ESTONIAN MARINE INSTITUTE REPORT SERIES, NO. 16

The MARMONI approach to marine biodiversity indicators

Volume I:
Development of indicators for assessing the state of marine biodiversity in the Baltic Sea within the LIFE MARMONI project

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Estonian Marine Institute, University of Tartu
2015

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Editorial

The LIFE-funded project "MARMONI" ("Innovative approaches for marine biodiversity monitoring and assessment of conservation status of nature values in the Baltic Sea") has been implemented from October 2010 and is coming to its end in March 2015. It aimed at contributing to a better assessment of marine biodiversity in the Baltic Sea, taking a regional approach on implementation of the Marine Strategy Framework Directive vis-a-vis the Birds and Habitats Directives, the Water Framework Directive and the HELCOM Baltic Sea Acton Plan. Amongst others, we wanted to elaborate innovative ecosystem based monitoring and assessment approaches based on a joint set of marine biodiversity indicators for assessment of conservation status of species and habitats as well as the impacts of human activities. Furthermore, we aimed to test these integrated assessment techniques and biodiversity indicators together with special techniques and equipment for monitoring, which enables us to apply them in pilot demonstration cases in Latvia, Estonia, Sweden and Finland, which were the project partner countries.

The perspective of our work was the state of marine biodiversity, not the pressures; we focussed our effort at descriptor 1 of the Marine Strategy Framework Directive and at species and habitats defined in the Birds and Habitats Directives. These directives are facing the problem that priority habitats and species lists currently used do not cover the particular diversity in the Baltic Sea. The main obstacles we faced were the lack of targeted monitoring schemes collecting relevant data for biodiversity elements, the lack of knowledge for describing the pressure-indicator relationships and cumulative effects of pressures.

Nevertheless, in 4.5 years of work 57 experts representing 14 institutions participated in the indicator work, resulting in a "boiled down" list of 49 marine biodiversity indicators presented in this publication. Here we describe the development of biodiversity indicators for making them operational, aiming at their inclusion in monitoring programmes and assessments of marine biodiversity at the member state and regional sea level. We highlight open issues, concerns, gaps and recommendations for future work on marine biodiversity indicators. Besides the text to follow (constituting Volume I of this publication), the report contains an electronic annex with the complete description of our indicators in PDF (Volume II of the publication) and data base format. We would be glad to receive feedback and comments at our web site http://marmoni.balticseaportal.net and continue this interesting and challenging work also beyond the project end.

The MARMONI work has contributed towards ongoing processes of the Marine Strategy Framework Directive in our project target countries, as well as into HELCOM work on CORESET indicator development and a regional approach to marine monitoring programmes and methods. This publication concludes our current indicator work. We hope that competent authorities and experts will embrace our results in their ongoing work concerning indicators as reflectors of the state of the marine environment.

Heidrun Fammler
LIFE MARMONI Project Manager
Riga, January 2015

Heiko Kruusi

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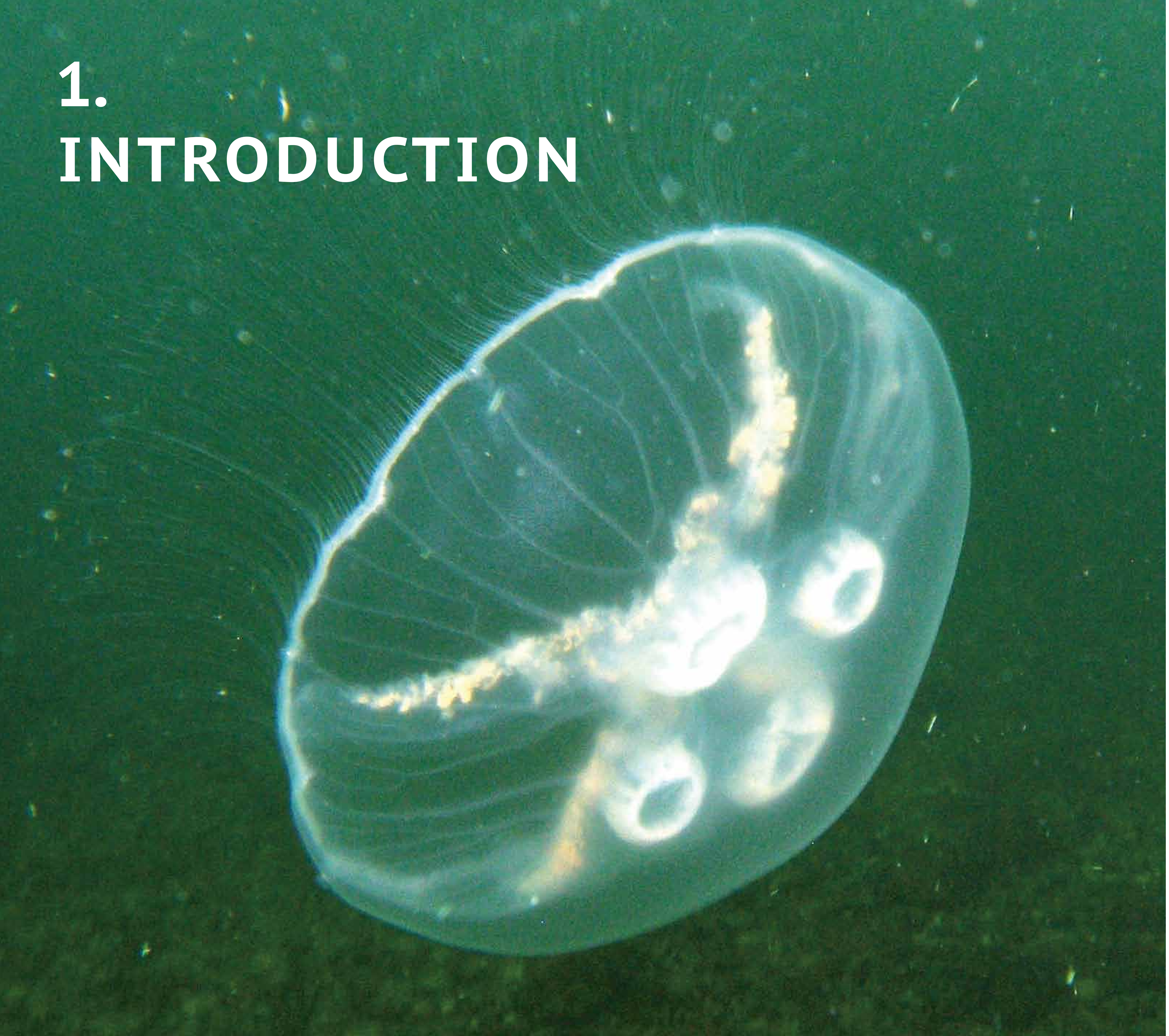
1. INTRODUCTION



Kaire Kaljurand (Estonian Marine Institute, University of Tartu (EMI))

1.1. Policy context of the MARMONI project

Ambitious policy goals in terms of what has to be achieved with regard to maintenance and conservation of marine biodiversity are set by European Community’s directives, such as the Marine Strategy Framework Directive, MSFD (EC, 2008), Water Framework Directive, WFD (EC, 2000), Habitats Directive, HD (EC, 1992), and Birds Directive, BD (EC, 2009), as well as international conventions including Regional Sea Conventions (RSC), for example the Convention on the Protection of the Marine Environment in the Baltic Sea Area (Helsinki Convention). These policy goals and tasks are translated into the national legislation of EU member states or into the legislation of the Contracting Parties of the RSC including their provisions on implementation.

The MSFD is the most recent environmental policy and the first EU legislative instrument related to the protection of marine biodiversity, since it contains the explicit regulatory objective that "marine biodiversity is maintained by 2020", as the cornerstone for achieving Good Environmental Status (GES). The MSFD defines the GES through marine waters that include ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations. A similar objective has been established by the WFD aiming at reaching good ecological status of freshwaters including coastal waters. The good ecological status of coastal waters means that biological quality elements such as phytoplankton, macroalgae and angiosperms, and benthic invertebrate fauna, show low levels of disturbance resulting from human activity.

The HD and BD are long-standing legal frameworks in the EU, which aim at protecting defined species and habitats that are of European importance. Both of these directives require member states to establish protected areas for safeguarding valuable species and habitat types as well as ensure that they are at a favourable conservation status throughout their natural range within the EU. Favourable conservation status is defined as the range and areas of the listed habitats, and the range and population of the listed species that are to be maintained or restored to a position where they are viable.

All Baltic Sea countries signed the Convention on the Protection of the Marine Environment in the Baltic Sea Area in 1992 as follow up of the Helsinki Convention from 1974. The countries have agreed on an ambitious goal - to restore the good ecological status of the Baltic Sea marine environment by 2021. To achieve this goal, the HELCOM Baltic Sea Action Plan (BSAP; HELCOM, 2007) was adopted in 2007 highlighting biodiversity as the core importance of the Baltic Sea environment. It sets straightforward objectives aiming to achieve favourable state of the Baltic Sea biodiversity. Favourable state of the Baltic Sea biodiversity is described by marine and coastal landscapes, thriving with balanced communities of plants and animals, as well as, including viable populations of species.

Common merganser (*Mergus merganser*)

Arne Ader

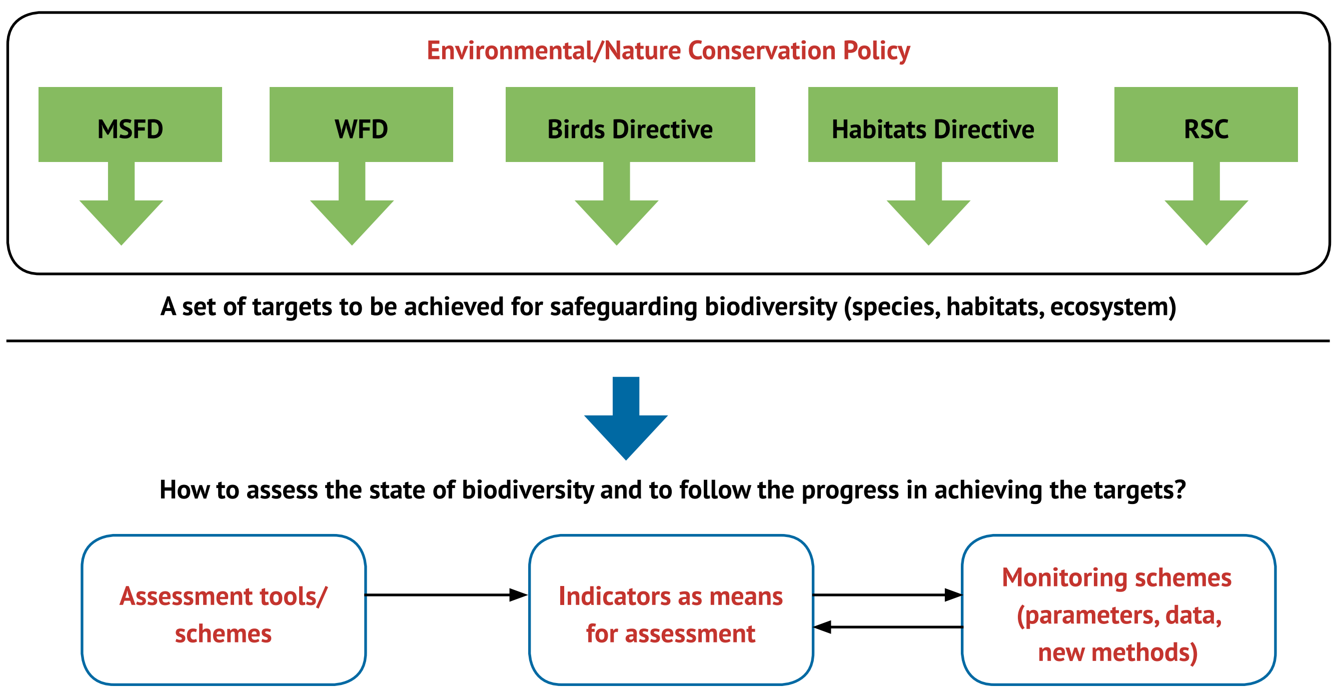


Figure 1. MARMONI framework for assessment of marine biodiversity.

1.2. Approach of the MARMONI project

All the above policy frameworks formed the background for the MARMONI project (Figure 1). One central aim of the project was developing concepts and tools to support policy makers in assessing the progress towards achieving the agreed goals and objectives. The MARMONI project has focused its work towards three major directions: 1) development of assessment concepts and tools, 2) elaboration of new and innovative indicators for assessment, and 3) development and testing of new monitoring methods.

The assessment of the state of marine biodiversity in the Baltic Sea area was a very new and developing topic in the first decade of the 21st century. By 2009 only some international efforts had been made to create a common understanding of methods and procedures to be utilized in performing biodiversity assessments, development of assessment criteria, and applying of thresholds and quality classification for the state of biodiversity. Consequently, no commonly agreed procedures and methods for the assessment of neither marine biodiversity nor conservation status of species and habitats were available at the beginning of the project in autumn 2010.

Nevertheless, an indicator-based approach for the evaluation and assessment either on the state or trends of phenomena has been practiced already for decades by different organisations: the OECD's (Organisation of Economic Development), EEA's (European Environmental Agency) as well as national indicators have been developed to review the performance of environmental policies or assess the state of the environment. However, the work has been mainly focused on terrestrial biodiversity, or on pressures to the marine environment, such as eutrophication and contamination with hazardous substances. An advantage in using indicators for environmental assessment is justified by their key characteristics: they shall be i) quantifiable – the status or a change in environment can be 'measured'; ii) policy relevant – they are set directly in relation to stated environmental policy goals and objectives to assist policy-makers in their evaluation of policies; and, iii) easily understandable for common people and managers by summarizing or simplifying the phenomenon in question.

The HELCOM BSAP already endorses the indicator approach to be used to evaluate effectiveness of the actions undertaken and to measure the progress towards the established targets for the Baltic Sea. Furthermore, the HELCOM BSAP includes a list of preliminary indicators which are further developed by the HELCOM projects CORESET I and CORESET II, which become a set of core indicators for measuring success of achieving the BSAP targets.

Further motivation to develop new biodiversity indicators was instigated by the requirements of the MSFD; the Initial Assessment (IA) of the environmental state of the waters concerned and the environmental impact of human activities had therefore to be prepared by July 2012 and reported to the European Commission. The use of indicators as an instrument in biodiversity assessment was also enforced by the Commission Decision (EC, 2010) relating to the im-

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plementation of the MSFD. The decision defines criteria and related indicators for assessing the extent to which good environmental state is being achieved. A distinguishable set of criteria is elaborated for the descriptor 1 determining good environmental state with regard to biodiversity. It is declared that biological diversity shall be maintained. Moreover, the quality and occurrence of habitats and the distribution and abundance of species are to be in line with prevailing physiographic, geographic and climatic conditions. The defined criteria and indicators of the Commission Decision (EC, 2010) as well as HELCOM work on the set of core indicators (HELCOM, 2013) have been also considered when evaluating the indicators developed within the MARMONI project.

Monitoring activities performed in the frame of regular national programmes or inventories provide data obtained either by sampling, observations, calculations or other scientifically sound monitoring methods. Here, the availability of monitoring data on required parameters is a key limiting factor for designing and developing marine biodiversity indicators; on the other hand, selected and agreed indicators based on research activities might streamline the existing and future monitoring activities to make them more policy-relevant or cost-effective. It is also important to stress that indicators are a product of monitoring activities, not a replacement. As most changes in biodiversity take place over periods of decades or longer, commitment and effort to carry out monitoring over the adequate timescales is essential for building up biodiversity indicators. It is crucial to ensure succession and continuity of monitoring of the major elements of biodiversity as some of the monitored parameters such as frequency or methods employed might change over the time.

During the course of implementation of the MARMONI project, we reviewed the previous developments of marine biodiversity indicators and identified major gaps in assessing the state of biodiversity in the Baltic Sea. So far, in the Baltic Sea, indicator-based marine biodiversity assessments have been rarely conducted. This is mostly due to the lack of good operational indicators describing different components of marine biodiversity, or due to the absence of monitoring data required by these indicators. Most of the EU member states have identified the lack of good operational indicators as a major problem in the implementation process of the MSFD. The absence of such indicators hinders policy makers in setting the quantifiable targets towards the stated goals and objectives. The results of the MARMONI project contribute to improving the situation with regard to availability of appropriate indicators to assess the state of biodiversity within the policy contexts.

1.3. Cross-project collaboration aiming to find and define indicators for the assessment of the Baltic Sea biodiversity

The development of new, innovative and cost-effective biodiversity indicators within the MARMONI project was performed in close cooperation with other parallel initiatives. The HELCOM CORESET and CORESET II projects, dealing with the selection of a core set of indicators among already existing monitoring schemes, have established active communication and cooperation with MARMONI activities through the HELCOM Zooplankton Expert Network, the HELCOM Phytoplankton Expert Group and the HELCOM Fish projects. The MARMONI Bird indicator coordinator was nominated to coordinate the HELCOM seabird indicator work and the MARMONI seabird indicators were included into the CORESET list. A number of indicators developed in MARMONI are also currently considered by the HELCOM CORESET II project to be included in the future programme for the next holistic assessment of the state of the Baltic Sea biodiversity (see Table 2).

Among the other projects dealing with similar matters, close cooperation with the FP7 project “DEVOTES” (DEVelopment Of innovative Tools for understanding marine biodiversity and assessing good Environmental Status) was established. MARMONI was able to provide information and results from its indicator and methodology development to be included in the European wide catalogue of indicators and monitoring methods compiled by the DEVOTES project. Finally, a group of leading MARMONI experts on seabirds and benthic habitats became active participants of the DG ENV funded project “BALSAM” (Baltic Sea Pilot Project: Testing new concepts for integrated environmental monitoring of the Baltic Sea) led by HELCOM secretariat and used the opportunity to bring MARMONI findings and results to the wider Baltic Sea Region expert groups and decision makers.

Merle Kuris

MARMONI workshop “Towards indicator based, cost effective and policy compliant monitoring and assessment of the marine biodiversity in the Baltic Sea” in May 2014

2. THE MARMONI INDICATOR DEVELOPMENT PROCESS

Aquatic sowbug (*Saduria entomon*)

Kaido Haagen

The assessment of biodiversity is a very challenging issue; both, due to the high level of complexity of structure and processes with relationships to human pressures, and due to the lack of basic knowledge and understanding of the marine nature. It is an especially challenging task in the Baltic Sea, where a multitude of local biotic and abiotic gradients create a particular mixture of natural and human induced pressures on marine environment and biodiversity. Metrics or indicators are needed to summarize or simplify the phenomena occurring in nature to a level that is easily understandable for both, managers and the public. Indicators are crucial instruments for understanding, communicating and evaluating environmental processes and policies, and are widely used in assessing the state of the environment. Indicators can provide data or information that represent natural processes and bring it into a compact format - such as a single value, index or similar - and make it easier to understand as well as summarize the complexity of the natural world.

The term "biodiversity indicator" may be used and treated at many different levels and with different meanings. In the MARMONI project, this term was treated in a wide sense, enabling different levels and types of information to be used for the assessment of the state of biodiversity. In the concept applied in the MARMONI project, a biodiversity indicator can be:

- a single measurable parameter (e.g. concentration of chlorophyll *a*, or number or abundance of a species);
- a parameter value integrated over time or in space (e.g. mean summer chlorophyll *a* concentration in a basin, total number of species in a sea area, habitat diversity measure for a certain area);
- a calculated index (e.g. Shannon-Wiener index, BQI);
- a trend in population or other quantitative feature of marine biodiversity.

The MARMONI project work included the development of both, indicators as well as monitoring methods for obtaining “raw” data for indicators. The development of new and the improvement of existing monitoring methods should be considered in combination with the development of the indicators themselves.

