## ICES CM 2012/A:23

# Atlantic and Arctic food web topologies of the Barents Sea (poster)

Susanne Kortsch, Michaela Aschan, Benjamin Planque, Magnus Aune Wiedmann, Lis Lindal Jørgensen, Padmini Dalpadado, Mette Skern-Mauritzen, Edda Johannesen, Kathrine Michalsen, Grégoire Certain, Sabine Cochrane & Raul Primicerio

**Extended abstract**

**Abstract**
The resilience of an ecosystem to environmental perturbations can be evaluated by analysing food web structure. Food web topology, the ensemble of species and their network of trophic interactions, can be described using a variety of metrics. Each topological metric or descriptor, including species richness, degree of connectedness, compartmentalization and omnivory, has implications for the dynamics, e.g. stability and resistance, of ecological communities. A better ecological understanding of ecosystem resilience can be achieved via assessment of the topological properties, and how the specific metrics relate to the dynamics of the system. Here we present an analysis of the food web topologies for the Atlantic and the Arctic regions of the Barents Sea. The Atlantic food web consists of 122 species and 958 links, whereas the Arctic food web consists of 79 species and 491 links. Yet, degree of compartmentalization and omnivory did not differ much. The food web metric that showed greatest difference between the areas is connectance, i.e. the proportion of possible links in a food web that actually occur. The food web topologies for these two regions are discussed in the context of ecosystem resilience.

Keywords: Trophic interactions, Food web structure, Compartmentalization, Ecosystem Resilience, Barents Sea

*Contact author: Susanne Kortsch, Norwegian College of Fishery Science, Faculty of Biosciences, Fisheries and Economics, University of Tromsø, Breivika, 9037 Tromsø. Email: susanne.kortsch@uit.no*

## Introduction

"*A better understanding of the properties that sustain the persistence of diverse ecosystems and their functions is crucial at this time of rapid environmental change and habitat loss, when perturbations of structure are unavoidable*" (M. Pascual & J. Dunne, 2006)

### The Barents Sea

The Barents Sea (BS) ecosystem is one of the richest, cleanest and most productive in the World (NorACIA 2010). It spans from Arctic waters in the northeast to Atlantic water in the southwest. It is an important nursery and feeding ground for commercial fish stocks such as cod, capelin and herring, and thus plays a great ecological and socio-economical role (Sakshaug et al. 2009).

The BS is exposed to both natural and human-induced perturbations. Apart from fisheries, the BS has, over the past 30 years, experienced a rise in temperature and a concurrent decline in sea-ice (Kortsch et al. 2012). These changes have already led to improved marine access for maritime transports and petroleum exploitation (NorACIA 2010). Activities that will put further pressure on the ecosystem. The individual impacts, but also the combined effects from all the stressors might result in reduced resilience of the ecosystem to perturbations such as fisheries (Planque et al. 2010).

At the core of an ecosystem is the food web that through trophic interactions maintains the flow of energy and biomass. Substantial reorganizations of the food web structure may be expected due to losses and gains of species as a response to climate change and fisheries, changing the pathways of energy transfer (Wassmann et al. 2011).

If one seeks to understand ecological resilience of ecosystems undergoing changes due to man-made or natural perturbations, it is important to investigate the structure of food webs in order to identify which food web properties, and which species may be important in maintaining a given ecosystem structure and function.

### Food web topology

The study of food web structure can be performed via a topological approach. Food web topology provides a description of the network of trophic interactions. The building blocks are the species and their interactions.

