From Particles to Priorities: Integrating Drift Modeling with Ecological Connectivity in the **Southern North Sea**

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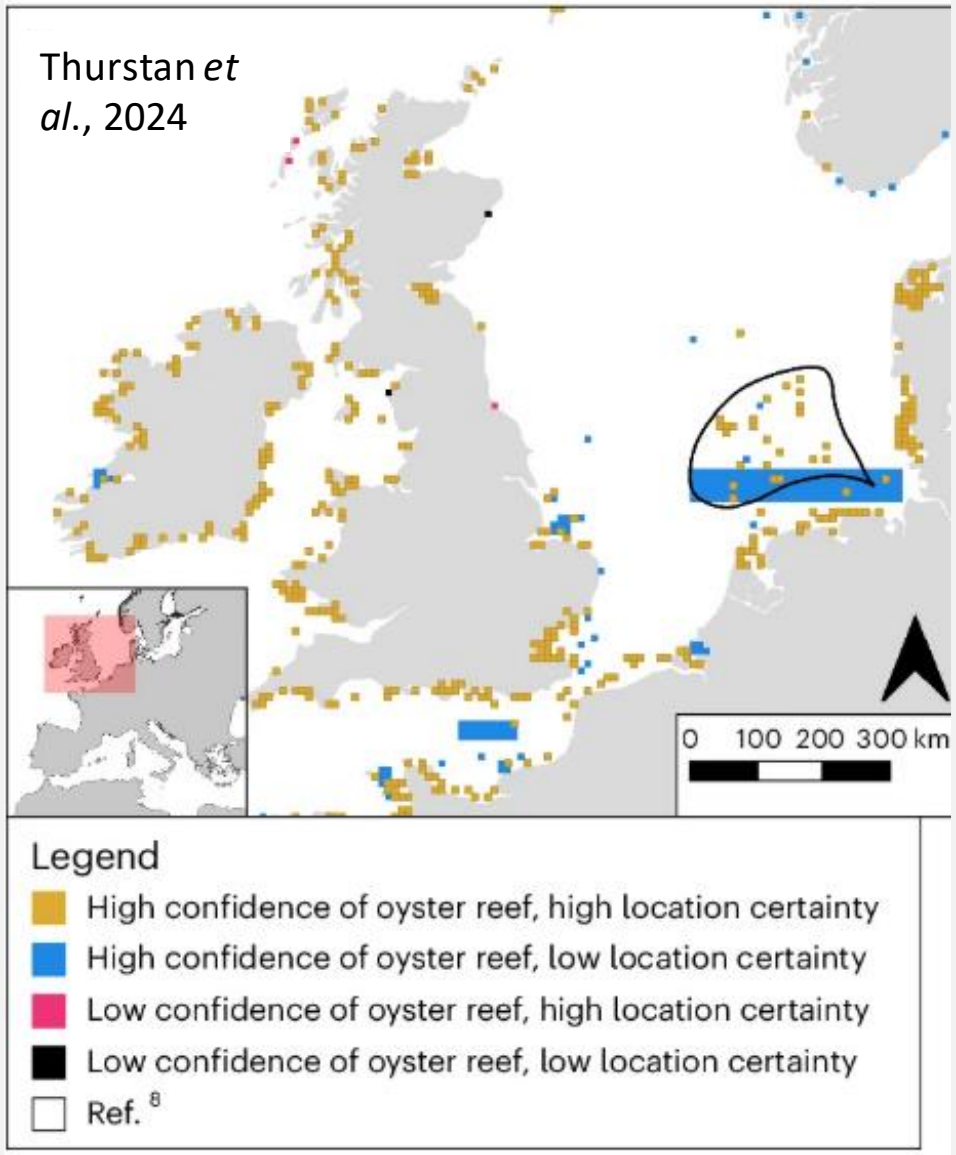
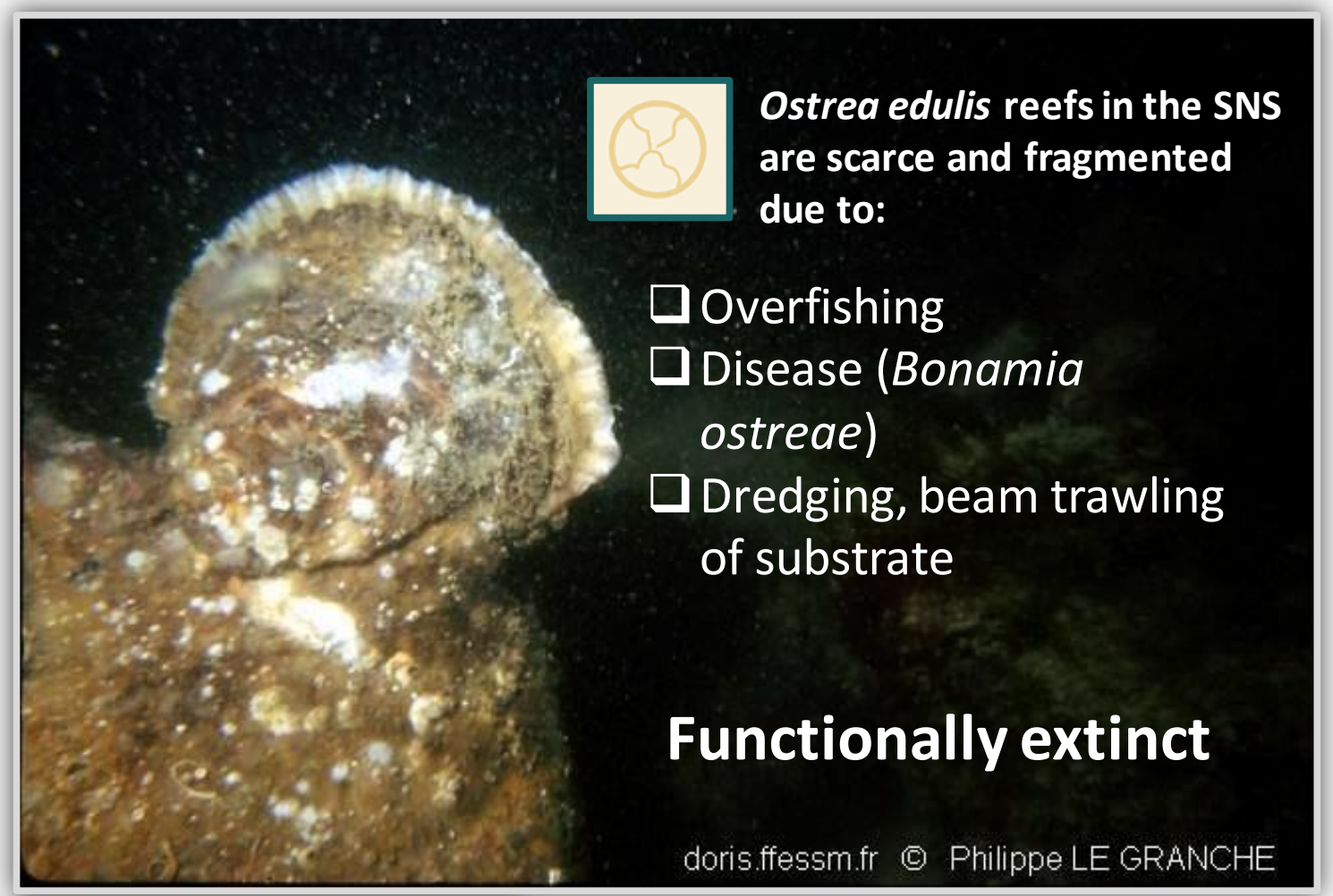
Marine Plan Final Event – Day 2 – 30/09/2025

