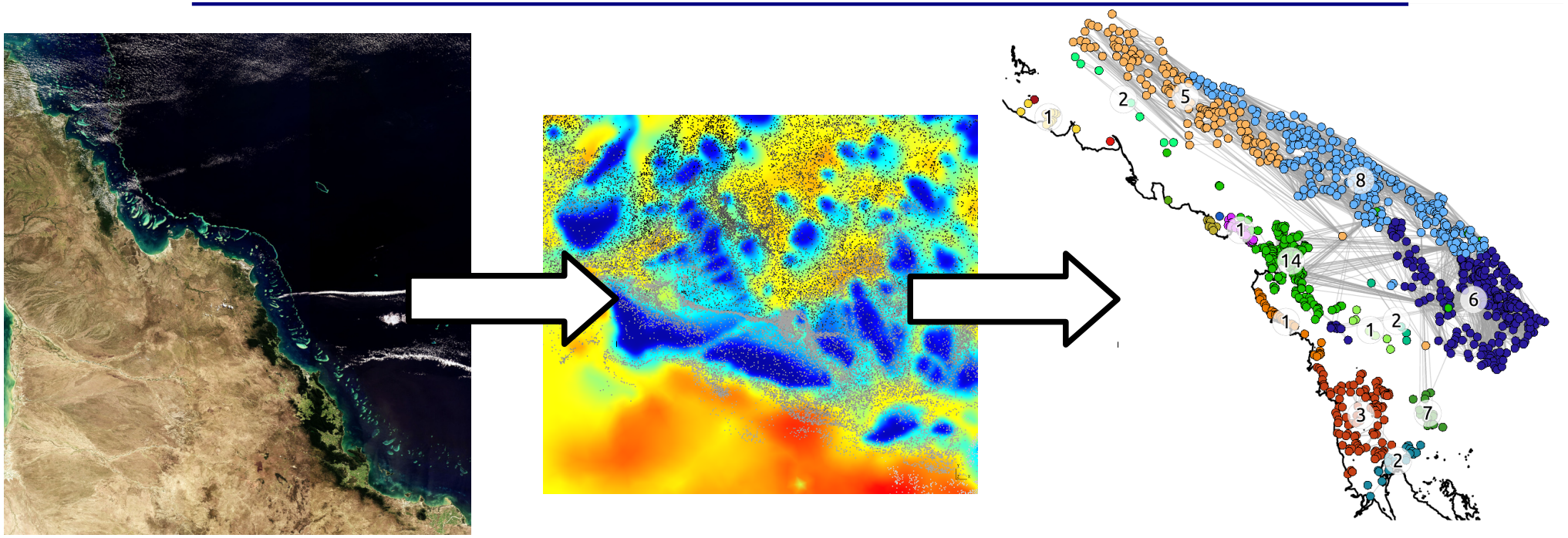
Biophysical modelling to study multi-scale ecological connectivity in the Great Barrier Reef



Christopher J. Thomas, Eric Deleersnijder, Emmanuel Hanert

Université catholique de Louvain, Louvain-la-Neuve, Belgium

JONSMOD Conference
Brussels, May 2014

What is the Great Barrier Reef (GBR)?

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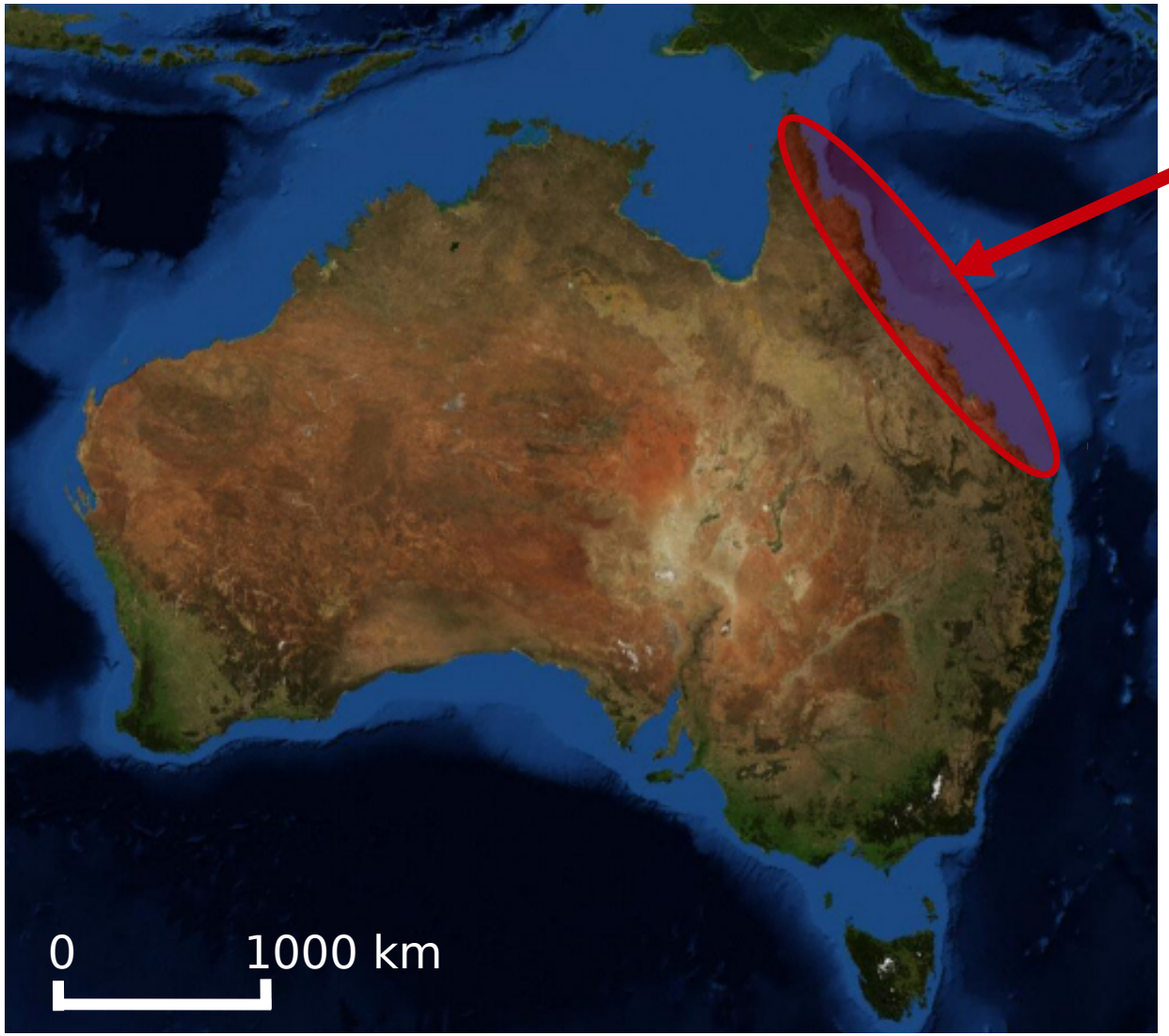

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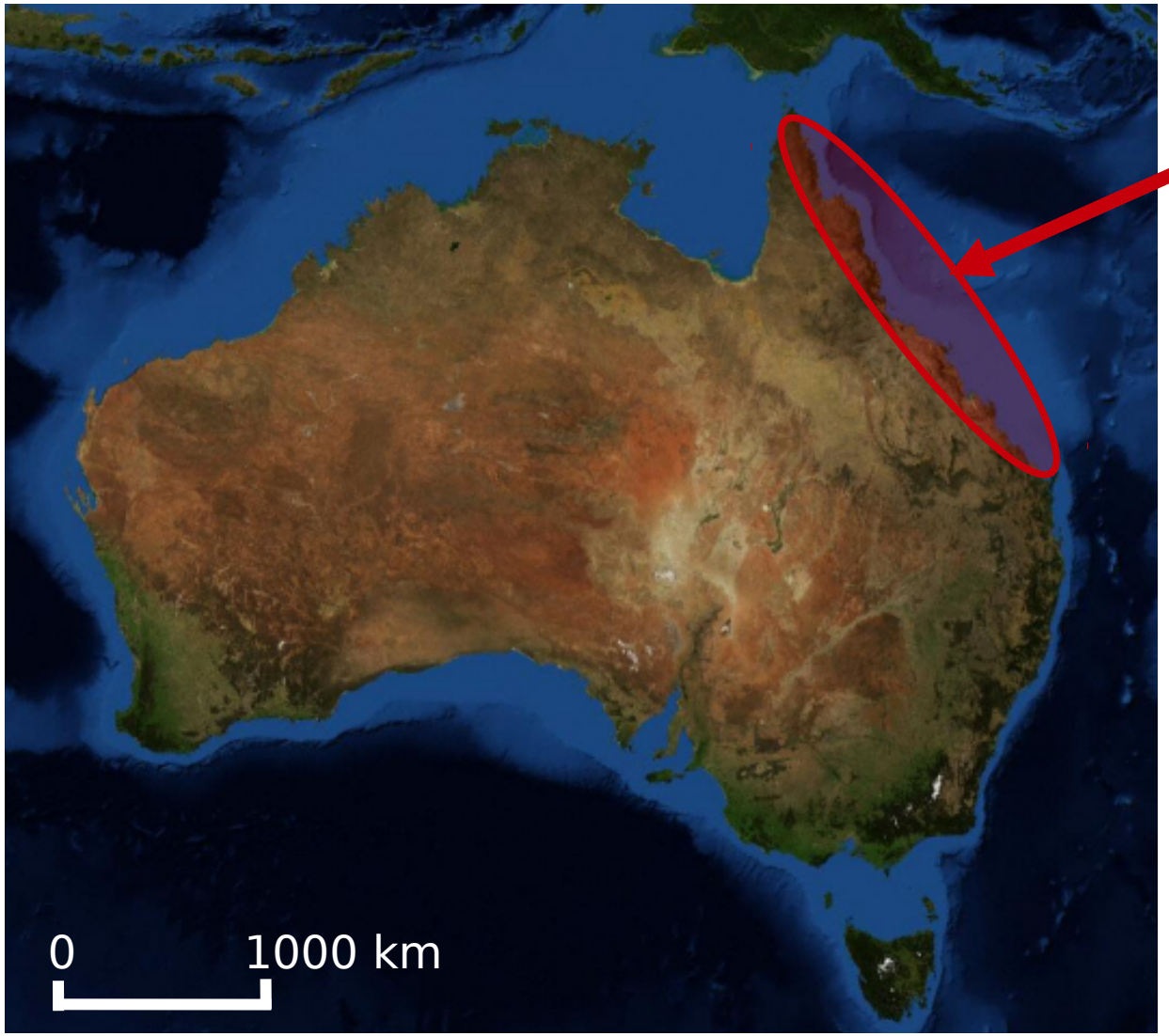

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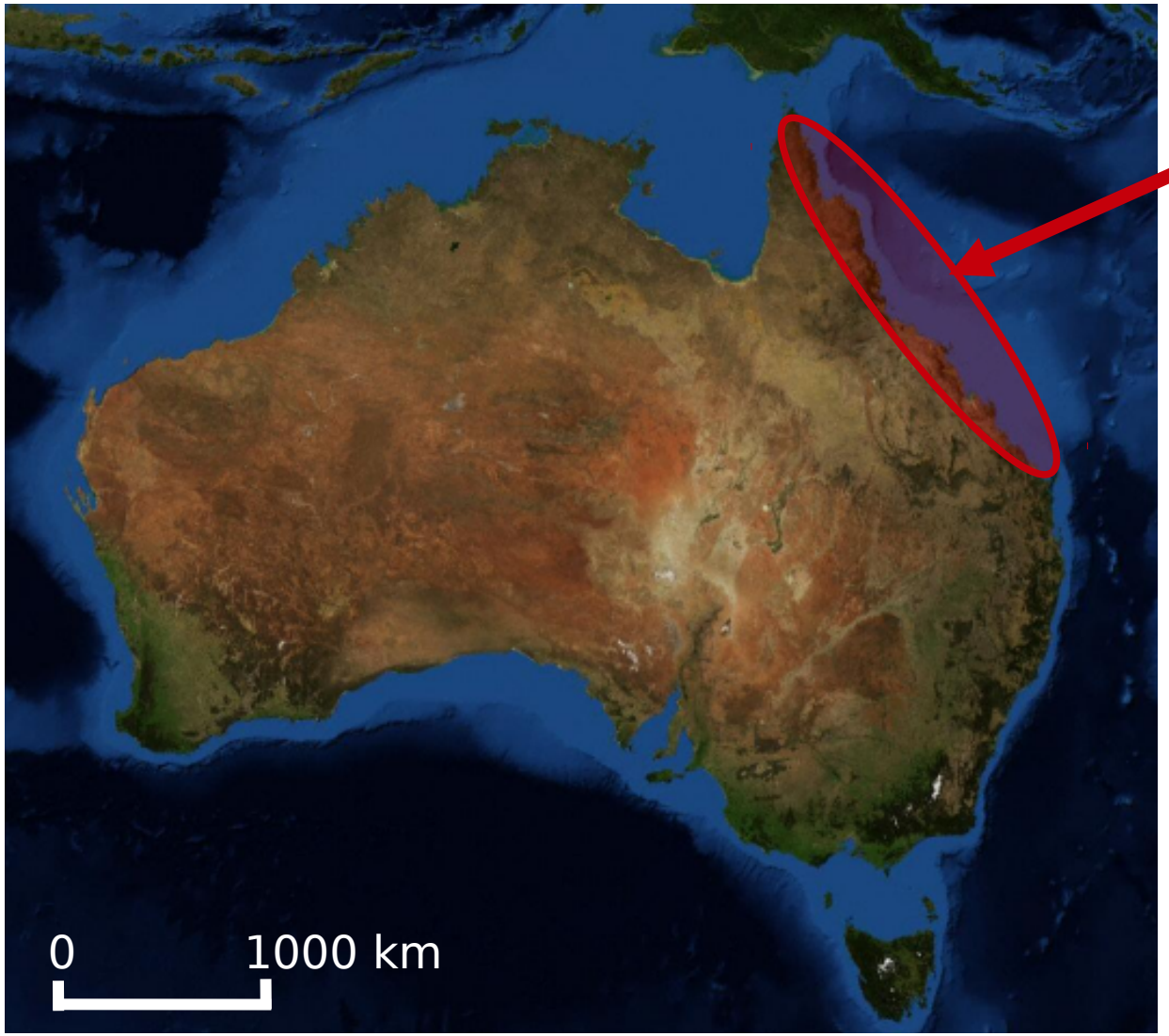

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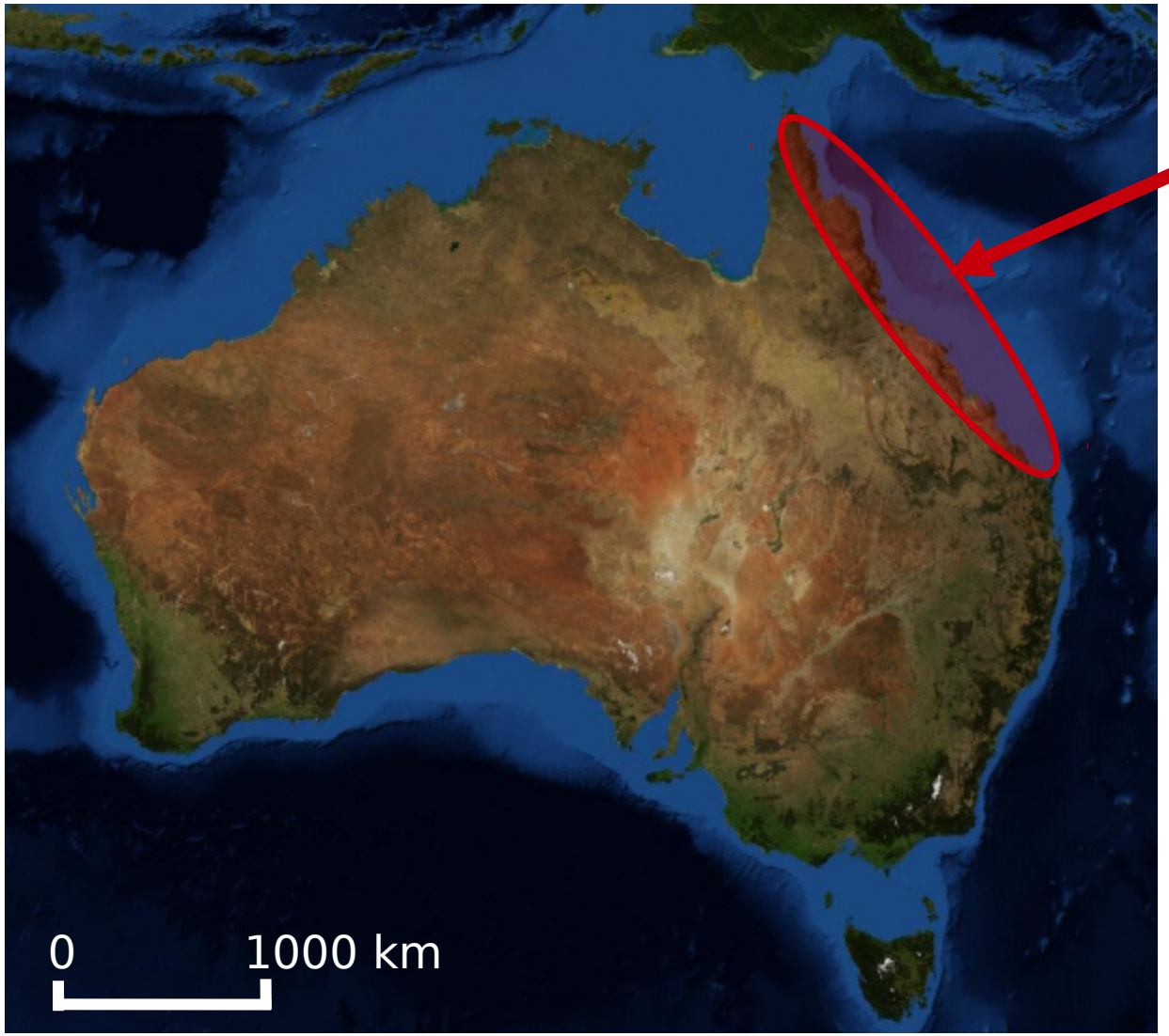

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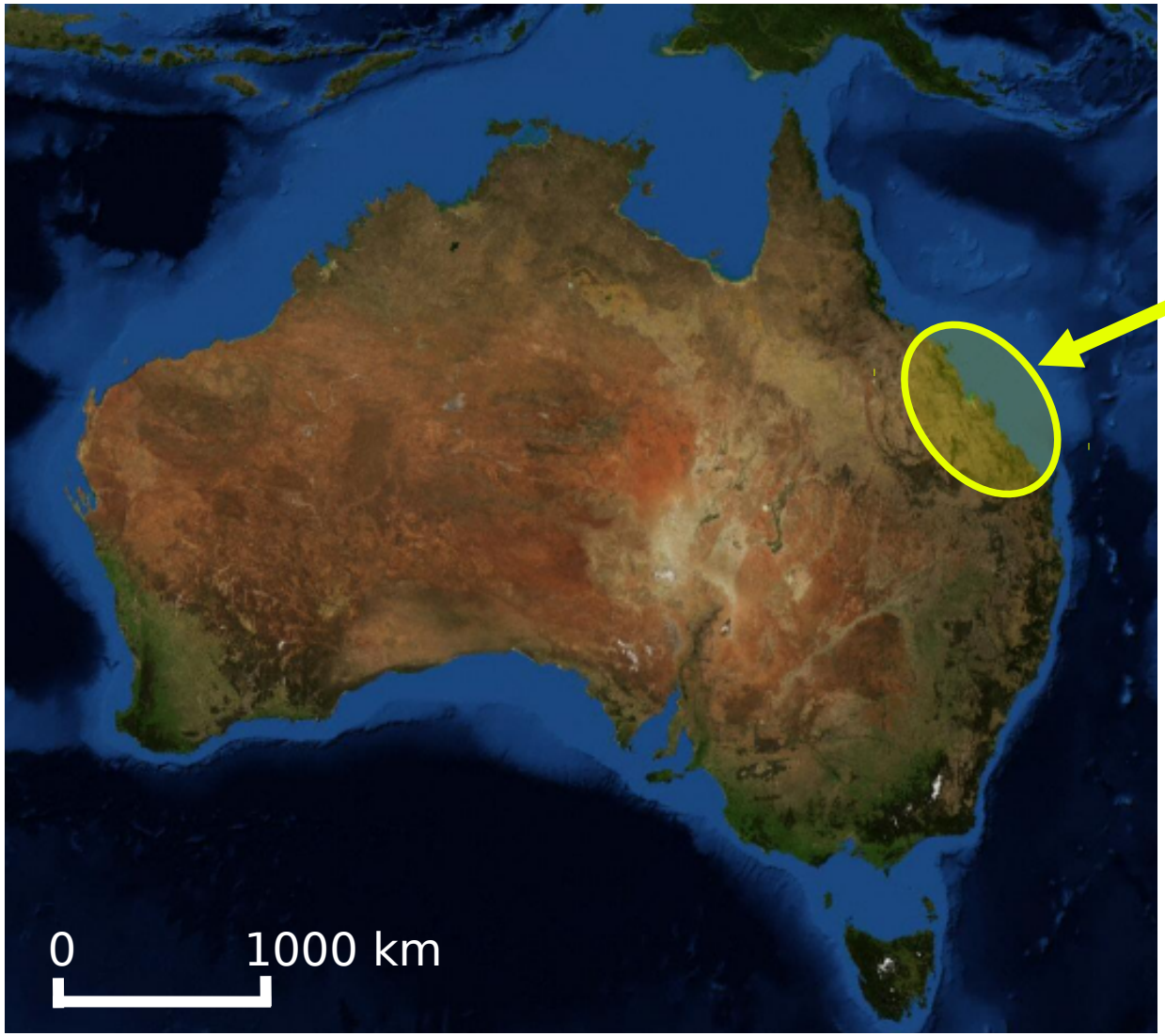

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Zooming in ...

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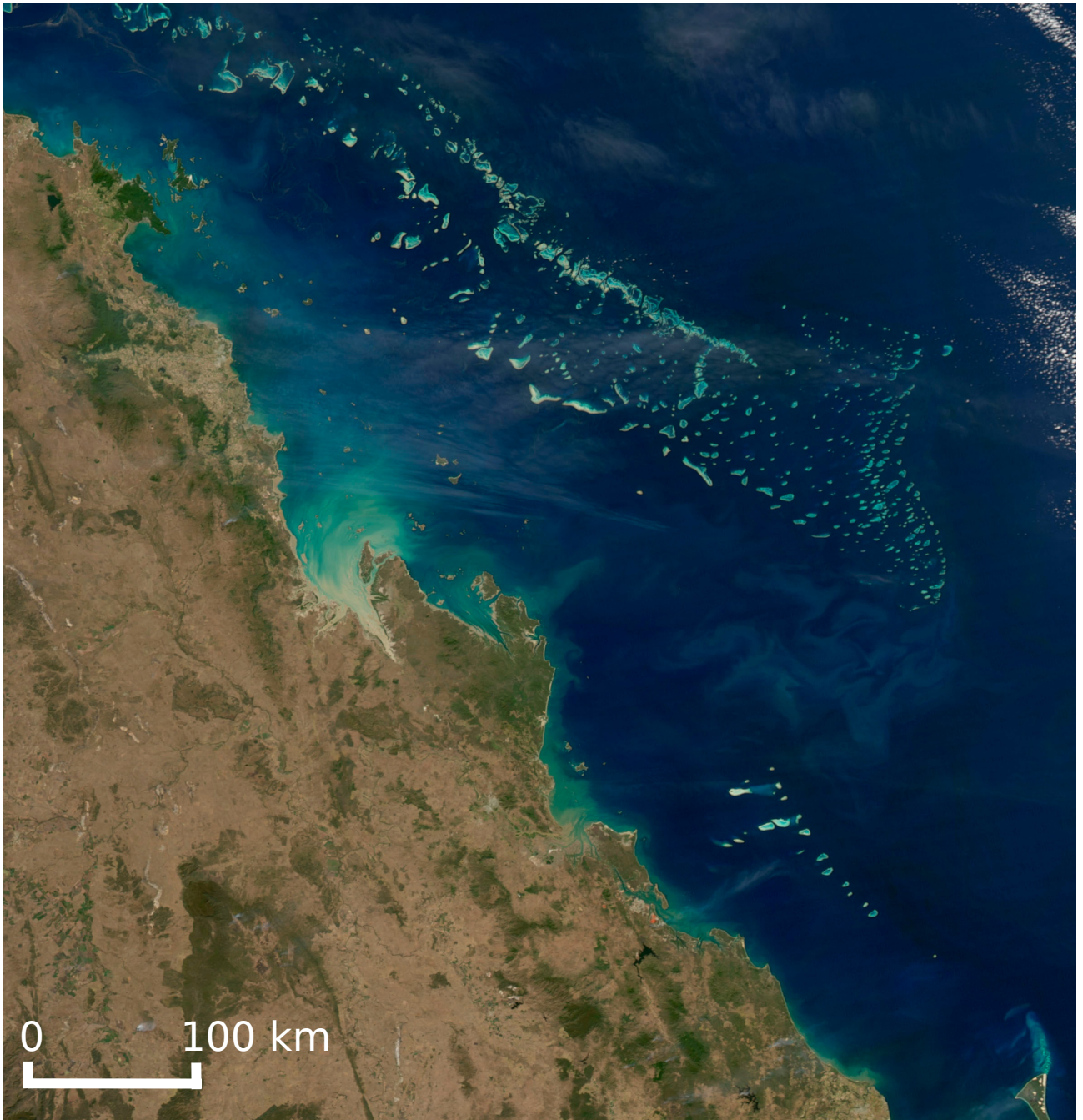

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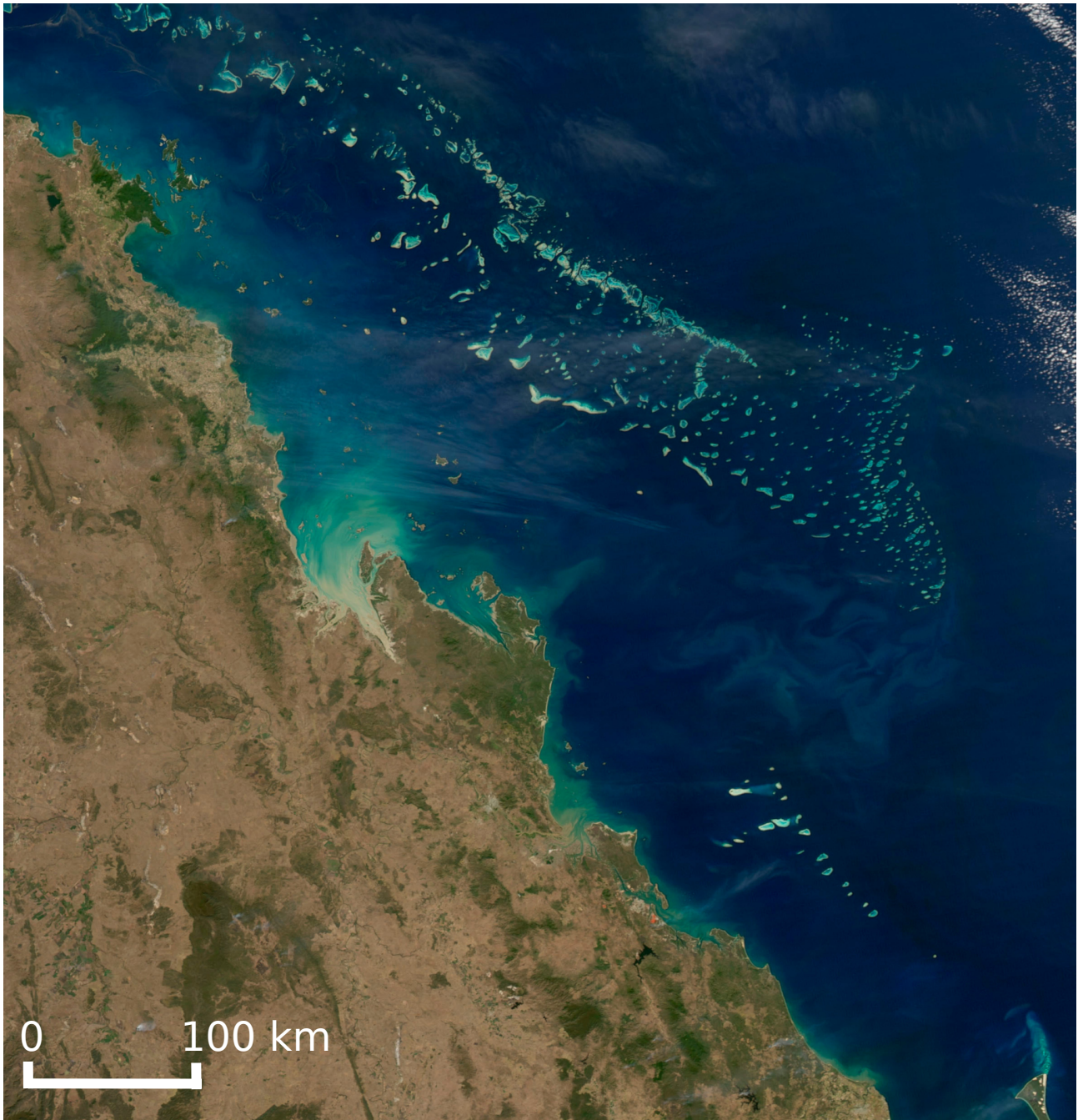

