BONUS BIO-C3

Biodiversity changes: causes, consequences and management implications

Deliverable No: 5.3		Workpackage number and leader: 5, Piotr Margonski	
Date:	28.12.2017	Delivery due date: 31.12.2017	Month 48
Title:	Report on evaluation framework for holistic management – summary of the concept, requirements and management implications		
Lead partner for deliverable:		Piotr Margoński, National Marine Fisheries Research (P5, NMFRI)	
Other contributing partners		P1-2, P4, P6-12	
Authors		Piotr Margonski, Helén Andersson, Burkhard von Dewitz, Margit Eero, Hans-Harald Hinrichsen, Per Jonsson, Jonne Kotta, Fritz Köster, Maiju Lehtiniemi, Brian MacKenzie, Anne Lise Middelboe, Daniel Oesterwind, Henn Ojaveer, Helen Orav-Kotta, Thorsten Reusch, Henrik Skov, Monika Winder, Anastasija Zaiko, Ramounas Zydelis	
Margonski P., Andersson H., von Dewitz B., Eero M., Hinrichsen H.-H., Jonsson P., Kotta J., Köster F., Lehtiniemi M., MacKenzie B., Middelboe A.L., Oesterwind D., Ojaveer H., Orav-Kotta H., Reusch T., Skov H., Winder M., Zaiko A., Zydelis R. (2017) *Report on evaluation framework for holistic management – summary of the concept, requirements and management implications* BIO-C3 Deliverable, D5.3. EU BONUS BIO-C3, 43 pp. DOI: 10.3289/BIO-C3_D5.3.			
Dissemination level (PU=public, PP=Restricted, CO=confidential)			PU
Nature of the Deliverable (RE=Report, OT=Other)			RE

Acknowledgements

The research leading to these results is part of the BIO-C3 project and has received funding from BONUS, the joint Baltic Sea research and development programme (Art 185), funded jointly from the European Union's Seventh Programme for research, technological development and demonstration and from national funding institutions.

BIO-C3 overview

The importance of biodiversity for ecosystems on land has long been acknowledged. In contrast, its role for marine ecosystems has gained less research attention. The overarching aim of BIO-C3 is to address biodiversity changes, their causes, consequences and possible management implications for the Baltic Sea. Scientists from 7 European countries and 13 partner institutes are involved. Project coordinator is the GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany, assisted by DTU Aqua, National Institute of Aquatic Resources, Technical University of Denmark.

Why is Biodiversity important?

An estimated 130 animal and plant species go extinct every day. In 1992 the United Nations tried countering this process with the "Biodiversity Convention". It labeled biodiversity as worthy of preservation – at land as well as at sea. Biological variety should not only be preserved for ethical reasons: It also fulfils key ecosystem functions and provides ecosystem services. In the sea this includes healthy fish stocks, clear water without algal blooms but also the absorption of nutrients from agriculture.

Biodiversity and BIO-C3

To assess the role of biodiversity in marine ecosystems, BIO-C3 uses a natural laboratory: the Baltic Sea. The Baltic is perfectly suited since its species composition is very young, with current salt level persisting for only a few thousand years. It is also relatively species poor, and extinctions of residents or invasions of new species is therefore expected to have a more dramatic effect compared to species rich and presumably more stable ecosystems.

Moreover, human impacts on the Baltic ecosystem are larger than in most other sea regions, as this marginal sea is surrounded by densely populated areas. A further BIO-C3 focus is to predict and assess future anthropogenic impacts such as fishing and eutrophication, as well as changes related to global (climate) change using a suite of models.

If talking about biological variety, it is important to consider genetic diversity as well, a largely neglected issue. A central question is whether important organisms such as zooplankton and fish can cope or even adapt on contemporary time scales to changed environmental conditions anticipated under different global change scenarios.

BIO-C3 aims to increase understanding of both temporal changes in biodiversity - on all levels from genetic diversity to ecosystem composition - and of the environmental and anthropogenic pressures driving this change. For this purpose, we are able to exploit numerous long term data sets available from the project partners, including on fish stocks, plankton and benthos organisms as well as abiotic environmental conditions. Data series are extended and expanded through a network of Baltic cruises with the research vessels linked to the consortium, and complemented by extensive experimental, laboratory, and modeling work.

From science to management

The ultimate BIO-C3 goal is to use understanding of what happened in the past to predict what will happen in the future, under different climate projections and management scenarios: essential information for resource managers and politicians to decide on the course of actions to maintain and improve the biodiversity status of the Baltic Sea for future generations.

Table of Contents

I. Executive Summary

Due to its unique characteristics with substantial drainage area and limited water exchange with the North Sea, considerable salinity gradient, permanent stratification as well as a combination of numerous, strong anthropogenic and climatic pressures the Baltic Sea environment is under constant stress. Considering the intensity of exploitation and complexity of pressures of natural and anthropogenic origin as well as their cumulative effects, the Baltic Sea biodiversity has to be investigated and managed in a holistic and integrated way. Even if some of those pressures cannot be successfully managed especially in a short-term perspective, it is absolutely crucial to consider their impact in suggested management actions. The approach needs to be adaptive to handle relevant spatial and temporal scales as well as foreseen and unforeseen changes.

The goal of the BIO-C3 project was to move from the current "single driver/threat" approach to a science based, comprehensive, and integrated approach. In this report we are presenting data, monitoring, and knowledge requirements as well as assessment and analytical tools that are needed to establish a management evaluation framework for an adaptive, integrated management of biodiversity in the Baltic Sea.

A comprehensive analysis of various aspects of drivers and pressures on marine biodiversity has been provided and discussed including the assessment of the cumulative effects of multiple human pressures as their perceived impacts on the Baltic ecosystem are in most cases a combination of different human induced pressures and an isolated analysis of the impact(s) of single pressures remain extremely challenging or impossible. The recently suggested risk management process to entrench the cumulative effect assessments adequately handles the associated uncertainty and streamlines the uptake of scientific outcomes into the science-policy interface.

The Baltic Sea is very often regarded as a data rich area with one of the longest, internationally coordinated monitoring programmes, however, within our work we were able to identify several areas of considerable data and knowledge shortfalls. Genetic and molecular data as well as experimental data on thresholds and tolerances for extremes for key species might be just an example. An extensive knowledge gap analysis summarizing the entire BIO-C3 project experience has been also provided.

An important part of the BIO-C3 work was a selection and testing of indicators performance (including stability and sensitivity) based on the analysis of the comprehensive catalogue of biodiversity indicators, developed in collaboration with the recent DEVOTES project. Moreover, BIO-C3 project partners actively contributed in the HELCOM and ICES work focused on developing biodiversity indicators and assessment of the biodiversity status. Advantages and limitations of this work have been taken into account. The existing and newly developed knowledge on relevant biodiversity indicators and their response to management measures has been synthesized. The main aim of this exercise was to deliver a tangible advice for stakeholders on relevant data and monitoring needs for robust biodiversity assessment, recommend biodiversity indicators and candidates for targets and threshold values, that will contribute to the development of the evaluation framework for holistic management of the Baltic Sea ecosystem.

Marine protected areas (MPAs) are key tools in EUs efforts to protect biodiversity. Therefore, BIO-C3 put much emphasis on new modelling tools and showed examples and suggestions for their use in operational MPA management to identify optimal MPA network and management units on larger scale complemented with sub-basin studies to identify sink and source hotspots, and assess adequacy and connectivity of MPAs. An integrated genetic and biophysical modeling was used to identify present and future challenges to ensure persistent and resilient populations through efficient larval supply. Secondly, the consequences of reduced nutrient supply for mussel biomass and water birds were assessed pointing at the need for tools that can quantify effects through several trophic levels in order to achieve future synergies and compliance between WFD, MSFD and NATURA 2000 plans and ensure biodiversity conservation in the Baltic Sea.

The existing monitoring programs are collecting data to provide information for different kinds of scientific and management questions. Decision about the final spatio-temporal resolution of sampling design is always a compromise between ambitious plans and logistic and financial constrains. Knowledge on spatial and temporal dynamics of different groups of organisms is crucial in planning an appropriate sampling strategy. Furthermore, assessing observed inter-annual variability and trends is also important in this process. As part of a joint initiative of the BONUS INSPIRE and BIO-C3 projects, the group of zooplankton experts analysed the spatio-temporal variability of Baltic Sea zooplankton using historical data from various monitoring programs. In most cases, temporal variability in a certain location exceeded the synoptic spatial variability, and smaller, faster reproducing cladocerans varied more in abundance than larger, slower reproducing copepods. In conclusion, sampling has to be tailored both to the specific questions asked and also to characteristics and dynamics of analysed ecosystem component. In the future, results of this analysis should be used to optimize the sampling effort of zooplankton in the Baltic Sea.

Non-indigenous species (NIS) monitoring is aimed to address all biotic components as NIS may belong to any trophic level and be found in various man-made as well as natural habitats. Some observations (e.g. plankton and soft bottom macrofauna species) are obtained through the HELCOM biological monitoring programme, which initially was not targeting NIS but many new species are found during those surveys as well as scientific projects cruises. The well-established COMBINE monitoring programme, which has comprehensive quality control, is currently used for records of presence-absence of NIS in a given area, for certain taxonomic groups covered by the programme.

A centralized database is the key element of the integrated NIS monitoring and reporting system. The AquaNIS (the Information system on Aquatic Non-Indigenous and Cryptogenic Species) database, complemented by data from coordinated monitoring, has been agreed, for the time being, to be the data storage platform for the HELCOM holistic assessments. AquaNIS goal is to meet the requirements for assembling, storing and disseminating data compiled from various research projects and monitoring programmes, and to cover the most up-do-date and free-access information/data on NIS and introduction events within the Baltic Sea and other regions of the world.

Currently, a variety of targeted approaches and methods have been and are being developed, which may complement, and ultimately improve NIS monitoring. These include rapid assessment surveys, monitoring of MPAs, molecular methods, automated image analysis, public involvement (citizen science) and impact assessments. These and other emerging approaches should be considered for integration in the holistic NIS monitoring programme.

Several BIO-C3 tasks particularly focused on biodiversity changes as well as on potential adaptations under the expected ecosystem change. Considering an impact of climate change a number of data collection and existing monitoring design modifications have been suggested as e.g.:

- increase of spatial and temporal pH measurement coverage,
- an expected increase in dispersal distance in a future climate may call for revision in management units and MPA size,

- due to the climate change and eutrophication impacts on reproductive habitat of various marine organisms, monitoring and data collection of the distribution and abundance of key biota has to be continued or even expanded,
- biological monitoring should be accompanied by continued development of integrated climate-ocean-biogeochemical models of the Baltic Sea.

Finally, as currently the most advanced management framework is implemented in fisheries, we elaborate on lessons learned from related management systems and to what extent similar approaches are applicable when moving towards cross-sectorial management framework and evaluations, and which developments are required. Notably, comparable systems to assure systematic coordinated collection and evaluation of monitoring data for management purposes as in fisheries, are not in place concerning other ecosystem components or drivers. The fisheries example also demonstrates an increasing need for understanding biological processes, driver impacts and related interactions when moving from status assessments to projections and management measures, especially at changing ecosystems. To be able to suggest management actions also in biodiversity context, first of all identification and quantification of pressure-state links is required, which remains as one of the major scientific challenges ahead. Furthermore, synthesis and integration of results across various research disciplines and sectors, and ultimately their application in management is a challenge requiring a dedicated interdisciplinary long-term programme, which would include filling knowledge gaps involving cumulative impacts of various drivers and internal ecosystem dynamics.

II. Introduction

Biodiversity should be investigated in a holistic way considering the complexity of pressures of natural and anthropogenic origin as well as their cumulative effects. The goal of the BIO-C3 project was to move from the current “single driver/threat” approach to a science based, comprehensive, and integrated approach. In this report we outline data, monitoring, and knowledge requirements as well as assessment and analytical tools that are needed to establish a management evaluation framework for an adaptive, integrated management of biodiversity in the Baltic Sea (Fig. 2.1). The evaluation framework needs to be able to handle relevant spatial and temporal scales, which is a major challenge that can only be expected to be realized in an incremental process. The final concept of the framework was developed by all partners involved (P2, P4-P6 and P8) based on results from work conducted in WP1-5.

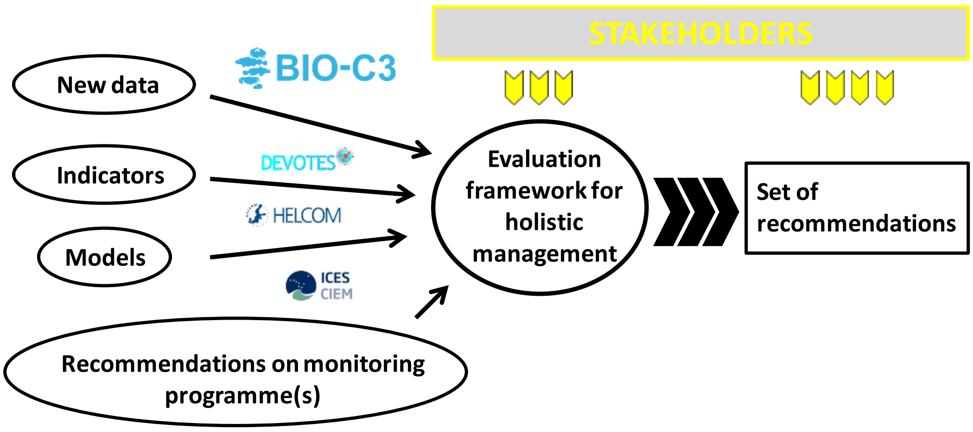

Fig. 2.1. Evaluation framework for holistic management and its recommendations

In several tasks of the BIO-C3 project we analyzed various aspects of drivers and pressures on marine biodiversity including their cumulative effects assessment as their impact is usually much more complex than a single pressure-response relationship. Although the Baltic Sea is regarded as a data rich area with one of the longest, internationally coordinated monitoring programmes, within our work we were able to identify several cases with considerable data and knowledge deficits. The latter was summarized in an extensive knowledge gap analysis across all the project activities. The selection of indicators was based on the analysis of the comprehensive catalogue of biodiversity indicators, developed in collaboration with the recent DEVOTES project (www.devotes-project.eu). Moreover, BIO-C3 project partners actively contributed in the HELCOM and ICES work focused on developing biodiversity indicators and assessment of the biodiversity status. Advantages and limitations of this work has been taken into account. Task 5.1 synthesized the existing and newly developed knowledge on relevant biodiversity indicators and their response to management measures. Marine protected areas (MPAs) are key tools in EUs effort to protect biodiversity, thus BIO-C3 put so much emphasis on new modelling tools and showed examples and suggestions for their use in operational MPA management to identify optimal MPA network and management units on larger scale complemented with sub-basin studies to identify sink and source hotspots, assess adequacy and connectivity of MPAs (Task 5.2). There were also several tasks especially focused on biodiversity changes as well as on potential adaptations under the expected ecosystem change. Finally, as currently the most advanced management framework is implemented in fisheries, we used here the fisheries example to elaborate on lessons learned from related management systems and to what extent similar approaches are applicable when moving towards cross-sectorial management framework and evaluations, and which developments are required (for details see the Chapter VII).

