Ecological connectivity in reserve prioritisation using simulated reef networks

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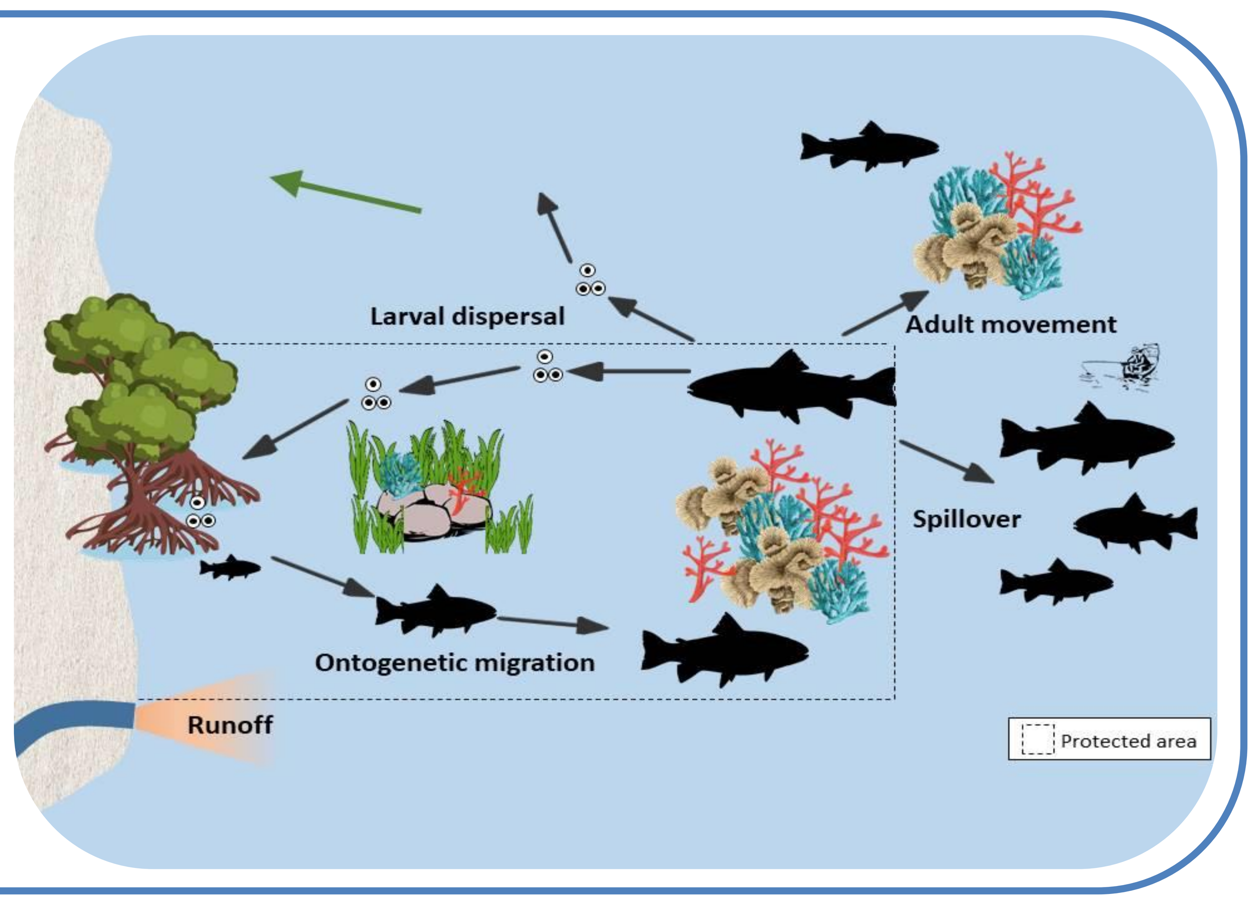
1. Background

Connectivity, the exchange of individuals between habitat patches, drives important dynamics of many marine systems. Greater connectivity improves population recovery following localised mortality events, increases metapopulation viability, enables migratory tracking of favourable climate conditions, and promotes genetic diversity, to give a few examples[1].

For these reasons, planners establishing marine reserves increasingly incorporate data on connectivity in systematic conservation planning.