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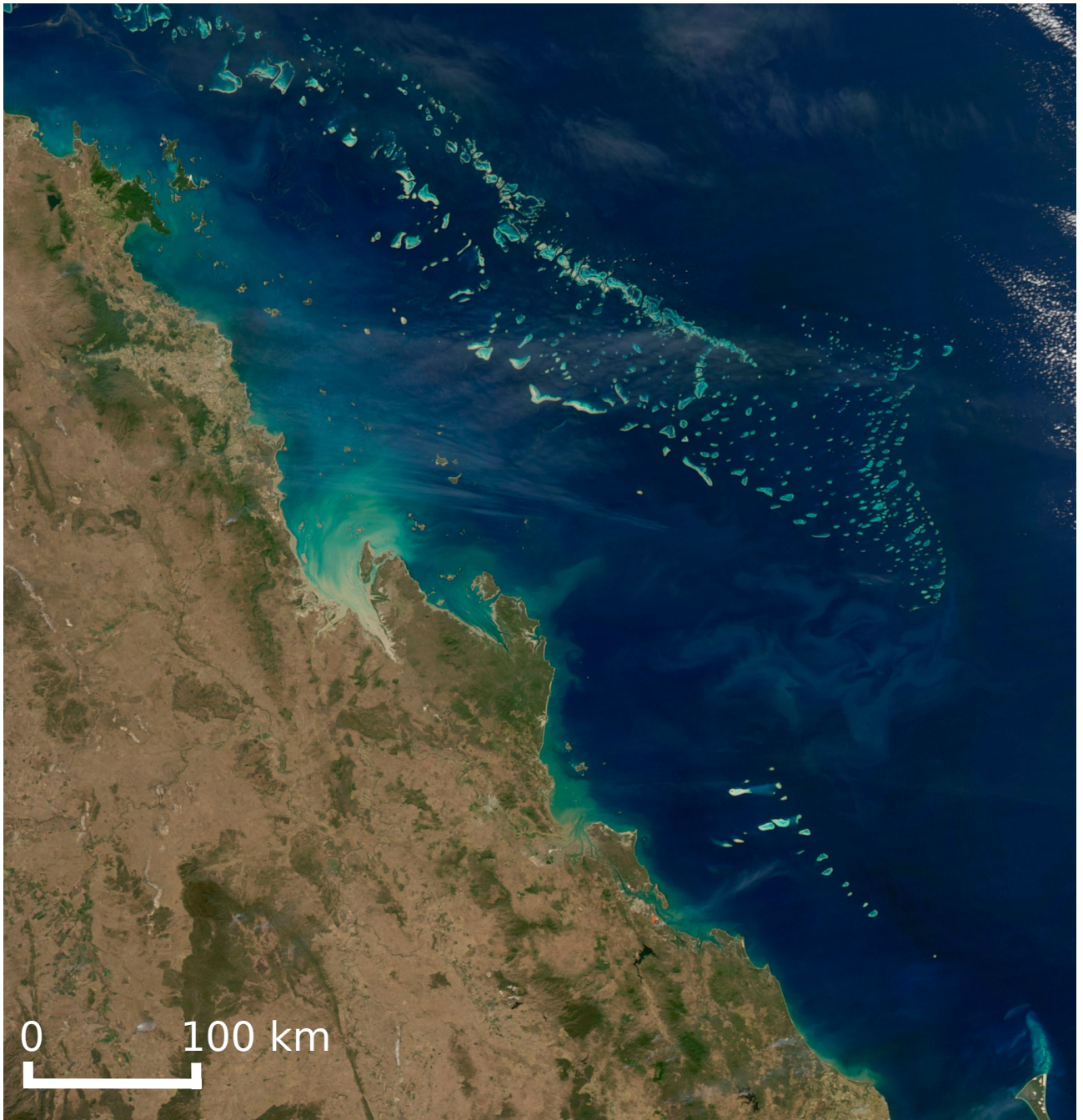

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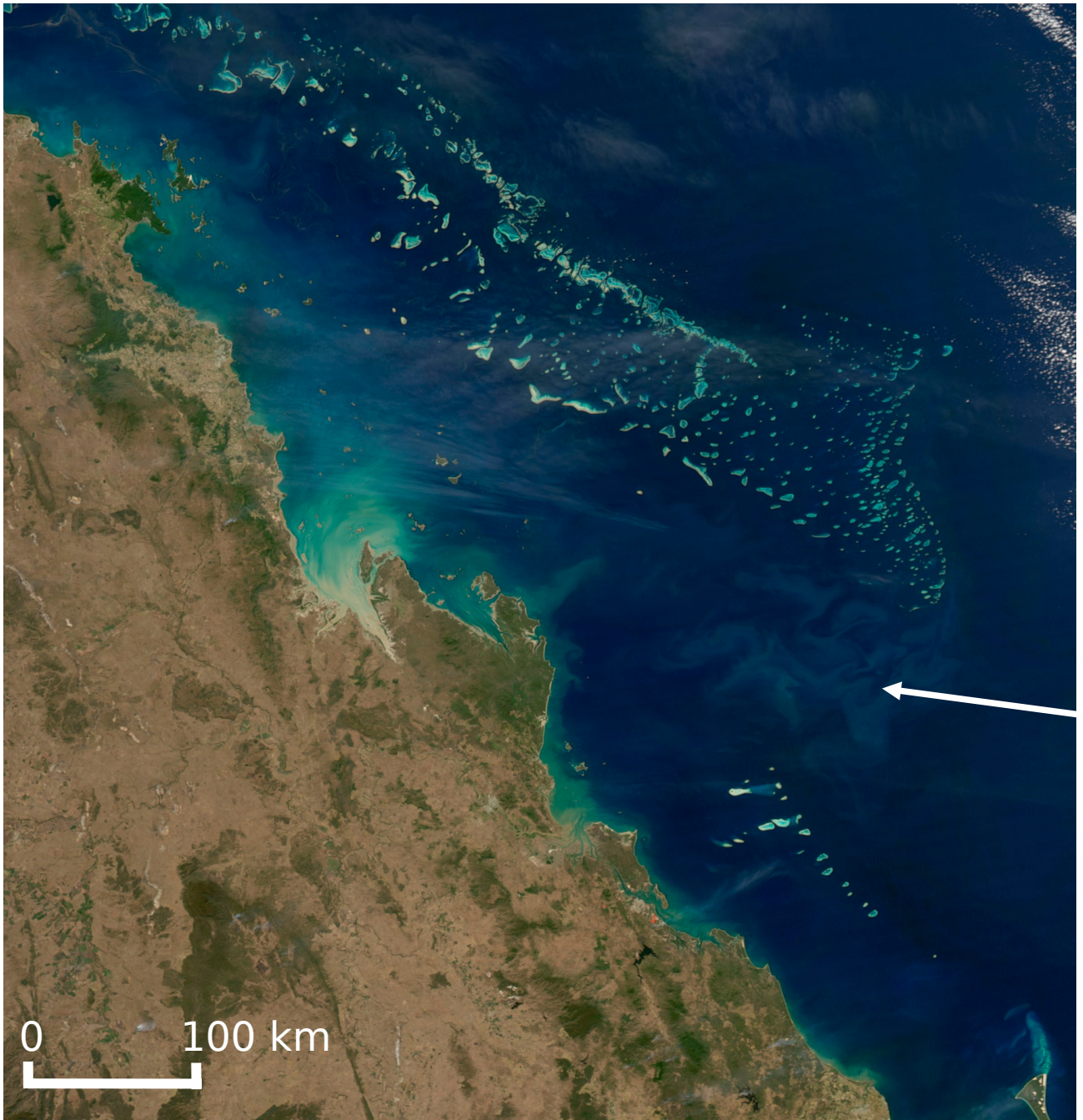

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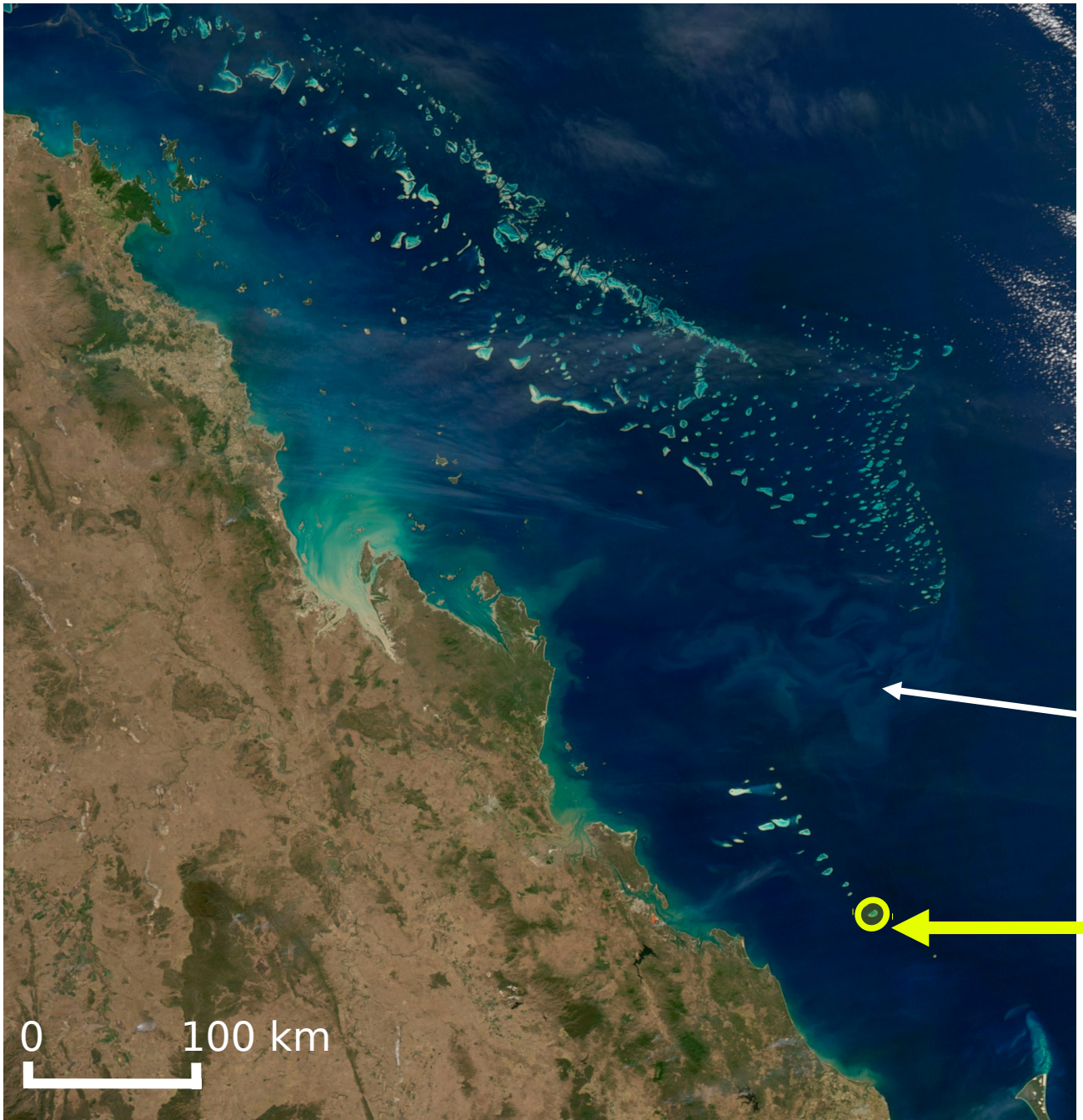

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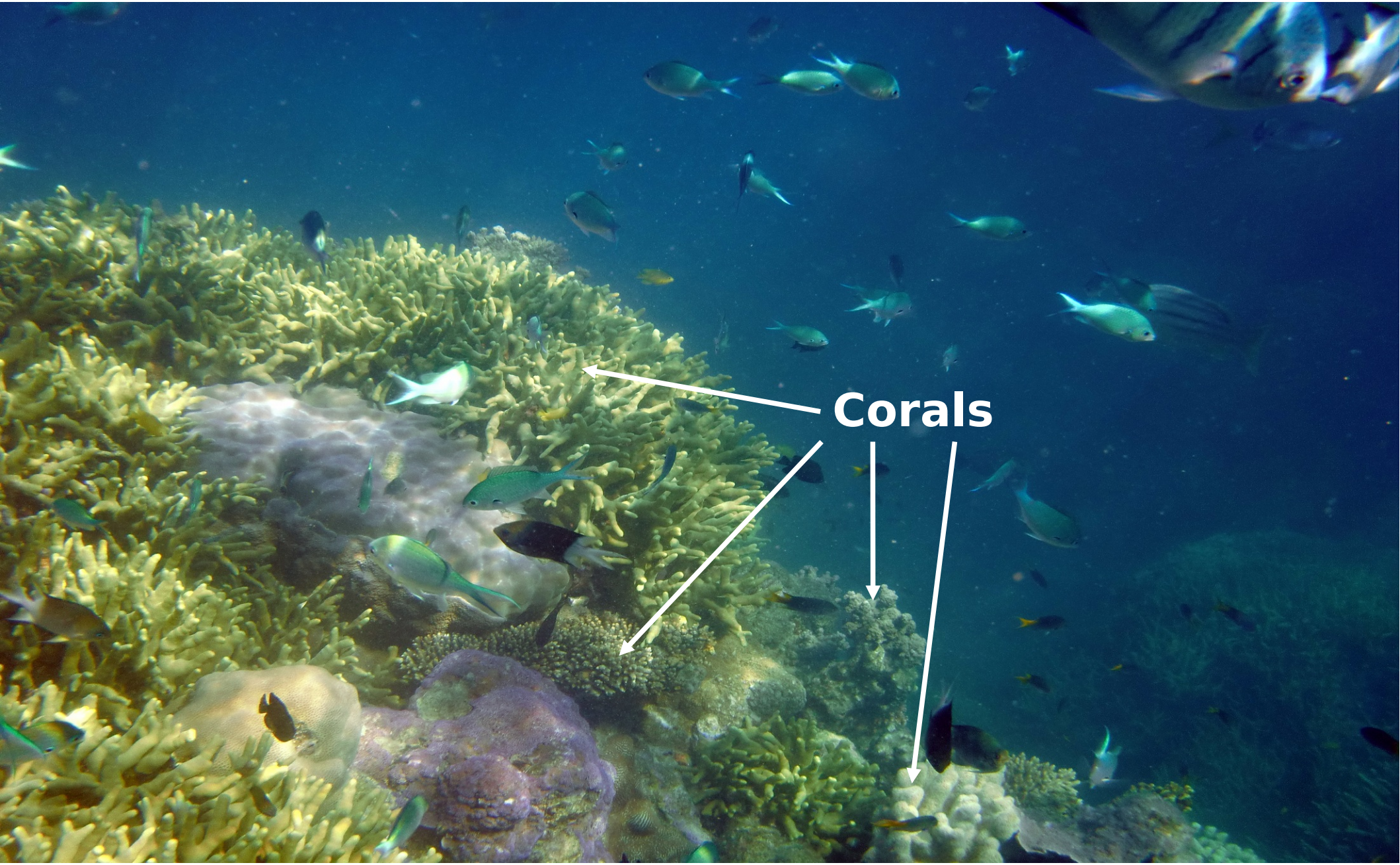

Corals can travel from reef to reef
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Acropora millepora spawning larvae

Image credit: National Geographic

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– But populations **can** migrate between reefs. How?

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Aim: Model this process numerically

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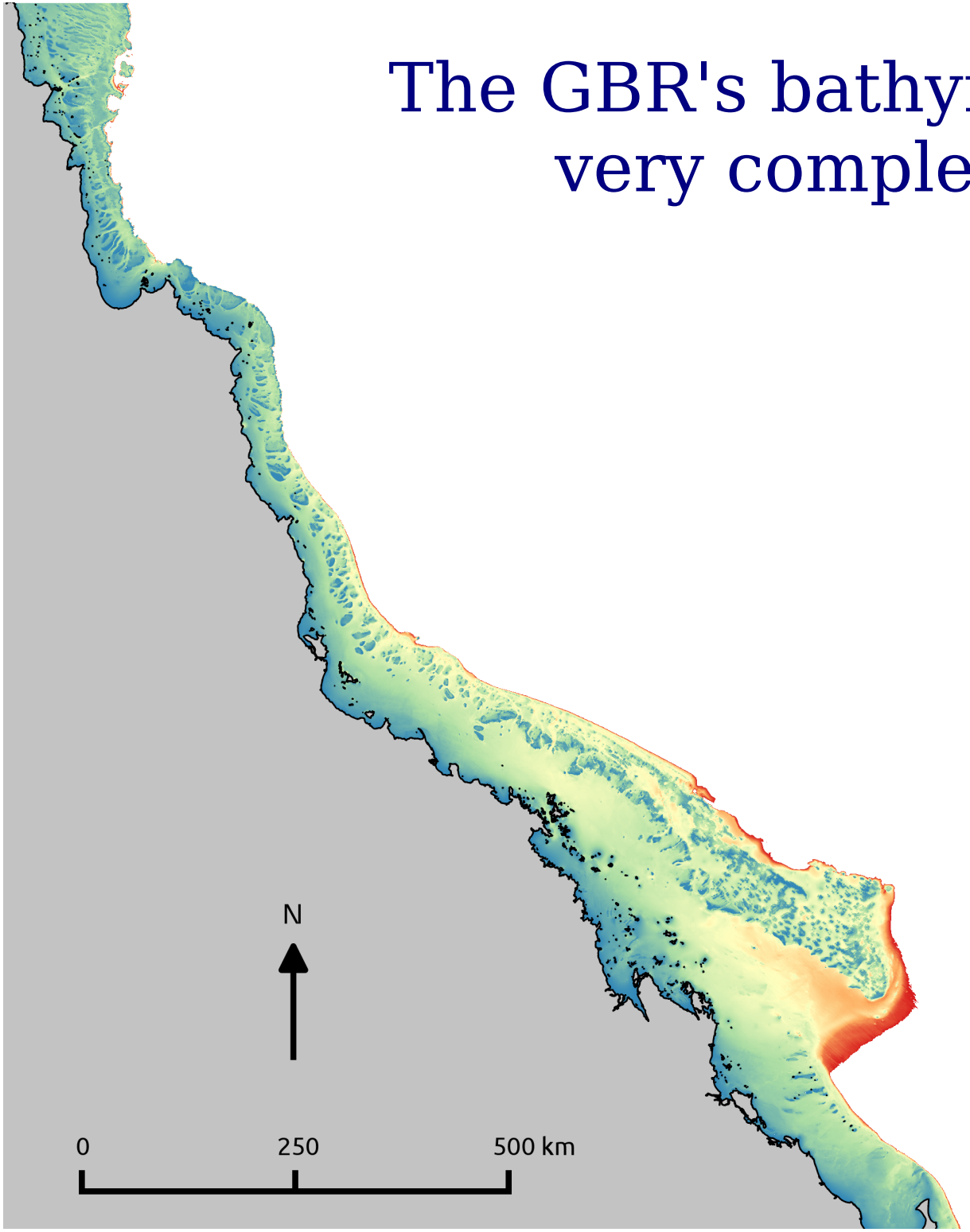

Water depth: 0 (blue) to 150m (red)

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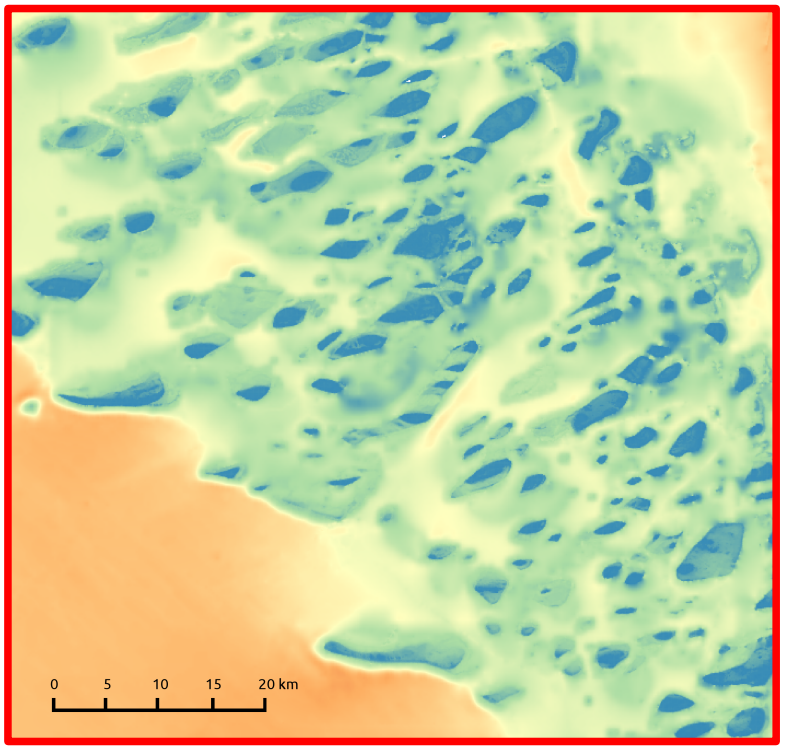
Many reefs/reef passages at scale of ~200-1000m



N

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250
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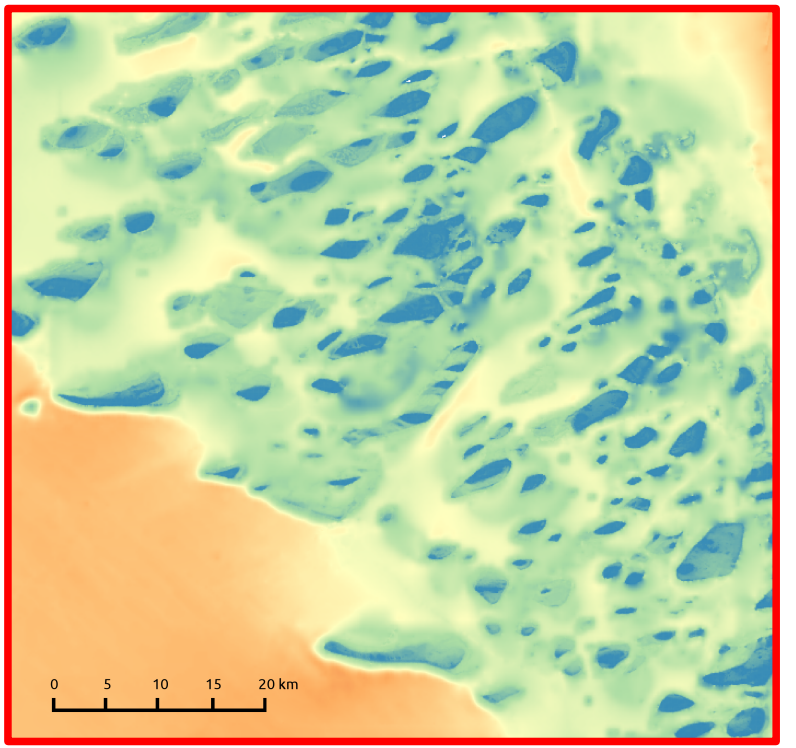

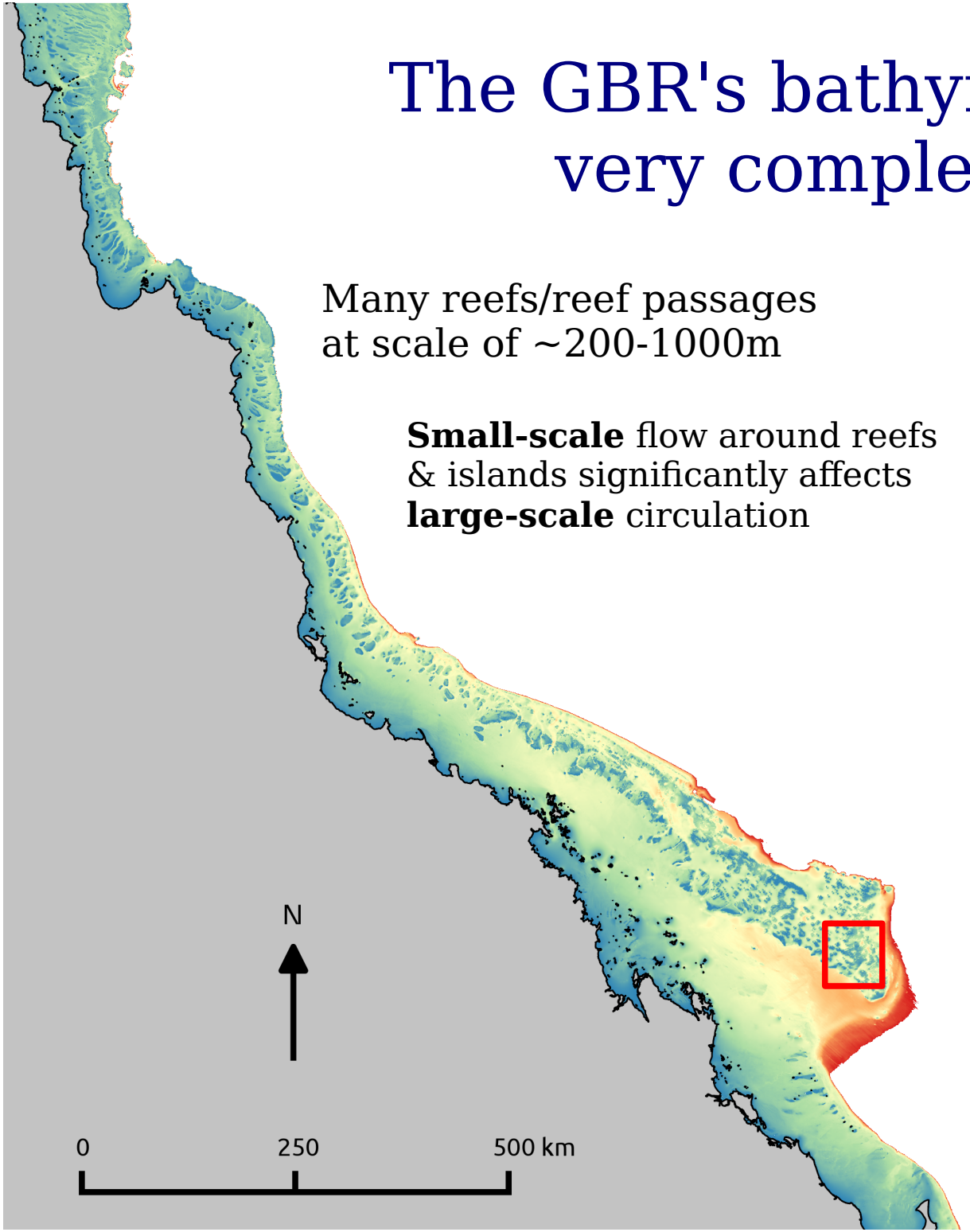

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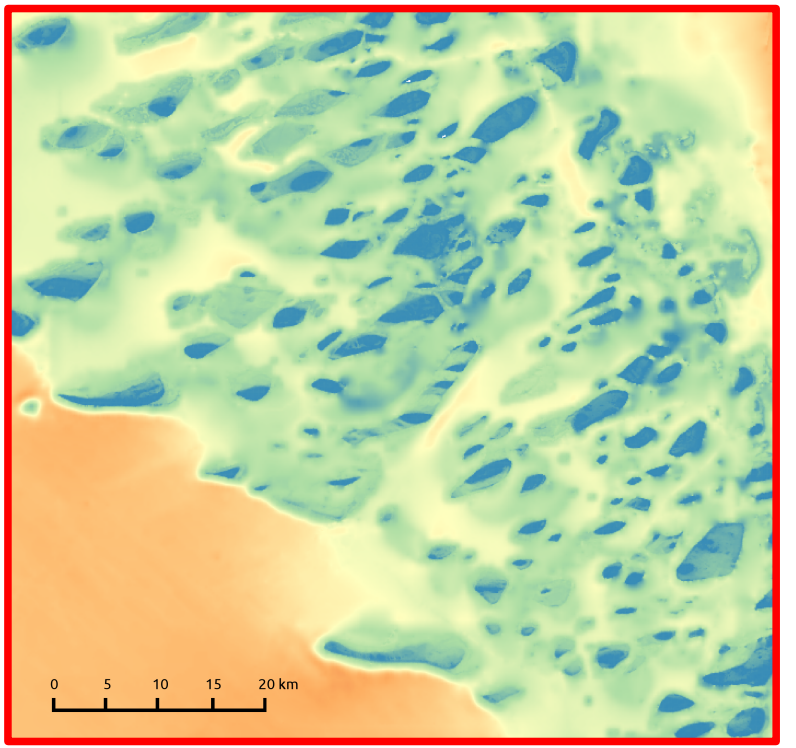

