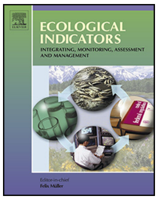
Ecological Indicators 77 (2017) 14–22

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind



Original Articles

Evaluating zooplankton indicators using signal detection theory

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ARTICLE INFO

Article history:
Received 13 October 2016
Received in revised form 30 January 2017
Accepted 30 January 2017
Available online 13 February 2017

Keywords:
Indicator
Mean size
Abundance
ROC
AUC
Baltic Sea

ABSTRACT

Indicators are used to help managers to conserve biodiversity and guarantee the sustainable use of marine resources. Good indicators are scientifically valid, ecologically relevant, respond to pressures, and it is possible to set target levels for them. Zooplankton is an important link in the food web as it transfers energy from primary producers (phytoplankton) to planktivorous fish, including the commercially important herring in the Baltic Sea. Eutrophication is known to increase zooplankton abundance and decrease the mean size of zooplankton individuals, while particularly herring prefers larger zooplankton as prey. Therefore, both the abundance/biomass and the size structure of the zooplankton community are highly relevant for the functioning of the pelagic food web, and their combination has been proposed as an indicator of the status of the pelagic food web. In this study, we evaluated the indicator performance of zooplankton abundance and mean size in the northern Baltic Sea using signal detection theory and annual zooplankton monitoring data from years 1979–2014. Herring weight-at-age and chlorophyll *a* levels were used to estimate the reference periods or "gold standard" of the food web status. The sensitivity and specificity of the indicator was evaluated using ROC curves. Thresholds were set and evaluated with positive and negative predictive values for the zooplankton mean size in three sub-basins of the Baltic Sea. The results suggest that zooplankton mean size is able to reflect the state of the food web in the Baltic Sea. Our study also confirms that signal detection theory is useful in evaluating ecological indicators with clear pressures. However, with parameters that are affected by multiple contrary pressures, such as zooplankton abundance, ROC curves cannot offer enough information about the performance of an indicator parameter.

1. Introduction

Human pressures are affecting the marine environment around the world, and to be able to conserve the marine biodiversity and achieve sustainable use and management of marine resources, we need to have knowledge about the state of the ecosystems and how management measures affect them. The EU Marine Strategy Framework Directive (MSFD) aims at promoting sustainable use of the seas and conserving marine ecosystems by requiring the EU member states to attain good environmental status in their marine areas by the year 2020 (MSFD, 2008/56/EC; European Commission, 2008). To be able to monitor the ecosystems, assess their health and implement the MSFD, establishment of several indicators for different ecosystem components is required.

Zooplankton is an important link in the aquatic food webs as it transfers energy from primary producers to higher trophic levels, such as planktivorous fish. In the Baltic Sea herring (*Clupea harengus membras)* is an economically important species. The stock sizes have varied depending on the area, and their condition (described as weight-at-age, WAA) has decreased in several areas of the Baltic Sea since the beginning of the 1980s (Flinkman et al., 1998; Cardinale and Arrhenius, 2000; Rahikainen and Stephenson, 2004; ICES, 2015). Decreased salinity correlates with the decrease in WAA. It has been suggested that the bottom-up effect through zooplankton quality and availability may act as a significant controller of herring condition (Flinkman et al., 1998; Lindegren et al., 2011). Herring feeds selectively on larger zooplankton species like copepods *Pseudocalanus elongatus* and *Limnocalanus macrurus* and changes in their populations are reflected in herring stock condition (Flinkman et al., 1998; Möllmann et al., 2003; Rönkkönen et al., 2004; Rajasilta et al., 2014; Livdāne et al., 2016). Zooplankton communities are affected by salinity (Vuorinen et al., 1998; Möllmann et al., 2000), temperature (Dippner et al., 2000; Möllmann et al., 2000; Suikkanen et al., 2013) and eutrophication (Hsieh et al., 2011). The zooplankton biomass has been reported to correlate with eutrophication (chlorophyll *a*) (Pace, 1986) and especially the abundance of smaller grazing zooplankton increases simultaneously with increasing nutrient levels (Hsieh et al., 2011).

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http://dx.doi.org/10.1016/j.ecolind.2017.01.038
1470-160X/

The central Baltic Sea ecosystem has undergone a trophic cascade where the dramatic reduction of cod (*Gadus morhua*), caused by increased fishing pressures and decreased salinities, has increased the abundance of its main prey sprat (*Sprattus sprattus*) (Casini et al., 2008; ICES, 2012). The system has shifted from a cod-dominated system to a clupeid-dominated system. The change can also be seen in the northern Baltic Sea plankton community which has shifted towards a food web structure with smaller sized organisms, resulting in less energy available for grazing zooplankton and planktivorous fish (Suikkanen et al., 2013).

Gorokhova et al. (2016) proposed an indicator that reflects the status of the zooplankton community, and thereby the status of the food web functioning. The idea is that zooplankton should be abundant enough to effectively graze phytoplankton and its mean size should be large enough to guarantee effective energy transfer to the higher trophic levels. Zooplankton mean size and total abundance is an indicator that refers especially to the MSFD descriptor 4 which deals with the food webs (MSFD, 2008/56/EC; European Commission, 2008). It reflects the food web status of the Baltic Sea area as it indicates both the fish feeding conditions and the eutrophication of the sea (Simm et al., 2014; Gorokhova et al., 2016). This indicator has also been adopted into the core set of indicators of the Baltic Marine Environment Protection Commission (HELCOM, 2013; Gorokhova et al., 2016).

