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Dependence of network metrics on model aggregation and throughflow calculations: Demonstration using the Sylt–Rømø Bight Ecosystem

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ABSTRACT

In this paper, we use data gathered from the Sylt–Rømø Bight Ecosystem in Germany to conduct an ecological network analysis. Specifically, we perform Network Environ Analysis to compare with results already published using EcoPath, which incorporates the ecological network analysis package NETWRK.

We focus on the issue of model aggregation in that the Sylt–Rømø Bight Ecosystem has data sets representing nine subsystems. We find that the network properties total system throughflow, cycling, indirect effects ratio, and path proliferation are not affected by aggregation whereas connectivity, homogenization, and synergism are affected. The most interesting result to emerge from this analysis is that careful attention is needed to the different use of total system throughflow and total system throughput (both of which are called TST in the literature). As a result of this difference, the calculations for the Finn Cycling Index differ between the various ecological network analysis packages. Noting that Finn based his index on the total system throughflow approach, a consistent method should be adopted if the metrics are reported as FCI. Further work is needed to determine if a simple correction factor can be applied to the NETWRK and EcoPath values or if the coding algorithms should be changed to reflect the FCI approach.

1. Introduction

Ecological network analysis (ENA) is a popular methodology to investigate whole system interactions and properties. Two distinct branches of ENA developed largely independently over the years starting in the 1970s with Network Environ Analysis (Hannon, 1973; Finn, 1976; Patten, 1978, see Fath and Patten, 1999 for a summary) and ascendency analysis in the 1980s (Ulanowicz, 1986, 1997). The first approach, Network Environ Analysis (NEA), was based on the Leontief's (1966) input–output analysis of monetary flows and adapted to energy and nutrient flows in ecosystems (Hannon, 1973). The second approach, ascendency analysis had its motivation from information theory (Rutledge et al., 1976) and the conditional probability of flow occurring along pathways of the network. Both methods have developed in parallel with promising and productive results in the theoretical and applied literature. Some research to compare the two methods has been published (Scharler and Fath, 2009; Latham, 2006), but overall there are some subtle differences that exist between the two approaches that are just now being thoroughly investigated as more collaborations between the different network groups ensued. This is important because to the novice, these approaches seem identical in many ways, such as in the use of the similar language (particularly TST), and therefore have been used interchangeable, when in fact there are differences which give different result. The goal of this paper is to use a common data set to compare the two approaches. We uncovered an important point that needs to reach the community of users of these methods regarding the reporting of the Finn Cycling Index (Finn, 1976), a measure commonly used to describe the degree of recycling within systems. Another objective of this paper is to investigate the influence of model aggregation on the resulting network properties.

Consistency in ecological modeling is hindered by the "modeling problem." In other words, the conceptualization of how the researcher envisions the system and the subsequent selection of state variables and interconnections. This is both the science and art of transforming a real system into a mathematical object. It can be influenced by focus on particular aspect of the system as well as data availability, or many other factors. The end result is that there are many possible representations of the system. A particular aspect of this that has been studied is the question of lumping

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or splitting into fewer or more state variables (e.g., Abarca-Arenas and Ulanowicz, 2002; Cale and O'Neill, 1988; Cale and Odell, 1979; Gardner et al., 1982; Pinnegar et al., 2005).

Since network properties are highly dependent on size and connectivity it makes sense that aggregation would impact these values. Baird et al. (2009) looked at the issue of aggregation using the entire Sylt Rømø data set in terms of three different scales: 18, 36, and 59 compartments. In a more recent study Baird et al. (2011) constructed 9 subsystem models and here we investigate the difference in network values based on whether it is analyzed with all 59 compartments or only that subset actually present in the subsystem.

2. Site description and data

The Sylt–Rømø Bight is a semi-enclosed basin between the islands of Sylt, Germany, and Rømø, Denmark, and is connected to the North Sea by a 2.8 km wide channel between the two islands (Fig. 1, from Baird et al., 2011). Detailed site description is given by Baird et al. (2011). Briefly, in 2009, the Wadden Sea, which the Bight belongs to, was declared a World Heritage Site by UNESCO. The Bight covers about 404 km^2 with an inter-tidal area of about 135 km^2. Water temperature ranges between −1 and 20, and salinity remains high (28–32‰) on the border between brackish and seawater since there is little fresh water discharged into the Bight. The average depth is 4.2 m at high tide, with a tidal range an average of about 2 m. The different habitats host different plant and animal communities in the inter-tidal reach of the Bight, while the sub-tidal area consists mainly of a sandy substrate which is rather poor in benthic macrofauna (Asmus and Asmus, 1998). The inter-tidal region is conceptualized in nine sub-ecosystems identified according to the dominant plant and faunal communities and by their characteristic habitat substrate, and are named accordingly. They include: (1) Pelagic domain, (2) Mussel beds, (3) Arenicola flats, (4) Sparse *Zostera noltii* beds, (5) Dense *Z. noltii* beds, (6) Mud flats, (7) Muddy sand flats, (8) Sandy shoals, and (9) Sandy beaches. The various inter-tidal sub-systems are contiguous, but nevertheless different due the nature of the substrate of each, and by its characteristic species diversity and abundance.