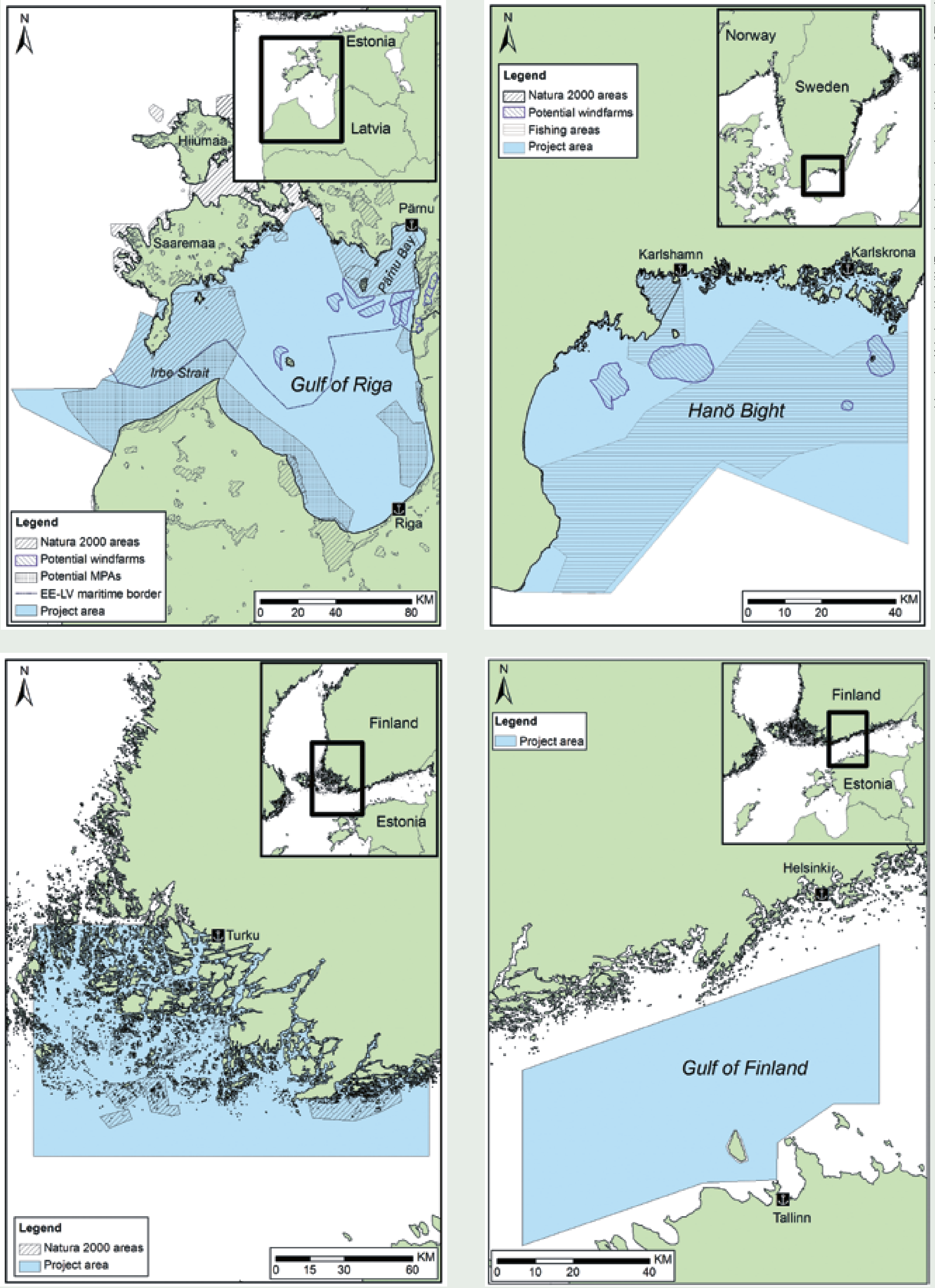
Marine biodiversity can be assessed on very different scales starting from the molecular level and ending with the ecosystem and sea basin. In the MARMONI project, it was decided to focus on the levels higher than the individual specimen – meaning that most of the developed indicators have an indicative value on population, community, habitat or ecosystem. Using the expertise available within the project, the development of indicators was organized within four thematic working groups:

- the fish group;
- the benthic group (including phytobenthos, zoobenthos and benthic habitat indicators);
- the pelagic group (including zooplankton and phytoplankton indicators);
- the bird group.

The development of indicators within the MARMONI project was organized as a creative process and included several phases:

- **Identification of existing and operational indicators** or monitoring parameters and relevant background data used in the routine monitoring or data collection covering the subject of interest (indicator group e.g. birds, habitats, etc.);
- **Analysis of the suitability of existing indicators** or monitoring parameters for assessment of the state of biodiversity on the relevant geographical scale. This was achieved by analyzing the spatial and temporal relevance of the indicator against the variability of pressures and other components of marine biodiversity;
- **Conceptual development** of new indicators based on the needs of the assessment, experience, and analysis of the gaps in the current monitoring schemes and programmes;
- **Testing of field methods** was an integral part of the process, especially for the novel indicators and methods. This work was time consuming and covered several field seasons;
- **Validation of indicators against human induced pressure:** the testing of pressure gradients has been a very challenging task since the pressure gradients should be identified within the given project areas and combined with actual sampling and observation activities;
- **Testing applicability of indicators** in different geographical areas was carried out by testing and evaluation of selected indicators in project areas other than the ones where they were originally developed;
- **Establishment of reference conditions** was a scientific exercise requiring the application of different approaches and strategies, including extensive data mining and analysis. Making indicators “operational“ in most cases involved the establishment of site- or area-specific levels or values of desirable state for the present condition of the indicator to be measured against;
- **Establishment of targets or level corresponding to GES**. “Environmental target” is the concept applied by the MSFD to identify the condition of the different components of, and pressures and impacts on, marine environment. The establishment of targets is both, a scientific and a political exercise, and is essential for the use of indicators in assessment schemes;
- **Standardized documentation** was set up to facilitate the application of the indicators in areas other than for which they were developed, and/or for them to be applied by persons other than those involved in the development of the indicators;
- **Using the indicators in a practical assessment exercise.** As a separate activity in the project, an assessment exercise was designed to include both previously available indicator data and indicators developed in the course of the MARMONI project.

The development of an indicator, especially from the very beginning (i.e. starting with conceptual thinking and building upon that) requires time and data resources for both the establishment of proper field



Maps by Kristjan Herkül (Estonian Marine Institute, University of Tartu)

Figure 2. The four MARMONI project pilot areas, from up left to down right: 1 – EST-LAT Irbe Strait and the Gulf of Riga, 2 – SWE Hanö Bight, 3 – FIN Coastal Area of SW Finland and 4 – FIN-EST Gulf of Finland.

Coastal area of SW Finland

Hanö Bight

Gulf of Finland near Tallinn

Latvian coast of Irbe Strait

measurement techniques and the validation of the indicator against potential pressure gradients. In the MARMONI project, the indicator development activities continued throughout the duration of the project, and especially the development of reference conditions and testing was performed in the terminal part of the project in parallel with the assessment exercise.

Geographically, the indicator development was focused on the four MARMONI pilot areas (Figure 2). Most of the indicators were developed in one of the project areas (except bird indicators, which were developed for the entire Baltic Sea); some of them were subsequently tested in one or several of the other project areas. However, despite the limited geographical range of the pilot areas, our approach enabled in many cases the demonstration of the applicability of the indicators on a wider geographical scale and in different environmental settings.

A part of the indicator development strategy in the MARMONI project was publishing the early draft versions of the indicator documentation on the project web site together with an interactive feedback collection system. It enabled to receive valuable feedback from national authorities and international experts working in the field. On the other hand, the draft list of indicators helped the MSFD implementation in the four partner countries by providing the possibility to consider indicators when compiling e.g. the national marine monitoring programmes.

The indicators developed and tested within the MARMONI project are presented in Chapter 3. Below we report on two key phases of the indicator development process, i.e. the analysis of existing biodiversity indicators in the Baltic Sea area, and the documentation of the novel biodiversity indicators.

2.1. Analysis of the previously existing biodiversity indicators in the Baltic Sea area

As a rule, governmentally funded, long-term monitoring programmes aiming to assess the state of biodiversity are lacking in the northern Baltic Sea. Most of the monitoring programmes have targeted problems related to and effects of eutrophication or hazardous substances (e.g. HELCOM COMBINE, national monitoring programmes). These programmes usually include several parameters or metrics that are related to different components of marine biodiversity, but in general the aim of data collection has not been to describe the state of biodiversity, or any particular component or element of the biodiversity, but to describe and follow the impacts of certain pressures.

As a first step in the process of developing new innovative biodiversity indicators in the MARMONI project, the existing biodiversity indicators and biodiversity-related indicators were reviewed. The four thematic working groups (fish, benthos, pelagic and birds; see above) evaluated the existing monitoring and data collection programmes in the Baltic Sea region. Based on this, they selected a set of already used or developed indicators, which appeared to have the potential to be used in the further development of indicators and assessment schemes for the assessment of marine biodiversity.

Properties of the reviewed indicators were then checked against a number of criteria derived from Rees *et al.* (2008) and the results from the project NordBio2010 (Normander *et al.*, 2009), as well as additional criteria tailored within the MARMONI project. All reviewed indicators and their performance in relation to certain key criteria are summarized in Table 1 (for full analysis see Volume II of the publication).

The reviewed indicators were classified according to the DPSIR (Drivers, Pressures, State, Impact, Response) framework (Smeets and Weterings, 1999). DPSIR provides a system's analysis framework for description of the causal relationships in the context of management, including socioeconomic driving forces and management responses to impacts. For the effective use of a DPSIR indicator in marine management, it should measure changes in the environment caused by human activity. The impact and significance of those changes should be known (Normander *et et al.*, 2009). Most of the reviewed existing indicators are indicating "state" or "pressure" only.

In order to assess the value of existing indicators for policy implementation, their relevance to the directives (such as the MSFD) and other international agreements was checked. Most of the reviewed indicators were found to be useful in providing adequate information for monitoring needs and therefore relevant for directives and international agreements.

The specific aim of the MARMONI indicator work was to develop new "true biodiversity indicators", i.e. indicators reflecting the state of a certain component of marine biodiversity or for assessing the conservation status of biodiversity. Out of the 28 reviewed biodiversity and biodiversity-related indicators, 13 were classified as "true biodiversity" indicators by the thematic working groups. Determining whether an indicator is a true biodiversity indicator or only indirectly measures a biodiversity component may be challenging. The NordBio2010 proposes an indicator network where indicators describe changes in biodiversity quality and biodiversity quantity (Normander *et al.*, 2009). For example, quantity indicators measure the area of different habitat types whereas quality indicators measure species populations or other quality parameters such as habitat structure (e.g. the proportion of perennial species). Among the reviewed indicators both, indices (such as BQI) and parameters (such as the number of species) were present. Some of the reviewed indicators are currently used in the existing monitoring programmes e.g. for assessment of ecological state for the WFD or for monitoring of fish stocks. Most of these indicators are no true biodiversity indicators, but are measuring performance of a certain biological component against different pressures and thus not related directly to assessing the state of marine biodiversity. However, some of these biodiversity-related indicators may potentially be adapted or developed further into true biodiversity indicators and therefore they were included in the indicator development process in MARMONI project (see Table 1).

Table 1. *Existing biodiversity indicators and biodiversity related indicators analysed against different criteria by Rees et al. (2008) and NordBio2010, as a first step in the MARMONI indicator development work (Martin, G. (ed.) 2012). Some of the 13 indicators identified as true biodiversity indicators (see right-hand column) were then taken up in detailed indicator development process.*

No	Name of the indicator	In use/proposed	Biodiversity component	True biodiversity indicator	Indicators further developed in MARMONI
1.	Depth distribution of *Fucus vesiculosus*	In use	phytobenthos	no	
2.	**Depth distribution of vegetation**	**In use**	**phytobenthos**	**yes**	
3.	**Share of annual and perennial species**	**In use**	**phytobenthos**	**yes**	
4.	**Number of species**	**In use**	**all**	**yes**	
5.	**ZKI macrozoobenthos community index**	**In use**	**zoobenthos**	**yes**	**Yes**
6.	**Species accumulation or rarefaction curves**	**proposed**	**zoobenthos**	**yes**	
7.	Relative abundance (or biomass) and species-rank curves	proposed	zoobenthos	no	
8.	**Number (diversity) of functional traits**	**proposed**	**zoobenthos**	**yes**	**Yes**
9.	Community wide synchronicity	proposed	zoobenthos	no	
10.	Community stability (the ratio between the mean and the standard deviation)	proposed	zoobenthos	no	
11.	**Number of perennial algal species**	**proposed**	**phytobenthos**	**yes**	
12.	**Total algal cover**	**In use**	**phytobenthos**	**yes**	
13.	**Cumulative algal cover**	**In use**	**phytobenthos**	**yes**	**Yes**
14.	Depth distribution of macroalgal species	In use	phytobenthos	no	
15.	Lower growth limit of perennials	In use	phytobenthos	no	
16.	**Multimetrics index (BQI)**	**In use**	**zoobenthos**	**yes**	
17.	Catch per unit effort (CPUE)	In use	fish	no	
18.	CPUE of large fish individuals	proposed	fish	no	
19.	Catch per unit effort (CPUE) of perch 25	proposed	fish	no	

No	Name of the indicator	In use/proposed	Biodiversity component	True biodiversity indicator	Indicators further developed in MARMONI
20.	Catch per unit effort (CPUE) of cyprinid fish	proposed	fish	no	
21.	Catch per unit effort (CPUE) of piscivorous fish	proposed	fish	no	
22.	Catch per unit effort (CPUE) of non-piscivorous fish	proposed	fish	no	
23.	Catch per unit effort (CPUE) of marine fish species	proposed	fish	no	
24.	**Mean trophic level**	**proposed**	**fish**	**yes**	
25.	Mean maximum length of fish	proposed	fish	no	
26.	**Species diversity**	**proposed**	**fish**	**yes**	
27.	Chl *a* measurement (HELCOM IFS part 1)	In use	phytoplankton	no	
28.	**Phytoplankton species succession (HELCOM IFS part 2)**	**proposed**	**phytoplankton**	**yes**	**Yes**

Bladder wrack (*Fucus vesiculosus*)

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2.2. Methodology for documentation of indicators developed in the MARMONI project

To facilitate a uniform and comprehensible presentation of the developed indicators, an Indicator Documentation Sheet was developed. The sheet includes the following data fields:

1. Name of the indicator
2. Type of the indicator (DPSIR)
3. Author(s) (people involved in the indicator development or testing)
4. Description of the indicator (introduction, simple narrative description of the indicator)
5. Relationship of the indicator to marine biodiversity (description of the indicative value of the indicator for detecting changes in any component of marine biodiversity)
6. Relevance of the indicator for different policy instruments (mainly EU directives and international conventions)
7. Relevance to the Commission Decision criteria and indicators (each indicator is attributed to one or several Commission Decision (EC, 2010) criteria or indicators)
8. Method(s) for obtaining indicator values
9. Documentation of relationship between the indicator and pressure (description of available documentation on evidence of relationship between indicator value and pressure)
10. Geographical relevance of the indicator (geographical relevance of the indicator is described on four levels from Baltic Sea wide relevance to local)
11. Reference Conditions for the indicator and how they were obtained
12. Method for determining GES (description of how the GES boundaries were set for the indicator)
13. References (list of references used for defining methods, describing the indicator-pressure relationships or other methodological matters)
14. Illustrative material for indicator documentation (illustrations of indicator-pressure relationships, data collection methods, or test cases)

The Indicator Documentation Sheets of the developed indicators are presented in Volume II of the current publication. A web based indicator database was created on the project web page to present the indicators and to communicate with interested stakeholders. Furthermore, scientific manuscripts concerning several of the indicators are currently in preparation.

It is important to note that the aim was not to develop a complete set of indicators covering all aspects and levels of biodiversity and to attain full compliance with the countries' reporting obligations to EU or with international agreements. The developed set should be used as a potential "shopping list" by the authorities developing monitoring and assessment programmes to fulfil the several national and international requirements. The present publication includes a list of the developed indicators with a short description of each indicator (Chapter 3).

3. LIST OF DEVELOPED AND PROPOSED INDICATORS FOR THE ASSESSMENT OF MARINE BIODIVERSITY IN THE BALTIC SEA

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Within the framework of the MARMONI project, a total of 49 indicators describing different aspects of marine biodiversity in the Baltic Sea were developed. The indicators are grouped into three categories – "ready", "in need of development" and "abandoned or refused" (see Table 2). The MARMONI indicators are considered "ready" in the sense that the applied concept has proven viable in the tested area(s). Concerning the majority of the indicators, reference conditions and GES boundaries have, however, to be set separately for each area to account for the characteristic differences in the area. Hence, "the" ready indicators cannot be considered operational in other than in the tested areas. Indicators in the "in need of development" category need some further development in terms of methodology or in defining reference values. The "abandoned or refused" category was used for indicators where development was stopped due to varying reasons.

In this chapter, short introductions of the four indicator groups are given, and all indicators are briefly presented. The complete documentation of the indicators, including information on the methodology for acquiring the indicators and relevant GES values, is presented in Volume II of the publication.

Table 2. *List of indicators developed by the MARMONI project.*

Name of indicator	Development Status	Relevance to EC criteria and indicators	Relevance to BD & HD	Relevant HELCOM CORESET indicator	Included in national monitoring programmes of countries involved in MARMONI project
Fish indicators					
1.1 Abundance and distribution of juvenile flounder (*Platichthys flesus*)	in need of development	1.1.1. 1.2.1 1.6.1			
1.2 Long term abundance and distribution of demersal fish in relation to benthic communities (fourhorn sculpin (*Myoxocephalus quadricornis*) and eelpout (*Zoarces viviparous*) example	refused	1.1.1 1.2.1 1.6.1			
1.3 Abundance and impact of non-native fish species (round goby (*Neogobius melanostomus*) example	ready	1.1.1 1.2.1			
1.4 Abundance index of large (TL>250 mm) perch (*Perca fluviatilis*) in monitoring catches	ready	1.3.1			Estonia
1.5 The length at sexual maturation of female pikeperch (*Sander lucioperca*) in monitoring catches	ready	1.3.1			
1.6 Abundance of Cyprinids	ready	1.2.1		CORESET Abundance of key coastal fish species (core, comparable indicator)	Finland
1.7 Trophic diversity index of juvenile fish	in need of development	1.6.1 1.6.2	important nursery habitats		
1.8 Habitat-related functional diversity of juvenile fish	in need of development	1.6.1 1.6.2	important nursery habitats		
Benthic indicators					
2.1 Accumulated cover of perennial macroalgae	ready	1.6.1 1.6.2	data for habitats such as 1170 (reefs)		Latvia

Name of indicator	Development Status	Relevance to EC criteria and indicators	Relevance to BD & HD	Relevant HELCOM CORESET indicator	Included in national monitoring programmes of countries involved in MARMONI project
2.2 Accumulated cover of submerged vascular plants	ready	1.6.1 1.6.2	data for habitats such as 1110 (sublittoral sandbanks)		
2.3 Beach wrack Macrovegetation Index (BMI)	ready	1.6.2 1.7.1			(Estonia)*
2.4 Indicator of macroalgal community structure (MCS)	ready	1.7.1	variability within habitat		Latvia, (Estonia)*
2.5 Habitat diversity index	ready	1.6.1			(Estonia)*
2.6 Seafloor exploitation index	ready	1.6			Finland (Estonia)*
2.7 Spectral variability index	ready	1.6.1 1.7.1			(Estonia)*
2.8 Condition of soft sediment habitats – the aRPD approach (Former name Condition of soft sediment habitats)	ready	1.6.3			
2.9 Population structure of *Macoma balthica*	ready	1.3.1		CORESET Population structure of long-lived macrozoobenthic species (core, MARMONI indicator has indirectly contributed to the development)	Latvia Finland
2.10 *Cladophora glomerata* growth rate (Former name *Cladophora glomerata* length)	ready	1.2.1			
2.11 Depth distribution of selected perennial macroalgae (Former name Abundance of selected perennial macroalgae)	ready	1.1.1		CORESET Lower depth distribution limit of macrophyte species (pre-core, MARMONI indicator has indirectly contributed to the development)	Estonia Latvia Finland Sweden

