BONUS BIO-C3 Final report (01.01.2014 – 31.12.2017)

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BONUS BIO-C3 PROJECT (01/01/2014 - 31/12/2017)
Final publishable summary, 1 March 2018

Goals and results envisaged at the beginning of the project cycle

The goal of BONUS BIO-C3 was to investigate the **causes and consequences of changes in biodiversity on all its biological scales –** genetic, taxonomic, functional, habitat and ecosystem diversity – in the Baltic Sea system. We wanted to **move away from a static to a dynamic system view** incorporating environmental change as well as the potential for species acclimation and adaptation, and to thus provide an **improved scientific basis for resource management in a changing world**. Essential features of the Baltic are low species diversity, many recent arrivals of non-indigenous species, presence of glacial relict species, and simple food webs that nevertheless sustain goods and services of high economic and societal value. Our specific interest was to assess effects of biodiversity changes on ecosystem function, food web dynamics, productivity, and implications for environmental management in this system. Key objectives were to i) investigate the relative roles of acclimation, adaptation and colonization of native vs. non-indigenous species, ii) advance understanding of functional links between biodiversity, external pressures and food-web interactions and iii) improve our capacity to project future biodiversity.

Work carried out in BIO-C3

Baltic biodiversity is dynamic, responding to various drivers operating at different scales. Using improved knowledge obtained in BIO-C3, and existing large-scale data sets, biodiversity responses in space and time were addressed by hindcasts and projections of abiotic/biotic/anthropogenic drivers including their interactions (climate change, eutrophication, species invasions, fisheries) in spatially explicit models. The identified gradients of human impacts were synthesized into impact assessments to guide management policies including improved operationalization of Good Environmental Status (GES) indicators, design of Marine Protected Areas (MPAs) and fisheries management.

To assess the role of biodiversity in marine ecosystems, BIO-C3 used the Baltic Sea as a natural laboratory. 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, which means that extinctions of resident species or introductions of new species can be expected to have a more dramatic effect compared to species rich and presumably more stable ecosystems.

BIO-C3 aimed 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 utilized 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 were 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.

Main results of BIO-C3

Scientific highlights

Biodiversity changes and their functional implications. - Biodiversity is most often perceived as the (number of) species present in a specific habitat, an environment or an area/region, but also encompasses genetic and functional diversity components. Biodiversity changes to the natural (salinity, oxygen) as well as large scale anthropogenic (eutrophication, sediment dumping, non-indigenous species) and climatic drivers were assessed using traditional biodiversity and quality indices as well as trait-based measures and approaches, through a broad set of statistical and modeling techniques. Using two long-term time series from the Baltic Sea, we evaluated coastal and offshore major phytoplankton taxonomic group biovolume patterns over annual and monthly time-scales and assessed their response to environmental drivers and biotic interactions. Overall, coastal phytoplankton responded more strongly to environmental anomalies than offshore phytoplankton, although the specific environmental driver changed with time scale. A downscaled benthic food-web model has been developed for Baltic sub-regions in order to reconstruct predator-prey interactions during the period of changing levels of eutrophication between 1990 and 2007, suggesting a strong nutrient control of the available food supply to predatory fish and birds in coastal areas with concomitant decline in bivalves and water birds as their predators.

BIO-C3 also focused on the functional properties of biodiversity, i.e. what do organisms do rather than who are they, and on temporal variation (i.e., species turnover). We show that in spite of relatively drastic and rapid changes in species composition, the functional properties are more robust, but do change over longer time scales. This is important background to predict the behavior of ecosystems under the large-scale impacts of e.g. climate change. Another important prerequisite of biodiversity research is the correct identification of the species, especially non-indigenous ones. High-throughput sequencing (HTS) meta-barcoding was applied for the surveillance of plankton communities within the southeastern Baltic Sea. In several cases, non-indigenous species were only identified by meta-barcoding, not by traditional sampling. ***Based on above results, BIO-C3 recommends to stakeholders such as HELCOM, ICES, as well as national and regional environmental bodies to make sure that coordination of sampling programs across trophic levels are in place and that these yield comparable data sets in space and time.*** Accurate assessments of past ecological changes are a prerequisite for predictive analysis. In the Baltic Sea, we have the unique possibility to rely on national and/or regionally sampled and collected monitoring data. **Second, *BIO-C3 recommends the inclusion of functional properties into national and regional advice and management action*** (e.g. HELCOM, ICES).

Species and population adaptation - Populations of species may evolve quickly in response to environmental drivers. This relatively new insight in marine ecology is particularly relevant in the Baltic Sea with its steep environmental gradients and ongoing change in salinity (desalination), temperature and other global change associated parameters that are exceeding rates in other world oceans. For two key native zooplankton species, the copepods *Eurytemora affinis* and *Temora longicornis*, a series of common-garden experiments was performed across different locations/populations to determine local tolerance and adaptation potential. Both species displayed pronounced local adaptations across the sampled locations with respect to temperature (*E. affinis*) and salinity (*E. affinis* and *T. longicornis)*, implying evolutionary potential on the one hand, but also prompting the need to conserve populations with their particular response traits rather than species *per se*. As a key example for a NIS, the comb jelly *Mnemiopsis leidyi*, genotypes present in the Baltic in a first invasion wave were replaced by novel ones in the period 2010-2013. In combination with the assessment of ocean currents as drivers of (re-)introduction, this is consistent with secondary spread and re-seeding of genotypes by the prevailing currents while it rules out local reproduction in the Eastern Baltic Sea. Genetic markers (SNPs) were also instructive to assess the level of population mixing and the degree of hybridization between the Western and Eastern Baltic cod stock. A remarkable stability of stock integrity was found with minimal hybridization, possibly reflecting strong selection against hybrids. These findings reinforce that both stocks need to be managed separately, and are likely locally adapted to the unique Baltic environment.

Non-indigenous species (NIS) - Several (NIS), such as the round goby, the Harris mud crab *Rhithropanopeus harrisii* and the polychate *Marenzelleria* spp., have altered the biodiversity and food-web structure of the Baltic Sea, introduced new nodes and have the potential to lead to regime shifts. Currently, there are 172 NIS recorded for the Baltic Sea (AquaNIS, http://www.corpi.ku.lt/databases/index.php/aquanis cited 28. February 2018). For most of them (except deliberate releases), we are unable to identify the specific introduction vector, but shipping and natural spread from the North Sea are the two dominating introduction pathways. There are marked subregional differences in the establishment of NIS. Thus, the Baltic Sea cannot be considered as an uniform water body in terms of the established NIS and at least two major regions with differing hydrographic conditions and prevailing introduction pathways can be distinguished: i) Baltic Proper with large gulfs in the NE Baltic Sea, and ii) NW part of the Baltic Sea, incl. the Danish Straits. Our current understanding on ecological impacts of NIS is very fragmentary and we lack critical information on even the most widespread NIS in the Baltic Sea. **Therefore, research on ecological impacts of NIS should be prioritized and the required funding should be secured.**

Current and anticipated food-web changes - Phytoplankton species composition is an important determinant for ecosystem health as these are the producers of essential compounds available for higher trophic level, such as fish. A comparison of essential biomolecules between phytoplankton taxonomic groups explains why a more diverse community composition leads to higher production rates of consumers than mono-specific diets. Microzooplankton, primary consumers in the pelagic food web can to some extent buffer effects of unbalanced stoichiometric ratios for higher trophic levels. For commercially important fish species, results showed that monitoring the growth rate of larvae and evaluation of factors affecting the growth rate should be considered as an important part of the studies related to ecology of larval fish. Further outcomes showed that bottom-up processes, such as prey availability and temperature should be considered among the key drivers for larval and early-juvenile sprat.

As for top-down effects, one focus was the interaction among clupeids and their copepod prey. Predation of the planktivorous fish herring and sprat on key copepod species in the Bornholm Basin showed that both were mainly zooplanktivorous feeding on copepods. The copepod *Pseudocalanus acuspes* evolved a behavioural response to escape peak predation pressure, which occurs mainly at peak spawning periods of sprat. If integrated over the year, the utilization of the copepod production by both clupeids is however comparatively low for the dominant prey species, *indicating an **overall poor trophic coupling between copepods and pelagic planktivorous fishes** in the Bornholm basin.* The grey seal (*Halichoerus grypus*) population in the Baltic Sea has increased considerably during the last decades, causing conflict between seals and commercial fisheries. Estimation of the magnitude and uncertainty in prey consumption revealed that for the most important commercial species (cod, herring and sprat), catches generally exceeded the seal consumption in the entire Baltic Sea but regionally, seal consumption could be more *important.* The varied nature of benthic-pelagic coupling processes and their potential sensitivity to climate, nutrient loading, and fishing was assessed using the Baltic Sea as case study. The magnitude and variability of biological processes, particularly those governed by complex food web feedbacks, were sensitive to all three anthropogenic pressures examined.

Effects and future projection of major environmental drivers - Climate change is predicted to impact the Baltic marine environment in several ways, including warmer temperatures, lower salinity and less sea ice in winter. Climate forcing on species composition is already visible now, and can be well documented in the Baltic owing to its very good long-term data series. For example, profound changes in zooplankton community were recorded at the deep-water stations of the southern Baltic Sea, with significant impacts of hydrological parameters (especially salinity) and climatic forcing on pelagic food web structure and dynamics. Climate projections show that river runoff will increase in future. This will bring more nutrients to the already eutrophicated Baltic Sea. Warmer water will alter biogeochemical cycles in water and sediment. This means that eutrophication can be more severe in future with extending low-oxygen areas and larger cyanobacteria blooms. **To combat eutrophication in a warming world it is even more essential that nutrient load reduction targets are met.** Ocean acidification levels in the Baltic Sea already exceeds values predicted for other ocean areas in the distant future. Effects on commercially important fishes include increased juvenile mortality, with possible negative effects on recruitment. A more in depth transcriptomic analysis of juveniles in OA experiments shows that the fish do not "feel" stress in any way when exposed to OA, which probably makes the situation worse as they cannot counter-regulate the proton excess.

Marine Protected Areas. – An underlying idea behind the designation of Marine Protected Areas (MPAs) is that they will have a positive effect on the entire metapopulation (i.e., including both populations in the MPAs and in the spatially usually more extensive unprotected areas), and thus a net benefit beyond the MPA network *per se*. The theoretical problem is to identify what areas to select as MPAs to obtain networks optimally suited to support this effect. With respect to marine protected areas in the Baltic Sea, BIO-C3 hydrodynamic modeling research revealed that connectivity within the **present HELCOM-MPA/Natura 2000 is generally sufficient, but that some specific improvements can be suggested**. This includes the addition of MPAs along the northwest margin of the Baltic Sea to enhance growth and persistence of target species in both protected and unprotected areas. Adequacy, here measured as local retention, is sufficient for sustaining local populations with larval dispersal for about 15% of the HELCOM-MPAs, while adequacy generally fails for the smaller Natura 2000 areas. Projected reduction in salinity, predicted population fragmentation, low dispersal ability, and the highly structured populations of *Fucus vesiculosus/radicans* may significantly shift the distribution of this canopy-forming alga, and this unique habitat may be lost from a large part of the Baltic Sea. For environmental protection measures to be effective, it is **vital to not only designate specific** (often rather small) sites as **MPAs, but also to be aware of and know several aspects of connectedness** both within and between such areas. Predicted range shifts of unique genotypes may be facilitated by stepping-stone dispersal between suitably connected MPAs, or through assisted translocation to protected refuges.

GES (Good Environmental Status) Indicators - Most indicators currently in use are “state indicators”, which means that they reflect anthropogenic impacts in terms of changes in ecosystem state. This can make it difficult to relate these indicators to a particular pressure (as state changes can result from a complex of anthropogenic pressures) and impedes focused management responses. However, comparing the Baltic to other regional seas, the ratio of pressure indicators specifically addressing a pressure and changes in its magnitude is higher, most focusing on specific target groups (e.g. non-indigenous species, fishes or benthic invertebrates) and anthropogenic activities (e.g. extraction of species). Looking at partitioning of indicators according to their relevance to pressures (either direct or indirect, inferred from the pressure-impact-state matrices), key pressures in the Baltic are well represented. As a case in point, many indicators address nutrient and organic matter enrichment, which reflects eutrophication that is still the most widespread pressure in marine and coastal waters in Europe and the Baltic Sea. Other pressures that are targeted by a few indicators, related to extraction of species (i.e. fishing), non-indigenous species (NIS), physical loss and physical damage to marine habitats. **Pressures that have been identified recently such as marine noise, litter or acidification are represented by few indicators and need further development.**

Synthesis - "The Baltic time Machine" - BIO-C3 scientists initiated and led the concept paper writing initiative *“The Baltic Sea: a time machine for the global future ocean?”* uniting 26 scientists from 8 BONUS projects. A manuscript under the same title was advanced jointly at two writing workshops supported by BONUS clustering funding, and was submitted to the journal “Science Advances” in December 2017. This will **promote the Baltic Sea world-wide as a model** not only for massive environmental degradation, but also for intergovernmental governance and science based management that was able to reverse some of the negative trends.

Dissemination Impact of the research

Throughout the duration of BONUS BIO-C3, we have made strong efforts to pass on the expertise of our project personnel, and to use the scientific output resulting from BIO-C3 to inform stakeholders and policy makers in the Baltic realm and beyond. To do so, we have actively pursued the dissemination of project output on various levels, from the scientific community, to resource managers and politicians, to the public, using a mix of traditional scientific channels, involvement in working groups and advisory councils, to interviews and media channels.

This included e.g., contributions to the implementation of the MSFD on multiple occasions, to the design of the Ballast Water Management Convention, to plans for an integrated non-native species monitoring programme within HELCOM, and to scientific fisheries management advice within ICES. The role of the BONUS BIO-C3 consortium in the science-policy interface was expressed in the strong membership and a total of **402 occasions in which BIO-C3 scientists contributed to stakeholder committees or working group meetings** over the project duration, including those of ICES, HELCOM, EC, MSFD, UN, and OSPAR, and including the presentation of major BIO-C3 results and conclusions at an ad-hoc HELCOM advisory meeting in October 2017. Scientifically, BIO-C3 results have been disseminated in 111 peer-reviewed publications (+ 11 further in review, and numerous in preparation) thus far and hundreds of presentations at scientific conferences and stakeholder events. These efforts included the organization of the successful BONUS theme session "*From genes to ecosystems: spatial heterogeneity and temporal dynamics of the Baltic Sea"* at the ICES Annual Science Conference 2015 in Copenhagen (co-organized with BONUS INSPIRE and BAMBI), bringing together more than 80 scientists from both within and outside the BONUS community, as well as stakeholders and policy makers, and amongst others resulting in an invited guest column in the BONUS in Brief December newsletter on "*Finding bridges between biodiversity research and ecosystem–based management*". A second highlight was the co-organization (with BONUS INSPIRE) of the 1st BONUS symposium "*Science delivery for sustainable use of the Baltic Sea living resources*" from 17-19 October 2017 in Tallinn, Estonia, to share results from BONUS projects with the larger scientific and stakeholder community and to foster science-stakeholder interactions. This event drew 110 scientific (including >70 oral) contributions, and concluded with a half-day stakeholder panel discussion event.

We pursued the **strategy "dissemination by training"** with a series of successful BIO-C3/BAMBI/INSPIRE/COCOA summer schools in 2015 ("*The Baltic Sea: a model for the global future ocean?*", Glücksburg, Germany, 32 PhD students and postdocs, 13 lecturers) and 2016 (*"Modelling biodiversity for sustainable use of Baltic Sea living resources"* , **Holbæk**, Denmark, 23 students and 10 lecturers) and the BIO-C3 high school teacher workshop "*Bringing Science to the class room: biodiversity in the Baltic realm – function, services and anthropogenic threats"* in Schloss Noer, Germany, from September 9-10 2016 to train teachers as "multiplicators" passing on knowledge about Baltic biodiversity. Finally, we used blogs, our project website, television, radio, and newspaper appearances, popular science articles, presentations at public outreach events, and a series of short movies on biodiversity in the Baltic realm produced by BIO-C3 and published in 2017, to disseminate the topic "biodiversity" to the wider public.

The continuity plan of BIO-C3

BIO-C3 continuity is pursued on several levels. Most directly, and ongoing since the end of the official project period, there is a large number of manuscripts on BIO-C3 results in preparation stage, many of them involving scientists from several of the BIO-C3 partners. We are expecting these joint scientific efforts to continue for years. Some of this work is going to be advanced further - including the use of some of the datasets resulting from BIO-C3 - within the ongoing BONUS project BLUEWEBS, in which several BIO-C3 partners are involved. Similarly, via the numerous continuing WG memberships of BIO-C3 scientists, past and new BIO-C3 scientific results will continue to enter the science-policy and science-management arena for years to come. As a consequence, the scientific and science-stakeholder networks created over the duration of BIO-C3 will remain operational.

On a second level, BIO-C3 leaves a **legacy of improved Baltic-scale scientific initiatives** that are now in place and will continue to operate. This includes the improved temporal and spatial coordination of scientific cruises in the open Baltic Sea (8-10 cruises by 4 BIO-C3 partner institutes per year on average), where overlap is avoided and annual coverage optimized. The partners have already jointly planned and harmonized the cruises schedules for 2018 and tentatively for 2019. Out of this network, one issue to pursue further in the future is the collaboration on joint synthesis efforts moving beyond datasets from individual cruises. Further examples are the expansion of the Baltic zooplankton network (http://kodu.ut.ee/~riina82/), which is continuing beyond BIO-C3, and the sample archives created by large-scale international sampling initiatives in the course of BIO-C3, e.g., of the invasive combjelly *Mnemiopsis leidyi* and the non-indigenous species round goby *Neogobius melanostomus* across the Baltic Sea. The latter is curated but still lacking analysis, and is a foundation for future follow up efforts.

On a third level, a feeling that has resonated strongly within the BIO-C3 consortium over the past year has been the **immense potential and interest to pursue joint synthesis efforts** based on the wealth of new information created in BIO-C3 as well as other BONUS projects over the past years. Examples here include the synthesis of the numerous studies on the role of non-indigenous species in Baltic food webs, on structural and functional changes of Baltic ecosystems under climate change and anthropogenic drivers, as well as taking stock of where we stand regarding the use of models in Baltic food web work and of the use of indicators in monitoring and management efforts. This has led to the idea for the BONUS synthesis project XWEBS led by and including both BIO-C3 and external partners, which received a positive evaluation and was invited to negotiations stage by BONUS. We are aiming to also use this platform to funnel BIO-C3 and BONUS project information into future synthesis and dissemination efforts. In parallel to these efforts, we are discussing the potential for a BIO-C3 focused paper about the major project results, conclusions, and recommendations.

Finally, we will continue to disseminate BIO-C3 knowledge to stakeholders on many levels, from interviews and outreach that will result from BIO-C3 publications yet to come, via the various WG memberships of BIO-C3 scientists, to a presentation of BIO-C3 highlights to EU parliament members organized by BONUS in May 2018.

More of BONUS BIO-C3…

The scientific highlight selection and project activities presented above represent but a fraction of the output of BIO-C3. For more information, including access to all of the in-depth scientific deliverable reports provided by our project tasks, an overview and in many cases direct access to BIO-C3 publications and presentations, links to our movies, event reports and lecturer presentations of our summer schools and teacher training camps, links to primary data resulting from our cruises, and much more visit our BIO-C3 homepage www.bio-c3.eu.

The BONUS BIO-C3 project has received funding from BONUS (Art 185), funded jointly by the EU and the Innovation Fund Denmark, Estonian Research Council, Academy of Finland, German Federal Ministry of Education and Research, Research Council of Lithuania, Polish National Centre for Research and Development, the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning and the Swedish Environmental Protection Agency.

Final scientific report

1. Scientific results during the reporting period (by work package)

WP1 – Genetic adaptation and ecophysiology

Lead: Dorte Bekkevold, P2 DTU Aqua

Overview:

The work-package "Genetic adaptation and eco-physiology", investigates physiological tolerances and adaptive variation of key Baltic Sea species. The goal is to provide a general understanding of principal determinants of the distribution of species and populations, which ultimately determine the functional diversity and resilience of Baltic Sea ecosystems in response to environmental drivers. WP1 activities fall into three overarching tasks, two of which have several sub-tasks dealing with specific key species. WP output feeds into WP2-4 activities, incorporating detailed information about species distributions and the novel generated knowledge of evolutionary processes into future projections of the Baltic Sea. Task 1 provides an authoritative review of distributions of select key Baltic Sea species and the environmental and eco-physiological conditions determining them. The information generated from this work was transferred into modeling activities in WP2-4. Task 2 exploits information provided in Task 1 further, in closing identified knowledge gaps about drivers of the distributions of native, as well as invasive species. The work also provides novel DNA sequencing based solutions to monitoring species diversity. Finally, the aim of work carried out under Task 3 is to gain knowledge about spatial and temporal distributions of evolutionary distinct populations within species and to gain understanding of how local populations may evolve in response to environmental drivers. Understanding such eco-evolutionary dynamics in the Baltic Sea is particularly relevant as a support for management decisions and projections of future environmental changes and the trajectories of non-indigenous species in the Baltic Sea.

Task 1.1: Environmental conditions, eco-physiology and species distribution

Lead: P3 UHH (Axel Temming), participation of Partners P1-8 and P11.

Deliverable 1.1. *Review of environmental factors influencing distributions of selected Baltic species*. **Month 22**. Accepted by BONUS, accessible at www.bio-c3.eu/publications.

Reference:

Temming, A., Niemax, J., Zaiko, A., Siaulys, A., Törnroos, A., Clemmesen, C., Jaspers, C., Oesterwind, D., Bonsdorff, E., Mittermayer, F., Kuosa, H., Ojaveer, H., Behrens, J., Peters, J., Renz, J., Kotta, J., Dutz, J., Lehtiniemi, M., Winder, M., Setälä, O., Kotterba, P., Puntila, R. and Neuenfeldt, S. (2015) *Review of environmental factors influencing distributions of selected*

Baltic species . BIO-C3 Deliverable, D1.1. EU BONUS project BIO-C3, 75 pp. DOI 10.3289/BIO-C3_D1.1.

Summary

This report presents a brief overview of ecologically or economically important species of different habitats and trophic levels in the Baltic. It supplied the modeling groups within BIO C3 with species specific information on environmental tolerances and preferences and identified some gaps in knowledge. Where possible, information was provided on the distribution of species in relation to depth, salinity, temperature and oxygen concentrations, in some cases supplemented with experimental results. The species were chosen according to their ecological or economic importance for the Baltic Sea and their relevance for modeling tasks in BIO-C3.

Introduction

The Baltic Sea with its extreme hydrographic conditions is an area of low species diversity with about 70 species forming self-sustained populations. However, due to the low number of species and the limited complexity of the food web the Baltic ecosystem is considered as a scientifically interesting test case to study the ecosystem effects of changing pressures, namely a combination of climate related changes in hydrography, fishing and eutrophication. Out of these 70 species almost 50% were selected for a review of their physiological tolerances and limits. The species, 9 benthic, 13 planktonic and 8 fish were chosen either because of their abundance in the system or because they were considered relevant, e.g. because of increasing biomass trends etc. Specific emphasis was given on species that were the subject of subsequent modelling exercises. One of the key applications of this rather unique compilation of information was the envelop modelling of their potential habitats using hydrodynamic models, both in hind cast and for future scenarios derived from down-scaled climate model predictions. These applications (WP 3, D3.3) produced insights into the expected magnitude of spatial distribution shifts and related effects on species assemblages and trophic interactions. The review also identified the variable degree of available information and identified especially a severe lack of experimental results on physiological limits and thresholds in many species.

Key results and conclusions

This unique compilation of physiological tolerances and limits for 30 relevant Baltic species provided a service to the modelling teams within BIOC3. The information was mainly used in WP3 in combination with hydrographic data from model output representing present and future condition to describe the changing envelops of the species' habitats. These applications (WP 3, D3.3) produced insights into the expected magnitude of spatial distribution shifts and related effects on species assemblages and trophic interactions. One key technical conclusion was that Baltic population specific tolerance and threshold limit information is currently still not available for a large proportion of Baltic species, and should be a target of future research efforts.

Key lessons

The compilation provides a valuable starting point for the search of information on physiologically tolerances and limits of species across all trophic levels in the Baltic including key references. It represented a service task to WP3 as well as WP2 and 4 within BIO-C3, there are therefore no specific key lessons from this task.

Applications

Information from D1.1 was used in modeling efforts in WP3, where it was used in combination with hydrographic data from model output representing present and future condition in the Baltic Sea to describe the changing envelops of the species' habitats. The information is freely available to other researchers using the link to the online table underlying D1.1 (see additional links below).

Knowledge gaps and future research needs

A main problem of the compilation is that the level of detail varies substantially between species. This reflects partly the fact that some (e.g., commercially important) species have been studied with a lot of effort, while for others only coarse information is available, but in part also depends on the personal familiarity of individual contributors with the respective species. The compilation is incomplete with regard to literature that is not available in digital formats or in Russian language.

Additional links

Link to the D1.1 appendix table (freely accessible, and open for use):
https://docs.google.com/spreadsheets/d/11zBNylWvdaQ8fEZ0JRgF6Ac5p75NbFWZcnecnkum8Hc/edit?pli=1#gid=2117449428

Task 1.2.: Physiological tolerance, preference and phenotypic plasticity

Lead: Catriona Clemmesen, P1 GEOMAR, participation of partners P2-P8.

Deliverable 1.2: *Documentation of key drivers and physiological tolerance limits for selected resident and invasive species*. **Month 26**. Accepted by BONUS, accessible at www.bio-c3.eu/publications.