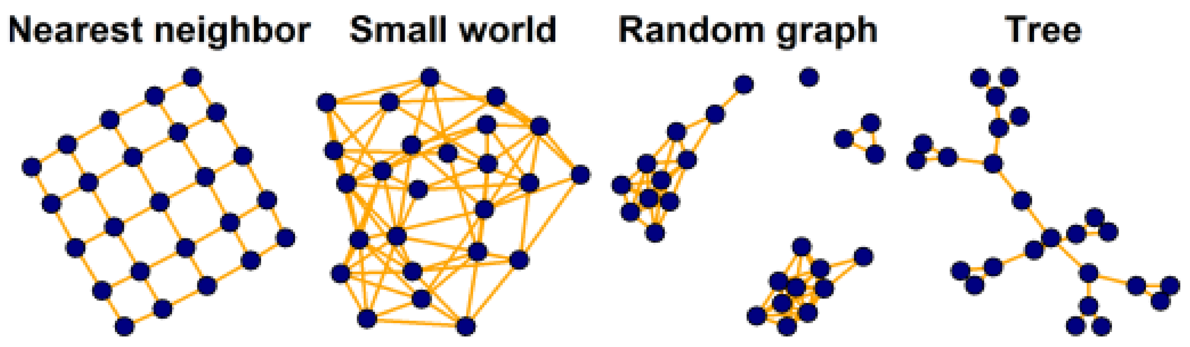
2. Questions

Many approaches have been developed over the years to integrate connectivity in reserve design tools. Here we focus on the most common used in the decision support tool Marxan to answer the following questions:

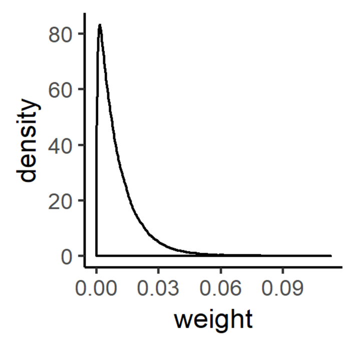
1. How do different methods of incorporating connectivity in spatial planning compare in achieving effective conservation outcomes?
2. Do differences between methods only emerge under certain conditions?
3. What is the value of using more data-intensive and complicated methods?

3. Methods

We simulate reef networks using a graph-theoretic approach where reef patches (nodes) are connected by larval exchange (edges). Different network arrangements (topologies) represent systems with varying levels of mixing and interconnectedness[2].



Larval exchange (edge weight) is sampled from an exponential distribution and patches are given uniform areas and costs.



Next we run Marxan reserve prioritisation to identify a subset of patches for designation as reserves with a 20% habitat target. The following are used to incorporate connectivity in Marxan:

Method 1. Connectivity as spatial dependencies to set the boundary cost between planning units[3]. *(bound.dat in Marxan)*

Methods 2-6. Metrics of connectivity are incorporated as conservation features with 20% targets[4].

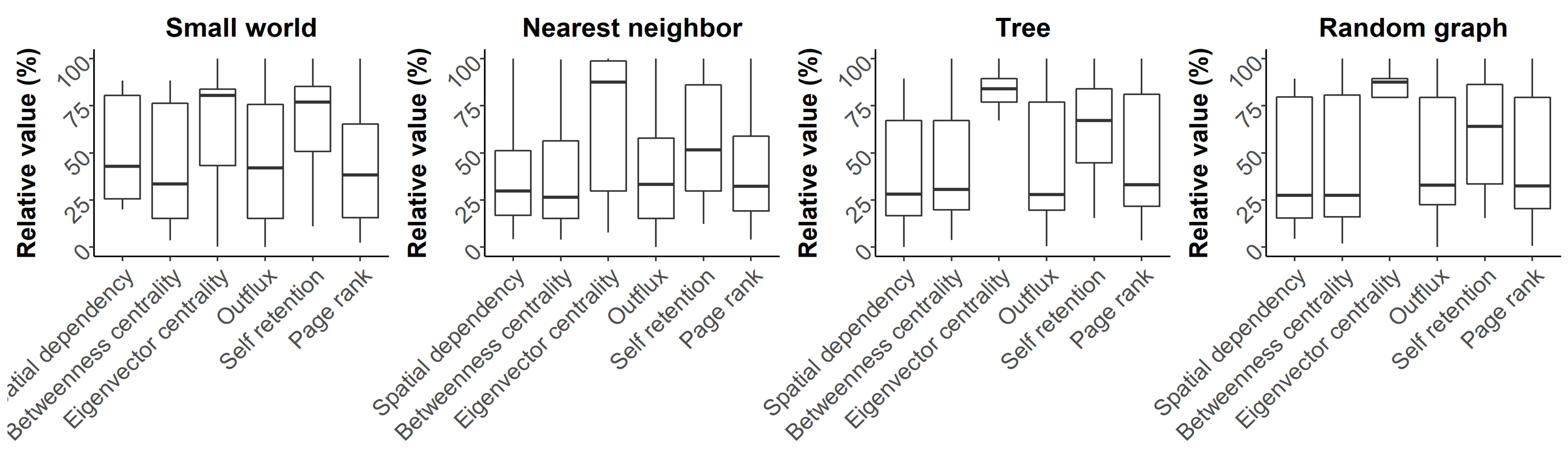
Metric	Possible objective
Betweenness centrality:	prioritise stepping stones
Eigenvector centrality:	prioritise patches influencing overall network
Outflux:	prioritise source patches
Self retention:	prioritise sink patches
Page rank:	prioritise patches influencing overall connectivity