Ecological Context





Initiatives support **restoration** of *O. edulis, but first:*

How do larvae **disperse**, how are they **transported** and what does that mean for **restoration**?

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Larval Transport Mechanisms

Net passive larval net transport (currents & tides)

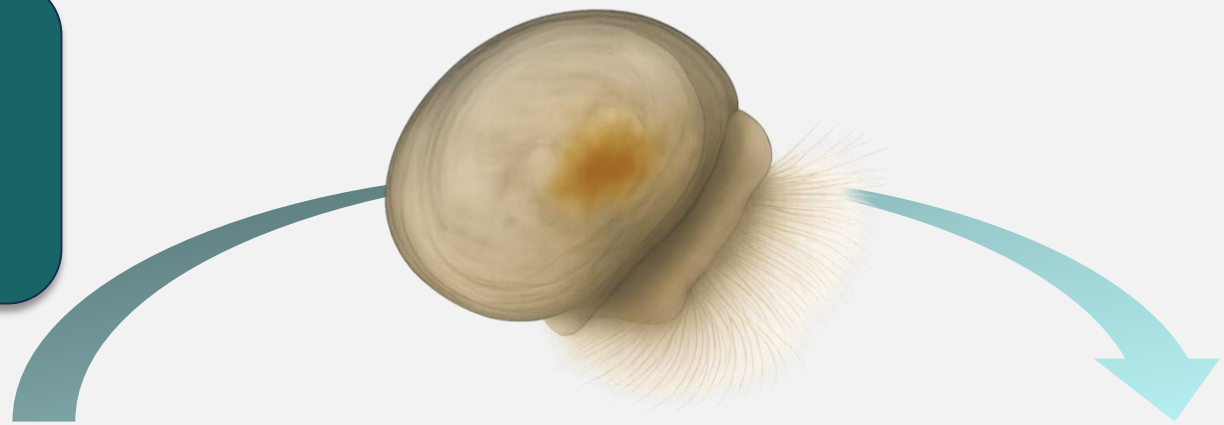
Pelagic larval dispersal

Initial release of **lecithotrophic** (yolk-dependent) larvae

- ❑ Larval behaviour
- ❑ Predation
- ❑ Food availability
- ❑ **Hydrodynamics**
- ❑ **Pelagic larval duration (mid-June-Mid-July, 14 days)**

Dispersal of **planktotrophic** (plankton-feeding) larvae by surface currents

Spawning:
- ❑ Food availability
- ❑ Local hydrodynamic conditions



Settlement success:
- ❑ Substate availability
- ❑ Hydrodynamic conditions

Population A

Population B

Ostrea edulis larvae **drift** → need **stepping stones** to survive

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Population Connectivity

Population: A group of individuals of the same species living and interbreeding within a given area

