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Sensitivity of indicators matters when using aggregation methods to assess marine environmental status

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ABSTRACT

The sensitivity of the 15 indicators included in a complex aggregation method (Nested Environmental status Assessment Tool), applied to a case study in the Caspian Sea in Iran, has been studied to discriminate between areas impacted and non-impacted by bathing activities. Two methods were used: (i) the 15 indicators were grouped into four groups (physicochemical, bacteria, plankton, and benthos) and each group was investigated separately (one-way sensitivity analysis), calculating NEAT values after omitting each group independently; and (ii) indicators were selected randomly, using 1000 Monte Carlo iterations, and removing from 1 to 14 indicators at each iteration. The results revealed that the abundance of *Pontogammarus* was the single indicator that made the difference in assessing the status among locations, differentiating bathing and non-bathing areas. Hence, this indicator is regarded as a monitoring element detecting the impacts produced by a management measure (beach nourishment) taken by the authorities to maintain the bathing activity.

1. Introduction

Assessing the environmental status of marine waters is becoming more and more necessary, since legislation worldwide is seeking for tools and methods to determine the ecological integrity and marine ecosystem health, for an effective ecosystem-based management of human activities at sea (Borja et al., 2008). These methods can include single indices (e.g. classical indices, such as richness, diversity, or evenness), multimetric indices (i.e. a combination of several indicators or metrics trying to reflect a more holistic evaluation of the ecological quality of the marine environment) (see many examples in Birk et al., 2012), but also complex aggregations of multiple variables, descriptors, indicators and ecosystem components, for an integrated ecosystem assessment (see a review in Borja et al., 2016).

Sometimes, in the case of multimetric indices, its performance tends to be dependent on the behavior of the single metric components and the way in which they are combined (Alvarez et al., 2013). Hence, in multimetric indices created to assess unique ecosystem components or biological elements, only single metrics not redundant (not correlated with others) are used in the calculation (Hering et al., 2006). In turn, in some complex aggregation methods, created to assess the status of the whole ecosystem (e.g., the Nested Environmental status Assessment Tool (NEAT), Borja et al. (2016)), no bias is introduced into the assessment by the choice of the indicators, which even can be correlated each other (Berg et al., 2017). However, the way in which this aggregation is produced can result in different environmental status (Borja et al., 2014; Probst and Lynam, 2016).

Although the response of these assessment methods to human pressures has been largely investigated (there is extensive literature, but see Halpern et al. (2008) and Reker et al. (2015)), little is known about the sensitivity of these assessment tools with regard to the variability of their single metric components. In this way, Alvarez et al. (2013) analysed the response of several fish multimetric indices to evaluate the importance of the different metrics in determining the final index score and quality status classification in Europe. On the other hand, for complex aggregation methods, Probst and Lynam (2016) analysed the influence of the aggregation type and the number of indicators in the assessment, whilst Uusitalo et al. (2016) analysed the sensitivity of NEAT, under several case studies in European regional seas, to the aggregation of indicators.

In this short research note, we have investigated the sensitivity of the different indicators included in a complex aggregation method (NEAT), applied recently to a case study in the Caspian Sea in Iran, to discriminate between areas impacted and non-impacted by bathing

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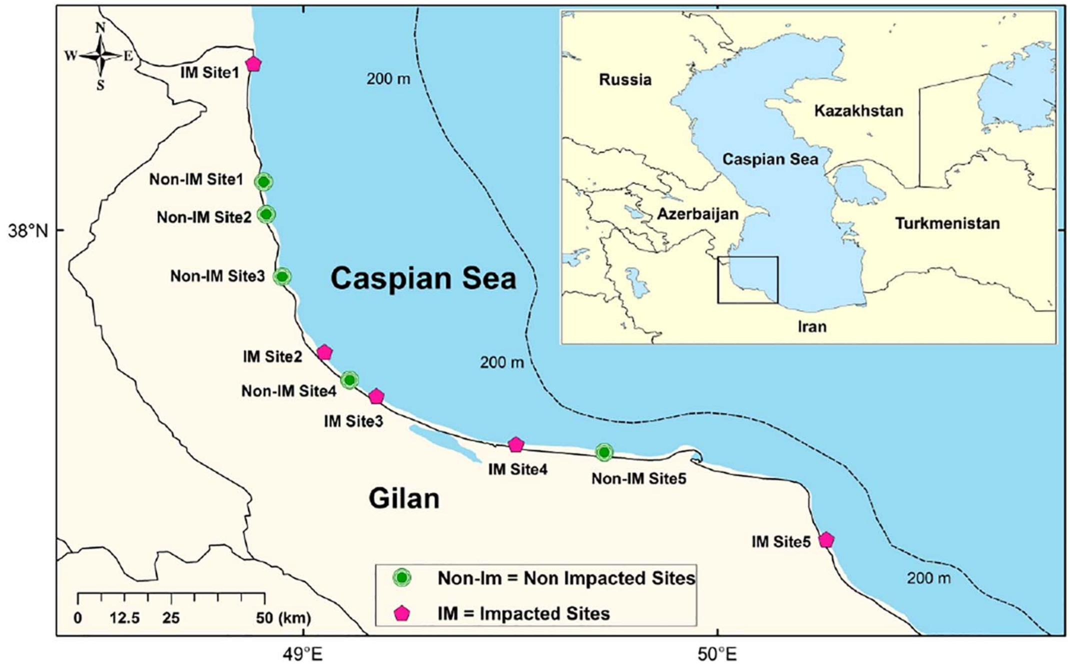