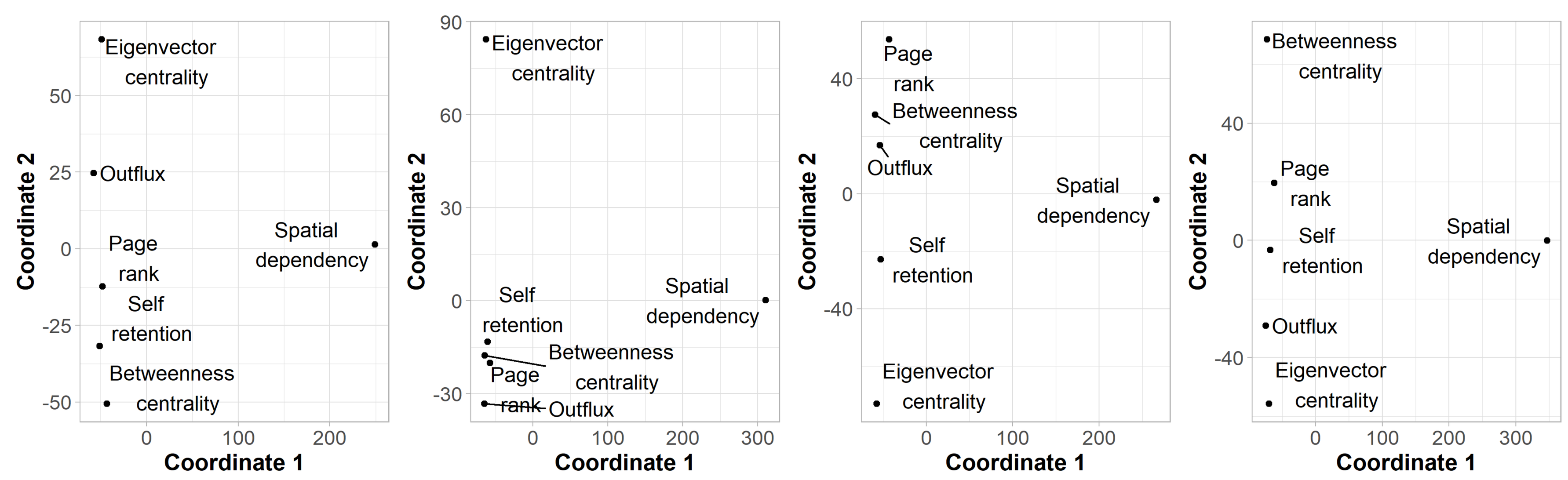
Finally we determine effectiveness of each reserve configuration by calculating metapopulation growth as the first eigenvalue of the larval flow matrix subsetted for patches designated as reserves.

4. Preliminary results

The top row gives metapopulation growth of reserve configurations created with the six methods. Large variability within each method arises from multiple resampling of reef network parameters and use of top ten solutions per Marxan run to calculate growth.

Eigenvector centrality appears to be the best method to achieve highest growth across different network structures, although the large variability makes conclusions tentative.





The bottom row shows the similarity of reserve configurations visualised in multidimensional scaling comparing selection probability of patches by different methods. Methods closer together are more likely to designate the same patches for reserves.

5. Next steps

- Revisit initial network set-up to see whether variability within methods can be reduced;
- Test effects of different probability distributions for larval dispersal kernels and other network topologies;
- Use additional conservation objectives such as metapopulation mean life time and spill over biomass to assess effectiveness of reserve networks;
- Introduce environmental and demographic stochasticity into model parameters;
- Use complex, dynamic models to incorporate metrics of persistence directly in the objective function.

References: 1 Cowen, R. K., & Sponaugle, S. (2009). Larval Dispersal and Marine Population Connectivity. Annual Review of Marine Science, 1, 443–466. https://doi.org/10.1146/annurev.marine.010908.163757
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