Reference:

Clemmesen, C., Behrens, J., Christensen, A., Christensen, E. A. F., Dutz, J., Jaspers, C., Flindt, E., Griniene, E., Günther, C., Herrmann, J. P., Hinrichsen, H. H., Huwer, B., Karlsson, K., Kolodzey, S., Kotta, J., Kuosa, H., Lehtiniemi, M., Matern, S., Meskendahl, L., Mittermayer, F.,

Nurske, K., Ojaveer, H., Petereit, C., Puiac, S., Puntila, R., Samuiloviene, A., Temming, A., van Deurs, M., Winder, M. and Zaiko, A. (2016) *Documentation on key drivers and physiological tolerance limits for resident and invasive species* . BIO-C3 Deliverable, D1.2. , 100 pp. DOI 10.3289/BIO-C3_D1.2.

Introduction

The objective of this task was to determine physiological tolerance, capacity for acclimatization, preference and phenotypic plasticity in relation to environmental factors in selected planktonic, benthic and bentho-pelagic species including invasive/nonindigenous species at different positions in the food web. Physiological tolerance and preference were experimentally studied in populations sampled across geographical scales and ecological gradients (e.g. salinity) and in the field. The goal was to provide a general understanding of principal determinants of the distribution of species and populations, which ultimately determine the functional diversity and resilience of Baltic Sea ecosystems in response to environmental drivers.

Key results and conclusions

Zooplankton

Zooplankton including microzooplankton is a critical link for energy and nutritional transfer from phytoplankton to upper trophic levels in the food web. Understanding physiological tolerance and zooplankton responses to predicted climate change in the Baltic Sea is a prerequisite for the prediction of changes in biodiversity. One approach is a comprehensive zooplankton survey conducted along at salinity gradient, where largest changes in pelagic patterns are expected, as performed in Lithuanian waters. By providing the data on the zooplankton distribution within the Lithuanian coastal zone as an example, new knowledge on spatial and temporal zooplankton variability with implications for monitoring design was achieved (Klais et al., 2016).

Another important prerequisite is the correct identification of the species, especially nonindigenous ones. High-throughput sequencing (HTS) metabarcoding was applied for the surveillance of plankton communities within the southeastern Baltic Sea coastal zone. Results were compared with those from routine monitoring surveys and morphological analyses. Four of five nonindigenous species found in the samples were identified exclusively by metabarcoding. All of them are considered as invasive in the Baltic Sea with reported impact on the ecosystem and biodiversity. It could be shown that HTS metabarcoding can provide information on the presence of exotic species and advantageously complement conventional approaches (Zaiko et al., 2015).

In addition to field observations, responses of offshore, deep basin copepods (*Acartia* and *Temora*), as well as nearshore coastal copopods (*Eurytemora*) were studied under laboratory conditions. Survival, feeding and egg production of *Acartia longiremis* decreased with decreasing salinity resulting in decreased feeding rates, which were not sufficient to sustain reproduction and high survival of this species at a salinity of 4. These results show that

Acartia longiremis persists close to its physiological limit in the Baltic Sea, which makes the species vulnerable to small changes in future salinity (Dutz & Christensen in review).

In a series of laboratory experiments on metabolic and reproductive responses of two populations of the calanoid copepod *Temora longicornis* from the Bornholm- and the Gotland Basin were performed. Ingestion, respiration, egestion, egg production and egg hatching success were compared at salinities ranging from 10 to 5. Both populations showed a decreasing ingestion and egg production with decreasing salinity, down to a critical salinity of 6 below which mortality increased to 100%. However, hatching success of eggs was high and respiration was generally constant at all salinities. The results suggest that energy partitioning of *T. longicornis* is significantly affected by decreased salinity (Dutz et al., in prep.).

In contrast to the polyhaline population of *Temora longicornis*, respiration rates in the mesohaline populations were not affected by reduced salinity indicating physiological differences between the poly- and mesohaline populations. These physiological differences are likely fundamentally important for the wide distribution and dominance of *T. longicornis* populations in the central Baltic Sea where salinity conditions are below 8. Our results confirm the broad euryhaline character of *T. longicornis*. Yet, this is based on population-specific responses rather than a broad species-specific physiological plasticity (Christensen & Dutz, in prep.).

Experiments with the coastal copepod (*Eurytemora affinis*) showed the optimum condition to be at an experimental temperature of 15°C and a salinity of 6, while the combination of high temperature with low salinity was the most detrimental (20°C and salinity 2). Additionally the laboratory experiments suggest that increased temperature appears to be especially stressful in the most northern populations, as they are at their outmost temperature range. Consequently, some coastal copepod populations likely have low tolerance levels to future climate change (Karlsson & Winder 2018).

Invasive/ non-indigenous species

The invasive round goby, *Neogobius melanostomus*, has spread rapidly in the western Baltic Sea during the last two decades. Modelling results show that the distribution of the round goby is primarily related to local abiotic hydrological conditions (wave exposure). Furthermore, the probability of round goby occurrence was very high in areas in close proximity to large cargo ports. This links patterns of the round goby distribution in the Baltic Sea to shipping traffic and suggests that human factors together with natural environmental conditions are responsible for the spread of NIS at a regional sea scale (Kotta et al., 2016). Results based on physiological tolerance and aerobic scope (AS, the difference between maximum and standard metabolic rate) measurements show that AS in round goby is reduced by 30% and blood plasma osmolality increased (indicating reduced capacity for osmoregulation) at salinities approaching oceanic conditions. Survival was also reduced at the highest salinities yet a significant proportion (61%) of the fish survived at 30 PSU. Reduced physiological performance at the highest salinities may affect growth and competitive ability under oceanic conditions, but to what extent reduced AS and osmoregulatory capacity will slow the current 30 km year-1 rate of advance of the species through the steep salinity gradient from the brackish Baltic Sea and into the oceanic North Sea remains speculative. An unintended natural experiment is in progress to test whether the rate of advance slows down. At the current rate of advance the species will reach the oceanic North Sea by 2018/2019, therefore time for taking preventative action is short (Behrens et al., 2017).

Fishes

Flounder: Vertical distribution of fish eggs as determined by egg specific gravity (ESG) and ambient salinity conditions have profound implications for the reproductive success and hence recruitment in fish. As an adaptation to salinity, ESG differed between areas; with three subpopulations of flounder having pelagic eggs in contrast to one subpopulation having demersal eggs. Egg diameter differed significantly between subpopulations for pelagic eggs and for demersal eggs, whereas egg dry weight was similar for pelagic and for demersal eggs. The adaptation to salinity is determined mainly by water content manifested as differences in egg diameter; increase in diameter with decreasing salinity for pelagic eggs, and decreased diameter resulting in demersal eggs (Nissling et al., 2017).

Sprat: Diel vertical migration (DVM) is a common behavior and often relates with the diurnal feeding periodicity. Nonetheless, sprat feeding behavior and daily ration (DR) estimation are usually based on daytime stomach contents from deeper layers. Within BIOC3 a new approach for DR estimation, taking into consideration the DVM associated feeding periodicity, was evaluated. The main outcome was that feeding in the deep during the day represented only 15-50% of the DR. Feeding rates were on average 3.2-times higher in upper layers when compared to daytime estimates from deep waters. Resulting DRs were 1.4-times higher using this new approach compared to the established approach. The results emphasize the importance of adapting the sampling design on the vertical feeding dynamics to avoid a biased picture of predator prey interactions (Kulke et al., in review).

Recruitment variability of Baltic sprat is still unexplained and the aim is to examine the fate of seasonal cohorts that start their life during the extended spawning season (February to August). The importance of post-larval stages, and the interaction between food availability and temperature that determines their feeding rate, maintenance and finally their growth performance and autumn condition of seasonal cohorts was analyzed in a backwards and forwards modelling approach. Feeding rate of sprat and functional response curves (snatching rate in relation to prey concentration) were fitted as a function of fish size and temperature. These curves were used as backbone for a numerical simulation model, where cohorts start as an egg each day during the spawning period. Until cohorts reach metamorphosis, their growth is determined by temperature only and when they reach a size of 25 mm standard length feeding rate is determined by temperature, plankton concentration and day length allowing for simulations of growth of sprat in their nursery in response to real plankton concentration and temperature. The autumn condition of the different seasonal cohorts - possible indicators of year-class strength- can be analyzed to estimate an "optimal survival corridor" (Kulke et al., in prep.).

Gobiidae: The diversity of larval gobiidae in the Gulf of Riga was examined using molecular tools revealing that sand goby (*Pomatoschistus minutus*) was the dominant species (82%) followed by the common goby (*Pomatoschistus microps*) with 12% and the Black goby (*Gobius niger*) with 6% showing differences in spatiotemporal distributions based on different habitat conditions (Ojaveer et al., 2017).

Cod: Ocean acidification, driven by rising atmospheric CO_2 levels, is ongoing and expected to worsen in the future. The experiments performed within in this Task 1.2 clearly show that larvae of Western Baltic and coastal Barents Sea cod are impacted by near future levels of ocean acidification (Stiasny et al., 2016). The results of the whole transcriptome sequencing on three larval stages of Atlantic cod exposed to predicted levels of pCO_2 have been analyzed. While the earlier two stages (6 and 13 dph) did not exhibit any large scale re-organization of the transcriptome (3 and 16 genes differentially expressed) the late larval stage (36 dph) showed 1413 differentially expressed genes. However, when examining the genes with the most severe fold changes and relating this information to the observed changes in phenotype (Stiasny et al., in review at Global Change Biology) it becomes evident that the observed changes in genes expression are most likely caused by the different growth and developmental speeds in response to the stressor. This in addition to the lack of differential expression of genes related to the cellular stress response in the earlier larval stages led to the conclusion that simulated ocean acidification is a "stealth stressor" for cod larvae (Mittermayer et al., in review): a stressor cod larvae cannot react to transcriptomically, although severe phenotypic changes ((Stiasny et al., in review at Global Change Biology) and increased mortality (Stiasny et al. 2016) were observed.

Key lessons

Combining laboratory approaches with field observations and modelling as performed in the case of round goby, flounder and sprat has proven a valid tool for the assessment of physiological tolerances and preferences as well as for predicting the reaction to environmental changes.

Using physiological approaches and synthesizing the physiological tolerances and preferences gives the ability to create spatial distribution maps and forecast changes in distribution patterns within the Baltic Sea.

Different populations of the same species, in case of the copepod *Eurytemora affinis* and *Temora longiformis* react differently to salinity and temperature changes based on the environmental conditions they are adapted to. The same holds true for the tolerance to decrease in pH (ocean acidification) in cod populations.

By comparing different subpopulations, differences in preferences and the importance of phenotypic plasticity necessary for the capacity for acclimatization (Task 1.3) have been shown. Different flounder populations as an example have shown an adaptive potential by switching from pelagic to demersal eggs based on egg specific gravity (Nissling et al., 2017).

An overarching lesson from Task 1.2 is that physiological responses show high variability on a local subpopulation level, which has to be taken into account when predicting the distribution patterns or adaptation potential of the species (see Task 1.3) into the future.

Knowledge gaps and future research needs

Although high-throughput sequencing (HTS) barcoding is currently in an immature status for zooplankton identification, the combination of HTS metabarcoding and observational records is recommended for the early detection of marine pests and delivery of the environmental status metrics of nonindigenous species (Zaiko et al., 2015) and should be further developed.

Reduced physiological performance of round goby at the highest salinities may affect growth and competitive ability under oceanic conditions, but to what extent reduced aerobic scope and osmoregulatory capacity will slow the current 30 km year-1 rate of advance of the species through the steep salinity gradient from the brackish Baltic Sea and into the oceanic North Sea remains speculative (Behrens et al., 2017) and needs to be further investigated.

Diel vertical migration (DVM) is a common behavior and often relates with the diurnal feeding periodicity. The importance of adapting the sampling design to the vertical feeding dynamics to avoid a biased picture of predator prey interactions (Kulke et al., in review) needs to be considered also for species other than sprat.

Results from transgenerational experiments with cod have led to the hypothesis, that population affiliation, egg size, parental treatment and parental condition should be taken into consideration and included into the experimental setup in the future when evaluating the effects of climate change, like ocean acidification, on early life stages of fishes (Mittermayer et al., in prep.).

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Task 1.3. *Adaptive evolution of resident versus invasive species*

Lead: Thorsten Reusch, P1 GEOMAR, participation of partners P2-5, P7, P11

Deliverable 1.3: *Report on adaptive evolution linking trait and functional genetic variance for selected species*. **Month 40**. Accepted by BONUS, accessible at www.bio-c3.eu/publications.

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Introduction

Populations of species may evolve quickly in response to environmental drivers. This relatively new insight in marine ecology is particularly relevant in the Baltic Sea with its steep environmental gradients and an ongoing change in salinity, temperature and other global change associated parameters that are exceeding rates in other world oceans.

Understanding the resulting eco-evolutionary dynamics in this system is thus particularly relevant. The BIO-C3 aim in Task 1.3 was to improve eco-evolutionary understanding by filling critical knowledge gaps on the spatial and temporal patterns in population structure, genetic diversity, and evolutionary adaptations of key resident and non-indigenous species (NIS) in the Baltic. Of central interest was an assessment of these population attributes in the context of temporal environmental datasets (in particular salinity and oxygen changes over the course of Major Baltic Inflow, MBI, events) and of the spatial gradient from marine conditions near the connection to the North Sea via Belt Sea and Kattegatt in the west to brackish- and even freshwater conditions in the eastern Baltic.

Ultimately, information provided here can support (fisheries) management decisions, and contribute to a better understanding of the possible biological consequences of projected future environmental changes – including an expected drastic decline in salinity, increase in temperatures, and expansion of anoxic zones, and of the trajectories of NIS after their introduction to the Baltic Sea.

Key results and conclusions

- For two key native zooplankton species, the copepods *Eurytemora affinis* and *Temora longicornis*, a series of common-garden experiments was performed across different locations/populations to determine local tolerance and adaptation potential. Both species displayed pronounced local adaptations across the sampled locations with respect to temperature (*E. affinis*) (Karlsson and Winder in review) and salinity (*E. affinis* and *T. longicornis)* (Christen et al. in prep, Christen & Dutz a, b, in prep.), implying evolutionary potential on the one hand, but also prompting the need to conserve populations with their particular response traits rather than species *per se*.

- As one key example for a NIS, the comb jelly *M. leidyi*, invasive genotypes initially present in the Baltic were replaced by a novel genotype pool during the period 2010-2013. In combination with the assessment of ocean currents as drivers of (re-)introductions and population structure, this is consistent with secondary spread and re-seeding of genotypes by the prevailing currents while it rules out local reproduction in the Baltic east of the southwestern Baltic (Jaspers et al. in press). Moreover, for the non-indigenous Ponto-Caspian fish species round goby (*N. melanostomus)* a large spatial sampling programme was completed and a curated sample archive is now available for further analysis in future projects.
- For the economic and ecologically important fish species Atlantic cod (*G. morhua*), two studies described patterns in spatio-temporal population structure in the Arkona Basin and the Eastern Baltic Sea and assessed correlations with environmental drivers (collaboration with WP3 providing hydrodynamic modeling data). In the Arkona Basin, we confirmed the presence of both eastern and western genotype in fluctuating proportions over time, but no genetic mixing of the two stocks in this contact zone. The MBI of 2015 had no detectable influence on the proportional contributions of the two stocks over time (Hemmer-Hansen et al. in prep.). This study also confirmed that the use of a “tuning” factor to account for the variable presence of Eastern Baltic cod in the Arkona Basin (managed as part of the Western Baltic cod stock) should be continued.
- Moreover, the Eastern Baltic cod population showed remarkable genetic integrity, with very rare occurrence of western Baltic cod genotypes, no evidence for hybridizations, and stable genetic diversity over time (past 21 yrs), despite strong environmental fluctuations. The rarity of divergent western genotypes, along with a lack of further sub-structure between eastern locations suggests that the current management of “Eastern Baltic cod” as a single stock is valid. Moreover, the consistent absence of Western Baltic cod in the Eastern Baltic, and Eastern Baltic cod in the Western Baltic (SD22) suggests that a “rescue” of stocks by immigration from neighbouring areas (e.g., Eastern Baltic cod providing spawners in the West after potential stock collapses) is unlikely (Dierking et al. in prep.).
- Time series data on the dramatic decrease of length at maturity in the eastern cod stock over the past 15 years also presented in this deliverable (Köster et al 2017) were thus due to endogenous factors and not to immigration or emigration of particular genotypes.

- Additional experimental work assessed the vulnerability of larval cod to ocean acidification, and the potential of acclimation and trans-generational effects to mitigate impairment of larval survival (Stiasny et al. 2016, Stiasny et al in review). We found that without evolutionary adaptation, the effects of ocean acidification levels expected for end of the 21st century on the survival of cod larvae of two separate stocks are severe and will translate to recruitment declines in the fished population of up to 90% (Stiasny et al. 2016). On the other hand, in an aquaculture stock, some buffering of ocean acidification effects occurred in the offspring when the parental generation had been exposed to ocean acidification, but only under high food supply (Stiasny et al in review).

Key lessons

An overarching lesson from Task 1.3 is that genetic information and information on the evolutionary potential of species should not be ignored by resource (including fisheries) managers anymore. In particular, rapid advances in genetic tools now make it possible to obtain information on the population structure, genetic diversity, loci under selection and even whole genomes of species rapidly and at ever-lower costs, and have led to the increased availability of datasets that are relevant for day-to-day management as well as strategic long-term management decision.

Specifically, genetic markers such as single nucleotide polymorphisms (SNPs) are now placing routine, temporally and spatially resolved genetic assessments of fish stocks within reach, and have strong potential to improve stock delineation in highly dynamic systems like the Baltic Sea. This was demonstrated here for cod in ICES SD24 and 25, and in particular in the application of “tuning factors” to account for stock mixing (i.e., the presence of both Eastern and Western Baltic cod individuals in an area managed as part of the western Baltic cod stock) and to thus improve quota recommendations for cod in Arkona Basin.

Information obtained via genetic markers are ideally complemented by classical experimentation that seeks to determine whether the performance of local populations has an adaptive component. Here, common-garden experiments along with genetic information improve our understanding of existing local adaptations in present-day populations as well as their adaptation potential in the context of rapidly changing environmental parameters. The resulting insights are essential to assess potential consequences of projected future environmental scenarios for the Baltic Sea.

Applications

Genetic assignment methods based on the same SNP panel as used in the cod SD24 study described above are currently applied in combination with otolith shape analyses to split catches of cod in ICES SD24 into eastern and western population components (ICES 2015; Hüssy et al. 2016). The majority of fish are assigned to population of origin through the analyses of otolith shape signatures. However, since otolith shapes are impacted by both population of origin (i.e. genetics) and environmental conditions, results from otolith based shape analyses have to be calibrated against a baseline of genetically assigned individuals. Continuous updating of the genetic baseline will be needed to increase robustness of results over time. Ultimately, with increasing cost efficiency, switching entirely to genetic instead of otolith shape based assignments may be the application of the future.

Knowledge gaps and future research needs

In line with the key lessons above, we consider the systematic use of the (genetic) tools now available to characterize the population structure, connectivity of sub-populations, and (local) evolutionary adaptations of species inhabiting the Baltic Sea a top priority. This should include: (1) Integration of genetic information in assessments of (key) NIS in the Baltic Sea to identify source populations and local adaptations to Baltic conditions; in this context, the curated sample archive of round goby, one of the key NIS in the Baltic Sea, provided by BIO-C3, would be a good start. (2) Increasing integration of genetic information in stock assessments, to improve the stock delineation of commercial fishes and more routinely support day-to-day fisheries management; a good target for the routine application in annual stock assessments would be cod in SD24. (3) Systematically and for an expanded number of Baltic Sea species address the question of the potential for evolutionary adaptations to environmental change, which will be essential in the light of drastic environmental changes expected for the Baltic Sea in the coming decades. In order to design cost-effective and rapidly scorable markers to address the goals 1) and 2) initial high-throughput genome scans, in particular, are highly recommended to derive a set of customized SNP markers for the delineation of stocks, and the assignment of individuals. Likewise, these tools allow for a rapid detection of novel immigrant genotypes in the case of NIS.

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BIO-C3 Peer reviewed (in preparation or in review) - see www.bio-c3.eu/publications for updates on the publications reported here.

Christensen AM, Dutz J. (in preparation): Population-specific salinity tolerance is key to the success of a marine copepod species in the Baltic Sea.
Christensen A, Dutz J, Koski M (in preparation): The effect of abrupt changes in salinity to the survival, feeding and respiration of *Temora longicornis*.
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WP2 – Food webs under changing biodiversity

Lead: Axel Temming, P3 UHH-IHF

Overview:

Biodiversity influences food web structure, ecosystem functioning, and stability. Recently, changes in community composition on nearly all trophic levels, including planktonic and benthic food webs and fishes were described in the Baltic Sea, but the underlying processes by which these changes impact coastal and pelagic systems are only partly understood. WP2 investigated the consequences of changing biodiversity including non-indigenous species on Baltic food web configurations, transfer of energy and essential compounds, and productivity of the system using a combination of existing information, field work, experiments, and modelling, and considering different trophic levels, functional groups and habitats.

The specific objectives were to:

- Task 1: Uncover bottom up control mechanisms influenced by climate changes and eutrophication, and consequences for transfer efficiency and food quality for higher trophic levels and biodiversity.
- Task 2: Describe top-down effects of shifts in species dominance and management strategy on food web composition, functioning and biodiversity.
- Task 3: Assess effects of non-indigenous species (e.g. round Goby, crustaceans, comb jellies, polychaetes) on food web stability, functioning and biodiversity.

The work in all three tasks of this WP progressed and was concluded as planned. Deliverable 2.1 - "*Report on effects of changing drivers on pelagic and benthic species composition and production*", Deliverable 2.2 – "*Report on effects of changing predation pressure on benthic and pelagic species*" and Deliverable 2.3 – "*Report assessing the effects of key NIS on ecosystem functioning*" were accepted by BONUS, and are available online on our BIO-C3 website www.bio-c3.eu/publications.

Task 2.1: Bottom up control

Lead: Monika Winder, P4 SU, participation of P1, P2, P3, P5, P9, P11.

Deliverable 2.1: *Report on effects of changing drivers on pelagic and benthic species composition and production.* **Month 24**. Accepted by BONUS in 2016, accessible at www.bio-c3.eu/publications.

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Introduction

Changes in community composition can have large effects on upper trophic level, such as fish and ecosystem functioning. The Baltic Sea has experienced considerable shifts in community composition in both the planktonic and benthic food webs and across trophic levels, yet the underlying processes by which these changes impact coastal and pelagic systems are only partly understood.

The objectives of BIO-C3 was to improve our understanding on how biodiversity changes at the base the food web propagate to higher trophic levels and limit overall ecosystem productivity. This overall question was addressed by focusing on processes in benthic, plankton and fish communities with a special focus on prey quantity and nutritional quality. This understanding is important in order to predict how direct and indirect effects of changing biodiversity under spatio-temporally varying drivers affect ecosystem functioning.

Key results and conclusions

- The biochemical food quality of phytoplankton is a major factor determining growth of consumers. We conducted a quantitative comparison of key food quality parameters (fatty acids, amino acids and C:N:P ratios) across four major groups of pelagic primary producers (diatoms, cyanobacteria, green algae and haptophytes). Results indicate that major taxonomic groups differ in the concentrations of important biochemical compounds (Galloway & Winder 2015).
- Laboratory experiments were conducted to investigate the functional role of microzooplankton in terms of stoichiometric homeostasis (Golz et al. 2015). This is important because microzooplankton is a major component in marine food webs, however little is known about their ability to maintain stoichiometric balance. We showed that the dependency of microzooplankton C:N:P ratios on C:nutrient ratios of their food source varies between species. This study implies that microzooplankton growth can be constrained by imbalanced resource supply and that these key primary consumers have the potential to trophically upgrade poor stoichiometric autotrophic food quality for higher trophic levels.
- Assessing energy transfer from phytoplankton to a widespread key copepod species (*Acartia* spp.) with compound-specific stable isotope ($\delta^{13}C$) of essential amino acids showed distinct seasonal differences between *Acartia* and seston $\delta^{13}C$ essential amino acid values. This indicates that *Acartia* preferentially utilized specific dietary resources that comprised only parts of the total phytoplankton composition (Nielsen & Winder 2015). Analysis of $\delta^{13}C$ values in essential amino acids showed to be a promising tool to accurately trace consumer resource use in natural systems.
- Trends of zooplankton mean size and total abundance (MSTS), a core HELCOM indicator, suggest whether the investigated pelagic food web structure is or is not optimal for energy transfer from primary producers to fish. Results show that the MSTS, a two-dimensional, multi-metric indicator representing a synthetic descriptor of zooplankton community structure is a promising tool to test the temporal dynamics and the present state of the pelagic food web (Margonski & Calkiewicz, in prep.).
- Investigations of larval growth rates and factors affecting their growth are important for assessing the health of fish stocks. Here, we described growth rate of larval sprat in years 2006-2010 and to evaluate the effect of temperature and zooplankton biomass on both

the differences among years and the differences between geographical areas (Bornholm Basin and Gdansk Basin). Results showed that growth rate of larval sprat in the southern Baltic is limited by prey (zooplankton) availability and that high food availability and temperature combined result in faster growth rates (Fey & Szymanek, in prep.).

