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# Intercalibration of benthic foraminiferal and macrofaunal biotic indices: An example from the Norwegian Skagerrak coast (NE North Sea)

Elisabeth Alve[a,*], Silvia Hess[a], Vincent M.P. Bouchet[a,b], Jane K. Dolven[a,c], Brage Rygg[d]

[a] Department of Geosciences, University of Oslo, P.O. Box 1047, Blindern, 0316 Oslo, Norway
[b] Univ. Lille, CNRS, Univ. Littoral Côte d'Opale, UMR 8187, LOG, Laboratoire d'Océanologie et de Géosciences, F 62930 Wimereux, France
[c] Norconsult AS, Apotekergaten 14, NO-3187 Horten, Norway
[d] Norwegian Institute for Water Research (NIVA), Gaustadalléen 21, 0349 Oslo, Norway

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ABSTRACT

The present study illustrates how benthic macrofauna indices can be adapted to foraminifera through intercalibration of data from common sites. As an example of how benthic foraminifera can fit into governmental monitoring programs, we focus on Norwegian conditions by proposing a new foraminifera-based multimetric index, $NQI_f$. The index is an adaptation of the Norwegian Quality Index (NQI), which is an internationally intercalibrated macrofauna index.

The study is based on published and new data for soft-bottom benthic foraminifera, macro invertebrates, and associated bottom water dissolved oxygen and sediment total organic carbon (TOC). Paired samples of foraminifera and macrofauna were collected at the same stations, at more or less the same time, along the Norwegian Skagerrak coast, NE North Sea. The intercalibration was based on linear regression and the EcoQS class boundary values for the foraminifera indices were derived from boundary values for the macrofauna indices defined by the Norwegian governmental guidelines. The correlations between foraminifera and macrofauna for the multimetric NQI and the diversity indices $H'log_2$ and $ES_{100}$ were all acceptable for intercalibration (according to the Water Framework Directive's guidelines) but NQI showed the best correlation. Both foraminifera- and macrofauna-indices showed significant correlations with the bottom water dissolved oxygen concentration, and for some indices, with the TOC content in the sediment. Overall, the foraminifera and macrofauna indices reflected the environmental conditions similarly but at the most oxygen depleted stations only foraminifera were present. Based on the present findings and on previous studies which show a potential of fossil foraminifera to define *in situ* reference conditions, we recommend that foraminifera are accepted as a Biological Quality Element within the WFD.

## 1. Introduction

The European Water Framework Directive (WFD, 2000) emphasises that the ecological quality status (EcoQS) of transitional and coastal waters shall be evaluated based on Biological Quality Elements (BQEs). Benthic macro invertebrates (from now on termed macrofauna) is one of the selected BQEs used. For each BQE, biotic indices have been developed that can classify transitional and coastal waters into five classes of EcoQS: «high», «good», «moderate», «poor», and «bad». In order to determine whether or not the EcoQS of a water body has been negatively impacted by human activity, information about the reference conditions is needed to calculate the Ecological Quality Ratio (EQR). "Reference conditions are a description of the biological quality elements at high status" (WFD, 2000, p. 39) and EQR quantifies (on a numerical scale from zero to one) the relation between observed and reference condition values of a BQE. Since defining the reference conditions is a recurring problem (WFD, 2000, p. 41) there is a need for alternative methods.

Like macrofauna, foraminifera (amoeboid protists), are important members of the marine benthic community. Living foraminifera reflect environmental conditions in the bottom water and sediment surface layers (see overview in e.g., Murray, 2006). Hence, they have recently been suggested as a monitoring tool to characterise the EcoQS (Alve et al., 2009). Later investigations from widely different environments in Greece to the Arctic support this view (e.g., Bouchet et al. 2012, 2018a; Dimiza et al., 2016; Dijkstra et al., 2017). Their small (usually < 0.5 mm) shells (tests) preserve well in ageing sediments, making the foraminifera a commonly used tool in paleoecology and, lately, in

* Corresponding author.
*E-mail address:* ealve@geo.uio.no (E. Alve).