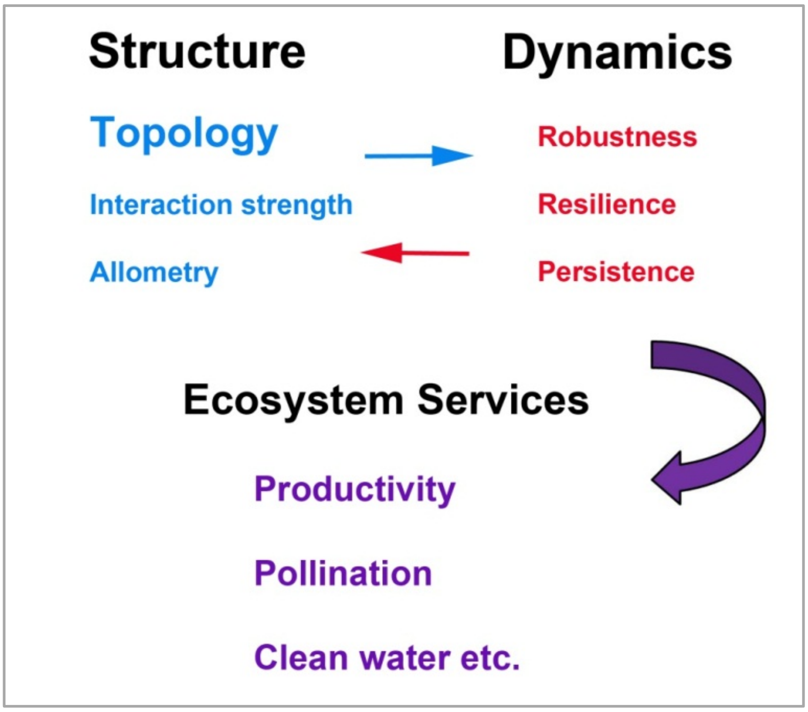



**Fig. 1.** Flow diagram showing how food web structure relates to the dynamics of the ecosystem, and how this, in turn, impacts on the services that ecosystems can provide (Redrawn from Pascual & Dunne, 2006).

Many topological descriptors (app. 15) have been presented in the literature (Dunne 2009). In the present work emphasis will be placed on three important food web properties: degree of connectance, compartmentalization and omnivory. All three have implications for the dynamics and functioning of ecosystems (Fig. 1, Pascual and Dunne, 2006).

Connectance is defined as the proportion of realized links relative to all possible links in the food web. Connectance influences the stability of communities (MacArthur 1955, May 1972, Dunne et al. 2002). Compartmentalization refers to the existence of subgroups of species interacting more with each other than with other subgroups. Compartmentalization is suggested to be of particular importance for the resilience of a food web, as it may determine the degree to which perturbations (e.g. from fisheries) will propagate through it. Theoretically, perturbations will propagate faster within compartments than between them (Krause et al., 2003), which implies that compartmentalisation may act as buffer to perturbations at the level of the entire food web. Omnivory is defined as feeding on more than one trophic level (Dunne 2009). Like connectance, the degree of omnivory of a food web influences community stability (Pimm and Lawton 1978, McCann and Hastings 1997). The present work investigates the food web topologies for the Atlantic and the Arctic regions of the Barents Sea. The food web topologies for these two regions are here discussed in the context of ecosystem resilience