Genetic Connectivity

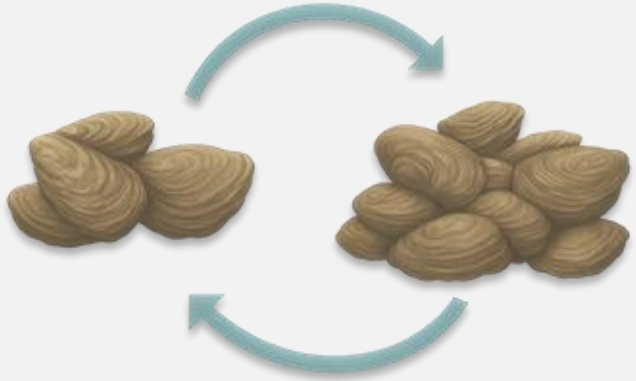
*The degree to which gene flow affects evolutionary processes **within** populations*

Lowe and Allendorf, 2010

Demographic Connectivity

*The degree of exchange of individuals (via immigration or emigration) **between** populations*

After Lowe and Allendorf, 2010



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Why Connectivity Matters for Restoration

Larval (**demographic**) **connectivity** is essential for understanding:

- ❑ Larval **supply**
- ❑ **Recolonisation** after disturbance
- ❑ **Self-sustaining** and persistent populations
- ❑ Restoration efforts/assess potential **success**

Restored **reefs** cannot function in isolation.
Marine spatial planning requires understanding of **larval exchange**.
Need to identify **receiving hotspots** and **key corridors**.

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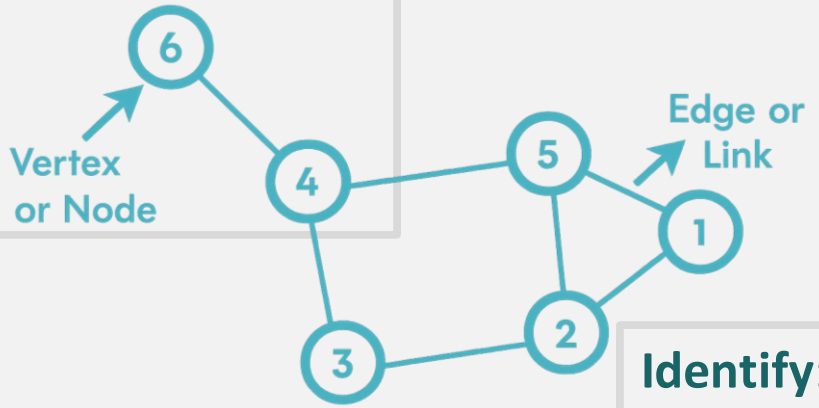
Marine Seascape as a Network

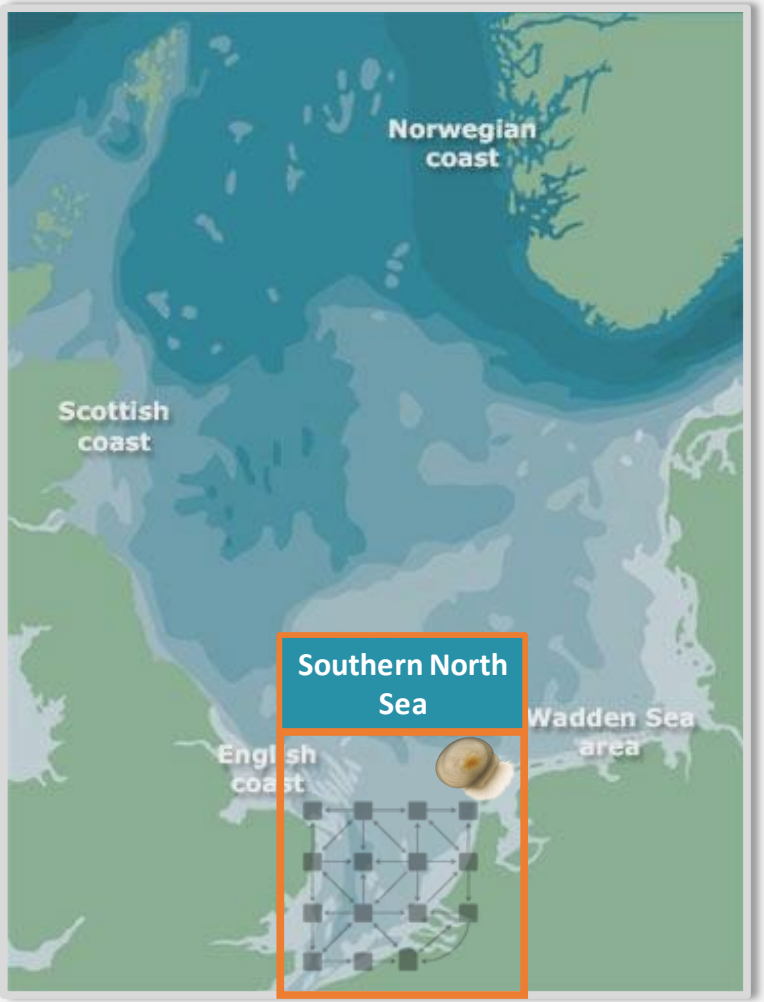
Nodes/Vertices: grid cells or habitat patches