In summary, the report is presenting and discussing a comprehensive framework in terms of guidelines for monitoring revision to collect appropriate data, using recommended biodiversity indicators as well as modeling and assessment tools.

III. Knowledge gaps and new data needs

1. Summary of drivers and pressures including knowledge gaps related to the cumulative effects assessments (Daniel Oesterwind & Henn Ojaveer)

Due to its catchment area which includes 14 countries, about 85 million people and around 200 rivers (Ducrotoy & Elliot, 2008; Ojaveer et al, 2010; Helcom 2013) it is not surprising that several human based drivers and pressures exist in the Baltic. Furthermore the perceived impacts on the Baltic ecosystem are in most cases a combination of different human induced pressures and an isolated analysis of the impact(s) of single pressures remain extremely challenging or impossible. When starting to discuss drivers and pressures it should be taken into account that the usage of these terms is imprecisely and that a clear definition has to be made. Furthermore we recommend to embed these definition into the DPSIR framework to provide a comprehensive approach to understand and illustrate the linkages between the different terms and establish the causalities of the observed status changes in the ecosystem (Oesterwind et al. 2016). The DPSIR-Framework was initially developed to provide decision-makers with simplified knowledge of interacting social and political structures in the ecosystem (Patricio et al. 2014, Svarstad et al. 2008). Using the DPSIR framework prevent a communication problem or misunderstanding of scientific recommendations which could lead to uncertainty about which management option to choose and wrong conclusions, which might result in unpredicted consequences. A relevant bad example refers to introductions of non-indigenous species and communication of the invasion biology related research. The inconsistent usage of terminology in this field has evoked unnecessary ethical and political debates resulting from misunderstanding of scientific vocabulary by managers and politicians (Larson 2005). Therefore we appeal for a consistent agreement on the DPSIR terminology in order to communicate scientific results in a coherent way. Scientists and policymakers will benefit from the following proposed definitions by Oesterwind et al. (2016) due to the clear differentiation of manageable and unmanageable elements that facilitate a quick decision making process and advance the management strategies:

- A **DRIVER** is a superior complex phenomenon governing the direction of the ecosystem change, which could be both of human and nature origin.
- A **PRESSURE** is a result of a mechanism through which both natural and/or anthropogenic drivers have an effect on any part of an ecosystem that may alter the environmental state.
- A **STATE** is the actual condition of the ecosystem and its components established in a certain area at a specific time frame, that can be quantitatively-qualitatively described based on physical (e.g. temperature, light), biological (e.g. genetic-, species-, community-, habitat-levels), and chemical (e.g. nitrogen level, atmospheric gas concentration) characteristics.
- An **IMPACT** can be defined as consequences of environmental state change in terms of substantial environmental or socio-economic effects which can be both, positive or negative.
- A **RESPONSE** is all management actions seeking to reduce or prevent unwanted change in the ecosystem.

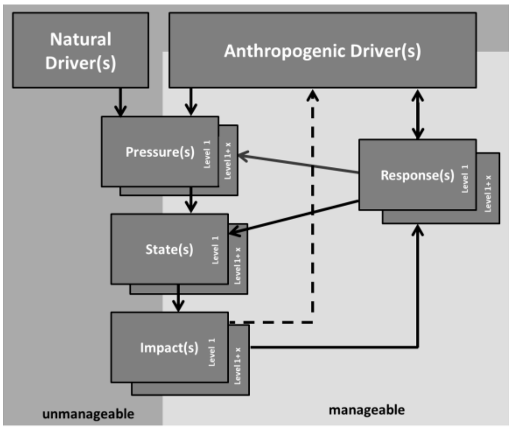

Figure 3.1.1. The Driving Force – Pressures – State – Impacts - Responses framework (DPSIR) modified after Gabrielsen and Bosch (2003). It is distinguished between anthropogenic and natural drivers which lead to manageable and unmanageable pressures, respectively (Oesterwind et al. 2016)

In general the Millennium Ecosystem Assessment (2005) gives a global overview about the most important drivers and pressures but mentioned that impacts and trends may be different in specific regions. In general fishing has been identified as the most important driver in the marine ecosystem within the last 5 decades while nutrient loading lead to ecosystem changes in terrestrial, limnic and coastal waters (MEAB, 2005). However, the Baltic Sea is a special ecosystem due to its brackish water, a restricted connection to the North Sea and its general small size. Therefore it can be assumed that the Baltic is highly impacted by various coastal drivers and pressures. Beside the following human induced pressures are a lot of additional pressures impacting the Baltic ecosystem like noise, marine litter for example which could not be dealt with due to different reasons. First the knowledge of the impacts on the flora and fauna is unknown or insufficient, on the other hand there was no expertise within the consortium. The following summary is not intended to be exhaustive, but it could be assumed that the most prominent and important human induced pressures were included. Furthermore there is a serious need to invest more research in the interaction and accumulation of different drivers, which were not dealt with here as well (for more information check the BONUS Bio-C3 Del3.1).

Introduction of non-Indigenous Species (NIS) is an important pressure in the Baltic Sea. 132 NIS and cryptogenic species, with in total of 440 introduction events have been documented in the Baltic Sea and were mainly caused by maritime transport (Ojaveer et al., 2017).

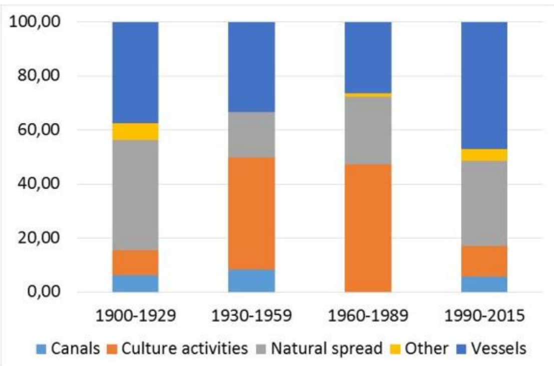

Figure 3.1.2. Relative importance of pathways (%) responsible for species invasions into the Baltic Sea over time (Ojaveer et al., 2017).

So far, all documented impacts are ecosystem and species-specific and have been and remain one of the major concerns associated with bioinvasions. Unfortunately, our current knowledge on bioinvasion impacts is very limited and insufficient for management actions (Ojaveer and Kotta 2015).
It should be recommended that research on ecological effects should be intensified. As per now, the relevant knowledge is very fragmentary and we lack critical information on even the most widespread (and potentially highly impacting) NIS in the Baltic Sea. Furthermore common, validated, routinely updated and free-access underlying information source (such as AquaNIS or similar) should be maintained. Amongst others, such an information source will serve both scientists, policymakers and managers.

In the Baltic Sea, **fishing** has been documented to have affected both the dynamics of target species as well the entire ecosystem structure and functioning (Casini et al. 2009; Möllmann et al. 2009). The present fishing impact and exploitation status of the main pelagic fisheries for sprat and herring are generally close to being in line with management targets but recruitment problems occur with herring, while fishing mortality for western Baltic cod is presently above the defined targets for maximum sustainable yield (ICES 2015a). For eastern Baltic cod the present exploitation status of the stock is unknown (ICES 2015b).

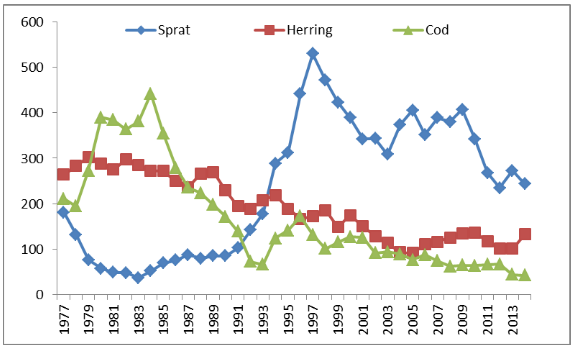

Figure 3.1.3. Landings of the major commercial fish species in the Baltic Sea, i.e. sprat, central Baltic herring and cod (eastern plus western) (data from ICES 2015).

The stock size of plaice in the Baltic Sea including the Kattegat has substantially increased in later years under stable or declining fishing pressure. Similarly, the stock size of flounders in the south-western Baltic Sea is increasing while the fishing pressure is estimate to be stable. However, an increasing fishing pressure and a declining stock size are identified for flounders in the eastern Baltic Sea. The harvest rate of salmon has decreased considerably since the beginning of the 1990s. Besides other factors, changes of fishing pressure depend on the fishing management, gear selectivity and fishing policy, for example. The Common Fisheries Policy has changed due to different reforms and regulations within the last decades. The last reform has been recently adopted and new regulations are implemented.

Climate change and oceanographic variables are important pressures in the Baltic as well. Sea surface temperatures in the Baltic Sea will increase slightly faster compared to the world oceans and exhibit also changes in seasonal and daily cycles. The increase however is not monotonic but shows a slight cooling between the 1930s and 1960s and a distinct warming period (more details HELCOM, 2013 & IPCC, 2014).
Beside the temperature the salinity conditions within the basins of the Baltic Sea with vertical stratification have various impacts on the environment e.g. on the reproduction of marine fish populations. All pelagic spawning species like cod, sprat and flounder need certain salinities for their buoyant eggs to stay above the sea floor. For the Baltic a reduction of salinity is predicted for

the next century caused by climate changes (Meier 2006). Consequences are a shift of the horohalinicum to the south and an increasing area of a salinity lower 7 which will affect species distribution and biodiversity (Vuorinen et al. 2015) of all taxonomic levels.

Impacts of ocean **acidification** on marine species do vary extensively between different classes of organisms, between closely related species and between life stages within the same species (Doney et al., 2009, 2012; Byrne, 2011).
Modelling approaches however indicate that a locally heterogenic pH decrease in deep waters of up to 0.5 pH units is most likely with the common scenarios of climate and nutrient loads developments within the next 60 to 100 years (Omstedt et al. 2012). However, due to the nature of climate models and their uncertainty together with the complex set of conditions triggering major Baltic sea inflows which then induce drastic changes to the water chemistry and characteristics of below halocline water and the mineralization and remineralization processes within unoxic or hypoxic waters which influences to the carbonate chemistry are poorly understood, the forecasting of the below halocline or near bottom acidification reaching further than a couple of years is uncertain to say the least. However, studies on *Mytilus edulis* from Thomsen et al. (2010) suggested that calcifying organisms are not generally negatively impacted. Additional results for larval growth, survival and calcifying ability partly support the theory that marine fish can also adapt to hypercapnia and acid stress. No significant negative effects were found, for example, on larvae of reef fish or for early life stages of Baltic cod (Munday et al, 2011; Frommel et al., 2012). On the other hand, data exists which suggests that Baltic Sea herring, living already in high variable pCO2 conditions, are still slightly affected by hypercapnia in their condition (RNA/DNA ratio, Franke & Clemmesen, 2011). The impact on species inhabiting the highly diverse pH-environment of the Baltic Sea is as yet only poorly understood. Impacts on primary producers, like the eelgrass *Zostera marina* and the planktonic community dominated by diatoms and cyanobacteria, are expected to be positive or absent concerning growth rates and population size (Riebesell et al., 2007; Hopkinson et al., 2011; Eklof et al., 2012).
There are no publications available to date investigating the impact of ocean acidification on zooplankton in the Baltic Sea by exposure to elevated pCO2 pressures in an experimental setup.

In addition, **nutrients or eutrophication** are also important human induced pressures. The bio-geochemical models show that nutrient concentrations have undergone major changes, involving significant enrichment followed by decreasing nutrient levels in some regions and habitats during 1970 – 2010. Nutrient concentrations increased up to the 1980s except for the Gulf of Finland, and nitrogen concentrations have declined in some areas, showing a high degree of spatial heterogeneity in the trends within the different regions of the Baltic Sea. In general, declining trends in nitrogen concentrations are seen in coastal waters shallower than 20 m. Within the more open waters and especially for the deeper basins trends are more variable. The declining trends in coastal areas are related to lower nutrient loads from land, while changes in the open waters are driven by changing volumes of hypoxia in the Baltic Proper which affect nutrient concentrations in bottom waters and subsequently in surface waters.

Marine ecosystems are increasingly threatened by the **cumulative effects of multiple human pressures.**

Cumulative effect is termed as aggregated, collective, accruing, and (or) combined changes to the environment that result from a combination of past, present and future human activities and natural processes. Cumulative effect can be:

i. additive (a combined effect produced by the action of two or more agents, being equal to the sum of their separate effects, i.e. the total impact is the sum of its parts);

ii. antagonistic (a combined effect produced by the action of two or more agents, being less than the sum of their separate effects);

iii. multiplicative (multiple activities have a total effect that is multiplicative and therefore larger than their sums);

iv. mitigative (some activities mitigate the effects of others and thus the total effect of multiple activities is lower than their sum);

v. synergistic (the interaction of two or more agents or actions so that their combined impact is greater than the sum of their individual impacts. Also, other impacts are included if their manners produce new impacts (Stelzenmüller et al., 2018).

