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Operationalizing ecological robustness and resilience for ecosystem based management

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The goal of an ecosystem based approach to management is to preserve robust ecosystems that can cope with the environmental pressure imposed by human activities. Vulnerable ecosystems exposed to strong environmental perturbation are at high risk of large impact. Ecosystem based management can mitigate impact by dealing with ecosystem properties that influence vulnerability. The challenge is to identify relevant ecosystem properties that can be effectively integrated in assessment and decision making so as to operationalize ecological robustness and resilience. Here we present the approach used in the project BarEcoRe to quantify, evaluate and integrate an ensemble of structural properties affecting ecosystem adaptability and sensitivity to environmental change. The ecosystem properties, which include functional diversity and redundancy, and food web compartmentalization, were quantified based on data from the Norwegian and Russian Barents Sea ecosystem surveys. The chosen structural ecosystem properties can be combined with early warning signals estimated from time series to monitor robustness and resilience of managed ecosystems and to guide decision making.

Keywords: resilience, functional diversity, functional redundancy, food-web compartmentalization, Barents Sea

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Introduction

The goal of an ecosystem approach to management is to preserve robust ecosystems that can cope with the pressure posed by human activities. Global environmental change modifies ecosystem vulnerability and the character of environmental perturbation. Vulnerable ecosystems under heavy pressure from environmental perturbation are exposed to strong impact. Ecosystem based management can avoid or at least mitigate ecological impact by dealing with ecosystem vulnerability. The problem then is to identify which properties of an ecological system influence its vulnerability to environmental stress. Those properties will be the focus of ecosystem based management.

Vulnerability to environmental perturbation depends on an ecosystem's sensitivity, i.e. its tendency to change state in response to perturbation, and adaptability, i.e. its ability to maintain function while changing structure due to perturbation. More robust ecosystems are less sensitive and more adaptable. Although the adaptability of an ecosystem is difficult to characterize and quantify, we know that biological diversity contributes to it. Diverse ecosystems can still function in spite of the loss or substitution of some of their component species (Levin and Lubchenco, 2008). Sensitivity to perturbation depends on ecosystem resistance, or buffer capacity, on stability, and on resilience, or return tendency. More resistant, stable and resilient ecosystems are less sensitive and therefore less vulnerable to perturbations. The technical definition of resilience as tendency to return to an original state after perturbation is somewhat narrow relative to its more colloquial uses. Ecologists and environmental managers often use a broader interpretation of resilience and equate it with robustness. Higher resilience of an ecological system will thereby imply lower sensitivity and greater adaptability.

Operationalizing ecological resilience

Three structural properties of natural communities are known to influence ecosystem robustness and resilience: functional diversity, functional redundancy and food web compartmentalization (Levin and Lubchenco, 2008). Whereas higher diversity promotes adaptability, as mentioned above, species' functional redundancy and food web modularity reduce an ecosystem's vulnerability by increasing its buffer capacity. Higher redundancy implies that more species have similar functional traits and can substitute each other in performing specific ecosystem functions. Higher modularity implies that species interact within separate compartments, thereby preventing the impact of perturbation on few species from propagating across an entire food web (Figure 1).

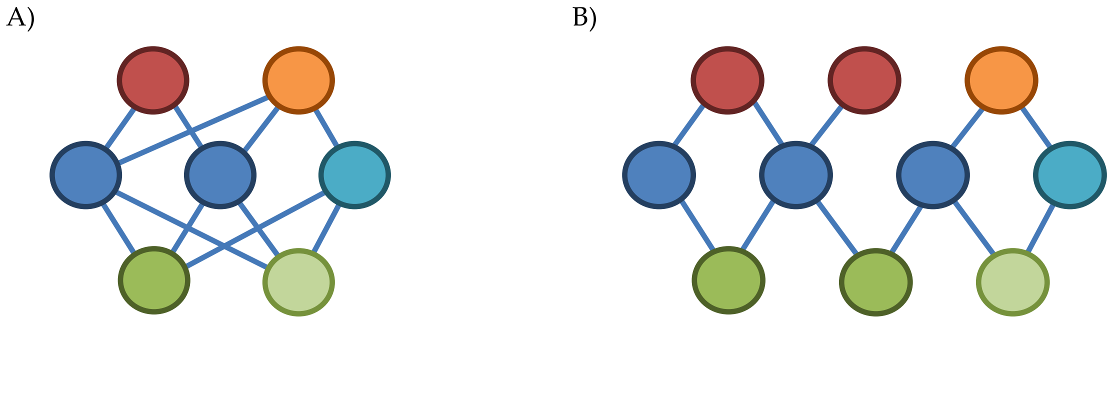

Figure 1. Food web representation of ecological communities (circles are species, lines are feeding relationships). The ecosystem depicted in panel A) is expected to be more vulnerable to environmental perturbation than that in B) because it has fewer species, with little functional overlap (similar color implies similar function), and it is less modular (in B species on the left handside do not interact with those on the right).