Edges: larval connections from current modelling (e.g., source to sink)

Graph Theory in ecology helps to quantify:

- ❑ Connectivity **strength**
- ❑ Node **importance**
- ❑ **Resilience** potential





Identify: highly connected areas or "**hubs**" in larval transport

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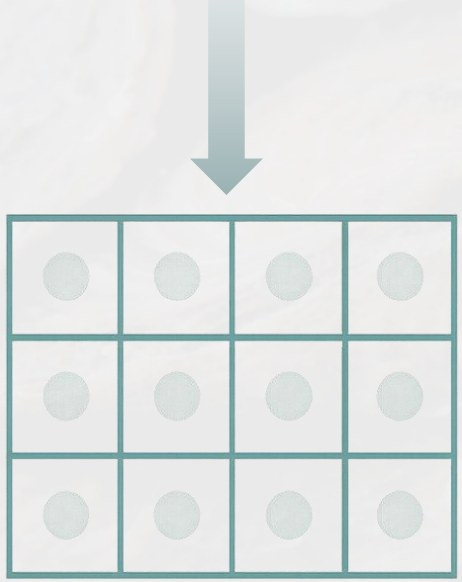
Methods: Connectivity Metrics

Practical applications for **conservation**

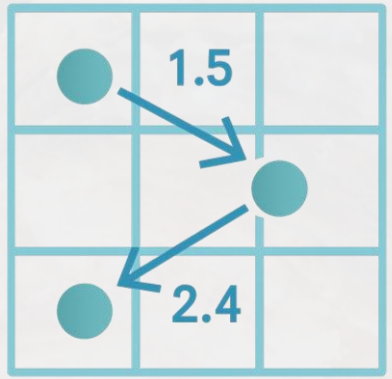
NetCDF model OUTPUT

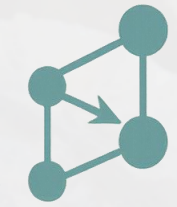
Build a Directed Weighted Graph

Calculate Connectivity Metrics



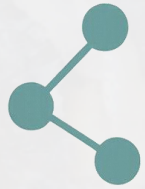
Probability matrix





In-degree

How many other nodes send larvae to this one – ***Connectedness***