## Methodology

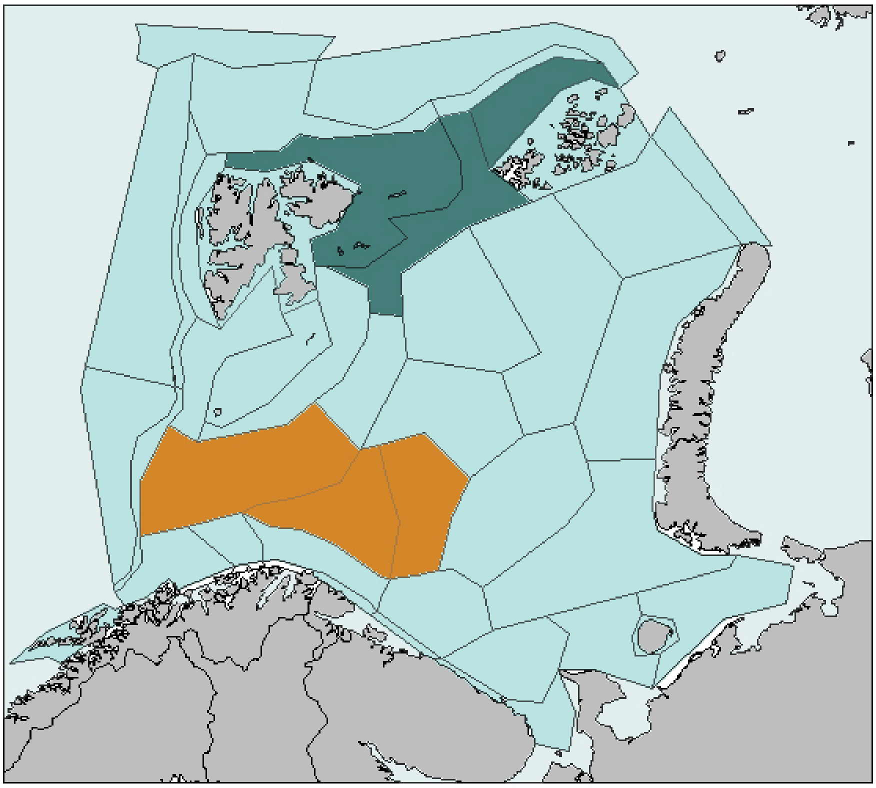
The topological calculations are based on a Barents Sea food web matrix that expands the one previously published by Bodini et al. 2009. Some species of the Bodini et al. topology were excluded, whereas others were included according to the following selection criteria: abundance (high), spatial distribution and existing knowledge of trophic relationships. The criteria were developed to avoid including species that are negligible when it comes to numbers of individuals or biomass, or those whose distribution is very restricted spatially or temporally, or for which no knowledge exists on their feeding relationships. In total 240 trophospecies are included in the matrix. Both pelagic and benthic trophospecies are included, spanning five trophic levels. Our food web matrix represents the whole Barents Sea, but for the purpose of topological analysis of realized food webs, we choose subsets of species and their interactions specific for given regions. To select species specific for the Atlantic and Arctic regions we relied on spatial presence-absence data based on the Russian-Norwegian Ecosystem survey database. The BS was subdivided into polygons (Fig. 2.A). For the purpose of this study, three Atlantic (orange) polygons and three Arctic (dark green) polygons were chosen. The areas were chosen based on cluster analysis of communities (species present in the polygons) and hydrographic parameters (e.g. salinity, depth, temperature). We compared connectance, compartmentalization and omnivory in these two regions.

## Results & discussion

The Atlantic region is more species-rich compared to the Arctic based on our food web matrix and based on the polygons chosen (Fig. 2b, Table 1). Doubling the number of species doubles the number of links. The most evident difference in the investigated topology between the two areas is connectance. Connectance, which is the relative number of realized links out of all possible, is lower for the Atlantic than for the Arctic region. Connectance ranges, typically, between 0.02- 0.3 depending on the food web investigated (Dunne 2009). For highly resolved food webs connectance is higher because of better knowledge about the species and their feeding links. This also means that connectance in many food webs is under-estimated. The resolution in our matrix is (number of feeding links) probably also underestimated, but fall within the range of previously investigated food webs. Connectance influences the stability of food webs. In the literature, it is debated whether connectance stabilizes or destabilizes food webs. The views on this questions are many and sometimes opposite (MacArthur 1955, May 1972, Dunne 2002). The discussion might be a reflection of the different configurations of food webs expressed in nature.

Atlantic and Arctic regions of the Barents Sea

A



B

| | S | L | Conn | Comp | Omni | Top | Int | Bas |
|---|---|---|---|---|---|---|---|---|
| Atlantic | 122 | 958 | 0.06 | 0.24 | 0.2 | 29 % | 64 % | 7 % |
| Arctic | 79 | 491 | 0.08 | 0.28 | 0.19 | 40 % | 51 % | 9 % |

**Fig. 2**. **A)** The study area in the Barents Sea. The Atlantic (orange) and Arctic (dark green) regions, chosen for the topological food web analysis, are highlighted. **B**) Table of preliminary results of the topological descriptors is included in the figure, see Table B below: S= Number of species, L= Number of links, Conn=Connectance, Comp=Compartmentalization, Omni=Omnivory, Top= Percentage of top taxa, Int= Percentage of intermediate taxa, Bas= Percentage of basal taxa.