The Sylt–Rømø Bight Ecosystem data have several unique features. First, the entire ecosystem is represented by a 59 compartment network model (Baird et al., 2011). Furthermore, data characterize multimedia in that separate flow and storage values are available for carbon, nitrogen, and phosphorus in the ecosystem. In this way, one can investigate different layers of activity of the different currencies. In addition, the ecosystem is partitioned into nine subsystems. These nine subsystems each comprise some subset of the total list of 59 compartments. And, although the

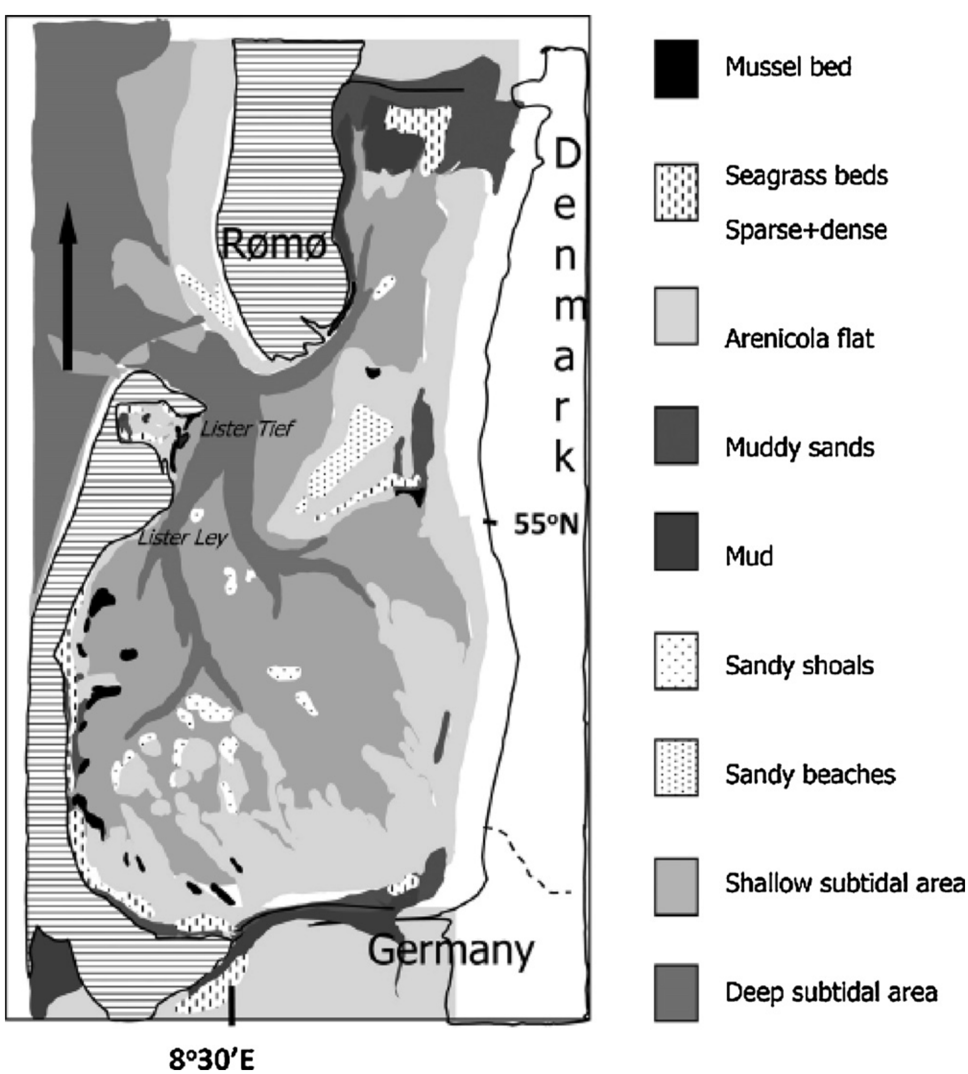

Fig. 1. Location of the Sylt–Rømø Bight Ecosystem and the nine subsystems.

From Baird et al. (2011).