Name of indicator	Development Status	Relevance to EC criteria and indicators	Relevance to BD & HD	Relevant HELCOM CORESET indicator	Included in national monitoring programmes of countries involved in MARMONI project
2.12 Community heterogeneity, CH	ready	1.6 1.7.1			(Estonia)*
2.13 Number of functional traits, NFT	ready	1.6.1 1.7.1			Finland, (Estonia)*
2.14 Macrozoobenthos community index, ZKI	ready	1.6.1 1.6.2 1.7.1		CORESET State of the soft-bottom macrofauna communities (BQI) (core, comparable indicator)	Similar type of index: Finland, Sweden, Estonia
2.15 Reed belt extent – the NDVI approach via high resolution satellite images (Former name Reed extent)	ready	1.5.1	State of coastal habitats		
Pelagic indicators					
3.1 Phytoplankton species assemblage clusters based on environmental factors.	ready	1.6.2 1.6.3 1.7.1.		CORESET II Proposed candidate indicator, MARMONI indicator being tested in other HELCOM areas	
3.2 Seasonal progression of phytoplankton functional groups	ready	1.6.1 1.6.2 1.7.1		CORESET II Proposed candidate indicator, MARMONI indicator being tested in other HELCOM areas	Latvia
3.3 Cyanobacterial surface accumulations - the CSA-index (Former name Cyanobacterial surface accumulations)	ready	1.6.2			Finland, (Estonia)*
3.4 Phytoplankton taxonomic diversity (Shannon95) (Former name Phytoplankton taxonomic diversity)	ready	1.6.1			Finland
3.5 Phytoplankton trait- and dendrogram based functional diversity index (FD) (Former name Phytoplankton functional diversity)	in need of development	1.7.1			(Estonia)*

Name of indicator	Development Status	Relevance to EC criteria and indicators	Relevance to BD & HD	Relevant HELCOM CORESET indicator	Included in national monitoring programmes of countries involved in MARMONI project
3.6 Spring bloom intensity index (Former name Spring bloom biomass)	ready	1.6.2		EUTRO-OPER Proposed candidate indicator, developing comparable indicator	Finland, (Estonia)*
3.7 Copepod biomass	ready	1.2.1 1.6.2			Latvia, (Estonia)*
3.8 Zooplankton diversity	in need of development	1.6.1			Latvia
3.9 Microphagous mesozooplankton biomass	ready	1.2.1 1.6.2			(Estonia)
3.10 Zooplankton mean size vs. total stock (MSTS) (Former name Zooplankton mean size total stock (MSTS))	ready	1.2.1 1.3.1 1.6.1		CORESET: Zooplankton mean size and total abundance (core, comparable indicator)	Finland, (Estonia)*
Bird indicators					
4.1 Abundance index of wintering waterbird species	ready	1.2.1 1.6.1	HD: Article 17, Habitat type 1110 and 1170; BD: Article 12	CORESET Abundance of waterbirds in the wintering season (core, MARMONI indicator has indirectly contributed to the development)	Latvia, Finland, Sweden, (Estonia)*
4.2 Wintering waterbird index (WWBI)	ready	1.6.1 1.7.1			Latvia, (Estonia)*
4.3 Wintering indices for waterbirds of different feeding guilds (WWBIFG)	ready	1.6.1 1.7.1			Latvia, (Estonia)*
4.4 Abundance index of breeding waterbird species	ready	1.2.1 1.6.1	BD: Article 12	CORESET Abundance of waterbirds in the breeding season (core, MARMONI indicator has indirectly contributed to the development)	Latvia, Sweden, Finland, (Estonia)*
4.5 Breeding waterbird index (BWBI)	ready	1.6.1 1.7.1			Latvia, (Estonia)*

Name of indicator	Development Status	Relevance to EC criteria and indicators	Relevance to BD & HD	Relevant HELCOM CORESET indicator	Included in national monitoring programmes of countries involved in MARMONI project
4.6 Distribution of wintering waterbird species	ready	1.1.1 1.1.2	HD: Article 17, Habitat type 1110 and 1170; BD: Article 12		Latvia, Finland, (Estonia)*
4.7 Distribution of wintering waterbirds (multi-species)	ready	1.6.1 1.7.1			Latvia, (Estonia)*
4.8 Distribution of wintering waterbirds of different feeding guilds (multi-species)	ready	1.6.1 1.7.1			Latvia, (Estonia)*
4.9 Distribution of breeding waterbird species	ready	1.1.1 1.1.2	BD: Article 12		Latvia, Finland, (Estonia)*
4.10 Breeding success: clutch and brood size of breeding species	ready	1.3.1 1.6.1			Latvia, Finland, (Estonia)*
4.11 Age/sex ratio of waterbird species (ARI/SRI)	ready	1.3.1 1.6.1			Latvia, (Estonia)*
4.12 Proportion of oiled waterbirds	ready	1.3.1 1.6.1	BD: Article 12		
4.13 Abundance index of beached birds	ready	1.3.1 1.6.1.	BD: Article 12		
4.14 Abundance index of by-caught birds	ready	1.3.1	BD: Article 12	CORESET Number of drowned mammals and waterbirds in fishing gears (core, MARMONI indicator has indirectly contributed to the development)	
4.15 Indicator on condition of waterbirds	ready	1.3.1 1.6.1	BD: Article 12		(Estonia)*
4.16 Feeding pressure on waterbird food sources	ready	1.6.1 1.6.2	HD: Article 17, Habitat type 1170		(Estonia)*

* *Mentioned in the new monitoring programme reported to EC*

Kaire Kaljurand (EMI)

Flounder (*Platichthys flesus*)

3.1. Fish indicators

There are around 110 fish species regularly occurring in the Baltic Sea. Several of them are important for the fishery. The species of importance such as the Baltic herring, sprat, cod, salmon and flatfish are internationally managed and the effects of fishery on the stocks of these species are annually assessed in co-operation between the Baltic Sea countries. These assessments also provide the necessary information of the effects of fishery on these stocks for the purposes of the MSFD (descriptor 3). There are, however, several other fish species important for the coastal fishery, at least on a regional scale. It has been acknowledged that the monitoring of these - often more or less local stocks - is not on an adequate level due to the lack of common indicators, sampling approaches and thus proper data. In addition to the species important to the fishery, there is an ample group of species - mostly small-sized - which are not fished or are only fished occasionally. Also, some alien species such as the round goby (*Neogobius melanostomus*) are nowadays common over extensive geographical areas in the coastal Baltic Sea.

Environmental changes and fishery constitute the main pressures for fish in the Baltic Sea. Environmental changes can affect early life stages of fish by altering the environmental as well as biological conditions of reproduction areas. The changes can also affect juvenile or adult populations via altered food-web dynamics. Altogether, the links between environmental changes and fish communities are complicated, making it difficult to detect any clear linkages and thus causing challenges for indicator development. The assessments of the internationally managed fish species are based on data collected regularly by standard methods. However, a great variety of sampling methods have been used to collect the data on other fish species. Thus, in the MARMONI project, we also put an effort on analytically evaluating different survey designs and sampling methods.

Two out of the eight fish indicators developed and tested in the MARMONI project directly focused on the effects of fishery on coastal species, five indicators focused on the complicated effects of changes in the coastal environment on fish, and one of the indicators focused on the distribution of alien species. The fish indicators were developed and tested by experts from the Estonian Marine Institute (Lauri Saks, Roland Svirgsden, Kristiina Jürgens, Aare Verliin, Markus Vetemaa), the Finnish Game and Fisheries Research Institute (Antti Lappalainen, Meri Kallasvuo, Mira Anttila, Outi Heikinheimo, Eevi Kokkonen and Mika Kurkilahti), the Latvian Institute of Aquatic Ecology (Eriks Kruze, Atis Minde) and AquaBiota Water Research (Martin Ogonowski, Göran Sundblad).

Abundance and distribution of juvenile flounder (*Platichthys flesus*). This indicator shows the link between the species reproduction and environmental state of the coastal waters. The abundance and distribution of juvenile flounders in shallow coastal sandy habitats is monitored with beach seine in autumn or spring. Most of the testing data was collected in the SW coast of Finland which is close to the northern edge of the distribution area of flounder. The data collected during the project revealed a huge annual variation in the yearly juvenile abundance. Any reasonable explanation (covariate) for the variation was not detected. Due to the high variation, this indicator is not operational yet, and it should be further developed and tested. Data on abundance and distribution of juvenile flounder will be collected widely around the Baltic Sea during 2014-2018 in a Bonus project (INSPIRE) possibly enabling further development of this indicator.

Long term abundance and distribution of demersal fish in relation to benthic communities (fourhorn sculpin *Myoxocephalus quadricornis* and eelpout *Zoarces viviparous* example). These two indicators aim to describe the abundance of key benthic fish species in the Gulf of Riga in relation to the benthic invertebrate community. Thus, serving as indicators of good quality of the sea environment and of natural biodiversity. The sampling of the fish is carried out annually in the Gulf of Riga and Irbe Strait at fixed survey stations using benthic trawls. Benthic invertebrate biomass data is gathered in the framework of the national Baltic Sea monitoring programme. The indicators were tested using data from 1993 to 2010. Abundance of both fourhorn sculpin and eelpout showed high and unexplained variation and any connections to the abundance of benthic communities were not detected. Due to these shortages, these indicators were finally rejected.

Tiit Hunt

Eelpout (*Zoarces viviparous*)

Tiit Hunt

Fourhorn sculpin (*Myoxocephalus quadricornis*)

Tiit Hunt

Round goby (*Neogobius melanostomus*)

Anu Albert (EMI)

Pikeperch (*Sander lucioperca*)

Kristiina Jürgens (EMI)

Fish sampling with hand seine

Abundance and impact of non-native fish species (round goby example). This indicator describes the invasions of a non-native species and is related to various pressures like shipping, ballast water discharge and climate change. Alien species can integrate in the native fauna without causing significant changes in the ecosystem or they can be ecologically aggressive and cause major changes in the natural food web structure and biodiversity in general. Populations of round goby can significantly decrease the biomass of benthic mussels and other benthic invertebrates, thus limiting the food supply for other benthic fish in the Baltic Sea, such as flounder. Thus, an increase in the biomass ratio of non-indigenous species and local species occupying the same niche indicate a loss of biodiversity and structural changes in the food webs. The data for this indicator was obtained from coastal gillnet monitoring. The indicator is ready to be used in areas where monitoring data is available.

Abundance index of large (TL>250 mm) perch (*Perca fluviatilis*) in monitoring catches. The indicator describes the effects of fishing pressure on local fish communities. A decrease in the values of this index may be symptomatic of heavy fishing pressure which may result in a decrease of the mean trophic level of the community, which in turn may be associated with a decline in local biodiversity. The data for this indicator was obtained from coastal gillnet monitoring. Clear associations between indicator values and fishing pressure were demonstrated by comparing monitoring areas near the Kihnu and Vilsandi islands, which have different commercial fishing pressures. The indicator is basically ready to be used in areas where monitoring data is available. However, more data collection and analysis are required to determine the quantitative reference conditions for this indicator.

The length at sexual maturation of female pikeperch (*Sander lucioperca*). The indicator describes the average size at which female pikeperch reach maturity. A decrease in the length-at-maturity is a symptom of strong selective fishing pressure which may have led to life-history shifts in local pikeperch populations. Thus, this indicator directly supports the monitoring of commercial fish stocks under descriptor 3 of the MSFD. Data for this indicator was gathered from annual trawl-surveys or by sampling of commercial fyke-net catches, included in the EU Data Collection Framework programme e.g. in Finland. Associations between indicator values and fishing pressure were demonstrated using all available data from Estonia and Finland. Some old reference data from the 1980's is available in both countries to set the target values. This new indicator is ready and will likely be included in the national MSFD monitoring programmes in Estonia and Finland, after the supporting results published in a scientific journal (Lappalainen *et al.* manuscript in preparation).

Abundance of Cyprinids. This indicator describes the measured abundance of Cyprinids (group of freshwater fish species) in the archipelago areas. Large cyprinid fish, such as bream (*Abramis brama*) and roach (*Rutilus rutilus*), have become increasingly abundant e.g. in the Finnish archipelago waters and the main reason for this development is coastal eutrophication. Abundance of roach in gill-net monitoring, measured as individuals/gill-net/night, has already been used in the assessment of coastal fish communities. A so-called "power analysis" of gill-net data carried out in the MARMONI project has, however, revealed that the variation is lower and power higher if the abundance is measured as weight rather than a number of individuals. The indicator is basically ready to be used in areas where monitoring data is available. The recommendations based on the power analysis should be taken into account and further analyses are required to determine the quantitative reference conditions of this indicator (Lappalainen & Kurkilahti, manuscript in preparation).

Trophic diversity index of juvenile fish. The indicator aims to pinpoint the biodiversity of juvenile fish species in relation to the mean trophic level of the community, and this diversity should in turn also represent the fish production potential in their habitats. Low values may indicate domination of species favoured by eutrophic conditions, and vice versa. The distribution and abundance of 0-group fish was sampled using small underwater detonations. This indicator should be further developed, tested and GES thresholds need to be determined.

Habitat-related functional diversity of juvenile fish. The indicator aims to express the biodiversity of juvenile fish within a habitat-based functional group. This diversity should in turn also indicate to what extent the habitat functions as a spawning and nursery area. The distribution and abundance data of 0-group fish was obtained using small underwater detonations. This indicator should be further developed, tested and GES thresholds need to be determined.

Blue mussel (*Mytilus trossulus*)

Kaido Hagen

3.2. Benthic indicators

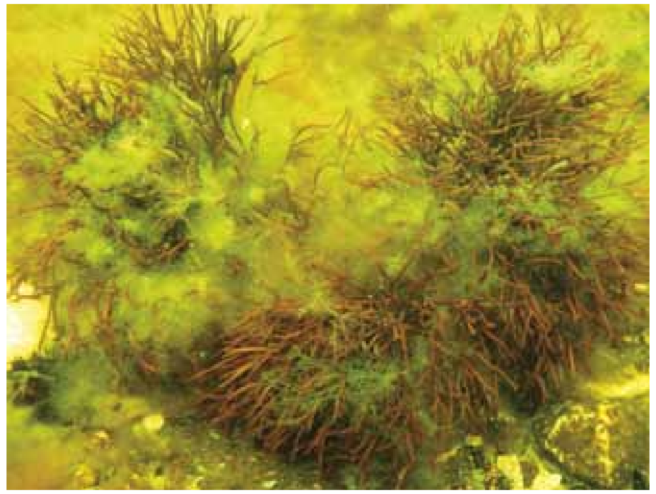
This group of indicators covers both, benthic species diversity indicators as well as indicators describing the status of benthic habitats. A total of 531 benthic macrophyte species and 1898 benthic invertebrate species have been listed for the Baltic Sea (HELCOM, 2012a, 2012b). The distribution of these species is not even and depends strongly on the set of natural environmental and human induced pressure gradients which make each of the local assemblages unique in terms of community properties and the environmental setting. This makes the assessment of the state of Baltic Sea marine benthic biodiversity very complicated and special approaches for developing indicators are necessary.

The main pressures on benthic habitats and communities in the Baltic Sea are related to eutrophication effects. On a local scale also other pressures resulting from human activities, such as mechanical damage of seafloor by dredging and dumping, construction activities, and fishing, are of importance. Recently the introduction of new, invasive species has been recognised as a potential threat for local benthic communities.

So far, benthic species and communities have been used in the assessment and monitoring of the Baltic Sea marine environment as indicators of eutrophication effects reflecting either the change in trophic conditions (change in abundance) or change in environmental setting (change in water transparency or oxygen conditions). The state of benthic biodiversity has not yet been targeted by the previous and current monitoring programmes and therefore a large part of information required for the implementation of the MSFD or the HD is not available.

The benthic indicators developed by the MARMONI project fulfil several of the identified gaps in marine biodiversity assessment. On species and community level, the indicators include more ways of reflecting changes in distribution patterns and community structure. On habitat level, new methods for data collection have been proposed to facilitate the collection of information that has been previously unavailable. Both, the utilization of the existing monitoring activities and the development of new methods and strategies for data collection were applied. In developing the new set of indicators and methods, a very important aspect was cost-efficiency. Several new methods are able to replace or complement the existing data collection strategies with raising the efficiency and adding additional value for the collected data. All benthic indicators described below are ready to be applied in the area(s) where they were tested as well as considered to be incorporated into the marine monitoring programmes (see Table 2).

The following experts and organisations were involved in developing the new set of indicators for assessing benthic biodiversity in different project areas of the Baltic Sea: AquaBiota Water Research (Nicklas Wijkmark), the Estonian Marine Institute, University of Tartu (Kaire Torn, Georg Martin, Tiia Möller, Kristjan Herkül, Jonne Kotta, Merli Pärnoja), the Latvian Institute of Aquatic Ecology (Madara Alberte, Vadims Jermakovs), and the Finnish Environment Institute SYKE (Henrik Nygård, Ari Ruuskanen, Hanna Piepponen, Meri Koskelainen and Kirsi Kostamo).



EMI

Furcellaria lumbricalis

Heiko Kruusi

Beach wrack reflects the structure of benthic vegetation of the adjacent sea area

Accumulated cover of perennial macroalgae. This indicator reflects the quantity of the perennial macroalgae community measured as accumulated cover, thus indicating the quantity of biodiversity as the amount of species living on and among the algae. It quantifies the biodiversity of shallow hard bottoms and may be used simultaneously with a vascular plant indicator for shallow soft bottoms (see "Accumulated cover of submerged vascular plants" below). The measured unit is accumulated %-cover and the assessment unit is the total aggregated accumulated cover within a predefined monitoring area. For calculation the cover of each species is summed including all layers and overlapping species. The recommended main data collection method is drop-video. Eutrophication is the main pressure reflected by this indicator. It is intended to be used in the entire Baltic Sea, but the establishment of new reference values is necessary when using the indicator in a new area. This indicator will be less applicable in the Gulf of Bothnia, especially in the northern parts (since macroalgal species gradually disappear further north as a result of lower salinity). If bryophytes wold be included in this indicator, it may be also applicable to the northern latitudes.

Accumulated cover of submerged vascular plants. This indicator reflects the quantity of the submerged vascular plant community measured as accumulated cover, thus indicating the quantity of biodiversity as the abundance and volume of the vascular plant community and associated species. It indicates biodiversity quantity on shallow soft bottoms in more sheltered areas and can be used simultaneously with the macroalgae indicator for shallow hard bottoms (see "Accumulated cover of perennial macroalgae" above). All species of submerged vascular plants are included in this indicator, both eelgrass (*Zostera*) meadows and mixed stands of taxa such as e.g. *Stuckenia, Potamogeton*, and *Myriophyllum*. The recommended main data collection method is drop-video. Eutrophication is the main pressure reflected by this indicator. For geographical aggregation, sampling may be performed in different ways, e.g. by sampling in a randomized stratified way within monitoring areas. Monitoring areas can be naturally delimited, such as coastal basins, or artificially delimited such as administrative units. The indicator itself can be applied all over the Baltic Sea area where vegetated soft bottoms occur.

Beach wrack Macrovegetation Index (BMI). The indicator is based on the macrovegetation species composition of beach wrack and reflects the structure of benthic vegetation of the adjacent sea area. During the development of the indicator, the representativeness of the composition of beach wrack was proved for the study areas. Compared to commonly applied monitoring methods, the BMI is easy to use and cost-effective since it enables the replacement of resource- and expertise-demanding conventional SCUBA diving sampling. The BMI was developed on data collected from the northern Gulf of Riga and tested in southern part of the Gulf of Riga. The indicator weighs the amount of "valuable" species against the total amount of species in the sample, taking into account total species richness. The indicator was tested on an eutrophication gradient (Suursaar *et al.,* 2014). This

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Common eelgrass (*Zostera marina*)

method can be recommended for areas not affected by frequent extreme storm events, strong tides, or strong currents. In the Baltic Sea area only the latter is relevant in potentially restricting the use of the indicator, otherwise it is ready for application.

Indicator of macroalgal community structure (MCS). The indicator focuses on the phytobenthic community and its structural features. Though focusing only on plants, the indicator illustrates the structural diversity of macroalgal community both on soft and hard substrates and through that the composition of accompanying fauna. The indicator values are based on coverage data of different functional and structural groups of macroalgae. Sampling is performed and coverage estimations of all distinguishable species are gained via diving or remote underwater video analysis. The indicator is applicable in all regions of the Baltic Sea but regional modifications should be done for defining structural groups.