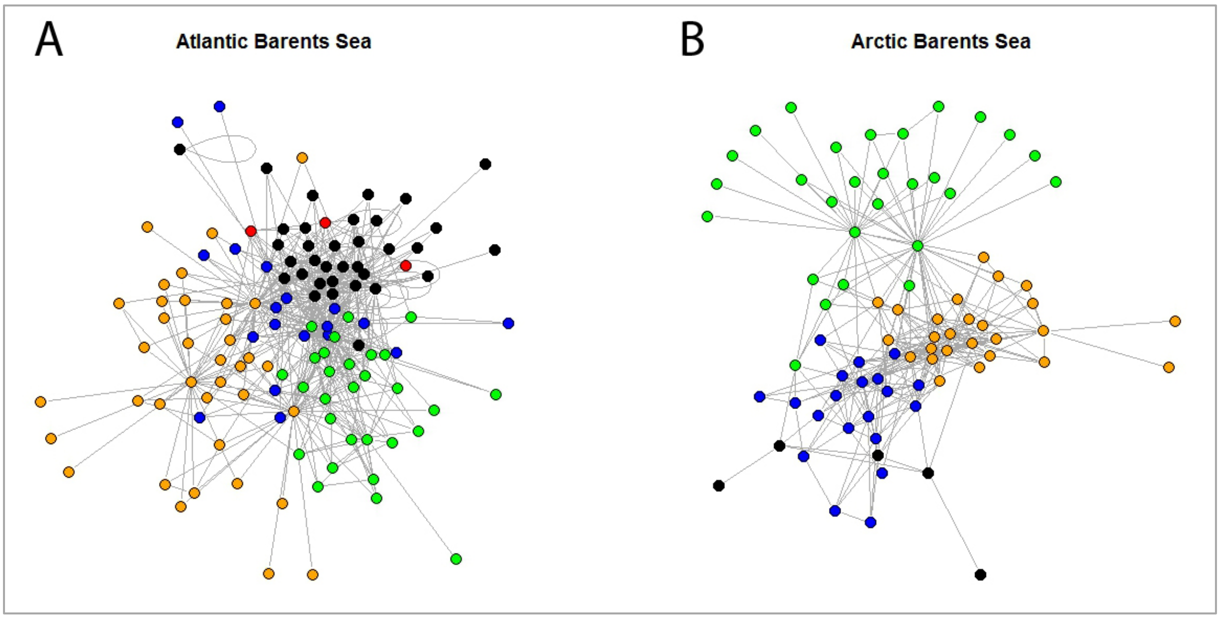



**Fig. 3.** Food web networks portraying the degree of compartmentalization in the: **A)** Atlantic Barents sea (comp=0.24). **B)** Arctic Barents sea (comp=0.28). The colors indicate the different compartments, which are subgroups of species interacting more with each other than with other subgroups The Atlantic region has 5 compartments (5 colors), whereas the Arctic regions has 4 (4 colors).

It is not alone the degree of connectance, but also the way the links are distributed and interconnected in the network and the strength of the interactions that determine the community and food web stability. In the Atlantic region, the intermediate taxa (63%), with both consumers and resources, are most abundant (Fig. 2.B). In the Arctic regions intermediate taxa (51%) are also most abundant, followed by top taxa (40%) with no consumers (Fig. 2.B). In both areas basal species are least abundant (7% and 9%). The latter is probably an artifact of the food web matrix. Often in food web analyses, the resolution of the higher trophic levels is greater, in particular, when it comes to feeding relationships. However, the differences between the areas with respect to top and intermediate taxa indicate how food webs display distinct configurations in nature. These configurations do play a role, in particular, with regard to direct and indirect effects and feedbacks in the system.