In-strength

Probability how much larval flux is received – ***Supply intensity***

Filter or mask nodes that are exact zeros

- ❑ Strategic nodes
- ❑ Corridors
- ❑ Priorities

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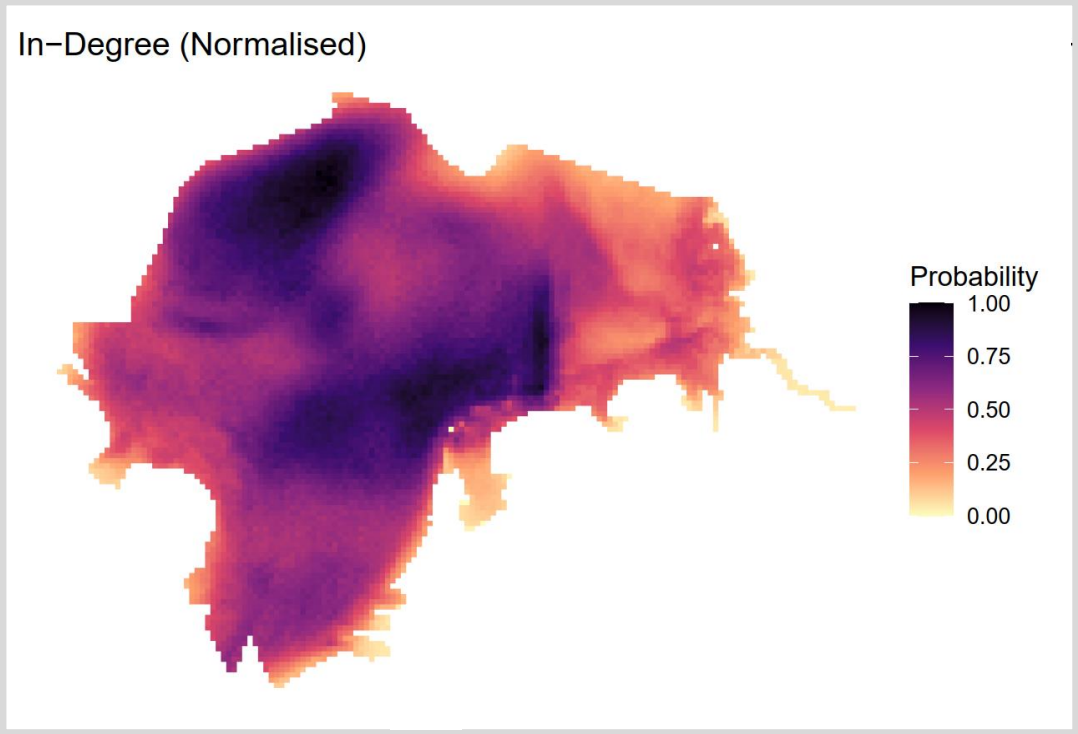
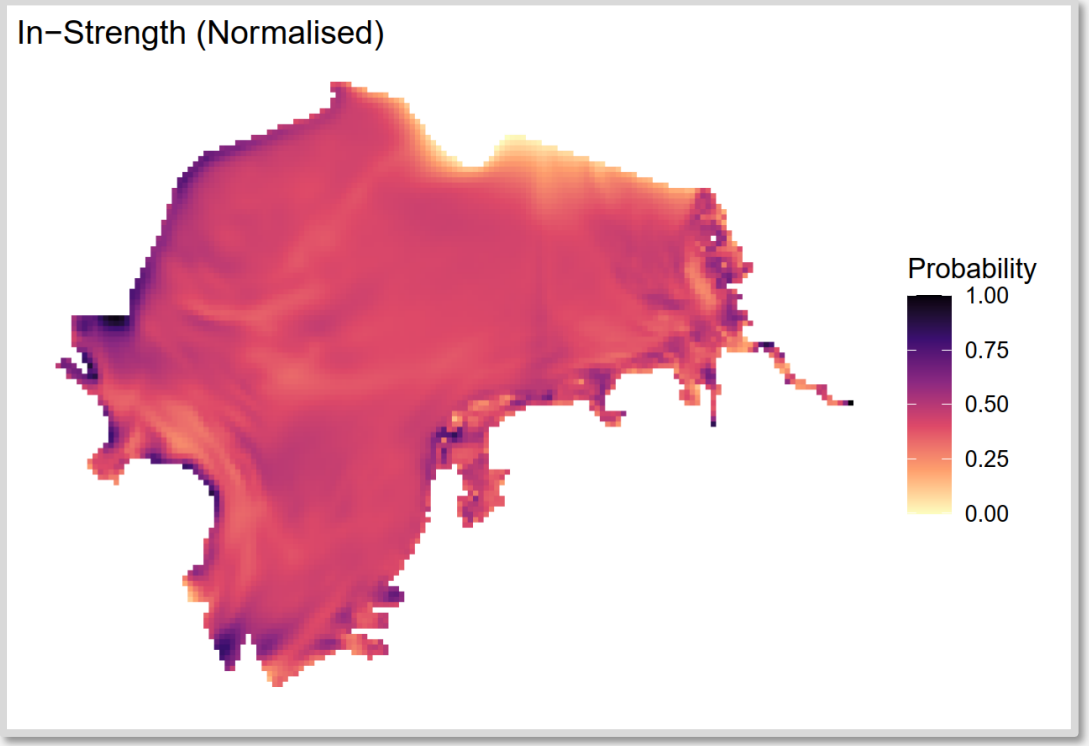
Results: Connectivity Metrics

- Receiving larvae from a wide range of locations
- **Connecting larvae** from many sources

- Receiving larvae in high volume
- High accumulation strength
- Likely larval **aggregation zones**





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- Ecological interpretation: **Sink zones** that might benefit from protection/restoration efforts
- Can inform e.g., the location and boundaries of **MPAs**