Habitat diversity index. The habitat diversity index indicates the level of diversity of marine benthic habitats by counting the number of different habitats in a predefined grid. The process of obtaining the indicator value has three steps: 1) a benthic habitat map is overlaid by a grid with predefined cell size in a geographical information system (GIS); 2) the number of different habitat types is counted in each grid cell, and 3) the average number of different habitats over all grid cells in a given area serves as the value of habitat diversity index. For the purposes of biodiversity monitoring, the method is more suitable for trend analysis based on a time-series of habitat maps than for episodic state assessments. The indicator can potentially be applied all over the Baltic Sea area where habitat distribution data exists.

Seafloor exploitation index. The seafloor exploitation index measures the extent (area) of seabed that is impacted by direct physical anthropogenic disturbances. In order to obtain the indicator value, all relevant information on direct anthropogenic physical disturbances of the seabed must be gathered in a georeferenced manner and compiled into a database of a geographical information system (GIS). The relevant georeferenced data include locations of seabed dredging and dumping of dredged material, bottom trawling fishery (VMS, Vessel Monitoring System), resource extraction (e.g. mining of sand and gravel), building and exploitation of marine constructions (cables, pipelines, windmills etc). The proportion of the area of different seabed substrate types, which are directly affected by human activities, is assessed by the means of overlay analysis in GIS. The average proportion of directly impacted seabed over all substrate types serves as the overall index value in a given area. The index is applicable all over the Baltic Sea area where georeferenced data on distribution of benthic habitats and human activities is available.

Spectral variability index. This indicator reflects the diversity of benthic habitats and is based on the spectral variation hypothesis that predicts a positive correlation between the spectral heterogeneity of a remote sensing image (air-borne or space-borne) and benthic biodiversity. The method is potentially useful in extensive shallow water areas that are difficult to reach with a vessel. Georeferenced remote sensing imagery of a sea area is needed for the calculation of the spectral variability index. The imagery must reflect seabed properties, i.e. the method can be used only in shallow and very clear waters. The values of spectral variability are calculated in each cell of a predefined grid. The suitable cell size depends on the extent of the area to be assessed and the spatial resolution of the remotely sensed imagery. Spectral variability is measured as the mean distance from the spectral centroid of a given cell. The spectral centroid is calculated as the mean value of each band or principal component in a given cell. The distance (difference) of each pixel from the spectral centroid is then determined within each cell. The mean distance of all pixels from the spectral centroid in a given cell is considered as the mean spectral variability of that cell. The mean value of spectral variability over all cells in a given area serves as the value of the spectral variability index. For the purposes of biodiversity monitoring, the method is more suitable for trend analysis based on a time-series of hyperspectral imagery than for episodic state assessments.

NASA

Satellite images can be used for monitoring benthic biodiversity in shallow areas

Henrik Nygård (SYKE)

Sediment cores are used to assess the condition of soft-sediment habitats

Tiia Möller (EMI)

Baltic macoma (*Macoma balthica*)

Condition of soft sediment habitats – the aRPD approach. This indicator shows the condition of soft bottom habitats through an estimation of the redox potential discontinuity (RPD) depth, thus being a proxy for conditions suitable for a diverse community. It also describes the successional stage and functionality of the benthic community, since long-lived and deep-burrowing species maintain sediment mixing and nutrient regeneration processes, thus increasing resilience. Sediment profile imagery (SPI) has been used to assess the RPD depth, offering an in situ characterization of the soft sediment habitat. In the sediment profile, the shift from brownish sediment where particles are covered by ferric hydroxide, to greyish-black sulphidic sediments, is used to identify the RPD depth and is referred to as the apparent redox potential discontinuity (aRPD). Our approach is to use sediment cores, which are photographed, after which the oxidized sediment layer is measured from the photographs of the sediment core. Using e.g. ImageJ software, the area of the oxidized sediment can then be measured. To attain the aRPD depth, the area has to be divided by the width of the sediment core. The indicator can be used to reflect the effect of eutrophication and is suitable for use in all Baltic Sea areas where the sediment mainly consists of clay.

Population structure of *Macoma balthica*. This indicator describes the size distribution of *Macoma balthica*, the dominant, long-lived bivalve species on soft bottoms in the northern Baltic Sea. Occurrence of new recruits, juveniles, as well as adults in all year classes in a population of *M. balthica* indicates that no severe disturbance has taken place and that the population is in a good state. The lack of juveniles or a year class of adults demonstrates adverse conditions. As the natural size distribution of *M. balthica* varies geographically and also by depth due to variation in growth rates, targets have to be adjusted to local conditions. Data needed for this indicator can be obtained by length measurements of *M. balthica* in samples from e.g. regular monitoring programmes. To avoid the high variation caused by variations in the number of settling recruits, only individuals larger than 5 mm are included in the indicator. The indicator value is the median length of *M. balthica* larger than 5 mm. The indicator reacts to several disturbances such as eutrophication, harmful substances or physical disturbance.

***Cladophora glomerata* growth rate.** The indicator describes the abundance of the green algae *Cladophora glomerata* in an assessment unit. Its seasonal occurrence and abundance is mainly determined by nutrient availability in the water column, as well as water temperature. The growth rate of *C. glomerata* vegetation is derived from information on frond length and the length of the growth period. The frond length of *C. glomerata* is a cost-efficient way to measure approximate nutrient concentrations in large areas where traditional sampling procedures or the use of measurement devices are not applicable. The growth of *C. glomerata* is approximated through measuring fronds of *C. glomerata* at a known time of its seasonal succession. To exclude sources of natural variation in abundance, frond length or growth rate, the samples are collected from

Algae zonation in Finnish archipelago

Essi Keskinen (Metsähallitus)

chosen navigation buoys located along ship routes. An important feature of navigation buoys is that the buoyancy effect keeps the *C. glomerata* canopy at a constant depth the whole growth season. From each sea mark at least eight fronds are collected, but a number of 20-30 fronds is recommended, and measured with the accuracy of one millimetre; thereafter their mean length is determined. After the mean length or growth rate of *C. glomerata* has been determined from all sea marks at the given site, the acquired values are compared to a reference growth rate value. Eutrophication level is the pressure reflected by this indicator.

Depth distribution of selected perennial macroalgae. The indicator is a multi-metric indicator comprising of a set of four perennial macroalgae indicator species, the red algae *Furcellaria lumbricalis*, *Polysiphonia fucoides*, *Phyllophora pseudoceranoides* and *Rhodomela confervoides*. The indicator describes long-term changes in water quality through measurements of the lower depth limit of a coverage of ⩾ 0,1% of the indicator species. The diver measures the depth of the lower growth limit of a coverage of ⩾ 0,1% of the indicator species with an accuracy of 10 cm. At least four sites per studied water area must be sampled, and three of the four indicator species are needed for attaining a reliable indicator value. The depth values measured for each indicator species is converted to EQR (Ecological Quality Ratio) values. For the calculation of the index of a water body, the average of the EQRs of all indicator species found at the site is calculated. The indicator is ready for the NE Baltic Sea, but can be adjusted for other areas of the Baltic Sea.

Community heterogeneity, CH. The index analyses the heterogeneity of communities at the landscape scale. In order to do so, the relative importance of scale-specific variability of macroalgal and benthic invertebrate communities is quantified. Using multivariate data analysis, dissimilarities between pairs of samples are calculated using a zero-adjusted Bray-Curtis coefficient. The geographical distances between the studied sites are then calculated and the distances are related to the dissimilarity matrices of biota. The ratio between the distance-based mean dissimilarities and its standard deviation is used as a proxy of the community heterogeneity at the landscape scale. As such, the index estimates the complexity of the spatial patterns of benthic communities with higher values of the statistic indicating more distinct and less variable (i.e. potentially less disturbed) communities at the studied spatial scale. The indicator has been tested on eutrophication gradients and can be applied all over the Baltic Sea area.

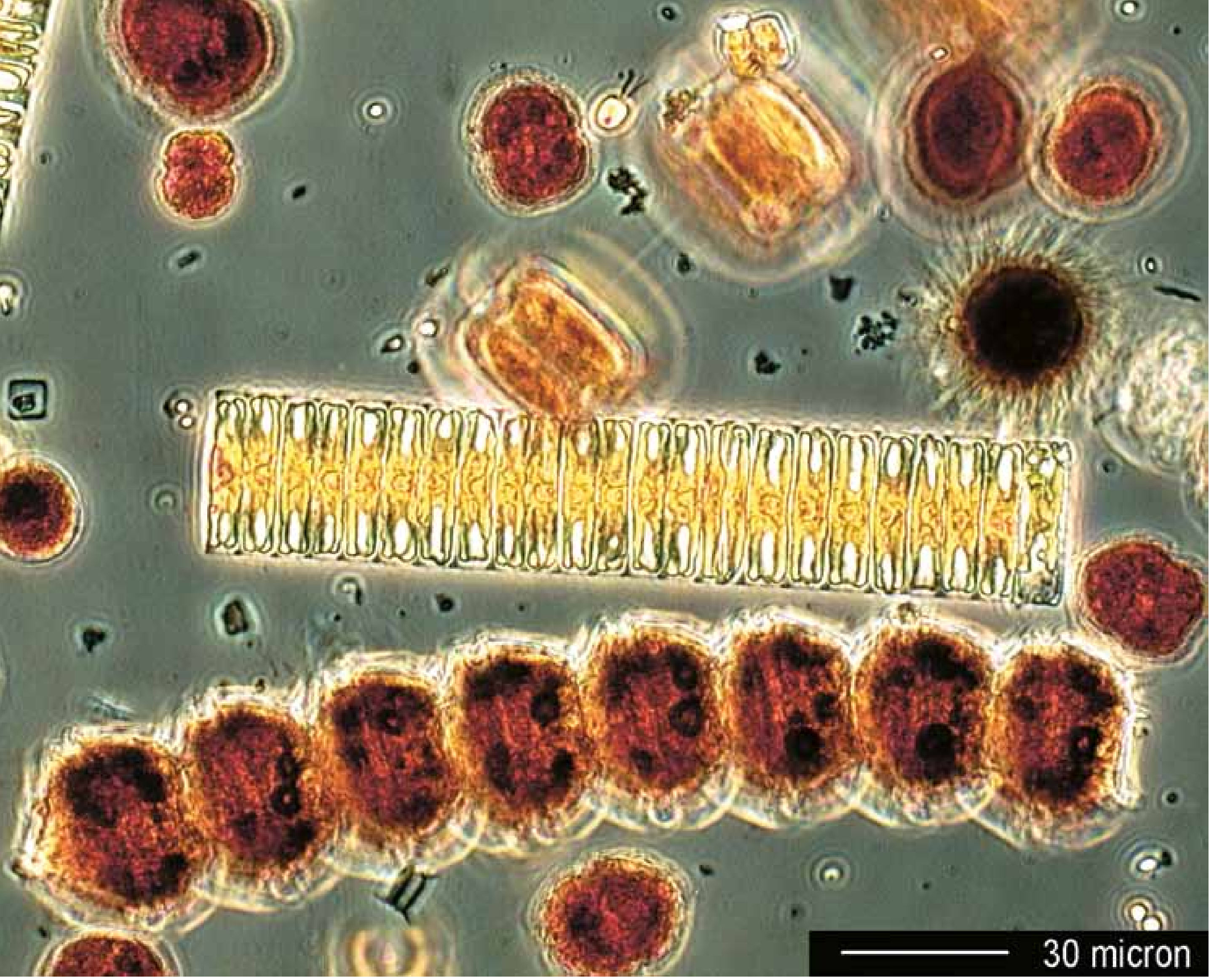
EMI

Ragworm (*Nereis diversicolor*)

Number of functional traits, NFT. The NFT index counts the number of functions (biological traits) in the system. A higher number of such functions reflects elevated functional diversity and, thus, such communities are able to provide more ecosystem services compared to those having a smaller number of functions. In the current index the observed benthic invertebrate species were classified according to their mobility (mobile and non-migratory) and feeding type (suspension feeders, herbivores, deposit-feeders, and carnivores) based on the available literature and field observations. Benthic macrophyte species were classified according to their growth form (coarsely branched, filamentous, sheet, thick leathery). The index responded differentially to the studied environmental variables. The links between environmental variables and the index were always the strongest at the 5 km spatial scale. At smaller spatial scales, the index reflected changes in local ice conditions and/or coastal topography. At the 5 km spatial scale, however, the index followed the variability in coastal eutrophication. The indicator can be used all over the Baltic Sea area.

Macrozoobenthos community index, ZKI. The ZKI is based on macrozoobenthos species biomass data and a defined species sensitivity classification. The ZKI index divides the macrofauna into three distinct groups according to their sensitivity to an increasing stress (including eutrophication). Species belonging to class 1 can be found in heavily eutrophied conditions, species belonging to class 2 gain biomass under moderately eutrophied conditions, and class 3 species are those typical to conditions undisturbed by eutrophication. The index also takes into account the species number at a given station and compensates this diversity term for salinity gradients. The compensation term is based on waterbody-specific maximum values for species number calculated using the entire content of the national database. The ZKI is ready and published (Kotta *et al.*, 2012) but can be used in other areas after the geographical adjustment of species sensitivity classes.

The reed belt extent – the NDVI approach via high resolution satellite images. The indicator expresses the extent of coastal reed belts, using information from remote sensing and exposition-depth data. The coverage of common reed is estimated by using information provided by satellite remote sensing (RapidEye 5m by 5m resolution and WorldView-2 2m by 2m resolution). The presence of reed vegetation is determined from the images by calculating the Normalized Difference Vegetation Index (NDVI), which is calculated from the band relations between red and infrared bands. The NDVI areas are extracted to water areas by clipping the data by shoreline, since it is assumed that all the vegetation in water is reed vegetation. The indicator utilizes depth-exposition data to determine the potential growing area of reed belts. The indicator mainly reflects eutrophication pressure. It was developed and is ready for the SW Finland, but can be adjusted to other areas with suitable conditions for reed belt development.



Algal bloom in spring as seen in microscope

3.3. Pelagic indicators

The pelagic indicators comprise phytoplankton and zooplankton indicators. In the Baltic Sea, some 1700 phytoplankton species (Hällfors, 2004; cf. Ojaveer *et al.*, 2010) and 210 zooplankton species (Telesh *et al.*, 2009) occur. In the pelagic ecosystem, phytoplankton is responsible for the primary production which constitutes the basis of all food webs. Eutrophication is the major anthropogenic driver of long-term changes in the phytoplankton community in the Baltic Sea (Suikkanen *et al.*, 2007, 2013; Fleming-Lehtinen *et al.*, 2008; Hällfors *et al.*, 2013). Zooplankton has a crucial role in the pelagic food web dynamics by transferring energy from primary producers to a form utilizable by fish. Zooplankton is affected by the changes in primary production, indicative of nutrient-load pressure, and by changes in the structure and abundance of the fish community, indicative of fishing pressure (e.g. Adrian *et al.*, 1999; Yan *et al.*, 2008). Hence zooplankton lives between top-down and bottom-up influences, and can potentially yield a lot of information on the state and dynamics of the aquatic ecosystem (Jeppesen *et al.*, 2011). Both phytoplankton and zooplankton communities are also strongly influenced by water temperature and salinity (Viitasalo *et al.*, 1995; Gasiùnaite *et al.*, 2005; Suikkanen *et al.*, 2007, 2013). The areas covered by the pelagic indicators should be delimited in such a way that no strong salinity and climatological gradients occur, i.e. the indicators should be tested separately for different sea areas in the Baltic Sea and consequently the GES boundaries set region-specifically. Since comparable historical observations are usually lacking, the reference levels and target values need to be derived from modern data and/or using expert judgment.

The HELCOM programme for monitoring of eutrophication and its effects in the Baltic Sea includes the monitoring of phytoplankton and mesozooplankton species composition and biomass (HELCOM, 2014). In order to obtain a detailed understanding of these very dynamic communities, spatially and temporally frequent sampling is necessary. This constitutes a challenge concerning the laborious and therefore costly species composition data which several of the biodiversity indicators rely on.

In the MARMONI project, indicator development and testing resulted in a total of 10 pelagic indicators of which eight proved viable. Of the five ready phytoplankton indicators, three require quantitative phytoplankton species data with as accurate taxonomic resolution as possible. The remaining two indicators utilize satellite remote sensing data combined with pigment measurement data, in one of them also other data such as citizens' observations can be used as complementing data. All three ready zooplankton indicators require either quantitative zooplankton species data or data acquired using an automatic image analysis method. Both phytoplankton and zooplankton indicators that need further development require quantitative species data.

All pelagic MARMONI indicators are state indicators, thus the primary aim was not to find relationships between the indicators and pressures. Not all pelagic MARMONI indicators have been directly linked to a particular pressure in the development work; more often the assumption is based on the available scientific knowledge. Instead, the aim was to find an indicator target value (i.e. GES level) to be used as a determinant of whether the biodiversity of the environment, as demonstrated by the indicator, is in Good Environmental State or not.

The pelagic indicators were developed and tested by experts from the Finnish Environment Institute SYKE (Saku Anttila, Jenni Attila, Vivi Fleming-Lehtinen, Heidi Hällfors, Seija Hällfors, Sofia Junttila, Sirpa Lehtinen, Maiju Lehtiniemi and Laura Uusitalo), the Latvian Institute of Aquatic Ecology (Ieva Bārda, Iveta Jurgensone, Jurate Lesutiene, Bärbel Müller-Karulis and Solvita Strake), the Estonian Marine Institute, University of Tartu (Andres Jaanus, Riina Klais and Lauri London), Stockholm University (Elena Gorokhova), Lithuanian Environmental Protection Agency (Natalja Demereckiene), and MEVEX AB (Callis Amid).

Phytoplankton species assemblage clusters based on environmental factors. This indicator describes the state of the summertime phytoplankton community in relation to biodiversity and eutrophication. Using cluster analysis, phytoplankton species clusters were obtained, and the relationship between these and environmental factors was tested with a GAM model. Consequently, a connection between nutrient loads and two of the species clusters were found. One cluster, consisting of a wide range of species representing high biodiversity, increased with decreasing N/P loads, thus displaying a negative relation to eutrophication, while the proportion of another cluster increased with increasing N/P loads. Reference conditions were estimated from the period when maximum biodiversity and, at the same time, minimum eutrophication indicator proportions were recorded. This indicator was developed using data from the Gulf of Riga; its geographical relevance is regional due to geographical differences in the phytoplankton communities in different parts of the Baltic Sea (Bārda *et al.*, manuscript in preparation).

Seasonal progression of phytoplankton functional groups. This indicator, which was originally proposed for British coastal waters (Devlin *et al.*, 2007), describes the state of the phytoplankton community in relation to nutrient pressure. In the seasonal cycle, a natural progression of dominant functional groups occurs. The indicator is based on the idea that deviations, such as a too high or too low biomass, or the absence of some dominating phytoplankton group(s), indicate an impairment of environmental status. Type- or site-specific seasonal growth curves were designed for each dominating phytoplankton functional group, and a monthly Z score was determined to establish comparable seasonal distributions for each functional group and sampling year. Percentage-based thresholds were established for each functional group to determine class boundaries (Ecological Quality Ratio values) for the assessment of the ecological status, and generic reference curves were established for each coastal water type or open sea basin. This index is applicable for coastal and open sea waters of the Gulf of Finland. This indicator was developed using data from the southern Gulf of Finland; its geographical relevance is regional due to geographical differences in the phytoplankton communities in different parts of the Baltic Sea.

Cyanobacterial surface accumulations – the CSA-index. Extensive cyanobacterial blooms have a potentially negative impact on the biodiversity of both pelagic and benthic communities. Nitrogen-fixing cyanobacteria are favoured by excess phosphorus in the water column; thus phosphorus load, especially in a dominantly nitrogen-limited environment, is considered the main anthropogenic pressure affecting the indicator. The indicator is based on information on the yearly intensity, duration and severity of cyanobacterial blooms. Variables describing these are normalized and combined to produce *a* Cyanobacterial Surface Accumulation index (CSA-index). The principal data source is satellite remote sensing surface algae classification based on chlorophyll a, but the indicator can be complemented with e.g. phycocyanin fluorescence measurements and citizens' observations. The data used for the indicator development covered the four MARMONI pilot areas and it is now applied for the majority of the open sea assessment areas of HELCOM. The geographical relevance of this indicator is Baltic Sea wide; its GES boundaries are set region-specifically, but it may be extended to cover all the Baltic open sea and outer coastal assessment units (Anttila *et al.*, manuscript in preparation).