The MSFD does not specifically address the cumulative effects as such nor the assessment of the cumulative effects. Article 13.3 of the MSFD makes reference to the impact assessments saying that Member States shall ensure that measures are cost-effective and technically feasible, and shall carry out impact assessments, including cost-benefit analyses, prior to the introduction of any new measure. Additionally, article 8.1 of the MSFD requires the initial assessments to include an analysis of the predominant pressures and impacts, including human activity, on the environmental status of marine waters that cover also the main cumulative and synergetic effects.

The global overview by Korpinen and Jespersen (2016), analyzing 40 recent marine cumulative pressures and impacts assessments with special focus on their methodological approaches, has identified several critical issues related to methodologies applied. These included, for instance i) spatial data on pressures (quantification of pressure, transforming and normalization of pressure, imprecise with regards to time of occurrence and duration), ii) linear relationship of pressure and impact, iii) insufficiency in validation of impacts, iv) potential accumulation of effects with time, v) historical impacts which already modified the environment, and vi) use of additive model.

However, cumulative effect assessments (CEA) are needed to inform environmental policy and guide ecosystem-based management. To better link CEAs to real-world management processes, entrenching CEAs in a risk management process was recently proposed. The process should be comprising the steps of risk identification, risk analysis and risk evaluation. The proposed risk-based approach to CEAs decreases complexity, adequately handles the associated uncertainty, allows for the transparent treatment of uncertainty and streamlines the uptake of scientific outcomes into the science-policy interface (Stelzenmüller et al., 2018). Thus, the proposed risk approach builds on the policy requirements and related management objectives – so it tries to help to focus on the ’components under threat due to combined pressures’. The next step in the process will be testing and selecting appropriate methodological approaches in data analysis and results interpretations, bridging thereby one of the major gaps between science and decision-making in ecosystem-based management.

2. Genetics and molecular data (Anastasija Zaiko & Thorsten Reusch)

In order to enable successful management of marine ecosystems, timely and robust scientific advice is required. It should inform managers and stakeholders on the magnitude of a pressure, the environmental state of an ecosystem, and the success of management response. Such advice often relies on the baseline biodiversity information. Conventional approaches to biodiversity surveillance require considerable taxonomic expertise, are laborious, and often fail to identify cryptic species or those at the larval stage (Zaiko et al. 2015). Additionally, the number of scientists working in the field of morphological taxonomy continues to decline, leading to considerable loss of taxonomical expertise worldwide (Hopkins and Freckleton 2002; Kim and Byrne 2006). As the result, the inconsistent, poorly resolved or biased biodiversity information can impede robust assessment of environmental state and timely, adequate managerial response to emerging ecological threats.

Recent technological development in molecular methods, allows utilizing a range of DNA/RNA-based techniques, for assessing biodiversity and improving resolution and precision of taxonomic identifications. These include end-point PCR-based amplification methods, Sanger sequencing, High-throughput sequencing (aka next-generation sequencing NGS), shotgun sequencing, etc. However, depending on the question addressed and biodiversity component targeted, applicability of these techniques has merits and limitations. The advantages and caveats of existing molecular methods need to be understood and weighed for the best suit-for-purpose method selection and correct interpretation of results derived by this method. Along with some existing caveats, there are avenues towards enhancement of these promising techniques and their successful uptake for improved marine monitoring and governance. To facilitate and encourage this uptake, there is a need for an international collaborative framework aimed at unifying molecular monitoring, sample processing and analysis methods. A focused research effort is also needed to address the major current gaps and knowledge uncertainties. For molecular methods to be applicable, it is also worth mentioning that species or operational taxonomic units need to be assigned as such and available in databases to allow for a sensible assessment and interpretation of high throughput molecular data.

Among molecular methods, metabarcoding is increasingly touted for application in marine biodiversity assessments as having a huge potential to provide more accurate and standardized, high-resolution taxonomic data on a range of taxa contained in environmental sample (water, sediments, biofilms, etc.). Metabarcoding allows taxonomical assignment of a specimen based on sequencing of a short standardised DNA fragment (molecular marker or barcode), across entire biotic assemblages (Ji et al. 2013). The recent development of High-Throughput Sequencing (HTS) offered massive sequencing depth, allowing multiple samples to be processed faster and more economically than traditional morphological approaches. This has the potential to revolutionize marine biology and environmental surveillance in particular. Metabarcoding can help detecting cryptic marine species, or those sparsely distributed or at early life stage, which identification can be difficult or impossible using microscopy. This is particularly important for non-indigenous species management and timely response to occurrence of new pests.

The biggest current limitation of metabarcoding application for environmental monitoring – is incompleteness of the reference sequence databases (Ratnasingham and Hebert 2007; Zaiko et al. 2015), this restricts robust taxonomic assignment of all taxonomic groups from an environmental sample. The use of multiple barcodes (and multiple databases) for biodiversity assessment from environmental samples could prevent some taxonomic groups from being misrecognized by individual markers (due to insufficient markers' resolution or incompleteness of reference data) and improve the number of retrieved species and overall taxonomic resolution of the assignment. However, to date, all databases remain incomplete and some taxonomic groups are underrepresented. Therefore, an operational reference database created cooperatively by the regional taxonomic and phylogenetic experts is highly recommended when using the metabarcoding approach as a tool for routine surveillance programs (Zaiko et al. 2015).

Ability to characterize comprehensive biodiversity from a small environmental sample using molecular approaches enables better research and consequently management opportunities in vulnerable habitats and ecosystems. However, currently there are no well-established or standardized sampling protocols or analytical guidelines for deriving molecular-based biodiversity information from environmental samples (both for multi- and single species detection assays). All empirical studies demonstrating their potential use are of rather local scale, not allowing for crossecosystem or cross-regional methodological comparisons and standardizations. Methods, used for acquiring environmental samples for conventional biodiversity assessments are not necessarily suitable and cross-applicable for molecular-based assessments, as do not account e.g. for the exceptional sensitivity of molecular assays and biased results due to contamination or “noise” signals from untargeted diversity. Therefore, development of standardized protocols and fit-for-purpose molecular biodiversity assessment guidelines is recommended before implementing the large scale molecular monitoring.

Handling of ever-increasing volumes of molecular data requires increased computational resources and analytical efforts. This affects the overall cost structure of a biodiversity research project and should be accounted for in the research planning and management process, by allocating larger budgets to the analysis component, comparing to traditional research where most of the cost is spent on experimental work and data generation (Sboner et al. 2011). In contrast, the costs for acquiring high throughput data will continue to decrease, owing to further drops in sequencing costs *per se*, and because more and more samples can be mutliplexed and handled semi-automatically within the same sequencing run. This puts additional emphasis on "brains"; i.e. people that are able to rapidly analyze data, and their education within academia.

Apart from biodiversity assessments and targeted species surveillance, gathering molecular data is advised for delivering genetic indicators for environmental status assessment and better understanding of functioning of marine populations. Thus, assessment of neutral genetic diversity is important for tracking population identity and population mixing, important for example, in tracking invasion routes (Reusch et al. 2010) or identifying distinct fish stocks (Nielsen et al. 2012). Addressing adaptive genetic diversity, would allow predictions if the genetic diversity that is prerequisite for adaptive evolution under global change is available (hereafter selection-based genetic indicators; see e.g. Nielsen et al. 2009). The latter however is more challenging because several intermediate steps need to be resolved. First, the link between genotype and phenotype of a particular relevant trait would need to be established. Second, a robust genotyping systems needs to be established and verified. Work in this direction is ongoing, in particular in selected fish species where full genome information plus several re-sequenced genomes are available, permitting to resolve the genotype-phenotype correlation (e.g. Hemmer-Hansen et al. 2013).

Genetically based markers of the "new" generation, i.e. those that are DNA-sequence based, are digital and hence, completely inter-calibrated over longer time scales of observation. Their acquisition will become cheaper and cheaper. The bottleneck at the moment is assigning function to their polymorphism. We envisage that functional knowledge will accumulate over the coming decades in many species and their important trails, so that it will become feasible to monitor the availability of adaptive variation via genetic indicators directly. Systematic collection of genetic information (with appropriate long-term sample storage for reference) would allow to monitor the availability of adaptive variation via genetic indicators directly, as the functional knowledge improves.

3. Call for experimental data on thresholds, tolerances and tolerances for extremes for key species (Monika Winder, Brian MacKenzie, and Piotr Margonski)

One of the BIO-C3 D4.3 tasks was to develop estimates of how the reproductive habitats for a numerous of species at different trophic levels and functional groups will change in the Baltic Sea under scenarios of climate change and eutrophication. It was based mostly on analyses of how combinations of temperature, salinity and oxygen concentration affect reproductive success. Then reproductive habitats dynamics were modeled according to selected scenarios.

Estimates of reproductive habitat size have been derived for a range of species in the Baltic Sea based partly on somewhat limited experimental data of the tolerances for reproduction considering ranges of temperature, salinity, and oxygen concentrations. During this work several knowledge gaps were identified:

- For some key species as e.g. *Saduria entomon* the reproductive requirements have never been experimentally investigated. *Saduria* plays an important role in benthic foodwebs in the Baltic Sea, both as a prey for higher trophic level species such as cod, and as a predator of other benthic animals. Its presence, abundance, and spatial distribution is frequently measured within various monitoring programmes and scientific projects but drivers controlling its spatial distribution have not been quantified. In *Saduria* case an alternative habitat modeling approach was implemented considering various environmental variables as depth, bottom temperature, bottom salinity, bottom oxygen concentration, organic matter content of sediments, bottom current stress, and ice coverage. Nevertheless, new experimental studies on the reproductive success of species playing major roles in Baltic foodwebs are necessary to fill this knowledge gap.
- Population-specific differences within species which could contribute to our understanding of e.g. their adaptation potential were usually not available and could not be directly accounted for. Our habitat estimates are most often based on physiological responses derived from typically only one local population within each species. They assume, therefore, that such responses apply to all local populations throughout the Baltic Sea. However, given the strong salinity and temperature gradients in the Baltic Sea it is possible that local populations may have different reproductive tolerances and thresholds. Consequently the role of intraspecific biodiversity on the habitat estimates is unclear and potentially can lead to an overestimate of the habitat loss that might occur with future climate and eutrophication scenarios. Presently, there are only few studies which have compared reproductive performance by different native populations throughout the Baltic Sea in a common-garden type experimental design. New studies considering and comparing multiple source populations are needed to investigate and quantify the levels of intraspecific adaptation. BIO-C3 delivered experimental data on thresholds, tolerances and adaptation potential for some key species, such as the calanoid copepod *Eurytemora affinis* tested on specimens collected from locations across the Baltic Sea and exposing them to different salinities and temperatures in common garden experiments.
- The extent of reproductive habitat loss may be reduced if species adjust behaviours or adapt to minimize physiological stress associated with the new conditions. For example, some species may alter their phenologies to spawn at other times of the year when e.g., temperature conditions might be suitable. This option may be feasible for those species where temperature is the main driver of habitat loss, instead of salinity or oxygen. However, even in such cases, a change in spawning time may increase other risks of mortality, e.g. due to increased exposure to predators or reduced exposure to sufficient food supplies.
- BIO-C3 modelling analyses revealed that changes in reproductive habitat as a response to foreseen changes is usually ecologically complex because in our case all species will be exposed to changes in three tested abiotic properties of their habitat (temperature, salinity and oxygen concentration). As a result a change in one variable which might be beneficial for its reproduction could be offset by a change in another variable which might have a negative effect. In addition, the shape of a given species functional response to a given variable may be quite different depending on the variable considered. In

consequence, a combined influences of changes in drivers need to be considered when estimating future habitat sizes and locations. The counteracting effects of changes in multiple variables on reproductive success were demonstrated for sprat. Baltic sprat eggs require a minimum of ca. 5-6 salinity (Ojaveer and Kalejs, 2010; Petereit et al., 2009) and 5^{o}C to hatch (Nissling, 2004). The expected changes in salinity (decrease) and temperature (increase) have therefore counter-acting effects on sprat egg hatch success. However, the expected range of future salinity in much of the Baltic will be below the minimum threshold for successful sprat egg development and hatching, whereas the increase in temperature has relatively small beneficial effects on sprat egg development because the future temperature is expected to be within a range where hatch success is relatively high and independent of temperature. As a result, the change in salinity dominates the change in size of sprat reproductive habitat, thereby leading to a large decrease in habitat that can support successful sprat egg development in the future Baltic Sea.

- Furthermore, BIO-C3 analyses draw attention to the necessity of testing and considering the interactive effects of salinity, temperature and oxygen concentration on reproductive success. Such effects have been demonstrated in some of the experimental studies from which we have extracted data and show that the sensitivity of metrics of reproductive success to a given environmental variable (e. g., salinity) also depend on a second variable (e. g. temperature). The implicit assumption that the abiotic factors are acting independently of each other means that the realized changes may differ in both magnitude and direction from those estimated.

4. Summary of the knowledge gaps and future research needs (WP & Task Leaders)

Various knowledge gaps and future research needs were identified by BIO-C3 workpackages and tasks. In summary, they might be grouped in several more-general categories described in details in the BIO-C3 Final Report:

1. **Biodiversity in general** including **indicators**
   - Improving baseline biodiversity information for all the Baltic Sea sub-regions including currently overlooked groups of organisms such as meiobenthos or microplankton.
   - A need for a comprehensive region-specific well-annotated biodiversity database.
   - Knowledge on predator-prey interactions is insufficient especially considering non-commercial species, in particular, in terms of their effects on the whole food web functioning.
   - Developing fit-to-purpose metabarcoding-based indicators addressing specific biodiversity components, ecosystem attributes, and pressures.
   - Identifying reference conditions and threshold values at sub-regional scale allowing for adaptive management in response to changing environment.
   - Refinement and validation of trait-based indicator framework.
   - Developing of the multi-trophic monitoring frameworks for holistic assessment of food web state and functioning.
   - Synthesis and integration of results across various research disciplines and sectors, and ultimately their application in management is a challenge requiring a dedicated interdisciplinary and in long-term viable programme.
2. **Data collection** including **genetic information**
   - Insufficient experimental data on thresholds and tolerances for extremes for key species.