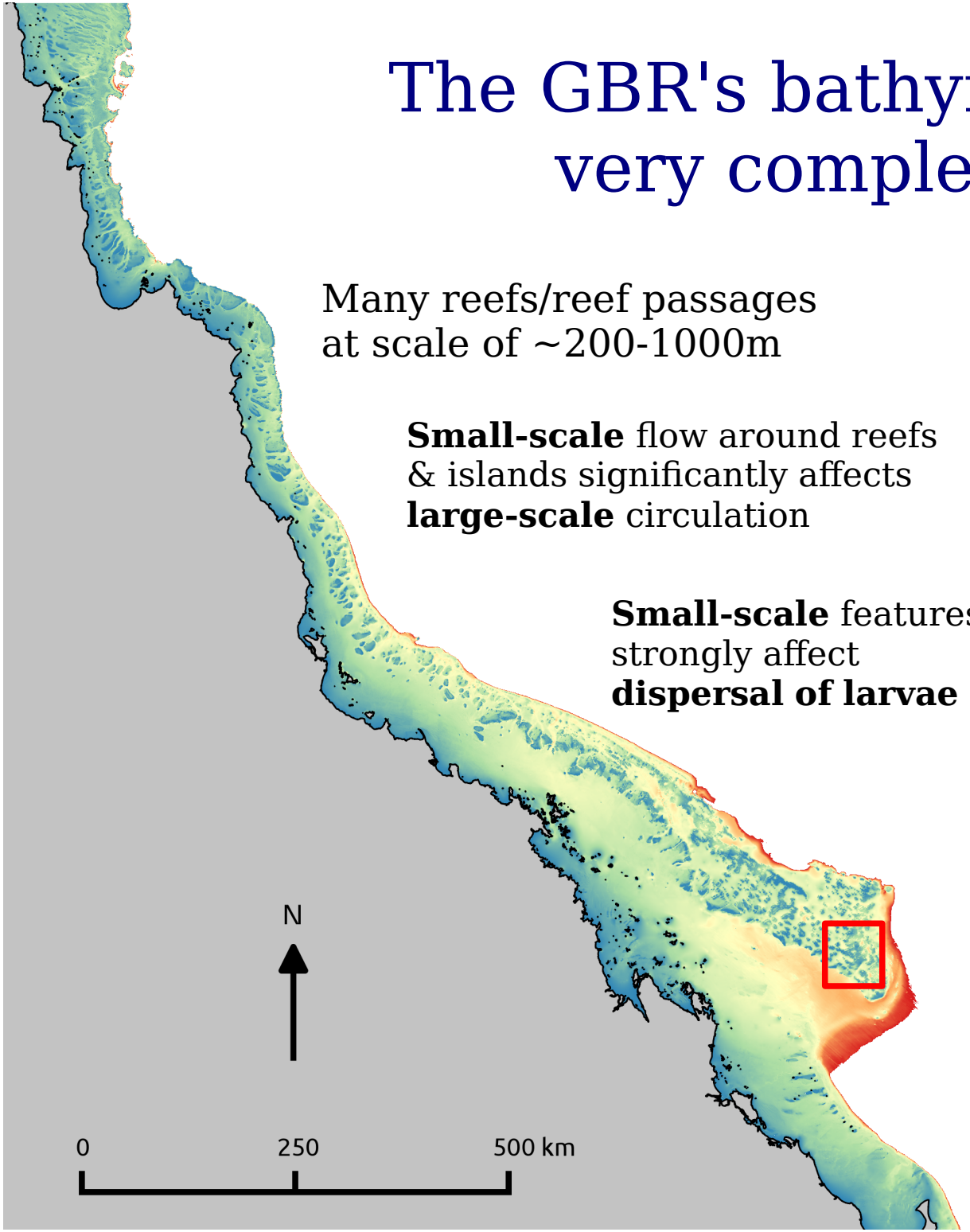

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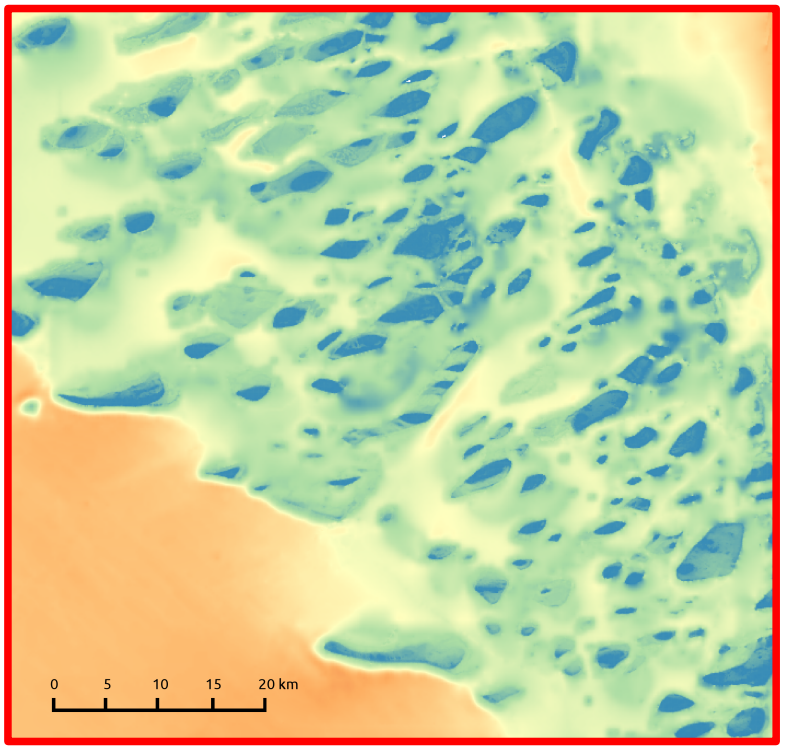

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We need to resolve flow at the reef scale

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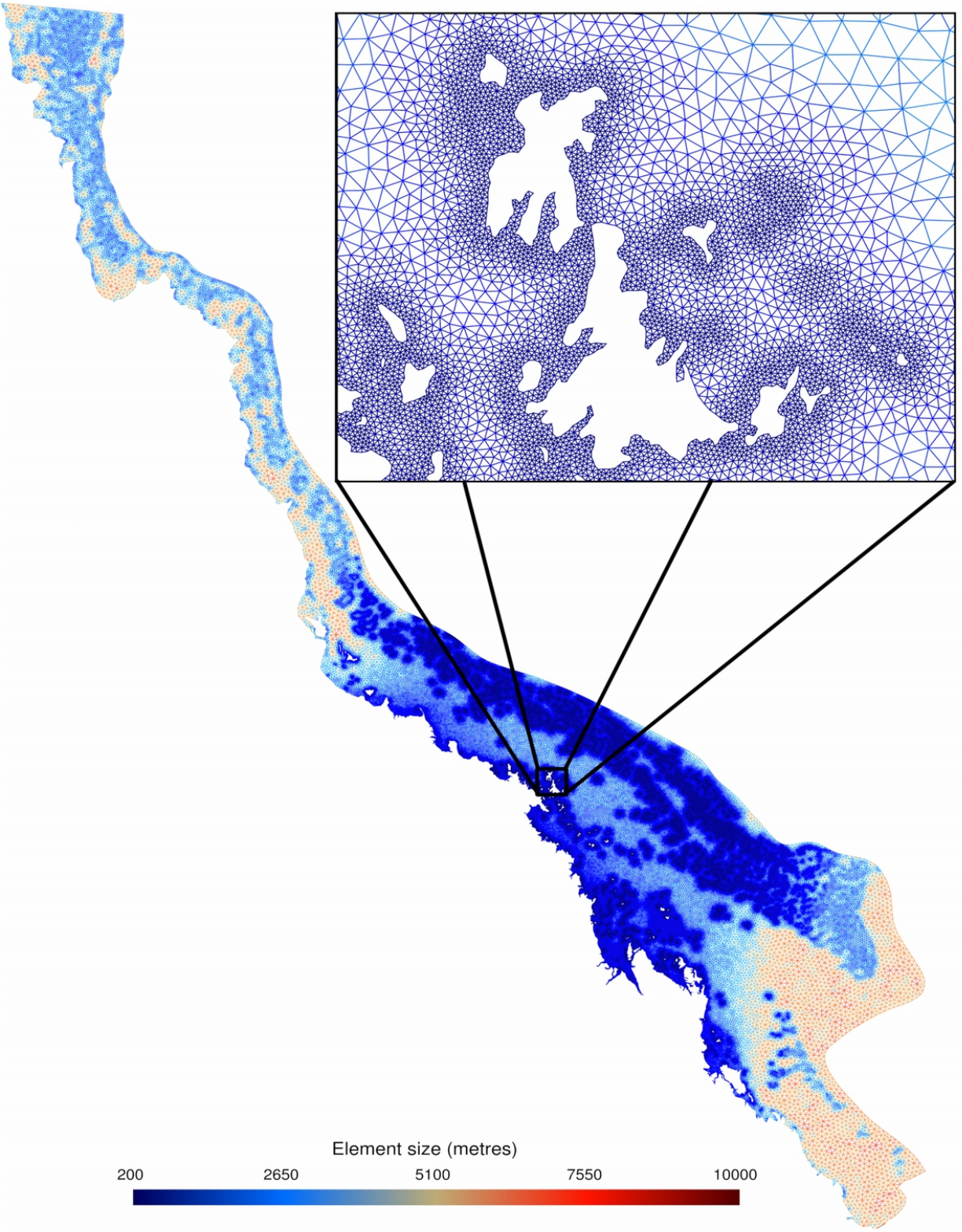

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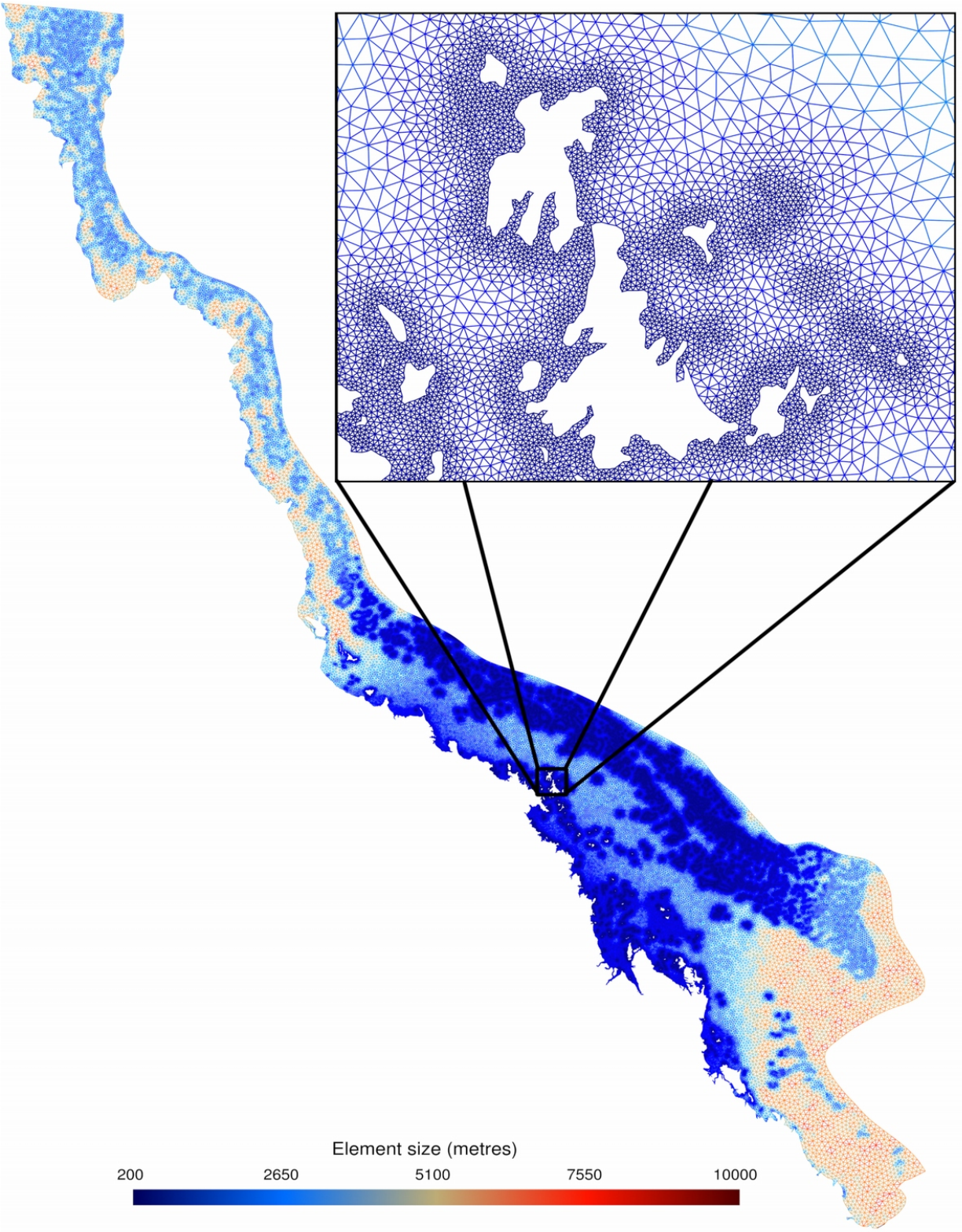
→ Shallow water equations

→ **Unstructured mesh**



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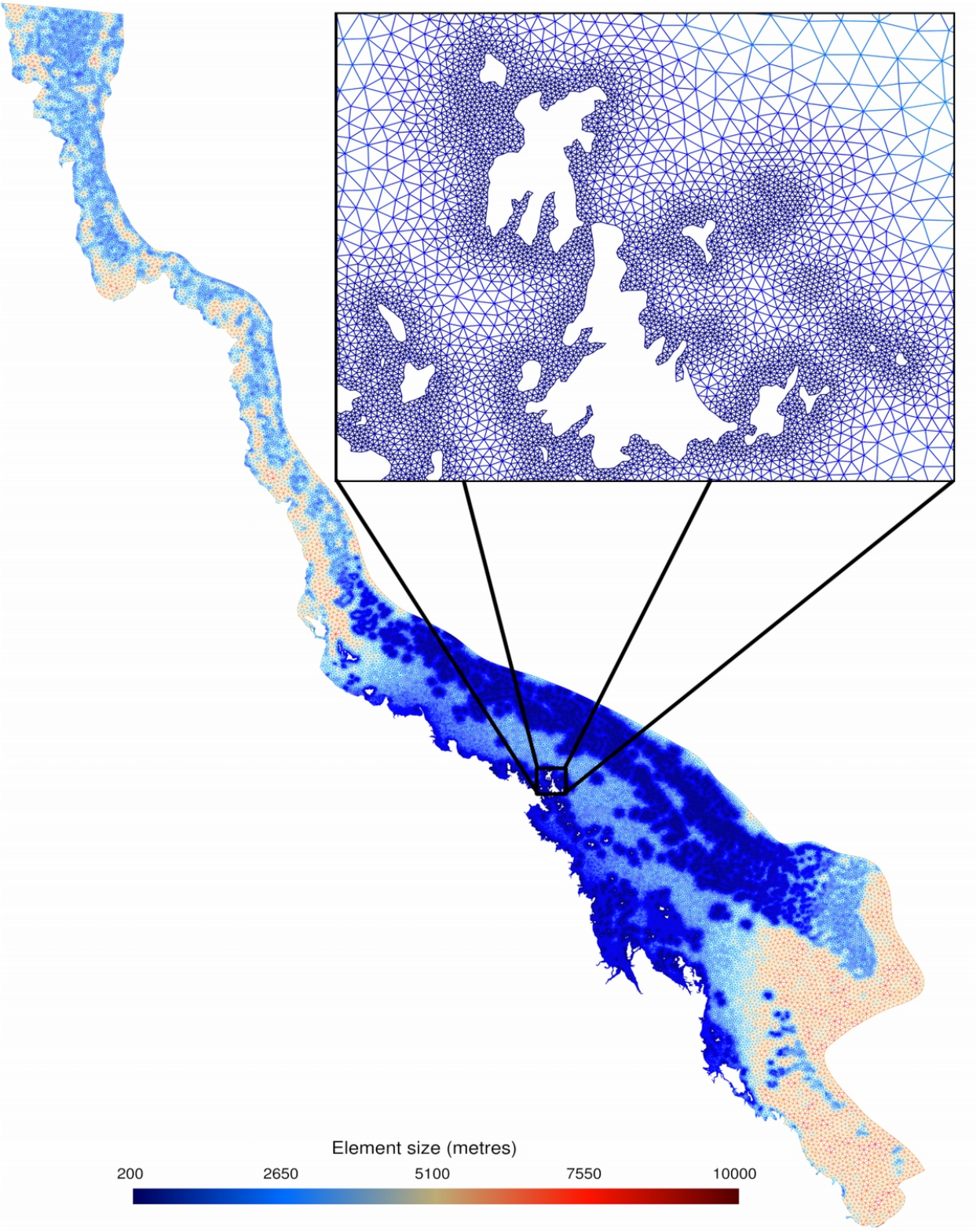

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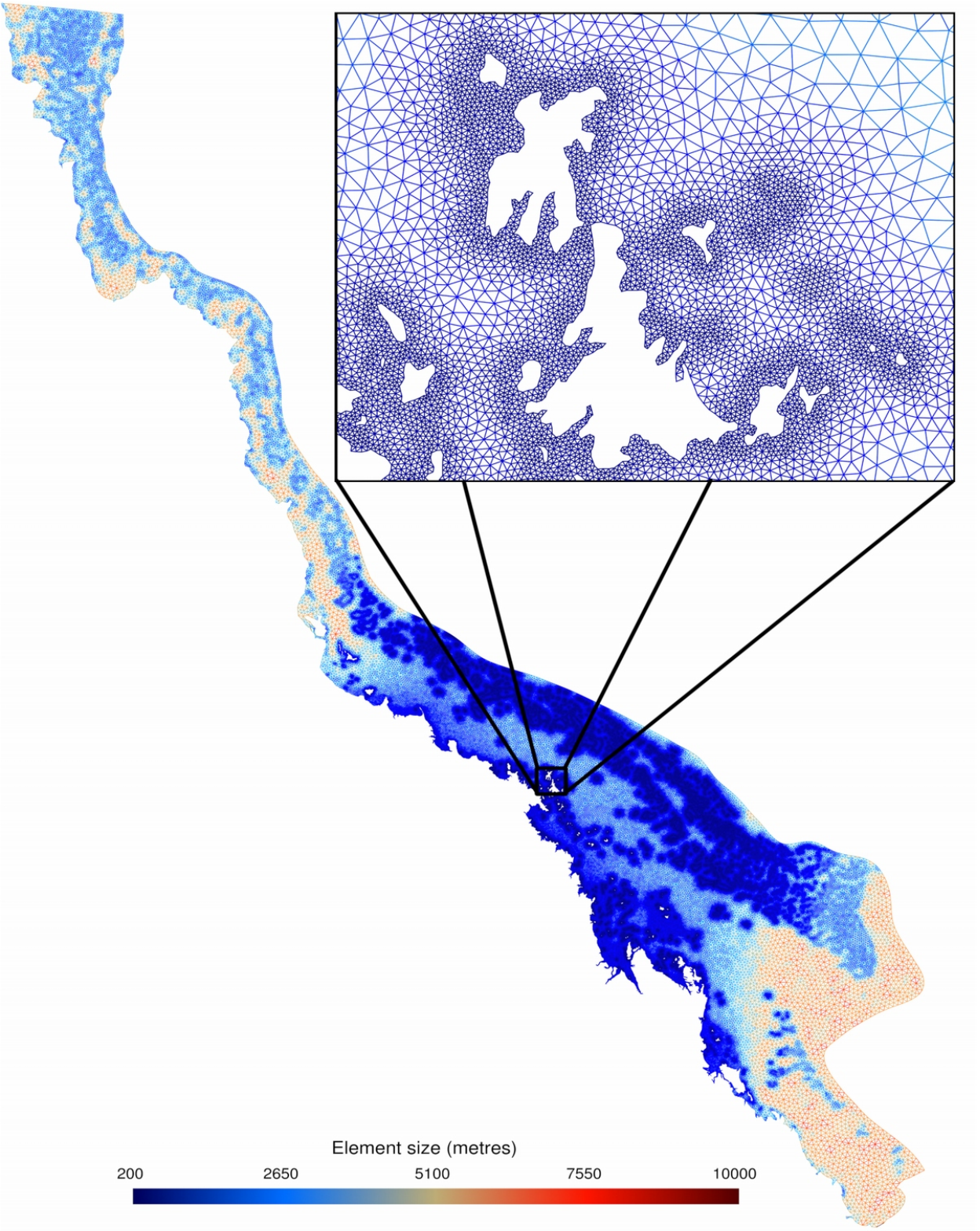

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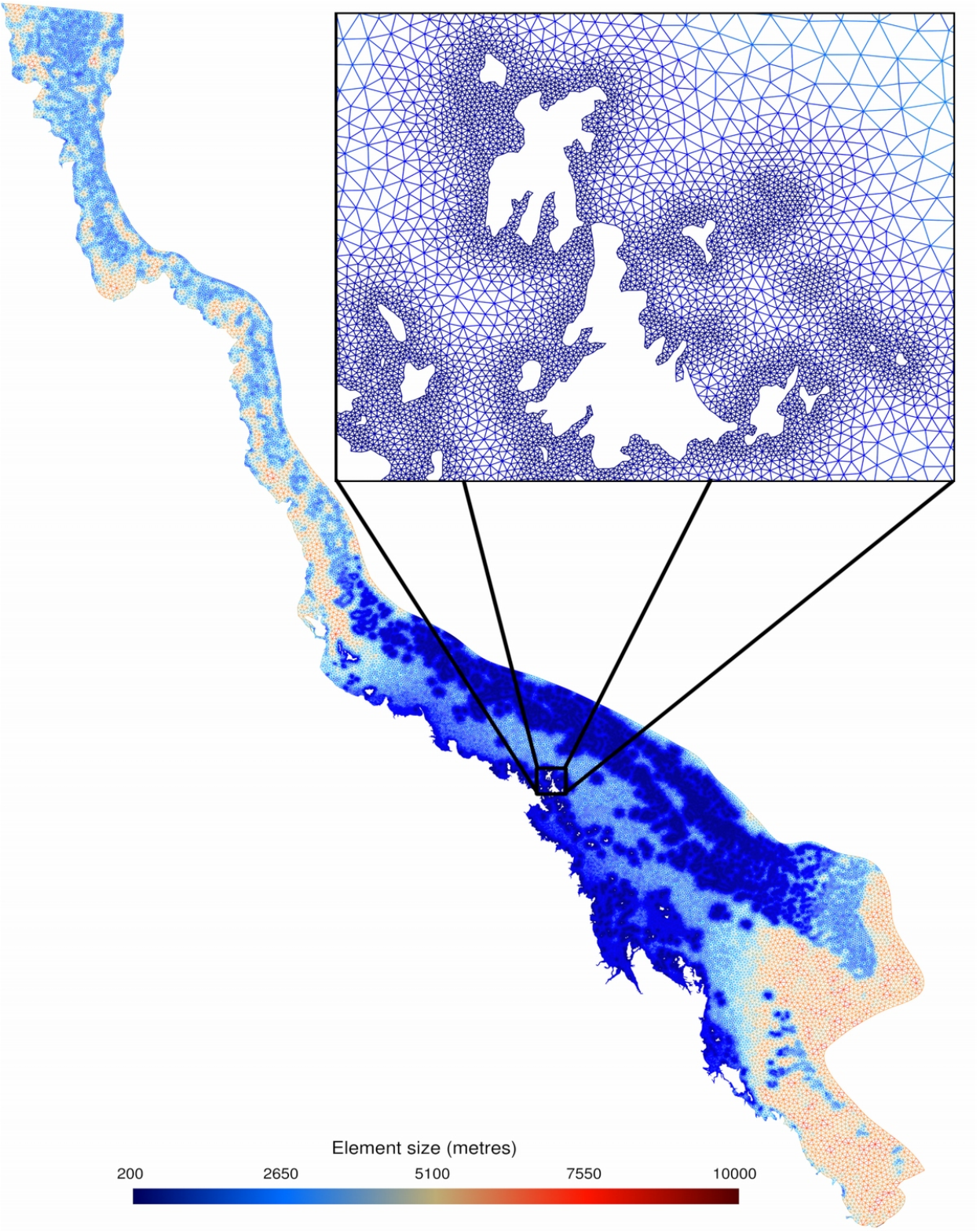
→ Sample mesh for central GBR simulations (left): 650,000 elements



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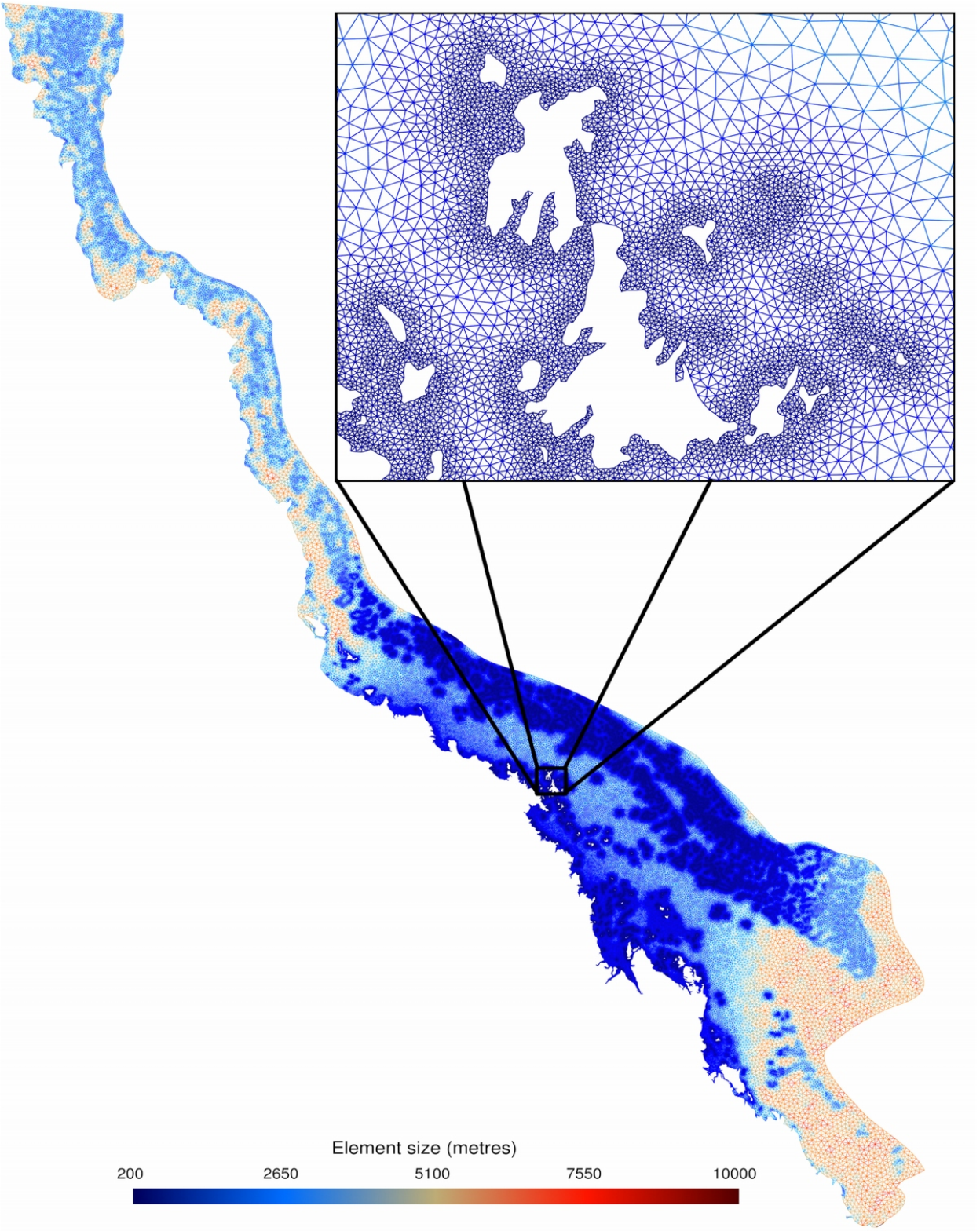

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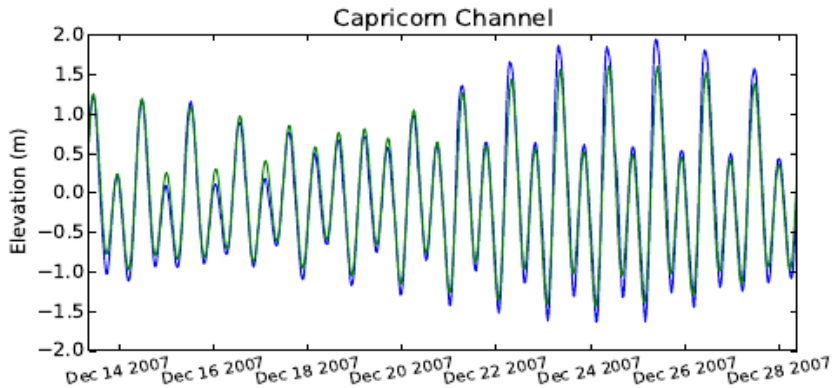
→ Model **forcings**:
Tides: Topex satellite data
Wind: Reanalysis data from NOAA/OAR/ESRL PSD
Mean residual current: data from satellite altimetry

Validation of hydrodynamics

Compared model predictions to observed data at various mooring sites in GBR:

Elevation:

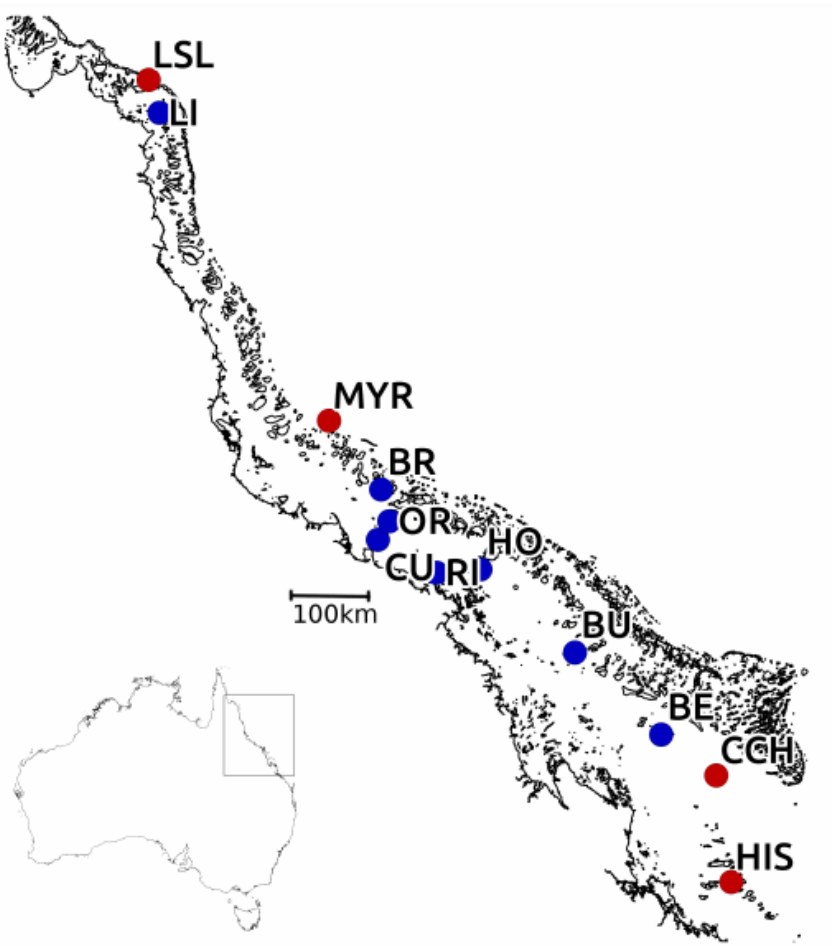
Data from the GBR Ocean Observing System (GBROOS) run by the Australian Institute for Marine Science (AIMS).