Species with many links (generalist species) may destabilize food webs if their presence or disappearance, due to perturbations, has great impact on (e.g. key species such as the capelin or the king crab) the distribution of many other species. At the same time generalist species can have stabilizing effects, because often they have lower average consumption rate per prey than specialist species. This means they have more weak interactions (McCann 2012). No conspicuous difference was observed in the degree of omnivory between the regions. The impact of omnivory on the stability of communities is also dependent on the strength of interactions between species. Compartmentalization was slightly higher in the Arctic compared to the Atlantic (Fig. 2 and 3). If communities are highly and strongly connected, and little compartmentalized, one might expect less resilient communities to perturbations. In our study, the most obvious differences in the metrics between areas are the number of species, links and their connectance.

**Conclusion**

We analyzed two regions of the Barents Sea in which ocean climate and ecological community structures are in sharp contrast: the Atlantic and Arctic waters. Despite large differences in species richness and composition, we found no strong differences in the food web topology characteristics of these regions, although connectance appears to be higher in the Arctic region. The food web descriptors of this analysis indicate that the ecosystem resilience to perturbations of Arctic and Atlantic communities in the Barents Sea may be similar. Yet, the food web matrix needs to be further developed to increase the resolution of the feeding relationships. In addition, more properties should be included in an extended analysis, e.g. loops, functional diversity, functional redundancy etc. Structural analysis brushes aside populations' dynamics, the quantification of links in terms of energy flow and interaction strength. Ideally, the structural and dynamical approaches will be performed together, in future studies, to better understand the relationship between the structural and dynamical properties and its implications for the functioning and the resilience of complex ecosystems.

## References


BODINI, A., BELLINGERI, M., ALLESINA, S. & BONDAVALLI, C. (2009.) Using food web dominator trees to catch secondary extinctions in action. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences : Biological Sciences,* 364**:** 1725-1731.

DUNNE, J. (2009) *Food Webs* (review). Santa Fe Institute, Santa Fe, USA.

DUNNE ET AL. (2002) Network structure and biodiversity loss in food webs: robustness increases with connectance. *Ecology letters,* 5: 558-567.

KRAUSE, A. E., ET AL. 2003. Compartments revealed in food-web structure. *Nature*, 426: 282-285.

MacARTHUR, RH (1955) Fluctuation of animal populations and a measure of community stability. *Ecology*, 36: 533-536

McCANN, K (2012) Food Webs, Princeton University Press, Princeton, New Yersey, pp. 68

McCANN, K. & HASTINGS, A. (1997). Re–evaluating the omnivory–stability relationship in food webs. *Proceedings of the Royal Society of London. Series B: Biological Sciences,* 264**:** 1249-1254.

NORACIA 2010. Klimaendringer i norsk arktis. Tromsø: Norsk Polarinstitut.

KORTSCH S. ET AL. (2012) Climate-driven regime shifts in arctic marine benthos, *Proceedings of national Academy of Science of United States of America.* doi:10.1073/pnas.1207509109

PASCUAL, M. & DUNNE, J. A. (2006) *Ecological Networks: Linking Structure to Dynamics in Food Webs,* Oxford University Press.

PIMM, S. & LAWTON, J. (1978) On feeding on more than one trophic level. *Nature,* 275**:** 542-544.

PLANQUE, B ET AL. (2010) How does fishing alter marine populations and ecosystems sensitivity to climate? *Journal of Marine Systems,* 79**:** 403-417.

SAKSHAUG, E., JOHNSEN, G. & KOVACS, K. (2009) *Ecosystem Barents Sea,* Akademika Publishing.

WASSMANN, P., DUARTE C.M., AGUSTI S., SEJR. M.K., 2011, Footprints of climate change in the Arctic marine ecosystem, *Global Change Biology*, 17, 1235-1249