- A need for experimental studies of reproductive success of key species in the Baltic Sea food web.
- Data collection has to be explicitly tailored to the specific questions asked and consider characteristics and dynamics of the ecosystem component under question.
- Lack of consistent monitoring programmes in some habitats, potentially vulnerable to arising and intensifying anthropogenic pressures, e.g. offshore reef habitats. As a result, their ecological status and trends of change are largely unknown impeding adaptive management in these areas.
- Monitoring system and management measures have to be adaptive as they need to consider the expected future change both in the human factor as well as in marine ecosystem.
- Systematic collection of genetic information to monitor availability of adaptive variation via genetic indicators.
- Numerous studies may considerably benefit from wider incorporation of genetic and molecular data.

3. **Impact of future climate**
   - Impact of future climate including Major Baltic Inflows (MBI) on food web structure and function is largely unknown especially on how it will influence species ability to adopt.
   - Various processes related to the impact of foreseen climate change are poorly understood e.g. regarding the sea level rise or haline structure.
   - Ecosystem will be more sensitive to extreme values thus there is a need to understand the future variability and extremes in key drivers.
   - There is an insufficient information on how ecosystem services will change in future.

4. **Non-indigenous and invasive species**
   - Ecological effects of NIS should be further investigated as one of the major research areas.
   - Identification of the specific donor areas.
   - Genotypic change over time for the key invasive species.
   - Identification of the most vulnerable key habitat forming species and areas that are in danger due to invaders.
   - Identification of NIS functional traits will increase our understanding of ecological consequences of invasions.
   - There is a need for an integrated and holistic NIS monitoring programme that should include variety of approaches, including rapid assessment surveys, monitoring of marine protected areas, molecular methods, automated image analysis, public involvement (citizen science) and impact assessments.

5. **Pressures**

- Impact of less known but potentially important pressures such as noise or marine litter.
- Spatial heterogeneity of different pressures is largely unknown.
- Clarifying and quantifying links between indicators and pressures including multi-pressure effects.
- The assessment of the cumulative effects of multiple human pressures has to be considered as an isolated analysis of the impact(s) of single pressures remain extremely challenging or even impossible.

6. **Improvement of models**

- Higher spatial resolution.

- Inclusion of missing transport processes in connectivity models is necessary.
- Uncertainty of important biological traits affecting dispersal as e.g. active migration.
- Validation against genetic data.
- Modelling may help to provide information where there is a lack of or insufficient monitoring.
- Temporal aspects of distribution modelling remained largely unstudied.
- Biological monitoring should be accompanied by further development of integrated climate-ocean-biogeochemical models to reduce uncertainties in model outputs and improve estimates of habitat sizes and locations.
- There is lack of knowledge about system response to stressors through various trophic levels.
- There is a need for modeling tools that can quantify effects through several trophic levels in order to achieve future synergies and compliance between WFD, MSFD and NATURA 2000 plans and ensure biodiversity conservation in the Baltic Sea.

IV. Indicators

1. Overview of the selection process (Anastasija Zaiko)

The success of management of marine resources is partially dependent on the availability of scientific tools to managers. Robust indicator selection, transparent use of information, and effective communication of results, awareness of potential caveats and emerging improvement opportunities constitute crucial parts of this process.

Selection of an appropriate indicator and clear understanding of all the caveats is often not a trivial task though. For example, in the recently compiled catalogue on indicators, there are over 600 biodiversity indicators listed for 4 regional seas (Teixeira et al. 2016). Many of those indicators have been developed and used in different world regions and their developmental stage varies (for more details see Zaiko et al. 2017).

Noticeably, nearly 200 indicators reported for the Baltic. This comparatively large number likely reflects overall governmental concern of environmental state in the region, as well as long-term history of biodiversity research.

The Baltic Sea indicators listed in the Catalogue (it is freely available through the DEVOTOOLS software, Teixeira et al. 2016), mostly cover 4 MSFD descriptors (D1: biological diversity, D2: non-indigenous species, D4: food webs, D6: seafloor integrity), although at varying numbers. All major biodiversity components (fish, macroalgae, birds, marine mammals, benthic invertebrates, angiosperms, zooplankton and phytoplankton) are well represented and there are operational indicators listed for all of them.

A set of indicators was selected from this extensive pool for testing their performance (including stability and sensitivity), within the framework of the BIO-C3 project. The main aim of this exercise was to deliver a tangible advice for stakeholders on relevant data and monitoring needs for robust biodiversity assessment, recommend biodiversity indicators and candidates for targets and threshold values, that will contribute to the development of the evaluation framework for holistic management of the Baltic Sea ecosystem.

A so-called "funnel approach“ (Figure 4.1.1) was followed for selecting and assessing the most relevant biodiversity indicators for addressing environmental management needs and based on their performance, actual and potential response to management activities. Their performance was tested in the course of case studies, modelling exercises and comprehensive literature reviews conducted within the BIO-C3 project.

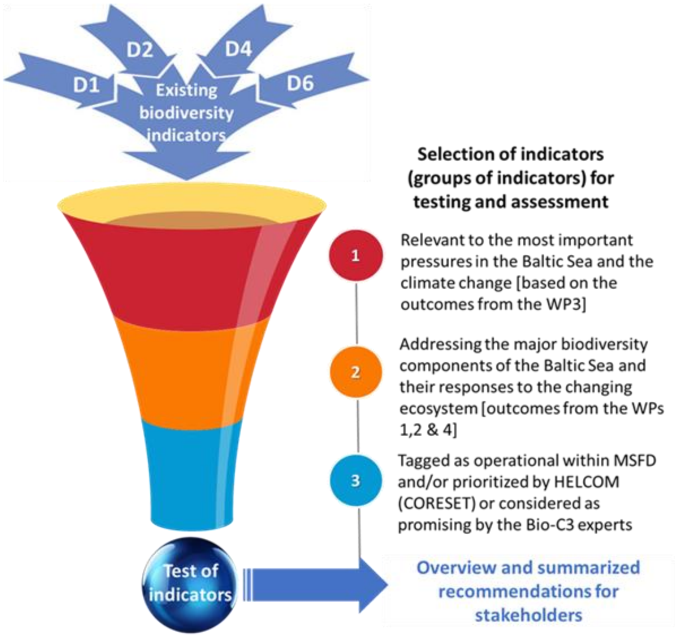

Figure 4.1.1. Conceptual scheme of selecting and prioritising indicators for testing within the Task 5.1 of the Bio-C3 project (Zaiko et al. 2017).

2. List of recommended indicators (Anastasija Zaiko)

The core activity of the indicator analysis has resulted in a series of comprehensive overviews on prioritized indicators (or group of indicators), scrutinized by the consortium in the course of case studies, modelling exercises and comprehensive literature reviews conducted within WPs 1, 2, 3 and 4 of the BIO-C3 project. These indicators were recommended for further consideration for the Baltic Sea monitoring programmes and included:

- Predator fish indicators
- NIS arrival indicators
- Benthic invertebrate indicators (e.g. Benthic Quality Index)
- Zooplankton indicators (e.g. Zooplankton Mean Size and Total Stock)
- Food web and phytoplankton indicators
- Trait-based and functional diversity indicators
- Metabarcoding-based indicators
- Genetic diversity indicators

Each of these overviews, besides from the general information on the current state of an indicator, its link to a particular pressure, data needs and potential constrains, contains information on the further improvement opportunities and summarized management advice, that can be easily translated to the stakeholders and decision-makers. For a detailed overview see the BIO-C3 Del5.1 report.

3. Summarized management advice (Anastasija Zaiko)

Some generalized advices to managers and stakeholders were derived from the results of indicators' assessment (see the BIO-C3 Del5.1 report). These included (but not limited to):

- Wider employment of ecosystem-based approaches in monitoring and environmental status assessment
- Development of adaptive and flexible monitoring frameworks
- Continued and consistent monitoring of all biodiversity components across Baltic sub-regions
- Uptake and further development of emerging molecular methods for routine monitoring (to address current uncertainties related to taxonomic resolution, etc.)
- Switching from simplistic biodiversity metrics towards complex, function-focused multi-trophic and condition-based indicators
- Work toward filling the existing gaps in knowledge on the synergetic effects of multiple pressures and relevant biodiversity response

V. Marine Protected Areas

BONUS BIO-C3 D5.2 presented new modelling tools for the design and assessment of ecologically coherent Marine Protected Areas (MPAs) networks. This work showed examples and suggestions for their use in operational management to identify optimal MPA networks with respect to connectivity as well as management units on the larger basin scale, complemented with sub-basin studies to identify sink and source hotspots and assessments of adequacy. An integrated genetic and biophysical modelling demonstrated how to identify present and future challenges to ensure persistent and resilient populations through efficient larval supply, with a call for adaptive management of MPAs. Finally, the consequences of reduced nutrient supply for mussel biomass and water birds were assessed pointing to the need for tools that can quantify effects through several trophic levels in order to achieve future synergies and compliance between WFD, MSFD and NATURA 2000 plans and ensure biodiversity conservation in the Baltic Sea.

1. **Connectivity (Anne Lise Middelboe, Hans-Harald Hinrichsen, Per Jonsson, Anastasija Zaiko)**

Our knowledge on connectivity is essential for ecosystem-based management and conservation strategies, e.g. for stock-separated management in fisheries. It is also crucial as a basis when designing the marine protected areas to maintain conservation features or population of exploited fish species. Furthermore, such knowledge is also helpful to assess the ecological coherence of MPA networks in terms of adequate MPA size and to identify important dispersal corridors and connectivity hubs.

MPAs are cornerstones in EUs effort to protect biodiversity. However, designation of MPAs is at present based on assessment of species and habitats within the individual potential MPAs and primarily seen from a national perspective. A wider, ecosystem-based approach to monitoring, status assessment and management require operational tools that can encompass the spatial and temporal complexity of the marine ecosystem. It is increasingly acknowledged that biophysical and biogeochemical ecosystem modelling approaches are the only feasible options to quantify complex interactions as connectivity across regional and local seas and effects of changes through trophic levels, and form the basis for state-of-tomorrows MPA management tools.

The distance and direction of dispersal have considerable influence on the demography and genetic structure of all populations. In marine benthic ecosystems, the connectivity of early life stages is generally crucial, since exchange during the adult stage may be limited, or in the case of sessile organism impossible. The mixing and exchange of individuals among habitats and populations is of particular importance from an ecological perspective, affecting e.g. species distribution ranges, species interaction, population dynamics, as well as the demographic and genetic structure of populations. Thus, our ability to understand and protect marine populations is linked to our knowledge about connectivity patterns and to our capability to use this knowledge in operational management decisions of MPAs at regional (basin-wide) and local scale (Gaines et al. 2003, Almany et al. 2009).

A BIO-C3 large scale connectivity study covering the entire Baltic Sea area indicated that there are large geographic differences within the Baltic Sea and a general trend towards shorter dispersal distances in the northern part compared to the western and central part. Mean patterns of dispersal rates for four selected subareas in the Baltic Sea, showed relatively high dispersal rates for the western and for the southern and central Baltic Sea. A study of temporal variability showed that many connectivity features across years are relatively consistent.

The other large-scale study simulated dispersal distance and connectivity in the whole HELCOM area. Dispersal distance varies considerably among areas and for different dispersal strategies with implications for local recruitment within and connectivity between MPAs in the HELCOM MPA network. Many MPAs seem too small for significant local recruitment. A novel framework to identify optimal MPA networks with regard to connectivity suggests that the HELCOM MPA network is reasonably well connected, although some gaps are identified, e.g. along the Swedish coast in the Gulf of Bothnia and Bothnian Bay, as well as along the Swedish coast between Stockholm and Öland. In those areas there is a potential for an extension of the present network.

The analysis of partial dispersal barriers (Fig. 5.1.1) indicates that there may be a few strong barriers that impede gene flow and facilitate local adaptations, and that there may be several areas that are sufficiently demographically independent to justify separate management units.

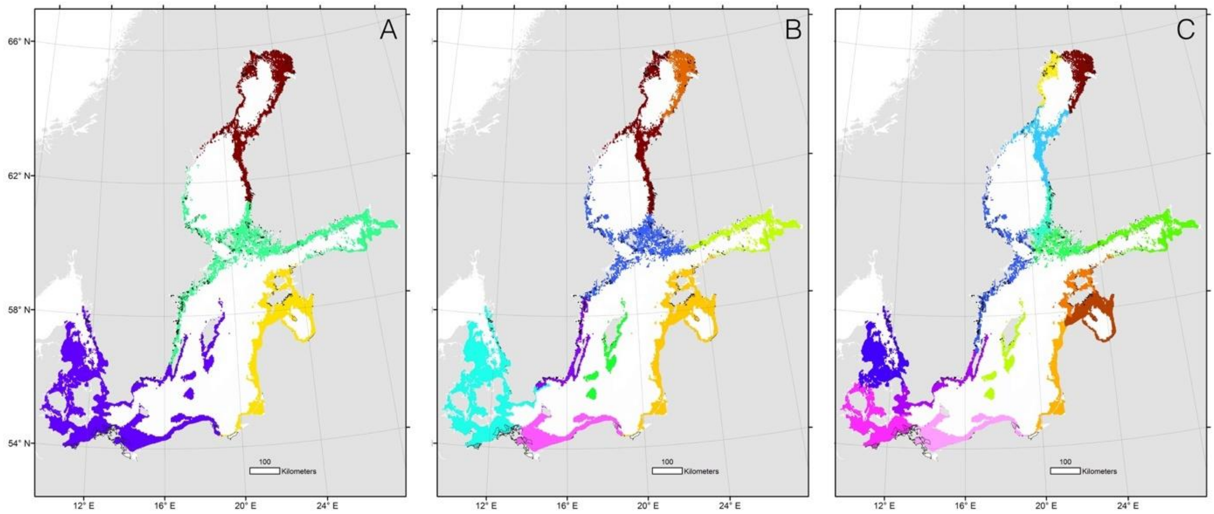

Fig. 5.1.1. Identification of dispersal barriers for a dispersal strategy similar to the blue mussel Mytilus spp. and a habitat specified by the depth interval 0-30 m. (A) Low allowed dispersal between areas producing 4 clusters. (B) Medium allowed dispersal between areas producing 9 clusters. (C) High allowed dispersal between areas producing 15 clusters.