Blue: observed, Green: SLIM prediction

Currents:

Compared mean currents and variance with GBROOS mooring data.



Fate of coral larvae modelled using an **Individual Based Model (IBM):**

- Transport of larvae modelled using a **Lagrangian** approach (advective component from SLIM + random component representing diffusion)

2D Random walk formulation of advection-diffusion equation:

$$\mathbf{x}_{n+1} = \mathbf{x}_n + \mathbf{v}_n \Delta t + \frac{\mathbf{R}_n}{\sqrt{r}} \sqrt{2K\Delta t}$$

$$\mathbf{v}_n = \left(\mathbf{u} + \frac{K}{H} \nabla H + \nabla K \right) \Big|_{\mathbf{x}_n}$$

$\boldsymbol{x_n}$: particle position at time index n
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- Larvae undergo simple **biological processes:**

  → **mortality**

  → after 3-4 days larvae acquire **competency to settle**

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Fate of coral larvae modelled using an **Individual Based Model (IBM):**

2D Random walk formulation of advection-diffusion equation:

$$\mathbf{x}_{n+1} = \mathbf{x}_n + \mathbf{v}_n \Delta t + \frac{\mathbf{R}_n}{\sqrt{r}} \sqrt{2K\Delta t}$$

$$\mathbf{v}_n = \left(\qquad H + \right.$$

Advective component

Random (diffusive) component

$\boldsymbol{x}_n$: particle position at time index n
Δt: time step
$\boldsymbol{R}_n$: array of random numbers with variance r
K: horizontal diffusivity coefficient
$\boldsymbol{u}$: depth-averaged water velocity (provided by **SLIM**)
H: water depth

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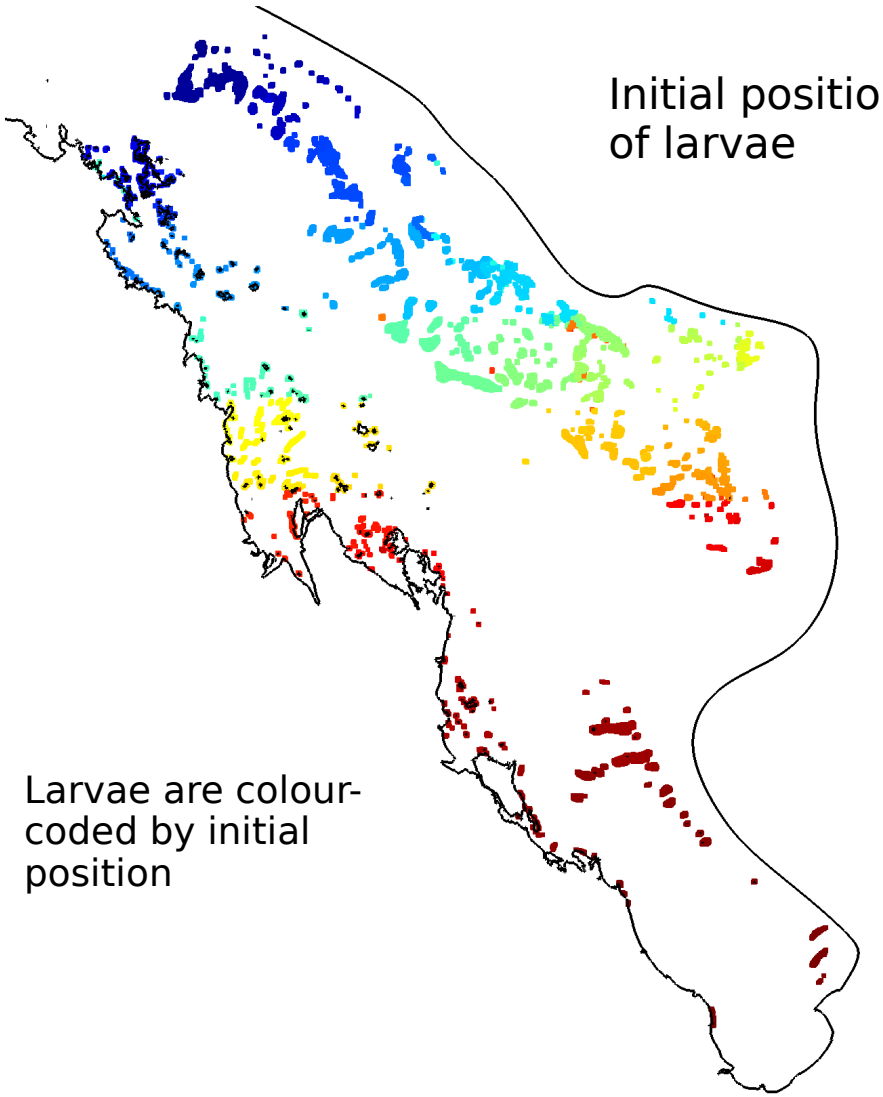

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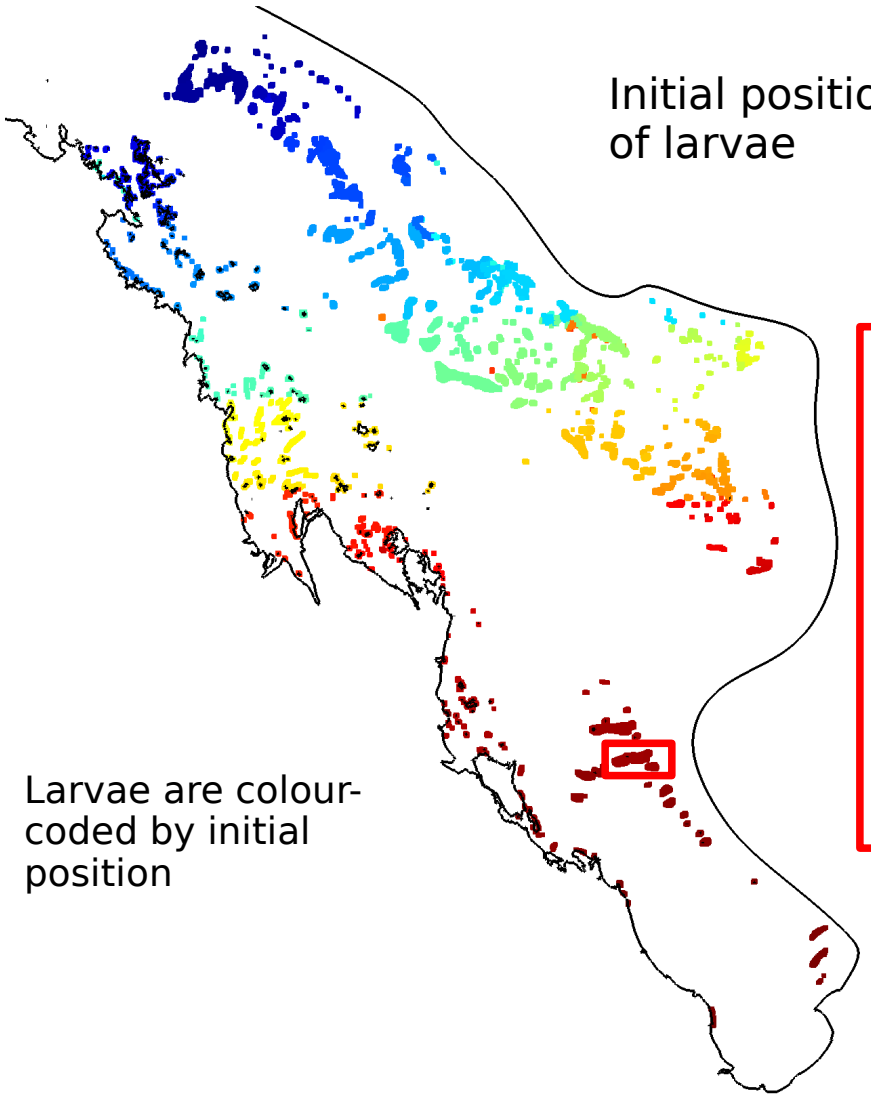

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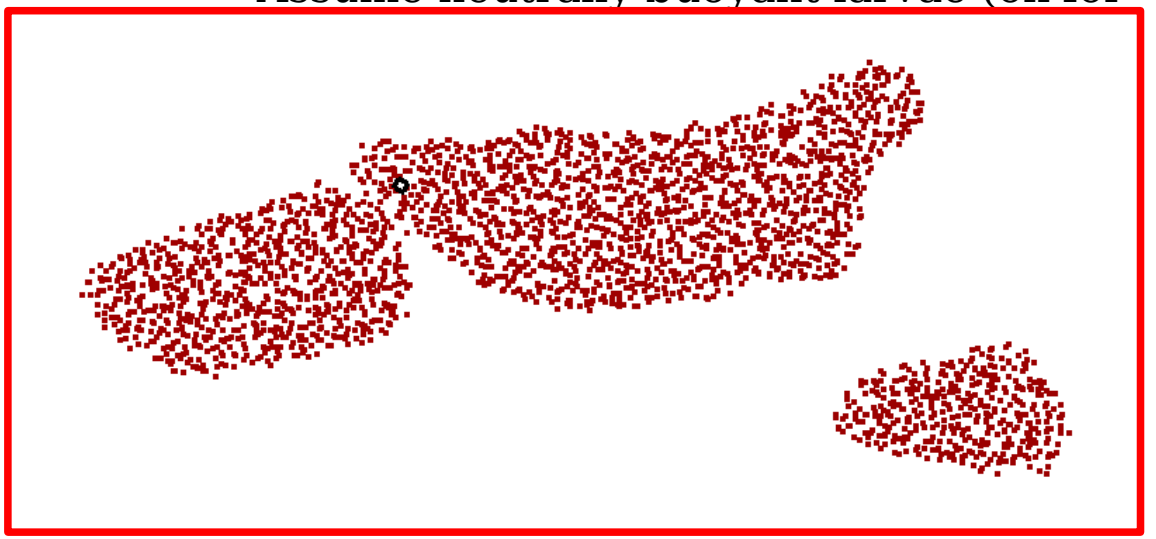

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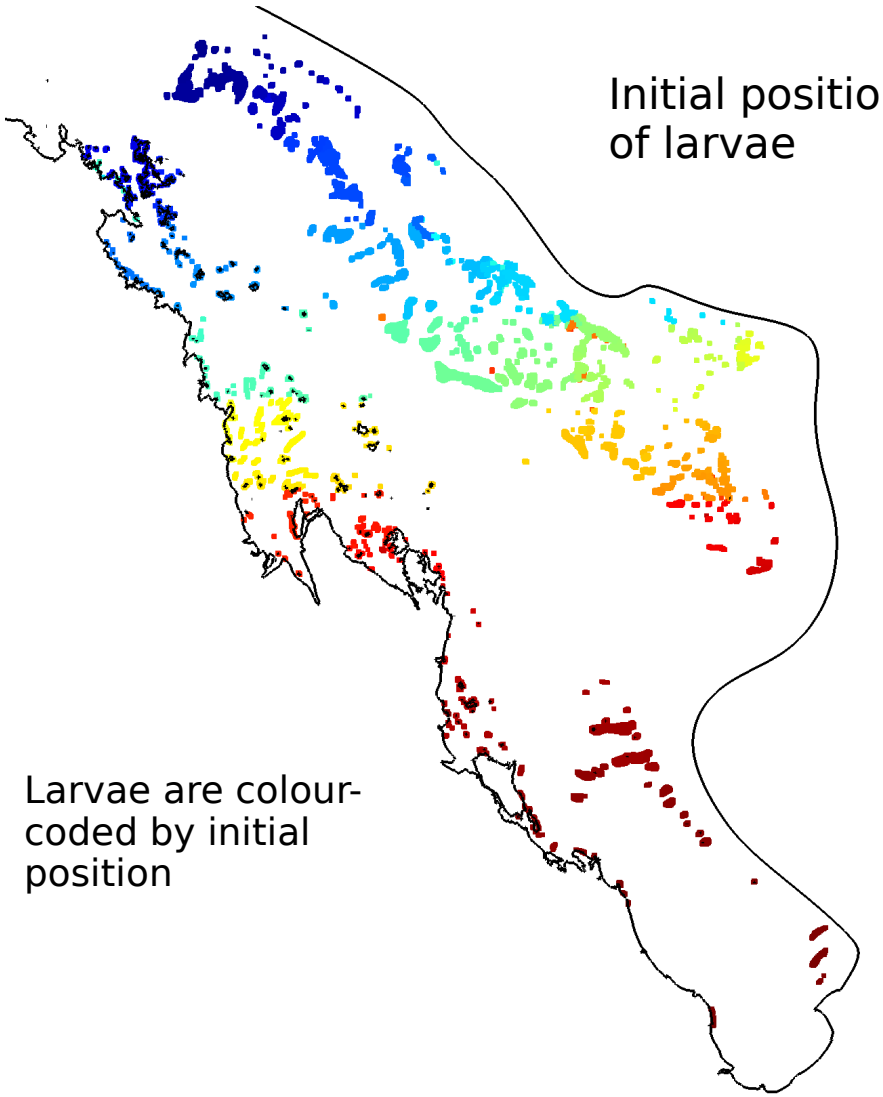

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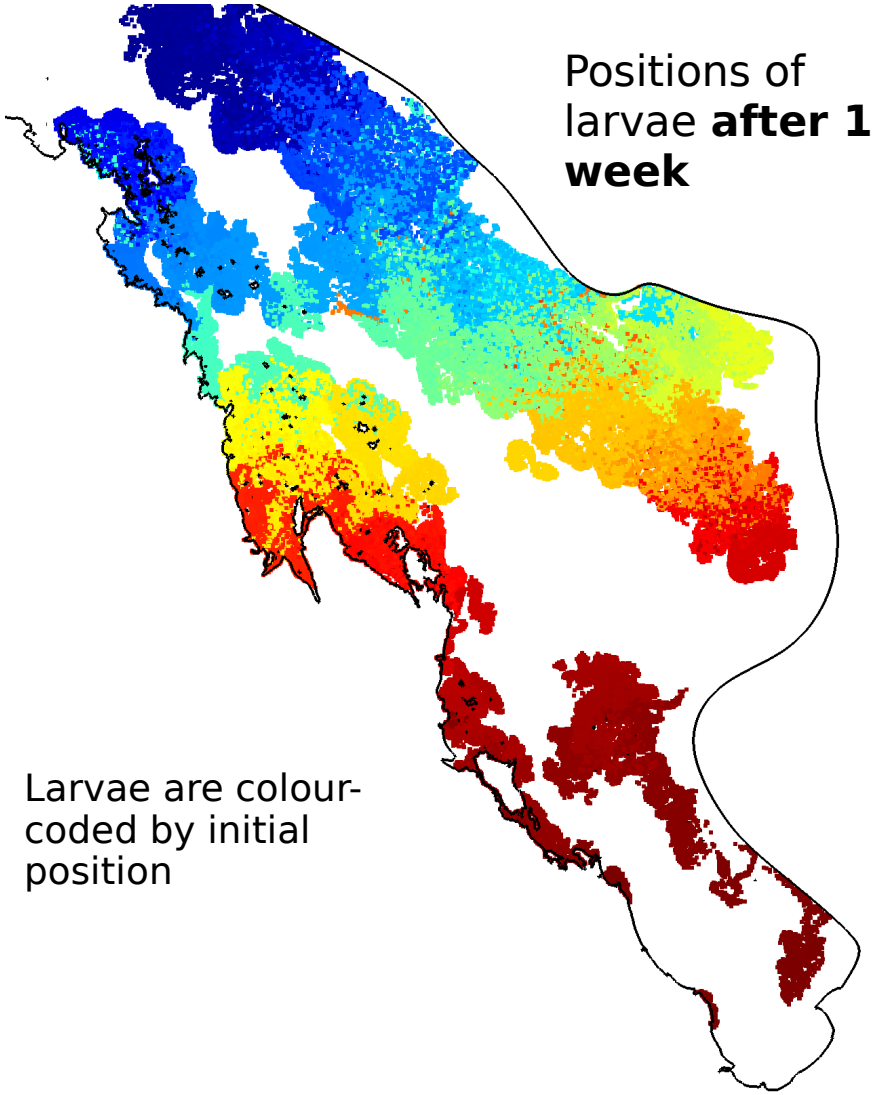

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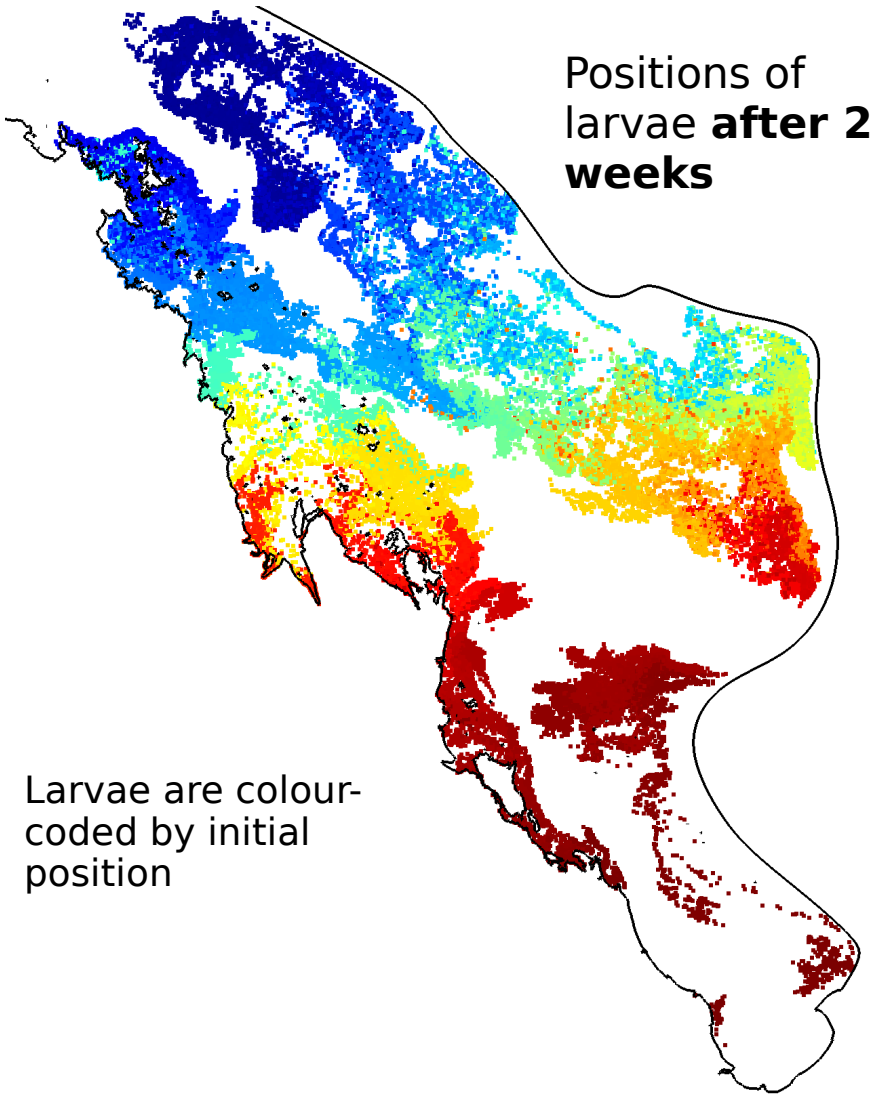

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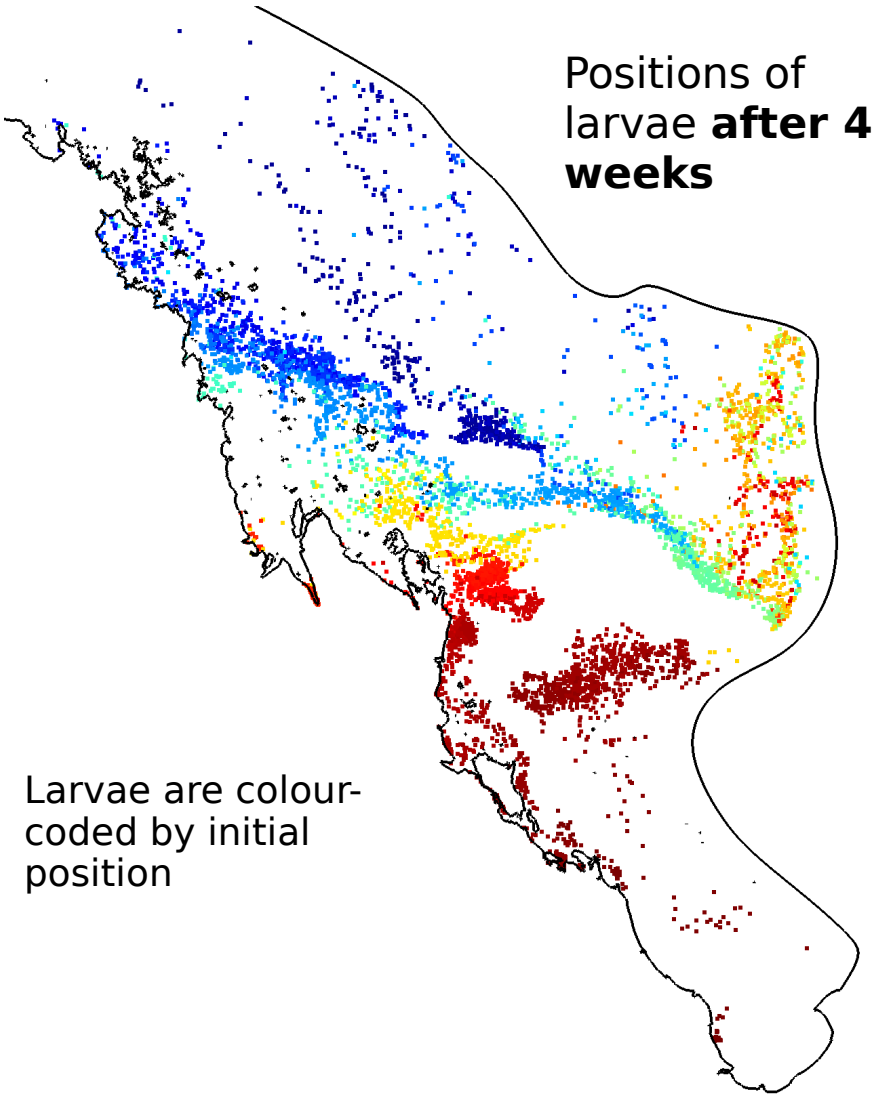

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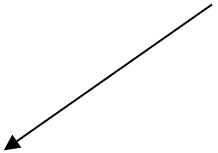

Statistical analysis

- Proportion of self-recruitment
- Average connection length

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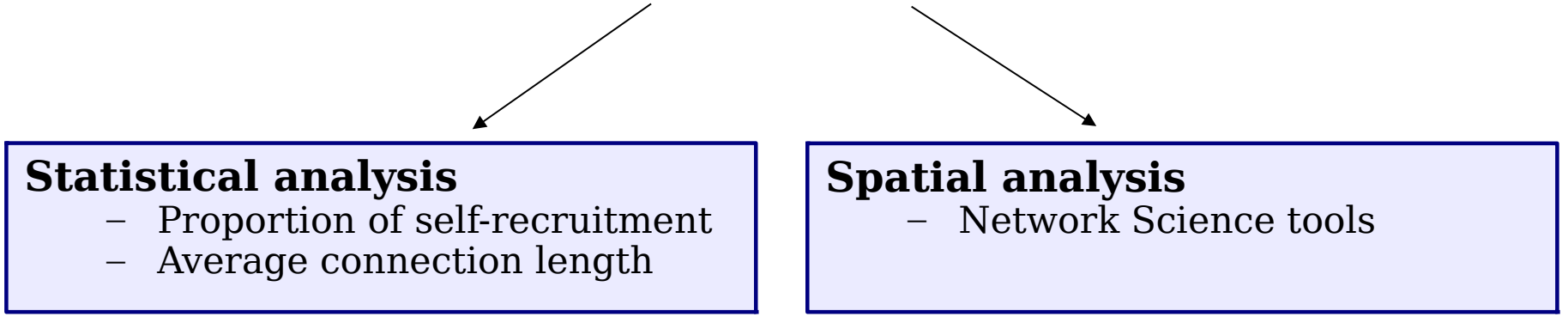
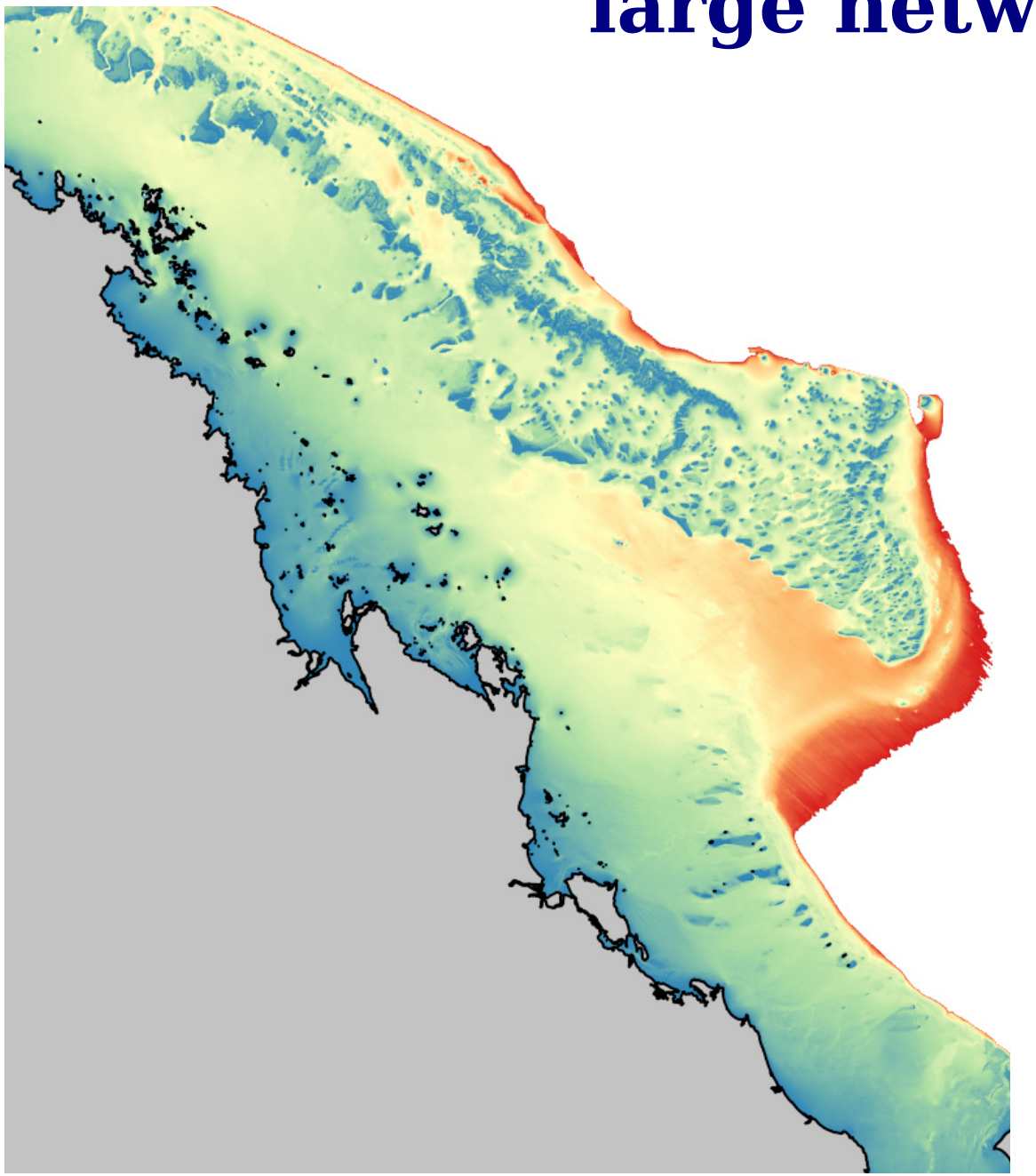