Phytoplankton taxonomic diversity (Shannon95). This indicator describes the taxonomic diversity of the summertime phytoplankton community by a metric which responds to the extent by which the community is dominated by just one or few taxa. For several reasons, the biodiversity of phytoplankton is difficult to determine; however this indicator utilizes a novel robust approach for detecting changes in phytoplankton diversity, the Shannon95 metric, introduced by Uusitalo *et al.* (2013). This method circumvents problems by computing the Shannon biodiversity index from the main body of the phytoplankton community, i.e. the taxa that cumulatively constitute 95% of total biomass. The Shannon95 metric is sensitive to eutrophication, and the indicator target (i.e. GES level) was estimated through harmonization to the HELCOM phytoplankton target, which uses chlorophyll *a* as a proxy. The indicator was developed using data from the open Gulf of Finland and its geographical relevance is regional due to geographical differences in the phytoplankton communities in different parts of the Baltic Sea; however, is likely applicable in other Baltic Sea areas also.

Phytoplankton trait- and dendrogram based functional diversity index (FD). The indicator aims to describe the trait-based functional diversity of Baltic Sea phytoplankton with a functional diversity index (FD), which is calculated based on the dendrogram method. It has previously been shown that taxonomic diversity predicts stability in natural phytoplankton communities. The hypothesis here was that also a more functionally diverse phytoplankton community is more stable and thus more resistant to different pressures. The index was tested as an ecosystem structure indicator, and thus the aim was not to find relationships between the index and pressures. Instead, the aim was to find a target value to indicate stability of the community when exposed to pressures. Eleven functional traits, such as motility and ability to fix nitrogen, were considered. The approach was tested using data from the coastal area of south-western Finland. It was concluded that further testing and development, including studies to uncover relationships between functional diversity and various traits and different ecological processes, are needed before the index is ready to be used as an indicator.

Spring bloom intensity index. This indicator estimates the annual total biomass of the phytoplankton spring bloom, which is responsible for the main part of the annual phytoplankton production and provides energy for both the pelagic and the benthic communities. The course of the spring bloom is determined by nutrient availability. Thus nutrient loading, to which spring bloom intensity responds positively, is considered its main anthropogenic pressure. To obtain maximum spatial and temporal coverage, spring bloom intensity was estimated by combining satellite remote sensing and ship-of-opportunity data. The indicator is based on methods developed by Fleming and Kaitala (2006), Platt and Sathyendranath (2008), and Platt *et al.* (2008). From the data, parameters such as the initiation, amplitude, timing of maximum, and duration of the spring bloom were defined. These were then used to derive a spring bloom intensity index which is an estimate of the total production. This indicator was developed using data from the open Gulf of Finland, the coastal area of south-western Finland, and the Gulf of Riga. Its geographical relevance is regional; in principle, the indicator is applicable to all Baltic Sea subbasins and both on local and regional scales. A master's thesis concerning this indicator was prepared by Junttila (2014).

MODIS satellite image (NASA)

Algal bloom in the NE Baltic Sea.

Copepod biomass. This indicator reflects the status of copepods, the members of the zooplankton community which are the most important for maintaining good growth conditions for pelagic fish stocks. Zooplankton is affected by changes in primary production, indicative of eutrophication as well as changes in the structure and abundance of the fish community can indicate overfishing. Copepods as selective feeders, can directly affect both the phytoplankton and zooplankton species composition and have the potential to affect the biodiversity of these communities. The indicator is based on the idea that zooplankton with a large mean size, i.e. copepods, would indicate good feeding conditions for zooplanktivorous fish as well as potentially high grazing on phytoplankton. The geographical relevance of this indicator is Baltic Sea wide, but its GES boundaries need to be set region-specifically due to differing reference periods between areas (Gorokhova *et al.*, manuscript in preparation).

Zooplankton diversity. This indicator aims to describe the species diversity of zooplankton in the Baltic Sea, because the ability to quantify diversity would be an important tool to describe zooplankton community structure. The biodiversity of zooplankton is expected to decrease 1) if the number of species decreases, e.g. due to deteriorating environmental conditions in which not all species survive, and 2) if the evenness of the species decreases due to the increase of certain species, caused e.g. by the introduction of invasive species, or by selectively favouring environmental conditions. The Shannon diversity index provides information about the rarity and commonness of species in a community; hence its applicability as a zooplankton biodiversity indicator was tested. The index was calculated for each sub-basin around Finland, including the project area in the Gulf of Finland. The results showed no relationship between Shannon index values, changes in the long-term data, and pressures. It was concluded that to obtain a species diversity index which could be used as a simple biodiversity indicator, further studies are needed to determine how zooplankton species diversity is related to ecological processes and pressures.

Microphagous mesozooplankton biomass. This indicator reflects changes in the zooplankton community in relation to environmental pressures. The indicator is based on zooplankton data obtained from routine zooplankton sampling. Individual numbers of species and life stages are counted either by conventional microscopical analysis, or by an automatic image analysis method using a scanner and suitable software. Microphagous mesozooplankton biomass can then be estimated based on the length measurements of individuals, or by using species and stages specific pre-established weight values. Eutrophication favours small-sized phytoplankton and detritus production, which in turn favours small-sized herbivorous zooplankton, i.e. microphagous zooplankton. Climate change induced warming favours many microphagous zooplankton due to their rapid parthenogenetic reproduction in warmer waters, and this potentially reduces zooplankton biodiversity and evenness within the community. The indicator is based on the idea that abundant microphagous mesozooplankton indicates a limitation in the ability of the zooplankton community to transfer energy from primary producers to higher trophic levels. The species composition in the zooplankton community affects directly both the phytoplankton and zooplankton species composition and has a potential to affect the biodiversity of these communities. The geographical relevance of this indicator is Baltic Sea wide, but its GES boundaries need to be set region-specifically due to differing reference periods between areas (Gorokhova *et al.*, manuscript in preparation).

Water flees from genus *Bosmina*

Zooplankton mean size vs. total stock (MSTS). This indicator reflects changes in the zooplankton community in relation to environmental pressures. Zooplankton biomass correlates positively with phytoplankton biomass and hence with eutrophication. Especially small-bodied zooplankton increase with increasing eutrophication, whereas large-bodied zooplankton represent the best-quality food for zooplanktivorous fish. Zooplankters are selective feeders, and their size affects their prey selection. Thus, zooplankton community composition directly affects both phytoplankton and zooplankton species composition and has the potential to affect the biodiversity of these communities. This indicator is based on the idea that zooplankton mean size and total biomass (or abundance), when examined together, provide more information than when the parameters are considered separately. Abundant zooplankton with a large mean size would indicate good feeding conditions for zooplanktivorous fish as well as high potential grazing pressure on phytoplankton. On the other hand, combinations such as small total stock, or small mean size, or both would indicate a limited ability of zooplankton to transfer energy to higher trophic levels. Thus, mean size and total zooplankton biomass (or abundance) values have to be considered in order to attain GES. The geographical relevance of this indicator is Baltic Sea wide, but its GES boundaries need to be set region-specifically due to differing reference periods between areas (Gorokhova *et al.*, manuscript in preparation).

Great cormorants (*Phalacrocorax carbo*)

3.4. Bird indicators

This group consisting of 16 indicators describes the biological diversity of the Baltic Sea, focusing on birds. The indicators address all levels of biological diversity (species, habitat, ecosystem) as prescribed by MSFD criteria for descriptor 1. The species level is the best represented, having indicators for species distribution (and range), population size (abundance) in both breeding and wintering seasons, as well as population condition (sex and age ratio, brood size and body fit). Many (13) of the indicators are useful to describe MSFD indicator 1.6.1 Condition of the typical species and communities at the habitat level and five indicators are useful to evaluate MSFD indicator 1.7.1 Composition and relative proportions of ecosystem components at the ecosystem level. The single species indicators are the most useful at the species level, while multispecies indicators serve best for the habitat and ecosystem levels. Single species indicators are available for 26 species in the winter season and 17 species in the breeding season, thus covering all species significantly connected with the marine environment of the Baltic Sea. The main known pressures on birds are by-catch, oiling, disturbance (e.g. by marine traffic and commercial fishing activities) and degradation of habitat quality (Skov *et al.*, 2011). The impact of all these pressures can be assessed by the developed indicators either directly or indirectly.

Previously, birds were almost neglected as biodiversity indicators. The HELCOM COMBINE manual (HELCOM, 2014) lists only bird eggs (Guillemot *Uria aalge*, Herring Gull *Larus argentatus* and Common Tern *Sterna hirundo* eggs) and population status of White-tailed Sea Eagle *Haliaeetus albicilla* as subjects to be monitored for contaminants and their effects. The BSAP (HELCOM, 2007) lists White-tailed Sea Eagle *Haliaeetus albicilla* (and/or Osprey *Pandion haliaetus*; their proportion of successfully reproducing pairs and mean brood size) among the indicators for the ecological objective "Healthy wildlife". Water birds were listed among the preliminary indicators for measuring ecological objectives of the BSAP (two for the ecological objective "Viable populations of species" and one for "Natural marine and coastal landscapes"); however, these indicators were not developed. Thus the few developed indicators exclude the main aspects important in describing biological diversity focusing on this organism group. None of them addressed criteria listed for the descriptor 1 of the Good Environmental Status as required by the MSFD at the species, habitat or ecosystem level. Thus the MARMONI project attempted to address this gap by developing a set of indicators with desirable properties (Gregory and van Strien, 2010; van Strien *et al.*, 2012) that would be relevant for each of these levels and would fully cover all the criteria at the species level (except genetic structure). The same data collection schemes provide the necessary data not only for single- and multi-species abundance indicators but also for single- and multi-species distribution indicators. Apart from the MSFD needs, the data collected for obtaining these indicators serve also for BD and HD reporting. As bird populations in non-breeding period are very mobile and their distribution and numbers may vary locally and regionally due to climatic factors, there is a need for synchronised monitoring efforts across the Baltic Sea, especially for indicators to be applied at the Baltic Sea wide scale. The indicators were developed by Ainars Aunins (Latvian Fund for Nature), Andres Kuresoo and Leho Luigujõe (Estonian University of Life Sciences), Leif Nilsson (Lund University) and Antra Stīpniece (Latvian Ornithological Society).

Abundance index of wintering waterbird species. This is a single species indicator that reflects the population level (abundance at the species level) in the wintering season of the particular species. 26 species are relevant for this indicator in the Baltic Sea. Additionally, it describes the condition of the "typical species" of a habitat at the habitat level (according to definition of MSFD). The index is calculated as the species population abundance relative to the population at base time (average of the 1991–2000 period). To obtain the population index, site- and year-specific counts of individuals of the particular species are related to the site and year effects (factors) and missing values are imputed from the data of all surveyed sites. Depending on the species for which the indicator is calculated it may respond to different pressures


Mati Kose

Common eider (*Somateria mollissima*)


Ainars Aunins

Smew (*Mergellus albellus*)


Ainars Aunins

Velvet scoters (*Melanitta fusca*)


Mati Kose

Long-tailed duck (*Clangula hyemalis*)


Ainars Aunins

Common goldeneye (*Bucephala clangula*)

including eutrophication, oil pollution and shipping, hazardous substances, fishing pressure, bycatch, hunting, fisheries discards, coastal development, wind energy, sand and gravel extraction, and climate. The indicator is scalable and can be used regionally, nationally or throughout the Baltic Sea area. The combination of national data collection schemes is recommended for wider assessments (van Strien *et al.*, 2001).

Wintering waterbird index (WWBI). This is a multi-species indicator that reflects the state of the wintering waterbird community. Single species indices (as described above) of up to 26 species are used to build this indicator. WWBI describes the composition and relative proportions of ecosystem components at the ecosystem level, and the condition of the typical species of the habitat at the habitat level. The index is calculated as the geometric mean of the single species indices of the included species (Gregory *et al.*, 2005). Each species is treated equally (no weighting). The indicator responds to all pressures (eutrophication, oil pollution, shipping, hazardous substances, fishing pressure, by-catch, hunting, fisheries discards, coastal development, wind energy, sand and gravel extraction, and climate change) of the component species used to build this indicator . However, it is not able to separate these effects. The indicator is scalable and can be used regionally, nationally or on the Baltic Sea scale.

Wintering indices for waterbirds of different feeding guilds. This is a multi-species indicator that reflects the state of specific feeding guilds within the wintering waterbird communities. Separate indices for four guilds are developed: the benthic herbivore index, the benthic invertebrate feeder index, the fish feeder index and the gull (surface feeder) index. It describes the condition of the typical species of the habitat at the habitat level, and the composition and relative proportions of ecosystem components at the ecosystem level. Each index is calculated as the geometric mean of the single species indices (Gregory *et al.*, 2005). Each species is treated equally (no weighting). The indicator responds to all pressures (eutrophication, oil pollution, shipping, hazardous substances, fishing pressure, by-catch, hunting, fisheries discards, coastal development, wind energy, sand and gravel extraction, and climate change) of the component species used to build this indicator. However, it is not able to separate these effects. The indicator is scalable and can be used regionally, nationally or on a Baltic Sea wide scale.

Abundance index of breeding waterbird species. This is a single species indicator that reflects the population level (abundance at the species level) in the breeding season of the selected species. 17 species are relevant for this indicator in the Baltic Sea. In addition, it describes the condition of the typical species of a habitat at the habitat level. The index is calculated as the species population abundance relative to the population at a base time (average of the 1991–2000 period) (van Strien *et al.*, 2001). To obtain the population index, site- and year-specific counts of individuals of the particular species are related to the site and year effects (factors) and missing values are imputed from the data of all surveyed sites. Depending on the species for which the indicator is calculated it may respond to different pressures: coastal development, eutrophication, hazardous substances, predation by non-native species (e.g. American Mink *Mustela vison*), fisheries discards and climate change, but also oil pollution and shipping, by-catch, wind energy and sand and gravel extraction,. The indicator is scalable and can be used regionally, nationally or throughout the Baltic Sea area. The combination of data from national datasets is recommended for wider assessments (van Strien *et al.*, 2001).

Breeding waterbird index (BWBI). This is a multi-species indicator that reflects the status of the breeding waterbird community. Single species indices of up to 17 species are used to build this indicator and it describes the composition and relative proportions of ecosystem components at the ecosystem level, and the condition of the typical species of the habitat at the habitat level. The index is calculated as the geometric mean of the single species indices of the included species (Gregory *et al.*, 2005). Each species is treated equally (no weighting). The indicator responds to all pressures affecting the species used to build this indicator: coastal development, eutrophication, hazardous substances, predation by non-native species (e.g. American Mink *Mustela vison*), fisheries discards and climate change, but also oil pollution, shipping, by-catch, wind energy and sand and gravel extraction. However, it is not able to separate these effects. The indicator is scalable and can be used regionally, nationally or throughout the Baltic Sea area.

Leif Nilsson

Razorbill (*Alca torda*)

Ainars Aunins

Common shelduck (*Tadorna tadorna*)

Heiko Kruusi

Nestlings of the Arctic tern (*Sterna paradisaea*)

Heiko Kruusi

The nest of the Little tern (*Sternula albifrons*)

Leho Luigujõe

Colony of Caspian tern (*Hydroprogne caspia*)

Distribution of wintering waterbird species. This is a single species indicator that reflects the distribution (population range and distribution pattern within the range at the species level) in the wintering season of the 26 species relevant for this indicator in the Baltic Sea. The indicator is calculated using a density surface modelling approach, i.e. GAM or machine learning models based on count data from line transects and spatial covariates. The result of the computation is a grid where the cell values represent estimated abundances or densities of the species in the particular location. Depending on the species for which the indicator is calculated, it may respond to different pressures including eutrophication, oil pollution, shipping, hazardous substances, fishing pressure, bycatch, hunting, fisheries discards, coastal development, wind energy, sand and gravel extraction, and climate change. The indicator is scalable and can be used at all scales: locally, regionally, nationally or throughout the Baltic Sea area.

Distribution of wintering waterbirds (multi-species). This is a multi-species indicator that reflects the distribution of wintering waterbirds. All species of divers, grebes, cormorants, swans, geese, ducks, mergansers, coots and auks are pooled for this indicator. This approach describes the composition and relative proportions of ecosystem components at the ecosystem level as well as the performance of frequently occurring species of the habitat at the habitat level, in a spatially explicit way. The indicator is calculated using a density surface modelling approach, i.e. GAM or machine learning models based on count data from line transects and spatial covariates. The result of the computation provides a grid where the cell values represent estimated abundances or densities of waterbirds in the particular location. The indicator responds to all various biotic and abiotic pressures affecting the species of interest. However, it has not been possible to separate these effects. The indicator can be used at variety of scales: locally, regionally, nationally or throughout the Baltic Sea area.

Distribution of wintering waterbirds of different feeding guilds (multi-species). This is a multi-species indicator that reflects the distribution of specific feeding guilds of wintering waterbirds. Separate grids for four guilds were developed: benthic herbivores, benthic invertebrate feeders, fish feeders and gulls (surface feeders). These guilds describe the condition of the typical species of the habitat at the habitat level as well as the composition and relative proportions of ecosystem components at the ecosystem level. The indicator is calculated using a density surface modelling approach, i.e. GAM or machine learning models based on count data from line transects and spatial covariates. The results of the computation establish a grid where the cell values represent estimated abundances or densities of waterbirds in the particular location. The indicator responds to various human mediated pressures affecting the species used for the indicator. However, the separation of these effects is not possible. The indicator can be used regionally, nationally as well as applied throughout the Baltic Sea area.

Distribution of breeding waterbird species. This is a single species indicator that reflects the distribution (population range and distribution pattern within the range at the species level) in the breeding season of the 17 species of interest. The indicator is calculated using a density surface modelling approach, i.e. GAM or machine learning models based on count data from sample plots and spatial covariates. The computation results in a grid with values representing an estimated abundances or densities of the species in the particular location. Depending on the species for which the indicator is calculated it may respond to different pressures: coastal development, eutrophication, hazardous substances, predation by non-native species (e.g. American Mink *Mustela vison*), fisheries discards and climate change, but also oil pollution and shipping, by-catch, wind energy and sand and gravel extraction. The indicator can be used at variety of scales: locally, regionally, nationally or on a Baltic Sea wide scale.

Breeding success: clutch and brood size of breeding species. This is a single species indicator that reflects population condition (demographic characteristics such as breeding success and productivity) at the species level, and the condition of the typical species at the habitats level of the particular species with two values: clutch size or number of eggs per clutch laid and number of juveniles per breeding female. 11 species are relevant for this indicator in the Baltic Sea. The clutch size is calculated as the mean number of eggs per nest. The brood size is calculated as the number of juveniles per a breeding female. The pressures associated with clutch size are those affecting the physical condition of female birds, such as decreased food quality and availability as well as reduction in suitable feeding grounds. The pressures associated with brood size are predation and disturbance during the nesting period. The indicator is scalable and can be used locally, regionally, nationally or throughout the Baltic Sea area.

Heiko Kruusi

An oiled Mute swan (*Cygnus olor*)

Age/sex ratio of waterbird species (ARI/SRI). This is a single species indicator that reflects population condition (demographic characteristics such as the age and sex ratio) at the species level, and the performance of condition of the typical species at the habitat level. Nine species are relevant for the age ratio and seven species for the sex ratio as an indicator in the Baltic Sea. The age ratio is calculated as the proportion of juveniles in the postbreeding population. The sex ratio is calculated by dividing the number of females with the number of males. The pressures associated to the sex ratio could increase female mortality during the breeding season as a result of increased predation by both native (White-tailed Eagle *Haliaeetus albicilla*) and alien species (American Mink *Mustela vison*). The pressures related to the age ratio are reducing breeding performance of the species: predation, insufficient food stocks, contamination of food sources, habitat loss, and coastal development. The indicator is scalable and can be used nationally or throughout the Baltic Sea area.