- Phenology and nutritional conditions of larval and adult cod was analysed in the Bornholm basin, the major cod spawning area for selected years. Highest growth and highest numbers of larvae in the plankton samples were found in the summer months correlating to highest production of the relevant zooplankton organisms. A positive correlation between nutritional condition of cod larvae and abundance of the most important food item copepodid C1 stages of *Pseudocalanus spp.* was found, reflecting the importance of adequate food for larval cod growth. Furthermore, years of higher recruitment were correlated with years of cod larvae being in a better nutritional condition. Correlations between larval cod growth rates based on biochemically derived estimates (RNA/DNA ratios), zooplankton abundance and numbers of recruits provide support for the “Match-Mismatch” and “Bigger is better” recruitment hypotheses.

- Data on individual cod sampled during the Danish part of the Baltic International Bottom Trawl Survey (BITS) ICES Sub-division 25 from 1995-2014 showed a significant decline in nutritional condition over time. Further, the onset of the inflow stagnation period since 1983 is reflected in the consumption, and condition of cod <40 cm. Most probably, the absence of sufficient benthic food forces relatively small cod to forage on sprat with relatively low success. Aggravated by decreasing sprat abundance in the central area of the cod distribution (additional decrease in the mid 90s), while cod >40 cm can compensate by feeding on herring, small cod, and benthic fishes.

- Similarly, size at sexual maturation of Baltic cod has significantly declined over time for both sexes (Köster et al. 2017). Danish BITS data 1995-2015, ICES Sub-division 25, show a decrease in the mean length at 50 % sexual maturity for females from 44 to 24 cm and of males from 35 to 19 cm. Histological analyses performed on samples from five Danish and German cruises (Nov. 2014 to Sept. 2015) reflecting the annual cycle confirmed the early maturation (females maturing from 18 cm, males 17) and participation of small specimens in spawning (females 20 and males 17 cm). The maturation and condition (K) were significantly positively related, i.e. early maturation related to low condition in both sexes (Tomkiewicz et al. in prep.).

- Annual trends in hydrological data in the Bornholm Basin show a moderate higher salinity and oxygen saturation in 2014 and a substantially higher salinity and oxygen concentration in 2015 in the deeper water layer of the Bornholm basin compared to the former years of 2012 and 2013. The vertical distribution of cod is linked to the oxygen and/or salinity concentration with higher abundance in the deeper water layer and data show a linkage between the better environmental conditions and cod fitness, indicating that environmental factors like oxygen concentration and salinity affect cod condition (Oesterwind & Siebert in prep).

Key lessons

A general pattern in Task 2.1 shows that environmental conditions affect the condition and nutritional status of organisms and that prey food quality is an important determinant in consumer fitness. Phytoplankton species composition is an important determinant for ecosystem health as these are the producers of essential compounds available for higher trophic level, such as fish. This is particularly important as results from this task show that conditions of commercial fisheries in the Baltic Sea depend strongly on environmental conditions and prey availability.

A comparison of essential biomolecules between phytoplankton taxonomic groups explains why a more diverse community composition leads to higher production rates of consumers than mono-specific diets. Thus, growth and reproduction of consumers can be constrained by taxonomic composition or food quality of primary producers. Microzooplankton, primary consumers in the pelagic food web can to some extent buffer effects of unbalanced stoichiometric ratios for higher trophic levels. Overall, the use of amino-acid specific carbon (C) stable isotope analysis in this study prove to be a promising tools that can improve our understanding of feeding interactions and Baltic Sea food web models.

For commercially important fish species, results showed that monitoring the growth rate of larvae and evaluation of factors affecting the growth rate should be considered as an important part of the studies related to ecology of larval fish. Further outcomes showed that bottom-up processes, such as prey availability and temperature should be considered among the key drivers for larval and early-juvenile sprat. Information about environmental conditions together with biology is also essential to expand the knowledge about the stock status for Baltic cod, which provides useful advice for sustainable management of the eastern Baltic stock. The finding of relationships between nutritional condition and growth of cod larvae, prey abundance and stock recruitment is a promising tool to validate bottlenecks for cod recruitment. Results provide insights into the complex interaction of the stock with its environmental condition, and are expected to contribute to the development of ecosystem based indicators of reproductive success and management considerations.

Knowledge gaps and future research needs

While processes at the phyto- and zooplankton interface are becoming better understand in terms of nutrient transfer, more research is needed to investigate how essential biomolecules propagate from primary producers to fish. For eastern Baltic cod stock it is still unclear if and how the major Baltic inflow affects the future of the stock. Relating the absence of inflows to cod diet and consumption is a promising tool to investigate the food web consequences of climate change in the Baltic Sea, and to understand changes in growth, condition and sexual maturation of this key commercial species, which needs however more investigation.

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Task 2.2: Top down control

Lead: Monika Winder, P4 SU, participation of P1, P2, P3, P5, P11.

Deliverable 2.2: *Report on effects of changing predation pressure on benthic and pelagic species*. **Month 26.** Accepted by BONUS in 2016, accessible at www.bio-c3.eu/publications.

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Introduction

The quantification of the trophic dynamics between predator and prey and the involved top down processes are of particular importance in understanding marine food webs as shifts in species composition and abundance at higher trophic levels have the potential to propagate through the entire fish web with impacts on lower trophic levels. This is particularly relevant for the Baltic Sea as changes in community composition have been described for nearly all trophic levels, but consequences for ecosystem functioning are only partly understood.

The goal of Task 2.2 was to describe top-down effects of shifts in species dominance on food web composition, functioning and biodiversity using a combination of existing information, field work, experiments, and modelling. We considered different trophic levels, functional groups and habitats, including pelagic, benthic, coastal, and offshore. While the quantification of the trophic dynamics between zooplankton and small pelagic fish and the involved top down and bottom up processes are of particular importance in understanding marine pelagic food webs. Understanding the feeding ecology at lower and higher trophic levels, such as commercial fish species is an essential component need for parameterizing food web models.

Key results and conclusions

- Using two long-term phytoplankton time series (28 and 20 years) from the Baltic Sea, we evaluated coastal and offshore phytoplankton class biovolume patterns over annual and monthly time-scales and assessed their response to environmental drivers and biotic interactions (Griffiths et al. 2015). Coastal phytoplankton responded more strongly to environmental variation than offshore phytoplankton, although the specific environmental driver changed with time scale.

- We used size-fractionation approach and dilution experiments and found that microzooplankton community was able to remove a substantial part of nanophytoplankton (2–20 µm) (78-83 %) and picophytoplankton (0.2–2 µm) (78-130%) standing stock in brackish water lagoon and freshwater (Grinienė et al. in review). These results, when applied to other areas, enable to develop more realistic view on the carbon flow in the Baltic Sea.

- We used video plankton recorder data to investigate if egg sac carrying *Pseudocalanus acuspes* females in the central Baltic Sea, Bornholm Basin showed diel vertical migration patterns (DVM) in the absence of sprat swarming fish. Results show that no DVM pattern can be observed for ovigerous *P. acuspes* females in years with low sprat abundances (Hänselmann et al. in prep.).

- A temporally investigation on the diet, feeding and predation impact of the two dominant planktivorous fish species, sprat (*Sprattus sprattus* L.) and herring (*Clupea harengus* L.) in the southern central Baltic Sea (Bornholm Basin) showed that both were mainly zooplanktivorous feeding on copepods. If integrated over the year, the utilization of the copepod production by both clupeids is comparatively low for the dominant prey species, indicating an overall poor trophic coupling between copepods and pelagic planktivores in the Bornholm basin (Bernreuther et al. 2018).

- Food composition and food selectivity investigations of herring in the Vistula Lagoon showed that the copepod *Eurytemora affinis* was the most important food component and it was highly selected even when significantly decreased in abundance (Vaniala & Margonski in prep.). High survival of early larvae was linked to the coupling of the hatching period with abundance peak of copepod nauplii (match-mismatch). Herring larvae and zooplankton abundance are correlated, suggesting that zooplankton abundance affect herring larvae survival, although the opposite scenario, assuming herring larvae effect on zooplankton abundance by feeding pressure (top-down), cannot be excluded, it seems to be of low probability (Fey & Szkudlarek-Pawełczyk in prep.).

- With a combination of earlier data from field investigations and predator exclusion field experiments, we were able to demonstrate a significant potential of sticklebacks to affect the survival of herring eggs providing that a spatio-temporal overlap is given (Kotterba et al. in prep.). Our results underline the urgent need for standardized monitoring approaches focusing on the Baltic small-fish fauna (not only sticklebacks) within the shallow littoral areas since a noticeable discrepancy exists between the great importance of these organisms for the Baltic ecosystem (including their effect on commercial species such as herring) and the lack of knowledge on their abundances, distributions and ecology.

- Estimations of cod prey consumption as well as benthic biomass and production showed that estimated cod consumption of benthos is sometimes larger than the estimated production, which indicates that cod could have a top-down control of some benthic prey (Asterhag 2016). However, the biomasses of benthic prey species seem to have increased rather than decreased the latest years when the cod condition has decreased. These results are contradicting and indicate that some other factor than food competition of benthic prey seems to be responsible for the declining individual condition in cod.

- Stable isotope analysis of commercial fish species showed the presence of systematic within and between basin differences in isotopic baselines, indicating spatial sub-structure in fish populations even within basins (Mohm & Dierking, in prep.). Three different case studies highlighted (1) spatial differences in cod feeding ecology, with different patterns in ontogenetic shift observed between basins of the Baltic Sea; (2) spatially consistent patterns of competitive interaction in herring and sprat that can help to identify size classes most likely to compete; (3) a surprising degree of intraspecific plasticity in several species.

- A feeding study for two jellyfish species using stable isotope showed the presence of a rapid dietary shift in *Aurelia aurita* within just a few months, and the potential importance of benthic material during part of the year (Javidpour et al. 2016). This study highlighted the potential for stable isotope studies in obtaining high resolution (temporal or spatial) feeding ecology datasets.
- Multispecies model runs imply that the decrease in cod condition is a consequence of decreasing sprat size in the core cod distribution area. Very small cod have to forage on sprat, which are also at the lowest limits of the sprat size distribution. Only a few good sprat recruitments, as observed in two cases in the 1980s, can release the sprat population from predator pressure and hence trophic control by cod.
- The grey seal (*Halichoerus grypus*) population in the Baltic Sea has increased considerably during the last decades, causing conflict between seals and commercial fisheries. Estimation of the magnitude and uncertainty in prey consumption revealed that for the most important commercial species (cod, herring and sprat), catches generally exceeded the seal consumption in the entire Baltic Sea but regionally, seal consumption could be more important (Lundström et al. In prep.).
- Finally, we illustrate the varied nature of benthic-pelagic coupling processes and their potential sensitivity to climate, nutrient loading, and fishing using the Baltic Sea as case study. While quantification of traditional benthic-pelagic coupling processes (e.g. sedimentation of organic matter) occurs to some extent, the magnitude and variability of biological processes, particularly those governed by complex food web feedbacks, are not well quantified. The sensitivity of biological coupling mechanism to all three anthropogenic pressures, however, is high and variable in space and time (Griffiths et al. 2017).

Key lessons

The general outcome of this task indicates that top-down effects are important for specific trophic interactions and that interactions at lower trophic levels are largely understudied. As shown in this task, top-down control at lower trophic levels, like microzooplankton exert a strong effect on primary producers and should be considered in estimating carbon flow in food web models. The study on phytoplankton interactions showed that there is little predictability at the base of the food web at the monthly scale whereas coherent patterns among sites were observed on annual scales reinforcing that temporal scale affects our ability to generalize about taxa and community responses.

For mesozooplankton, studies showed that the copepod *Pseudocalanus acuspes* evolved a behavioural response and a protection mechanism to escape peak predation pressure, which occurs mainly at peak spawning periods of sprat. Predation of the planktivores fish herring and sprat on key copepod species in the Bornholm Basin showed that both were mainly zooplanktivorous feeding on copepods. If integrated over the year, the utilization of the copepod production by both clupeids is however comparatively low for the dominant prey species, indicating an overall poor trophic coupling between copepods and pelagic planktivores in the Bornholm basin (Bernreuther et al. in prep). On the other side, herring larvae in the Vistula Lagoon showed that the copepod *Eurytemora affinis* was an important food component and likely affect herring larvae survival.

Predation studies on small-sized and non-commercial fish species are rare and investigations on their general effect on the recruitment of commercially important species are important. In this task we show that for example sticklebacks affect the survival of herring eggs and demonstrate the need for standardized monitoring approaches focusing on the Baltic small-fish fauna and improved understanding of their population dynamics and ecology.

Stable isotope analysis of Baltic commercial fish species demonstrated that this type of studies are useful to obtain long-term feeding estimates for multiple species and reveal new insights into connectivity of fish populations between and within basins. This is confirmed on a study on jellyfish feeding ecology, showing new insights into carbon source of these organisms. In addition, population dynamics models of Baltic cod, herring and sprat showed that decrease in predator growth rate is decoupled from prey abundance, and that prey is decoupled from cod predation at increasing prey density, which however needs to be further investigated.

Studies further showed that prey consumption by grey seal is uncertain for some prey species and up-to-date diet composition and size estimations as well as distribution and structure of the grey seal population are needed for prey consumption *calculation. Finally,* oxygen availability governs major spatial and temporal dynamics of abiotic and biological interactions between the benthic and pelagic habitats, which result in major inorganic nutrient and organic matter exchange.

Knowledge gaps and future research needs

Within this task, top-down effects of were largely described regionally for specific time period, for example for micro- and mesozooplankton grazing on primary producers. For ecosystem modelling, they should be investigated at Baltic system-wide scale over annual cycles. Similar, little is known about the predation pressure for small-sized fish species, such as on eggs of commercial important species, which should be included in monitoring programs. Future studies should combine diet studies with stable isotope analysis, which can provide useful insight in predator-prey interactions.

Some counterintuitive results were observed with regards to cod consumption of benthos and benthic production and the link between benthos prey availability and declining cod conditions need to be investigated further. Similarly, model runs of cod feeding interactions revealed counter intuitive results and deserves further attention.

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Kotterba P, Hammer C, Peck, MA, Oesterwind, D and Polte, P (in prep.) Resident evil? - Predation on Atlantic herring *Clupea harengus* eggs in vege-tated spawning beds in a Baltic Sea lagoon

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Task 2.3 Changes in food web function and diversity due to non-indigenous species

Lead: Maiju Lehtiniemi, P7 SYKE, participation of P1, P2, P3, P5, P6, P8, P11, P13

Deliverable 2.3: *Report assessing the effects of key NIS on ecosystem functioning*. **Month 40.** Submitted in line with the BIO-C3 schedule of deliverables, accepted in September 2017, and accessible at www.bio-c3.eu/publications.

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Introduction

Biodiversity changes are intimately linked to food web functioning. Changes in species and population distribution and abundance partly reflect the natural dynamics of habitats in the Baltic Sea and partly the growing importance of multiple human drivers including introductions of non-indigenous species. Biodiversity influences food web structure, ecosystem functioning, and stability. Low local species richness and resulting tight trophic links make the Baltic Sea food webs susceptible to impacts of invasion of non-indigenous species NIS). It has been shown and predicted that disturbed aquatic systems are especially susceptible to invasions and appear to be especially vulnerable. Compositional changes due to increasing arrival and establishment of non-indigenous species have been documented for the Baltic Sea and colonization will depend on their physiological adaptation to low salinities, which currently limits invasion. Therefore, food web processes need to be investigated from a physiological and competition aspect to understand the cumulative effects of non-indigenous species and climate change for structure, functioning and consequently biodiversity of the ecosystem.

This task focused on direct and indirect food-web effects of increasing abundance and expanding ranges of NIS as well as habitat engineering through these effects on native populations. Focus was given on the NIS which are expanding along the coastal ecosystems, affecting a range of trophic interactions including direct predation, competition with native species and potential population regulation by their predators and parasites. These NIS provide new trophic links with organisms ranging from mussels and crustacean grazers to fish (e.g. cod, perch) and birds (cormorants), and may indirectly interfere with native species on several trophic levels.

Key results and conclusions

The main focus of the work was to investigate feeding and trophic position of the round goby (*Neogobius melanostomus*) in various areas of the Baltic Sea. The laboratory experiments and field results showed that the round goby is able to effectively consume a diverse variety of prey and it is very flexible and non-selective feeder, preying usually on the most abundant prey. The broad diet suggests that shifting densities of benthic invertebrate prey has little influence on the further dispersal of the round goby in the Baltic Sea as the species is potentially able to switch between several native invertebrate taxa. This opportunistic feeding behaviour has likely favoured the invasion and ensured success of the species in the invaded ecosystem. The results also revealed that the magnitude of interspecific competition with other predators varies widely between Baltic areas and is strong in the central Baltic where round goby has a large effect on blue mussel communities. The task further studied the potential predators of the round goby and showed that at least cod, perch, whitefish and cormorants are preying upon this NIS having potential to regulate population increase in certain areas. With the results, the role of the round goby in the Baltic Sea food webs can be further assessed.

Based on the results of the task the second studied NIS, the Harris mud crabs (*Rhithropanopeus harrisii*) are shown to be mainly second-degree predators utilising a variety of invertebrate prey in the more recently invaded areas (Northern Baltic Sea). Furthermore, they occupy habitats that are very valuable for the coastal ecosystems (*Fucus*- and *Zostera*-beds) and prey upon the grazers in these systems. Conversely, the native predators have adopted the novel item in their diet. Mud crabs are found in the stomachs of several fish, and most often in a generalist benthic predator, the four horned sculpin. The magnitude of the effects of the third studied NIS, the Grass prawn (*Palaemon elegans*) on the food web depends largely on the population densities and the history of the invasion. For example the prawn is a frequent prey to fishes in Lithuania by contributing significantly to perch and cod diets. This implies to at least some potential for predation control over this NIS. Conversely, in the northern parts perch do not seem to prey upon them. Thus regional differences in top-down control are clear and understanding the mechanisms affecting these interactions require more studies. The results on the fourth NIS studied, the *Marenzelleria* spp. polychaetes, indicate their role in significant changes in the Baltic Sea. Due to their unique ability to burrow deeper than native species, they are able to alter the physical characteristics of the sediment and impact the nutrient cycling. From this point of view their impacts can be considered “positive”. However, in other areas they appear to have colonized areas where they may compete with native species. Furthermore, in areas where they are abundant, they can become a frequent component in the diet of predatory fishes. For the fifth studied NIS the American comb jelly (*Mnemiopsis leidyi)*, the results show that low winter temperatures in combination with ocean current connectivity set the scene for their range occupancy in non-native habitats. Highly inter-connected hot-spot areas of the comb jelly *M. leidyi* are important for maintaining populations in northern Europe and especially the Baltic Sea.

Key lessons

- NIS cause various impacts on ecosystem functioning in the Baltic Sea from changing the predator-prey interactions and energy flows in the food web to habitat alteration.
- The types of impacts these species may cause can in some cases be found from earlier studies conducted in other world regions but the task results indicate them to largely differ locally even on a Baltic scale. This means that to construct relevant food web models or management schemes local population information on NIS is highly needed.

- The results of the modelling exercise of the holoplanktonic NIS point out the high risk areas where ballast water release should be prevented by all means without any exceptions.

Applications

- The results of BONUS BIO-C3 task 2.3 research related to the interactions between 8 NIS and native species are currently being used when constructing food web models in the BONUS BLUEWEBS project.
- The results are also used in the ongoing updating process of the HELCOM environmental fact sheets (e.g. round goby fact sheet).

Knowledge gaps and future research needs

- The results obtained in this task concerning predator-prey relationships and prey preferences should be put into a larger framework by modelling tools to gain knowledge on the effects of these species in the whole food web functioning.
- It would be important to assess the most critical donor areas of no-indigenous species both from outside the Baltic Sea to the Baltic, and for the spread of non-indigenous species within the Baltic Sea.
- Furthermore, the assessment of the most vulnerable key habitat forming species as well as the areas in the Baltic Sea where they are in largest danger due to non-indigenous species would be important. This information is crucial for marine spatial planning including marine conservation planning.
- One important consideration for the future work would be research and monitoring considering genotypic change over time for key non-indigenous species.

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Funk, S. 2017. Depth-specific patterns in distribution and food intake of cod (*Gadus morhua*) in the western Baltic Sea; Master thesis, Institute for Hydrobiology and Fisheries Science University of Hamburg. (P3)

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Herlevi, H., Aarnio, K., Puntila, R., Bonsdorff, E. (in review). The food web positioning and trophic niche of the non-indigenous round goby - a comparison between two Baltic Sea populations. (P13 & P7)

Korhonen, A., Master's thesis (in prep): The battle of the prawns – interactions between the invasive Grass prawn (*Palemon elegans*) and the native *Palaemon adsersus.* Katkarapujen taisto – Vieraslaji sirokatkaravun (*Palaemon elegans*) ja alkuperäislaji leväkatkaravun (*P. adspersus*) väliset vuorovaikutukset. In Finnish. (P7)

Kotta, J., Wernberg, T., Jänes, H., Kotta, I., Nurkse, K., Pärnoja, M., Orav-Kotta, H. (in prep): Introduction of a new ecological function causes marine ecosystem regime shift. (P6)

Puntila R., Fowler A., Riipinen K., Vesakoski O. & Lehtiniemi M. (in prep.): Invasive Harris mud crab (*Rhithropanopeus harrisii*) prefers isopod prey in the Northern Baltic Sea. (P7)

Puntila, R., Herlevi, H., Arciszewski, B., Lozys, L., Behrens, J. and Ojaveer, H. (in prep): Feeding preferences of the invasive Round goby (*Neogobius melanostomus*) in the Baltic Sea. (P6, P7, P2, P13)

Puntila, R., Loisa, O., Fowler, A. & Riipinen, K. (in prep.): A taste for aliens? Incorporation of a novel prey item into native fishes diet. (P7)

Puntila, R. et al. (in prep): The abundance and impacts of non-native shrimp *Palaemon elegans* in coastal vegetated habitats in the Gulf of Finland. (P7)

Skabeikis, A., Lesutienė, J. Morkūnė, R. et al. (in prep): An effect of round goby invasion to mussel beds and its consequences to winter diet of the long-tailed duck. (P8)

Skabeikis A. PhD theses (in prep): The role of round goby (*Neogobius melanostomus*) in the food web of SE Baltic Sea open coast food web. (P8)

Smoliński S. (in prep). Effect of non-indigenous round goby (*Neogobius melanostomus*) on the native European flounder (*Platichthys flesus*) biomass density in the southern Baltic Sea. (P5)
Vaitkute K., BS thesis (in prep): The reproduction and population dynamic of invasive prawn *Palaemon elegans*. Invazinės krevetės *Palaemon elegans* reprodukcijos dėsningumai ir gausumo sezoninė dinamika. In Lithuanian. (P8)
Warzocha J. (in prep.) Impact of non-indigenous macrobenthic species on structural and functional diversity in the Vistula Lagoon (Southern Baltic Sea). (P5)

WP3: Natural and anthropogenic drivers of biodiversity

Lead: Helén Andersson, P12 - SMHI

Overview:

WP3 was concerned with the examination of historical and contemporary data and development of models for future scenarios of the spatio-temporal variation of drivers. The ultimate goal was to improve the understanding of environmental changes in the Baltic Sea ecosystem and the specific objectives were to:

- Assemble and synthesis knowledge on spatial patterns and temporal dynamics of various natural and anthropogenic drivers affecting marine biodiversity, including selected socio-economic aspects.
- Identify and quantify the interactions of drivers.
- Assemble and synthesis knowledge on spatial patterns and temporal dynamics of benthic and pelagic habitats and analyses interconnectivity of these habitats.
- Identify vulnerable/critical habitats based on overlay mapping of drivers and habitats.

For this work WP 3 was divided into four different tasks:

Task 3.1 Dynamics of drivers including socio-economy

This task carried out a comprehensive review of drivers of biodiversity in the Baltic Sea, including the assessment of their spatial heterogeneity. Published and unpublished sources, together with most recently established and not yet widely accessible databases were exploited. The pressures were reviewed concerning status, impact and outlook or model.

Task 3.2 Driver interactions

This task investigated a set of key interactions of selected natural and anthropogenic drivers in space and time, e.g., physico-chemical features *vs* climate forcing; eutrophication *vs* oxygen deficiency *vs* bio-invasions; fisheries *vs* climate change impacts by using overlay-mapping and sensitivity analyses. The benthic ecosystem models developed under Task 2.1 were used to investigate interactions between sea temperature and eutrophication for various depth strata in coastal and offshore areas of the Baltic Sea. This also included investigation on how the frequency and magnitude of deep-water inflow events determines volume and variance of salinity and temperature under the halocline, deep-water oxygen levels and sediment fluxes of nutrients, using observations and model results from 1850 to present.

Task 3.3 Connectivity

Analyses of the connectivity patterns and processes in shallow coastal and offshore areas were performed for selected species. Effects of predicted changes in environmental forcing (e.g. climate alteration) on transport and connectivity within coastal meta-populations were explored. The task covered a range of species from macro-algae to fish and native and non-native species. Studies included large-scale analyses of the whole Baltic Sea as well as detailed, highly-resolved studies of sub-basins. A case where connectivity is largely controlled by organism migration was also covered where empirical methods of acoustic surveys, trawling and stomach analysis were used. This task also included an analysis of potential changes of connectivity assuming a changing climate using scenario modelling.

Task 3.4 Dynamics of habitats in space and time under driver forcing

This task investigated spatial patterns and temporal dynamics of benthic and pelagic habitats at fine-scale resolution in coastal and offshore areas in the south-western and central-northern Baltic Sea. This was based on empirical data from national surveys and monitoring activities and predictors processed from the benthic ecosystem models. In addition, scenarios of the combined impact of nutrient loads and climate change were used to investigate climate-related changes of salinity and oxygen in order to derive indicators relating the environmental pressures to habitat impacts.