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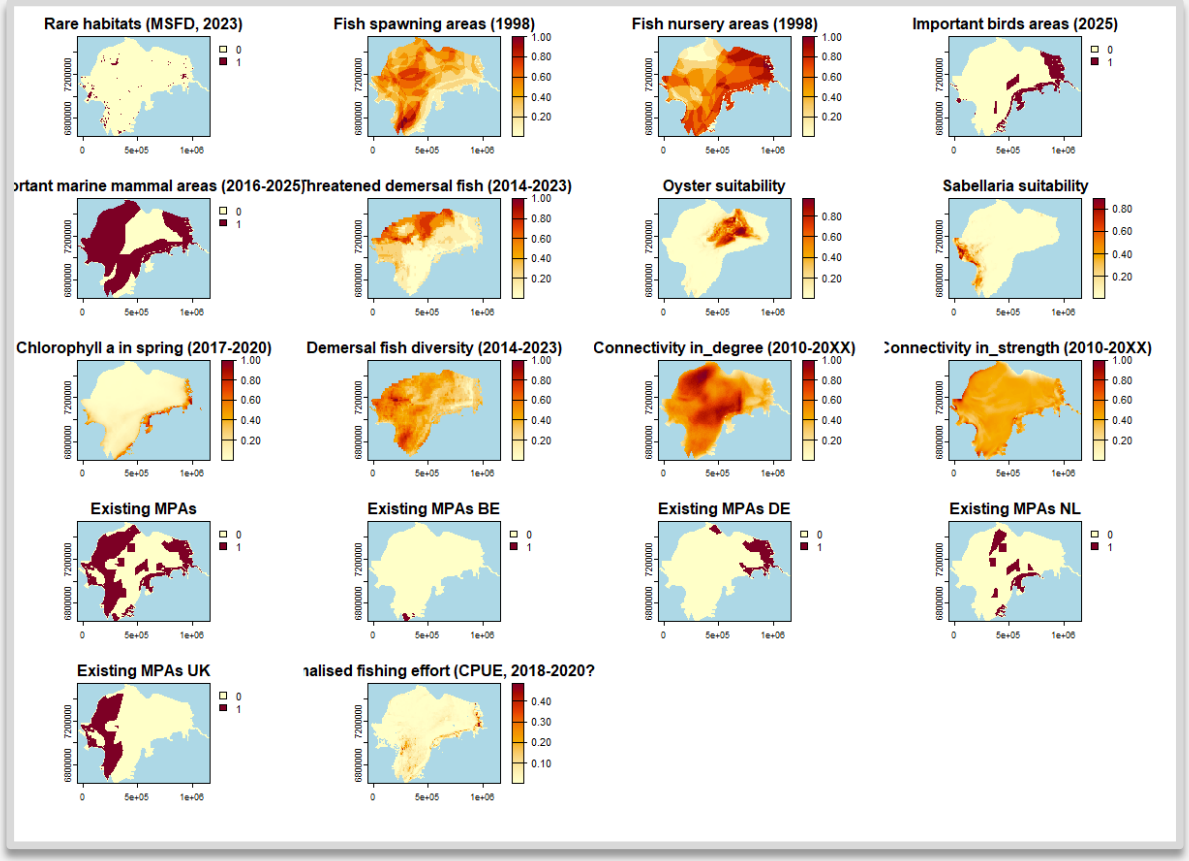
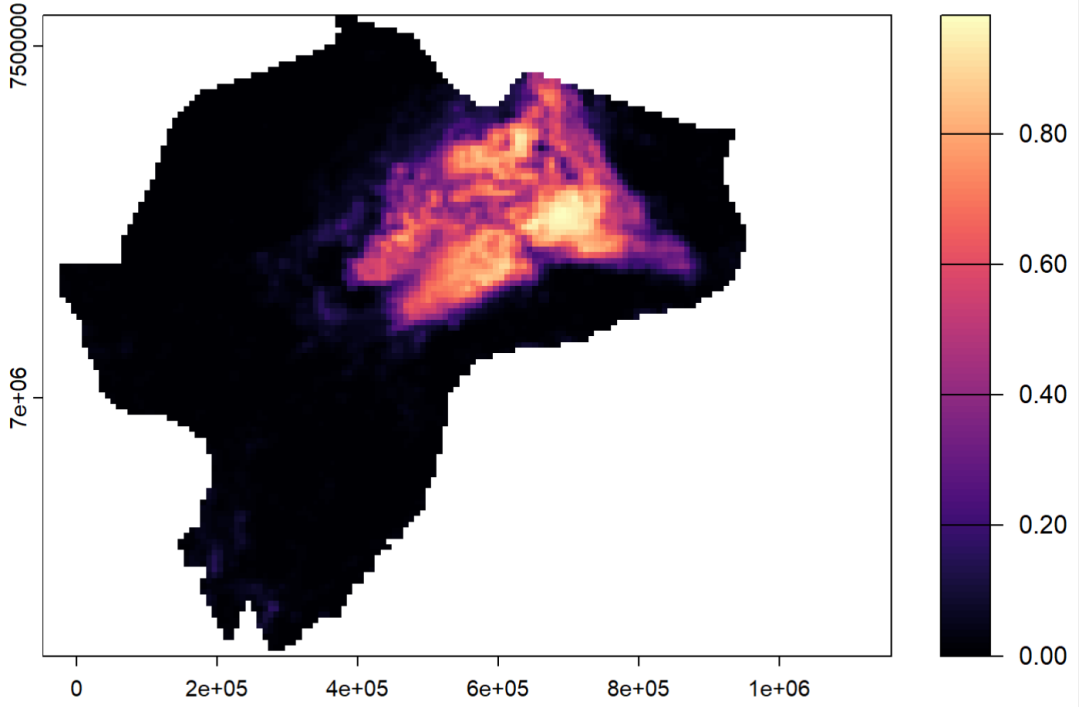
Results: EBSA Layers

Ecologically or Biologically Significant Areas

CBD, 2008



Combining with complementary **predicted oyster suitability** raster may narrow down restoration-ready cells



Sas, et al., 2023

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Oyster restoration target: Could combine **predicted habitat suitability** with connectivity data of both high larval influx and suitable conditions to **identify sink zones**.

