SOFTWARE METAPAPER

BEAT 3.0 – a Tool for Integrated Biodiversity Assessments

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BEAT 3.0 is a multi-metric indicator-based tool for integrated assessments of marine biodiversity status implemented in R. It follows the structure and requirements of the EU Marine Strategy Framework Directive and allows for use of monotonic, unimodal, conditional, trend-based and qualitative indicators. The tool handles tabular data files (.txt format), in which the assessment structure and indicator results are specified. Integration of indicators is primarily based on weighted averaging, where both spatial assessment scale and ecosystem level are considered. Parallel to the biodiversity status assessment, a confidence assessment is also included. BEAT 3.0 uses HELCOM Assessment units and HELCOM core indicators as default but can be customized for use in any geographical region and any set of indicators.

(1) Overview

Introduction

Current environmental policies emphasize the need for ecosystem based and holistic assessments [1]. Instead of using single state indicators, the requirement is for integrated indicator-based assessments [2]. The HELCOM Biodiversity Assessment tool BEAT is a multi-metric indicator-based tool for integrated assessments of marine biodiversity. In the Baltic Sea, the first steps towards a tool for integrating biodiversity indicators were taken in the initial holistic assessment of the Baltic Sea [3, 4]. At that time, the tool was tested on a set of case studies in the lack of Baltic-wide agreed indicators. The prototype of BEAT was further developed to better fit the EU Marine Strategy Framework Directive (MSFD) objectives and an approach for confidence rating was introduced in BEAT 2.0 [5].

BEAT 3.0 was developed for and used in the second holistic assessment of the ecosystem health of the Baltic Sea [6] and complies with the MSFD requirements. For biodiversity, MSFD describes five ecosystem components that are to be assessed by indicators: marine mammals, sea birds, fish, pelagic habitats and benthic habitats [7]. A prerequisite of the tool is that indicator results are calculated for a specified spatial assessment unit. The tool handles the indicator types (monotonic, unimodal, trend-based, conditional and qualitative) used in the set of HELCOM core indicators (http://www.helcom.fi/baltic-sea-trends/indicators/). A review of available integrated biodiversity assessment tools done as a start in the development work found no suitable tool to deal with all the different indicator types, but the basic features of the earlier versions of BEAT [3, 5] and the Nested Environmental status Assessment Tool (NEAT) [8] were considered useful. These features, a hierarchical nested structure, weighing of indicators and an accompanying assessment of confidence, are implemented in BEAT 3.0.

Implementation and architecture

Previous versions of the BEAT tool were developed as Microsoft Excel workbooks. BEAT 3.0 runs as an R script making use of several input files in text format (**Table 1**). The tool follows two hierarchical nested structures; a spatial structure and an ecosystem component structure. The spatial structure follows the HELCOM assessment unit structure using four spatial levels following the HELCOM monitoring and assessment strategy (http://www.helcom.fi/action-areas/monitoring-and-assessment/monitoring-and-assessment-strategy/). The spatial structure is defined in the input file SAU.txt.

The ecosystem component structure stems from the MSFD and has five components at the first split level (marine mammals, seabirds, fish, pelagic habitats and

Table 1: Descriptions of the input files to BEAT 3.0.

File name	Description
SAU.txt	Defines the spatial assessment units and consists of a hierarchical list of the assessment units with four levels (according to the HELCOM spatial assessment unit levels: 1 = Baltic Sea, 2 = HELCOM Sub-basins, 3 = HELCOM Sub-basins with coastal and offshore division, 4 = HELCOM Sub-basins with coastal WFD water types of water bodies. The area (km²) of all spatial assessment units are specified here if applying the area-weighted spatial aggregation option.
EcosystemComponents.txt	Defines the hierarchical structure of ecosystem components. (birds, fish, mammals, pelagic habitats, benthic habitats) with four levels (1 = Biodiversity, 2 = Ecosystem component, 3 = Species group/broad habitat type, 4 = Species/habitat element). Each component is linked to the relevant higher level ecosystem component.
descriptors.txt	Lists the MSFD descriptors.
criteria.txt	Lists the MSFD criteria according to the revised European Commission Decision on GES criteria.
IndicatorCatalogue.txt	Lists the indicators and assigns them to relevant ecosystem component and MSFD criteria.
indicators.txt	The table where indicator results are inserted. This table contains the minimum and maximum values, threshold value and observed value (indicator result). Also the indicator type and confidence evaluations are inserted here. One row is added for each assessment unit the indicator is used in, note that the minimum, maximum and threshold values can vary between assessment units.
ooao.txt	In this file parameters used in conditional indicators can be grouped to be treated with the OOAO approach, i.e. using the parameter with poorest status classification in further integration steps.

benthic habitats). The marine mammals, seabirds and fish are split into species groups and species at the lowest ecosystem component level, whereas pelagic and benthic habitats are split into broad habitat types and further into habitats. The ecosystem component structure is defined in the EcosystemComponent.txt input file.