The work in WP3 was completed without major deviations from the original work plan. The deliverable D3.1 “*Report on patterns and dynamic of drivers of biodiversity”* was completed in 2015, D3.2 “*Report on the nature and types of driver interactions including their potential future*” and D3.3 “*Report on the importance of connectivity as a driver of biodiversity (populations, species, communities, habitats)*” in 2016, and D3.4 “*Report on dynamics of benthic and pelagic habitats in space and time under different driver forcing, including identification of vulnerable habitats*” in the 2017 reporting period. All four deliverable reports are available online on our BIO-C3 website www.bio-c3.eu/publications.

Task 3.1: Dynamics of drivers including socio-economy (Month 1-24)

Lead: Daniel Oesterwind, P11 TI-OF, participation of P1, P2, P6, P8, P9.

Deliverable 3.1: *Report on patterns and dynamic of drivers of biodiversity (species, communities, habitats) across Baltic Sea ecosystems in space and time including socio-economy.* **Month 26**. Accepted by BONUS, available at www.bio-c3.eu/publications.

Reference:

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*. BONUS BIO-C3 Deliverable, D3.1. 102 pp. DOI 10.3289/BIO-C3_D3.1.

Introduction

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 2013a) 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. However, the task presents a comprehensive review of pressures on biodiversity in the Baltic Sea. Published and unpublished sources, together with most recently established and not yet widely accessible databases (e.g. AquaNIS) were included. Furthermore the dynamics of hydro-climatic conditions and eutrophication were analysed based on conducted ecosystem models. Beside those aspects a socio-economic analysis of different drivers and pressures were performed. However, even if the task report is not intended to be exhaustive, it can be assumed that the most prominent and important human induced pressures are included.

Key results and conclusions

An analysis by BIO-C3 revealed that the terms “drivers” and “pressures” are used and understood differently by different stakeholders. To avoid confusion and facilitate future discussions, we recommend a clear definition of the terms, and embedding these definitions into the DPSIR framework. Ultimately, this more comprehensive approach and terminology will assist discussions to establish the causalities of the observed status changes in the ecosystem (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, the small 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.

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).

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).

In the Baltic Sea, fishing has been documented to have affected both, the dynamics of target species as well as 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).
The stock size of plaice in the Baltic Sea including the Kattegat and the stock size of flounder in the south-western Baltic Sea has substantially increased in later years under stable or declining fishing pressure in contrast to a declining stock size of flounders in the eastern Baltic Sea due to an increasing fishing pressure. The harvest rate of salmon has decreased considerably since the beginning of the 1990s.

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.

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, 2013b & IPCC, 2014).

Beside the temperature the salinity conditions have various impacts on the environment e.g. on the reproduction of marine fish populations. All pelagic spawning species 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.

Modelling approaches 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 the forecasting of the below halocline or near bottom acidification reaching further than a couple of years is uncertain. However, studies 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). Impacts on primary producers 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).

Key lessons

- A clear communication between scientists, stakeholders and policy makers is the basis for a scientific based management. Therefore in our case we appeal for a consistent agreement on the Driver-Pressure- State- Impact-Response Framework (DPSIR) with a consistent definition of the terminology to communicate the scientific results in a coherent way.
- For their strategy, decision makers should have in mind 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.
- While the impact of some pressures is assessable, some human induced pressures are measurable but the impact on the ecosystem is still unclear. Therefore research on the impacts of different pressures should be increased to figure out if those pressures have to be included into the management strategy. Otherwise it might be happen that the management policy failed due a wrong management strategy which is based on a wrong selection of manageable pressures.
- Two groups of pressures have to be differentiated: pressures which are manageable and pressures which are not manageable. For the management success it is very important to distinguish between both and to concentrate on the manageable.

Knowledge gaps and future research needs

- Important knowledge gaps regarding pressures, as well as their interaction, in the Baltic Sea are remaining, and closing these gaps will be an essential task to improve the knowledge base for Baltic Sea resource management.

- Some potentially important pressures, like noise and marine litter, have not been well characterized, and/or monitoring data are missing. Such “novel” or little assessed pressures should be addressed as soon as possible.

- At present, critical information on even the most widespread (and potentially highly impacting) NIS in the Baltic Sea is fragmentary or missing. Research on ecological effects of non-indigenous species (NIS) should be intensified.

- Information about the spatial heterogeneity of different pressures is lacking, but is essential in the highly heterogenous Baltic Sea ecosystem. This needs to be incorporated in scientific studies and monitoring programs.

- Due to the nature of climate models and their uncertainty, the complex set of conditions triggering major Baltic sea inflow events (with their strong hydrographic “downstream” consequences), and the complex carbon chemistry and mineralization and remineralization processes within anoxic or hypoxic waters, the forecasting of the below halocline or near bottom acidification is currently difficult. Reliable estimates reaching further than a couple of years would be a major step forward in our projections of future Baltic conditions. In this context, the impact o of ocean acidification on species inhabiting the highly diverse pH-environment of the Baltic Sea is as yet also poorly understood or lacking (e.g., for zooplankton), and should be a focus of future research.

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Task 3.2 Driver interactions

Lead: Jonne Kotta, P6 UT-EMI, participation of P1, P2, P9, P12.

Deliverable 3.2: *Report on the nature and types of driver interactions including their potential future.* **Month 32.** Accepted by BONUS, available at www.bio-c3.eu/publications.

Reference:

Kotta, J., Almroth-Rosell, E., Andersson, H. c., Eero, M., Eilola, K., Hinrichsen, H. H., Jänes, H., MacKenzie, B., Meier, H. E. M., Ojaveer, H., Pärnoja, M., Skov, H. and von Dewitz, B. (2016) *Report on the nature and types of driver interactions including their potential future.* . BIO-C3 Deliverable, D3.2. , 110 pp. DOI 10.3289/BIO-C3_D3.2.

Introduction

The Baltic Sea is a dynamic environment responding to various drivers operating at different temporal and spatial scales. In response to climate change, the Baltic Sea is warming and the frequency of extreme climatic events is increasing. Coastal development, human population growth and globalization intensify stressors associated with human activities, such as nutrient loading, fisheries and proliferation of non-indigenous and bloom-forming species. Such abrupt changes have consequences for the biodiversity and the function of food webs and may result in loss of ecological key species, alteration and fragmentation of habitats. To mitigate undesired effects on the Baltic ecosystem, efficient marine management depends on the understanding of historical and current drivers, i.e. physical and chemical environmental conditions and human activities that exert pressures on the environment.

A key objective of the task 3.2 was to develop scenarios of spatio-temporally varying pressures of human stressors and their interaction considering natural as well as socio-economic drivers to characterize historic, current and future habitats in the Baltic Sea.

The aims and goals of Task 3.2 were divided between 5 different project partners (P1, P2, P6, P9, P12), who covered a range of topics from abiotic climate forcings to biological interactions of fauna and flora as well as to economically important topics such as fishing and shipping. We specifically investigated a set of key interactions of selected natural and anthropogenic drivers in space and time, identified in Task 3.1 as well as WP1 and WP2 (e.g., physico-chemical features vs climate forcing; eutrophication vs oxygen deficiency vs bio-invasions; fisheries vs climate change impacts) by using overlay-mapping and sensitivity analyses.

The deliverable 3.2 was divided into 8 subsections as follows:

1. Baltic inflow events and the prediction of the eastern Baltic cod spawning environment (P1)
2. Impact of increased eutrophication on production of forage fish in the 20th century (P2)
3. Current status of shipping in the Baltic Sea (P6)
4. Current status of fishing in the Baltic Sea (P6)
5. Current status of non-indigenous species (NIS) in the Baltic Sea (P6)
6. Interactions between eutrophication and temperature (P9)
7. Relationships between Baltic Sea inflows and physical and biochemical parameters (P12)
8. Habitat sensitivity to eutrophication of selected pelagic species in the Baltic Sea (P1)

Key results and conclusions

This task examined a set of key interactions of natural and anthropogenic drivers in space and time, identified in Task 3.1 as well as WP1 and WP2 (e.g. physico-chemical features vs climate forcing; eutrophication vs oxygen deficiency vs bio-invasions; fisheries vs climate change impacts) by using overlay-mapping and sensitivity analyses. The benthic ecosystem models developed under Task 2.1 were used to investigate interactions between sea temperature and eutrophication for various depth strata in coastal (P9) and offshore areas (P1) of the Baltic Sea. This also included investigation on how the frequency and magnitude of deep-water inflow events determines volume and variance of salinity and temperature under the halocline, deep-water oxygen levels and sediment fluxes of nutrients, using observations and model results from 1850 to present (Eero et al. 2016, Ojaveer et al 2017, Hordoir et al 2017, Eilola et al 2014, Almroth-Rosell et al 2015; P1, P2, P6, P9, P12).

Key conclusions included:

- The main factor determining the dynamics of suitable water masses for cod reproduction in the eastern Baltic Sea is the advection of highly saline and well-oxygenated water masses from the North Sea. We observed high correlations between mid-depth salinity levels in the Arkona Basin early in the year and the oxygen-dependent cod spawning environment in the Bornholm Basin.
- Historically, eutrophication enhanced the biomass level of forage fish by up to 50 % in individual years and areas. However, major trends in sprat biomass in past decades have occurred independently of nutrient dynamics, largely driven by climate and top-down control (predation, fishing).

- Regarding shipping, the most intensive traffic occurs in the central Baltic Sea and the Gulf of Finland. The volume of transported goods has increased substantially in recent decades, and is expected to double again by 2050. Intensively used shipping routes can have negative impacts (e.g., disturbance, oil spills) on areas of high ecological value.
- We found that out of the total of 132 non-indigenous species (NIS) recorded for the Baltic Sea, 59 % are established in at least one country. On average, each country currently hosts 27 NIS, with 15 % of the established species found in at least 50 % of the countries. Benthic macroinvertebrates dominate. Shipping, deliberate stocking and natural spread of NIS previously introduced to the North Sea are the main introduction pathways, with considerable dynamics over time. However, uncertainty in the information on introduction pathways hampers detailed analyses and poses major challenges for management. Spatio-temporal variability in the invasion dynamics reflects the environmental gradients throughout the Baltic Sea as well as different introduction pathways. We conclude that the Baltic Sea cannot be considered as a uniform waterbody in terms of the established NIS and at least two major regions with differing hydrographic conditions and introduction pathways can be clearly distinguished.
- In the Baltic, sea level rise may be associated with an intensified ventilation as saltwater inflows become stronger, longer, and more frequent. In particular, we modeled that a sea level rise of 1 m would result in a salinity increase by 1 PSU in the deeper Baltic, due to the increasing cross section of the Danish Straits amplified by reduced vertical mixing.
- Regarding eutrophication, we consider the direct impact of major Baltic inflows on the annual uplift of nutrients from below the halocline to the surface waters as low, with vertical transports comparably large also during periods without inflows. Our model results further suggest that phosphorus released from the sediments between 60 and 100 m depth in the East Gotland Basin contributes to eutrophication, especially in the coastal regions of the eastern Baltic Proper.
- Our models indicate that habitats in the eastern Baltic sub basins Gdansk Deep and Gotland Basin will be more sensitive to changes in eutrophication than the Bornholm Basin and western Baltic. Under decreasing eutrophication scenarios, the eastern areas showed large potential to provide suitable habitats for Eastern Baltic cod and flounder reproduction. At the same time, under increasing eutrophication, the Bornholm Basin spawning habitat quality for cod would also decline, with lower survival chances of eggs and larvae spawned by young females of the stock. The inflow events remain the most influential mechanism determining habitat extensions and quality in the Baltic Sea, but curbing eutrophication could dampen the effect of less frequent inflow events.

Key lessons

Activities in Task 3.2 resulted in multiple lessons with management implications, including:

- The International Council for the Exploration of the Seas (ICES) specifically acknowledged the need to develop and identify ways forward to include environmental and economic considerations in standard fishery advice. Our finding that future oxygen conditions in the Bornholm Basin, the major spawning ground for eastern Baltic cod, can be predicted based on measurements made in the western Baltic suggest a possible way forward in towards integrated advice for Baltic cod management. For short-term predictions already existing observational platforms can be used, whereas additional salinity measurements using new platforms at the Darss Sill, the Drogden Sill, and in the centre of the Arkona Basin would further improve the performance of short-term predictions.

- For sprat management, the effect of eutrophication appears minor compared to the more than fivefold fluctuations in sprat biomass that have occurred over time due to other drivers. Future biomass trajectories may thus not follow changes in nutrient dynamics, but will probably largely depend on other ecosystem and climate conditions.
- Projected future changes in shipping will result in cross-disciplinary conflicts with environmental protection and fisheries. Specifically, intensively used shipping routes can have negative impacts (disturbance, oil spills etc.) on areas of high ecological value. Sensitive areas should be avoided wherever possible, although this may entail commercial and environmental conflicts related to fuel consumption, since rerouting will increase the travel distances and result in potentially higher costs and CO_2 emissions.
- BIO-C3 work indicated a lack of knowledge regarding Baltic specific physical tolerance levels of different organisms. Most of the information we have about habitat characteristics, also put together in Task 1.1 of this project, is derived from field observations. To produce future distribution maps and species composition scenarios in the Baltic through modelling exercises this gap would need to be closed.

Knowledge gaps and future research needs

- A number of caveats were identified under the Core Activity 4 of the Task 3.2 relative to the fishing pressure maps produced (ICES 2015). In particular, (1) methods to identify fishing activity from the VMS data varied between countries; therefore there may be country-specific biases that ICES cannot evaluate. Additionally, activities other than active towing of gear may have been incorrectly identified as fishing activity, which would lead to an overestimating of fishing intensity. (2) Many countries have substantial fleets of smaller vessels not equipped with VMS (<15 m prior to 2012, <12 m thereafter); logbook data were use in these cases but resolution relative to VMS data needs to be checked. (3) The fishing abrasion pressure methodology is based on broad assumptions. A single speed and gear width was applied across each gear category here, which can lead to both under- and overestimates in actual surface and subsurface abrasion. These considerations need to be addressed to harmonise the data recording by countries and to improve spatial estimates of fishing pressure at the pan-Baltic scale.
- The Core Activity 5 suggested that the knowledge on the impacts of non-indigenous species (NIS) is very limited and should stand as one of the major research fields in the future, the outcomes of which should not only contribute to the advanced understanding of ecosystem structure and dynamics, but also be utilized in ecosystem-based management decisions. Prior to the systematic and comprehensive evaluation of NIS impacts, the respective framework needs to be first designed and tested.

- Core activies 1 and 7 showed that the effect of sea level rise on the overall haline structure of the Baltic Sea, as well as the coupling of inflows with biogeochemical and biological (e.g., cod reproductive volume) characteristics, require further investigation. This is also true for the time-scale of sediment uptake of phosphate, and ecosystem effects of deep water uplifting, e.g., acidification.
- Finally, our analysis under Core Activity 8 revealed significant knowledge gaps regarding the physical tolerance levels of pelagic organisms, despite their importance for reliable scenario-specific species distribution maps.

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<u>Task 3.3: Connectivity (Month 8-32)</u>

Lead: Per Jonsson, P10 UGOT, participation of P1, P6, P10, P11, P13.

Deliverable 3.3: *Report on the importance of connectivity as a driver of biodiversity (populations, species, communities, habitats).* **Month 34.** Accepted by BONUS, available at www.bio-c3.eu/publications.

Reference:

Jonsson, P. R., Hinrichsen, H. H., Kotta, J., Kotterba, P., Middelboe, A. L., Oesterwind, D. and Bonsdorff, E. (2016) *Report on the importance of connectivity as a driver of biodiversity (populations, species, communities, habitats)* . BIO-C3 Deliverable, D3.3. EU BONUS project BIO-C3, 27 pp. DOI 10.3289/BIO-C3_D3.3.

Introduction

Most species occur as metapopulations (Hanski 1999) where more or less spatially separated subpopulations interact through dispersal. We here use dispersal in a broad sense including organism movements that may affect either demography or gene flow. The dispersal between subpopulations determines their connectivity where immigration may lead to new colonization, density-dependent competition, and gene flow if immigrants are reproductively successful. On ecological time scales dispersal reduces the risk of local extinctions and on evolutionary time scales the realized gene flow affects genetic diversity and evolution of local adaptations (Sanford and Kelly 2011). Metapopulation dynamics is particularly relevant in spatial management of harvested stocks and conservation, e.g. through marine protected areas (MPA) where it is assumed that populations will persist in often small and widely separated habitats, preferably also with a positive effect on unprotected areas (Jonsson et al. 2016). The Baltic Sea has a complex circulation pattern with multiple basins and connectivity in the Baltic seascape is presently poorly known. The Baltic Sea is also expected to be particularly impacted by global change (e.g. Kotta et al. 2014) and an important question is if this may also change connectivity (e.g. Gerber et al. 2014).

Within WP 3.3 we aimed to estimate connectivity and its variability on the scale of the whole Baltic Sea as well as with a detailed study of the Gulf of Riga. This was carried out for a selection of species including macroalgae, invertebrates, fish and one invasive species. WP 3.3 also includes predictions of future connectivity based on climate scenario models. Most studies are based on bio-physical modelling (e.g. Hinrichsen et al. 2016a), but also empirical approaches, e.g. using acoustic sampling of fish were employed.

The overall objectives were to understand how different parts of the Baltic Sea may be linked through dispersal and where we may expect dispersal barriers, and how this differs for species with different dispersal strategies. Examples are studies of relative effects of habitat quality, larval dispersal and food availability for bivalve recruitment, stock mixing of cod, connectivity between coast and offshore for herring, and spread of an invasive comb-jelly. This information is important when identifying management and evolutionary significant units. Results from WP 3.3 are also used within WP 3.4 to combine connectivity and habitat/species distribution models into model predictions of metapopulation persistence. The estimates of connectivity within WP 3.3 is also essential in the assessment of marine protected areas (MPAs) and network properties in WP 5.2.

Key results and conclusions

A biophysical model covering the whole Baltic Sea showed that there are large geographic differences of dispersal distance in the Baltic seascape. Distances become shorter in the Gulf of Bothnia and in the Gulf of Finland compared to the Baltic proper. Dispersal distances also significantly depend on the dispersal strategy where pelagic larval duration and drift depth are important traits. Based on modelled connectivity it was possible to identify the major dispersal barriers in the Baltic Sea showing that connectivity along coasts within sub-basins is generally high but that there exist several inter-basin barriers. This indicates the scale of local adaptations and possible management units. Another study focusing on the variability of Baltic Sea connectivity between years showed that there are several consistent patterns across years, which suggests that it is meaningful to generalize connectivity also over longer time scales. This insight is important for including connectivity into management strategies. Since dispersal and connectivity are important drivers of biodiversity the task 3.3 also included an attempt to explore possible changes in connectivity caused by climate-driven changes of the environment. Based on future predictions of ocean circulation and temperature bio-physical and metabolic modelling suggested that dispersal distance may on average increase, especially in the southern Baltic. 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.

In addition to the large-scale general model predictions of Baltic Sea connectivity one high-resolution focus study was also included in task 3.3. A detailed bio-physical model of the Gulf of Riga showed that settlement areas varied significantly between years, and that the intensity of larval settlement was strongly correlated with food availability and dispersal duration. It is suggested that biophysical models can be a versatile tool to develop management strategies and in decision support, e.g. guiding design and assessment of protected areas (see D 5.2).

The dispersal of fish eggs and larvae, e.g. of flounder and cod (Hinrichsen et al. 2016b, c), is particularly sensitive to water density and the occurrence of hypoxic areas. Bio-physical modelling showed that ocean circulation together with egg buoyancy and bathymetry may act to reduce connectivity between the basins in central and eastern Baltic, which supports actions to consider these as separate management units (Hüssy et al. 2016). Also from otolith and model studies of the potential mixing between the Eastern and Western cod stocks it was concluded that egg and larval connectivity was low between the areas mainly because of low survival of immigrants. In contrast, modelled dispersal of cod eggs and larvae showed that connectivity is high within the transition zone between Kattegat and the Baltic Sea (Huwer et al. 2016). The cod in this area is likely demographically correlated.

Movement of organisms may constitute a significant flow of biomass between environments and also change the intensity of ecological interactions like competition and predation. This type of habitat connectivity was studied within task 3.3 with herring as a model where spawning individuals migrate from offshore feeding areas to coastal spawning beds. Acoustic and trawling surveys showed that often sensitive inshore waters may be highly important for offshore fish, and that the temporary spawning population may transfer massive biomass. Surprisingly, the predation rate was found to be low on herring larvae within inshore waters (Kotterba et al. 2017). Also, a novel finding was that adult herring consumed large numbers of estuarine fish, mainly gobies, highlighting the potential food-web consequences of mass migrations.

A bio-physical model was also used to show how to identify sources of invasive species. A model of dispersal of the comb-jelly *Mnemiopsis leidyi* suggested that the transition between the North Sea and the Baltic Sea within Limfjorden may act as a refuge and may re-seed Kattegat and the southern Baltic after years with local extinction.

Finally, task 3.3 also included one study about evolutionary consequences of connectivity. A combined approach using a population genetic analysis and a larval dispersal model was used to understand the processes responsible for the hybrid zone of the blue mussel species *Mytilus trossulus* and *M. edulis* (Stuckas et al. 2017). Results suggested that dispersal distances of larvae are generally too short to explain the extended cline in allele frequencies across the Kattegat-Baltic Sea transition.

In summary, task 3.3 presents maps of how connectivity of eggs, spores and larvae are expected to vary within the Baltic Sea, and also how dispersal distance is expected to change in the future. This general information is complemented with a number of focus studies exploring in detail how dispersal and connectivity may affect patterns of recruitment, stock separation, transport of biomass, and invasion routes of non-native species.

Key lessons

There is no sub-basin that is totally isolated although most dispersal occurs within sub-basins, indicating that basin-scale is of the same magnitude as the tail of the dispersal distance distribution in most cases. The area-specific dispersal distance should also guide the design of MPAs where mean dispersal distance will indicate the MPA size resulting in sufficient local retention and recruitment. The analysis of partial dispersal barriers may indicate the presence of unique local adaptations to different regions in the strong Baltic Sea environmental gradients. Barriers may also slow down recolonization and reduce resilience to regional disturbances, and barriers may impede range shifts as a response to future climate.

The task also included a case study with the Gulf of Riga where a fine-scale hydrodynamic model was combined with ecological and agent-based modelling. This study illustrates an efficient tool at the scale of marine planning can be developed, e.g. for management of marine protected areas (MPA) where connectivity is implemented.

Task 3.3 also included a unique model of future connectivity where the projected increase in dispersal distance, mainly in the southern Baltic Sea will affect local retention and connectivity between sub-basins in the Baltic Sea. This may increase stock mixing and also the spread of non-native species. The increased dispersal distance in many areas may also cause lower local retention within MPAs, and may call for a revision of some MPAs.

A large part of Task 3.3 considered connectivity of fish eggs and larvae. Models of cod egg buoyancy in relation to topographic features suggest that sills and strong bottom slopes could appear as a barrier and may limit the connectivity of Baltic cod early life stages between the different basins in the western and eastern Baltic Sea. This supports actions to consider these populations as separate management units.

The study supports the recent change to stock-specific management rather than management of fixed geographical areas (SD 22-24), and it is recommended that the monitoring of proportion of “Eastern” and “Western” cod populations within the western Baltic Sea is continued.

The high exchange rate of modelled larvae between areas suggest that these are demographically correlated. The combined effects of adult homing and the suggested high exchange of early life stages make spatial management in this region complex. This calls for better understanding of realized connectivity and further development of stock assessment models.

Our results indicate a great importance of inshore waters for the successful reproduction of an ocean-going commercial fish species. Considering the ubiquity of anadromous species among economically and ecologically important fish species, our studies highlight the importance of increasing our knowledge on the functioning and vulnerability of inshore systems in order to establish a sustainable utilization of these marine resources. Besides the impact on the recruitment of commercial species, the relevance of the connectivity between offshore and inshore systems for the resident communities (including non-commercial but ecologically important species) needs to be evaluated.

The drift model results combined with empirical observations suggest that Limfjorden has the potential to act as source region seeding *M. leidyi* into the Baltic Sea, hence assuring reinvasions after extinction of local *M. leidyi* populations following harsh winter conditions.

Applications

Results on connectivity within Task 3.3 are already used by the Swedish Agency for Marine and Water Management in the revision of MPA network. Also, HELCOM has discussed these results in connection with the Seventh Meeting of the HELCOM Working Group on the State of the Environment and Nature Conservation (STATE & CONSERVATION 7-2017) October 22-27, 2017 in Sopot, Poland.

Knowledge gaps and future research needs

Much of the connectivity analyses in Task 3.3 are based on biophysical models, where the core is hind-cast predictions of ocean circulation. In this project, state-of-the-art circulation models were used. However, there are still much room for future improvement of oceanographic models, e.g. higher spatial resolution of bathymetry and forcing data, as well as inclusion of some missing transport process, e.g. Stokes drift due to gravity waves. There are still much uncertainty of important biological traits that may affect dispersal, e.g. drift depth of larvae, ontogenetic shifts in drift depth, and settling behavior. Connectivity estimated from biophysical models also needs validation, where possible, with genetic data, which is an important task for the future. Also, Task 3.3 mainly considered dispersal where oceanographic water transport is important (with the exception of the acoustic study of active migration of herring). Many species, mainly fish and marine mammals, disperse through active migration and here methods other than biophysical models have to be used, e.g. mark-recapture or active tracking, which is an area where future development of data-storage tags and cheap GPS tracking look promising.