Fig. 1. Study area within the Caspian Sea.

activities (Nemati et al., 2017). Our aim is to determine if some indicators are more suitable than others in assessing the final environmental status and the importance they can have in taking decisions for future monitoring and assessment.

2. Methods

2.1. Study area

The study area is located on the southwest coast of Caspian Sea, in Gilan Province (Iran). Sampling was carried out at 10 sites: five sites were at recreational bathing areas (Impacted Sites 1–5), and five sites were not affected by bathing (Non-Impacted Sites 1–5) (Fig. 1).

The sampling was undertaken in February 2015 (non-bathing period), and once a month from July to September 2015 (bathing period). The variables analysed include: (i) water column: temperature, salinity, pH, oxygen saturation, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), phosphate, nitrate, nitrite, Total Suspended Solids (TSS), turbidity, Total Coliforms, Faecal Coliforms, *Escherichia coli*, *Staphylococcus aureus*, phytoplankton and zooplankton; and (ii) sediment: grain size, organic matter and macroinvertebrate composition. For field and laboratory methods see Nemati et al. (2017).

2.2. NEAT description and application

The NEAT software was downloaded from the DEVOTES project web page (www.devotes-project.eu/neat), and version 1.2 was used. From the abovementioned variables, next 15 variables were used in the assessment and sensitivity analysis, within four ecosystem groups: (i) physicochemical indicators: Turbidity, TSS, oxygen saturation, COD, BOD, nitrite, nitrate and phosphate; (ii) faecal bacteria: Total Coliforms, Faecal Coliforms, *E. coli*, and *S. aureus*; (iii) plankton: diversity of phytoplankton and zooplankton; and (iv) benthos: only one species was identified, *Pontogammarus maeoticus*, and its abundance was used in the analysis. The remainder indicators were not included in the analysis since they are not related to pressures (i.e. temperature, salinity, pH) or their range of variation was very low within the samples (i.e. grain size and organic matter), after the analyses undertook by Nemati et al. (2017).

These variables were primarily selected by Nemati et al. (2017) to identify different pressures produced by bathing activities (i.e. use/not use for bathing, bathing use itself, number of swimmers, sand nourishment to beaches, etc.). The reference conditions and targets for each indicator were obtained from different sources, detailed in Nemati et al. (2017).

2.3. Sensitivity analysis theory

The simplest way of sensitivity analysis (one-way sensitivity analysis) consists of varying only one metric or indicator in the model at a time by a given amount and examining the impact of that change on the model result (Flanangan and Norman, 1993; Taylor, 2009). However, when considering multimetric indices, each metric cannot be expected to be mutually exclusive or independent, since in natural systems, the linkages between ecological processes often induce correlation between metrics (Alvarez et al., 2013). In fact, in complex aggregation methods, such as NEAT, this is expected, since they are developed to assess the status of the whole ecosystem (i.e. ecosystem-based assessment), and many indicators will be correlated each other, within or between the ecosystem components. Hence, NEAT avoids the dominance of certain indicators by a proper weighting procedure, reducing the risk of bias in an assessment coming from the use of many tightly correlated indicators on the same issue, because the weighting is hierarchical (Berg et al., 2017). However, to take account of potential changes in the sensitivity of the assessment, more complex alternatives must be explored, such as Montecarlo iterations, as shown below.

2.4. Statistical methods

We applied two analyses to investigate the sensitivity of the indicators. In the first analysis, the 15 indicators were grouped into four groups (physicochemical, bacteria, plankton, and benthos) and each group was investigated separately (one-way sensitivity analysis), calculating NEAT values after omitting each group independently. Then, a multifactorial ANOVA analysis was performed to find significant differences between NEAT values with all indicators and after deleting each group. This was calculated using Statgraphics17.

In the second analysis, to test the sensitivity of the NEAT assessment