Indicators need to be assigned to their relevant ecosystem component level and spatial assessment scale, i.e. the tool does not handle geospatial data, but only links the indicator results to the predefined spatial assessment units (SAU.txt file). In the spatial structure, weights are assigned to indicators based on the area represented by the assessed spatial unit, i.e. area-based weighting. The hierarchical structure of ecosystem components follows a balanced weighting so that within each branch all elements at same level have similar weight (**Figure 1**). Assessment units or ecosystem components to which no indicators are assigned are not included in the assessment.

In order to integrate the result of indicators of different type and with different unit, normalization to a common scale is needed. BEAT 3.0 uses Biodiversity Quality Ratio (BQR) as a common scale, ranging from 0 to 1 where 1 is the best score achievable and with the threshold value between "not good" and "good" set at 0.6. To normalize the indicators to BQR, minimum and maximum values need to be defined for each indicator. Detailed methodology on how to normalize the different types of indicators and how to define minimum and maximum values is provided in the report 'The integrated assessment of biodiversity – supplementary report to the first version of the 'State of the Baltic Sea' report 2017' [9].

The basic integration rule used in BEAT 3.0 is weighted averaging, where indicators are weighted based on the spatial unit and ecosystem component they are assigned to, as described above. An option for applying the one-out-all-out (OOAO) principle is also available and was utilized for marine mammals in the HELCOM assessment. When applying OOAO, the indicator with the lowest BQR is used in the integration steps to a higher hierarchical level.

Parallel to the integrated biodiversity assessment, BEAT 3.0 also performs an integrated confidence assessment. The integrated confidence assessment is based on the confidence evaluations made for the indicators and their underlying data. Four aspects of confidence are evaluated: confidence of classification, temporal confidence, spatial confidence and methodological confidence. The methodology for confidence evaluations of indicators is presented in in the report 'The integrated assessment of biodiversity – supplementary report to the first version of the 'State of the Baltic Sea' report 2017' [9]. BEAT 3.0 first averages the confidence evaluations per indicator and integrates the indicator confidence following the same structures and weights used in the integrated biodiversity assessment. An optional feature of the tool is to take into account the overall assessment confidence, i.e. how well the ecosystem components and MSFD criteria are covered, based on pre-set conditions. If a pre-set condition is not met a penalty (–25% confidence) is applied. To enable this feature, line 21 (file_conf <- "./confidence_penalties.R") needs to be active (commented out by default).

BEAT 3.0 creates several result outputs; for spatial assessment units, for ecosystem components and for these combined, both for the biodiversity assessment
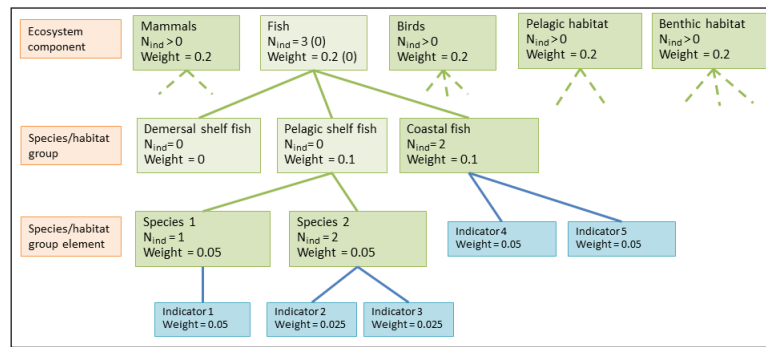
Figure 1: An example of how weights are distributed among indicators. The structure is balanced so that all ecosystem elements at same level (that have indicators assigned) have equal weights.

and the confidence assessment. In addition, outputs with scaled indicators results (including their weights) and a summary of number of indicators used are produced. All output files are .txt files.