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Task 3.4 Dynamics of habitats in space and time under driver forcing (Month 14-38)

Lead: Helén Andersson, P12 SMHI, participation of P2, P6, P8, P9, P11

Deliverable 3.4: *Report on dynamics of benthic and pelagic habitats in space and time under different driver forcing, including identification of vulnerable habitats.* **Month 40.** Accepted by BONUS, available at www.bio-c3.eu/publications.

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Introduction

The Baltic Sea is one of the world´s largest estuaries with limited water exchange with adjacent seas but with major Baltic inflows (MBIs) that are a prominent feature for this area. In the Baltic Sea the frequencies and magnitudes of the MBIs are important as they impact for instance the oxygen levels and nutrient concentrations in the Baltic Sea. It has a unique setting with its brackish water environment where relatively few species have had the ability to adapt, even though the species are of both marine and freshwater origin. This sea is a dynamic environment that responds to various drivers at different temporal and spatial scales. Changes in drivers will affect the Baltic Sea and change the prerequisites of the current ecosystem. The area is also exposed to many anthropogenic stressors e.g. pollutions and ship trafficking. Pollution of different sorts is brought to the sea by diffusive flow, point sources and with the river discharge. The ship traffic is among the heaviest in the world and can potentially increase both biological (e. g., introduction of non-native species) and chemical pollution. Altogether, this has made the Baltic Sea a much polluted inland sea with huge problems with eutrophication and consequently, harmful algal blooms and large hypoxic areas. This stressed marine environment is, and will be further, pressured by the ongoing climate change. 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 ocean acidification. Furthermore, increased precipitation and river runoff are projected, which will increase the nutrient loads from land to the sea that have the potential to affect the biogeochemical processes. Consequently, the marine habitats may change in a number of ways, which will have different implications on the different life stages of the inhabitant species. However, the changes could also give habitat advantages to non-native species, which also will impact the current ecosystem structure and functioning.

It is of great importance to understand how the changes in the different drivers impact the dynamics of current habitats in the Baltic Sea and how environmental changes, from e.g. eutrophication and climate change will change the habitats in different parts and on different temporal and spatial scales. This was the overall objective of task 3.4, which will aid to the understanding on how resilient the system is to changes, identify trends and predict future changes in biodiversity.

This task was central within BIO-C3 as it interlinked with all other WP's, e.g. using tolerance and threshold knowledge generated under WP1 and 2 and the outcome of the task feed into hind- and forecasting under WP3. The outcomes of the task are also essential for other work packages, e.g. WP4 where BONUS BIO-C3 wants to assess the impacts of changing biodiversity on ecosystem functioning. It is also feeding into WP5 through input to the understanding on how management of e.g. pollution and non- indigenous species can influence biodiversity and through input on relevant indicators of biodiversity and environmental change.

Key results and conclusions

The WP 3.4 produced many different studies and many extensive datasets, both observational and from models. The results show that eutrophication and climate change causes oxygen levels to decline in many benthic areas in the Baltic Sea (Wåhlström et. al. in D3.4) and consequently, there is an increased risk of frequent periods with hypoxia or anoxia. It is evident that this will cause a decline in the size and extent of benthic habitats and may have contributed to the decline of e.g. the Western Baltic Spring Spawning Herring due to lower oxygen levels in preferred spawning areas. However, other studies within task 3.4 suggest that many species could benefit from expected environmental changes; e.g. climate-change related warming could give enhanced biomasses of some species through the positive relation between temperature and growth (Kotta et al. 2014). A larger threat to native species can be the impact of invasive species, as seen on the rapid decline of blue mussels at the Lithuanian coast (Šiaulys et. al., in D3.4).

Benthic species display patchiness in their distribution and it was concluded that this gives important implications for the requirement of high-resolution model data, in order to establish status and trends of benthic habitats (Skov et. al., in preparation). An investigation on the possibility to create high-resolution biodiversity maps from special predictive modelling, biodiversity data and georeferenced environmental data layers where performed.

The results were encouraging, with high correlation between observations and models in studied areas (Peterson et. al, 2017).

Many of the Baltic Sea habitats are conditioned by the larger scale water circulation. A study within the task on the influence of the recent MBIs and the consequential re-oxygenation of Baltic proper showed that the deep water had a large impact on benthic nutrient fluxes (Hall et. al., 2017). There was an observed increase in the DIN:DIP relation in the water column, showing the significant influence of MBIs on the eutrophication status. The results from another model study indicate that the largest inter-annual coherence of phytoplankton is with the limiting nutrient (Hieronymus et. al., in review). The interannual variations have affected the primary production mostly through the limiting nutrient phosphate before 1950. After that nutrients and phytoplankton exists in the water column at such high concentrations that smaller interannual variations have much less effect.

The future evolution of MBI occurrences is still uncertain. A model study in the task reveals that there are indications of a decreasing overturning circulation under climate change (Hordoir et. al., 2017). The different IPCC climate scenarios analyzed show the importance of mitigation of greenhouse-gas concentrations and that the future marine changes in salinity, temperature, nutrients etc. will be more drastic in the higher emission scenarios (Hordoir et. al., 2017, Wåhlström et. al., in D3.4). Due to these changes, the cod reproductive volume, which depends on the both salinity and oxygen, might decrease in a future climate (Wåhlström et. al., in D3.4). Furthermore, to combat eutrophication a successful implementation of the HELCOM Baltic Sea Action Plan will be of even more importance in a warmer world (Wåhlström et. al., in D3.4).

Key lessons

The already stressed marine environment in the Baltic Sea will be further pressured by the ongoing climate change and in addition, the nutrient load from land will probably increase in a the future climate. These pressures may change the marine habitats in a number of ways, both positive and negative, which will have different implications on different life stages of the inhabitant species, e.g. a decrease in the size and extent of the spawning area for the western Baltic herring due to lower oxygen levels. However, the changes could also give habitat advantages to non-native species, which will have the potential to impact the current ecosystem structure and functioning.

Implications for the requirement of high-resolution model data and with repeated *in situ* measurements is important data in order to establish status and trends of marine habitats. Furthermore, to combat eutrophication in this area, a successful implementation of the HELCOM Baltic Sea Action Plan will be of even more importance under the pressure from climate change.

Knowledge gaps and future research needs

The spatial distribution and productivity of the biota in the Baltic Sea are heavily influenced by the hydrographic conditions, especially salinity, temperature and oxygen conditions. As a result, changes in these conditions can be expected to have major impacts on biota distribution, as well as on the overall biodiversity and functioning of Baltic Sea ecosystems and food webs.

It is imperative to understand the fundamental processes governing the Baltic Sea marine environment and how climate change will alter the present state. Further, it is necessary to understand the rate of predicted changes since this will influence species ability to adapt to new conditions. For instance, climate change is projected to increase the sea temperatures and the increase will likely be higher than the increase in global mean temperature. Precipitation is also expected to increase in the area, which can lead to reduced salinities. Improvements of process understanding and descriptions in global and regional climate models will aid the efforts to reduce the uncertainty of today's climate projections.

The major Baltic inflows (MBIs), occur irregularly and have a significant impact on the marine ecosystem since biogeochemical processes and nutrient fluxes from the sediments are different in oxygenated and anoxic environments. Further research is needed to understand how these will change and impact the future Baltic Sea, so is the link between MBIs and the Baltic proper phosphorous and nitrogen budgets. Climate change has also been shown to alter ecological quality indicators, nutrient fluxes and transports in the Baltic Sea and also here further research is needed in order to understand processes and future changes. Since the ecosystem is usually more sensitive to extreme values, more than changes in mean values (lower salinity or oxygen extremes for example), there is also reasons to further understand future variability and extremes in the drivers.

It is fair to assume that future ecosystem services will change relative present ones. Both improvements of monitoring and modelling tools will aid our understanding of these changes. These are both essential in order to help managers to establish marine protected areas that can resist the projected influences of climate change and thereby minimizing the risk of population collapses. Modelling efforts can also help to provide information where there is lack of national and international monitoring, e.g. with ecosystem models that can strengthen the assessment of the status of protected areas. For instance, marine benthic habitats are difficult to reach and are therefore expensive and time consuming to study and consequently, have poor spatial and historical data coverage compared to terrestrial habitats. For that reason, modeling techniques and remote sensing applications are especially needful in marine environment to fill in data gaps in both space and time. More than providing *in-situ* estimates of biomass and productivity, the models could also be used to predict changes in populations under different regimes of eutrophication and identify the main drivers within the interplay between environmental changes and anthropogenic pressures. However, shallow areas are significantly more diverse and heterogeneous compared to deep areas, and thus, higher number of sampling sites are necessary in shallower areas to reflect natural patterns.

The temporal aspects of distribution modeling, i.e. how species distributions and relationships between biota and environment change over time, have largely remained unstudied. Moreover, biotic interactions (e.g. competition, predation, grazing) are commonly also neglected in species distribution modeling studies. Successful inclusion of temporal aspects and biotic interaction into species distribution modeling would enable addressing future challenges in the context of climate change and also with regards to the impact of non-native species invasions.

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WP4 – Impacts of changing biodiversity on ecosystem functioning

Lead: Brian MacKenzie, P2 DTU Aqua
Co-Lead: Erik Bonsdorff, P13 AAU

Overview:

This work package has taken both a retrospective and a future look at biodiversity changes and ecosystem functioning in the Baltic Sea, linked these changes to changes in food web interactions. More specifically, the objectives were three-fold: to i) review hypotheses regarding relationships between biodiversity and ecosystem functioning for major functional groups and various trophic levels, ii) evaluate and synthesize effects of changing biodiversity on food web interactions and ecosystem functioning using process and trait-based models, and iii) develop scenarios of future biodiversity of the Baltic Sea at various levels of biological organization and ecosystem functioning under multiple drivers.

The WP has made advances both methodologically/conceptually and in understanding how biodiversity affects ecosystem functioning. For example, the WP has used both traditional and functional-based metrics of biodiversity for assessing how biodiversity and ecosystem function has changed in time and space, and how it might continue to change in the future. As a result, new datasets on the major traits of several key functional groups in the Baltic Sea have been created, including for benthic fauna and fish.

These databases have been instrumental building blocks for developing new approaches to investigations of biodiversity and ecosystem functioning in the Baltic Sea and can be considered part of the legacy of BIO-C3 to future investigations and scientists. The benefits of including functional biodiversity descriptors were evident in studies of both benthos and fish, and provided new insights to ecosystem functions and their dependence on particular functional groups and / or species not obtainable by more traditional species-based approaches.

Furthermore, as the entire field of trait-based marine ecology is relatively new, there has been a huge need for innovative statistical and modelling approaches for analysing and interpreting such datasets. BIO-C3 WP4 scientists have been pioneering new methods of analysis and interpretation of traits in a marine biodiversity-ecosystem functioning context, and have made significant advances in developing and applying such methods to real community-level datasets.

Using these new datasets and approaches, scientists have demonstrated how the links between species occurrence and ecosystem function varies in space throughout the Baltic Sea, i.e., how many functions continue to be present in the Baltic Sea as species numbers decline when entering the Baltic Sea along the salinity gradient from marine to brackish to near-freshwater conditions. This comparison showed that the number of functions remained relatively high despite a reduction in species number, indicating possible redundancy of species in some areas, but highlighting the potential vulnerability of Baltic food webs to loss of those few key groups that perform most of the functions in a given ecological category. These patterns were evident both for benthic fauna and fish communities.

The WP also developed new datasets enabling quantification of abundances and distributions of several key but previously poorly studied species and functional groups (e. g, benthic prey for fish predators; plankton). These datasets enabled new studies of food web and species interactions, including those with non-indigenous species, and will be major building blocks for new conceptual models of food web dynamics and ecosystem functioning in the Baltic Sea in future investigations. Analyses demonstrated, for example, that the seasonality, species composition and nutritional quality of the spring phytoplankton bloom is changing, with potential major consequences for other bloom-dependent species and ecological functions, including the feeding success and growth of fish larvae belonging to commercially important species.

A series of modelling investigations spanning a range of biological levels of organization (populations, species, and food webs) has shown how biodiversity, ecosystem functions and their links will likely be affected by combinations of anthropogenic impacts including exploitation, climate change, eutrophication and introduction of non-indigenous species. These models demonstrated for example how reproductive habitats of several key functional groups and species could change size and location, how the recovery of some top predators and exploitation affect trophic flows and cascade potential in Baltic food webs and how eutrophication can affect local biomasses of benthos and sea-birds.

There remain many gaps in knowledge and sampling needs which introduce uncertainties to forward-looking views of how Baltic Sea biodiversity and ecosystem functioning will develop in future. There is a need to continue, and improve, monitoring frameworks, such as by sampling across trophic levels at the same time and place. This will facilitate investigations of how trophic interactions and food web flows are affected by different levels of biodiversity e.g., how the diversity of plankton might affect growth or population dynamics of consumers.

The WP was also active in training new scientists in some of its methodological and conceptual approaches. For example, several principal investigators in the WP, including the WP lead, were heavily involved in organizing and teaching a 5-day Ph.d. course on “Modelling Biodiversity for Sustainable Use of Baltic Sea Living Resources” held in 2016, with capacity attendance of 23 students from the Baltic Sea region and beyond.

Task 4.1: Retrospective analyses of biodiversity and ecosystem functioning

Lead: Erik Bonsdorff, P13 AAU, participation of P2, P4, P5, P6, P7, P8.

Deliverable 4.1: *Retrospective analysis of changes to biodiversity and ecosystem functioning: Report on responses of biodiversity indicators (species, communities, traits) to past abiotic variables and relationships between biodiversity and ecosystem functioning in the Baltic Sea.* **Month 32.** Accepted by BONUS, accessible at www.bio-c3.eu/publications.

Reference:

Törnroos, A., Bonsdorff, E., MacKenzie, B., Winder, M., Margonski, P., Ojaveer, H., Kuosa, H. and Zaiko, A. (2016) *Retrospective analysis of changes to biodiversity and ecosystem functioning: Report on responses of biodiversity indicators (species, communities, traits) to*

past abiotic variables and relationships between biodiversity and ecosystem functioning in the Baltic Sea . BIO-C3 Deliverable, D4.1. 15 pp. DOI 10.22031/BIO-C3_D4.1.

Introduction

Understanding past changes in the Baltic Sea ecosystem is pivotal in order to predict any future ones, may it be within the food web, for future scenarios, or in order to provide successful management options. Thus, the overarching **goal of Task 4.1 was to assess how biodiversity** (species, communities, traits) **respond to (past) abiotic variables** and **how the relationships between biodiversity and ecosystem functioning in the Baltic Sea may have changed over time and/or in response to environmental change over time** (from species to their functions to the community-level functioning)?

In this task, we have investigated producer and consumer levels and targeted both the pelagic and the benthic food chain and its functioning by investigating e.g. long-term changes in community and populations of zooplankton, temporal changes in pelagically feeding fish, functional changes in coastal benthic macrofauna and fish and the offshore benthic feeding fish community. We have related these changes to the natural (salinity, oxygen) as well as large scale anthropogenic (eutrophication, sediment dumping, non-indigenous species) and climatic drivers by assessing traditional biodiversity and quality indices as well as trait-based measures and approaches, through a broad set of statistical and modelling techniques. The focus has been on synthesising and harmonising long-term datasets from various national and international sources (e.g. ICES, HELCOM, SMHI). Many studies have been able to investigate data series spanning the suggested regime shift periods in the Baltic Sea (1980s-90s) or the resulting products of it. The geographical coverage of studies has been broad, including Baltic Sea-wide or basin-wide scale to more local or regional scale studies serving as model systems.

Key results and conclusions

Understanding how primary producers, such as the Baltic Sea phytoplankton respond to changes over time is important in regard to e.g. trophic transfer, an essential ecosystem function. Cross-comparative estuarine data of Baltic Sea and Chesapeake Bay, show that intermediate to higher salinity regions produce phytoplankton of higher food quality for consumers and less pronounced seasonal changes, compared to low-salinity areas (Winder et al. 2017). Detecting temporal signals within the Baltic Sea communities indicating potential changes in bentho-pelagic transfer may crucially depend on time of the year of observations and geographic area. Hjerne et al. (in rev.) show that Baltic Proper phytoplankton blooms 1-2 weeks earlier in spring than before, correlated to higher water temperatures and involves a shift from early blooming diatoms to later blooming dinoflagellates. On the other hand, for summer phytoplankton, no common temporal trend in biomass across the Baltic Sea was found or could be well-explained by regional climate variables (Griffiths et al. 2016).

Long-term changes in both pelagic and benthic consumer species, assemblages and trophic groups were also found, highlighting temporal trait-specific changes, discrepancies along geographical gradients and differences between deeper offshore and shallower coastal areas. In terms of primary consumers, profound changes in the deep-water mesozooplankton community were recorded in the southern Baltic Sea, with decreases in key copepod species related to deep water salinity changes (Margonski & Calkiewicz in prep.). In a shallow coastal area, the seasonal dynamics and abundance of two key zooplankton species were linked to winter severity, while population structure was related to ambient sea-surface temperature, suggesting that climate effect acts through multiple and partly independent mechanisms (Klais et al. 2017). Zoobenthic consumers, such as the non-indigenous *Marenzelleria* sp. species were found to be driven primarily by sediment characteristics (Šiaulys et al. in prep.), and the species induced a clear functional change over time on the benthic community as a whole (Weigel et al. 2016). Another key benthic consumer in the food web, *Saduria entomon,* have shown changes in spatial and temporal distribution (MacKenzie et al. in prep) which could influence predator diets and productivity. Long-term functional trends rather than abrupt shifts were also found for coastal benthic and fish communities across the Baltic Sea (Törnroos et al. in prep.). A community-wide assessment of the demersal fish community showed a marked decline in species- and functional richness, explained by decreasing salinities but also habitat complexity and oxygen (Pecuchet et al. 2016). In the more marine part of the Baltic (e.g., Kattegat), species richness of the fish community has increased during the past 2 decades (Bryndum et al. in prep.). Two dominant small pelagic fish species showed strong inter-annual variations in feeding (Ojaveer et al. 2016). Results of an entire sub-system and cross-trophic level analysis of Bothnian Sea also showed long-term changes in phyto and zooplankton communities as well as fish populations, pointing towards a deteriorating eutrophication trend in the area (Kuosa et al. 2017).

In these studies, various traditional biodiversity and quality indices as well as trait-based approaches were applied, but they were also explicitly evaluated. The performance of benthic diversity and quality indices over time provided a good understanding of macrofaunal long-term progression (Warzocha et al. in prep.), and a fair response to eutrophication and sediment dumping pressures, although assessments should be adjusted for the ecosystem in question and be habitat-specific (Zaiko & Daunys 2015, Chuševė et al. 2016). Functional trait measures and approaches proved valuable for evaluating long-term changes in soft-bottom macrofauna and fish, interlinkages between organism groups and in order to predict e.g. primary production of macrophytes (Jänes et al. 2017).

Key lessons

We formulate the key lessons from this task into two recommendations. First, we **call for and recommend to stakeholders such as HELCOM, ICES, as well as national and regional environmental bodies to make sure that coordination of sampling programs across trophic levels are in place and that these yield comparable data sets in space and time**. Accurate assessments of past ecological changes are a prerequisite for predictive analysis. In the Baltic Sea, we have the unique possibility to rely on national and/or regionally sampled and collected monitoring data. However, the difficulty in finding comparable data sets with several trophic or organismal groups sampled within an ecologically relevant area (i.e. where interactions can take place) was evident in many activities within this task and WP as a whole.

Second, we **recommend the inclusion of functional properties into national and regional advice and management actions** (e.g. HELCOM, ICES). Although traditional quality and biodiversity indices provide a good understanding of long-term progressions and respond to pressures fairly well, our work, using physiological, life-history, behavioral and morphological information have proven to be an essential way forward for understanding (past) functional changes in the Baltic Sea ecosystem. The knowledge-gains and the usefulness of trait-based approaches and functional measures is a way forward in addition to the use of traditional numerical indices as the overall analysis moves beyond species-identities. In addition, such taxa transcending methods and measures provide possibilities for linking ecosystem functioning with the food web.

Knowledge gaps and future research needs

The major conclusion from the majority of studies in this task, highlight the need for further assessment, inclusion and combination of spatio-temporal aspects and trophic interactions for understanding community, population and species-specific (e.g. non-indigenous species) dynamics in a changing Baltic Sea. Addressing these in future studies, will increase our mechanistic understanding of the Baltic Sea ecosystem as a whole, within sub-basins and in regard to interlinkages between open sea and coastal areas. This aspect is also key for any future integrated and holistic assessments.

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Griffiths JR, Hajdu S, Downing AS, Hjerne O, Larsson U, Winder M (2016) Phytoplankton community interactions and environmental sensitivity in coastal and offshore habitats. Oikos 125:1134–1143 (Note: also contributing to Task 4.2)

Jänes, H., Kotta, J., Pärnoja., M., Crowe., T.P., Rindi, F., Orav-Kotta, H. (2017) Functional traits of marine macrophytes predict primary production. Functional Ecology, 31, 975-986. doi: 10.1111/1365-2435.12798

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Bryndum, K. M., Christensen, A., She, J., Richardson, K., and Mackenzie, B. R. Biogeographic changes in fish diversity in the Kattegat-Belt Sea driven by changes in climate and exploitation. Mar. Ecol. Prog. Ser. (in prep.)

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Hjerne et al. Climate driven changes in timing, composition and size of the Baltic Sea phytoplankton spring bloom (in prep.)

MacKenzie, B. R., Gogina, M., and Zettler, M. L. 2017. Development of a Baltic-wide database of occurrence, abundance and biomass of *Saduria entomon*. Scientific Data (in prep.).

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Törnroos et al. Long-term functional trends of coastal zoobenthos and fish in the Baltic Sea (in prep.)

Warzocha et al. Performance of macrozoobenthos diversity indices: Benthic Quality Index (BQI), Shannon-Wiener diversity (H), Margalef diversity (d). (in prep.)

Zaiko et al. Empirical model of *Marenzelleria* spp. distribution - analysis of importance environmental factors and drivers (in prep.)

Task 4.2 Dynamics of populations, traits and ecosystems

Lead: Stefan Neuenfeldt, P2 – DTU Aqua; participants: P1, 5, 4, 9, 3

Deliverable 4.2: *Report summarising food web responses and interactions to changes in biodiversity and community species / trait composition*. **Month 42.** Accepted by BONUS, accessible at www.bio-c3.eu/publications.

Reference:

Neuenfeldt, S., von Dewitz, B., Winder, M. and Middelboe, A. L. (2017) *Report summarizing food web responses and interactions to changes in biodiversity and community species/trait composition.* BIO-C3 Deliverable, D4.2. EU BONUS project BIO-C3, 15 pp. DOI 10.3289/BIO-C3_D4.2.

Introduction

In Task 4.2, the goal was to synthesize and scale the process knowledge generated in WPs 1-3 using (i) existing population and ecosystem models and (ii) food web models developed in task 2.1. These models were applied for case study regions and subsequently applied for projections (Task 4.3) and to derive MSFD indicators. The outputs were used in WP5 analyses of indicator sensitivities to external forcing, and quantification of impacts for marine protected areas.

Key results and conclusions

- The high-resolution ice ocean model BSIOM for the whole Baltic Sea was used to reconstruct property fields of salinity, temperature and oxygen in a monthly resolution for the time period between 1979 and 2015. This data base will be used for modelling habitat extensions of various taxa in WP3 task 3.2 and 3.4. The resulting time series and BSIOM model data are available for approaches coupling these with biological data from WP1 and 2. Here input from other tasks is needed to identify possible biological processes to be investigated by this approach. Requests should be made in a timely fashion to be able to produce results in the given time frame. Hydrographic measurements from the ICES data base and age resolved stock data for Eastern Baltic Cod was coupled to be used as a hypothetical driver for cod genetic diversity. The core concept for this driver comprises known relationships between mean weight and mean length at age to fecundity, egg buoyancy and oxygen depending egg mortality. Results feed into Task 1.3 where the genetic analyses and results are being reported (P1).