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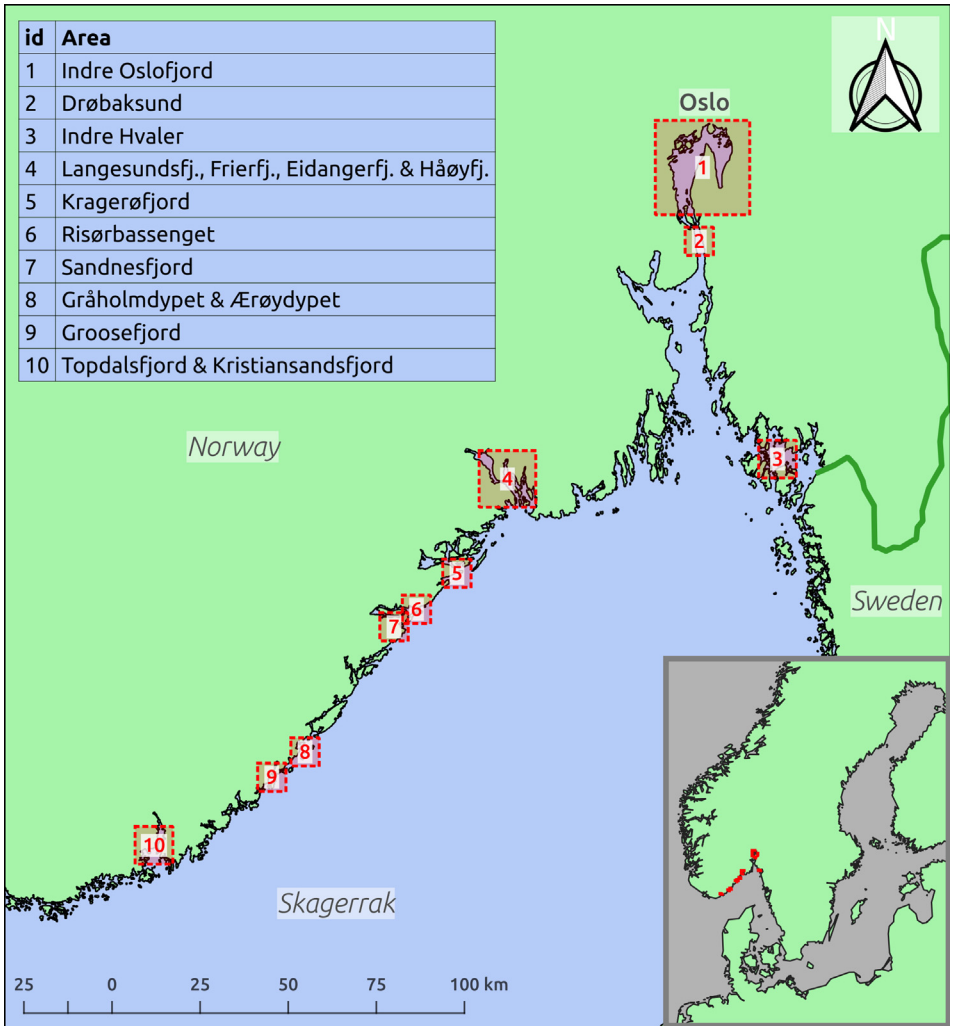


**Fig. 1.** Study areas along the Norwegian Skagerrak coast, NE North Sea.

reconstruction of past ecological quality status, PaleoEcoQS, and *in situ* reference conditions (e.g., Alve et al., 2009; Dolven et al., 2013; Polovodova Asteman et al., 2015; Romano et al., 2016; Francescangeli et al., 2016). Hence, foraminifera can complement macrofauna-based monitoring and could be included as a governmental assessment tool for EcoQS in soft-bottom habitats. A foraminifera-based classification system intercalibrated with that for macrofauna is then required. Internationally, there are numerous biotic indices in use for both groups of organisms, but the present study focuses on foraminiferal indices equivalent to the macrofauna indices used in the Norwegian classification system.

The usefulness of biodiversity as a measure of ecosystem quality is widely recognized (Laurila-Pant et al., 2015, and references therein) but most countries, including Norway, use multimetric indices that include a sensitivity component in addition to the diversity component (Veileder, 2013). The diversity indices $H'log_2$ (Shannon and Weaver, 1963) and $ES_{100}$ (Hurlbert, 1971) as well as the multimetric Norwegian Quality Index (NQI, Rygg, 2006) are used in the Norwegian classification system. NQI includes a sensitivity component (AMBI) and a diversity factor (lnS/ln(lnN)). A foraminifera equivalent to the macrofauna-based sensitivity index AMBI (Borja et al., 2000), was recently developed based on benthic foraminiferal assemblages from North-East Atlantic and Arctic shelves and fjords (Alve et al., 2016). The Foram-AMBI ($AMBI_f$) provides a potential sensitivity component for a multimetric index and opens an opportunity for defining a foraminifera index which can be compared to and intercalibrated with the already internationally intercalibrated macrofauna counterpart, NQI. Hence, this study proposes $NQI_f$, a foraminifera-based index similar to the macrofauna-based NQI.

Internationally, vast efforts have been put into intercalibrating EcoQS class boundaries, especially between countries where the same types of water bodies occur (e.g., Borja et al., 2007, 2009; Grémare et al., 2009). The intercalibrations aim to secure a comparable status classification and a valid implementation of the Water Framework Directive throughout e.g., the North-East Atlantic Geographical Intercalibration Group (NEAGIG) which includes the Atlantic coastal areas from northern Norway to Gibraltar. NQI is one among several macrofaunal indices in NEAGIG. NQI has been intercalibrated with indices used in other countries for the water types NEA1/26 (shallow, fully saline) and NEA7 (deep, fully saline) in 2006 (Borja et al., 2007; Carletti and Heiskanen. 2009), in the NEA8/9/10 (Skagerrak and Kattegat) in 2011 (8.10.2013 Official Journal of the European Union L 266/1), and in the NEA1/26 and NEA7 in 2015 (Van Hoey et al., 2018). A comparison of performance along stress gradients of three Scandinavian indices, NQI (Norway), BQI (Sweden) and DKI (Denmark), was made by Josefson et al. (2009). Valid intercalibration procedures are outlined in several documents (e.g. EC, 2011; Van Hoey et al. 2007, 2010, 2015).

As a possible first step to implement foraminifera in official monitoring systems, the present study from Norwegian waters aims to 1) define a multimetric foraminifera-based biotic index, $NQI_f$, similar to the macrofauna-based NQI (from now on termed $NQI_m$), 2)