Quality control
The script has been tested during the development phase using test cases and successfully run for the second holistic assessment of the ecosystem health of the Baltic Sea [6]. A brief manual is provided in the BalticBOOST project report Appendix 1 [10]. Example input files are provided to facilitate the use of the tool. The README file in the GitHub repository includes instructions for reproducing the results obtained by the authors. Copies of the resulting output files are also available, which users can compare with their own results.

The tool does not explicitly assess the quality of indicators, but the confidence assessment run in parallel to the biodiversity assessment integrates the indicator result confidence (temporal, spatial and methodological confidence as well as confidence of classification). Thus, an estimate of the quality of the final biodiversity assessment result is obtained.

(2) Availability
Operating system
Development was done on a Windows 10 64-bit operating system but there are no specific requirements to operating system.

Programming language
The script was developed and tested in RStudio with R version 3.3.1.

Additional system requirements
There are minimal requirements to memory, disk space and processor. Any user with an R installation should be able to run the script without problems.

Dependencies
The script requires that the R packages *dplyr* and *sqldf* are installed. The script does not install the packages.

List of contributors
· Henrik Nygård[1], Lead developer and tester.
· Ciarán Murray[2], Lead programmer and tester.

· Jesper Andersen[2], Georg Martin[3], Samuli Korpinen[1], Kaire Torn[3], Vivi Fleming-Lehtinen[1], Lena Bergström[4], Lena Avellan[4] and Ulla Li Zweifel[4] contributed to the development work.

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Software location
Archive
Name: Zenodo
Persistent identifier: https://doi.org/10.5281/zenodo.1288315
Licence: MIT
Publisher: Ciarán Murray
Version published: v1.0.1
Date published: 07/11/17

Code repository
Name: GitHub
Identifier: https://github.com/NIVA-Denmark/BalticBOOST
Licence: MIT
Date published: 07/11/17

Language
English

(3) Reuse potential
BEAT 3.0 performs indicator-based status assessments. At present, the tool use HELCOM Core biodiversity indicators and follows the HELCOM spatial assessment structure. Additional indicators can be added by entering them into the IndicatorCatalogue.txt file. As the tool follows the MSFD structure of ecosystem components, it can also be applied in other European sea areas or used for national reporting purposes. In such cases the spatial assessment units need to be changed to a hierarchical structure of the sea area in question (see below for instructions). By modifying the ecosystem component structure, the tool can also be utilized in other contexts than in assessments responding to MSFD requirements.

Thus, the tool can be applied in any geographical area and indicator-based assessment, not only restricted to the marine environment.

In the SAU.txt input file the spatial assessment unit name, hierarchical level, links between hierarchical levels and area can be modified. The linking of spatial assessment units to a spatial assessment unit at a higher hierarchical level is done in the column ParentID, where the id number (SAUID) of the higher level spatial assessment unit is specified. For the area-based weighing to work properly, it should be checked that the areas of lower level spatial assessment units sum up to the area of the higher level spatial assessment unit. Similarly, the EcosystemComponent.txt file can be modified. In this file the id number of the ecosystem component (ECID) of a higher level is specified in the ParentID column of the lower level ecosystem component to link the two.

As the tool integrates indicator results to assess overall biodiversity status, it is recommended that the indicators used cover the relevant ecosystem components in the areas of interest. The tool does not indicate missing ecosystem component (apart from lowering the confidence of the overall assessment when enabling confidence penalties), so this information should be presented in parallel to the assessment results. Especially if results are only presented at a higher integrated level, it is recommended to present a table showing the indicators used (and potential gaps) as well. The indicator results should be used at an ecologically relevant spatial scale, i.e. the scale on which responses can be measured if there is a change in environmental parameters or anthropogenic pressures. For example, motile species are expected to be assessed in larger assessment units than resident species. When using indicators assigned to different spatial assessment unit levels, it should be noted that the area-based weighing used in the integration will only be balanced if all assessment units at the lower spatial assessment unit level are covered. For example, if a spatial assessment unit has no indicator results, it will not be assessed and subsequently the area of the assessed spatial assessment units will be smaller than the area of the spatial assessment unit at the higher hierarchical level.

Whilst the authors welcome any reuse of the tool and are happy to hear from potential users (contact henrik. nygard@ymparisto.fi or CJM@niva-dk.dk), it must be noted that support cannot be guaranteed for use of the tool.

Acknowledgements

Competing Interests

The authors have no competing interests to declare.

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