The GBR can be represented as a **large network**



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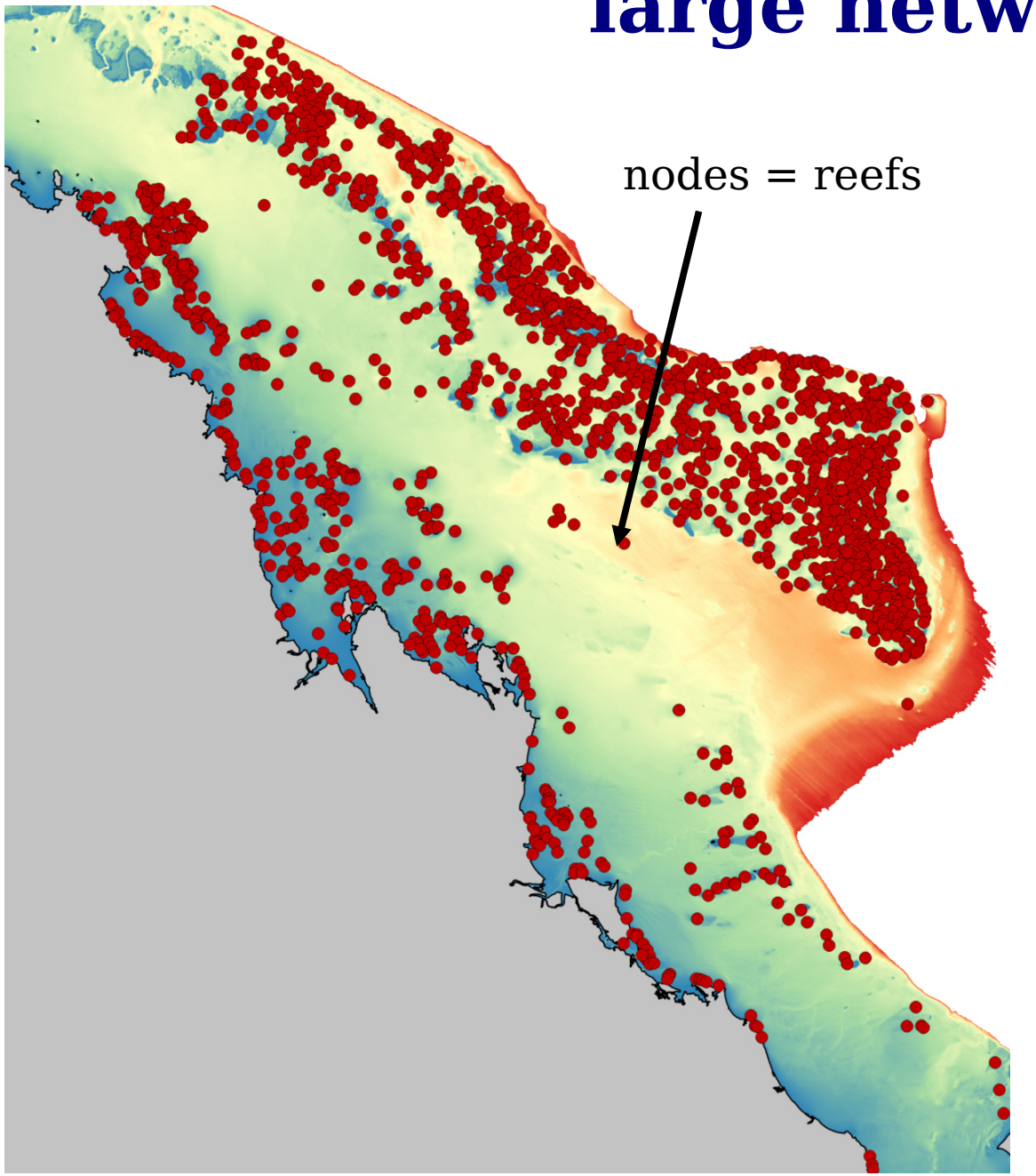

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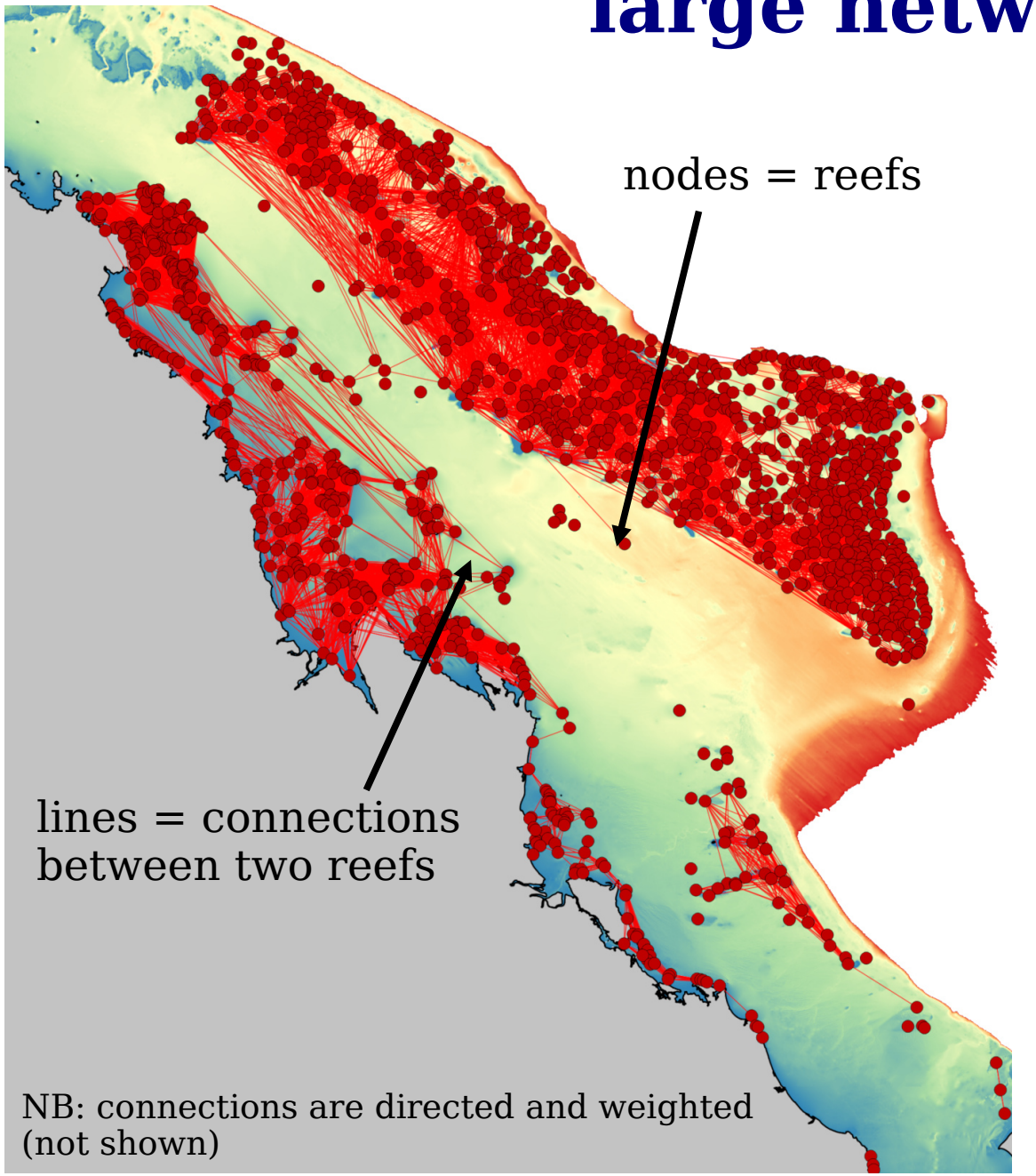

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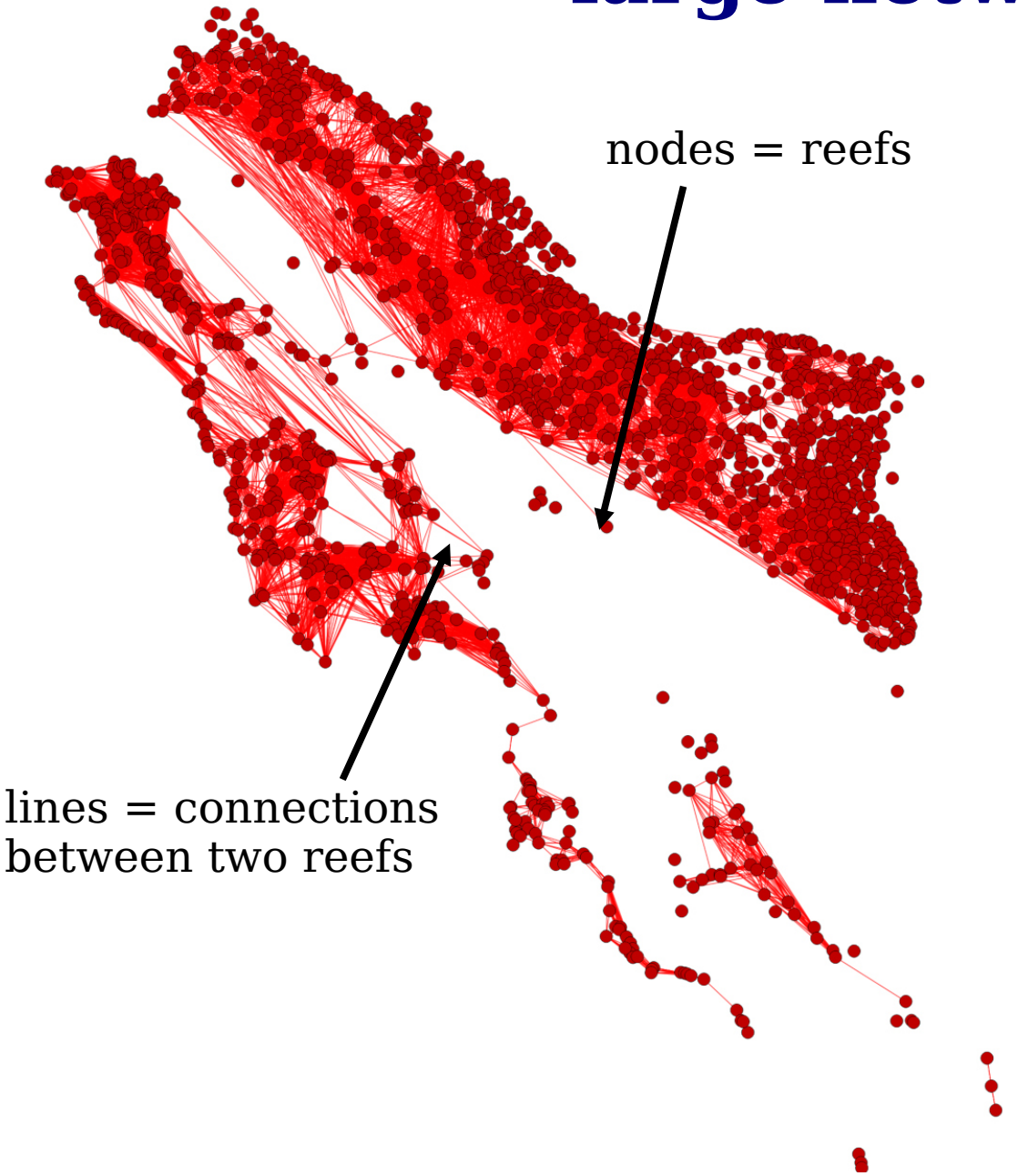

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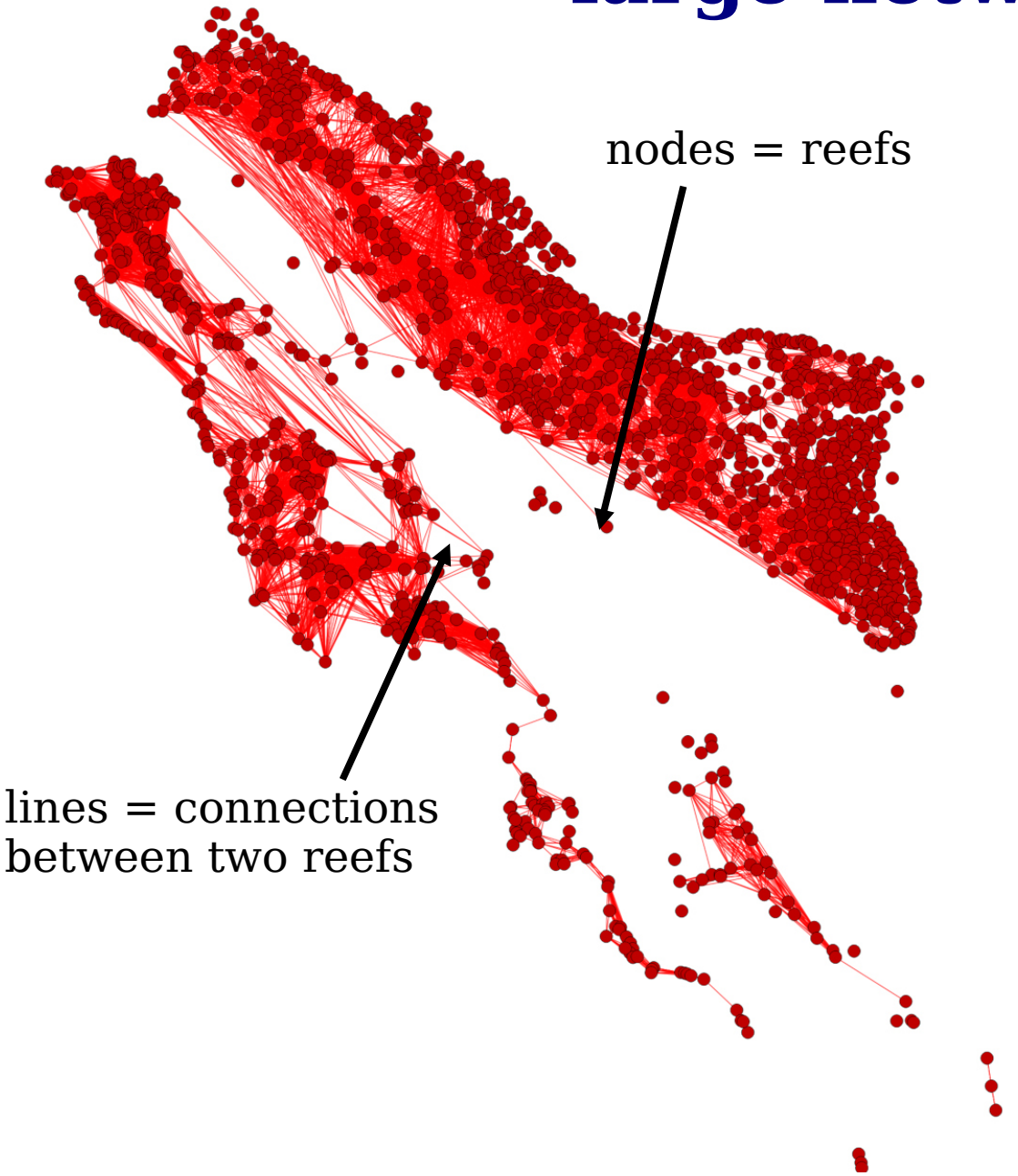

Definition:

Reef community: a cluster of reefs whose members are strongly connected with each other, and weakly connected with reefs outside their community

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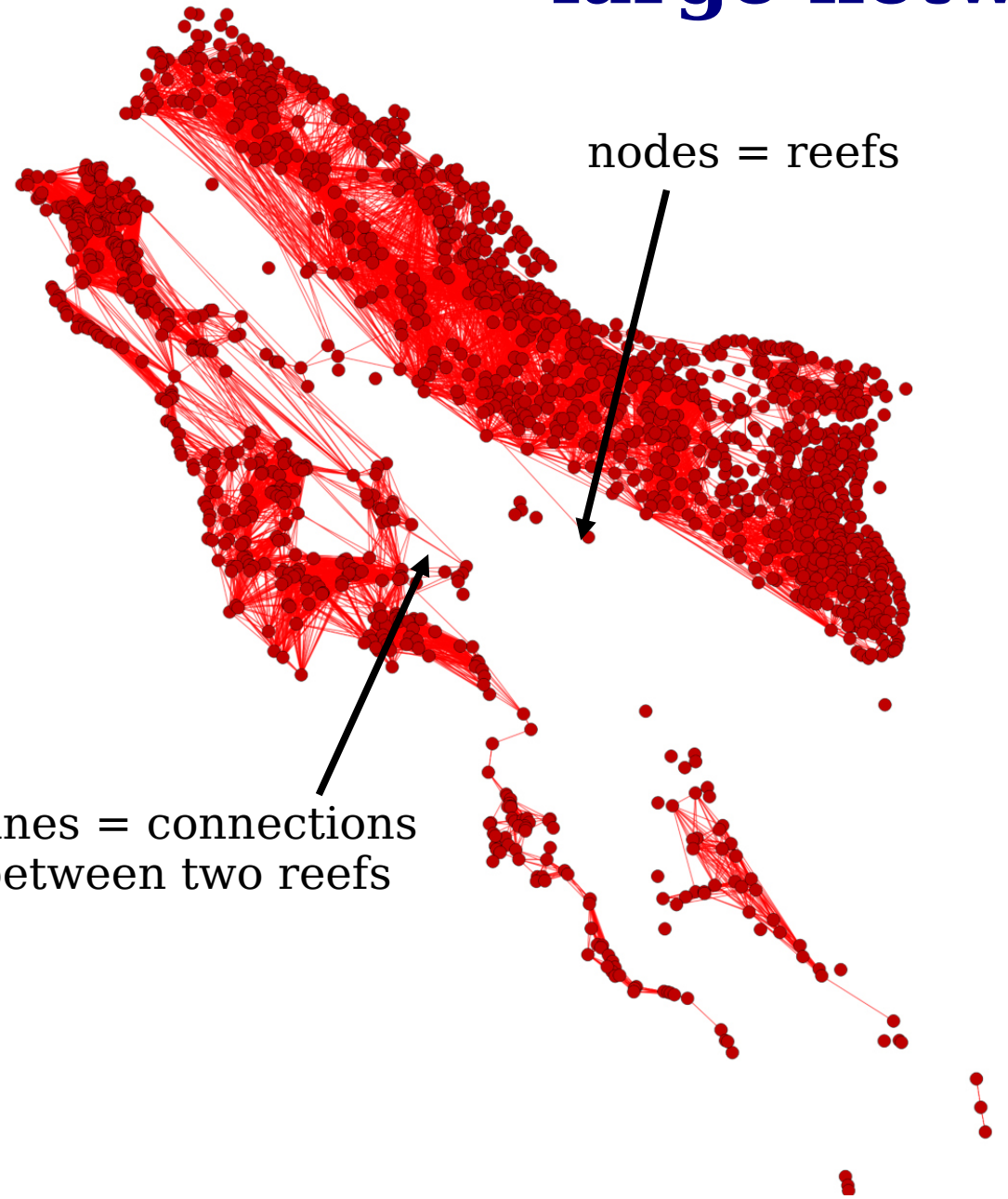

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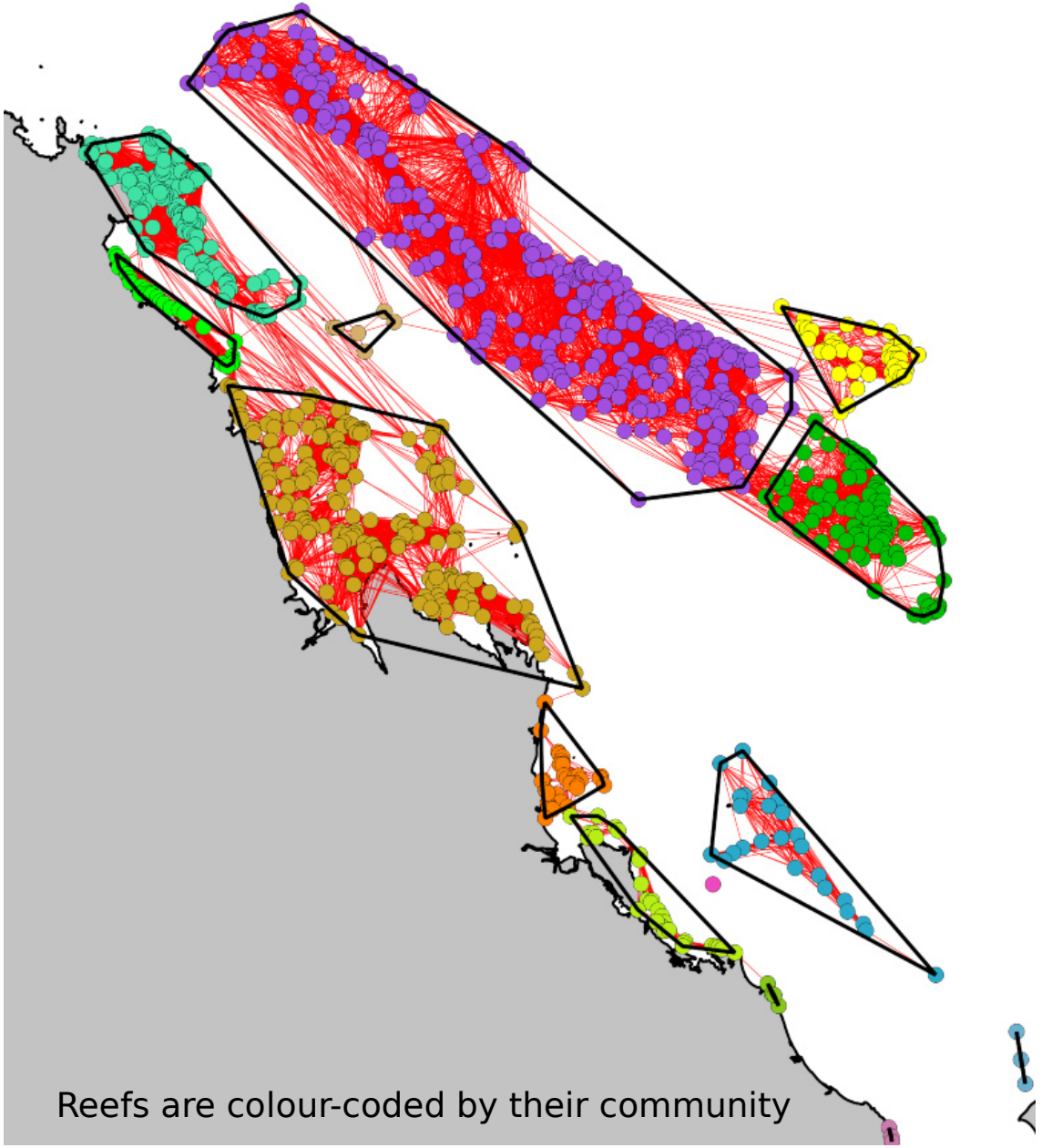

Reefs are colour-coded by their community

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Reef “communities” = ecologically isolated groups of reefs (very little transport between them)

How does the community detection method work?

– The community detection method partitions the network into **a set of communities**

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   → **members of the same community are highly connected amongst themselves** (on average)

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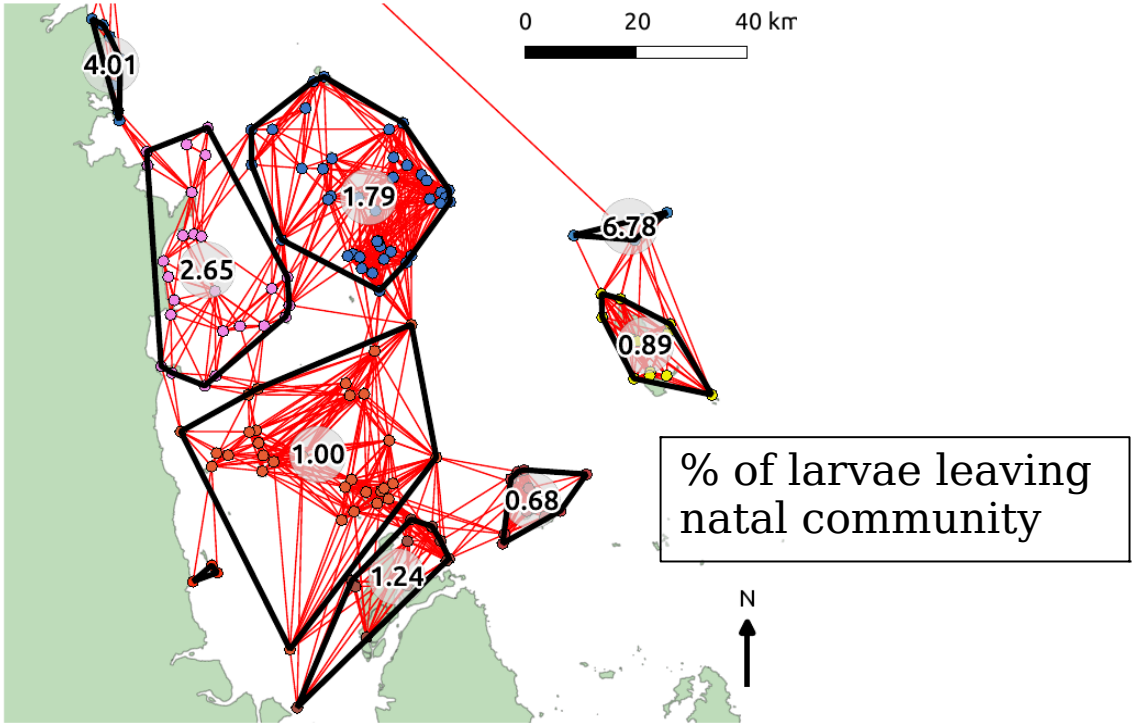
γ **is a threshold value** which controls how strongly defined the community boundaries are

So γ represents a “threshold” level of connectivity…

Low-γ communities:



– Very few larvae exchanged between communities
– Almost all larvae **settle inside their natal community**

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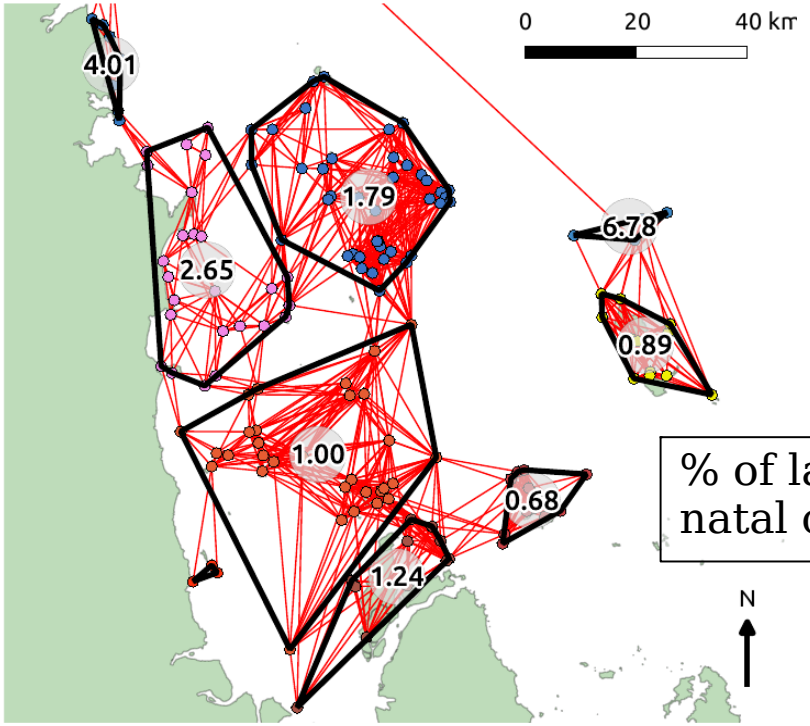

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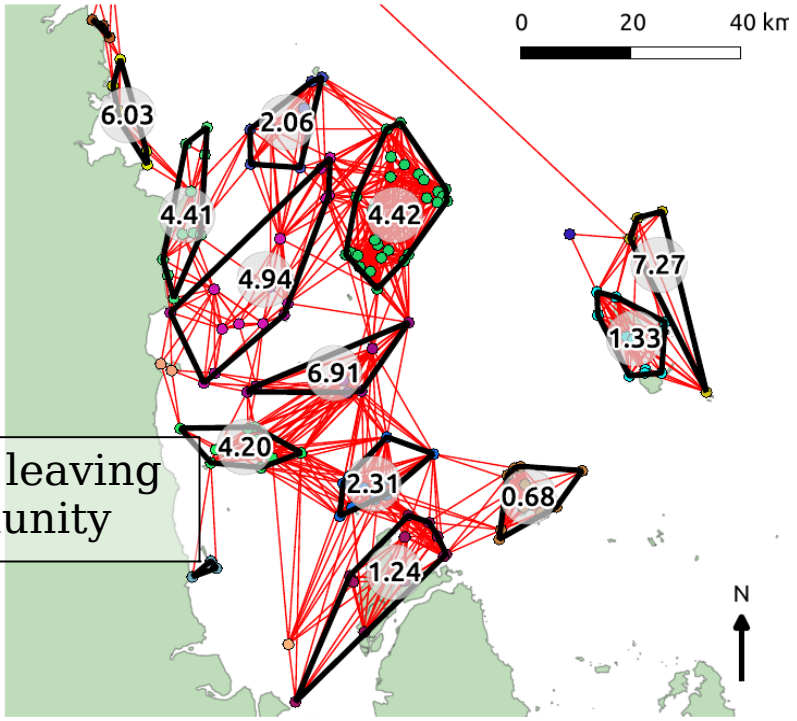
% of larvae leaving natal community

High-γ communities:



– A greater proportion of larvae settle outside their natal community

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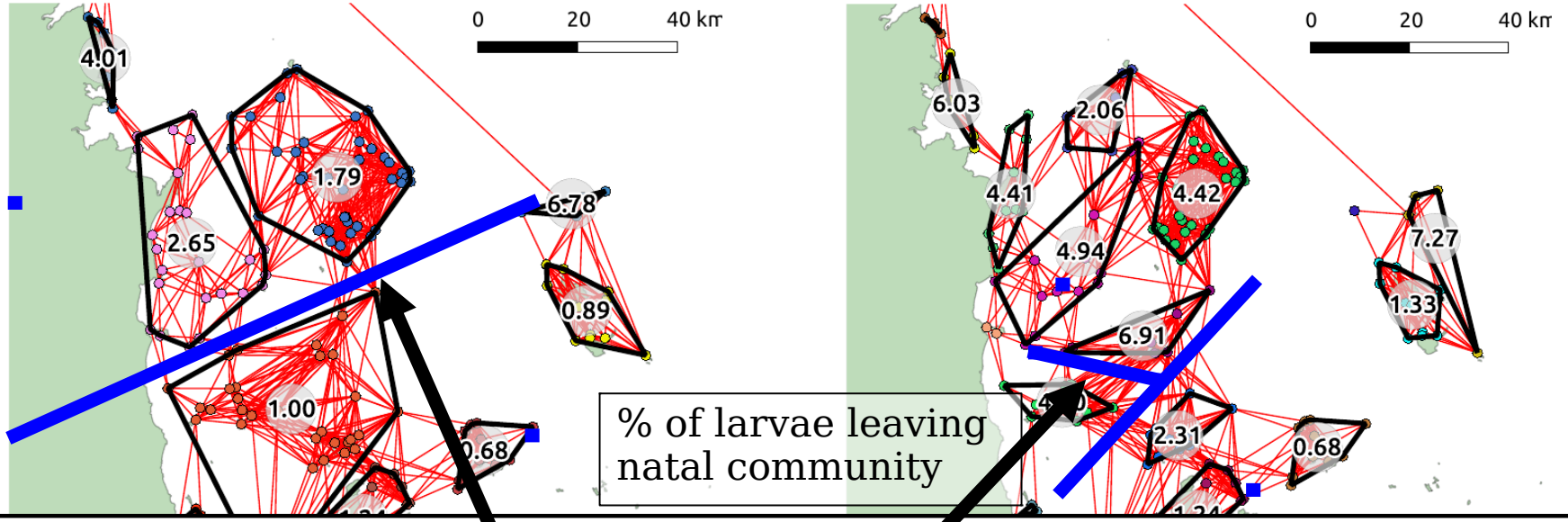

We can identify **stronger** and **weaker** “barriers to dispersal” by changing this parameter

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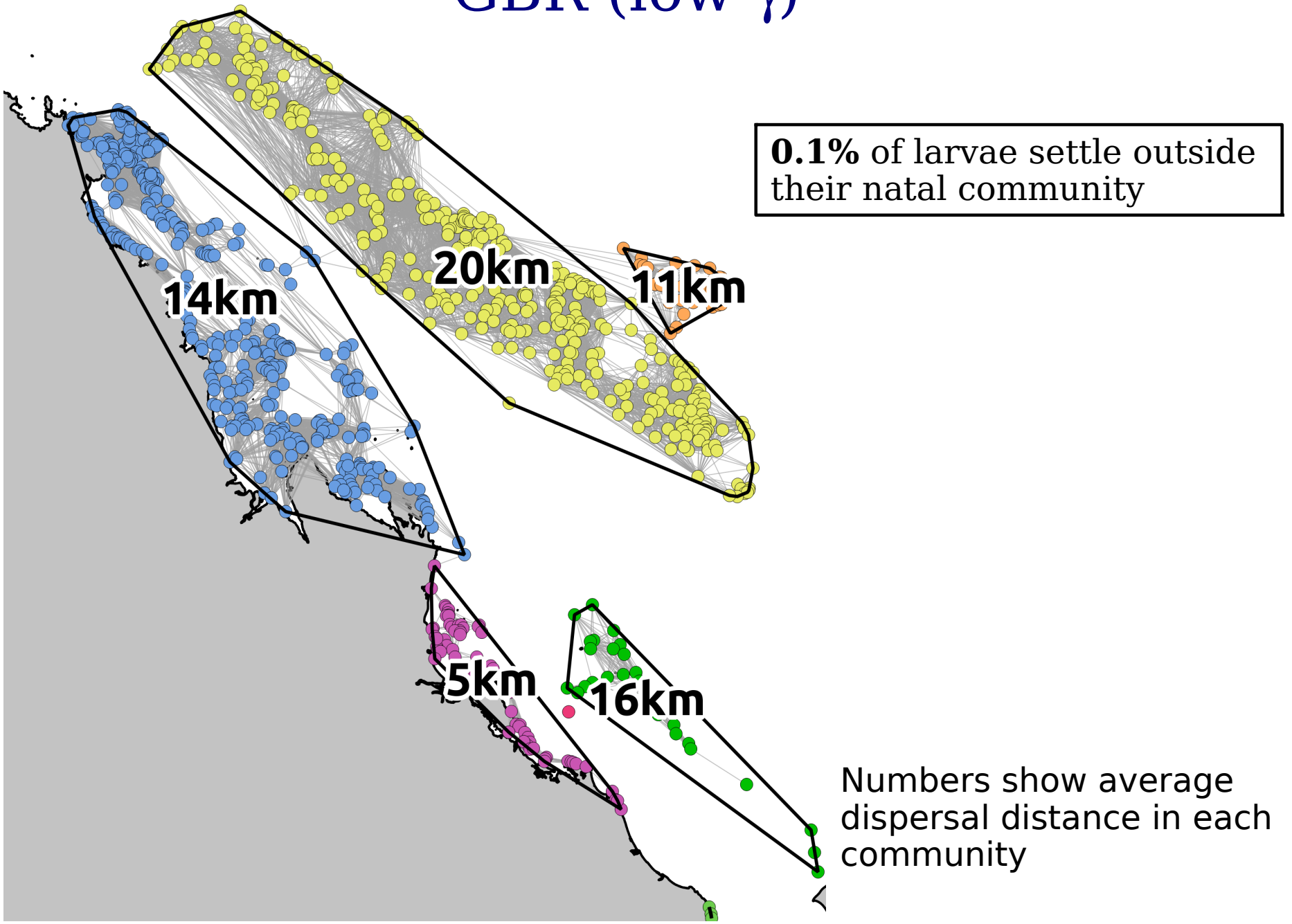
– A greater proportion of larvae settle outside their natal community

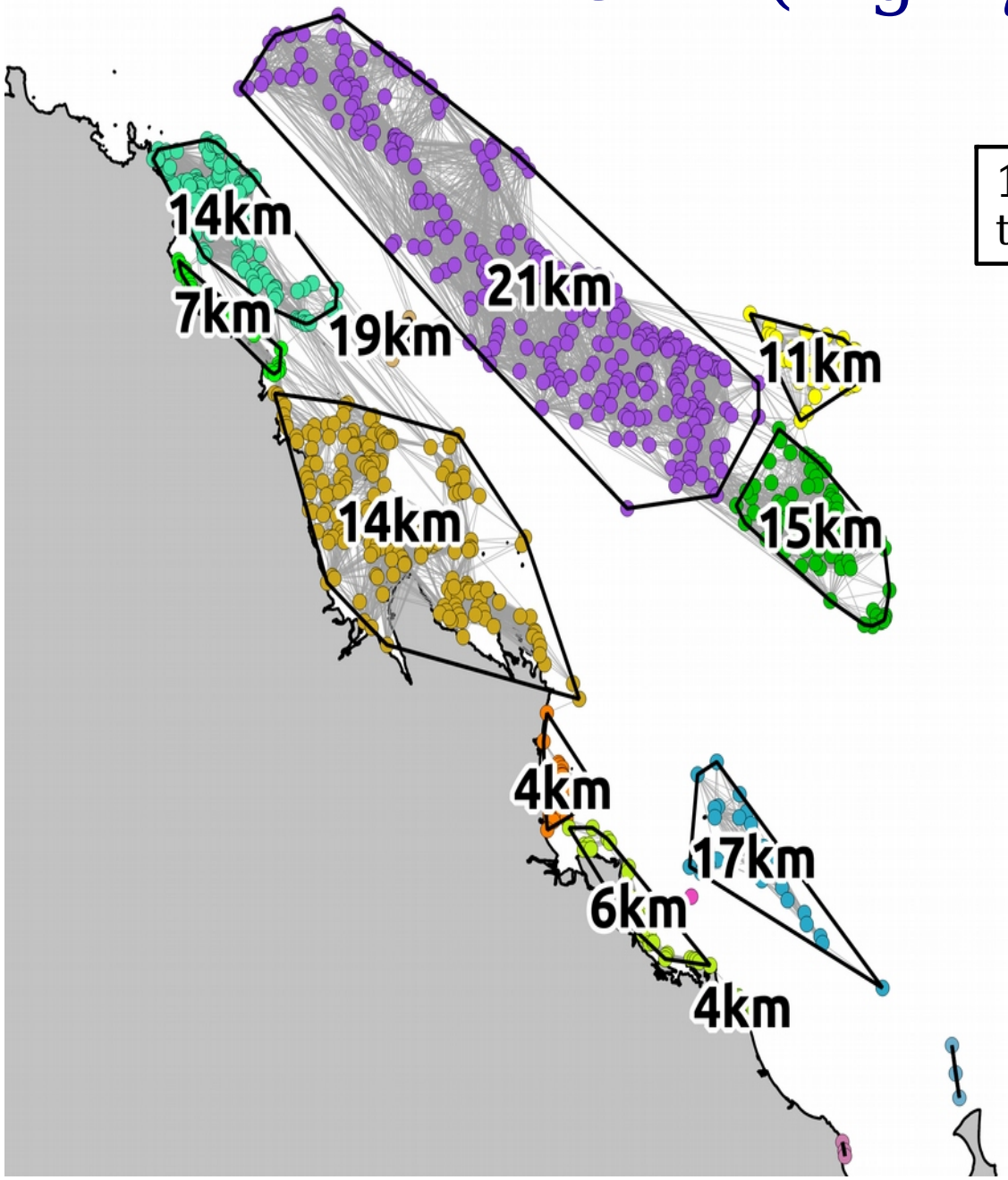
Communities for A. humilis in the southern GBR (low γ)



0.1% of larvae settle outside their natal community

Numbers show average dispersal distance in each community

Communities for A. humilis in the southern GBR (high γ)



1% of larvae settle outside their natal community

Numbers show average dispersal distance in each community

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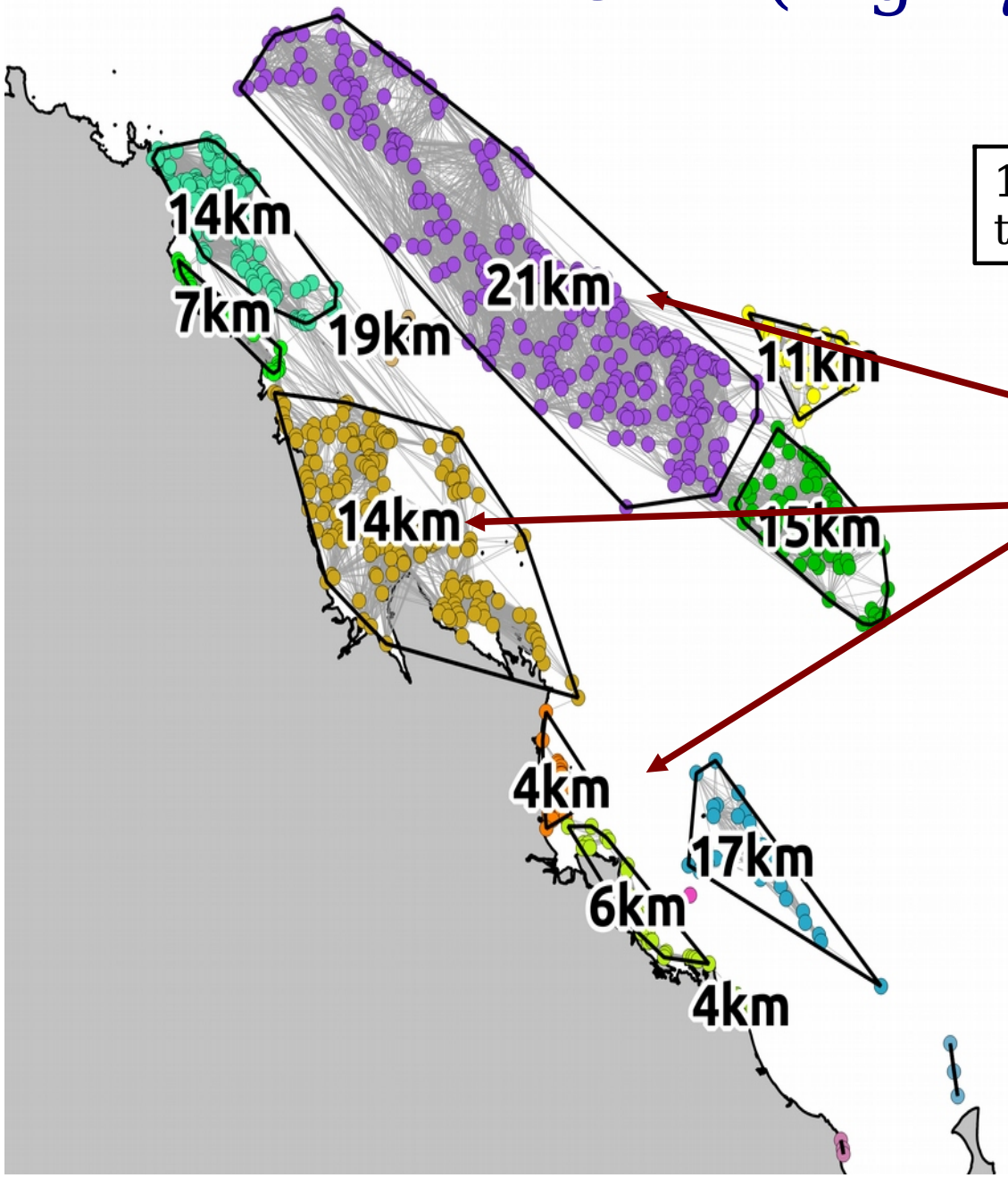

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Note:
Connectivity length-scales are very different in each community!

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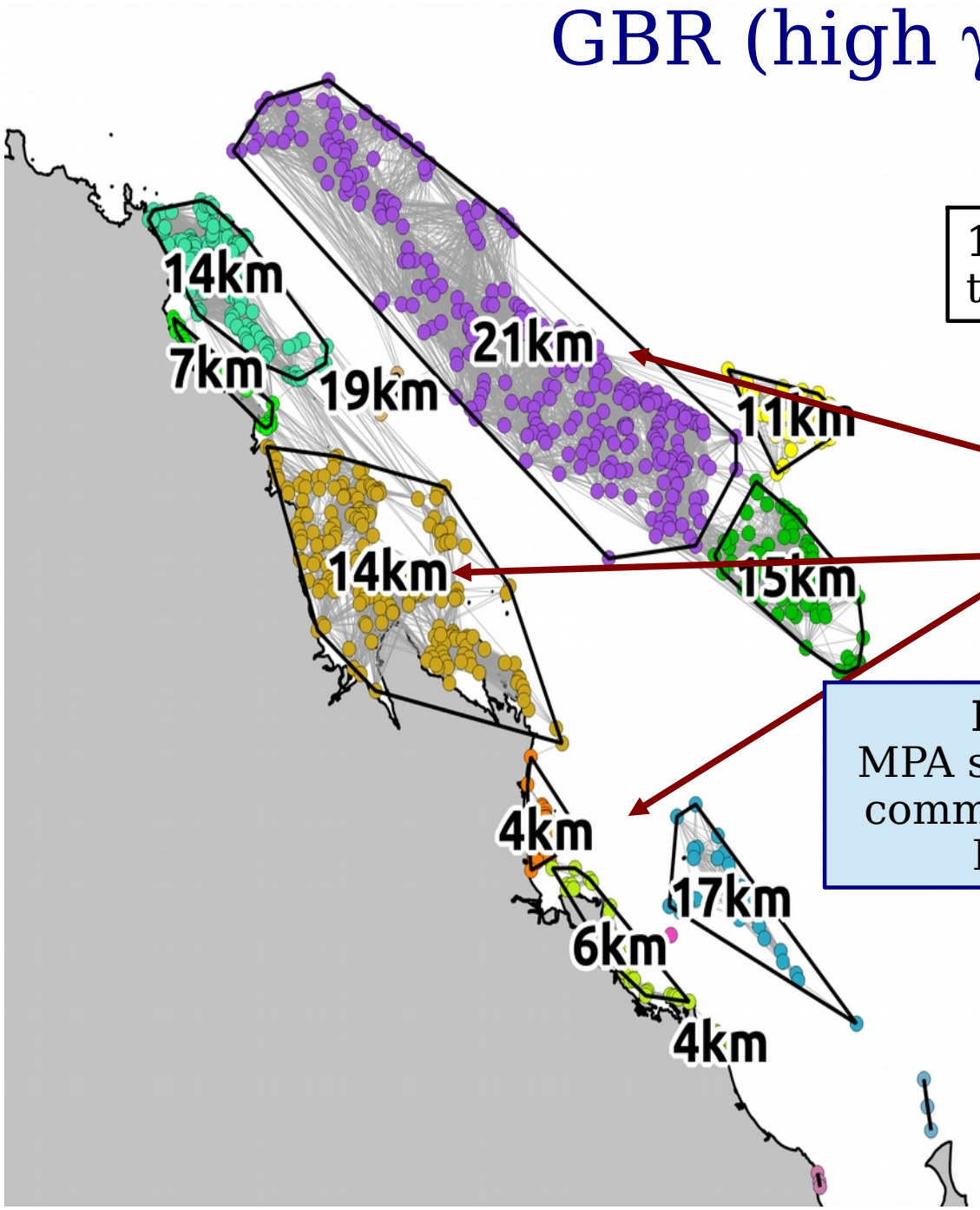

1% of larvae settle outside their natal community

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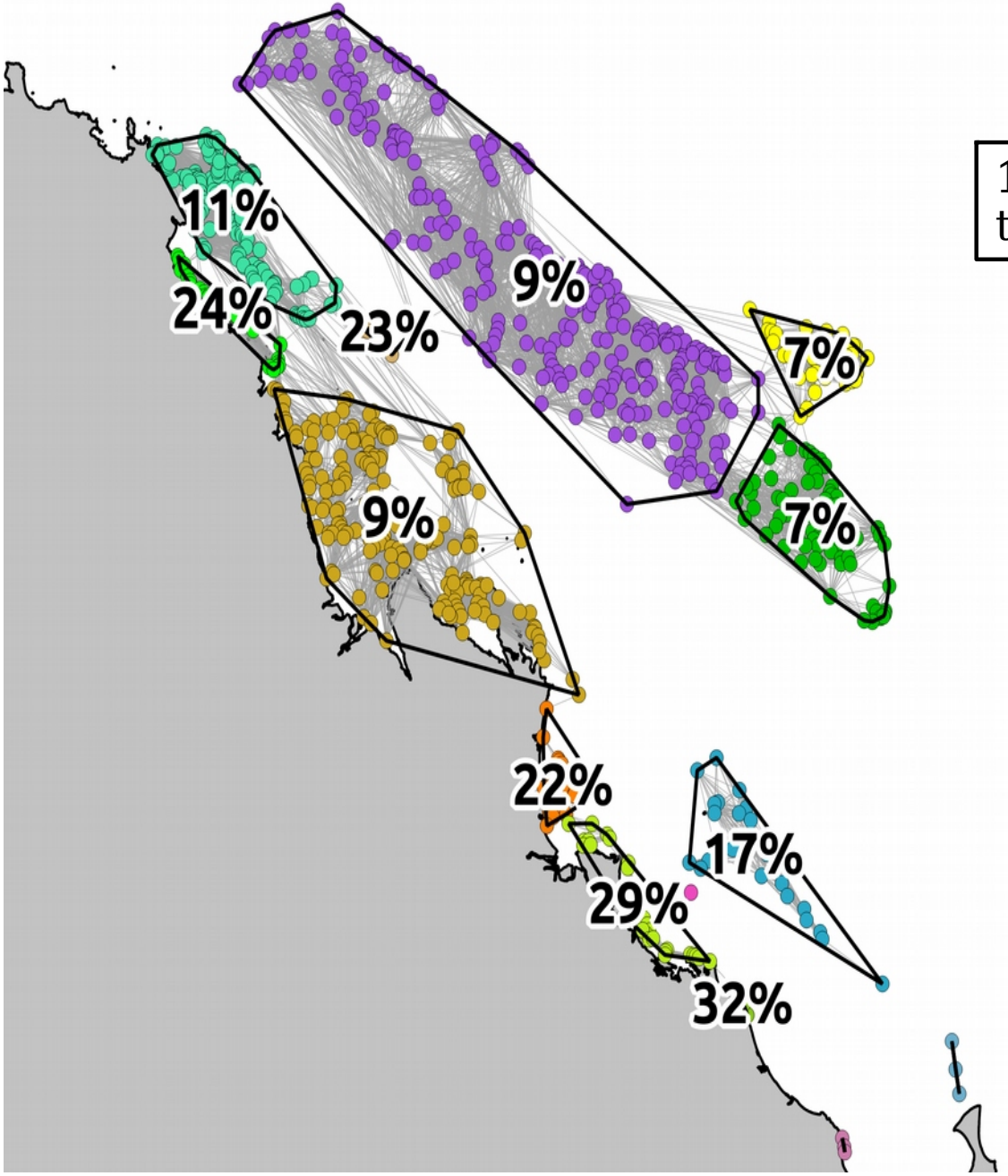
Connectivity length-scales are very different in each community!

Ecological implication:
MPA spacing may need to vary from community to community to ensure MPA-to-MPA connectivity

Numbers show average dispersal distance in each community

Self-recuitment rates are also different in each community …



1% of larvae settle outside their natal community

Numbers show percentage of larvae settling over same reef they were released on

Why are communities shapes so irregular?

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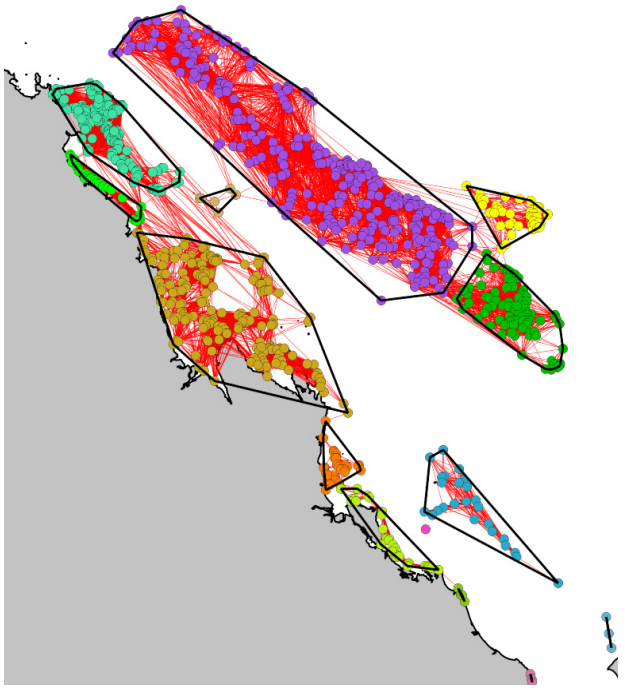

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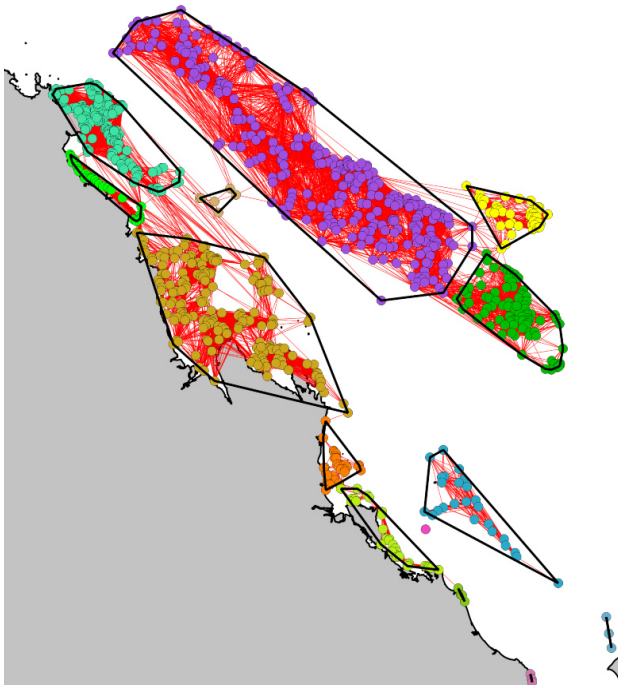

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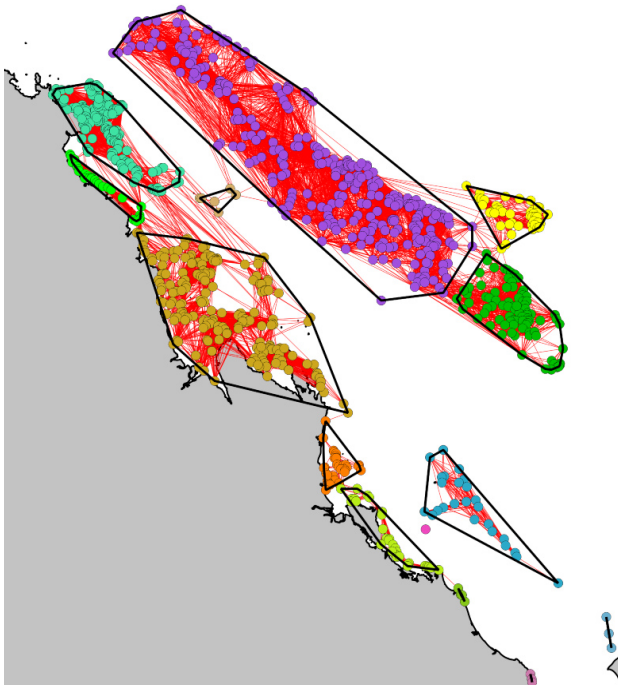
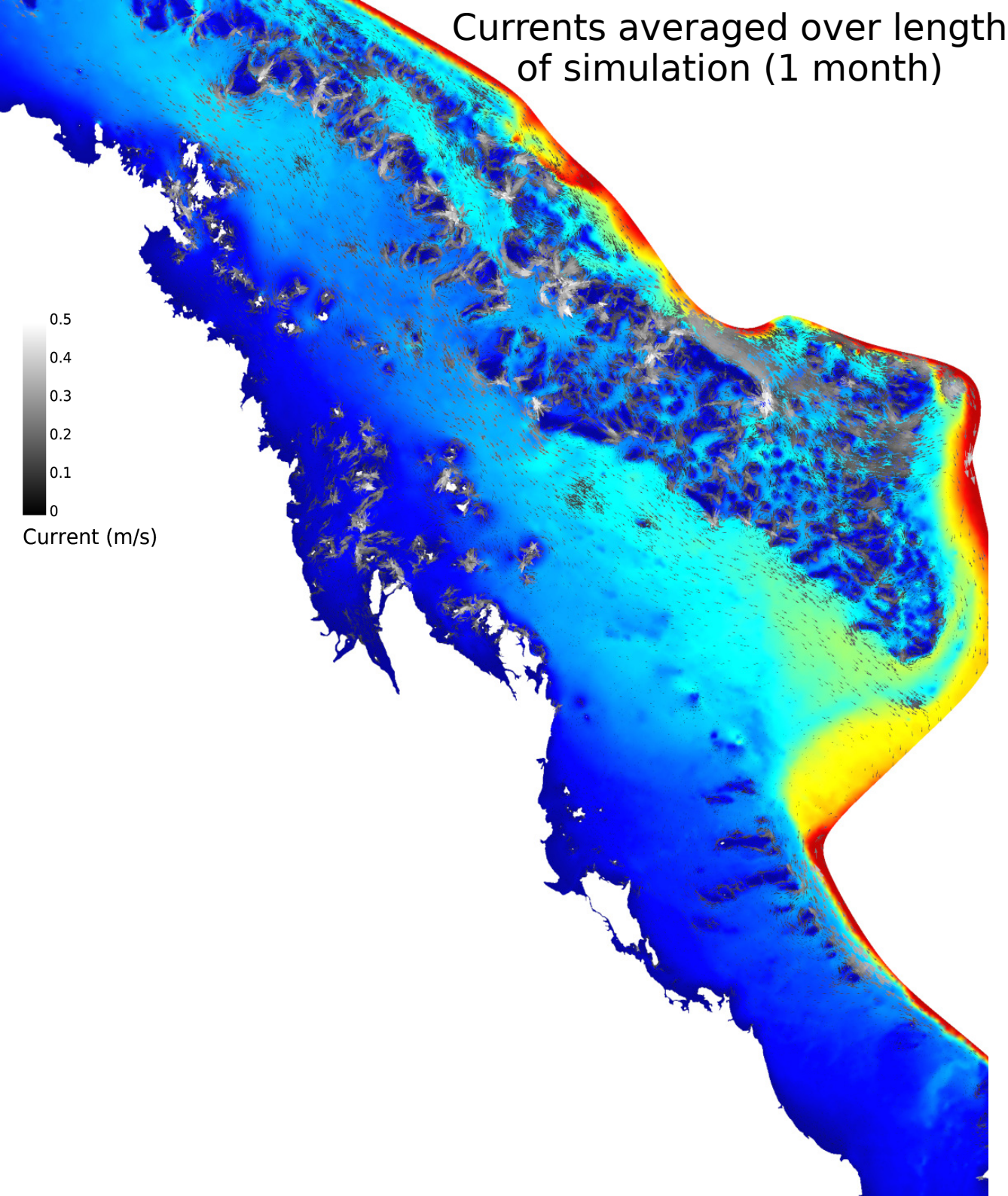


Why?

