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Setting thresholds for management Advice – Environmental indicators as a tool for an integrated assessment of Eastern Baltic cod (*Gadus morhua*).

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Summary
Supplementing fish stock assessment with environmental indicators is the core of ecosystem-based fisheries management. Indicator based approaches are important for fish populations that are strongly affected by climate-induced changes in the environment, such as Baltic cod (*Gadus morhua*). Besides the effects of over-fishing, reproductive success is a crucial process in cod population dynamics; hence, indicators that reliably contribute to forecast recruitment are candidates for integrated advice. Our study focuses on the identification of potential environmental indicators for cod recruitment success, including the setting of thresholds discriminating between good and bad environmental conditions for recruitment.
The present study shows that (i) biotic and abiotic indicators explain variation in recruitment success of Eastern Baltic cod (BE) after accounting for the effect of spawning stock size, and that for this case study (ii) spatially explicit indicators and thresholds must be considered.
Here we show that depending on stock and environmental conditions, thresholds are inevitable and essential tools in supporting assessment-model based stock advice for predicting recruitment success and providing first steps towards ecosystem-based fisheries management.

Introduction

Cod (*Gadus morhua*) is the most important predator for the Baltic ecosystem and states and had to face difficult times during the last century: Over-fishing and climate driven large-scale reorganizations, so called regime shifts, lead to a decrease in the EB cod stock at the beginning of the 90's, leaving the top predator yet to recover (Frank et al., 2005; Köster et al., 2005b; Möllmann et al., 2009; Gårdmark et al., 2011). Here we use biotic and abiotic indicators that display the essential necessities for the EB cod stock recruitment environment and try to find correlations that give an insight of what is important for recruitment success.

Since ecological thresholds are defined as points where small changes in the system can have large changes in the ecosystems' dynamic or state, it is essential in a management context to have knowledge about the function of the system of concern and also to be aware of differences between ecosystems (Samhouri et al., 2010). Working towards understanding the importance of well defined thresholds can be used globally as essential tools in marine management and Ecosystem-Based Management (EBM) contexts in order to reach healthy and sustainable ecosystem criteria as set i.e. by HELCOM (2007).

Material and Methods

Annual spawning stock biomass (SSB) and recruitment success estimates of EB cod were compiled (ICES, 2012a) and 19 biotic and abiotic potential indicators were evaluated regarding their suitability explaining residual variation in recruitment for the time period 1977 - 2011 (ICES, 2012b). The stock-recruitment relationship was fitted by a linear model using generalized least squares. The suitability for explaining residual variation in recruitment was explored per potential indicator by using linear and polynomial regression models as well as by generalized fluctuation tests using cumulative sums of the residuals. From indicators, that showed significant relationships with recruitment residuals, we

derived informative thresholds for a good or bad recruitment environment for the BE cod population. Consequences of different methods for setting thresholds with regard to environmental conditions for recruitment were evaluated. For the derived indicators, the current state and possible future conditions for cod recruitment success was calculated.

Results and Discussion

The present study defines and sets thresholds as a tool for implementing successful management actions and found Reproductive Volume (RV), its components (depth at 11 psu and oxygen concentration, respectively) and *Pseudocalanus acuspes* biomass as the most important indicators for reproduction success for the EB cod stock. Even after implementing different statistical approaches regarding the accuracy of scaling, i.e. looking at separate basins relevant to the cod stock, as well as different time scales and ages of cod, the results remained similar.

By defining the recruitment threshold as e.g. the mean of recruitment residuals or changes in prefix of the applied model, we can calculate in an easy and understandable way the possible impact on cod recruitment success if data is available.
Difficulties lie in the choice and availability of appropriate indicators that represent the ecosystem in hand. Indicators are widely used in management contexts as tools for evaluating the status of marine environments (CEC, 2008; USCOP, 2004) and are sometimes not easy to assess.

The study discusses the special need of differentiating between ecosystems and species when defining recruitment indicators, since it is extremely important to investigate an ecosystem holistically because different species in different habitats demand for different needs. Therefore, information on species specific physiology, biology and ecology as well as on dynamics of (sub-)systems and economy is more needed than ever to push many EBM approaches forward towards future goals that have been set in the past.

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