The Gulf of Riga area is characterised by several internationally important bird protection areas and a series of habitat protection areas were chosen for several case studies. Studies of fine-scale dispersal patterns in Gulf of Riga area showed that source and sink hotspots were only partly included in the existing network of MPAs, and important hotspots were not protected. The study suggests that all MPAs in the area received larvae from other areas (sink) and provided larvae to other areas (source). Hotspot analysis together with information on pressures proved to be a useful tool as decision support to protect important source areas and thereby ensure efficient larval supply for maintaining the mussel populations in the Gulf of Riga area, and thus ensuring food availability for the wintering ducks, that occur in international important numbers in the area. Furthermore, in case of significant disturbance to local populations the degree of local retention and specific knowledge about source population is essential as basis for restoration decisions.

A study of the larvae movement using large (basin-wide) and fine-scale (Gulf of Riga area) connectivity modelling was carried out to calculate dispersal distances of larvae spawned in MPAs, the degrees of local retention and assess the optimal MPA network. As modelled based on the Gulf of Riga case study, local retention was strongly related to MPA size, but even small areas have some degree of local retention. In this case, using Mytilus larvae as model organisms, a MPA size of > 1000 km2 or a ratio between MPA radius (assuming a circular form) and average dispersal distance > 1.5 was predicted to ensure > 30% local retention. The larvae dispersal strategy was characterised by many larvae being transported relatively short distances (average 34 km).

Relationships between MPA size and dispersal distance of the organism may be used to estimate the adequacy of MPAs to ensure sufficient levels of local retention. Also, the probability distribution of dispersal distances may be used to evaluate the likelihood for genetically significant connectivity. The overall conclusion from the basin-wide exercise is that many MPAs within the HELCOM MPA network may be too small for significant local recruitment, but that there is good network connectivity, although connectivity may be enhanced in certain areas by adding strategically placed new sites (Fig. 5.1.2). The study shows that a combination of large- and fine-scale models are useful as decision support as they provide operational management tools.

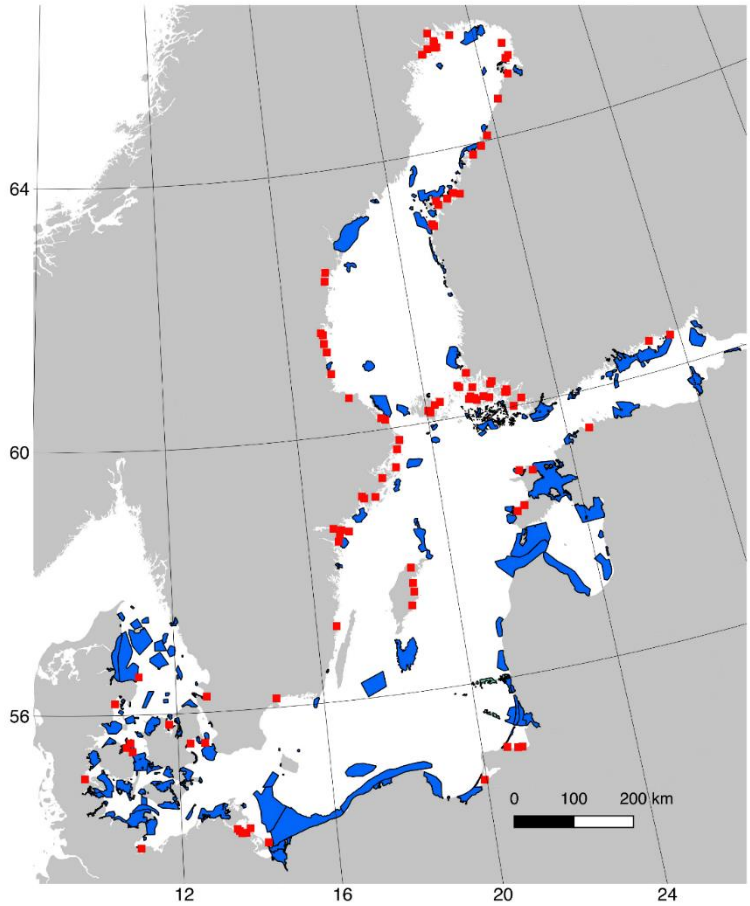

Fig. 5.1.2. Optimal extension (red squares) of the present HELCOM MPA network (blue polygons) based on a multi-species strategy.

Basically, the national and regional MPA networks designed earlier, did not take into account all the diversifying, intensifying and emerging pressures. Thus, protection of these valuable habitats and species may be compromised and allocation of current MPAs might need re-consideration to account for the rapidly changing environmental settings and potential implications for habitat connectivity. Based on the Lithuanian EEZ regional case study, it was exemplified how changes in the connectivity patterns and unprecedented impact of an invasive predator (round goby) can jeopardise the current and projected effectiveness of MPAs. This study was approached by applying tiered connectivity assessment based on gene flow analysis and hydrodynamic modelling, including climate projections for two emission scenarios. The lower local retention and reduced inter-reef connectivity, especially from offshore to coastal reefs, predicted by the climate-scenario model may call for larger MPAs, stronger protection of offshore reefs, and focusing more on selected locations, which is expected to maintain highest local retention. The current results are particularly alarming in the light of the continuing round goby impact on mussel reefs along the SE Baltic coasts. Loss of self-sustainable coastal populations and decrease of larval supply from southerly reefs can make the recovery of coastal mussel reefs impossible in the longer-term perspective. The absence of ongoing national monitoring at these habitats as well as absence of rapid response to biological invasions and mitigation plans impede adequate protection regime. The MPA status of the vulnerable reef habitats plays a controversial role here, restricting options for active response measures to the round goby expansion and largely serving as a 'no-take zone' for the thriving invasive species population. For improved governance of MPAs and marine ecosystems in general, we suggest considering an adaptive ecosystem-based management approach, allowing for flexible response to both continuous ecosystem dynamics and emerging environmental challenges. In the context of the current study, adaptive management would imply re-consideration of the current SE Baltic MPAs taking into account the future change scenarios and development of mitigation strategies for emerging and prospective risks, cascading from different pressures.

2. Productivity of the coastal ecosystems and food limitation (Ramounas Zydelis & Henrik Skov)

In the last decades, an important environmental targets for the WFD have been reducing loads of nitrogen and phosphorous to the marine environment, in order to reduce plankton dominance and improve oxygen conditions at the bottom (HELCOM, 2010). A possible consequence of the expected oligotrophication is a lower productivity in the marine ecosystem resulting in reduced biomasses of organism that feed on phytoplankton (assuming nutrient limited growth) as e.g. filter feeding mussels and the higher trophic levels as ducks feeding on mussels. To understand the full consequences of management decisions and be able to choose cost-efficient measures to improve the marine environment we need tools that can quantify the effect of bottom-up control on higher trophic levels.

A downscaled benthic food-web model for the Gulf of Riga (GoR) was applied in hindcast and forecast mode to study the past and future levels of nutrient control of the available food supply for higher trophic levels. The projected decline in *Mytilus* biomass was predicted to have a significant impact on the energetics of the Long-tailed Duck in terms of increased foraging effort and mortality. The predicted annual mortality of Long-tailed Ducks in the GoR at the end of the 21st century (60,000) in the Baltic Sea Action Plan (BSAP) scenario would lead to a significant decline in the number of Long-tailed Ducks in MPAs and the entire the Gulf. Adding 25% predation by round goby *Neogobius melanostomus* to the BSAP scenario lead to further reductions in the carrying capacity of the area for Long-tailed Ducks (Fig. 3).

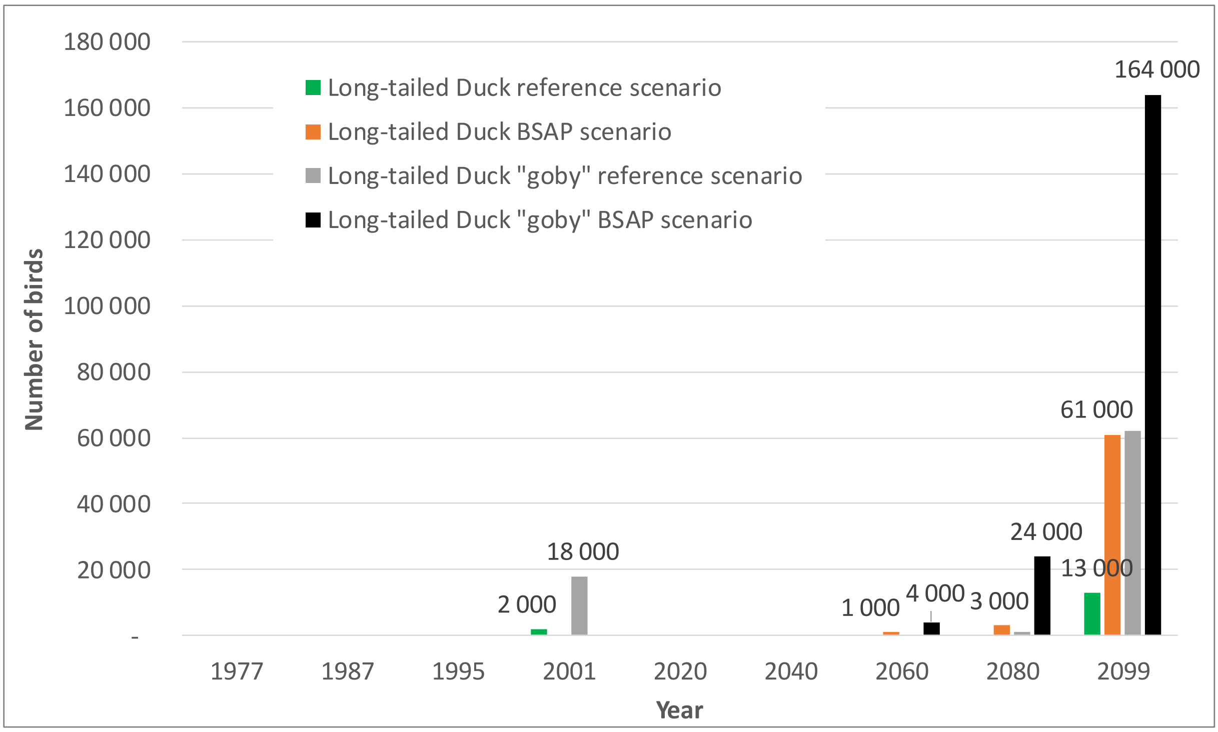

Fig. 3. Predicted mortality of Long-tailed Ducks due to starvation under different scenarios. "Reference scenario" – business as usual and condition of the Baltic Sea continues under the current state of nutrient input. "BSAP scenario" – if Baltic Sea Action Plan reducing nutrient input into the Baltic Sea is implemented. "Goby reference scenario" – "reference scenario" with additional predation by round gobies assuming that fish reduce bivalve biomass by 25% at depths below 15 meters. "Goby BSAP scenario" – "BSAP scenario" with additional predation by round gobies assuming that fish reduce bivalve biomass by 25% at depths below 15 meters

The model predictions indicated a severe knock-on effect of improved water quality management and reductions in nutrient (nitrate) concentrations driven by WFD goals, on the carrying capacity of the NATURA 2000 areas in the GoR, counteracting bird population goals for the protected areas. The range of predicted scenarios strongly suggests that with the implementation of the BSAP and the continued abundance of round gobies major challenges will be ahead in order to achieve synergies between targets for water quality and biodiversity conservation. The model predictions have been verified by significant recent declines in observed abundance of the two studied seaduck species in the GoR (Skov et al. 2011). Definitely, local ecosystem models like the presented one for the Gulf of Riga may provide useful decision support tools in order to achieve future synergies and compliance between the WFD, the MSFD and the NATURA 2000 plans and goals for water quality and biodiversity conservation in many coastal areas of the Baltic Sea.

VI. Revision of monitoring programme(s)

1. **An example of recommendations on spatial and temporal resolution (Piotr Margonski)**

The existing monitoring programs are collecting data to provide information for different kind of scientific and managerial questions. Decision about the final spatio-temporal resolution of sampling design is always a compromise between ambitious plans and logistic and financial constrains. Knowledge on spatial and temporal dynamics of different groups of organisms is absolutely crucial in planning an appropriate sampling strategy. It is also important to assess observed inter-annual variability and trends.

As initiated by the joint BONUS INSPIRE and BIO-C3 projects (Baltic Sea mesozooplankton study) the group of zooplankton experts analysed the spatio-temporal variability of Baltic Sea zooplankton using historical data from various monitoring programs (Klais et al. 2016). Analysed zooplankton data were collected between 1957 and 2012 within the nine institutional monitoring programs. The data covered three small lagoons or bays (Vistula Lagoon, Curonian Lagoon, Parnu Bay), one larger gulf (Gulf of Riga), and the northern, central and southern Baltic Proper.

Differently sized organism groups, i.e., small and large copepods and cladocerans were analysed in different hydrological regions. In most cases, temporal variability in one place exceeded the synoptic spatial variability, and smaller, faster reproducing cladocerans varied more in abundance than larger, slower reproducing copepods. The desirable sampling intervals detected were 20–23 days for copepods, and 2 weeks for cladocerans.