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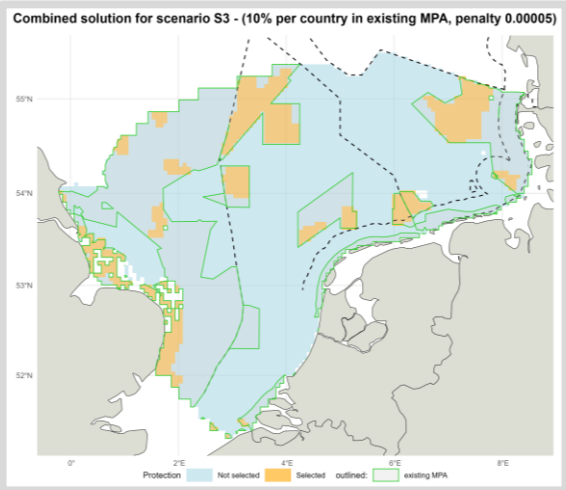
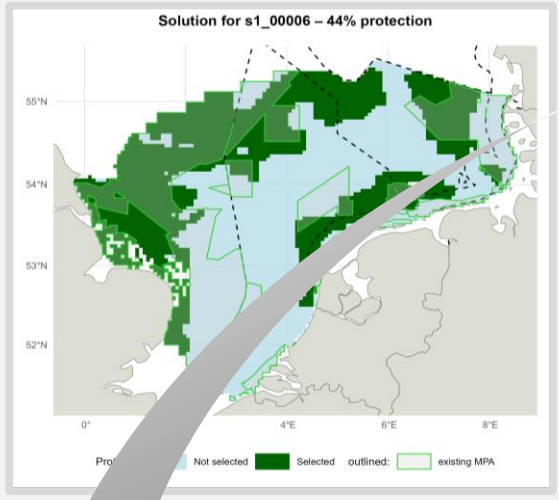
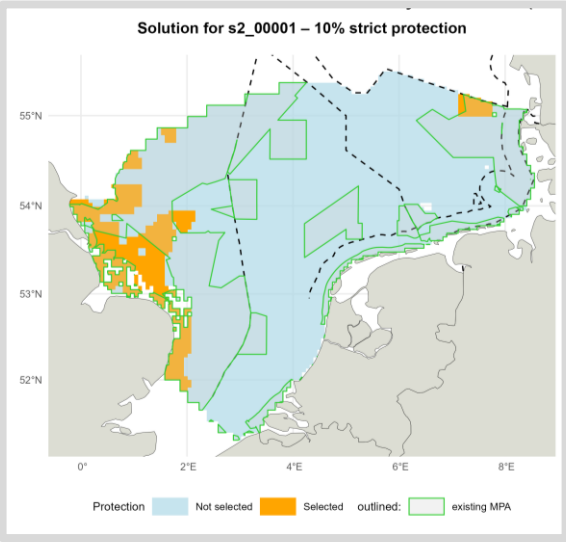
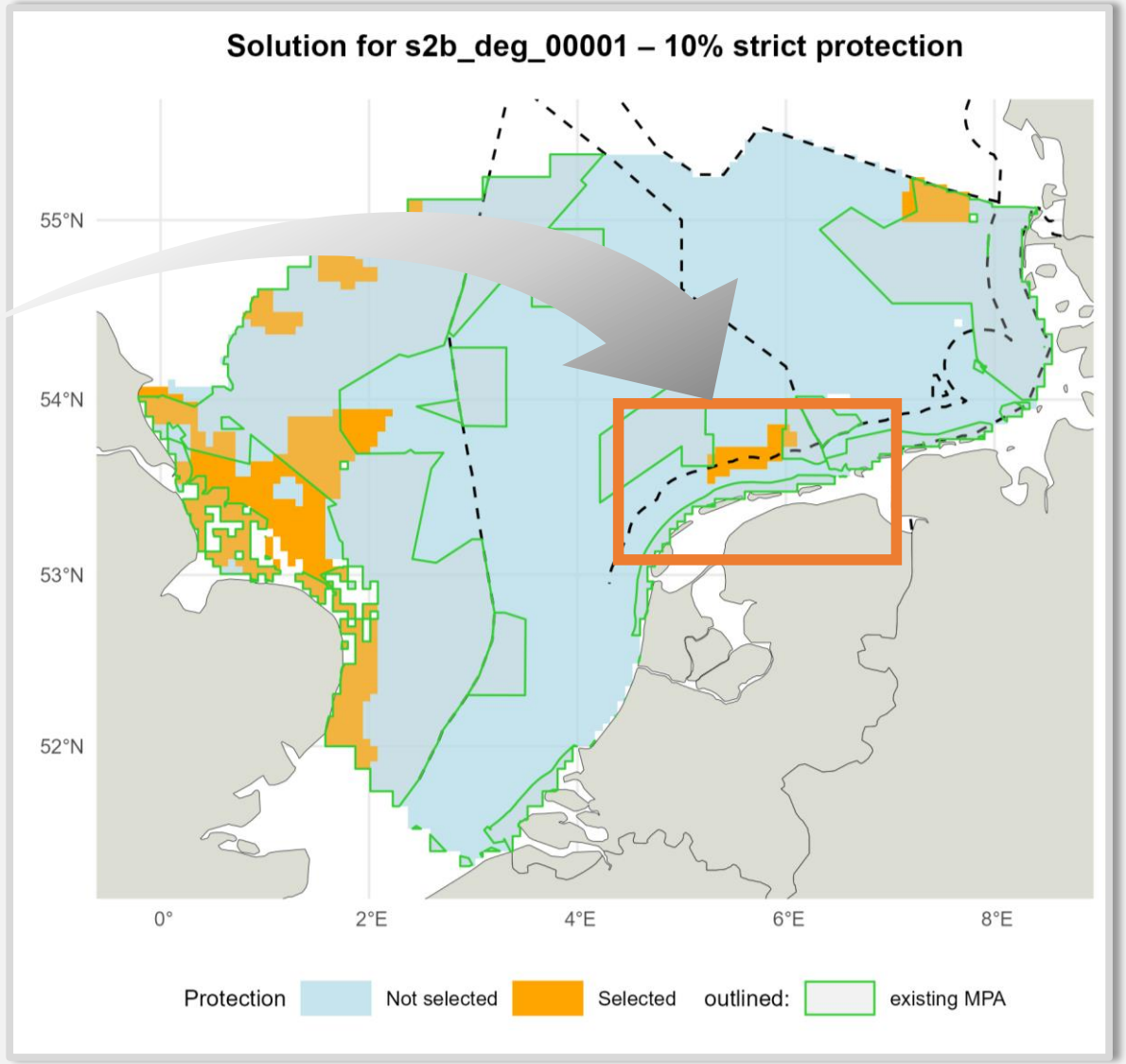
Results: *Prioritizr R*