Creating accurate measures of good environmental status for different marine ecosystem components should be considered carefully (Mee et al., 2008; Borja et al., 2012). The definitions of a good ecological indicator include the following characteristics: the indicator should be easy to measure and sensitive to a particular pressure, its response should be predictable, well-known, and have low natural variability, and the information the indicator offers should have clear management implications, i.e. points towards a clearly identified management action (Dale and Beyeler, 2001; Rice and Rochet, 2005; Queirós et al., 2016). Well established and tested indicators guarantee the basis for efficient management decisions.

In this study, we present an application of the signal detection theory to evaluate the sensitivity and specificity of zooplankton indicator parameters mean size and total abundance in four areas of the Baltic Sea. ROC (receiver operating characteristics) curves and AUC (area under curve) values are produced to demonstrate the behavior of the indicator, particularly its sensitivity and specificity. Signal detection theory has been widely used in medical research (Murtaugh, 1996) and it has recently been applied in the evaluation of ecological indicators as well (Hale and Heltshe, 2008; Chuševė et al., 2016). It is also a useful tool for deliberate threshold-setting for analyzed parameters, and we propose thresholds of a good environmental status for zooplankton mean size to be utilized in environmental decision-making.

2. Material and methods

2.1. Study area

The Baltic Sea is a brackish water basin with mean depth of 55 m and area 422 000 km^2. The only connection to the North Sea is through the narrow Danish straits. There are both horizontal and vertical salinity gradients and a permanent halocline at a depth of 60–80 m (Leppäranta and Myrberg, 2009). Our study area covers the most northern parts of the Baltic Sea: the Bothnian Bay, the Bothnian Sea, the Åland Sea and the Gulf of Finland (Fig. 1) The Bothnian Bay and the Bothnian Sea are partly separated basins from the rest of the Baltic Sea as the southern part of the Bothnian Sea is separated by a shallower sill and the water exchange from the main basin is slow. The whole Baltic Sea shows clear signs of eutrophication (Fleming-Lehtinen et al., 2015) and the Gulf of Finland, which has a direct connection to the main basin has also been suffering from anoxia during the last decades (Carstensen et al., 2014).

The Baltic Sea ecosystem is very sensitive to changes as most of the species are from marine or limnic environments and thus occur at the limits of their distribution. The catchment area is large compared to the sea area and the food web structure is simple compared to ocean food webs in general (HELCOM, 2010a).

2.2. Data collection

The long-term zooplankton data has been collected by the Finnish Institute of Marine Research and Finnish Environment Institute in connection with the HELCOM COMBINE monitoring program. The data have been collected and analysed for 1979–2014. Seven off-shore monitoring stations are included in this study: one in the Åland Sea and two in the Bothnian Bay, Bothnian Sea and Gulf of Finland. We used samples taken in August as this time had the best data coverage over the study years. Zooplankton was collected by vertical tows of the WP-2 plankton net (mesh 100 μm) and preserved in 4% buffered formaldehyde. The sampling was performed according to the COMBINE manual (HELCOM, 2010b). The zooplankton were identified to the lowest possible taxonomic level and the mean size of zooplankters was calculated using the standard species and stage specific wet weights (Hernroth, 1975) with modifications by HELCOM ZEN expert group for certain species. The nauplii were excluded as the mesh used does not sample them comprehensively. The zooplankton total abundance and mean size were calculated for each station for each year. The data from the two stations in each sub-basin was averaged and the total abundance and mean size were calculated for each four sub-areas.

2.3. Signal detection theory

Signal detection approach is suitable for dichotomous situations where there are only two possible outcomes. For example the ecological condition can be expressed as “acceptable” and “unacceptable” levels and signal detection approach allows to evaluate, how well an indicator with continuous values can reflect these levels (Murtaugh, 1996). A recent application comes from Chuševė et al. (2016) who analyzed Benthic Quality Index (BQI) and its response to eutrophication.

Signal detection theory uses a matrix that includes the real status of the ecosystem, and the indicator values or predictions (Table 1). The positive indicator response refers to a situation where an indicator detects the bad environmental condition and hence gives an “alarm” or “a positive signal”, whereas negative indicator response means that there is nothing to alarm about. The table can be used in multiple ways: sensitivity, i.e. the true positive rate (TPR) is the probability of a positive indicator response (unacceptable environmental condition) given that the true condition of environment is positive ($TPR=TP/(TP+FN)$). Specificity, i.e. the true negative rate (TNR), is the probability of a negative indicator response (acceptable environmental condition) given that the true condition is negative ($TNR=TN/(TN+FP)$). In addition, the analysis enables the assessment of positive predictive value (PPV) and negative predictive value (NPV); i.e. if the indicator predicts a positive outcome, what is the probability that the true status is positive, and similarly, if the prediction is negative, what is the probability that the true status is negative. These are calculated as $PPV=TP/(TP+FP)$ and $NPV=TN/(TN+FN)$. PPV and NPV take into account the prevalence of real positives in the data set, which affect the probabilities of different outcomes (Murtaugh, 1996).

Finding a good indicator threshold often involves a trade-off between the false positive and false negative rates: as an extreme example, if we classify everything as negative, there will be no false