Antra Stipniece

A beached diver (*Gavia sp.*)

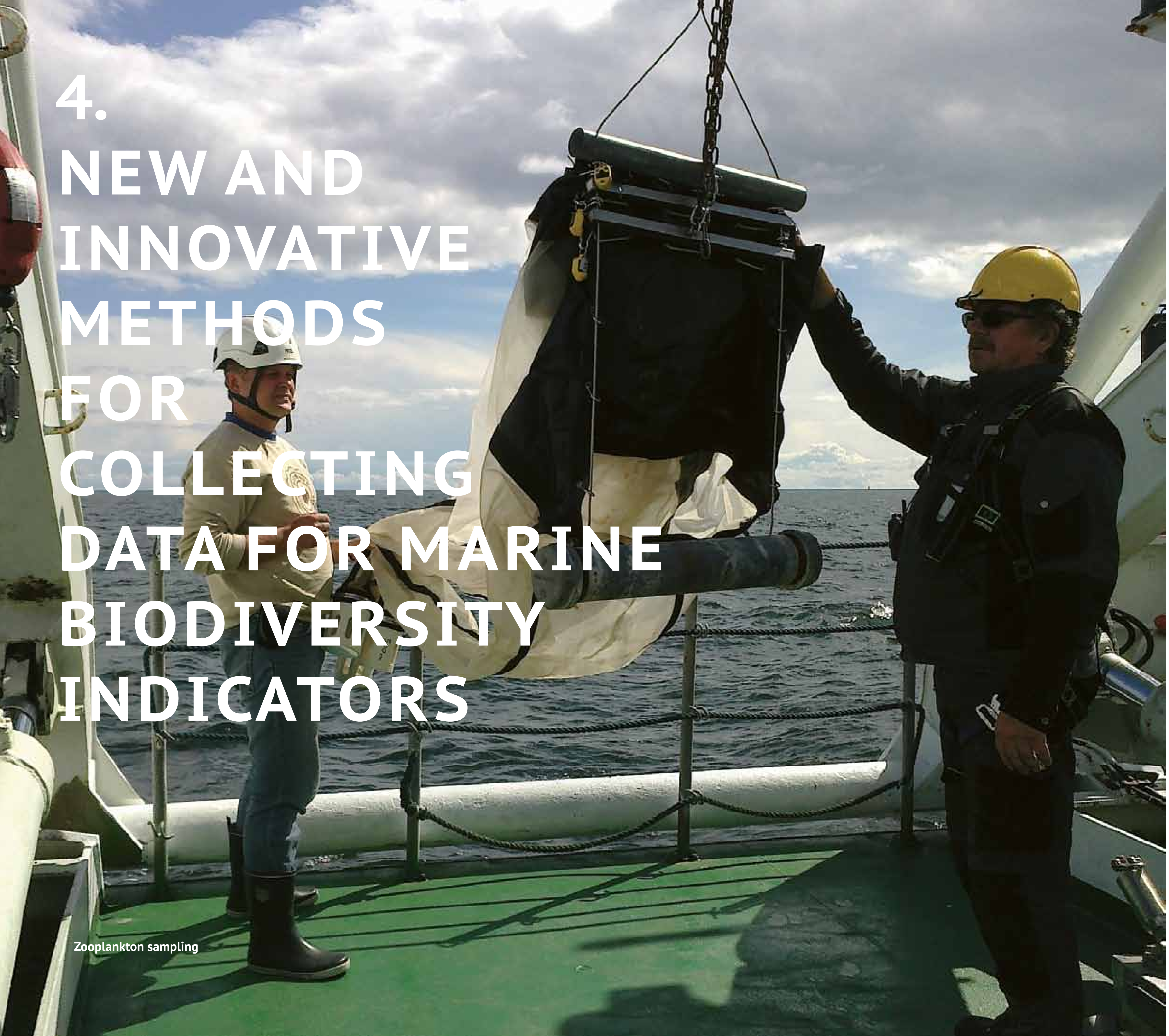
Proportion of oiled waterbirds. The indicator reflects population condition (demographic characteristics such as mortality risk and health) at the species level, and the condition (GES criteria, MSFD) of waterbirds at the habitat level due to exposed oil pollution in marine environment. The proportion of birds affected by oiling has been demonstrated. Eight species are relevant for this indicator in the Baltic Sea. The indicator is calculated as a proportion (%) of oiled birds from all birds collected in the specific survey. This indicator has a direct relationship with oil pollution as a pressure source. The indicator is scalable and can be used locally, regionally, nationally or throughout the Baltic Sea area.

Abundance index of beached birds. The indicator reflects population condition (demographic characteristics such as mortality) at the species level, and the condition of the frequently occurring species at the habitat level. Nine species are relevant for this indicator in the Baltic Sea. The indicator value is expressed either as an abundance index, i.e. the abundance of beached birds in a focal year relative to the abundance of beached birds at the base year (time period), or it is standardised as a density – the number of counted beached birds (individuals) per route unit. This indicator has a direct relationship with pollution (including oiling) and bycatch as pressures. The indicator is scalable and can be used locally, regionally, nationally or throughout the Baltic Sea area.

Abundance index of by-caught birds. This single species indicator reflects population condition (demographic characteristics such as mortality) at the species level, and the condition of frequently occurring species at the habitat level. 19 species are relevant for this indicator in the Baltic Sea. The indicator value is expressed as the number of birds drowned per 1000 m of fishing net per day (birds/NMD). However, in most countries no systemic monitoring for such indicator exists and commercial fishermen try to avoid reporting on by-catch. The indicator has a direct relationship with bycatch (gill-net fisheries) as a pressure. The indicator can be used locally, regionally, nationally or on a Baltic Sea wide scale.

Indicator on condition of waterbirds. The indicator reflects population condition (demographic characteristics such as risk of mortality) at the species level and the physiological condition of the commonly noted species at the habitats level. This is a body condition index based on three components: pectoral flight muscles, the presence and quantity of subcutaneous and intestinal fat depots. These are scored on a scale ranging from 0 to 3. Subsequently, these scores are summed up to a condition index. Thus, the total score for each bird can be in the range from 0 to 9. This indicator has a direct relationship with the removal of prey, disturbance, disease, and hazardous substances as pressures. The indicator is scalable and can be used regionally or nationally.

Feeding pressure on waterbird food sources. The indicator reflects the impact and specific pressure of feeding marine birds on their food resources (other organisms in their food-chain) as well as the structure and conditions of their habitat and the habitat forming species. Thus, it is a habitat-level indicator describing the condition of the typical species and communities as well as the relative abundance of species at one of the trophic levels. The indicator is expressed as number of "bird days" per area unit. If the pressure exceeds the carrying capacity of the site, the affected benthic or pelagic communities become unsustainable. The indicator can be used locally, regionally, nationally or throughout the Baltic Sea area.



4. NEW AND INNOVATIVE METHODS FOR COLLECTING DATA FOR MARINE BIODIVERSITY INDICATORS

Zooplankton sampling

Maiju Lehtiniemi (SYKE)

As mentioned above, biodiversity and its relationship to anthropogenic pressure gradients in the environment is a highly complex subject to study, and the demands on monitoring methods are therefore often somewhat different from conventional methods for assessing the state of the biodiversity as a consequence of e.g. eutrophication. Although some of the new and innovative biodiversity indicators may be calculated from data acquired by conventional monitoring methods, in many cases novel methods or modifications of existing methods are required. Moreover, some indicators require quantities or areal cover of data impossible (or too expensive) to achieve with conventional methods. Therefore not only new indicators but also novel methods for obtaining data for these indicators were developed in the frame of the MARMONI project. In all, 17 new, partially new, or modified existing monitoring methods were tested in order to provide data needed for the development and testing of the new indicators as well as for spatial modelling in the study areas.

Most of the new methods tested were methods for the collection of benthos and plankton; eight were benthic monitoring methods (Table 3), seven were pelagic monitoring methods for plankton and chlorophyll *a* (Table 4), and two were bird monitoring methods (Table 5). In addition to these new or modified methods, several conventional monitoring methods were utilised to collect data needed for indicator development and testing, including also methods for fish and birds. The conventional methods utilised in already established ways are not treated in this chapter; all field work (both using new and conventional methods) performed within MARMONI are described in the report "Field, Laboratory and Experimental Work within the MARMONI Project – Report on Survey Results and Obtained Data" (Wijkmark, N. (ed.) 2014). The majority of the methods tested were developed to facilitate data collection in a more time- and cost-effective way than traditional methods and/or to provide a better spatial and/or temporal cover.

The main challenge in developing innovative time- and cost-effective monitoring methods, or monitoring methods that have a better spatial and/or temporal coverage, is to maintain a high quality of the attained data, as well as sufficiently detailed data. Many conventional methods were developed as reliable methods for the collection of datasets containing highly detailed information from each surveyed station. Such conventional methods usually provide data of high quality, but are often time-consuming and laborious, which strongly limits the number of samples that can be collected with available resources, thus, also affecting the spatial and temporal coverage.

The level of detail required depends on the purpose of the survey or monitoring programme in which the method is applied. Another consideration when choosing monitoring methods is whether the chosen methods provide data for more than one indicator or reporting need or not. Combinations of several methods during the same survey from the same vessel generally also save costs and monitoring methods that provide data for several indicators as well combined surveys are therefore recommended.

Although combinations and prioritizations are done, new sets of indicators, in many cases, will demand new monitoring activities and skills. In order to decrease the costs of the new monitoring activities several of the new monitoring methods are automated alternatives to manual methods. In these new methods parts of the process are performed by machines or algorithms instead of experts. Methods for the automatic identification or measurements of benthic fauna, phytoplankton, zooplankton and birds were tested. Such methods can potentially reduce the number of working hours needed and thus also save costs since conventional methods involving manual identification of organisms are often time-consuming. Automated alternatives to manual methods were tested for several pelagic indicators where identifications, counts, or measurements of plankton species are needed. A similar approach was performed for the benthic indicator "Population structure of *Macoma balthica*" where manual measurements of the size distribution of mussel shells were replaced by an automatic measuring method.

Bird indicators are usually calculated from bird data collected during bird inventories where experts manually count the birds they observe from ships, airplanes, or from the shore. Such inventories are costly and time-consuming. Automated methods for data collection for several of the bird indicators were developed and tested as alternatives to the conventional methods.

Nicklas Wijkmark (AquaBiota Water Research)

Drop video camera

Automated methods can decrease subjectivity and eliminate biases caused by differences in the knowledge level of experts. However, many of these novel methods require further development to be fully operational, and some manual labour is still needed. In the most cases where biodiversity monitoring is involved, the new cost-effective methods will always need to be used in combination with conventional methods for calibration and/or verification purposes. In this sense, biodiversity indicators, many of which rely on species composition data, differ from certain other indicators (such as some eutrophication indicators). Therefore, it is not realistic that biodiversity monitoring methods will ever be fully automated.

The testing of the methods was performed in four project study areas, i.e. 1EST-LAT Irbe Strait and the Gulf of Riga, 2SWE Hanö Bight, 3FIN Coastal Area of SW Finland and 4FIN-EST Gulf of Finland (Figure 2). Since the aims and techniques of the tested methods varied notably, the testing strategies differed among methods. Some methods were shown to function well in a technical and practical aspect but failed to fulfil the requirement of cost-effectiveness, while others were rejected due to technical or practical issues. A majority of the methods however successfully passed the evaluation and should be considered as functional and effective monitoring methods, or potentially effective methods that need some further development in order to be fully operative.

4.1 Benthic methods

The monitoring of benthic species and habitats has traditionally been performed using laborious methods such as transect diving or soft bottom sampling with associated laboratory analyses. In total eight new benthic monitoring methods were examined and at least five of these were tested for being time- and cost-effective alternatives to conventional monitoring methods. The aim was also to find methods that facilitate the survey of larger areas such as cost-effective methods for collecting point-based datasets over large areas. Such methods are also applicable for the monitoring of species distribution and habitats, for mapping and for spatial modelling purposes where a large number of stations are needed.

Tom Staveley (AquaBiota Water Research)

Small Van Veen grab

Table 3. *Benthic monitoring methods tested within the MARMONI project.*

Method	Applicable for the following MARMONI indicators	Study area	Primary aims of new method	Evaluation
Aquatic Crustacean Scan Analyser (ACSA) image recognition software for monitoring zoobenthos community composition	2.9 Population structure of *Macoma balthica*	3FIN Coastal Area of SW Finland and nearby sea areas	Increase efficiency by saving time and costs	Functional cost-saving alternative to traditional sample analysis method, ready for application in marine monitoring programme
Using sediment cores to measure the apparent redox potential discontinuity (aRPD) depth	2.8 Condition of soft sediment habitats – the aRDP approach	3FIN Coastal Area of SW Finland	Save costs by using less expensive technique	Functional in certain sediment types, but not in all. Present sampling method causes inaccuracies in measuring the oxygenated sediment layer
Satellite observations in monitoring a macroalgae indicator	2.10 *Cladophora glomerata* growth rate	3FIN Coastal Area of SW Finland	Increase efficiency by saving time and costs	Promising method, but further work required to make the method operational
Using beach wrack for assessing coastal benthic biodiversity	2.3 Beach wrack Macrovegetation index (BMI)	1EST-LAT Irbe Strait and the Gulf of Riga	Increase efficiency by saving time and costs	Promising cost effective alternative to traditional methods. Its applicability in other areas needs to be tested, not applicable at open coasts

Method	Applicable for the following MARMONI indicators	Study area	Primary aims of new method	Evaluation
Simplified grab method using a small Van Veen grab	2.5 Habitat diversity index, 2.12 Community heterogeneity, 2.13 Number of functional traits,* 2.14 Macrozoo-benthos community index, ZKI	2SWE Hanö Bight	Increase efficiency by saving time and costs	Functional cost saving monitoring method, ready for application in marine monitoring programme
Further development of the drop-video method and the combination of drop-video and small Van Veen grabs	2.1 Accumulated cover of perennial macroalgae, 2.2 Accumulated cover of submerged vascular plants, 2.5 Habitat diversity index	2SWE Hanö Bight	Increase efficiency by saving time and costs	Functional cost saving monitoring method and combination, ready for application in marine monitoring programme
Further developments in dive method for phytobenthic monitoring	**2.1 Accumulated cover of perennial macroalgae,** 2.2 Accumulated cover of submerged vascular plants	2SWE Hanö Bight	More accurate and more statistically sound	Technical issues need to be solved. Only useful in some environments. Labour intensive.
Colonisation pattern of new hard substrate as function of human stressors (e.g. eutrophication)	None	1EST-LAT Irbe Strait and the Gulf of Riga	Provides new data	Promising method for monitoring human pressure on benthic communities

* Samples need to be analysed in the laboratory if the method is used for this indicator.
**Applicable but not recommended for this indicator.

4.2 Pelagic methods

Seven pelagic methods were examined. Like the benthic methods, these were tested as time- and cost-effective alternatives to traditional pelagic monitoring methods. Several of the methods also increase spatial and temporal cover.

Laura Uusitalo (SYKE)

Zooplankton sampling with Continuous Plankton Recorder

Table 4. *Pelagic monitoring methods tested within the MARMONI project.*

Method	Applicable for the following MARMONI indicators	Study area	Primary aims of new method	Evaluation
Bio-optical methods for identifying phytoplankton community composition	None	3FIN Coastal Area of SW Finland, 4FIN-EST Gulf of Finland, and nearby areas	Increase efficiency by saving time and costs	May be used in order to increase the spatial and temporal coverage of certain aspects of phytoplankton monitoring, but cannot replace traditional light microscopic analysis
Satellite observations in phytoplankton bloom indicators	3.3 Cyanobacterial surface accumulations – the CSA-index, 3.6 Spring bloom intensity index	3FIN Coastal Area of SW Finland, 4FIN-EST Gulf of Finland, and 1EST-LAT Irbe Strait and the Gulf of Riga	Increase spatio-temporal coverage	Functional method which will improve further with future development of satellite instruments, ready for application in marine monitoring programme
Continuous Plankton Recorder (CPR) in monitoring zooplankton community composition	None	3FIN Coastal Area of SW Finland, 4FIN-EST Gulf of Finland, and nearby areas	Increase efficiency by saving time and costs, increase in spatial coverage	Technically functional method but does not increase cost-efficiency in the Baltic Sea and therefore not recommended as an alternative to traditional zooplankton net sampling
ZooImage software in monitoring zooplankton community composition	3.7 Copepod biomass, 3.9 Microphagous mesozooplankton biomass, 3.10 Zooplankton mean size vs. Total stock (MSTS)	3FIN Coastal Area of SW Finland, 4FIN-EST Gulf of Finland, and nearby areas	Increase efficiency by saving time and costs	Functional method which may improve cost-efficiency of sample analysis, ready for application in marine monitoring programme
Application of hyperspectral airborne remote sensing for mapping of chlorophyll a distribution	None	1EST-LAT Irbe Strait and the Gulf of Riga	Increase efficiency by saving time and costs, increase spatiotemporal coverage	Remote sensing may reduce but not replace field sampling. Method increases only spatial resolution, not temporal. Data fusion from satellite data, airborne sensors and field sampling is recommended
FerryBox method (traffic line Rīga-Stockholm) for evaluation of the phytoplankton bloom intensity	3.6 Spring bloom intensity index	1EST-LAT Irbe Strait and the Gulf of Riga (Riga-Stockholm traffic line)	Increase efficiency by saving time and costs, increase spatiotemporal coverage	The tested technique was not judged applicable for monitoring purposes. A more advanced FerryBox system would be needed.
The use of hydroacoustics for surveys of zooplankton	None	2SWE Hanö Bight	Increase efficiency by saving time and costs, increase in spatial coverage	Several zooplankton groups were successfully detected but methods for calculating actual abundance and biomass remain to be developed

4.3
Bird methods

Birds are traditionally counted visually by field staff either from land, from ships or from aircrafts. Such surveys were performed also within the MARMONI project in order to collect required data for indicator development and testing. In addition to this, new methods for the automatic identification of birds using aerial RGB imaging and thermal imaging were explored. An automatic identification will provide results unbiased by the different accuracy of observers. It will also allow storage of collected samples for later use as well and reduce man hours needed for the field surveys. The tested methods are however dependent on weather conditions and the technique is currently not in a state ready to replace conventional methods.

Ainars Aunins

Latvian ornithologists going to aerial bird count

Table 5. *Summary of the new bird monitoring methods tested within the MARMONI project.*

Method	Applicable method for following MARMONI-indicators	Study area	Primary aims of new method	Evaluation
Automatic identification of birds using aerial RGB imaging	4.1 Abundance of wintering waterbird species, 4.6 Distribution of wintering waterbird species, 4.7 Distribution of wintering waterbirds (multi-species), 4.8 Distribution of wintering waterbirds of different feeding guilds (multi-species)	1EST-LAT Irbe Strait and the Gulf of Riga	Improve precision of results, by improving bird detection and reducing biases due to incomplete (and differing between observers) detectability of birds in conventional methods; establish a sampling method which allows storing of collected samples for later use; reduce man-time needed during the field survey	The method facilitates obtaining of unbiased data. Performance of the method decreases with worsening sea conditions, best results were obtained at calm sea (sea state not exceeding Beaufort 1). Overlap of consecutive images by half an image or more is important to mask out sun affected areas. Bird recognition algorithm (rule-set) needs to be improved to reduce proportion of missed and false detected birds below 5%. Rule-set needs to be adjusted for each new batch of images. Attributing species to detected birds needs manual human input.The method is not yet ready to replace the conventional methods
Thermal imaging along with RGB imaging to improve detection of birds	The same as above	1EST-LAT Irbe Strait and the Gulf of Riga	Improve bird detection using the method above and better separation between "true" and "false" bird detections by the algorithm.	The method has potential in improving the method above. Current shortcoming is differing fields of view of RGB and thermal cameras in the tested setup. The main method (automated bird detection in RGB images) itself is not ready to replace the conventional methods for routine monitoring.