Conclusion: Sampling has to be tailored both to the specific questions asked and also characteristics and dynamics of analysed ecosystem component. In the future, results of this analysis should be used to optimize the sampling effort of zooplankton in the Baltic Sea.

2. **Recommendations for monitoring of non-indigenous species[1] (Henn Ojaveer, Maiju Lehtiniemi & Anastasija Zaiko)**

Ongoing monitoring approaches

Non-indigenous species (NIS) monitoring is aimed to address all biotic components as NIS may belong to any trophic level and be found in various man-made as well as natural habitats. NIS data is needed to update HELCOM core indicator and to report for EU Marine Strategy Framework Directive (MSFD; 2008/56/EC), EU Regulation on the prevention and management of the introduction and spread of invasive alien species (IAS Regulation; 2014/1143/EU) for those HELCOM countries being EU members, and to fulfill the data needs for exemptions from the Ballast Water Management Convention (BWMC; www.imo.org). There is currently no coordinated monitoring specifically targeting NIS in the Baltic Sea. Some observations (e.g. plankton and soft bottom macrofauna species) are obtained through the HELCOM biological monitoring programme, which initially was not targeting NIS but many new species are found during surveys and scientific projects. The well-established COMBINE monitoring programme, which has comprehensive quality control, is currently used for records of presence-absence of NIS in a given area, for certain taxonomic groups covered by the programme. However, while the HELCOM joint programme itself is far from sufficient both temporally and spatially (fixed sampling stations) to obtain the required

[1] The contribution is further advancing the following document: HELCOM 2017. Outcome of STATE & CONSERVATION 5-2016, para. 5J.4. Working Group on the State of the Environment and Conservation. Sopot, Poland, 23-27 October 2017 (Title: HELCOM NIS monitoring programme in the introduction of the Monitoring Manual). Further explanation: three BIO-C3 partner institutes (P06-EMI-UT, P07-SYKE, and P08-KU) prepared the respective draft document for HELCOM.

information on NIS, there are certainly several elements which are very useful to exploit for NIS monitoring purposes.

In addition to joint monitoring programme, HELCOM coastal fish gill-net monitoring and BITS surveys provide information on NIS presence-absence, spread and abundance/biomass. During such surveys, non-indigenous fish and mobile epifauna (e.g. crabs) can be caught and such records should be made available for the national authority responsible for managing NIS records.

The only targeted method to monitor NIS is the HELCOM/OSPAR Port survey protocol, which provides information on NIS found in ports to support decisions on granting exemptions. The protocol is a part of the "Joint HELCOM/OSPAR Guidelines on the granting of exemptions under the International Convention for the Control and Management of Ships' Ballast Water and Sediments, Regulation A-4". The protocol has been tested in several ports around the Baltic Sea, is regularly updated and ready for routine use. Information obtained during port surveys (available on-line) should also be used to complete NIS assessments for HELCOM and the MSFD (D2) reporting purposes for those HELCOM countries being EU members.

A centralized database is the key element of the integrated NIS monitoring and reporting system. Thus AquaNIS (the Information system on Aquatic Non-Indigenous and Cryptogenic Species) database, complemented by data from coordinated monitoring, has been agreed, for the time being, to be the data storage platform for the HELCOM holistic assessments. AquaNIS goal is to meet the requirements for assembling, storing and disseminating data compiled from various research projects and monitoring programmes, and to cover the most up-do-date and free-access information/data on NIS and introduction events within the Baltic Sea and other regions of the world.

Prospective monitoring approaches

A variety of targeted approaches and methods have been and are being developed, which may complement, and ultimately improve NIS monitoring. These include rapid assessment surveys, monitoring of Marine Protected Areas, molecular methods, automated image analysis, public involvement (citizen science) and impact assessments. These and other emerging approaches should be considered for integration in the holistic NIS monitoring programme.

Rapid assessment survey

A rapid assessment survey (RAS) is a method to detect species that can be recognized in the wild from conspicuous morphological characteristics and whose abundance and distribution can be determined for a particular area. RAS may be part of a regular monitoring program and may also be activated following a particular NIS event, e.g. a report of a NIS finding, requiring confirmation for management actions to take place. Target lists of NIS reduce sampling effort, over full inventories of biota present, and are more relevant for a swift management response. One approach to select NIS for a RAS is to follow IMO definition of target species: "…Species identified by a Party that meet specific criteria indicating that they may impair or damage the environment, human health, property or resources and are defined for a specific port, State or biogeographic region…" (www.imo.org/en/KnowledgeCentre/.../Marine.../MEPC.162(56).pdf). However, not all NIS may be easily recognized in the field and further systematic examination in laboratory may be required. This, in turn, may essentially increase time needed to obtain RAS results.

Extended Rapid Assessment Survey (eRAS) monitoring of NIS, as one method in a larger framework of methods for monitoring of NIS was endorsed for publication in the HELCOM Monitoring Manual by State & Conservation 6-2017 (Outcome of State & Conservation 6-2017, para 5J.3). It is not limited to target species but includes specific habitats in hotspot areas for NIS introduction e.g. ports, marinas, aquaculture spots, artificial hard substrates. eRAS may be arranged simultaneously by several countries within the Baltic Sea, in the same way as it is done for fishery surveys. The RAS method is cost-efficient and may provide timely information for managers and policy-advisers focusing on particular NIS at particular localities.

Monitoring of Marine Protected Areas

A Marine Protected Areas (MPAs) observation program has been successfully used to identify occurrences of NIS around the UK coast (Stebbing et al. 2014). This approach could be useful in the Baltic Sea region as well. In UK a standard list of NIS was compiled against which, infauna and epifaunal data records from the MPAs were compared and reported to the appropriate national authorities. Within MPAs monitoring programmes a series of conventional and novel methods of surveillance are likely to become part of a protocol, and their potential use for detection of NIS should be considered.

The list of target species for monitoring should be revised regularly to allow adaptive management strategies in response to emerging incursions. The species to be ultimately considered for monitoring in MPAs at present are the round goby Neogobius melanostomus and the Harris mud crab Rhithropanopeus harrisii, which are likely to compromise the management objectives in MPAs. For both species, efficient monitoring methods and sampling design needs to be developed. In addition to traps, SCUBA diving and visual observations might be needed.

Molecular methods

Molecular methods are rapidly evolving and may readily become established within monitoring protocols. Such methods will be helpful in multiple purposes: early detection, determining marine NIS identities, determining source and routes of invasions, and the genetic make-up of founding populations. Molecular methods can also be used for the rapid identification of target species (e.g. cholera bacteria relevant for e.g. BWMC exemption surveys in ports) and generalized screening for established and new NIS from environmental samples (water, sediments, biofilms, ballast water). Molecular methods are particularly useful for NIS detection at early life-history stages (due to difficulties in their identifications), at initial stages of invasions, and when occurring at low densities.

As the major pathway for new NIS introductions into the Baltic Sea is maritime transport, it might make sense to complement the port biological survey protocol with molecular methods, which will allow early detection of new NIS at early stages of invasion (i.e. at low population size). However, for efficient embracing of these advantageous techniques, a comprehensive and up-to-date molecular reference database is needed. This can be achieved by populating the existing global databases (e.g. NCBI, BOLD, PR2) with the region-specific references for native diversity and NIS, or developing a well-annotated Baltic Sea focused database.

Automated image analysis

Another rapidly developing approaches are automated systems, which may pick up unfamiliar biological shapes. Such in-situ continuous monitoring capacity initially images aliquots of sea water and rejects images of low-risk objects. A managed web-based image database may be developed that acts as a repository for images of identified NIS, together with metadata reflecting the scale of the object, its location, depth and date of image collection, and collector. Currently, these methods may be used for abundance and biomass estimates of already known NIS in the sample which are identifiable by automatic image analysis.

Public involvement

Public involvement can aid in detection of certain easily identifiable NIS. Divers, anglers, leisure craft users, students and schoolchildren may help tracking the spread of NIS. Volunteers (citizen scientists) may look for a restricted number of species, and the data can be used to identify range expansions. Partnerships with the aquaculture, fisheries and leisure craft industries may enable early detection of NIS arrivals. The advent of electronic communication facilitates the usage of online websites in reporting NIS observations. Websites also aid in providing up-to-date information on identification, distribution and means of preventing further spread.

Public involvement in NIS monitoring requires setup of appropriate dataportals nationally where new findings are reported and species identities are verified (to avoid misidentifications). International cooperation regionally is inevitable, as the required taxonomic expertise might be not readily available in national institutes and to share first detection information.

Monitoring mobile epifauna

There is no monitoring programme for mobile epifauna. Two benthic NIS (round goby and the Harris mud crab) are currently highly invasive, but we even lack reliable information on spatial spread on these species. There are however suitable methods (baited traps and habitat traps) in the port survey protocol which should be tested also in natural habitats and very likely, some gear development is necessary before starting monitoring. Detection of mobile fauna can be aided by molecular (eDNA/eRNA based) techniques as well. Also different approaches to data treatment and analyses should be used, potentially requiring switching from traditional accounting (abundance-focused) techniques to occupancy-based methods.

Monitoring the spatial spread

To be able for HELCOM countries being EU members to meet the requirements of the most recent amendment of the MSFD (2017/845/EU) and the Commission Decision on criteria and methodological standards on good environmental status of marine waters (2017/848/EC), spatial spread of NIS needs to be monitored. As HELCOM monitoring programme is relying on sampling at fixed stations, a taxon-specific approach needs to be applied in order to obtain information on presently spreading NIS. Also, underwater habitat surveys, which are being conducted in many Baltic Sea countries, may provide information on the spread of conspicuous NIS such as mobile epifauna (e.g. crabs) and habitat engineers, e.g. zebra mussels. Unmanned and preprogrammed underwater vehicles may make video surveys on extensive areas of seabed at comparatively low overall cost.

The fixed station approach could be refined by using a risk-based approach focusing on potential hotspots with varying temporal intensity. This would facilitate early detection and help to identify pathways in order to meet the demands of the IAS regulation. However, the fixed station approach does not meet the requirement of the new Commission Decision (2017/848/EC) to evaluate ’the spatial extent of the broad habitat type which is adversely altered due to non-indigenous species’.

Evaluation of impacts

Monitoring data obtained with the above described approaches can be applied for the assessment of impacts of NIS, for developing target species list of NIS, and reporting for several legislative acts. As our mechanistic and process-based understanding of NIS impacts on various features of marine ecosystems is still very poor and concerns only a limited number of species, fundamental research (incl. controlled laboratory/field experiments) efforts should be encouraged to widen our knowledge base essentially for the most invasive or currently spreading NIS. However, of vital importance is knowledge about the expected impacts of newly established species exhibiting some signs of invasive potential (e.g. successful establishment and local spread). This could help informing targeted and focused management response. As in addition to environmental impacts, NIS may also cause impacts on human health, ecosystem services and economy, these elements should be added to the impacts evaluation framework.

3. **Climate change consideration (how to adapt to the foreseen changes in terms of data collection and monitoring design) (Helén Andersson, Burkhard von Dewitz, Per Jonsson, Jonne Kotta, Brian MacKenzie, Helen Orav-Kotta, Monika Winder & Piotr Margonski)**

As summarized in BIO-C3 D3.4 report the expected climate change will further put pressure on the already stressed Baltic Sea marine environment. Regional projections of global IPCC climate scenarios indicate that there will be significant changes in water temperature, surface and bottom salinity, ice coverage, oxygen levels and acidification. The nutrient loads from land might increase due to increased precipitation and river runoff. This will influence various changes in marine habitats with clear consequences for different life stages of species representing all foodweb levels. The foreseen changes may also give habitat advantages to non-native species, which also will impact the current ecosystem structure and functioning. Although sea surface temperature in the Baltic Sea is expected to increase slightly faster compared to the world oceans, the most influential driver remains Major Baltic Inflows (BIO-C3 D3.1). Inflows not only change hydrological conditions but also influence bio-chemical and biological processes. Inflow events are causing an increase in salinity and oxygen, a decrease or increase in temperature and usually a decrease in acidification. Climate change will impact the patterns of precipitation and a subsequent reduction of salinity is predicted in the Baltic Sea area for the next century (Meier 2006).

Data collection and existing monitoring design has to be modified to match potential severe impacts of climate change:

- Spatial and temporal coverage of in situ pH measurements are highly heterogeneous. Relatively good coverage was found in regularly assessed areas like the Bornholm Basin or the Gotland Basin but data e.g. for the Gdansk Deep showed substantial gaps with missing data. For the period before 1990 the temporal data coverage was so poor that the missing value reconstruction procedure was not possible. **Increasing the spatial and temporal pH measurement coverage is strongly recommended**.
- On average future circulation is expected to lead to longer dispersal distances and this effect is strongest in the southern Baltic Sea (BIO-C3 D3.3). The effect of increasing sea surface temperature was also assessed and indicates that the resulting acceleration of larval development partly counteract the circulation-based increase in dispersal distance. However, this effect is rather weak in the southern Baltic Sea. **The increase in dispersal distance in a future climate may call for revision in management units and MPA size**. It will affect local retention and connectivity between sub-basins in the Baltic Sea. Generally, the local retention is expected to decrease while export to other sub-basins may increase. This may increase stock mixing and also the spread of non-native species.
- Climate change and eutrophication impacts on reproductive habitat of various marine organisms (BIO-C3 D4.3). A key prerequisite for the continued presence or the potential for new species to become established is whether they will be able to reproduce under the probable abiotic conditions in future. It is likely that temperature, salinity and oxygen conditions are going to change systematically during the 21st century. As a result some species could suffer while others benefit as the abiotic conditions progressively changes during the coming decades. Our results show that many key species will experience conditions which can potentially lead to major decreases or increases in reproductive success. As a consequence, species distributions will have to change, or pressure for adaptation to the changing conditions will increase. **Therefore, It is also recommended that monitoring and data collection should be continued and expanded for the distribution and abundance of key biota.** Regular and frequent observations are needed to detect changes,

to enable attribution of such changes to changes in potential drivers and to compare with and validate models of habitat and abundance dynamics. **Biological monitoring should be accompanied by continued development of integrated climate-ocean-biogeochemical models of the Baltic Sea** to reduce uncertainties in model outputs and improve estimates of habitat sizes and locations.