→ **Hydrodynamics**

→ Community boundaries often **represent boundaries between different circulation regimes …**


Currents averaged over length
of simulation (1 month)
0.5
0.4
0.3
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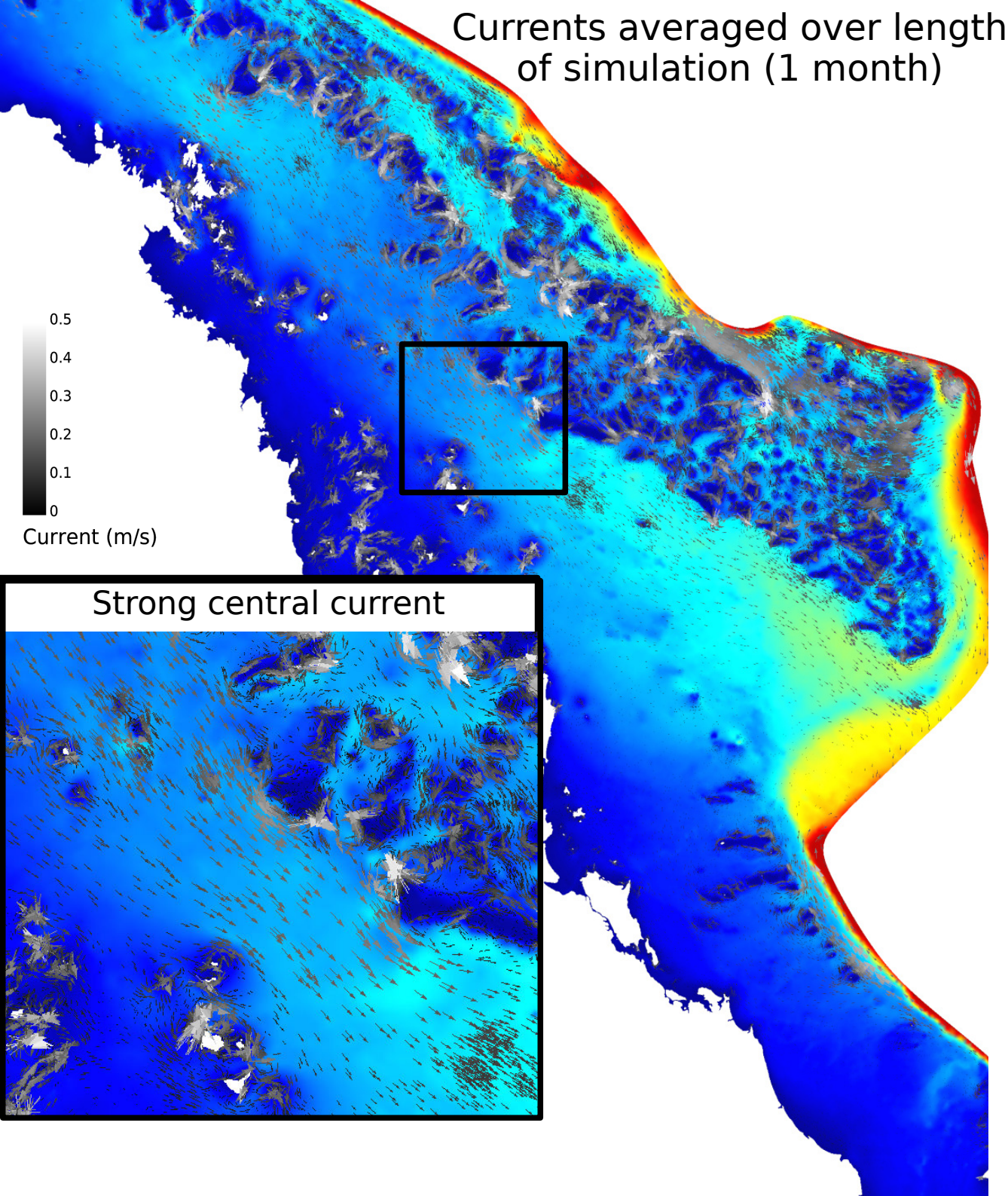
Current (m/s)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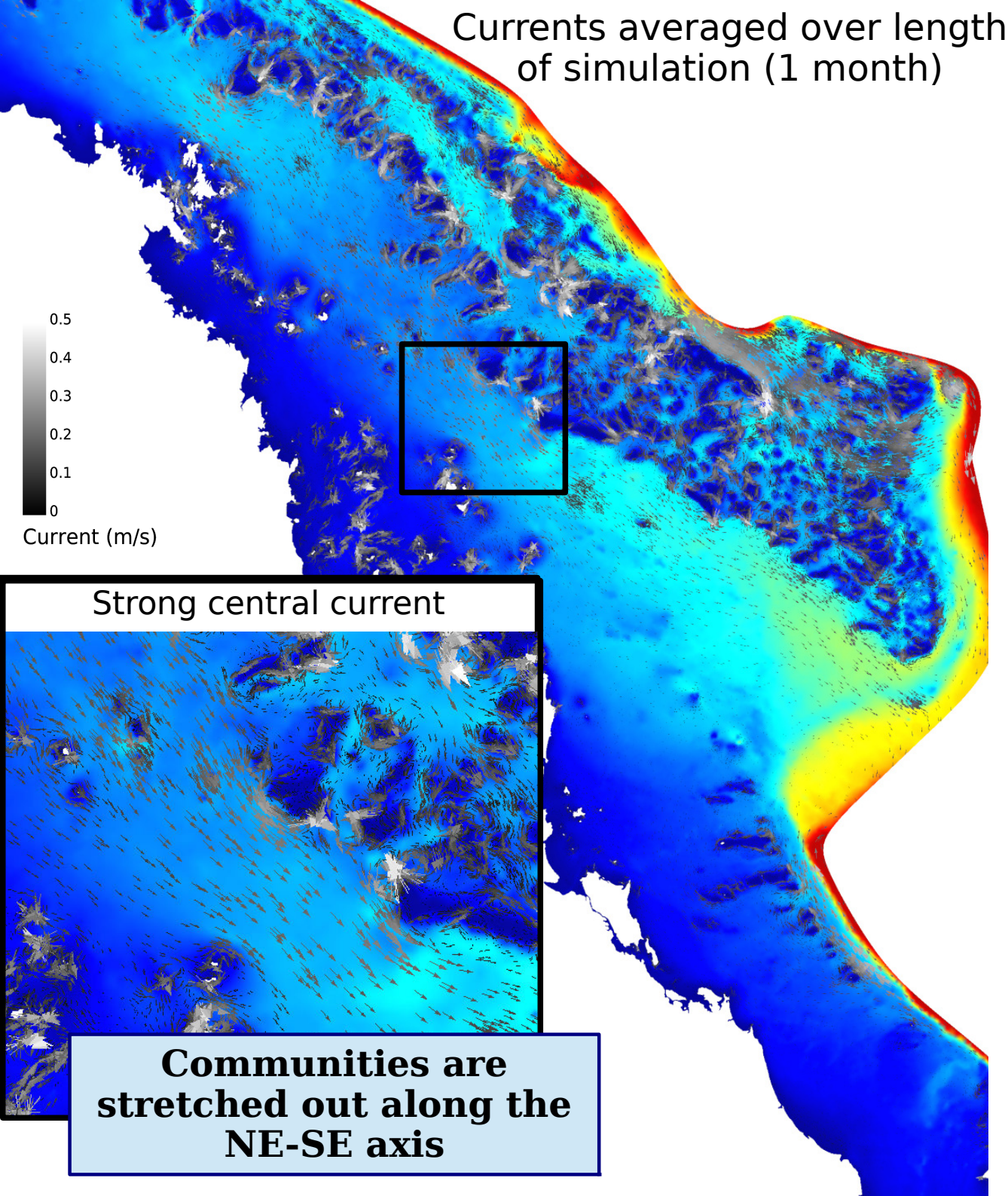
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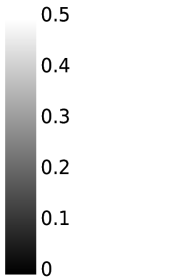
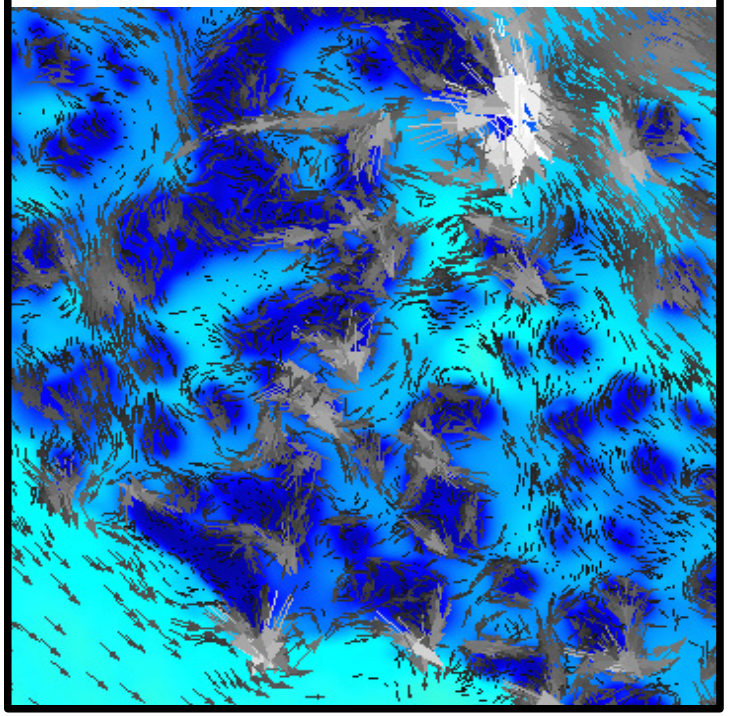
Current (m/s)
Strong central current
Communities are stretched out along the NE-SE axis

Currents averaged over length of simulation (1 month)



Strong inter-reef currents



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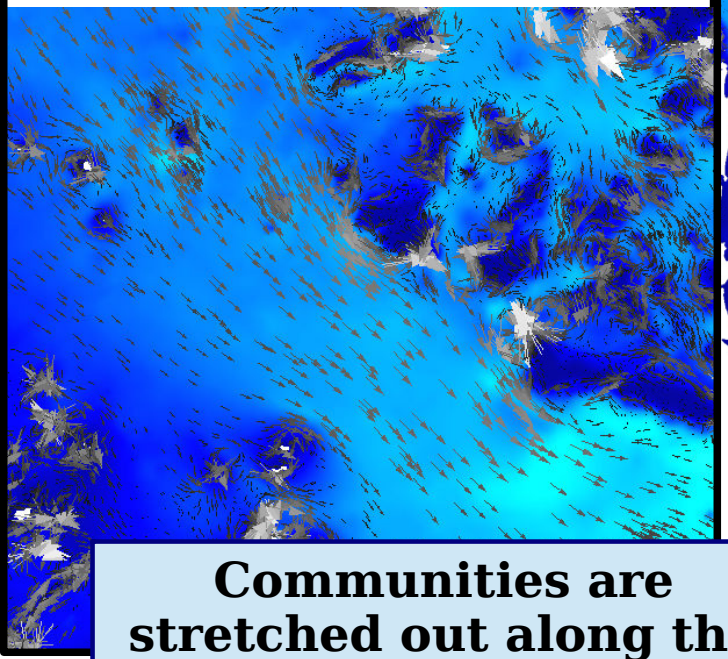
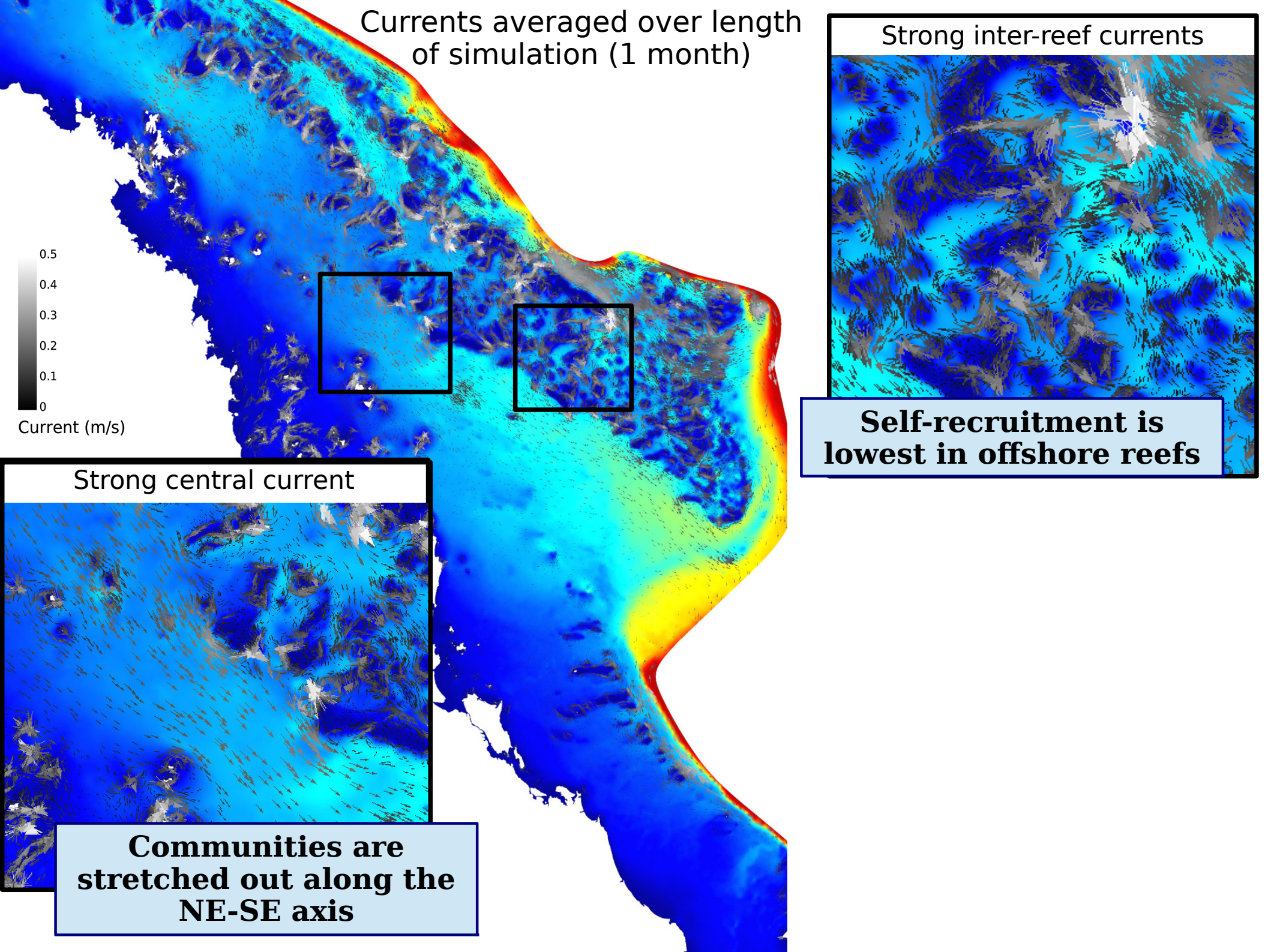


Communities are stretched out along the NE-SE axis


Currents averaged over length of simulation (1 month)
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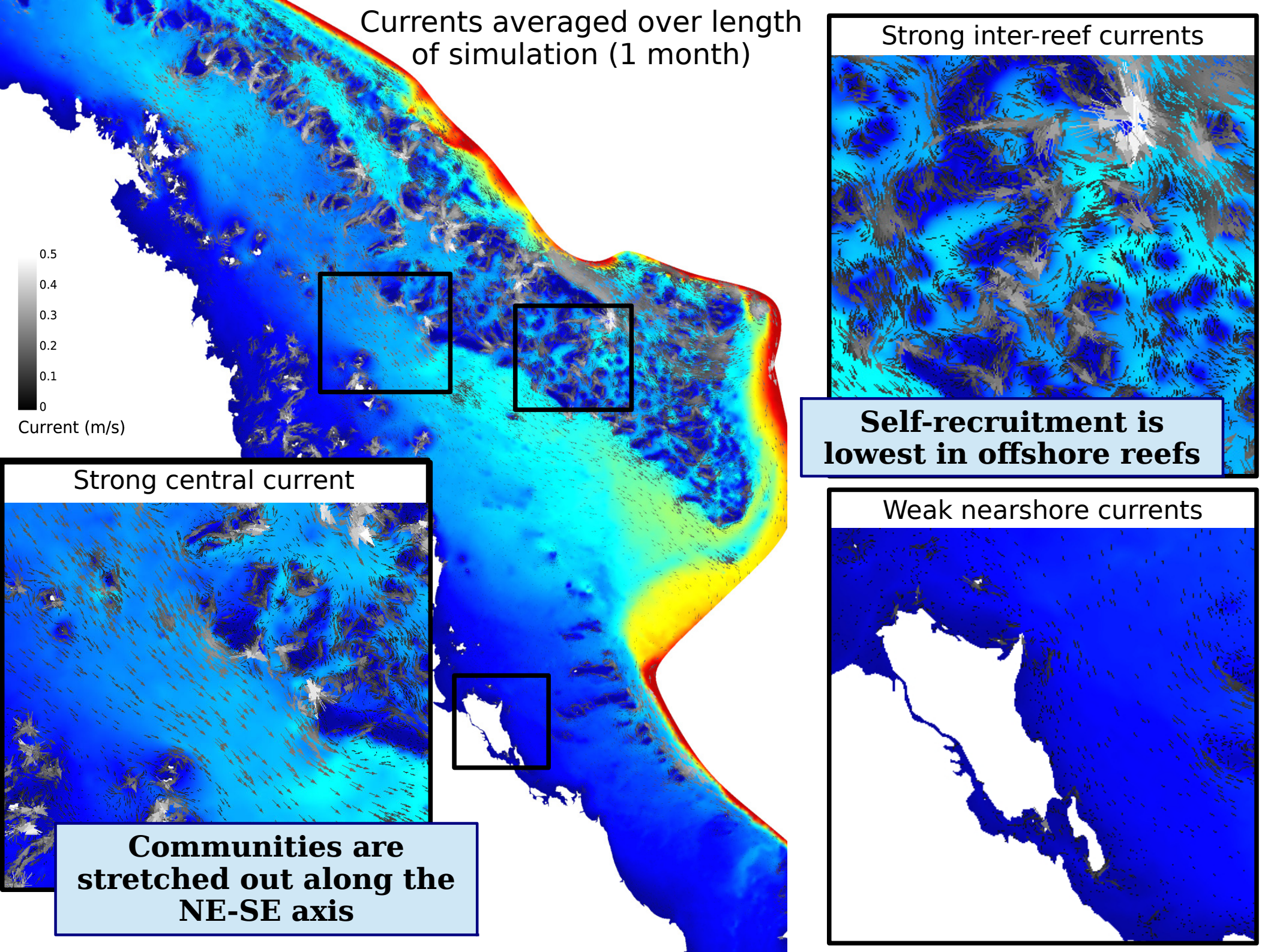
Current (m/s)
Strong inter-reef currents
Self-recruitment is lowest in offshore reefs
Strong central current
Communities are stretched out along the NE-SE axis


Currents averaged over length of simulation (1 month)
0.5
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0.3
0.2
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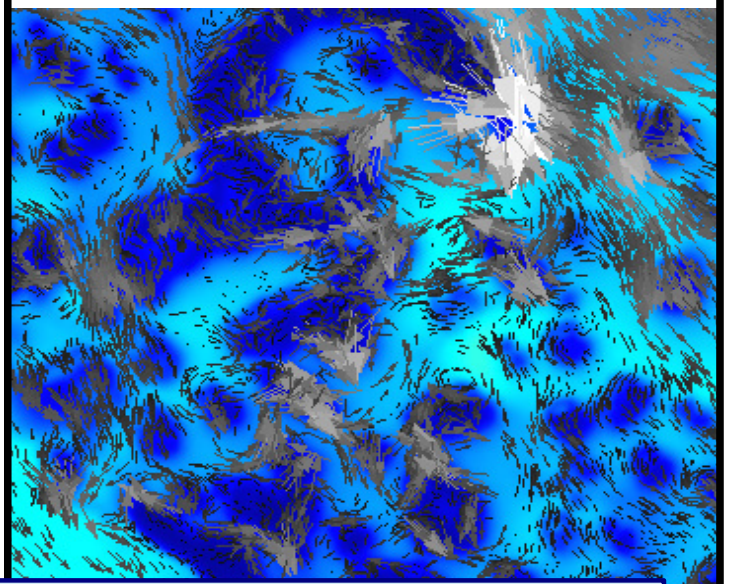

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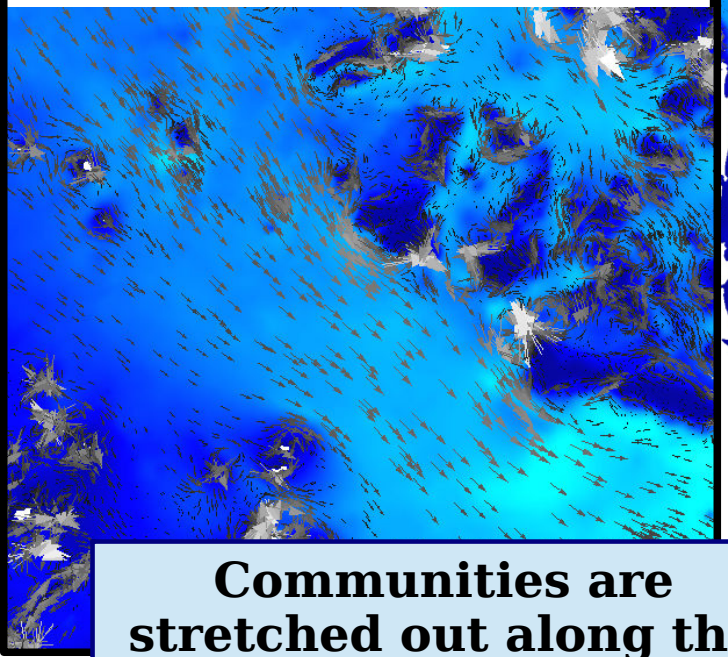

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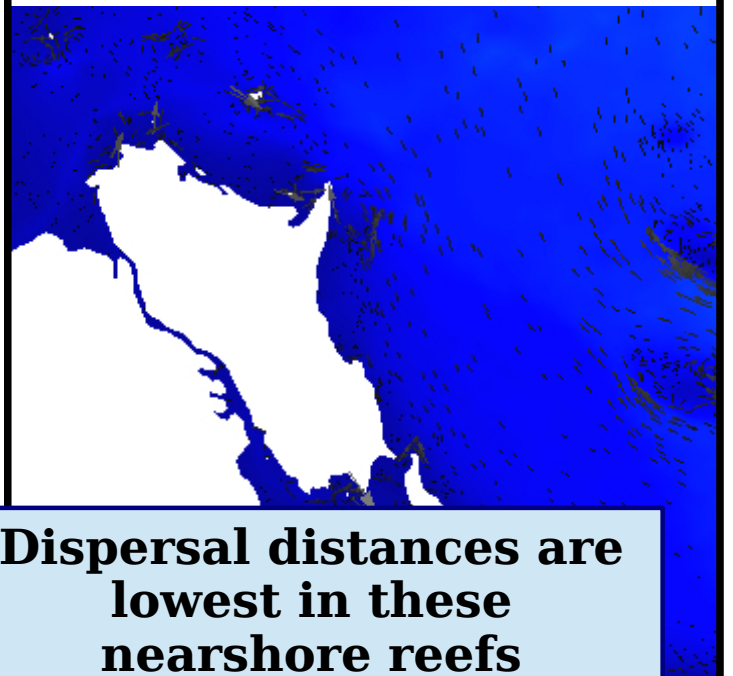
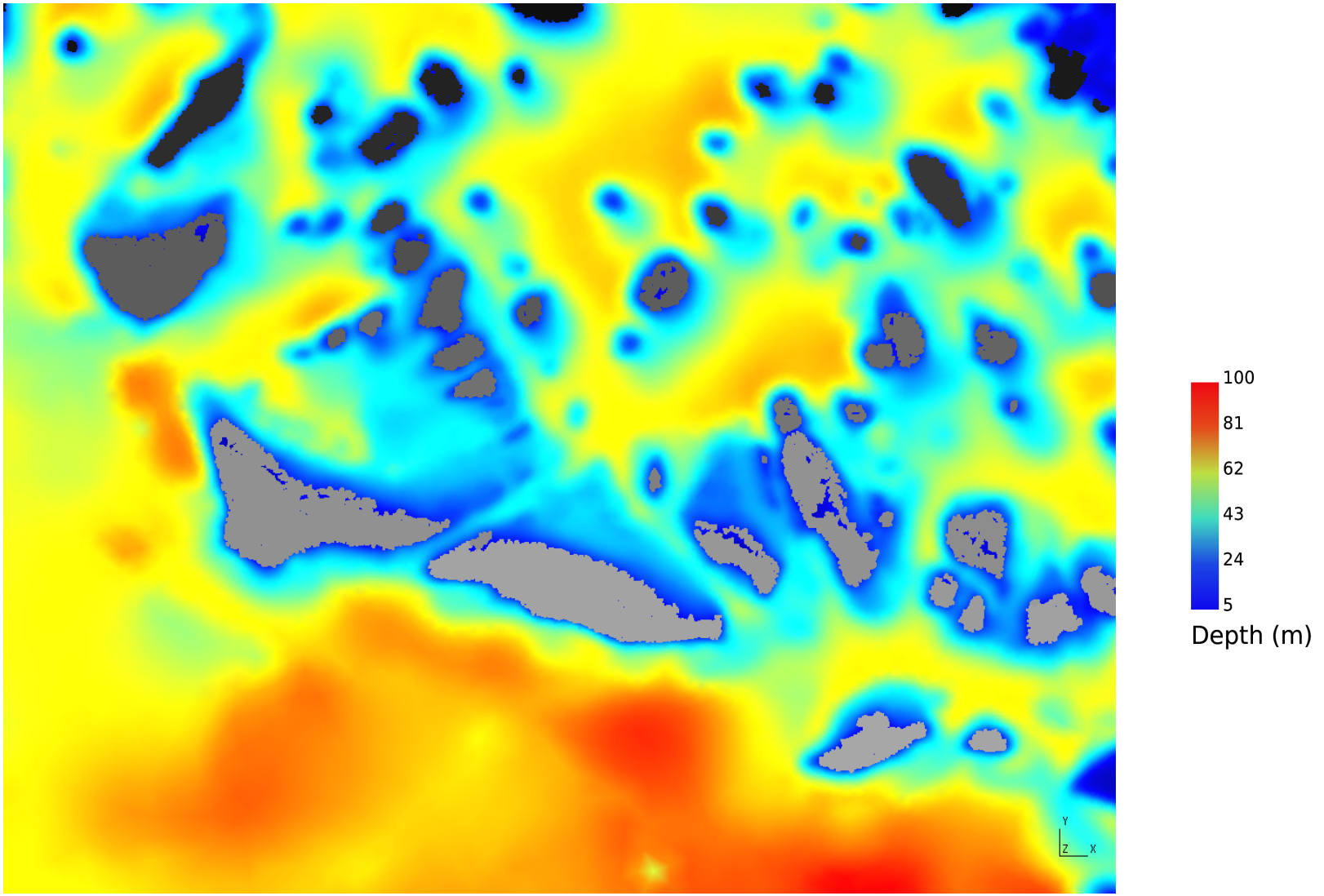


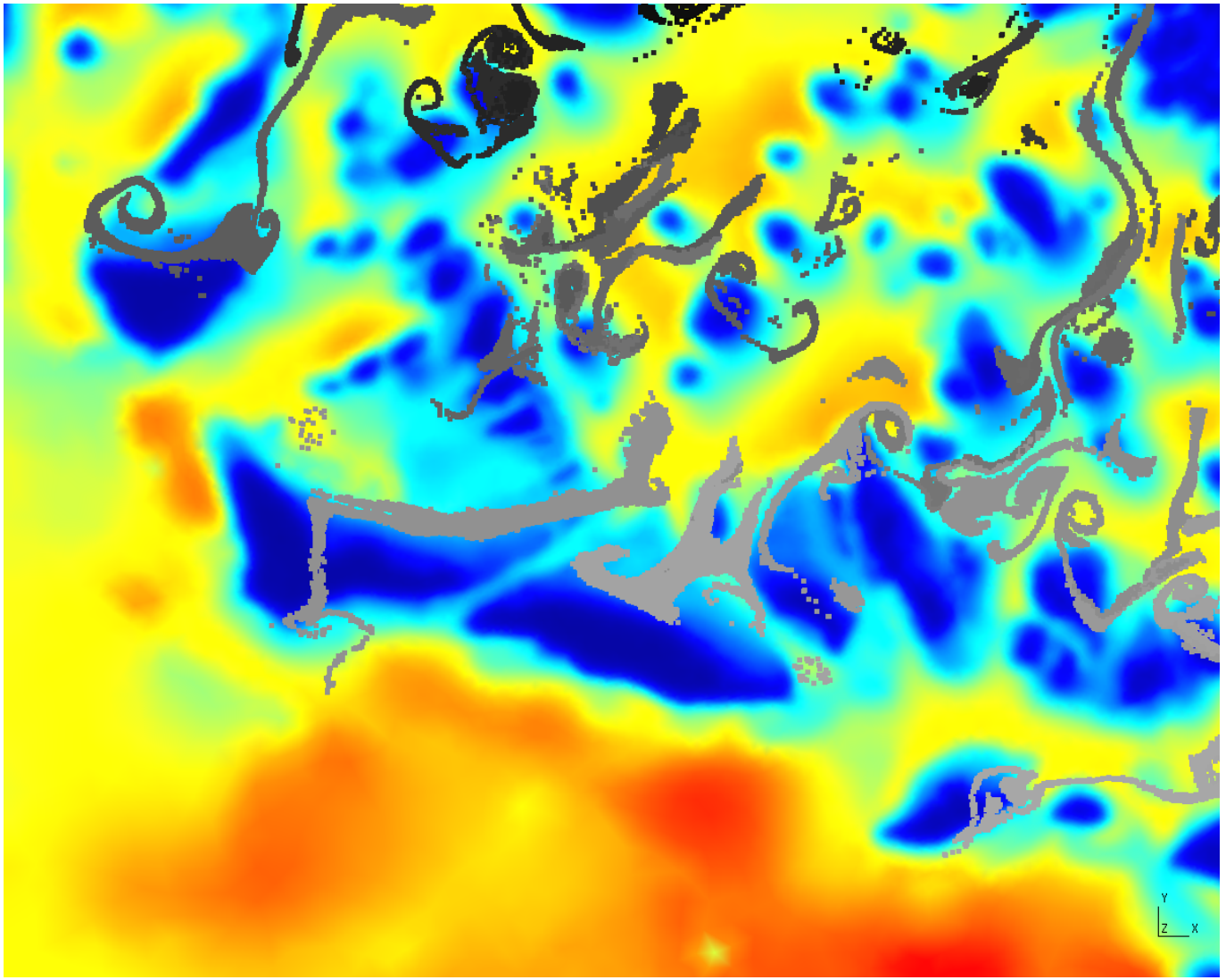
Dispersal distances are lowest in these nearshore reefs