- Prey-dependent growth, including a bioenergetics sub-model and predator-prey-overlap, has been implemented in a multispecies model for Eastern Baltic cod, and sprat and benthic species. Prey energy density is explicitly accounted for. The benthic species are represented by two different traits with different energy densities. Besides predation

rates on sprat and small cod, the model can be used to assess the effects of changing benthic biodiversity on cod growth, but also secondary effects on compensatory feeding. The model can be falsified with historical growth rates, stomachs content information and survey data. The model is purely length based and circumnavigates the problem with age reading of Eastern Baltic cod. With the accumulation of historical growth rates (from the BONUS INSPIRE project) and monitoring cod growth in the future (currently initiated in a Baltic wide programme), the model will hopefully also be applicable in stock assessment.
Managing fisheries presents trade-offs between objectives, for example yields, profits, minimizing ecosystem impact, that have to be weighed against one another. These trade-offs are compounded by interacting species and fisheries at the ecosystem level. Weighing objectives becomes increasingly challenging when managers have to consider opposing objectives from different stakeholders. An alternative to weighing incomparable and conflicting objectives is to focus on win–wins until Pareto efficiency is achieved: a state from which it is impossible to improve with respect to any objective without regressing at least one other. We investigated the ecosystem-level efficiency of fisheries in the Baltic and compared it to four other large marine ecosystems (LMEs) with respect to yield and an aggregate measure of ecosystem impact using a novel calibration of size-based ecosystem models. We estimated that fishing patterns in three LMEs (North Sea, Barents Sea and Benguela Current) are nearly efficient with respect to long-term yield and ecosystem impact and that efficiency has improved over the last 30 years. In two LM s (Baltic Sea and North East US Continental Shelf), fishing is inefficient and win–wins remain available. We additionally examined the efficiency of North Sea and Baltic Sea fisheries with respect to economic rent and ecosystem impact, finding both to be inefficient but steadily improving. Our results suggest the following: (i) a broad and encouraging trend towards ecosystem-level efficiency of fisheries; (ii) that ecosystem-scale win–wins, especially with respect to conservation and profits, may still be common; and (iii) single-species assessment approaches may overestimate the availability of win–wins by failing to account for trade-offs across interacting species. (P2)

- Assessing the relative importance of environmental conditions and community interactions is necessary for evaluating the sensitivity of biological communities to anthropogenic change. Phytoplankton communities have a central role in aquatic food webs and biogeochemical cycles, therefore, consequences of differing community sensitivities may have broad ecosystem effects. Using two long-term time series (28 and 20 years) from the Baltic Sea, we evaluated coastal and offshore major phytoplankton taxonomic group biovolume patterns over annual and monthly time-scales and assessed their response to environmental drivers and biotic interactions. Overall, coastal phytoplankton responded more strongly to environmental anomalies than offshore phytoplankton, although the specific environmental driver changed with time scale. A trend indicating a state shift in annual biovolume anomalies occurred at both sites and the shift's timing at the coastal site closely tracked other long-term Baltic Sea ecosystem shifts. Cyanobacteria and the autotrophic ciliate Mesodinium rubrum were more strongly related than other groups to this trend with opposing relationships that were consistent across sites. On a monthly scale, biotic interactions within communities were rare and did not overlap between the coastal and offshore sites. Annual scales may be better able to assess general patterns across habitat types in the Baltic Sea, but monthly community dynamics may differ at relatively small spatial scales and consequently respond differently to future change (P4).

- A downscaled benthic food-web model has been developed for the Gulf of Riga in order to reconstruct predator-prey interactions during the period of changing levels of eutrophication between 1990 and 2007. The coupled hydrodynamic, bio-geochemical and waterbird energetics modules predicted nutrient-related changes in phytoplankton growth, bivalve biomass and waterbird fitness. The results showed significant fine-scale covariance patterns across the entire food web with synchronous spatio-temporal trends between components. A 50 % decline in bivalve biomass was predicted in a well-defined zone characterised by the overall highest biomass of bivalves and highest densities of bivalve-feeding waterbirds. The nutrient-driven localised decline in productivity affected the entire food web with a predicted annual mortality of 72,000 Long-tailed Ducks. This model-based study suggests a strong nutrient control of the available food supply to predatory fish and birds in coastal areas. However, our results show that these effects are heterogenic with changing trends over the scale of less than 20 km. We argue that fine-scale ecosystem models are necessary tools to supplement national monitoring data and needed to achieve a process-based understanding of the ecological status of water bodies or MPAs.

Key lessons

An overarching lesson from Task 4.2 was that with increasing use of the marine environment, spatial aspects also in food-web modelling are getting increasingly important including conservation issues which are becoming an integral part of the overall spatial planning. Implementation of the ecosystem approach to fisheries management and the Marine Strategic Framewok Directive should be seen in conjunction with this process, given the spatial heterogeneity in marine populations.

Especially in a multispecies context, when several species interact in a system (e.g. through predator-prey interactions or competition), it is of fundamental importance to understand the spatial patterns of the different species and the causes and consequences of their distribution changes. This is a fundamental step for an improved management of the, not only, Baltic Sea resources.

We suggest using Pareto efficiency as a concept to guide management of exploited populations with conflicting objectives. The framework presented here emphasizes that the challenge of weighing objectives against one another does not have to impede consensus or progress as long as win–wins exist. In many of the cases in which the Pareto framework has been used – here included – available win–wins have been found to be common.

Fine-scale ecosystem models provide strong tools to determine spatial gradients in the changes of coastal ecosystems. As such these models provide for an important supplement to monitoring activities in order to achieve a process-based understanding of the functioning and status required for a successful management of specific areas like marine protected areas.

Applications

The work in this task was conducted in close collaboration to the ICES Workshop on Spatial Processes in the Baltic Sea (WKSPATIAL) and the ICES Working Group on Baltic Sea Fisheries Assessments (WGBFAS). BIO-C3 results on predation rates of commercial species and changes in spatial distributions have been applied in the groups.

Knowledge gaps and future research needs

It has shown that biodiversity has a massive impact on the food web, but that it is crucial how biodiversity is formulated. Using plainly the number of species in a system renders the accumulation of mechanistic knowledge almost impossible. On the other hand, accounting for all species in the system the same way might easily become very complex. One compromise would be a trait-based approach, and to this end, it appears useful to lump prey species together according to their energy content.

In many aspects, the Baltic Sea can serve as a case study for the world's estuaries due to its abiotic gradients and the many anthropogenic challenges facing it (e.g. eutrophication, fishing, non-indigenous species). Yet we find that there is little predictability at the base of the food web as we investigate the monthly scale interactions of these rapidly responding primary producers. More coherent patterns among sites were observed on annual scales reinforcing that temporal scale affects our ability to generalize about taxa and community responses. Furthermore, capturing how complex ecological interactions will alter ecosystem functioning, and in turn services provided to people, is critical. Here we have taken the first step of evaluating plankton community interactions in a coastal and offshore site in the northern Baltic Sea. Analyses that broadly assess community interactions across the Baltic gradient, evaluate their dynamics over time, and connect them to emergent ecosystem properties are appropriate next steps to improve our understanding of community–ecosystem dynamics

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BIO-C3 Peer reviewed (in preparation or in review) - see www.bio-c3.eu/publications for updates on the publications reported here and expected to come out in the course of 2018.

Neuenfeldt, S., Casini, M., Bartolino, V., Orio, A., Andersen, K.H. Spatio-temporal changes in prey-dependent growth of Baltic cod. In prep.
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Task 4.3 Projection of impacts of changed drivers on future biodiversity

Lead: Monika Winder, P4 SU, participation of P2, P5, P6, P7, P8, P9, P12, P13

Deliverable 4.3: *Report summarizing scenarios of future change of biodiversity and ecosystem functioning of the Baltic Sea under combinations of drivers*. **Month 46.** Accepted by BONUS, accessible at www.bio-c3.eu/publications.

Reference:

Winder, M, Aarnio, K., Andersson, H., Bauer, B., Bonsdorff, E., Björklung, C., Costalago, D., Gogina, M., Gröger, M., Herkül, K., Kock Rasmussen, E., Kotta, J., Lauringson, V., Lundström, K., MacKenzie, B.R, Margonski, P., Möller, T., Nyström, K., Ojaveer, H., Orav-Kotta, H, Puntila, R., Pärnoja, M., Skov, H., Tomczak, M.T., Törnroos, A., Warzocha, J., Wåhlström, I., Zaiko, A., Zettler, M.L. (2017). *Projection of impacts of changed drivers on future biodiversity*. BIO-C3 Deliverable, D4.3. EU BONUS BIO-C3. 16 p. + 10 appendices. DOI: 10.3289/BIO-C3_D4.3.

Introduction

The future biodiversity of the Baltic Sea depends crucially on the ability of species and populations being able to successfully reproduce and maintain viable populations as environmental conditions change. Some of the most likely changes will involve increases in temperature, a reduction in salinity, continued frequent periods of anoxia and biological invasions. Little is known about how species might respond to stressors and this lack of knowledge limits our ability to manage coastal ecosystems under contemporary environmental change.

The goal of deliverable 4.3 was to investigate how distributions and abundances of species and populations important for food web functioning may change under different scenarios of anticipated changes of major drivers, and how this would affect entire species assemblages in the Baltic Sea.

Key results and conclusions

- We have developed estimates of how the reproductive habitats for a large number of species at different trophic levels and functional groups will change in the Baltic Sea under scenarios of climate change and eutrophication. The models reveal large differences between species with more than half of decrease in abundance for some and several-fold increase for others, which implies that some species must change distributions, adapt relatively quickly to keep pace with expected changes or alter their phenologies to avoid local extinction (Gogina et al. in prep., MacKenzie et al. in prep. 1-2).

- Seal populations are recovering in many regions around the world and, consequently, they are increasingly interacting with fisheries. Ecopath with Ecosim models showed that the assumed environmental scenarios modified seal predation impacts on fish. Overall, in the case of the offshore Central Baltic Sea we showed that fish biomass and catches are affected to a larger extent by fishing mortality and the environment than by seals. Additionally, seals' net impact on sprat and herring biomass was positive due to consuming their predator cod. Finally, we suggest that an increasing seal population is not likely to hinder the preservation of the main Baltic fish stocks (Costalago et al., in review).
- Using Boosted Regression Trees modelling to relate the cover of submerged aquatic vegetation to the abiotic environment showed that the majority of submerged aquatic Baltic Sea species are most sensitive to changes in water temperature, current velocity and winter ice scour. Water salinity, turbidity and eutrophication have little impact on the distributional pattern of the studied biota. Under the projected influences of climate change, all of the studied submerged aquatic species are resilient to a broad range of environmental perturbation and biomass gains are expected when seawater temperature increases. This is mainly because vegetation develops faster in spring and has a longer growing season under the projected climate change scenario (Kotta et al., 2015).
- Niche separation and specialization of invasive and closely related native sympatric species are not well understood. Applying the species marginality index (OMI) and species distribution modeling (SDM) in the northern Baltic Proper showed that both methods agreed in notably narrower and more segregated realized niche of invasive *Gammarus tigrinus* compared to the studied native gammarids. Our results confirm that widespread colonization does not require a wide niche of the colonizer, but may rather be a function of other biological traits and/or the saturation of the recipient ecosystem (Herkül et al. 2016).
- Reviewing the roles of the selected non-indigenous species (NIS) indicated that round goby has successfully established in the various coastal ecosystems in the Baltic Sea. They are simultaneously both predators for native prey and prey for native predators as well as competitors to some native species, as well as host for native generalist parasites and may cause cascading impacts in the ecosystem. In addition, Harris mud crad has established in the ecosystems, which is both predators and prey in the food webs. The implications to the other trophic levels including detritus consumption are still unknown. Consumption of grazers may result in impacts on *Fucus vesiculosus*, as decline in grazing may lead to changes in the algal composition in hard bottom habitats. (Puntila et al. in prep.)

- Downscaling benthic-pelagic food-web model for the Gulf of Riga has been applied in hindcast and forecast mode to study the past and future levels of nutrient control of the carrying capacity of bivalves in coastal areas of the Baltic Sea. Using one climate scenario and two eutrophication scenarios (reference/Baltic Sea Action Plan (BSAP)) from BONUS Ecosupport showed that the biomass of *Mytilus* bivalves was predicted to decline in the reference scenario over the whole period, but intensified after 2050. During the BSAP scenario, the decline in predicted *Mytilus* biomass started earlier and amplified the trend in the reference scenario. By 2020, the level of *Mytilus* biomass in the BSAP scenario was predicted to be 70% of the biomass in 2008 (Skov & Kock Rasmussen in prep.).
- We investigated the trophic position and role of the recent coloniser North American Harris mud crab, *Rhithropanopeus harrisii* in the coastal food web by combining spatial and temporal estimates of trophic position using stable isotopes ($\delta^{13}C$ and $\delta^{15}N$), with short-term food- and habitat-choice experiments. We observed a stable pattern in the trophic position over the production season and a natural breakpoint in carbon stable isotopes at the size of 12 mm carapace width, suggesting a presence of an ontogenetic diet shift, which was confirmed experimentally (Aarnio et al. 2015).

Key lessons

In general, this task showed that drivers of climate change, eutrophication and invasion will largely affect Baltic Sea biodiversity with consequences for native species and food web functioning. Projecting impact of drivers highlights the need for the consideration of a range of possible ecosystem contexts when evaluating potential impacts of species, as has been shown for grey seals. For this species, results suggest that an increasing seal population is not likely to hinder the preservation of the main Baltic fish stocks. For gammarid species, the niche divergence and wider environmental niche space of native species are likely to safeguard their existence in habitats less suitable for *G. tigrinus*.

Outcomes from the West Estonian Archipelago Sea suggest that practically all of the studied submerged aquatic species benefit from the projected influences of climate change with no indication of local extinction. These results are, however, study area specific and can potentially not be extrapolated to other seas. The study on distribution and niche assessment of NIS reminds that wide environmental tolerance of a species does not necessarily result in a wide realized niche in the course of an invasion process. Our results also suggest 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 the novelty of the pre-adaptations of the colonizer. Despite the decline in specialist species worldwide, anthropogenic introductions may thus regionally increase the proportion of relatively specialized taxa.

The investigated NIS, round goby and the Harris mud crab, have successfully established into their ecosystems. Further, Harris mud crab chooses its habitat and food actively, but has few preferences. In terms of its trait characteristics it is similar to the native northern Baltic Sea invertebrate fauna, potentially contributing functionally to bioturbation, decomposition and benthic-pelagic coupling, in addition to the proven secondary production. The model predictions for the development of the benthic ecosystem in the Gulf of Riga indicated significant impacts of the continued control of eutrophication and derived reductions in nutrient concentrations. Local ecosystem models like this one may provide useful decision support tools in order to achieve future synergies between targets for water quality and biodiversity conservation in many coastal areas of the Baltic Sea.

Knowledge gaps and future research needs

- Identifying resource use and functional traits of non-indigenous species are promising means to increase the ability to predict ecological consequences of invasions, however, this remains to be fully explored and applied in the Baltic Sea.
- Similarly, estimates of reproductive habitat size have been derived for a range of species in the Baltic Sea. The estimates are based partly on somewhat limited experimental data of the tolerances for reproduction across temperature, salinity and oxygen concentration ranges, thus, new experimental studies of the reproductive success of selected species and populations with major roles in Baltic food webs are necessary to fill knowledge gaps.
- It is also recommended that monitoring and data collection 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 changes.
- 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.

References and links

<u>BIO-C3 Peer-reviewed (published)</u>

Aarnio K, A Törnroos, C Björklund, E Bonsdorff (2016) Food web positioning of a recent coloniser: the North American Harris mud crab *Rhithropanopeus harrisii* (Gould, 1841) in the northern Baltic Sea. Invasions, 10, 399-413. (Note: also a contribution to Task 2.3).

Kotta, J.; Möller, T.; Orav-Kotta, H.; Pärnoja, M. 2014. Realized niche width of a brackish water submerged aquatic vegetation under current environmental conditions and projected influences of climate change. Marine Environmental Research, 102, 88–101.

Herkül, K.; Lauringson, V.; Kotta, J. 2016. Specialization among amphipods: the invasive *Gammarus tigrinus* has narrower niche space compared to native gammarids. Ecosphere, 7, e01306.

Törnroos, A., M. C. Nordström, K. Aarnio & E. Bonsdorff, 2015: Environmental context and trophic trait plasticity in a key species, the tellinid clam *Macoma balthica* L. -J. Exp. Mar. Biol. Ecol. 472: 32-40. doi:10.1016/j.jembe.2015.06.015

BIO-C3 Peer reviewed (in preparation or in review) - see www.bio-c3.eu/publications for updates on the publications reported here and expected to come out in the course of 2018.

Costalago D, Bauer B, Tomczak MT, Lundström K, Winder M (in review) The necessity of a holistic approach when managing marine mammal- fisheries interactions. Oikos**.**

Gogina M, MacKenzie BR, Zettler ML, Nyström K, Wåhlström I, Andersson H (in prep.) The past and future habitats of a key benthic animal, *Saduria entomon*, in the Baltic Sea – combined impacts of climate change and nutrient loading scenarios (also a contribution to Task 4.2)

MacKenzie BR, Gröger M, Wåhlström I, Andersson H (in prep.) Future climate change and nutrient loading alter reproductive habitat size and location for Baltic Sea species

MacKenzie BR, Zaiko A, Ojaveer H, Gröger M, Wåhlström I, Andersson H (in prep.) An approach for estimating the risk of the Baltic Sea for establishment and spread of non-indigenous species.

Puntila R (in prep.) Role of invasive species in the food webs – the cases of the round goby and Harris mud crab.

Skov H & Kock Rasmussen E (in prep.) Predicted impacts of changes in intensity of eutrophication on future carrying capacity of the Gulf of Riga.

WP5 – Biodiversity indicators and tools for adaptive management

Lead: Piotr Margonski, P5 NMFRI

Overview:

Biodiversity is influenced by a variety of human activities on land and at sea, as well as by climate change, ecological interactions and conservation measures, which calls for systematic analyses and robust indicators to assess the status of biodiversity. Much of the indicator development so far has focused on the ecosystem state, while establishing links between state and pressure largely remains a future challenge. Further, it is necessary to identify relevant measures to mitigate threats to biodiversity, and adapt to the dynamic nature of ecosystems in response to expected changes in natural and human drivers. This includes identification and design of monitoring systems and evaluation frameworks capable of testing management measures and strategies in order to improve GES with respect to MSFD descriptors 1, 2, 6, but also 3 and 4.

Only a subset of drivers (direct anthropogenic) can be influenced by direct management actions, e.g. fisheries, and advanced management evaluation frameworks related to fisheries have been developed. The management aspects of other drivers influencing biodiversity, i.e. introduction of non-indigenous species, eutrophication and pollution are generally addressed in semi-quantitative decision-support tools. A series of quantitative models exist for the Baltic Sea, which address wider ecosystem components and pressures. Further progress towards using information provided by these models in developing adaptive management strategies for the Baltic ecosystem are needed.

The overall objective of WP5 is to synthesize the knowledge developed within the other BIO-C3 work packages and to provide a science based evaluation framework and progress towards adaptive management of biodiversity in the Baltic Sea. This WP developed recommendations on relevant data and monitoring needs, recommend biodiversity indicators as well as contributed to relevant modelling and assessment tools development.

Tasks 5.1, 5.2 and 5.3 as well as the resulting deliverables D5.1, 5.2 and 5.3 were all completed in the reporting period 2017, and are accessible via our BONUS BIO-C3 webpage www.bio-c3.eu/publications.

Task 5.1: Response of MSFD indicators to various management measures to achieve Good Environmental Status

Lead: Anastasija Zaiko, P8 KU-CORPI, participation of P2, P4, P5, P6, P7, P11 (P1 also contributed, not initially planned)

Deliverable 5.1: *Report on response of biodiversity indicators to management measures (test of indicators).* **Month 46.** Accepted by BONUS, accessible at www.bio-c3.eu/publications.

Reference:

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., DOI 10.3289/BIO-C3_D5.1.

Introduction

The success of management is partially dependent on the availability of scientific tools to managers (Rist et al. 2013; Knights et al. 2014). 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. Therefore, the main aim of this task (Deliverable 5.1) 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*.

Key results and conclusions

Relevant indicators have been selected based on their relevance to: (i) the important anthropogenic pressures in the Baltic Sea and the climate change; (ii) major biodiversity components (i.e. phyto- and zooplankton, benthic invertebrates, fish and NIS); (iii) HELCOM policies, current trends in marine research and methodological developments.

The selection of indicators for testing was based on the analysis of the comprehensive catalogue of biodiversity indicators, developed in collaboration with the recent DEVOTES project (Teixeira et al. 2016). In this catalogue, over 600 indicators were compiled, which were developed and used in the framework of different initiatives (e.g., EU policies, research projects) and in national and international contexts (e.g., Regional Seas Conventions, and assessments in non-European seas). Out of these, nearly 200 indicators were reported for the Baltic Sea, representing different pressures, DPSIR stages and target biodiversity groups. For the purposed of the Deliverable 5.1, these indicators have been reviewed separately in regards to their typology (DPSIR relevance, see e.g. Oesterwind et al. 2016), data requirements, development status, relevance to biodiversity components, and related human pressures.

Many of the Baltic Sea indicators have been specifically developed or modified for application in this ecosystem, with absolute majority addressing biodiversity descriptor D1 of the MSFD. In general, the existing indicators adequately represent all major biodiversity components of the Baltic Sea.

Comparing to other regional seas considered in the catalogue, the Baltic Sea has higher number of the pressure indicators (15%). Most of them are focusing on the specific target groups (e.g. non-indigenous species) and anthropogenic activities (e.g., fish or benthic invertebrates).

In terms of addressing the most important Baltic Sea pressures, the existing suite of the Baltic Sea indicators compiled in the catalogue has a fair coverage. Many indicators address nutrient and organic matter enrichment, which reflect eutrophication that is still the most widespread pressure in marine and coastal waters in Europe (EEA, 2013, 2015). Other pressures that were targeted by a few indicators (either directly or indirectly) were related to extraction of species (i.e. fishing), non-indigenous species (NIS), physical loss and physical damage to marine habitats. These reflect the abrasion pressures caused by demersal fishing and aggregate dredging, but also silting, smothering, and increase of turbidity due to coastal and underwater constructions (e.g., Oesterwind et al. 2016). A third group of indicators reflect the effects caused by interference with hydrodynamic processes contamination and extraction (i.e. by-catch and other species removal) pressures. Pressures that have been identified recently such as marine noise, litter or acidification are represented by few indicators.

The following indicators/groups of indicators were prioritized for consideration in Task 5.1 and testing their performance:

- *Predator fish indicators*
- *NIS indicators*
- *Benthic invertebrate indicators*
- *Zooplankton indicators*
- *Food web and phytoplankton indicators*

- *Trait-based and functional diversity indicators*
- *Metabarcoding-based indicators*
- *Genetic diversity indicators*

The selected indicators were tested for their performance (incl. stability and sensitivity), based on the outcomes of the Bio-C3 case studies, modelling results and literature reviews, as well as high-level expert knowledge represented by the project consortium. Along with the generalized summary, Deliverable 5.1 provided practical observations, recommendations and precautions for using the existing and newly developed biodiversity indicators.

Key lessons

- Wider employment of ecosystem-based approaches in monitoring and environmental status assessment is needed
- Development of adaptive and flexible management frameworks is advised
- For improved and robust environmental status assessment, continued and consistent monitoring of all biodiversity components across Baltic sub-regions required
- Uptake and further development of emerging molecular methods for routine monitoring will improve our ability to timely and precisely identify emerging threats and provide adequate management advice
- It is recommended to switching from simplistic biodiversity metrics towards complex, function-focused multi-trophic indicators, involving tiered assessment approaches
- Further work toward filling the existing gaps in knowledge on the synergetic effects of multiple pressures and relevant biodiversity response is needed

Knowledge gaps and future research needs

- Further research on clarifying and quantifying links between indicators and pressures, including multi-pressure effects (where applicable)
- Improving baseline biodiversity information for all Baltic Sea subregions, including currently overlooked groups of organisms (such as meiobenthos, microplancton, etc.) and involving molecular reference information (for future development of molecular-based indicators)
- Ideally, a comprehensive, region-specific, well-annotated database covering all levels of the Baltic Sea biodiversity and a range of marker genes, is required. However, filling the most prominent gaps in the global databases (e.g. GeneBank, PR2, BOLD), would be an acceptable alternative short-to-medium term solution
- A dedicated scientific effort is needed to develop fit-for-purpose metabarcoding-based indicators addressing specific biodiversity components, ecosystem attributes and pressures in the Baltic Sea
- Future refinement and validation of suggested trait-based indicator frameworks (e.g. Beauchard et al. 2017), delineating the pressure (non-human or human mediated), the

state (effects on multiple traits) and responses (resistance, resilience or damage of traits), ultimately integrating trait-based measures in decision-support tools

- Identify reference (or target) conditions for different biodiversity components, at a sub-regional scale to more accurately reflect the spatial dynamics
- Calibration of developed indicators and their threshold values on long-term sub-regional monitoring datasets (regular cross-calibration exercises would allow for adaptive adjustments in response to changing environmental context)
- Development of the multi-trophic monitoring frameworks for holistic assessment of food web functioning and healthiness and following the synchronous changes across the trophic levels
- Working forward to improve knowledge on functional traits relatedness to genetic polymorphism
- Systematic collection of genetic information (with appropriate long-term sample storage for reference) to monitor the availability of adaptive variation via genetic indicators directly, as the functional knowledge improves

References and links

<u>BIO-C3 Peer-reviewed (published)</u>

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 (also a contribution to Task 3.1)

Olenin S., Gollasch S., Lehtiniemi M., Sapota M., Zaiko A. 2017. Chapter 5: Biological Invasions. In: Snoeijs Leijonmalm P., Schubert H., Radziejewska T. (Eds.) Biological Oceanography of the Baltic Sea, Springer, p. 193-232.

Rossberg A.G., Uusitalo L., Berg T., Zaiko A., Chenuil A., Maria C. Uyarra, Borja A., Lynam C.P. 2017. Quantitative criteria for choosing targets and indicators for sustainable use of ecosystems. Ecological Indicators 72: 215-224.

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Knights A.M., F. Culhane, S.S. Hussain, K.N. Papadopoulou, G.J. Piet, J. Raakær, S.I. Rogers, L.A. Robinson. 2014. A step-wise process of decision-making under uncertainty when implementing environmental policy. Environmental Science and Policy, 39: 56-64.

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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.

Task 5.2: MPA implications

Lead: Anne Lise Middleboe, P9 DHI, participation of P1, P5, P8, P10.

Deliverable 5.2: *Report on MPA tool -Development of methods to describe connectivity and importance of the MPAs network and MPA tool testing in two selected case studies.* **Month 46.** Accepted by BONUS and accessible at www.bio-c3.eu/publications.