- BIO-C3 study suggested that wide environmental tolerance of a species does not necessarily result in a wide realized niche in the course of an invasion process (BIO-C3 D4.3). Our results also suggested that colonization success and wide distribution do not necessarily require a broad environmental niche of the colonizer, but may instead rely on the saturation of the recipient ecosystem and an ability to optimally utilize previously under-occupied environmental niche. **For more detailed recommendations on non-indigenous species monitoring see the Chapter VI.2**.

VII. Stakeholder’s consultations on biodiversity management tools

1. **Workshop of the eight BONUS projects focusing on climate change, nutrients, biodiversity and social and economic analysis, 6 November 2017, Stockholm, Sweden (Thorsten Reusch)**

Upon the initiative of the HELCOM Secretariat, a workshop to present the results of the eight BONUS projects focusing on climate change, nutrients, biodiversity and social and economic analysis was held on 6 November 2017 in Stockholm, Sweden, hosted by the Baltic Nest Institute.

The workshop was attended by the representatives of the BONUS projects, the Chairs of HELCOM Pressure and State and Conservation working groups, the BONUS and HELCOM Secretariats. BIO-C3 was represented at the meeting by the project Coordinator.

After projects presentations an overarching context to evaluate the results and their relevance for HELCOM work were discussed. HELCOM-BONUS projects joint document has been prepared to i) start informing the management level in the Contracting Parties of new scientific results, ii) consider next opportunities for knowledge exchange between HELCOM and BONUS projects, iii) support in general the envisaged Ministerial Meeting (March 2018, in Brussels) outcomes.

Based on the HELCOM-BONUS projects joint document the overarching conclusions include the following statements:

- Climate-change impacts such as warmer temperatures, changed biogeochemical processes and more river-run off can intensify the symptoms of eutrophication.
- Provided that the BSAP is fully implemented it would lead to improved Baltic Sea water quality, even under the worst climate change scenario.
- Changes in salinity, temperature and oxygen concentration will reduce available habitat sizes for successful reproduction in many fish species.
- Profound changes in zooplankton community were recorded at the deep-water stations of the southern Baltic Sea.
- Significant impacts of hydrological parameters and climatic forcing are to be expected on pelagic food-web structure and dynamics. This in turn will affect how the Baltic Sea provides goods and services such as food, clean water and employment to society.
- Identified the need to consider the functional properties of biodiversity, i.e. what do organisms do rather than to what species they belong.
- The functional traits approach may better reflect our human needs and impacts on the marine ecosystem, compared to traditional taxonomical ones.
- The functional properties are more robust, but over time function will also change, providing indications of how the ecosystem may be developing under given large-scale impacts of e.g. climate change.
- For environmental protection measures to be effective, it is vital to not only designate specific sites as marine protected areas, but also to be aware of and understand aspects of connectivity both within and between areas.
- BIO-C3 project can suggest some specific connectivity improvements for the existing HELCOM-MPA/N2000 network.
- Adequacy, measured as local retention, is generally acceptable in the HELCOM-MPA network but fails in many N2000 areas.

2. BIO-C3 webinars for stakeholders (Piotr Margonski)

Two BIO-C3 stakeholder's consultations on biodiversity management tools were organized on October 31st and November 10th. During those webinar conferences several presentations were provided and discussed:

- Short into to the BIO-C3 project goals (Piotr Margonski)
- Knowledge gaps and new data needs (Monika Winder and Piotr Margonski)
- Biodiversity indicators (Anastasija Zaiko, presented by Piotr Margonski)
- Modelling tools for management of the Baltic Sea: Large and fine-scale connectivity patterns used for MPA assessments (Anne Lise Middelboe and Per Jonsson)
- Benthic ecosystem dynamics in the coastal parts of the Baltic Sea (Henrik Skov and Anne Lise Middelboe)

In both webinars six stakeholders representing several organizations participated:

- Ingela Isaksson, County Administrative Board, Västra Götaland
- Sally Clink, Baltic Sea Advisory Council
- Ivo Bobsien, State Agency for Agriculture, Environment and Rural Areas Schleswig-Holstein (LLUR)
- Katarzyna Kaminska, Department of Fisheries, Ministry of Maritime Economy and Inland Navigation, Poland
- Claus Reedtz Sparrevohn, Danish Pelagic Producer Organisation (DPPO)
- Monika Zakrzewska, Maritime Office in Gdynia

After the meeting, presentations were distributed also to those who expressed their interests but were not able to participate in web conferences.

There was a vivid discussion, after presentations, mostly focus on results of MPA modeling analyses in two main aspects: connectivity issues and the resulting MPA network to secure it and on carrying capacity of coastal ecosystems and the foreseen consequences of reduced nutrient loads as a base for the productivity of the entire foodweb including upper trophic levels. Both aspects have significant consequences for various coastal stakeholder groups including fishermen but are also important in the process of Marine Spatial Planning negotiations. BIO-C3 team was invited to give presentations on MPA connectivity at the PanBalticScope project kickoff meeting that is planned in April/May, most probably in Denmark. We were invited to informally discuss presented issues with Nils Höglund, Chair of the BSAC Sub-group on ecosystem based management at the BSAC Executive Committee meeting.

It was agreed that the final report will be distributed among all interested stakeholders once it is accepted by the BONUS Secretariat.

VIII. Holistic management: concepts, knowledge requirements, tools. A fisheries management perspective (Margit Eero & Fritz Köster)

Biodiversity in the Baltic Sea is influenced by a number of drivers and pressures including those related to eutrophication, pollution, resource extraction, noise, introduction of non-indigenous species, constructions, climate change etc., addressed in detail in BIO-C3 WP3 (D3.1; D3.2). All of these drivers and related pressures have impacts on the ecosystem components and functioning, while the degree by which these can be controlled by management actions and at what time scales is largely different. Natural processes and interactions occurring in the ecosystem can only be partly and indirectly influenced by management measures, but related impacts influence the outcome of any management actions, and would thus need to be considered in holistic management evaluation frameworks covering wider aspects of the ecosystems, including biodiversity. Among the major drivers on the Baltic ecosystem, most advanced management frameworks are in place regarding fisheries. Therefore, we use here the fisheries example to elaborate on lessons learned from related management systems and to what extent similar approaches are applicable when moving towards cross-sectorial management framework and evaluations, and which developments are required.

An essential step in the management process is assessing the current status (Figure 8.1), where data collection and monitoring provide the underlying basis. Sampling, quality assurance and handling of data for fisheries management purposes, specifically for providing catch advice, are internationally coordinated through EU Data Collection Framework (DCF) and a number of expert groups within ICES addressing both commercial fisheries data and research surveys (e.g. ICES Planning Group on Commercial Catches, Discards and Biological Sampling (PGCCDBS), ICES Working Group on Data Needs for Assessments and Advice (PGDATA), Baltic International Fish Survey Working Group (WGBIFS)). Also, Regional Coordination Meetings (RCM) take place, to coordinate the fisheries data collection carried out by EU Members States. Comparable systems to assure systematic coordinated collection and evaluation of monitoring data for management purposes are not in place concerning other ecosystem components or drivers, besides fisheries (see chapters III, VI). Thus, a direct link between which data are needed to address specific management questions in biodiversity context and which data are collected through monitoring programs, is in many cases not present.

The underlying monitoring data defines available input to conducting assessments of the current status of the ecosystems or its individual components. In case of fish, for many species and stocks the assessments are based on quantitative modelling, where the purposely collected monitoring data are directly used as input. In these assessments, process understanding or knowledge on causal links is generally not used or required as models are parameterized in adequate time steps. This implies that parameters which are not being regularly monitored (e.g. mortality due to natural causes), are assumed constant over time. However, the recent developments with the eastern Baltic cod (BIO-C3 D2.1, D2.2, D4.2 D5.1) have demonstrated, that when ecosystem conditions are changing, e.g. due to climate change, assumptions of stable states do not hold. This creates higher demands for monitoring as well, as assuming parameters remaining constant over time can falsify the assessment outcome (Eero et al. 2015). Generally, rapid changes in ecosystems require a higher degree of process understanding to be able to adequately assess the current status and attempt projection of future development.

For most components of the ecosystems, assessments using analytical quantitative modelling tools are not possible, and the assessment is therefore based on selected indicators (BIO-C3 D5.1). The HELCOM overview of the state of the Baltic Sea (http://stateofthebalticsea.helcom.fi/biodiversity-and-its-status/) includes an indicator-based assessment of biodiversity. However, datasets available from regular monitoring set also the stage, which time series are possible to use as indicators for assessment purposes. Further, the assessments need to be conducted relative to pre-defined reference levels defining good or bad status, to be useful for management purposes. As demonstrated in the examples in BIO-C3 (D 5.1), substantial process knowledge is required for setting meaningful reference levels for the indicators. Also, the management process involves forecasting the future developments, which requires understanding of the driver impacts and interactions in the ecosystem, to be reliable. Therefore, the need for understanding biological processes, driver impacts and related interactions is generally increasing when moving from status assessments to projections and actual management (Figure 8.1). While assessments can in many cases be conducted simply based on time series obtained directly from monitoring, being able to recommend management measures, which are most appropriate at a given ecosystem setup requires understanding the processes and mechanisms behind.

Figure 8.1. Schematic illustration of the steps included in the management process and the increasing need of process understanding along these steps.

One of the most frequently used management tools for protecting biodiversity is closed areas, such as MPAs (BIO-C3 D5.2). Spatio-temporal measures are also applied in single-driver management context, i.e. in fisheries. The spawning closures applied for cod fisheries in the Baltic Sea can be used as an example in this context, being at the interface between moving from highly quantitative fisheries management frameworks related to catch advice toward a more holistic ecosystem and biodiversity management, which needs to consider a multitude of combinations of drivers and processes. In contrast to the straightforward link between the total catch and remaining biomass in the sea, which is the core of traditional fisheries quota management, the effects of spatio-temporal closures on fish, as well as on other components of the ecosystem, can involve a variety of mechanisms. For fish, closures can achieve greater reproductive output, have positive effects on stock structure and reduce evolutionary effects of fishing (van Overzee and Rijnsdorp, 2015 and references therein). Clear understanding of the mechanism how a management measure is expected to benefit the ecosystem or a stock, is required for its appropriate design, to ensure its effectiveness and avoid potentially counter-productive effects.

An attempt to evaluate the effects of the established spawning closures on Baltic cod (Eero et al. submitted) revealed that for several aspects, the present data and knowledge is insufficient for drawing firm conclusions of the effectiveness of these closures, and through which mechanism these potentially benefit the stocks and thus the ecosystem state. Amongst others, it became obvious that evaluating the effects of closures as a management measure requires different types of data and knowledge than routinely collected for fisheries management purposes, focusing on fishing quotas. It would require, for example, spatially and temporally resolved data on early life stage production and survival, as well as knowledge on behaviour and physiology of the fish. Such information is today solely produced via scientific programs, which are generally decoupled from monitoring for management needs, implying that the information is often not sufficient or tailored to the purpose of evaluating management measures.

From fisheries management perspective, the current status in terms of knowledge and tools as well as some critical steps needed can be outlined in the following points:

We have:

- Long-term institutional knowledge
- Long time series
- Undigitized data & unprocessed samples
- Process knowledge on various species & life stages
- Progress in observation technology & molecular biology
- Development of advanced modelling tools

We need a combination of:

- Empirical analyses
- Controlled laboratory experiments
- Appropriately scaled field experiments
- Process modelling
- Integration into mechanistic and analytical model environments

This requires:

- Sustained funding for process research
- Utilizing knowledge across geographical areas & species
- Enhanced cooperation with other research areas
- Integrated regional monitoring systems
- Access to samples, data & information to all users

The complexities and knowledge gaps encountered in evaluating a management measure directed towards a single driver (i.e. fisheries) to enhance a single ecosystem component (i.e. a fish stock), represented by the example of Baltic cod closures, indicates that when moving to a more holistic ecosystem and biodiversity management, the level of complexity and data and process understanding needs will increase substantially. The more holistic integrated approaches so far applied for the Baltic Sea covering different ecosystem components, also in the context of biodiversity, are largely focused on status assessments, e.g. HELCOM Holistic Assessment for the State of the Baltic Sea, ICES Integrated Assessments of the Baltic Sea ecosystems (WGIAB). The subsequent steps towards management recommendations and evaluations are lagging behind, likely due to the complexities and insufficient process understanding and knowledge base. To be able to suggest management actions, which could or should be taken in response to the observed ecosystem status requires first of all identification and quantification of pressure-state links of biodiversity indicators, which remains as one of the major scientific challenges ahead (see section III of this report).

Knowledge on Baltic Sea ecosystem functioning has grown exponentially, not least through the targeted efforts of the BONUS program (Snoeijs-Leijonmalm et al. 2017). BIO-C3 has substantially moved forward the knowledge and understanding of the Baltic ecosystem concerning driver impacts, food web dynamics under changing biodiversity as well as relationships between biodiversity and ecosystem functioning. However, significant knowledge gaps are still remaining (e.g. coastal-offshore and pelagic-benthic coupling, role of invasive species and predicting food web dynamics under global and regional anthropogenic change, etc). Furthermore, synthesis and integration of results across various research disciplines and sectors, and ultimately their application in management is a challenge requiring a dedicated interdisciplinary long-term programme, which would include filling knowledge gaps involving cumulative impacts of various drivers and internal ecosystem dynamics. Based on the advancements of BIO-C3 and its sister projects, BONUS Synthesis projects are expected to outline next steps to achieve better integration and uptake of available knowledge in management frameworks.

