Using the power of community detection in marine networks

Keywords: Marine conservation · Clustering · Connectivity · Dispersal· Management

Extended Abstract

Habitat loss, fragmentation, and degradation primarily resulting from human activities pose a significant threat to global biodiversity [1] [2]. The marine environment, in particular, faces increasing human activities such as aquaculture, seabed mining, renewable energy development and coastal development, exacerbating the already crowded seascape occupied by shipping, oil extraction, tourism, and fisheries [3] [4]. Due to these growing pressures, the effective management and monitoring of populations becomes exceptionally urgent, requiring the development of ecologically meaningful planning units or management zones [5]. Over the past few decades, efforts have been made to delineate marine systems into management zones, and in the last 20 years these systems have been conceptualized as networks, enabling the identification of distinct communities within them [6]. The application of network theory has since become integral to understanding ecological landscapes [7]. Here, networks consist of a set of nodes (e.g., habitat patches, islands or populations) connected by edges or links (e.g., animal movement or dispersal probability). In ecology, strongly connected nodes can be interpreted as single ecological units with strong interactions and cohesive dynamics. In network terms, tightly grouped nodes are considered communities that exhibit a higher likelihood of connecting to each other than with nodes from other communities [8] [9]. Applying these network-based community detection algorithms to the marine seascape can help efficiently identify ecologically relevant planning zones. This novel network perspective for quantifying emergent structure in ecological systems is particularly relevant in the marine environment, where applications range from selecting marine protected areas and delineating fisheries zones, to managing and monitoring marine pollution and invasive species. Despite these advantages, there is no consensus on the best approach or algorithms for identifying ecologically meaningful communities. This study evaluates 9 community detection algorithms and demonstrates their effectiveness using two marine case studies: a larval dispersal network and a ship traffic network.

We show where algorithms generally agree in detecting communities and highlight the importance of aligning the nature of the algorithm, connectivity data, and management goals. We also suggest that disagreements between algorithms may indicate areas where management boundaries should be flexible or fluid to better reflect the system's true nature. This study proposes an improved approach to partitioning of these systems and provides recommendations for optimal conservation and management outcomes.

References

[1] Pereira, H. M. et al. Scenarios for global biodiversity in the 21st century. Science (1979) 330, 1496–1501 (2010).
[2] Halpern, B. S. et al. Spatial and temporal changes in cumulative human impacts on the world's ocean. Nat Commun 6, 1–7 (2015).
[3] Spalding, M. D. et al. Building towards the marine conservation end-game: consolidating the role of MPAs in a future ocean. Aquat Conserv 26, 185–199 (2016).

[4] Lubchenco, J. *et al.* Priorities for progress towards Sustainable Development Goal 14 'Life below water'. *Nat Ecol Evol* **7**, 1564–1569 (2023).
[5] Margules, C. R., & Pressey, R. L. (2000). Systematic conservation planning. Nature, 405(May), 243–253.
[6] Berline, L. O., Rammou, A.-M., Doglioli, A., Molcard, A. & Petrenko, A. A Connectivity-Based Eco-Regionalization Method of the Mediterranean Sea. PLoS One (2014) doi:10.1371/journal.pone.0111978.
[7] Treml, E. A. & Halpin, P. N. Marine population connectivity identifies ecological neighbors for conservation planning in the Coral Triangle. Conserv Lett 5, 441–449 (2012).
[8] Radicchi, F., Castellano, C., Cecconi, F., Loreto, V.& Parisi, D. Defining and identifying communities in networks. *PNAS* **101**, 2658–2663 (2004).
[9] Newman, M. E. J. & Girvan, M. Finding and evaluating community structure in networks. Phys Rev E 69, 1–16 (2004).

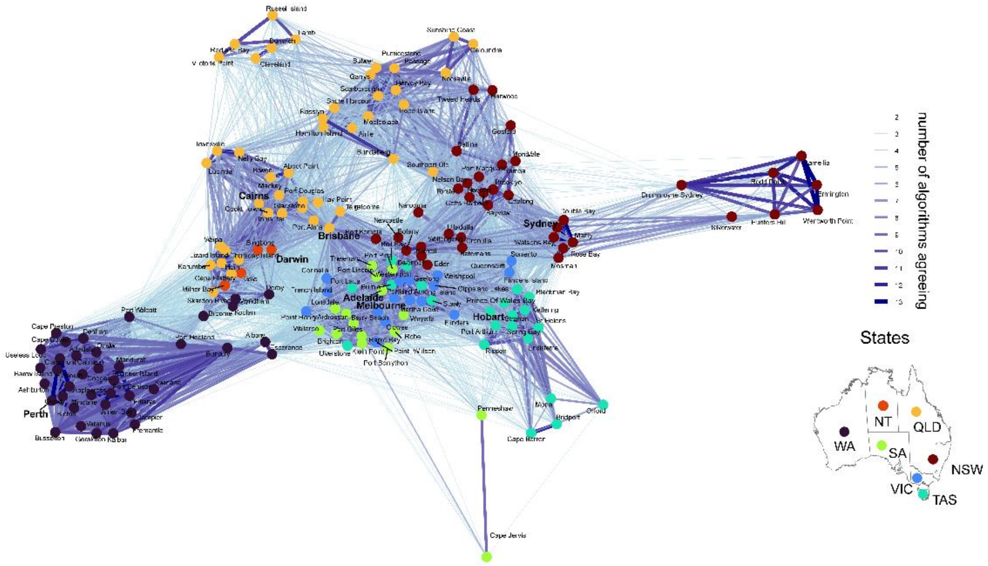

Figure 1. **Traffic network of Australian ports**. Nodes are coloured by state, representing New South Wales (NSW), Northern Territory (NT), Queensland (QLD), South Australia (SA), Tasmania (TAS), Victoria (VIC) and Western Australia (WA). Edges represent the number of algorithms that agree to cluster a given node i to a node j. The layout for this network places nodes according to the force-directed algorithm of Fruchterman and Reingold. Figure created using R v.4.2.2 (www.r-project.org).