Reference:

Middelboe, A.L., Closter, R.M., Corell, H., Hinrichsen, H.-H., Jacobi, M.N., Jonsson, P., Kotta, J., Potthoff, M., Samuilovienė, A., Šiaulys, A., Skov, H., Zaiko, A., Žydelis, R. (2017) *Report on MPA tool - Development of methods to describe connectivity and importance of the MPAs network and MPA tool testing in selected case studies* BIO-C3 Deliverable, D5.2. EU BONUS BIO-C3, 34 pp. + Appendices. DOI 10.3289/BIO-C3_D5.2.

Introduction

The network of marine protected areas (MPAs) in the Baltic Sea, including marine EU Natura 2000 areas constitutes a cornerstone in the effort of the Baltic countries to protect marine biodiversity. Partly overlapping with Natura 2000 is the HELCOM-MPA network, which aims toward an ecologically coherent network based on scientific understanding. However, HELCOM MPAs do not enjoy the extensive legal status as do the Natura 2000 areas. Designation of MPAs is presently based on assessment of the occurrence of species and habitats within the individual potential MPAs and with the exception of birds and marine mammals the designation is typically seen from a national perspective. Further, the criteria for designation of MPAs like the Special Areas of Conservation (SACs) *sensu* the EU Habitats Directive or Special Protected Areas for Birds (SPAs) *sensu* the EC Birds Directive do not relate to the provision of critical ecological processes and supporting food webs and can be seen as reflecting a static state of affairs in terms of biodiversity and bioproductivity. Accordingly, there is a great need for developing tools, which can assess the importance and connectivity of MPAs given current and future ecosystem dynamics. 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. Increasingly, it is 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 the state-of-tomorrow MPA management tools.

The objective of this task was to develop tools and methods to quantify the current function of the Baltic MPA network and to assess possible changes given the expected development of drivers (e.g. climate change and nutrient input).

Key results and conclusions

Two large-scale connectivity studies provided information on connectivity and dispersal patterns for the entire Baltic Sea and found that dispersal distance varied considerably among regions within the Baltic Sea. The results 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. Dispersal distance also varies for different dispersal strategies. The overall conclusion was 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.

The Gulf of Riga is characterized by several internationally important bird protection areas and a series of habitat protection areas was chosen for several case studies. Using fine-scale dispersal patterns of blue mussels as case, indicated that source and sink hotspots were only partly included in the existent network of MPAs. Local retention was strongly related to size, but even small areas have some degree of local retention. In this case, a MPA size of > 1000 km^2 or a ratio between MPA radius (assuming a circular form) and average dispersal distance > 1.5 was predicted to ensure > 30% local retention.

An integrated gene and biophysical modelling connectivity study in Lithuania waters exemplified how changes in the connectivity patterns and impact of an invasive predator can jeopardize the current and projected effectiveness of MPA. The results showed rather consistent present connectivity patterns from both the biophysical model and gene flow analysis, suggesting that mussel reefs in the coastal zone are sinks rather than sources for *Mytilus* larvae. The future increase in larval dispersal distance and decrease in connectivity between reefs, predicted by the climate scenario model, may have several consequences. If there is no efficient larval supply from other nearby reefs, the decrease in local retention and inter-reef connectivity will reduce recruitment and may make the mussel populations on all considered reefs less persistent and resilient.

A downscaled benthic food-web model for the Gulf of Riga was applied in hindcast and forecast mode to study the past and future levels of nutrient control of the available food supply in terms of bivalves to top predators. The projected decline in the biomass of blue mussels 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 Gulf at the end of the 21st century in the Baltic Sea Action Plan (BSAP) scenario would lead to a significant decline in the number of Long-tailed Ducks in the whole area as well as in the MPAs. The predicted decline following the BSAP scenario will have a serious effect on the importance of the Natura 2000 network of bird protection areas (SPAs) relative to the size of the bio-geographic population, albeit the predicted overall distribution of waterbirds relative to the SPAs will not change markedly (10% less waterbirds in SPAs).

Key lessons

The studies demonstrated the huge potential in development of operational management tools that are based on biophysical, connectivity and ecosystem models to quantify ecosystem responses to impacts, plans and measures.

The identification of connectivity of populations between subareas of a regional sea like the Baltic Sea indicate that human coastal communities are linked and management of one part of the sea may affect the quality and use of another part of the ecosystem. Furthermore, the analysis of partial dispersal barriers may indicate demographic independence and the presence of unique local adaptations and thus suggest management units. A comparison shows that HELCOM MPAs are fairly well distributed between many of these suggested management units. There are some exceptions where MPAs are scarcer, mainly along the Swedish coast in the Gulf of Bothnia and Bothnian Bay, as well as along the Swedish coast between Stockholm and Öland. The hotspot analysis is a useful tool together with information on pressures as decision support to protect important source areas and thereby ensure efficient larvae supply to maintain the mussel populations, and thus ensure food availability for the wintering ducks that occur in numbers international significance 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 restauration decisions. Relationships between MPA size and dispersal distance of the organism in focus for protection can be used estimate the adequacy of MPAs to ensure sufficient levels of local retention. The *Mytilus* larvae dispersal strategy was characterised by many larvae being transported relatively short distances (average 34 km) and few long-distances. This is good news for management since it ensures both a high degree of local retention to ensure sustainable local populations and long-distance dispersal important for genetic diversity. However, especially for the long-distance dispersal strategies many HELCOM MPAs seem too small to allow significant local recruitment.

The lower local retention and reduced inter-reef connectivity for the reef in Lithuanian 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.

Moreover the modelled bottom-up control of bird populations demonstrated here suggest that the local ecosystem models, like this one for the Gulf of Riga, may provide useful decision support tools. Especially, 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.

Applications

We demonstrated and discussed the new tools with a wide range of national and regional stakeholders around the Baltic Sea. There is a serious interest in implementing new quantitative management tools including the one developed in this project. Thus although they are not yet used, we are confident they will be.

Knowledge gaps and future research needs

While the studies here well demonstrate the usefulness of ecosystem models as important tools to quantify responses in the marine ecosystem, we expect this is only the beginning. In the years to come the demand will increase for tools that can encompass the complexity of the marine ecosystem and assess the cost-benefits of actions and prioritize between the existing more or less realistic measures to improve the sea status. The connectivity based tools estimated from biophysical models needs validation, where possible, with genetic data, which is an important task for the future. Also, most connectivity studies are mainly based on hydrodynamics, the significance of biological parameters or the dispersal patterns should be further investigated. In general, we lack knowledge about the system responses to stressors, as for example the responses through various trophic levels.

Also, a very important task for future research is to translate the results of the excellent science being done into operational ready-to-use management ready tools that are easy to access and easy to use.

<u>Task 5.3: Evaluation framework for holistic management</u>

Lead: Piotr Margonski, P5 NMFRI, participation of P2, P4, P6, P8 (P1 also contributed, not initially planned)

Deliverable 5.3: *Report on evaluation framework for holistic management – summary of the concept, requirements and management implications.* **Month 48.** Submitted and in review by BONUS, for updates see www.bio-c3.eu/publications.

Reference:

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, 44 pp. (in review)

Introduction

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. Although 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. Task 5.3 outlined 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. 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 based on results from work conducted in WP1-5.

Key results and conclusions

WP5 summarized knowledge developed in the entire BIO-C3 project providing a series of recommendations on holistic and adaptive management of biodiversity.

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 an example. An extensive knowledge gap analysis summarizing the entire BIO-C3 project experience has been also provided.

The existing and newly developed knowledge on relevant biodiversity indicators and their response to management measures has been synthesized (for details see Deliverable 5.1). 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 that will contribute to the development of the evaluation framework for holistic management of the Baltic Sea ecosystem.

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 as well as sub-basin scale to identify sink and source hotspots, and assess adequacy and connectivity of MPAs (for details see Deliverable 5.2). An integrated genetic and biophysical modeling was used to identify present and future challenges to ensure persistent and resilient populations through efficient larval supply. Moreover, 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 constraints. 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 analyzed the spatio-temporal variability of Baltic Sea zooplankton using historical data from various monitoring programs. In conclusion, sampling has to be tailored both to the specific questions asked and also to characteristics and dynamics of analyzed ecosystem component.

Non-indigenous species (NIS) monitoring has 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. A centralized database is the key element of the integrated NIS monitoring and reporting system and the AquaNIS (the Information system on Aquatic Non-Indigenous and Cryptogenic Species) database has been agreed to be a data storage platform for the current HELCOM holistic assessment. 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.

Finally, as currently the most advanced management framework is implemented in fisheries, we elaborated 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. The fisheries example 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.

Key lessons

- Although the Baltic Sea is very often regarded as a data rich area considerable data and knowledge gaps have been identified within the BIO-C3 project and listed in Task 5.3.
- An analysis of human pressures on marine biodiversity has to consider their cumulative effects.
- Development of adaptive and in long-term viable monitoring and management frameworks is crucial to achieve ambitious environmental status goals as stated by EU legislative acts.
- Member States are seeking for solutions to optimize the existing monitoring programmes to fulfill increasing demands rising from implementation of MSFD, it is however, absolutely crucial that all biodiversity components across the Baltic Sea sub-regions have to be monitored in a continued and consistent way.
- 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,
    - adaptive re-consideration of the current MPAs (specifically in the SE Baltic), taking into account the future change scenarios and dynamics in anthropogenic pressures (relying both on empirical evidence from appropriate environmental surveillance and modelled projections)

- development of fit-for-purpose mitigation strategies for emerging and prospective risks, cascading from different pressures
- 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.

Applications

Stakeholders expressed their interests in implementing parts of MPA modeling especially focused on two aspects:

1. The BIO-C3 team was invited to give presentations on MPA connectivity analyses at the Pan-Baltic scope project kickoff meeting that is planned in April/May 2018, most probably in Denmark.
2. The chair of the BSAC Sub-group on ecosystem based management expressed an interest in considering of the analysis on coastal ecosystems carrying capacity in terms of foreseen consequences of reduced nutrient loads as a base for the productivity of the entire food web including upper trophic levels.

Knowledge gaps and future research needs

- Several areas of considerable data and knowledge shortfalls were identified. Insufficient experimental data on thresholds and tolerances for extremes for key species might be an example. Moreover, numerous studies may considerably benefit from wider incorporation of genetic and molecular data.
- 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.
- Data collection has to be explicitly tailored to the specific questions asked and consider characteristics and dynamics of the ecosystem component under question.
- There is 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.
- An integrated and holistic non-indigenous species monitoring programme 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.

- 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.
- The fisheries example demonstrates an increasing need for an advanced understanding in underlying biological processes, driver impacts and related interactions when moving from status assessments to projections and management measures, especially considering continuously changing ecosystems.
- 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.

References and links

BIO-C3 Peer-reviewed (submitted) - see www.bio-c3.eu/publications for updates on the publications reported here and expected to come out in the course of 2018.

Eero M., Hinrichsen H.-H., Hjelm J., Huwer B., Hüssy K., Köster F.W., Margonski P., Plikshs M., Storr-Paulsen M., Zimmermann C. (in review). Do spawning closures promote cod recovery in the Baltic Sea? ICES Journal of Marine Science

WP6 – Project management and dissemination

Lead: Thorsten Reusch, P1 GEOMAR

Task 6.1 Dissemination and communication strategy (lead: P1; participants: P2-13)

Deliverable 6.1: *Homepage and leaflet produced and publicised.* **(Month 8,** completed**)**

Milestone 6.2: *Communication and dissemination strategy developed.* **(Month 14**, completed/ongoing**)**

Throughout the project duration, we have systematically pursued the BIO-C3 dissemination and communication strategy established in 2014 (Deliverable 6.1 approved by BONUS in 2014).

This has included strong efforts to pass on the expertise of our project personnel, and to use the scientific output resulting from BIO-C3 to inform stakeholders and policy makers in the Baltic realm and beyond. To do so, we have actively pursued the dissemination of project output on various levels, from the scientific community, to resource managers and politicians, to the public, using a mix of traditional scientific channels, involvement in working groups and advisory councils, to interviews and media channels.

One important puzzle piece in our dissemination strategy has been our BIO-C3 website (www.bio-c3.eu) (Appendix 3). This site consists of public pages, **including a section giving access to all BIO-C3 output produced to date**, including public deliverables, publications, reports, and presentations (www.bio-c3.eu/publications) and updates on BIO-C3 news and events, including the 2015 and 2016 BIO-C3 summer schools and teacher training workshops, our annual meetings (including the 2017 public mini-symposium), and the 2017 BONUS Symposium in Tallinn (www.bio-c3.eu/links). The internal section of the site is regularly used for document exchanges within the consortium. User stats of the website have been steadily increasing over time, reaching an average number of unique visitors per month of around 3000 and peaks of over 5000 in 2017 (Figure 6.1.1).

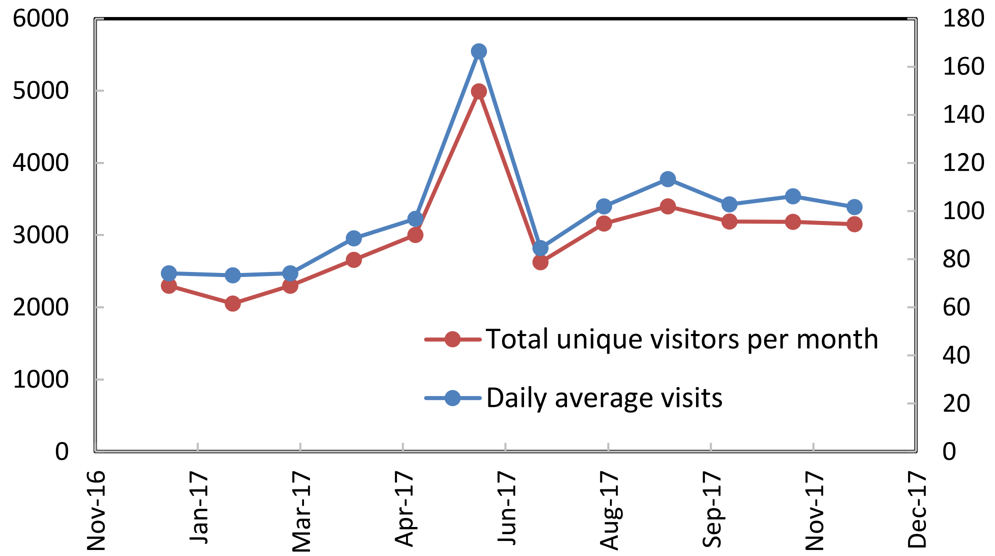

Figure 6.1.1 User statistics of the BONUS BIO-C3 website.

We have also regularly contributed BIO-C3 content to the BONUS website (www.bonusportal.org), e.g., with our three BONUS BIO-C3 blogs "Baltic biodiversity notes" by Anna Törnroos, (P13), "Data cruncher" by Riina Klais (P06), and "The Baltic Seal" by David Costalago (P04) (http://www.bonusprojects.org/bonusprojects/blogs/) and news reports on project highlights. We have also made two invited contributions to the BONUS in Brief Newsletter[1]. Moreover, we have distributed our project flyer (Appendix 2) at numerous outreach events and conferences.

The BIO-C3 mailing lists ("All project personnel", "Young scientists", "Steering committee", "Work package and Task leaders") were established at the project start and have been in

[1]Neuenfeldt S, Ojaveer H, Dierking J (2017) Guest column: Science delivery for sustainable use of the Baltic Sea living resources. Highlights from the BONUS projects INSPIRE and BIO-C3. BONUS in Brief October 2017:1-3.
Dierking, J., Hüssy, K., Laikre, L. 2015. Guest column: Finding bridges between biodiversity research and ecosystem–based management. BONUS in Brief December 2015:2.

regular use for discussions, posting of initiatives and job offers, and scientific coordination within BIO-C3 since then.

The dissemination efforts resulting from this strategy are in part described in Section 4. below, and in details in the periodic reports 2014-2017.

Task 6.2 Project organisation and milestone-trend analysis (lead: P1; participants: P2-13)

Milestone 6.1: *Kick-off meeting executed.* **(Month 4,** completed**)**

Milestone 6.3: *Annual project meetings* **(Month 18, 32,** completed**)**

Our strategy here has relied both on large-scale meetings and smaller scale exchanges between coordinators and WPs/Tasks, within and between WPs, between the steering committee members, and the BIO-C3 advisory board. We organized one kick-off meeting in Copenhagen, Denmark, in March 2014, and three annual 4-day project meetings in June 2015 in Kiel, Germany, June 2016 in Tallinn, Estonia, and 2017 again in Kiel. These meetings always started with 1 day scientific mini-symposium open to the public and to stakeholders, followed by internal project exchanges on the remaining days. The average number of participants was ~35, and included the large majority of BIO-C3 institute PIs, WP and Task leaders and fulltime project scientists, and representatives of advisory board. Further SC meetings with all partner institute PIs took place bi-annually.

Task 6.3 Financial administration and reporting to the Commission (lead: P1; participants: P2-13)

Deliverable 6.2, 6.3, 6.4: *First, second and third periodic report to the BONUS Secretariat, including reporting to meta database.* **(Month 14, 26, 38,** completed)

Deliverable 6.6: *Fourth periodic report to the BONUS Secretariat, including reporting to meta database.* **(Month 50** – this report**)**

The administration of the project coordinator GEOMAR has facilitated the distribution of funds to participants, and the relevant financial information for all participants have been submitted with the periodic reports. Throughout the project period, we have continuously expanded the BONUS BIO-C3 meta-data collection of datasets underlying publications, now reaching 75 contributions, 18 of which are available via public repositories such as Dryad (http://datadryad.org/), Pangaea (http://www.pangaea.de/) and the ICES database (http://www.ices.dk/marine-data/data-portals/Pages/ocean.aspx) (see Appendix 5). In addition, data and metadata resulting from BIO-C3 cruises are available via the GEOMAR data portal (https://www.bio-c3.eu/de/osis), and regularly reported to the ICES database.

2. Summary of the produced scientific and technological foreground capable of industrial or commercial application, plan for the use and dissemination of this foreground and measures taken for its protection

Summary of the produced scientific foreground: BONUS BIO-C3 has produced exclusively scientific output (i.e., no technological foreground), none of which is capable of industrial or commercial application. The objective of new knowledge produced in BIO-C3 was rather to enhance knowledge of the Baltic Sea system, targeting the scientific community, stakeholders in the resource management and policy realm, and the general public.

Protection of the foreground: No foreground capable of industrial or commercial application was produced, and thus no measures (e.g., patents) were taken to protect this foreground (e.g., no patents, copyrights requested). In the case of long-term data series and datasets extended or produced by BIO-C3 that have not yet been published, the owners guard the right to use these datasets first before making them publicly available. At the same time, even datasets not published yet can be accessed by interested parties by contacting the communicating author/originator (listed in Meta-data sheet).

Dissemination of foreground:
Datasets underlying BIO-C3 publications are accessible either directly via public repositories (e.g., Dryad, Pangaea, ICES data base GenBank), or via institutional databases or the communicating author, as detailed in the BIO-C3 metadata collection (also see Appendix 5). Much of the research of BIO-C3 has been published in “open access” format, and all deliverable reports resulting from BIO-C3 are freely available online in the GEOMAR Oceanrep repository (with unique an permanent DOIs), accessible via Oceanrep and our website www.bio-c3.eu/publications.

3. Further research needed in the field

On an overarching level, one clear need highlighted at the end of the BIO-C3 project concerns the importance to take a step back and conduct synthesis work based on the wealth of new information created in BIO-C3 as well as other BONUS projects over the past years. Examples here include the synthesis of the numerous studies on the role of non-indigenous species in Baltic food webs, on structural and functional changes of Baltic ecosystems under climate change and anthropogenic drivers, as well as taking stock of where we stand regarding the use of models in Baltic food web work and of the status and use of indicators in monitoring and management efforts. We hope to partly address this need as part of the BONUS XWEBS (“*Taking stock of Baltic Sea food webs: synthesis for sustainable use of ecosystem goods and services*”) synthesis project, which received favourable reviews from BONUS and was invited to proceed to negotiations.
Regarding knowledge gaps in the individual research lines of BIO-C3, each task section in this report contains an extended paragraph on “Knowledge gaps and future research needs”.

4. Promoting an effective science-policy interface to ensure optimal take up of research results (performance statistics 1-4)

Science-based management can only work if the necessary science a) exists AND b) actually reaches the policy makers and managers. Much of the scientific output of BIO-C3 had direct policy or management relevance. We have made strong efforts to pass on the expertise of our project personnel, and to use the scientific output resulting from BIO-C3 to inform stakeholders and policy makers in the Baltic realm and beyond.

Regarding **performance indicators 1 and 2**, this has included contributions to (1) the implementation of the MSFD and MSFD Programme of Measures on multiple occasions, (2) the design of the Ballast Water Management Convention (ratified in 2016), (3) plans for an integrated non-indigenous species monitoring programme within HELCOM, (4) the update of the Baltic Sea Action plan, (5) advice regarding the improved design of MPA networks, and (6) on numerous occasions to scientific advice into fisheries management via ICES, amongst others (cumulative totals of activities: 13 and 29 for performance indicators 1 and 2, respectively, panning all levels from national to regional and international) .

This strong role of the BONUS BIO-C3 consortium in the science-policy interface was also expressed in the strong membership and participation in a total of 402 stakeholder committees and working groups over the project duration (**performance indicator 3,** see Appendix 4 for 2017 list), including those of ICES, HELCOM, EC, MSFD, UN, and OSPAR, and the presentation of major BIO-C3 results and conclusions at an ad-hoc HELCOM advisory meeting in October 2017.

Under **performance indicator 4** (cumulative total of activities = 11), two outstanding highlights were:

- The organization of the successful BONUS theme session “*From genes to ecosystems: spatial heterogeneity and temporal dynamics of the Baltic Sea”* at the ICES Annual Science Conference on September 24 2015 in Copenhagen (co-organized with BONUS INSPIRE and BAMBI), bringing together more than 80 scientists from both within and outside the BONUS community, as well as stakeholders and policy makers, and amongst others resulting in an invited guest column in the BONUS in Brief December newsletter on “*Finding bridges between biodiversity research and ecosystem–based management*”.
- The coorganization (with BONUS INSPIRE) of the 1st BONUS symposium "*Science delivery for sustainable use of the Baltic Sea living resources*" from 17-19 October 2017 in Tallinn, Estonia, to share results from BONUS projects with the larger scientific and stakeholder community. The event included a designated stakeholder day and panel discussion. See www.bonus-inspire.org/symposium and www.bio-c3.eu

Examples of other activities demonstrating the breadth of efforts included:

- A series of two BIO-C3 stakeholder consultations on biodiversity management tools, co-organized by DHI and NMFRI. Biodiversity management tools developed for the Baltic Sea was presented at two webinars (31 October and 10 November 2017) with participants from Länsstyrelsen (SE), WWF, Dansk Pelagisk Producentorganisation (DK), Baltic Sea Advisory Council, Ministery of Environment Estonia, Marine Institute (PL), LLUR (DE).
- A workshop to discuss the biological effects of spatial fisheries management measures (MPAs) in the Baltic Sea, with participants from Danish fishing industry, Ministry of Environment and Food of Denmark and DTU Aqua. DTU Aqua, Charlottenlund, 3 June 2016, 25 participants
- A stakeholder training day on Baltic fish species and ecosystems, with foci on cod and sea trout biology and management, for the German federal State of Schleswig Holstein State agency LLUR Fisheries Department. 26 participants. GEOMAR Kiel, Germany, September 14
- The National BONUS BAMBI/BIO-C3/INSPIRE seminar on ’The new challenges in management of the Baltic Sea’, Tallinn, Estonia, 27 April 2016. Attended by about 30 participants from Ministry of Environment, Ministry of Rural Affairs and Ministry of Education and Research.
- The BONUS BIO-C3 high-school teacher training workshop *Bringing Science to the class room: biodiversity in the Baltic realm – function, services and anthropogenic threats*, with 28 participating teachers from Northern Germany. Schloss Noer, Germany, September 9-10 2016. (www.bio-c3/links). The principle here was to train teachers as ”multiplicators” who can pass on knowledge about Baltic biodiversity.

Common denominator behind all of the activities was to pass on the new knowledge generated in BIO-C3 to stakeholders, to enhance understanding of problems and solutions, and to provide information that can support informed management decision making.

5. Collaboration with research programmes and the science communities in other European sea basins and on an international level (performance statistic 5)

Over the project duration, BIO-C3 scientists have engaged in a cumulative total of 47 collaborations with a range of different research programmes and individual scientists from beyond the Baltic region, including most European countries, the USA, Russia, Australia, New Zealand, and global networks, and focusing on seas including the Arctic Seas, North Sea, Atlantic, Mediterranean and Black Sea. The Artic is emerging as one area where BIO-C3 scientists are particularly involved, in part because knowledge on governance, monitoring and environmental problems from the Baltic may in part be transferrable and benefit Arctic programmes. These exchanges have been highly relevant for the project, since scientifically and for management purposes, they are placing the Baltic Sea results in a larger context. Research areas of interest include bio-invasions, environmental/global change, connectivity, and comparative studies in which the Baltic populations are interesting additions due to the brackish water conditions (e.g., population genetics and local adaptations). One effort to highlight in this context is the BIO-C3 led concept paper "*The Baltic as a time machine for the future coastal ocean*" (in review with Science Advances), which if finally published would put the Baltic even more strongly on the global map and would open new doors for collaborations.