References

Almany GR, Connolly SR, Heath DD, Hogan JD, Jones GP, McCook LJ, Mills M, Pressey RL, Williamson DH (2009) Connectivity, biodiversity conservation and the design of marine reserve networks for coral reefs. Coral Reefs 28:339-351.

Byrne, M. 2011. Impact of ocean warming and ocean acidification on marine invertebrate life history stages: Vulnerabilities and potential for persistence in a changing ocean, Pages 1-42 in R. N. Gibson, R. J. A. Atkinson, and J. D. M. Gordon, eds. Oceanography and Marine Biology: an Annual Review, Vol 49. Oceanography and Marine Biology. Boca Raton, Crc Press-Taylor & Francis Group.

Casini, M., J. Hjelm, J. C. Molinero, J. Lövgren, M. Cardinale,V. Bartolino, A. Belgrano, and G. Kornilovs. 2009. Trophic cascades promote threshold-like shifts in pelagic marine ecosystems. Proceedings of the National Academy of Sciences USA 106:197–202.

Doney, S. C., V. J. Fabry, R. A. Feely, and J. A. Kleypas, 2009. Ocean Acidification: The Other CO2 Problem, Pages 169-192 Annual Review of Marine Science. Annual Review of Marine Science. Palo Alto, Annual Reviews.

Doney, S. C., M. Ruckelshaus, J. E. Duffy, J. P. Barry, F. Chan, C. A. English, H. M. Galindo et al., 2012. Climate Change Impacts on Marine Ecosystems. Annual Review of Marine Science, Vol 4 4:11-37.

Eero, M., Hjelm, J., Behrens, J.,Buchmann, K., Cardinale, M., Casini, M.,Gasyukov, P., Holmgren, N.,Horbowy, J.,Hüssy, K., Kirkegaard, E., Kornilovs, G., Krumme, U., Köster, F. W., Oeberst, R., Plikshs, M., Radtke, K., Raid, T., Schmidt, J., Tomczak, M. T., Vinther, M., Zimmermann, C., and Storr-Paulsen, M. 2015. Eastern Baltic cod in distress: biological changes and challenges for stock assessment. ICES Journal of Marine Science, 72: 2180-2186

Eklof, J. S., C. Alsterberg, J. N. Havenhand, K. Sundback, H. L. Wood, and L. Gamfeldt, 2012. Experimental climate change weakens the insurance effect of biodiversity. Ecology Letters 15:864-872.

Franke, A., and C. Clemmesen, 2011. Effect of ocean acidification on early life stages of Atlantic herring (Clupea harengus L.). Biogeosciences 8:3697-3707.

Frommel, A., A. Schubert, U. Piatkowski, and C. Clemmesen, 2012. Egg and early larval stages of Baltic cod, Gadus morhua , are robust to high levels of ocean acidification. Marine Biology:1-10.

Gaines SD, Gaylord B, Largier JL (2003) Avoiding current oversights in marine reserve design. Ecological Applications 13:S32-S46.

Hopkins, G.W., Freckleton, R.P., 2002. Declines in the numbers of amateur and professional taxonomists: implications for conservation. Anim. Conserv. 5: 245–249.

HELCOM, 2013b. Climate change in the Baltic Sea Area: HELCOM thematic assessment in 2013. Balt. Sea Environ. Proc. No. 137.

Hopkinson, B. M., C. L. Dupont, A. E. Allen, and F. M. M. Morel, 2011. Efficiency of the CO2-concentrating mechanism of diatoms. Proceedings of the National Academy of Sciences of the United States of America 108:3830-3837.

ICES, 2015a. ICES Advice 2015, Book 8.

ICES, 2015b. Report of the Baltic Fisheries Assessment Working Group (WGBFAS), 14–21 April 2015 ICES HQ. ICES DocumentCM2015/ACOM: 10. Copenhagen, Denmark.

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Ji, Y., Ashton, L., Pedley, S.M., Edwards, D.P., Tang, Y., Nakamura, A., Kitching, R., Dolman, P.M., Woodcock, P., Edwards, F.A., Larsen, T.H., Hsu, W.W., Benedick, S., Hamer, K.C., Wilcove, D.S., Bruce, C., Wang, X., Levi, T., Lott, M., Emerson, B.C., Yu, D.W., 2013. Reliable, verifiable and efficient monitoring of biodiversity via metabarcoding. Ecol. Lett. 16: 1245–1257.

Kim, K.C., Byrne, L.B., 2006. Biodiversity loss and the taxonomic bottleneck: emergingbiodiversity science. Ecol. Res. 21: 794–810.

Klais R., Lehtiniemi M., Rubene G., Semenova A., Margonski P., Ikauniece A., Simm M., Põllumäe A., Grinienė E., Mäkinen K., Ojaveer H. 2016. Spatial and temporal variability of zooplankton in a temperate semi-enclosed sea: implications for monitoring design and long-term studies. Journal of Plankton Research, 38 (3): 652-661, DOI: 10.1093/plankt/fbw022

Korpinen, S. and Andersen, JH. 2016. A Global Review of Cumulative Pressure and Impact Assessments in Marine Environments. Front. Mar. Sci. 3:153. doi: 10.3389/fmars.2016.00153

Larson B.M.H., 2005. The war of the roses: demilitarizing invasion biology. Front. Ecol. Environ. 3(9): 495-500.

MEAB, 2005. Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Meier, H.E.M., 2006. Baltic Sea climate in the late twenty-first century: a dynamical downscaling approach using two global models and two emission scenarios Climate Dynamics, 27 (1) 39–68 http://dx.doi.org/10.1007/s00382-006-0124-x

Möllmann, C., R. Diekmann, B. Müller-Karulis, G. Kornilovs, M. Plikshs, and P. Axe, 2009. Reorganization of a large marine ecosystem due to atmospheric and anthropogenic pressure: a discontinuous regime shift in the Central BalticbSea. Global Change Biology 15:1377–1393.

Munday, P. L., M. Gagliano, J. M. Donelson, D. L. Dixson, and S. R. Thorrold, 2011. Ocean acidification does not affect the early life history development of a tropical marine fish. Marine Ecology-Progress Series 423:211-221.

Nielsen E.E., Cariani A., Aoidh E.M., Maes G.E., Milano I., Ogden R., Taylor M., Hemmer-Hansen J., Babbucci M., Bargelloni L., Bekkevold D., Diopere E., Grenfell L., Helyar S., Limborg M.T., Martinsohn J.T., McEwing R., Panitz F., Patarnello T., Tinti F., Van Houdt J.K.J., Volckaert F.A.M., Waples R.S., Carvalho G.R. 2012. Gene-associated markers provide tools for tackling illegal fishing and false eco-certification. Nat Commun 3: 851.

Nielsen E.E., Hemmer-Hansen J., Larsen P.F., Bekkevold D. 2009. Population genomics of marine fishes: identifying adaptive variation in space and time. Molecular Ecology 18: 3128-3150.

Nissling, A. 2004. Effects of temperature on egg and larval survival of cod (*Gadus morhua*) and sprat (*Sprattus sprattus*) in the Baltic Sea - implications for stock development. Hydrobiologia, 514: 115–123.

Oesterwind, D., Dewitz, B. v., Döring, R., Eero, M., Goti, L., Kotta, J., Nurske, K., Ojaveer, H., Rau, A., Skov, H., Stepputtis, D. and Zaiko, A. (2016) Review on patterns and dynamics of drivers of biodiversity (species, communities, habitats) across Baltic Sea ecosystems in space and time including socio-economy . BIO-C3 Deliverable, D3.1, 102 pp. DOI 10.3289/BIO-C3_D3.1

Oesterwind, D., Rau, A., Zaiko, A., 2016. Drivers and pressures – untangling the terms commonly used in marine science and policy. Journal of Environmental Management, 181: 8 – 15. doi: 10.1016/j.jenvman.2016.05.058

Ojaveer, E., and Kalejs, M. 2010. Ecology and long-term forecasting of sprat (*Sprattus sprattus balticus*) stock in the Baltic Sea: a review. Reviews in Fish Biology and Fisheries, 20: 203–217.

Ojaveer, H. and Kotta, J., 2015. Ecosystem impacts of the widespread non-indigenous species in the Baltic Sea: literature survey evidences major limitations in knowledge. Hydrobiologia, 750: 171−185.

Ojaveer, H., Olenin, S., Narščius, A., Ezhova, E., Florin, A.B., Gollasch, S., Jensen, K.R., Lehtiniemi, M., Normant-Saremba, M. and Strāke, S. (2017). Dynamics of biological invasions and pathways over time: a case study of a temperate coastal sea. Biological Invasions, 19 (3), 799−813.

Omstedt, A. and Edman, M. and Claremar, B. and Frodin, P. and Gustafsson, E. and Humborg, C. and Hagg, H. and Morth, M. and Rutgersson, A. and Schurgers, G. and Smith, B. and Wallstedt, T. and Yurova, A, 2012. Future changes in the Baltic Sea acid-base (pH) and oxygen balances. Tellus Series B-Chemical and Physical Meteorology 64: 0280-6509. doi: 10.3402/tellusb.v64i0.19586.

van Overzee, H.M.J, and Rijnsdorp, A.D. 2015. Effects of fishing during the spawning period: implications for sustainable management. Reviews in Fish Biology and Fisheries, 25: 65–83.

Patricio, J., Teixeira, H., Borja, A., Elliott, M., Berg, T., Papadopoulou, N., Smith, C., Uusitalo, L., Wilson, C., Mazik, K., Niquil, N., Cochrane, S., Andersen, J.H., Boyes, S., Burdon, D., Carugati, L., Danovaro, R., Hoepffner, N., 2014a. DEVOTES recommendations for the implementation of the Marine Strategy Framework Directive. DEVOTES Deliverable 1.5, 198pp. DEVOTES FP7 Project. JRC90864.

Petereit, C., Hinrichsen, H. H., Voss, R., Kraus, G., Freese, M., and Clemmesen, C. 2009. The influence of different salinity conditions on egg buoyancy and development and yolk sac larval survival and morphometric traits of Baltic Sea sprat (*Sprattus sprattus balticus* Schneider). Scientia Marina, 73: 59–72. ISI:000271157200006.

Ratnasingham, S., Hebert, P.D.N., 2007. BOLD: the barcode of life data system (www.Barcodinglife.org). Mol. Ecol. Notes 7: 355–364.

Reusch T.B.H., Bolte S., Sparwel M., Moss A., Javidpour J. 2010. Microsatellites reveal origin and genetic diversity of Eurasian invasions by one of the world's most notorious marine invader, *Mnemiopsis leidyi* (Ctenophora). Mol Ecol 19:2690–2699

Riebesell, U., K. G. Schulz, R. G. J. Bellerby, M. Botros, P. Fritsche, M. Meyerhofer, C. Neill et al., 2007. Enhanced biological carbon consumption in a high CO2 ocean. Nature 450:545-U510.

Sboner A, Mu XJ, Greenbaum D, Auerbach RK, Gerstein MB (2011) The real cost of sequencing: higher than you think! Genome Biology 12: 125.

Snoeijs-Leijonmalm, P., Barnard, S., Elliott, M., Andrusaitis, A., Kononen, K., Sirola, M. 2017. Towards better integration of environmental science in society: Lessons from BONUS, the joint Baltic Sea environmental research and development programme. Environmental Science and Policy, 78: 193–209.

Stebbing, P., Murray, J., Whomersley, P. and Tidbury, H. 2014. Monitoring and surveillance for non-indigenous species in UK marine waters. Centre for Environment, Fisheries & Aquaculture Science. Lowestoft, UK. 46 pp.

Stelzenmuller, V., Coll, M., Mazaris, A. D., Giakoumi, S., Katsanevakis, S., Portman, M. E., Degen, R., et al. 2018. A risk-based approach to cumulative effect assessments for marine management. Science of the Total Environment, 612: 1132-1140.

Svarstad, H., Petersen, L.K., Rothman, D., Siepel, H., Wätzold, F., 2008. Discursive Biases of the Environmental Research Framework DPSIR, Land Use Policy. 25 (1), 116-125.

Teixeira H., Berg T., Uusitalo L., Fürhaupter K., Heiskanen A.-S., Mazik K., Lynam C.P., Neville S., Rodriguez J.G., Papadopoulou N., Moncheva S., Churilova T., Kryvenko O., Krause-Jensen D., Zaiko A., Verissimo H., Pantazi M., Carvalho S., Patricio J., Uyarra M.C., Borja A. 2016. A catalogue of marine biodiversity indicators. Frontiers in Marine Science 3: Article207.

Thomsen, J., M. A. Gutowska, J. Saphorster, A. Heinemann, K. Trubenbach, J. Fietzke, C. Hiebenthal et al. 2010. Calcifying invertebrates succeed in a naturally CO2-rich coastal habitat but are threatened by high levels of future acidification. Biogeosciences 7:3879-3891.

Vuorinen, I., Hänninen, J., Rajasilta, M., Laine, P., Eklund, J., Montesino-Pouzols, F., Corona, F., Junker, K., Meier, H.E.M., Dippner, J.W., 2015. Scenario simulations of future salinity and eco-logical consequences in the Baltic Sea and adjacent North Sea areas-implications for environmen-tal monitoring. Ecological Indicators, 50, 196-205.

Zaiko A., Calkiewicz J., Eero M., von Dorrien C., Kuosa H., Klais R., Lehtiniemi M., Margonski P., Oesterwind D., Ojaveer H., Rau A., Reusch T., Törnroos A., Warzocha J., Winder M. 2017. Response of biodiversity indicators to management measures (test of indicators) BIO-C3 Deliverable, D5.1. EU BONUS BIO-C3, 50 pp., with Appendices.

Zaiko A., Samuiloviene A., Ardura A., Garcia-Vazquez E. 2015. Metabarcoding approach for nonindigenous species surveillance in marine coastal waters. Marine Pollution Bulletin 100: 53-59.