Example: New method combination for the monitoring of benthic biotope and habitat biodiversity indicators.
In order to meet new reporting demands novel monitoring is needed. One such example is area-based monitoring, which is required for analysing habitat distribution and extent (MSFD criteria 1.4 and 1.5) as well as related indicators. The spatial coverage and number of stations in existing benthic monitoring programmes are insufficient for these purposes. New cost-effective methods that allow the surveying large number of stations are therefore required. Drop-video and a simplified grab method were identified as suitable cost-effective methods and tested in order to find a combination of methods that can be used for monitoring a wide range of benthic habitat indicators on different substrate types. The testing was performed in the MARMONI study area in the Hanö Bight. Both methods were performed from the same small vessel by a field team of two to three people. Over 1000 randomly distributed stations were visited in the area. Drop-video was used in all stations in order to detect bottom type and to select the survey method and for the inventory of hard and mixed bottoms as well as vegetation and epifauna on soft substrates. The grab was used wherever sand or other soft substrates were detected during the inventory of infauna. The grab (small Van Veen grab) was also used for taking algal samples on hard bottoms whenever extra information was needed to support the drop-video interpretations. Grab samples were sieved and sorted in the field in order to save time and costs. Using small grabs enables samples to be collected in shallow environments where conventional monitoring of infauna is not performed. Infauna indicators may therefore also be calculated for shallow soft bottoms when this method is used. Although transect diving can be used to collect data for phytobenthic biodiversity indicators such as the MARMONI indicators Accumulated cover of perennial macroalgae or Accumulated cover of submerged vascular plants, drop-video provides equivalent data at lower costs and allows many more evenly distributed stations to be sampled over large geographical areas. This time- and cost-effective combination of methods provided a large area-based dataset from both hard- and soft bottom benthic biotopes in the area. The data collected were successfully used for spatial modelling of habitats, biotopes, macroalgae, vascular plants, blue mussels and infauna. This resulted in 66 maps of benthic habitats, biotopes and species in the study area. Such maps can provide important inputs for spatial indicators such as the Habitat diversity index.These methods and method combinations are considered functional and operative and no further technical development is needed. The use of these methods in monitoring programmes for benthic habitats and biotopes are further analysed within the HELCOM BALSAM project (2013-2015), which is utilising results of MARMONI and brings them on the Baltic Sea Region level. The methods will form the basis of the benthic monitoring manual written in the project and examples from the use of these methods for the monitoring of benthic HELCOM HUB biotopes in different study areas are given. The monitoring of a variety of different benthic biotopes will require a combination of methods and although the proposed methods will cover most benthic habitats and ecosystems, the combination with other methods may be considered. This may include both traditional methods (such as diving) for verification or calibration purposes, and more advanced technical methods such as hydroacoustics. Since there is no standardised methodology for drop-video, this method is performed in slightly different ways in different countries and institutes. The HELCOM BALSAM project will also produce a common method description for the drop-video method.

5. TESTING OF INDICATORS IN INTEGRATED BIODIVERSITY ASSESSMENT

Karl Floren (AquaBiota Water Research)

The MARMONI indicator work included, besides the development and testing of indicators, also an exercise to assess the marine biodiversity with the idea in mind to test the applicability of the developed indicators. This indicator-based integrated assessment (Auniņš, A., Martin, G. (eds) (2015) performed at the final stage of the project revealed several issues, potential obstacles and drawbacks, which should be addressed in the course of developing indicators and when applying them for various assessments. The issues relate to data quality and availability but also to the structure and character of the indicators themselves. In this chapter we give a short overview on the issues, problems encountered, lessons learned and give some recommendations on how the challenges might be mitigated.

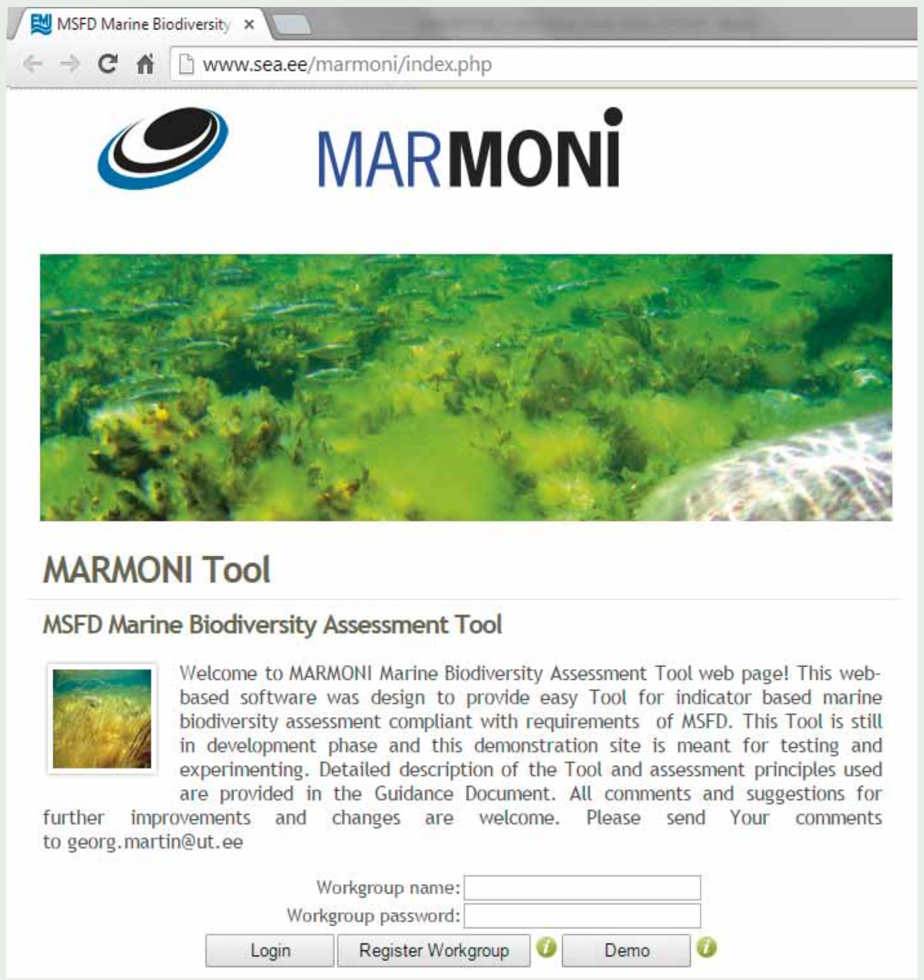
Such indicator-based integrated assessments were performed in the four project study areas, i.e. the Gulf of Riga, the Hanö Bight, the Coastal area of SW Finland and the Gulf of Finland.

5.1. Use of indicators for assessing the Good Environmental Status

The total number of indicators and MSFD descriptor 1 criteria that were assessed varied between the study areas, mostly depending on availability of data or of GES-levels (GES boundaries) for the indicators. The data used for the assessments originated from the indicator development and testing process carried out within MARMONI project and other available sources (national monitoring programmes, international reports, Initial Assessment reports under MSFD etc.). The assessment was performed with the help of the newly developed "MARMONI Marine Biodiversity Assessment Tool" (http://www.sea.ee/marmoni/index.php), a publicly available web-based tool for policy makers, experts and stakeholders to easily assess the state of biodiversity according to the criteria set by the MSFD.

The main results and a description of the indicator information used in the assessment exercise are presented in Table 6 (see below). Higher scores were obtained for the Gulf of Riga and the Hanö Bight study areas compared to the Coastal area of SW Finland and the Gulf of Finland. Only for the Gulf of Riga study area all criteria were represented by indicators while in the other study areas many criteria were not covered due to lack of data. The biggest gaps of available data seem to be with regard to indicators describing habitat distribution (MSFD criterion 1.4), Habitat extent (criterion 1.5), Population condition (criterion 1.3) and different biodiversity components (mammals and zooplankton). On the other hand, the best representation was achieved for those groups with the largest amount of indicators (phytoplankton, sea birds). This reflects both, a lack of operational indicators as well as shortages in monitoring programmes as well as a different purpose of the original monitoring programmes.

The assessment tool also contains a function to classify the uncertainty of the assessment at indicator level. The uncertainty classification includes four different elements: i) spatial uncertainty, ii) temporal uncertainty, iii) uncertainty associated with measurement of the indicator, and iv) uncertainty associated with defining the GES level. The outcome of the study demonstrates a relatively high indicator level confidence for all four areas which is a result of well-developed indicators with reliable data for the exercise. However, the present method of evaluating overall uncertainty does not take into account the number of used indicators. In the following sections the major issues which became apparent while applying the indicators in the marine biodiversity assessments shall be discussed.



The "MARMONI Marine Biodiversity Assessment Tool"

enables the aggregation of information from the single indicator level to higher hierarchical levels according to the divisions and system required by the MSFD and its implementation guidance (EC, 2010). For the aggregation of information a scoring system is used, in which a higher score indicates a larger proportion of indicators reaching GES in each geographical area, and where each hierarchical level can be assessed independently. At the same time the Tool reacts on data availability and data quality in the illustration of its assessment output and gave us valuable input for our indicator development approach.

Table 6. *Summary of assessment results performed in MARMONI study areas with help of the MARMONI Marine Biodiversity Assessment Tool. For detailed methodology description see Auniņš, A., Martin, G. (eds) 2015. (http://marmoni.balticseaportal.net)*

	Gulf of Riga	Hanö Bight	Coastal area of SW Finland	Gulf of Finland
GES score* obtained from MARMONI Marine Biodiversity Assessment Tool	66	87	38	29
Uncertainty score of the assessment**	3	2	2	3
Number of indicators used in assessment	44	27	11	12
Number of indicators reaching GES in assessment unit	28	23	5	5
Number of species distribution indicators (MSFD criterion 1.1.)	5	1	3	4
Number of population size indicators (MSFD criterion 1.2.)	7	15	2	0
Number of population condition indicators (MSFD criterion 1.3.)	3	0	2	0
Number of habitat distribution indicators (MSFD criterion 1.4.)	7	0	0	0
Number of habitat extent indicators (MSFD criterion 1.5.)	4	0	1	0
Number of habitat condition indicators (MSFD criterion 1.6.)	8	5	3	7
Number of ecosystem structure indicators (MSFD criterion 1.7.)	10	6	0	1
Number of angiosperm indicators	6	4	1	0
Number of macroalgae indicators	14	4	2	0
Number of invertebrate bottom fauna indicators	4	3	2	1
Number of fish indicators	6	1	4	0
Number of marine mammals indicators	2	0	0	4
Number of seabird indicators	12	19	0	0
Number of phytoplankton indicators	2	0	2	4
Number of zooplankton indicators	1	0	0	3
Number of indicators covering abiotic features	1	0	1	0

*maximum value =100 - when all indicators are in GES
** uncertainty score: 1- high, 2- moderate; 3 – low

5.1.1. Data availability

The assessment exercise revealed that data availability was the most problematic factor setting the quality of the integrated indicator based assessment. For example, indicators for the MSFD criteria 1.1 species distribution and 1.6 habitat condition were successfully assessed in all study areas showing that data on these criteria as well as operational indicators were available. The MSFD criteria 1.2 population size and 1.7 ecosystem structure were represented by at least one indicator in three of four study areas.

Indicators for habitat distribution and extent could only be assessed in one area (habitat distribution) and two areas (habitat extent) respectively. This is caused mostly by missing monitoring data for these indicators. In order to monitor habitat distribution and the extent of it, good spatial coverage is needed. Whereas most traditional monitoring methods are station-based (and monitoring restricted to a rather small number of stations). Therefore, data for the assessment of these criteria either need to fully cover areas, delineate the boundaries of habitats, or include relatively large amounts of samples distributed over the monitored areas.

Lessons learned: In order to perform an indicator-based biodiversity assessment which represents all descriptor 1 criteria and all important ecosystem components, current monitoring programmes need to be reformed. The severe data gaps in habitat distribution and extent data highlight the need for new area based monitoring methods. Monitoring programmes facilitating sufficient data availability will serve to decrease uncertainty of the assessment results.

5.1.2. Scale applicability

Each of the indicators developed or used has a certain geographical scale or range of scales at which it is intended to work and at which it gives a relevant message. The scale ranges from “local” through “regional” and “national” up to “Baltic Sea wide” (Table 7). Some of the wintering seabird indicators are even affected by changes in breeding areas far away from the Baltic Sea area. The MARMONI benthic, pelagic and fish indicators are meant to be used at local and regional geographical scales only. Of these, the majority of indicators were relevant at the regional scale at which also the assessment of the pilot areas was carried out. The indicators working at local and national scale were fewer in number - only 2 and 3 fish indicators are relevant at the local and the national scales, respectively.

Table 7. *Number of MARMONI indicators applicable at the different scales*

Scale	Local	Regional	National	Baltic Sea wide
Fish indicators	2	3	3	
Benthic indicators		8		5
Pelagic indicators		4		4
Bird indicators	9	15	16	15

The fish indicators developed and tested in MARMONI were focused on coastal fish species. Populations of these species are often local or regional and the populations and communities are mostly affected by local or regional factors. Fishery management of coastal species is also carried out on the same scale. Hence, the indicators should in most cases be applied on local or regional scale, thus, setting limits for the recommended assessment units.

Benthic communities are strongly affected by factors such as seafloor substrate, wave exposure, salinity and available light (depending on depth and water transparency). Although several of these factors differ between different areas in the Baltic Sea, the benthic indicators developed within MARMONI can potentially be used over the whole Baltic Sea. In order to do this, regional GES-boundaries need to be set for these indicators.

Both phytoplankton and zooplankton communities are strongly influenced by water temperature and salinity (Viitasalo *et al.*, 1995; Gasiùnaite *et al.*, 2005; Suikkanen *et al.*, 2007, 2013). Thus the areas covered by the pelagic MARMONI indicator data should be delimited in such a way that no strong salinity and climatological gradients occur, i.e. the indicators should be tested separately for different sea areas in the Baltic Sea and consequently the GES boundaries set region-specifically. The current understanding is that all eight ready pelagic indicators have the potential to be extended over the whole Baltic Sea, providing GES boundaries are set region-specifically.

All bird indicators are scalable. Nine MARMONI bird indicators can be applied at all geographical scales while seven can be applied at three or two different scales. Depending on scale, the message provided by the indicator may differ. For example, the indicator “Breeding success: clutch and brood size of breeding species” applied at the local scale tells about local processes (e.g. predation or disturbance) going on at the particular site or set of sites which cannot be extended to other areas where these processes might be different. Different sites can be compared on the basis of this locally applied indicator, and thus the indicator can be used to identify “problem sites”. The same indicator applied at regional or national scale levels out the site level processes, and these factors become relevant only if they are consistent over larger (regional or national) geographical areas. Then they would indicate existence of regional or national drivers (e.g. result of existing or missing legislation or existing or lacking financial instruments) that impact the performance of the indicator. When applied at the Baltic Sea wide scale the indicator is linked to continental or global processes affecting the whole Baltic Sea population of the species (e.g. climate change, or Baltic wide decrease of food stocks).

It is expected that most of the indicators will be used at a regional or national scale due to requirements of international reporting according to the MSFD, HD or BD. However, application of indicators at the Baltic Sea wide scale is becoming more common. Thus single species or composite abundance indicators such as the “Abundance index of wintering waterbird species” and “Wintering indices for waterbirds of different feeding guilds” which initially were tested in regional and national scales were successfully applied at the Baltic Sea wide scale as the HELCOM CORESET (HELCOM, 2013) indicator “Abundance of waterbirds in the wintering season”(Auninš *et al.*, 2013).

Lessons learned: More indicators covering processes of different geographical scales are needed especially for those components of biodiversity that possess higher relevance on geographical scales larger than national territorial waters (e.g. seabirds, mammals, fish populations). Availability of these indicators and data will help to assess the biodiversity features against stressors having e.g. global character (as climate change).

5.1.3. Number of indicators used in the assessment

Since data availability varies between study areas, the number of indicators used in the assessment also varies considerably between criteria, areas and ecosystem components. Assessment results for criteria or ecosystem components represented by only one or few indicators will generally be less reliable and robust than assessment results based on several indicators. The confidence of the overall assessment is dependent both on the number of habitats or species (i.e. indicators) included, but also the assessment certainty of the individual indicators. To a certain extent one can compensate for the other. A wide variety of indicators is therefore preferable. Some indicators are very specific and include a narrow portion of the ecosystem only (e.g. single species indicators) while others are broader and more inclusive (e.g. indices including several species). Such indicators should therefore be prioritized for criteria or ecosystem components when only a few indicators will be used.

The use of more indicators will not always require more monitoring since several indicators may be calculated from the same monitoring datasets. This should be taken into account when designing new monitoring programmes. The newly developed MARMONI indicators will fill gaps and improve biodiversity monitoring, but other indicators should also be used in order to provide a complete and integrated biodiversity assessment and increase the robustness of the assessment.

Lessons learned: For assessing the state of marine biodiversity a higher number of indicators is needed than currently available. A higher number of indicators covering different components of marine biodiversity and different assessment criteria will increase the overall confidence of the assessment. This conclusion is contrary to the HELCOM CORESET idea of a few indicators which all countries shall monitor as minimum – an issue open for discussion at regional sea level.

5.2. Use of indicators for assessing the conservation status of species and habitats

In addition to the indicator-based biodiversity assessment, we also assessed the conservation status of target species and habitats in the four study areas (Auniņš, A., Martin, G. (eds) 2015). Traditionally this type of assessment is applied on the national scale for BD and HD reporting on Favourable Conservation Status of species and habitats. We applied it on the regional scale which involved a cross-boundary evaluation for two of the sites (the Gulf of Riga and the Gulf of Finland). The assessment was based on a predefined set of indicators (both quantitative and qualitative; Table 8). To assess whether the indicator is at a favourable status the quantitative indicators of distribution range, population and habitat were compared with favourable reference values – the values at which species or habitat can be considered (known or assumed) as safe. The favourable reference values were the target values for these indicators and the outcome of the assessment reflected whether the target is achieved (favourable, if achieved, and unfavourable, if not) and also distance to the target, if not achieved (unfavourable-inadequate or unfavourable-bad). Trend information was used to reflect whether the situation is improving, stable or deteriorating. The rest of the indicators were mainly qualitative and although based on numerical information, the outcome was not based on numerical targets. The outcomes of all assessment categories were combined into an overall assessment of the conservation status based on the lowest acquired status in the individual assessment categories.

Table 8. *Indicators and parameters used for assessment of conservation status of species and habitats.*

Indicator (parameter)	Type	Numerical target	Habitats	Non-bird species	Birds
Distribution range					
Range area	Quantitative	Yes	X	X	X
Range trend	Categorical		X	X	X
Population					
Population size	Quantitative	Yes		X	X
Population trend	Categorical			X	X
Habitat					
Area	Quantitative	Yes	X		
Area trend	Categorical		X		
Habitat for species					
Area	Quantitative			X	
Quality	Categorical			X	
Trend	Categorical			X	
Specific structures and functions	Categorical		X		
Future prospects (based on pressures and threats)	Categorical		X	X	X

The results of the conservation status assessments of individual species and habitats were used to calculate an area score that shows the performance of the area and confidence of this evaluation. The area score was the percentage of points achieved among assessed species and habitats with known conservation status out of number of points that could be achieved if all assessed objects were at favourable conservation status. The confidence of the score was based on percentage of assessed objects with a known conservation status out of all assessed species and habitats. The higher the proportion of objects was, the higher the confidence of the achieved area scores.