Southern North Sea map showing the **priority areas** to select to achieve the 10% strict protection target with a focus on ***Ostrea edulis*** reef restoration (**amber polygons**), based on the first application of **EBSA criteria**, particle drift modelling, and intentionally disregarding political boundaries.

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Considerations/Next Steps

Connectivity is only one part of the puzzle. **Stratification** (e.g., near the Frisian Front) and near-bed food limitation are not in the **2D** model (**structural not functional** connectivity)

Particles are **confined** to the **SNS** system, no regional/inter-basin modelling (yet)

Event **start window** is mid-June to end July. **Long-term, inter-annual, seasonality** influence (2010-2024) not yet factored in

No **sensitivity analysis** with spatial/temporal subset or with another forcing model (yet)

No mortality/settlement success → no **nursery** information → would require **monitoring** of the selected sites

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Conclusions

Graph Theory metrics offer evidence-based guidance for a forward-looking planning tool, to identify **widely connected cells** and **larval aggregation zones**.

Including **connectivity** changes **prioritisation** outcomes. Identifies where **populations** would be **supported** if oysters were seeded.

Adopted approach → ID optimal sites for **prioritised restoration** → Avoid costly attempts at restoration undertaken on a trial-and-error basis.

Enables targeted, **ecologically informed restoration decisions** which also support EU biodiversity goals

Still a need for **improved communication** between practitioners and scientists

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Take-Home Messages

- Derived **results** provide a **successful** proof-of-concept for an effective evidence-based **decision support tool**.
- Physical and biological **processes** across the SNS are at a **basin-scale**.
- Consequently, prevailing **policy**, governance, and administrative landscape is too complex and **fragmented** when it comes to effective delivery on many aspects of MSP.

Main **recommendations** from the **SNS** Team

1. **Transboundary** approach. The SNS (or even the NS) should be considered as one entity for MSP.
2. **Communication** and **alignment** of MSP processes/coordinated onset timing, co-design/-planning.
3. **Stakeholder involvement** from the get-go and throughout the planning process.

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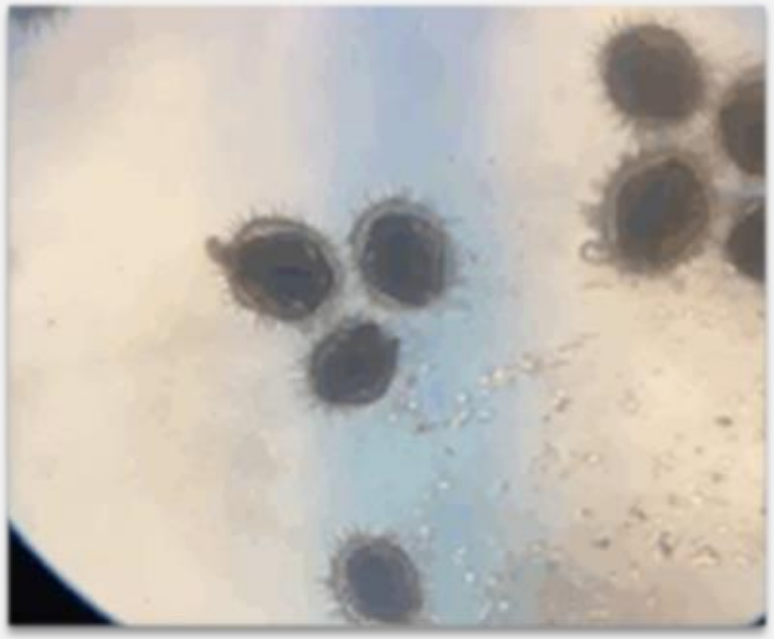
Thank you for your attention!



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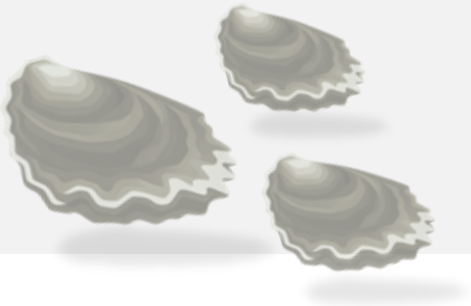

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