Formation of reef wake eddies enhances self-recruitment



Formation of reef wake eddies enhances self-recruitment

+12hrs



Formation of reef wake eddies enhances self-recruitment

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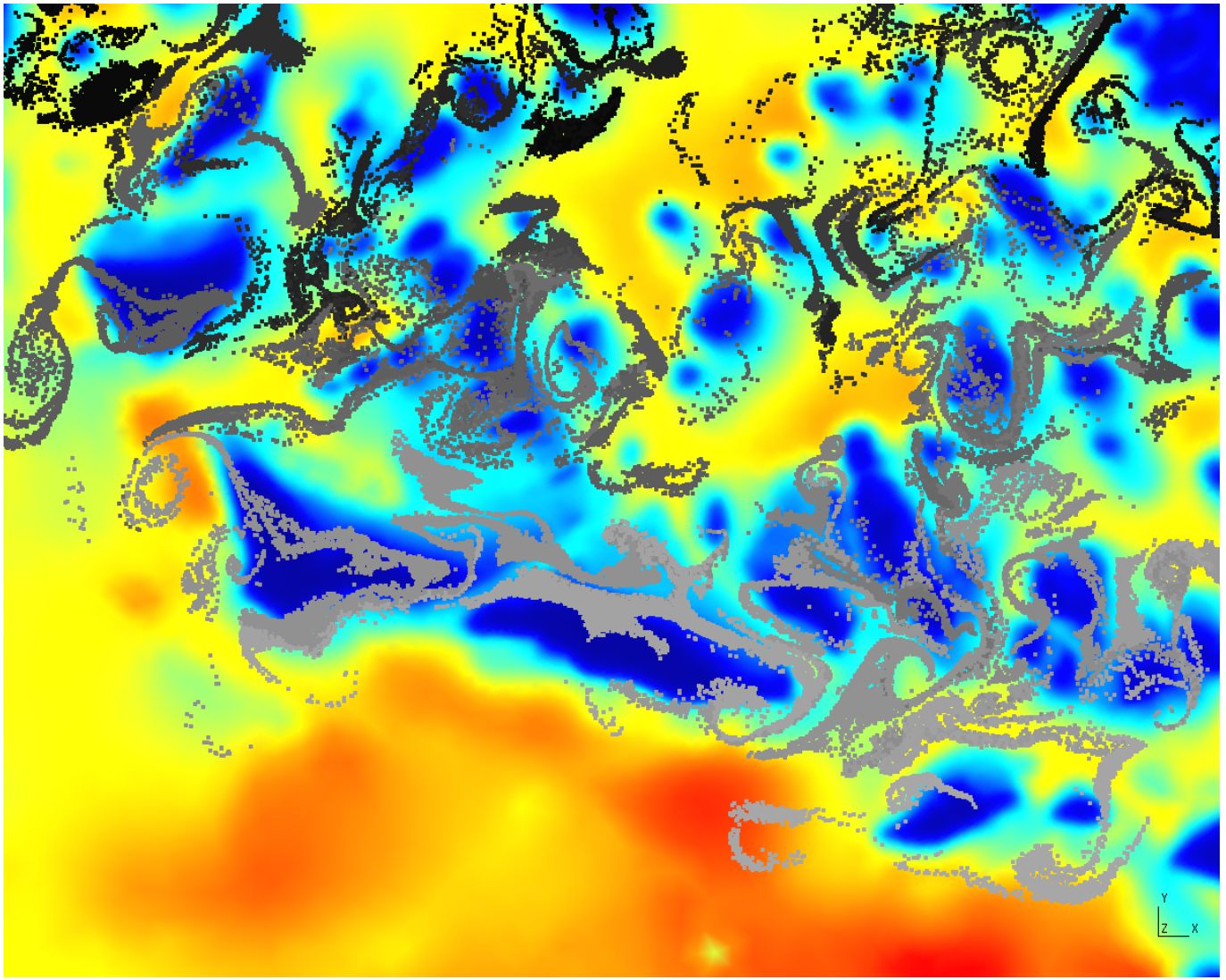
+24hrs



Formation of reef wake eddies enhances self-recruitment

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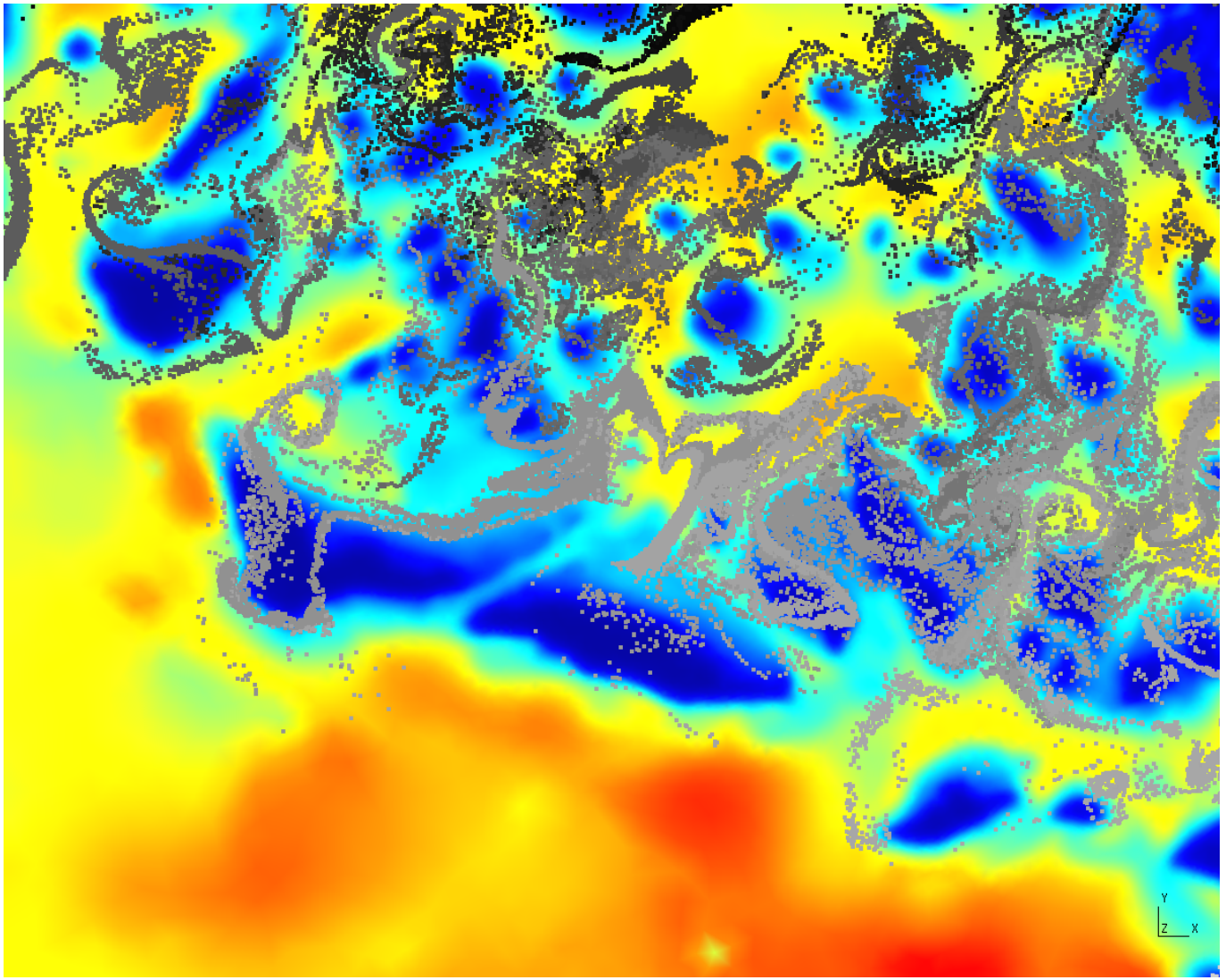
+24hrs
+36hrs



Formation of reef wake eddies enhances self-recruitment

+12hrs
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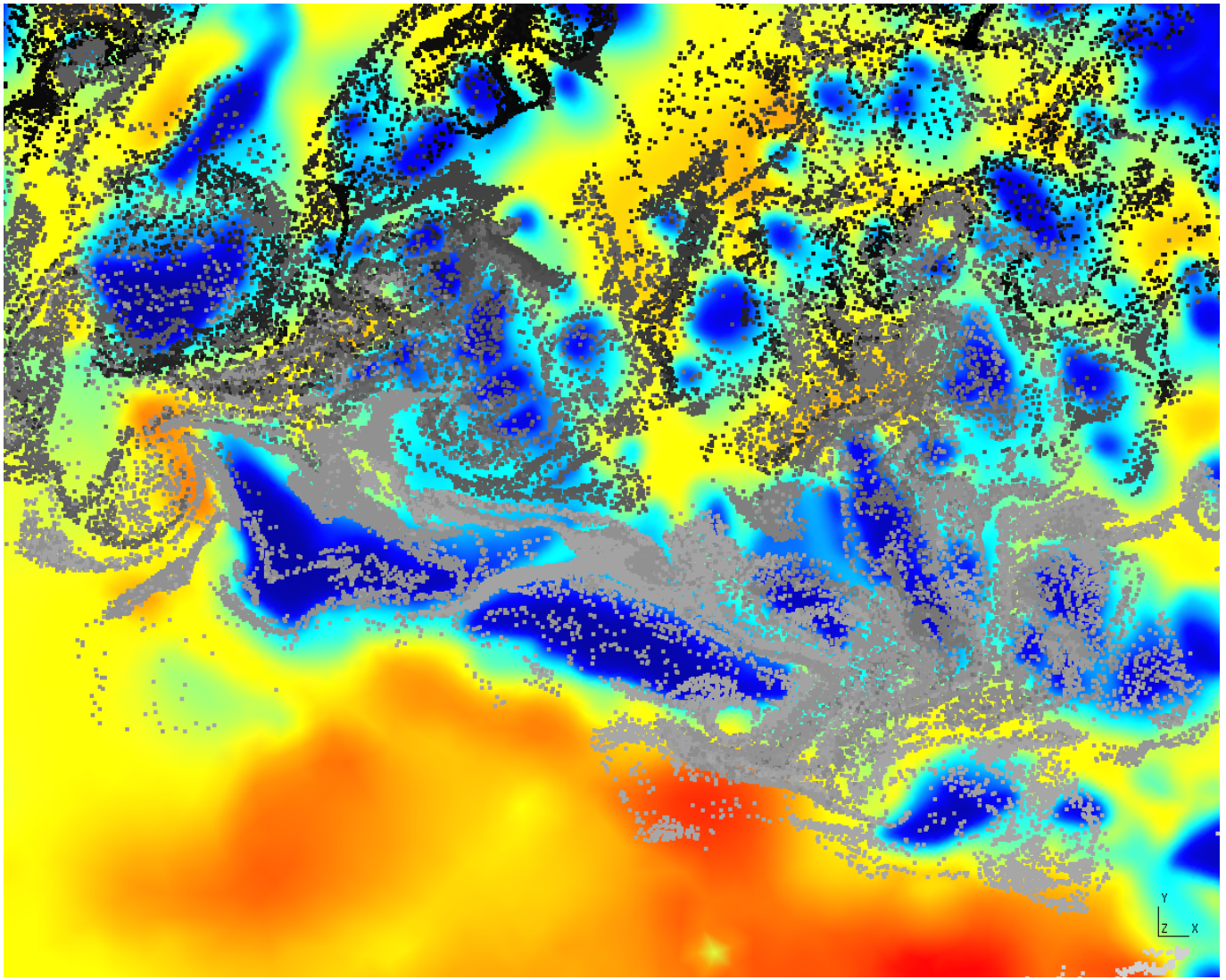
+48hrs



Some other ecological questions we can attempt to answer ...

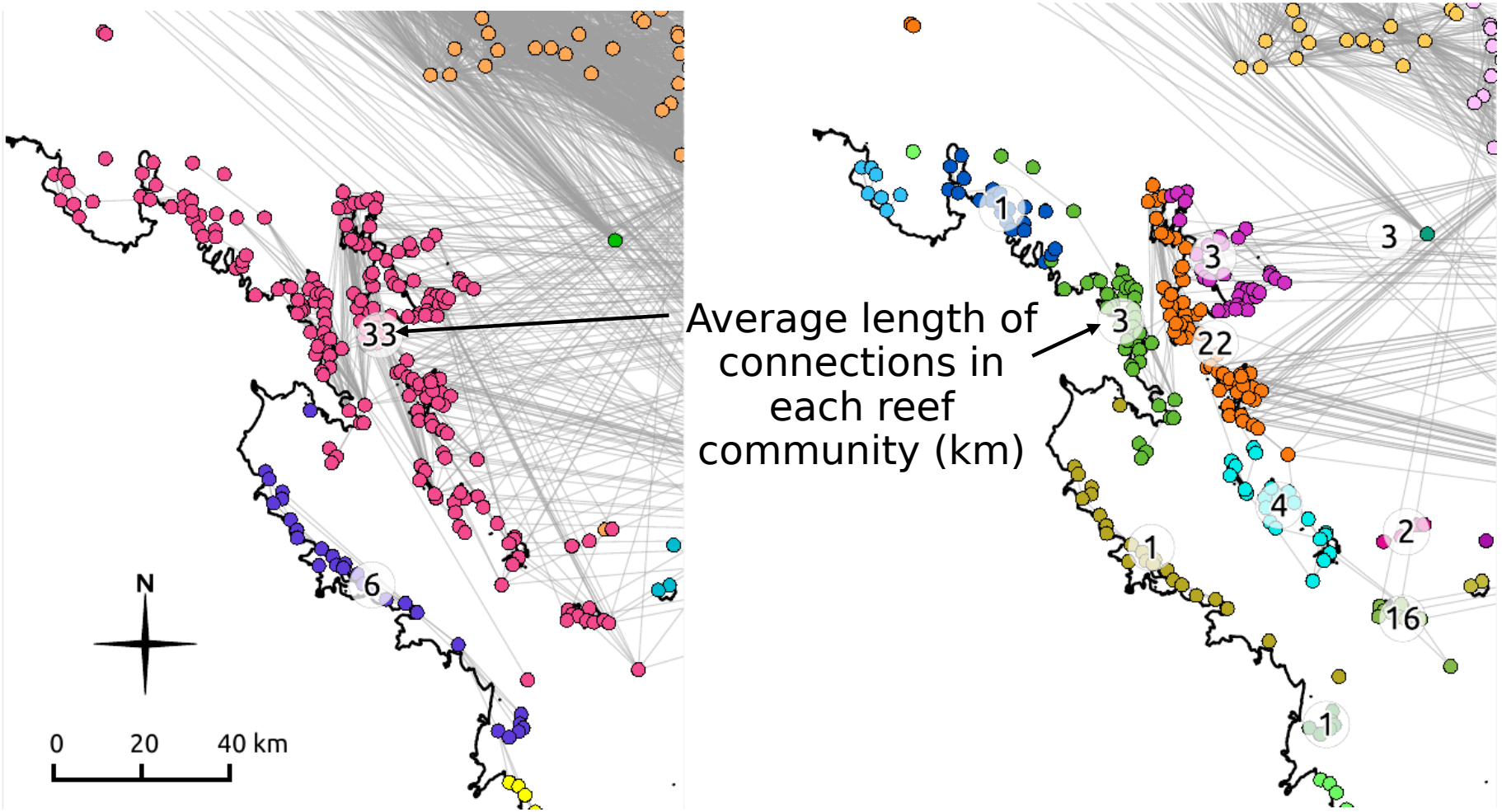
Are connectivity patterns different for different species?

A. Millepora

(long pre-competency period)

G. Retiformis

(very short pre-competency period)



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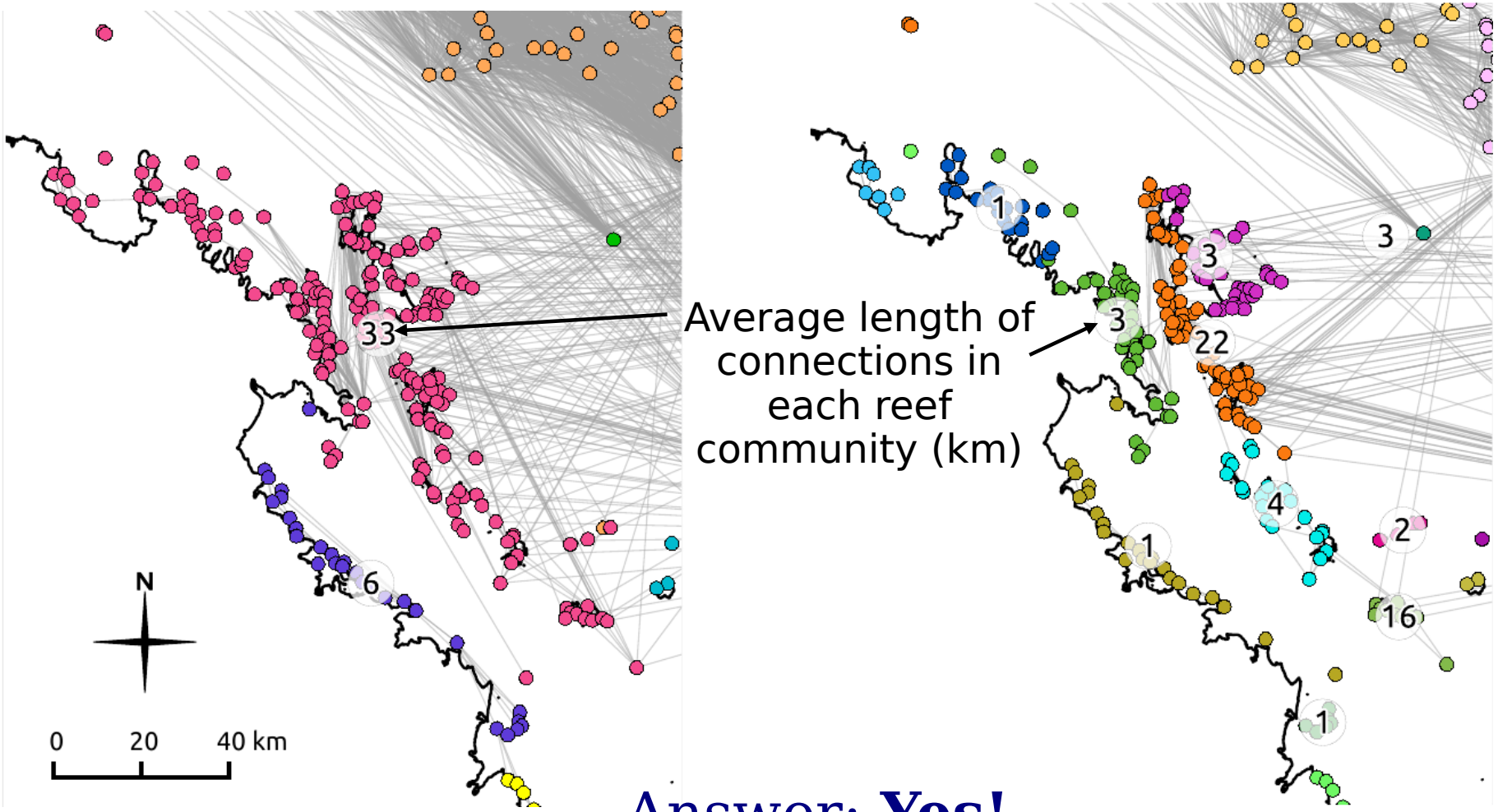

Answer: **Yes!**

Do connectivity patterns vary from year to year?

Currents on GBR shelf strongly **wind-driven**
→ high annual variability possible

But strongest currents are **tidal**

} Impact on larval dispersion/connectivity?

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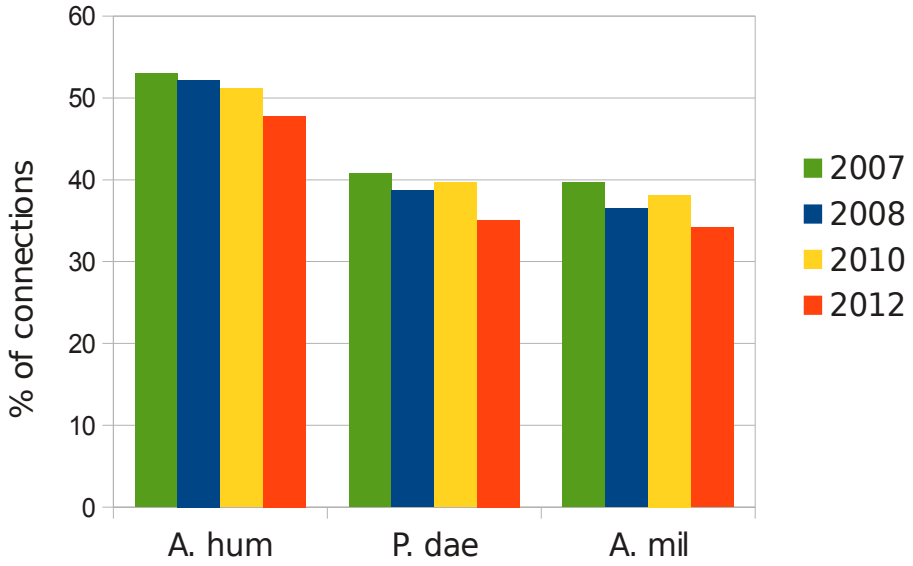

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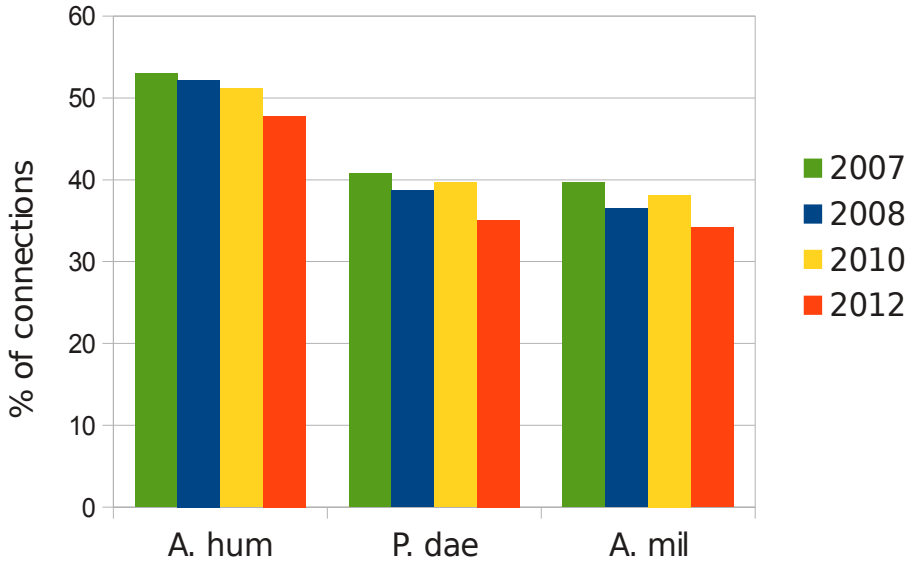
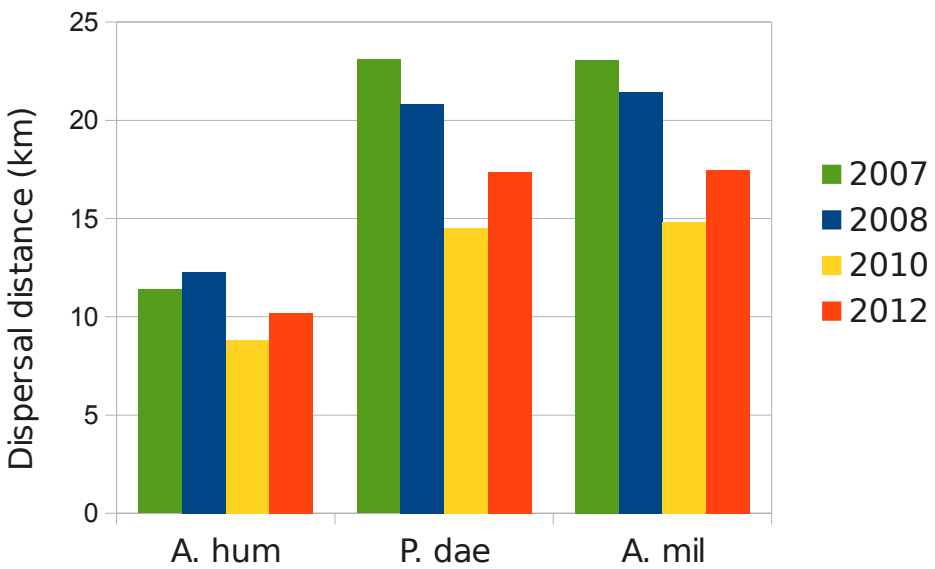


Dispersal distance by year on emergent reefs



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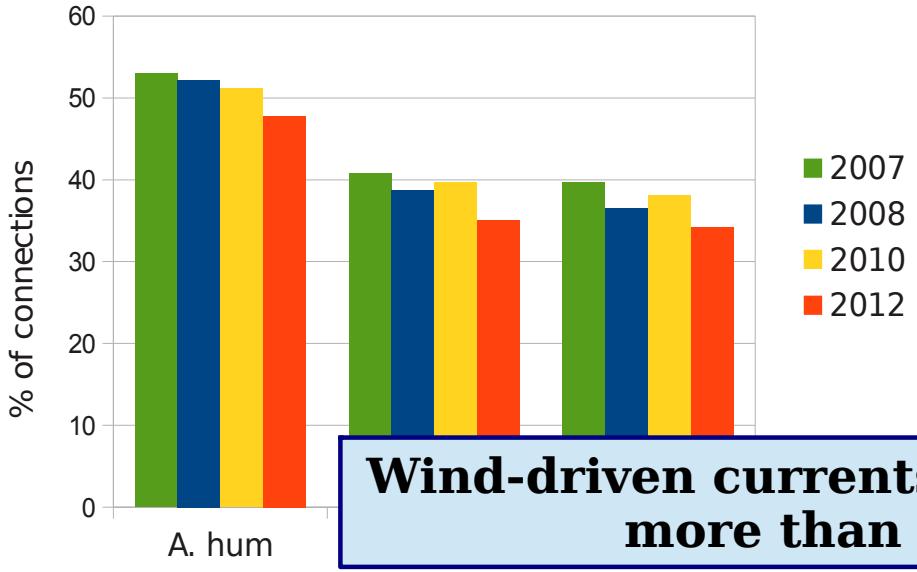

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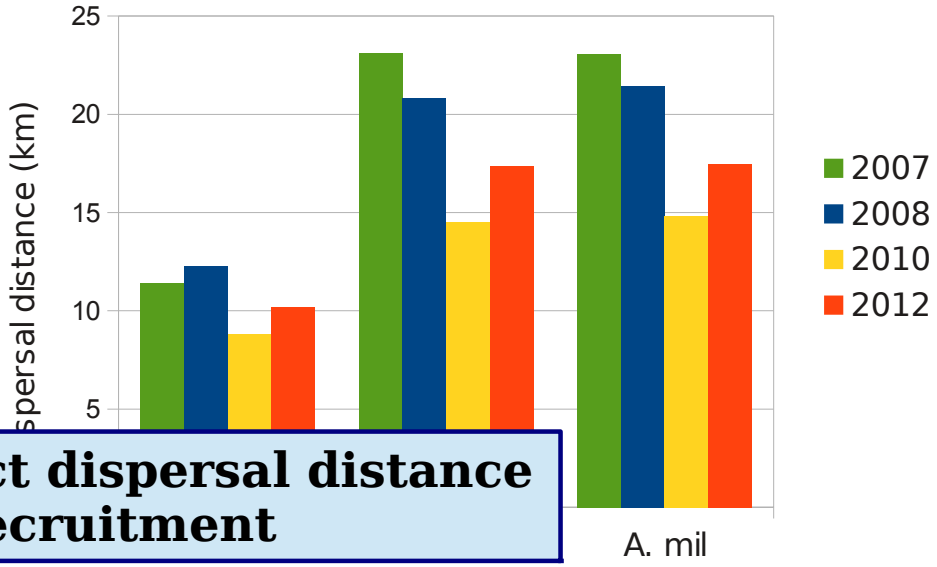

Wind-driven currents affect dispersal distance more than self-recruitment

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Dispersal patterns of **deep reef corals** (30m < Depth < 100m)

→ Can deep reefs repopulate shallow reefs?

→ 3D model needed

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Reference:

C. Thomas, J. Lambrechts, E. Wolanski, V.A. Traag, V.D. Blondel, E. Deleersnijder, E. Hanert (2014) *Numerical modelling and graph theory tools to study ecological connectivity in the Great Barrier Reef*, Ecological Modelling 272 160:174


Thank you for your attention
Questions ...?
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