Recent development in ecosystem analysis, through community, diversity and network metrics now allows to investigate the past and possible future effects of climate and fisheries on ecosystem structure and properties (Wilmers, 2007). In particular, network analysis of food web data provides estimates of connectivity and compartmentalization (May *et al.*, 2007), and allows to evaluate the implications of environmental perturbations including the risk of secondary extinctions (Allesina et al., 2009, Bodini et al., 2009). These methods provide powerful assessment tools that can be integrated in ecosystem management practice, but require extensive ecosystem data collection to be implemented. The joint Norwegian-Russian Barents Sea ecosystem survey has generated the necessary data for the assessment of ecosystem vulnerability of the Barents Sea (Johannesen et al., 2012).

Barents Sea ecosystem resilience management

In the last decades, the Barents Sea ecosystem has experienced rapid climate warming (Skagseth et al., 2008) in combination with other environmental stressors like harvesting and pollution. The magnitude of the ecological impact of these stressors depends on the ecosystem vulnerability of the Barents Sea. The project *Barents Sea Ecosystem Resilience under global environmental change* (BarEcoRe), through an analysis of ecosystem survey data has revealed that the Barents Sea is characterized by extensive spatial variation in functional diversity (figure 2A), functional redundancy and food web compartmentalization (figure 2B), suggesting ample variation in ecosystem robustness and resilience.

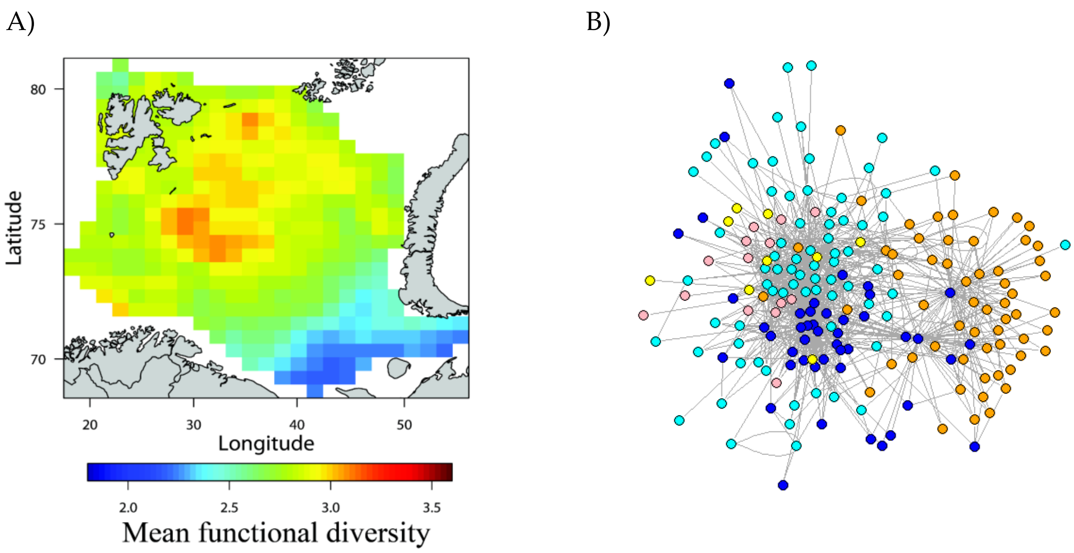

Figure 2. Structural properties of the Barents Sea ecosystem influencing its resilience and robustness. A) Spatial variation in fish functional diversity (FD) averaged over the period 2004-2009. Ecosystems with high FD (red areas) are expected to be less vulnerable to environmental perturbation than those with low FD (blue areas). B) Barents Sea food web topology. The circles depict tropho-species and their color indicates the affiliation to one of the five detected food-web compartments.

Knowledge of the spatial patterns in the above structural properties of ecosystems can inform regional management planning. Productive areas with high functional diversity (e.g. central Barents Sea) driven by high species richness are expected to be resilient and can be harvested without endangering ecosystem functioning. Areas with high functional diversity driven by high functional dispersion of few functionally heterogeneous species (e.g. central-eastern Barents Sea) call for caution in exploitation of those species. Finally, areas with low functional diversity (e.g. northern and south-eastern Barents Sea) should not be exposed to high levels of human exploitation due to their low adaptability.

Norway has decided to approach the new era of Ecosystem Based Management (EBM) by using management plans for the Norwegian part of the Barents Sea, including the fishery protection zone around Svalbard (Anon 2006), the Norwegian Sea (Anon 2009), and North Sea. Following international guidelines for EBM, the plans provide an overall framework for managing all human activities in the areas to ensure the continued health, production, and function of the ecosystems (Olsen et al. 2007). However, the Barents Sea management plan now relies on single species indicators and the integrated ecosystem measures provided by BarEcoRe will open for a more genuine ecosystem approach in future management plans.

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