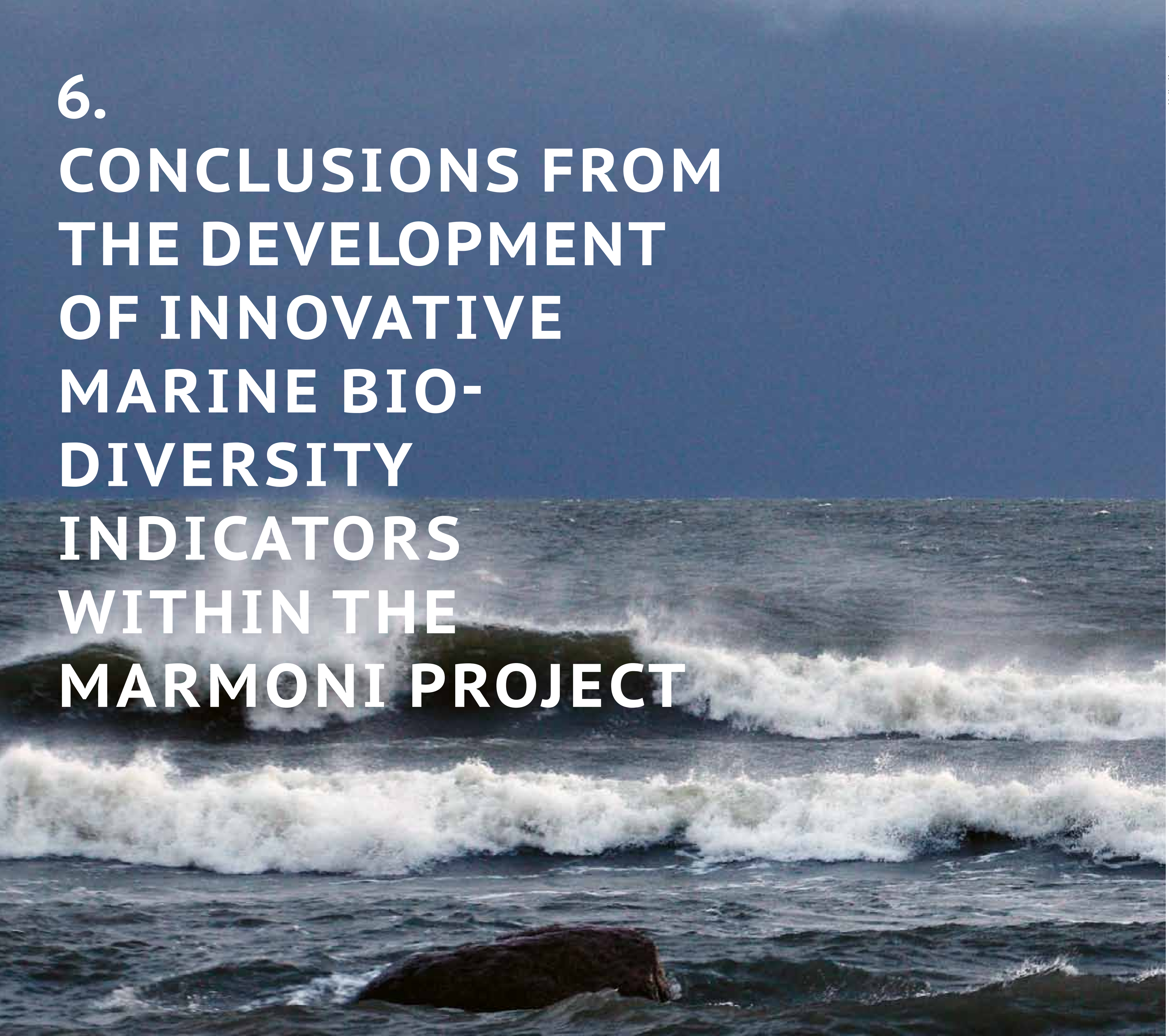
The main results of the favourable conservation status assessment are presented in Table 9. Higher scores were obtained for the Gulf of Riga than the other areas, and the number of objects with unknown status was not higher than in other areas. This suggests that the assessment outcome can possibly be affected by the availability of data where data for species and habitats not considered as being at risk is lacking. On the other hand, where the assessment score for particular assessment category reached maximum 100% it was often based on limited number of assessed objects and thus low percentage of objects with known conservation status. The assessment category "Specific structures and functions" achieved lower scores than other assessment categories and although mainly based on expert judgement conservation status of all assessed objects was known.

Although none of the MARMONI indicators could be used directly for the conservation status assessment, several of these were still closely related. Thus MARMONI indicator "4.6 Distribution of wintering waterbird species" was used to obtain Distribution Range area indicator for conservation status assessment. Similarly, population size used in conservation status assessment largely reflects the same population characteristic as MARMONI indicators "4.1 Abundance index of wintering waterbird species" and "4.4 Abundance index of breeding waterbird species" expressed differently (in absolute or relative numbers).

Lessons learned: The examples show that data collection schemes established for one type of assessment can be successfully used to obtain parts of the data needed for other type of assessment.

Table 9. *Status assessment area scores of the four MARMONI pilot areas*

Category	Gulf of Riga	Hanö Bight	Coastal area of SW Finland	Gulf of Finland
Distribution	95	100	89	100
Population/area	80	88	87	100
Habitat for species	100	50	100	50
Specific structures and functions incl. typical species	80	50	38	75
Future prospects	80	75	73	63
Overall assessment	74	65	66	63



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6. CONCLUSIONS FROM THE DEVELOPMENT OF INNOVATIVE MARINE BIO-DIVERSITY INDICATORS WITHIN THE MARMONI PROJECT

The conclusions from the MARMONI indicator development work can be divided into three parts: i) conclusions related to the policy frames in which MARMONI has been acting and addressing its contribution towards implementation, ii) conclusions on methodological aspects of the indicators, and iii) conclusions derived from testing the applicability of indicators in biodiversity assessment schemes.

6.1 Conclusions related to policy frames

Marine Strategy Framework Directive

The implementation of the MARMONI project fell into the timeline of the first two implementation steps of MSFD, the Initial Assessment (of the marine environment of the member states) and the design of the national monitoring programmes and accompanied their implementation in the project's target countries.

The Initial Assessment in most countries was carried out based on available knowledge, data and information without carrying out new baseline surveys. With regard to descriptor 1, Biodiversity, the Initial Assessment revealed the same findings as the MARMONI indicator work: true biodiversity indicators are lacking, until now pressures to biodiversity have been defined by indicators rather than the state of biodiversity itself. In this sense the MARMONI project has had a pioneering function in pinpointing the problem and putting an emphasis on the development of true biodiversity indicators to serve the future implementation of the MSFD.

The analyses carried out in the MARMONI project showed also that currently existing national monitoring programmes cannot adequately provide data for the assessment of the state of marine biodiversity in the way it is required by the MSFD. Some elements of the existing monitoring programmes can be used but considerable changes are required for the both, utilised methodology (parameters, indicators, monitoring methods) and the employed strategy (spatial and temporal resolution of data collection). The currently ongoing review of national marine monitoring programmes according to the MSFD implementation process gives a good opportunity in that context. Although several Baltic Sea countries have developed and approved their new monitoring programme according to schedule, the MARMONI results are aimed to provide input and support for those countries which have not yet finalised their programmes, as well as for the next revision period in six years' time.

Habitats and Birds Directives

The information needed for the BD and the HD reporting partly overlap with the requirements of biodiversity reporting in the MSFD. Although the established reporting units and reporting parameters cannot directly be used as indicators in GES assessment, they are often similar due to the same field procedures. The best conformance was with bird indicators. Most of them either can be calculated from the same datasets that can be used for Article 12 BD reporting or they could be used as additional information in the additional information fields of the report.

Baltic Sea Action Plan

HELCOM has adopted the indicator-based assessment approach and has been performing the assessment on the indicator information available from member states. Previous assessments suffered from lack of operational indicators reflecting the state of marine biodiversity in the Baltic Sea. HELCOM is currently developing a set of common, Baltic Sea wide indicators (CORESET) to be applied in the future assessment activities. The MARMONI project has contributed to this process by providing a set of indicators together with developed monitoring methodology and the necessary supporting information (e.g. region specific reference conditions and target values).

The collaboration between MARMONI and the HELCOM CORESET I and II projects has resulted in direct input from MARMONI to the list of CORESET indicators as well as in indirect impacts in the course of the Baltic Sea wide indicator development (e.g. sharing of the lessons learned from results of indicator testing as well as applied methods and interpretation). The main difference in the approach of the two projects was that the CORESET list is formed by operational indicators that can be applicable by all 10 HELCOM contracting parties, while MARMONI developed new innovative indicators, based on data and field testing at the four MARMONI project areas. Thus the uptake of the indicators, developed by the MARMONI project, in the CORESET list means assessing of their applicability by all 10 contracting parties and modifying them, if necessary, to be suitable as Baltic Sea wide indicators.

National monitoring programmes

Within the framework of the MARMONI project it was not possible to develop a complete list of indicators covering all possible aspects of marine biodiversity and fulfilling all assessment needs set by different policy instruments. Instead, the aim was to concentrate on increasing the cost-effectiveness of monitoring and introducing new, innovative approaches for the monitoring and assessment of marine biodiversity. Consequently the indicators and methods developed in the project, although not constituting a complete palette of indicators or an all-inclusive monitoring scheme, fulfil their aim in serving to support the modernization of national marine monitoring programmes. The indicators developed in MARMONI have been documented meticulously which makes it much easier to evaluate them for inclusion into future assessment schemes. A large number of the indicators developed are already taken up by national authorities and for others further development is foreseen on the national level.

6.2 Conclusions on methodological aspects of the indicators

The indicators developed in the MARMONI project to reflect the state of different elements of marine biodiversity in the Baltic Sea give a possibility to review and streamline the approaches for both data collection and assessment. Especially in cases of shared marine basins the applications of similar monitoring methods and indicators should ideally lead to comparable assessment results among different member states.

There is a slight difference in the state of development and application as well as methodological applicability among the four different indicator thematic groups defined in the MARMONI project (fish, benthic, pelagic and bird indicators). In addition to the conclusions common to all four thematic indicator groups, some specific conclusions could be drawn for each indicator topic group:

Conclusions common for all topic groups

- Increase of sampling effort using traditional methods and approaches will not provide all necessary additional data to cover all assessment needs, or will lead to a tremendous increase in monitoring costs.
- New methods and approaches proven viable by testing in the MARMONI project should be applied both to data collection, aggregation and assessment procedures to fully comply with the assessment requirements of MSFD.
- Most of the indicators developed in the MARMONI project do not have regional restrictions to their applicability in the Baltic Sea, hence their application in marine monitoring programmes will increase the ability of those programmes to meet the assessment needs according to the MSFD and benefit the regional harmonization of monitoring programmes.
- Application of indicators developed in the MARMONI project will fill many gaps in previous monitoring activities and enable to increase the amount of information generated by monitoring programme.

Fish indicators

- There is a well acknowledged need to get better knowledge (and indicators) of the effects of fishery on the coastal fish stocks and communities.
- Existing data sources, such as the log-book data of commercial fishery, could possibly be used more effectively.
- Co-operation between commercial fishermen and institutes responsible for monitoring could offer new and cost effective ways to gather data of coastal fish stocks.

Benthic indicators

- Application of indicators and monitoring methods developed in the MARMONI project will enable to increase areal coverage of assessment of benthic biodiversity extending the assessment to habitats not covered so far.
- Application of indicators and methods developed in the MARMONI project enables to better address cumulative pressures affecting the benthic biodiversity in the Baltic Sea.

Pelagic indicators

- In order to obtain a detailed understanding of the dynamic pelagic communities and to attain sufficient data for the indicators, spatially and temporally frequent sampling is necessary. This constitutes a challenge concerning the laborious and therefore costly quantitative species composition data which several of the phytoplankton biodiversity indicators rely on. Concerning the zooplankton indicators however, an automated method for analysing zooplankton community composition was developed (see section 4.2 in the present publication and Wijkmark (ed) *et al*. 2014)
- The biodiversity of phytoplankton is often very difficult to estimate since the community includes a great number of taxa, many of which occur in too low quantities to be recorded in routine sampling. Moreover, even an experienced taxonomist cannot identify all taxa to species level by the methods applicable within routine phytoplankton monitoring. Furthermore, it was found that the Phytoplankton trait- and dendrogram based functional diversity index (FD) is sensitive to changes relating to microscopy methods and the accuracy of species identification, as likely are other similar (phytoplankton) indicators. This emphasizes the importance of maintaining and developing taxonomical expertise and a standardized methodology common for all.
- Very few quantitative historical phytoplankton and zooplankton data from the Baltic Sea exist, hence the reference levels and target values of pelagic indicators need to be derived from modern data and/or using expert judgment.
- The HELCOM CORESET project final report lists no ready phytoplankton biodiversity core indicators, pointing out that phytoplankton

indicator development turned out to be both time-consuming and scientifically challenging (HELCOM, 2013). HELCOM MONAS noted the need to develop indicators for phytoplankton, and requested experts to further develop them by 2015 (HELCOM, 2013). Within the MARMONI project, five phytoplankton biodiversity indicators were successfully developed.

Bird indicators

- The distribution areas of several species cover large parts of the Baltic Sea and the individuals belong to the same population. The conservation status of the populations can often be effectively maintained or improved only by large-scale management plans, typically because the populations are affected by various additive pressures in different regions of the Baltic Sea or even outside the region. Therefore, monitoring programmes and assessment units based on national borders or Baltic Sea sub-regions might be too narrow, and even Baltic Sea wide assessments should be carried out - at least in the background - for several seabird species. Sufficiently wide assessment units and monitoring approaches could enable the production of high-quality assessments for the MSFD and BSAP. The sharing of tasks and international optimization of monitoring activities could reduce the total costs of assessment.
- Mobility of marine birds during non-breeding period allows them to adjust their territorial distribution according to changing ice conditions. Thus counting birds in different parts of the Baltic Sea in different years may cause difficulties to carry out Baltic Sea wide scale assessments. To avoid the risk of missing or double-counting the birds during nationally restricted counting sessions, which have different distribution patterns coordination of data collection schemes among the Baltic Sea countries is required. Therefore, it is important that all countries perform large scale counts in the same winter.
- The same data collection schemes can provide data for the calculation of several indicators thus reducing the cost per indicator. Additionally these schemes may serve the data collection needs for BD and HD reporting.

6.3 Conclusions derived from the application of indicators for the biodiversity assessment

Testing the indicators in the MARMONI integrated biodiversity assessment tool led to the following recommendations with regard to data quality and availability, as well as the structure and character of the indicators:

- **Number of indicators** – a higher number of indicators in the assessment gives a more robust assessment result with a higher confidence level. Whenever possible, a high number of indicators should be used, preferably evenly distributed between different MSFD descriptor 1 criteria and covering all or most of the biodiversity components and elements.
- **Quality of the indicators** – a high number of available indicators may provide the opportunity for selection of indicators with higher certainty levels for the assessment. At the same time it is important to use as much information as available and all indicators fulfilling minimum quality requirements should be considered for inclusion in the assessment.
- **Data availability** – systematic data collection should be carried out in the assessment area in order to fulfill all requirements of the indicators. Current monitoring schemes are not able to provide all the data required for the performing of indicator based assessments. Changes in current monitoring and data collection procedures need to be introduced.
- **Need for indicator development** – there is a need for further development of biodiversity indicators in order to gain better coverage and representation of all required biodiversity characteristics and elements. New indicators may be developed based on existing data collection mechanisms but the need for new data collection programmes and methods in the areas not covered by existing data collection schemes is evident and will require time and resources.


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- **Assessment areas** – the size and geographical location of an assessment area has an important implication on the assessment procedure. The size of an assessment area should be in accordance with available data and vice versa. Usually larger assessment units will have more data available and more operational indicators. On the other hand if an assessment unit is too large, the need for adequate spatial aggregation procedures within the assessment unit is obvious. Also variation in the environmental conditions related to geographical features needs to be considered when defining the borders of assessment areas.
- **Scale issue** – different indicators have different operational geographical scales. The indicators good for describing Baltic Sea wide processes may not be the best on the local or basin scale. This should be considered very carefully when relevant indicators are selected for assessments.
- **Assessment procedure** – the assessment procedure should be in accordance with the assessment task, i.e. it is important to consider the relevance to the particular directive or regulation requiring the assessment. Different assessment tasks may give assessment results that are not fully comparable. For example, assessment results of ecological status of coastal waters carried out according to the WFD may not necessarily correspond to the results of assessments carried out according to the HD. This means that careful interpretation of the results should be considered in each case and conclusions from the assessment should be formulated strictly following the context of the assessment procedure.

All in all, we can state that the MARMONI project has significantly contributed to supporting the implementation of the Marine Strategy Framework Directive and the Habitats and Birds Directives in the project target countries and thus contributed to an overall improvement of the assessment capacity of the status of marine biodiversity in the Baltic Sea. In particular, the knowledge gained through indicator development, field works, modelling and data analysis about the status and distribution of species and habitats will help the state authorities to define appropriate management for particular areas and assess their conservation status as well as their contribution to the state of biodiversity in the Baltic Sea.

Related MARMONI reports and information sources

Detailed descriptions of the indicators developed within MARMONI

Database of indicators developed within the MARMONI project. Available online: http://marmoni.balticseaportal.net/wp/category/biodiversity-indicators/

Martin, G. (ed.) 2012. Draft list of the new, innovative and cost-effective indicators for monitoring of biodiversity in the Baltic Sea. 225 pp. Available online: http://marmoni.balticseaportal.net

Martin, G. (ed.) 2015. The MARMONI approach to marine biodiversity indicators. Vol. II: List of indicators for assessing marine biodiversity in the Baltic Sea developed by the LIFE MARMONI project. 169 pp. (Estonian Marine Institute Report Series, No. 16). Available online: http://marmoni.balticseaportal.net

Scientific articles published:

Kotta, J., Orav-Kotta, H., Pärnoja, M. 2013. Role of physical water properties and environmental disturbances on the diversity of coastal macrophyte and invertebrate communities in a brackish water ecosystem". WIT Transaction on Ecology and the Environment, 77–88 pp.

Suursaar, Ü., Torn, K., Martin, G., Herkül, K., Kullas, T. 2014. Formation and species composition of stormcast beach wrack in the Gulf of Riga, Baltic Sea. Oceanologia 56 (4), 673–695 pp.

Uusitalo, L., Fleming-Lehtinen, V., Hällfors, H., Jaanus, A., Hällfors, S. & London, L. 2013. A novel approach for estimating phytoplankton biodiversity. - ICES Journal of Marine Science 70(2):408-417.

Detailed descriptions of all new monitoring methods, field work and modelling performed within MARMONI project

Wijkmark, N. (ed.) 2014. Field, Laboratory and Experimental Work within the MARMONI project – Report on Survey Results and Obtained Data. 242 pp. Available online: http://marmoni.balticseaportal.net

MSFD Marine Biodiversity Assessment Tool developed within the MARMONI project. Available online: http://www.sea.ee/marmoni/index.php

Manuscripts in preparation:

A manuscript by Saku Anttila, Vivi Fleming-Lehtinen, Jenni Attila, Sofia Junttila and Heidi Hällfors concerning indicator Cyanobacterial surface accumulations – the CSA-index.

Auniņš, A., Martin, G. (eds) 2015. Demonstration of biodiversity assessment in MARMONI Project areas.

A manuscript by Ieva Bārda, Bärbel Müller-Karulis and Iveta Jurgensone concerning the indicator Phytoplankton species assemblage clusters based on environmental factors

A manuscript by Elena Gorokhova, Maiju Lehtiniemi, Callis Amid, Jurate Lesutiene, Solvita Strake, Laura Uusitalo and Natalja Demereckiene concerning the indicator Copepod biomass

A manuscript by Elena Gorokhova, Maiju Lehtiniemi, Callis Amid, Jurate Lesutiene, Solvita Strake, Laura Uusitalo and Natalja Demereckiene concerning the indicator Microphagous mesozooplankton biomass

A manuscript by Elena Gorokhova, Maiju Lehtiniemi, Callis Amid, Jurate Lesutiene, Solvita Strake, Laura Uusitalo and Natalja Demereckiene concerning the indicator Zooplankton mean size vs. total stock (MSTS)

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A manuscript by Antti Lappalainen and Mika Kurkilahti concerning results of the power analysis of data on indicator Abundance of Cyprinids

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MARMONI project team in October 2012 on Tjärø Island, Sweden

MARMONI consortium

Baltic Environmental Forum Latvia (co-ordinating beneficiary)

Latvian Institute of Aquatic Ecology

Institute for Environmental Solutions (Latvia)

Latvian Fund for Nature

Nature Conservation Agency (Latvia)

Baltic Environmental Forum Estonia

Estonian Marine Institute, University of Tartu

Finnish Environment Institute (SYKE)

Finnish Game and Fisheries Research Institute

Swedish Environmental Protection Agency

Swedish Agency for Marine and Water Management

AquaBiota Water Research (Sweden)

Blekinge County Administrative Board (Sweden)

Skåne County Administrative Board (Sweden)

Lund University, Department of Biology (Sweden)

Latvian Ornithological Society

Estonian University of Life Sciences, Institute of Agricultural and Environmental Sciences

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