6. BONUS BIO-C3 list of international peer-reviewed publications and PhD dissertations[2]

International peer-reviewed publications (n = 121[3] as of March 1st 2018):

Aarnio K, Törnroos A, Björklund C, Bonsdorff EC (2015) Food web positioning of a recent coloniser: the North American Harris mud crab Rhithropanopeus harrisii (Gould, 1841) in the northern Baltic Sea. Aquatic Invasions 10:399-413.

Almroth-Rosell E, Eilola K, Kuznetsov I, Hall POJ, Meier HEM (2015) A new approach to model oxygen dependent benthic phosphate fluxes in the Baltic Sea. Journal of Marine Systems 144:127-141. DOI: http://dx.doi.org/10.1016/j.jmarsys.2014.11.007

Andersen KH, Jacobsen NS, Jansen T, Beyer JE (2017) When in life does density dependence occur in fish populations? Fish and Fisheries 18:656-667. DOI: 10.1111/faf.12195

Angeler DG, Allen CR, Garmestani AS, Gunderson LH, Hjerne O, Winder M (2015) Quantifying the Adaptive Cycle. PLoS ONE 10:e0146053.

Ardura A, Zaiko A, Martinez JL, Samulioviene A, Semenova A, Garcia-Vazquez E (2015) eDNA and specific primers for early detection of invasive species - A case study on the bivalve Rangia cuneata, currently spreading in Europe. Marine Environmental Research 112, Part B:48-55. DOI: http://dx.doi.org/10.1016/j.marenvres.2015.09.013

Arula T, Laur K, Simm M, Ojaveer H (2015a) Dual impact of temperature on growth and mortality of marine fish larvae in a shallow estuarine habitat. Estuarine, Coastal and Shelf Science 167, Part B:326-335. DOI: http://dx.doi.org/10.1016/j.ecss.2015.10.004

Arula T, Raid T, Simm M, Ojaveer H (2015b) Temperature-driven changes in early life-history stages influence the Gulf of Riga spring spawning herring (Clupea harengus m.) recruitment abundance. Hydrobiologia 767:125-135. DOI: 10.1007/s10750-015-2486-8

Beer S, Garm A, Huwer B, Dierking J, Nielsen TG (2018) No increase in marine microplastic concentration over the last three decades - A case study from the Baltic Sea. Science of The Total Environment 621:1272-1279. DOI: https://doi.org/10.1016/j.scitotenv.2017.10.101

Behrens JW, van Deurs M, Christensen EAF (2017) Evaluating dispersal potential of an invasive fish by the use of aerobic scope and osmoregulation capacity. PLOS ONE 12:e0176038. DOI: 10.1371/journal.pone.0176038

Bekkevold D, Gross R, Arula T, Helyar SJ, Ojaveer H (2016) Outlier Loci Detect Intraspecific Biodiversity amongst Spring and Autumn Spawning Herring across Local Scales. PLoS ONE 11:e0148499. doi: 0148410.0141371/journal.pone.0148499

Bernreuther M, Peters J, Möllmann C, Renz J, Dutz J, Herrmann J-P, Temming A (in press) Trophic decoupling of mesozooplankton production and pelagic planktivores sprat (Sprattus sprattus) and herring (Clupea harengus) in the Central Baltic Sea. Marine Ecology Progress Series.

[2]Only publications with BIO-C3 acknowledgements listed, with two exceptions (see comment [3] below).
[3]Of these 110 are published or in press and 11 in review.

Burian A, Grosse J, Winder M, Boschker HTS (2017) Nutrient deficiencies and the restriction of compensatory mechanisms in copepods. Functional Ecology 00:1-12. DOI: 10.1111/1365-2435.13016

Cardeccia A, Marchini A, Occhipinti-Ambrogi A, Galil B, Gollasch S, Minchin D, Narščius A, Olenin S, Ojaveer H (2018) Assessing biological invasions in European Seas: Biological traits of the most widespread non-indigenous species. Estuarine, Coastal and Shelf Science 201:17-28. DOI: http://dx.doi.org/10.1016/j.ecss.2016.02.014

Chuševė R, Nygård H, Vaičiūtė D, Daunys D, Zaiko A (2016) Application of signal detection theory approach for setting thresholds in benthic quality assessments. Ecological Indicators 60:420-427. DOI: http://dx.doi.org/10.1016/j.ecolind.2015.07.018

Drillet G, Wisz MS, Le Berre Lemaire-Lyons Y, Baumler R, Ojaveer H, Bondad-Reantaso MG, Xu J, Alday-Sanz V, Saunders J, McOwen CG, Eikaas H (2016) Food security: Protect aquaculture from ship pathogens. Nature 539:31.[4]

Dutz J, Christensen AM (in review) Broad plasticity in the salinity tolerance of a marine copepod species in the Baltic Sea. Journal of Plankton Research.

Eero M, Andersson HC, Almroth-Rosell E, MacKenzie BR (2016) Has eutrophication promoted forage fish production in the Baltic Sea? Ambio 45:649-660. DOI: 10.1007/s13280-016-0788-3

Eero M, Hinrichsen H-H, Hjelm J, Huwer B, Hüssy K, Köster FW, Margonski P, Plikshs M, Storr-Paulsen M, Zimmermann C (in review) Do spawning closures promote cod recovery in the Baltic Sea? ICES J Mar Sci.

Eero M, Hjelm J, Behrens J, Buchmann K, Cardinale M, Casini M, Gasyukov P, Holmgren Nl, Horbowy J, Hüssy K, Kirkegaard E, Kornilovs G, Krumme U, Köster FW, Oeberst R, Plikshs M, Radtke K, Raid T, Schmidt J, Tomczak MT, Vinther M, Zimmermann C, Storr-Paulsen M (2015) Eastern Baltic cod in distress: biological changes and challenges for stock assessment. ICES Journal of Marine Science: Journal du Conseil 72:2180-2186. 10.1093/icesjms/fsv109

Eilola K, Almroth-Rosell E, Meier HEM (2014) Impact of saltwater inflows on phosphorus cycling and eutrophication in the Baltic Sea: a 3D model study. Tellus A 66:23985. DOI: 10.3402/tellusa.v66.23985

Florin AB, Hüssy K, Blass M, Oesterwind D, Puntila R, Ustups D, Albrecht C, Heimbrand Y, Knospina E, Koszarowski K, Odelström A (2017) How old are you—Evaluation of age reading methods for the invasive round goby (Neogobius melanostomus, Pallas 1814). Journal of Applied Ichthyology:1-6. DOI: 10.1111/jai.13596

Golz A-L, Burian A, Winder M (2015) Stoichiometric regulation in micro- and mesozooplankton. Journal of Plankton Research 37:293-305. DOI: 10.1093/plankt/fbu109

Griffiths JR, Hajdu S, Downing AS, Hjerne O, Larsson U, Winder M (2016) Phytoplankton community interactions and environmental sensitivity in coastal and offshore habitats. Oikos 125:1134-1143. DOI: 10.1111/oik.02405

Griffiths JR, Kadin M, Nascimento FJA, Tamelander T, Törnroos A, Bonaglia S, Bonsdorff E, Brüchert V, Gårdmark A, Järnström M, Kotta J, Lindegren M, Nordström MC, Norkko A, Olsson J, Weigel B, Žydelis R, Blenckner T, Niiranen S, Winder M (2017) The importance of benthic–pelagic coupling for marine ecosystem functioning in a changing world. Global Change Biology 23:2179-2196. 10.1111/gcb.13642

Grinienė E, Šulčius S, Kuosa H (2016) Size-selective microzooplankton grazing on the phytoplankton in the Curonian Lagoon (SE Baltic Sea). Oceanologia 58:292-301. DOI: http://dx.doi.org/10.1016/j.oceano.2016.05.002

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[4]No BIO-C3 acknowledgement due to "Nature" regulations on text length.

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Dissertations (n = 7 as of December 31 2017)[5]

[5] For a list also including MSc and BSc theses, see Appendix 2.

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7. Progress in comparison with the original research plan and the schedule of deliverables

All objectives of the original research plan were achieved. This included the successful completion of all milestones and deliverables originally laid down in the DOW, in line with the timeline laid down in the official schedule of deliverables (SOD) (update 2016).

In 2016, we applied for and were granted by the BONUS Secretariat (after consulting all national funding agencies) the cost-neutral extension of BIO-C3 by 6 months from 30 June to 31 December 2017. This extension allowed us (1) to strengthen the synthesis tasks in work packages 4 and 5 of BIO-C3 and to (2) to invest additional effort into the communication of project results to stakeholders and thus our project outreach and knowledge transfer components. The latter included the joint organization with BONUS INSPIRE of the international BONUS symposium "*Science delivery for sustainable use of the Baltic Sea living resources*" in Tallinn, Estonia, from 17-19 October 2017 (i.e., after our original project end date).

8. Wider societal implications

One of the key conclusions of the BIO-C3 led concept paper "*The Baltic as a time machine for the future coastal ocean*", submitted by BONUS clustering funds and in review in the journal "Science Advances", is that science-based management has been essential for the successful trend reversals of some of the pressing regional environmental problems in the Baltic Sea from a low point in the 1970s/1980s. Examples have included the improvement of eutrophication status (though still on a bad absolute level) since the 1980s, the improvement of several fish stocks, and the return of the top predators in the Baltic Sea, making the Baltic Sea a possible example for other world regions facing environmental degradation.

At the same time, the Baltic Sea is experiencing environmental changes in the context of global change that are occurring more rapidly than on a global average (oxygen minimum zone expansion, temperature increase, pH decrease), leading to interactions of pressures and new challenges for Baltic Sea management. In this situation, scientific information that can help resource managers and politicians to make informed decisions is and will be essential to maintain the health of the Baltic Sea.

Much of the information produced in BIO-C3 is either directly or indirectly relevant for resource management, including for example input to fisheries management, understanding of the role of NIS in Baltic ecoystems, the optimum design of MPA networks, as well as the assessment of indicators. Via the numerous activities of BIO-C3 in the science-policy arena, much of this information is either already used in an applied setting or has the strong potential to be used.

While BIO-C3 output is not directly producing economic value or creating jobs, we are hopeful that it strengthens the scientific foundation and makes specific recommendations that allow politicians and resource managers to make informed decisions that support the maintenance of ecosystem integrity of the Baltic Sea, despite the challenging situation of mounting global and continuing regional pressures and their interactions. Ultimately, a healthy ecosystem is the foundation for everything else, from human well-being to sustainable ecosystem goods and services including healthy tourism and fisheries.

Appendix 1: BIO-C3 and the coordination of pan-Baltic sampling and research initiatives

BIO-C3 has offered the unique opportunity to continue to strengthen collaborations and to improve coordination of sampling and research initiatives in the Baltic region. This has had clear benefits for the scientific output of the consortium and beyond. Initiatives include:

The improved coordination of research cruises in the Baltic region:

Over the course of BIO-C3, the timing of research cruises by the four project partners with own cruise programs (DTU Aqua, GEOMAR, NMFRI and UHH-IHF) was adjusted to avoid previous overlaps in survey coverage and to optimize temporal coverage. In addition, the regular exchange of survey staff between the institutes was strengthened. An example for the close cooperation is given for 2017 (Figure A1-1), when 8 research cruises to the Bornholm Basin and other deep basins of the Baltic were coordinated in systematic fashion, with intensive coverage of the summer months and an almost monthly survey coverage from March to November (exception September – October). Temporal coverage was clearly improved relative to the pre-BIO-C3 situation in 2014.

January		February		March		April		May		June		July		August		September		October		November		December	
1		1		1		1		1		1		1		1	IHF	1		1		1		1	
2		2		2		2		2		2		2		2	Uni	2		2		2		2	
3		3		3		3		3		3		3		3	Hamburg	3		3		3	**DANA**	3	
4		4		4		4		4		4		4		4	30.07.-11.08.	4		4		4	03.-20.11.	4	
5		5		5		5		5		5		5		5		5		5		5	DTU Aqua	5	
6		6		6		6		6		6		6		6	Herrmann	6		6		6		6	
7		7		7	**DANA**	7		7		7		7		7		7		7		7	Storr-	7	
8		8		8		8		8		8		8		8	Fishery	8		8		8	Paulsen	8	
9		9		9	DTU Aqua	9		9		9		9		9	Plankton	9		9		9	Huwer	9	
10		10		10	07.-25.03.	10		10		10		10		10		10		10		10		10	
11		11		11		11		11		11		11		11		11		11		11	Fishery	11	
12		12		12	Degel	12		12		12		12		12		12		12		12		12	
13		13		13	Huwer	13	**ALKOR 491**	13	**ALKOR 493**	13		13		13		13		13		13	Plankton	13	
14		14		14		14		14		14		14		14	**ALKOR 499**	14		14		14	on 1. leg	14	
15		15		15	Fishery	15	GEOMAR	15	GEOMAR	15		15	**ALKOR 497**	15	14.-26.08.	15		15		15	03.-11.	15	
16		16		16		16	13.-28.04.	16	13.-29.05.	16		16		16	GEOMAR	16		16		16		16	
17		17		17	Plankton	17		17		17		17	IHF	17	**Baltica**	17		17		17		17	
18		18		18	on 2. leg	18		18		18		18	Uni	18	17.-29.08.	18		18		18		18	
19		19		19	16.-25.	19		19		19	**Baltica**	19	Hamburg	19	NMFRI	19		19		19		19	
20		20		20		20	Dierking	20	von Dewitz	20	NMFRI	20	15.-29.07.	20	Jaspers	20		20		20		20	
21		21		21		21		21		21	DTUAqua	21		21	Huwer	21		21		21		21	
22		22		22		22	Plankton	22	Plankton	22	(joint)	22	Herrmann	22	Margonski	22		22		22		22	
23		23		23		23	Fishery	23	Fishery	23	19.-30.06.	23		23	Wozniczka	23		23		23		23	
24		24		24		24		24		24	Wodzinowski	24	Fishery	24		24		24		24		24	
25		25		25		25		25		25	Huwer	25	Plankton	25	Plankton	25		25		25		25	
26		26		26		26		26		26		26		26		26		26		26		26	
27		27		27		27		27		27		27		27		27		27		27		27	
28		28		28		28		28		28	Plankton	28		28	Plankton	28		28		28		28	
29				29		29		29		29	Fishery	29		29		29		29		29		29	
30				30		30		30		30		30	**ALKOR 498**	30		30		30		30		30	
31				31				31				31		31				31				31	

Figure A.1.1 Baltic cruises with BIO-C3 context in 2017.

The partners have already jointly planned and harmonized the cruises schedules for 2018 and tentatively for 2019. Out of this network, one issue to pursue further in the future is the collaboration on joint synthesis efforts moving beyond datasets from individual cruises.

The Baltic Sea mesozooplankton initiative:

This effort was started in 2014 and grew rapidly into a large dataset, involving the contributions from 11 institutions and 8 countries (http://kodu.ut.ee/~riina82/providers.html for the full list) by the end of 2017. The dataset is steadily growing, with regular updates by the current contributors, and was expanded with a new focus on essential functional trait information (body size, complexity, feeding type) that was compiled for 204 taxa in 2017. Moreover, monthly mean values of the salinity, temperature and oxygen from a 3D coupled sea-ice ocean model were added to the zooplankton data collected after 1979. To avoid any data misuse issues, and to protect the data providers, a data use policy was set in place, describing the principles of collaboration (http://kodu.ut.ee/~riina82/policy.html).

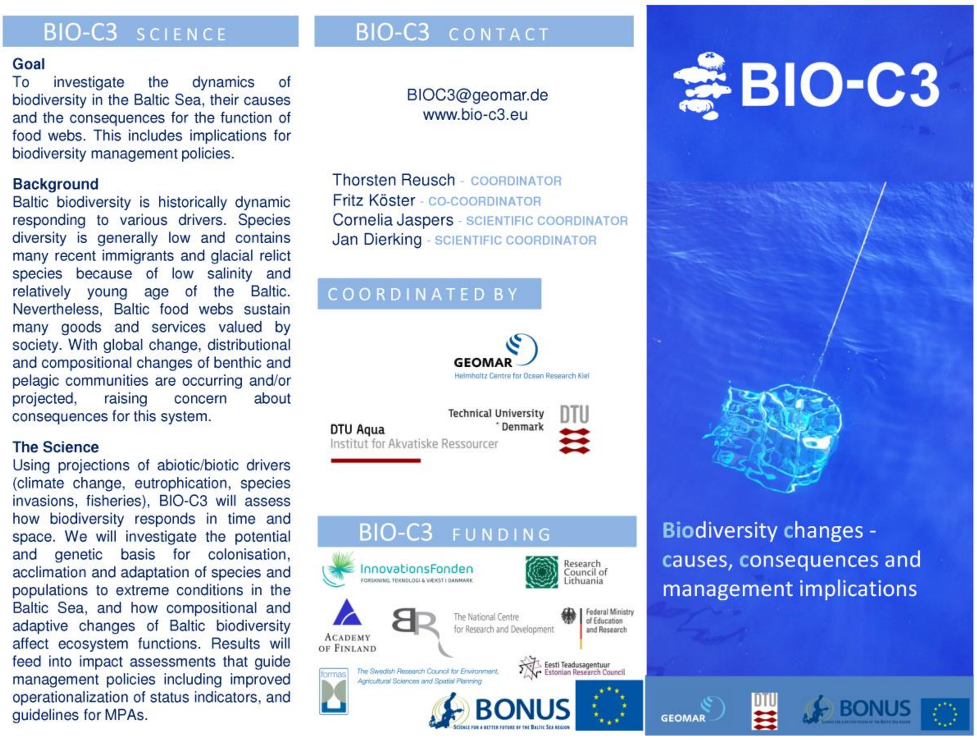
Appendix 2: List of PhD, MSc and BSc theses defended over the course of BIO-C3

Partner	Student	Title	Year
PhD theses			
P02 - DTU Aqua	Anette Maria Christensen	Marine copepods in the Baltic Sea – physiological responses and adaptation to low salinity. 182pp. DTU Aqua, Technical University of Denmark.	2017
P02 - DTU Aqua	Laurene Pécuchet	A trait-based approach to understanding marine communities composition, assembly and diversity. 126 pp. DTU Aqua, Technical University of Denmark.	2017
P02 - DTU Aqua	Viola Neumann	Trophic Interactions in the Baltic Sea: Predation on cod eggs by clupeids. 180 pp. DTU Aqua, Technical University of Denmark.	2017
P04 - SU	Jens Nielsen	Species interactions and energy transfer in aquatic food webs. 40 p. Department of Ecology, Environment and Plant Sciences, Stockholm University, Sweden	2016
P04 - SU	Alfred Burian	From biomolecules to populations: Effects of food quality on aquatic food-webs. 39p. Department of Ecology, Environment and Plant Sciences, Stockholm University, Sweden	2016
P07 – SYKE P06 – UT-EMI,	Riikka Puntila	Trophic interactions and impacts of non-indigenous species in the Baltic Sea coastal ecosystems (supervisors M. Lehtiniemi and H. Ojaveer). 48 p. Faculty of Biological and Environmental Sciences, University of Helsinki, Finland.	2016
P03 – UHH P11 – TI-OF	Paul Kotterba	Atlantic herring (*Clupea harengus*) within the estuarine food web of a southern Baltic Sea lagoon. 173pp. Hamburg University, Germany.	2015
MSc theses			
P01 – GEOMAR P02 – DTU Aqua	Moritz Ehrlich	Invasion Genomics: Population structure and diversity patterns in the invasive ctenophore *Mnemiopsis leidyi* based on whole-genome re-sequencing.	2017
P02 - DTU Aqua	Maria Sokolova	Comparison of prevalence and intensity of infection of the parasitic nematode *Contracaecum osculatum* s.s. (liver worm) in Baltic cod from different areas.	2017
P03 – UHH	Richard Klinger	Food conversion efficiency of western Baltic cod feeding on natural diets	2017
P03 – UHH	Viola Bödewadt	Untersuchungen zur Nahrungskomposition der Ostseesprotte in der Arkonasee und der Koinzidenz mit dem lokalen Zooplanktonvorkommen	2017
P03 - UHH	Steffen Funk	Depth-specific patterns in distribution and food intake of cod (*Gadus morhua*) in the western Baltic Sea; Master thesis, Institute for Hydrobiology and Fisheries Science University of Hamburg.	2017
P07-SYKE	Heidi Herlevi	Feeding ecology and food web position of two Baltic Sea populations of round goby (Neogobius melanostomus, Pallas 1814)	2017
P11 – TI-OF	Joschka Wiegleb	About the feeding ecology of the round goby Neogobius melanostomus (Pallas, 1814)	2017
P01 – GEOMAR	Luisa Berghoff	Seasonal condition growth and performance of Eastern Baltic cod larvae based on RNA/DNA ratios. Kiel University	2016
P01 – GEOMAR	Hennrike Wunderow	The impact of ocean acidification on the skeletal ossification in herring larvae (*Clupea harengus*, L.). Kiel University, Germany	2016

P02 - DTU Aqua	Alondra Sofía Rodríguez Buelna	Inter-annual variation in abundance of three species of jellyfish in the Bornholm Basin. DTU Aqua + GEOMAR	2016
P01 – GEOMAR P02 – DTU Aqua	Sarah Kaehlert	Larval Reproduction - a life-history trait exemplified by the American comb jelly *Mnemiopsis leidyi.* Kiel University, Germany.	2016
P03 – UHH	Sven Matern	Spread of invasive round goby (*Neogobius melanostomus*) and food competition with native black goby (*Gobius niger*) in the Western Baltic Sea. Hamburg University, Germany.	2016
P08 – KU	Aistė Stupelytė	"Distribution dynamics of blue mussel (*Mytilus* sp.) in the Lithuanian coastal waters of the Baltic Sea". Klaipeda University, Lithania.	2016
P01 – GEOMAR	Ramona Beckmann	Effects of microzooplankton on the planktonic food web. Kiel University	2015
P01 – GEOMAR	Lea Kraienhemke	Stable isotope fractionation rate in the carnivorous jellyfish *Mnemiopsis leidyi.* Kiel University.	2015
P02 – DTU Aqua	Katharina Bading	Healing & regeneration assessments on the ctenophore *Mnemiopsis leidyi* in its larval life cycle stage with observations on larval reproduction. DTU Aqua	2015
P04 – SU	Lia Simona Puiac	Effects of salinity and temperature on the development of *Eurytemora affinis* from the Baltic Sea. Stockholm University	2015
P11 – TI-OF	V. Siebert	The Spatial and Temporal Distribution of Cod (*Gadus morhua*), Herring (*Clupea harengus*) and Sprat (*Sprattus sprattus*) in the Bornholm Basin as resolved by hydroacoustics. Rostock University	2015
P11 – TI-OF	M. Gabel	Rolle der Schwarzmundgrundel (*Neogobius melanostomus*) in der Ernährung des Kormorans (*Phalacrocorax carbo sinensis*) an der Vorpommerschen Küste. Universität Rostock	2015
P11 – TI-OF	C. Bock	Seasonal habitat utilization and feeding ecology of round goby (*Neogobius melanostomus*) within the Pomeranian Bight. Universität Rostock,	2015
P11 – TI-OF	C. Henseler	Habitat specific feeding ecology of the round goby (*Neogobius melanostomus*) in the Greifswald Bay. Universität Rostock	2015
BSc theses			
P01 – GEOMAR	Robert Priester	Otolith time machine: 40 year history of Baltic cod feeding ecology reconstructed with otolith protein C, N, and S stable isotope analysis	2018
P03 – UHH	Jan Isfrid Römer	Verteilung von Fischeiern in der westlichen Ostsee	2017
P01 – GEOMAR	Paulina Urban	Unlocking the potential of biological sample archives: benthic-pelagic feeding of Baltic cod assessed by otolith protein amino-acid specific stable isotope analysis	2016
Co-supervision INSPIRE and BIO-C3 P01 – GEOMAR	Sophia Nyberg	Egg buoyancy and survival probabilities of Baltic Flounder (*Platichthys flesus*) – Differences between spawning areas and inter-annual variation in conditions for reproduction	2015

Appendix 3: BIO-C3 project flyer and website

1. Front page of the BIO-C3 flyer distributed at numerous occasions in 2017



BIO-C3 SCIENCE

Goal

To investigate the dynamics of biodiversity in the Baltic Sea, their causes and the consequences for the function of food webs. This includes implications for biodiversity management policies.

Background

Baltic biodiversity is historically dynamic responding to various drivers. Species diversity is generally low and contains many recent immigrants and glacial relict species because of low salinity and relatively young age of the Baltic. Nevertheless, Baltic food webs sustain many goods and services valued by society. With global change, distributional and compositional changes of benthic and pelagic communities are occurring and/or projected, raising concern about consequences for this system.

The Science

Using projections of abiotic/biotic drivers (climate change, eutrophication, species invasions, fisheries), BIO-C3 will assess how biodiversity responds in time and space. We will investigate the potential and genetic basis for colonisation, acclimation and adaptation of species and populations to extreme conditions in the Baltic Sea, and how compositional and adaptive changes of Baltic biodiversity affect ecosystem functions. Results will feed into impact assessments that guide management policies including improved operationalization of status indicators, and guidelines for MPAs.

BIO-C3 CONTACT

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Fritz Köster - CO-COORDINATOR
Cornelia Jaspers - SCIENTIFIC COORDINATOR
Jan Dierking - SCIENTIFIC COORDINATOR

COORDINATED BY

GEOMAR Helmholtz Centre for Ocean Research Kiel
DTU Aqua Institut for Akvatiske Ressourcer
Technical University of Denmark

BIO-C3 FUNDING

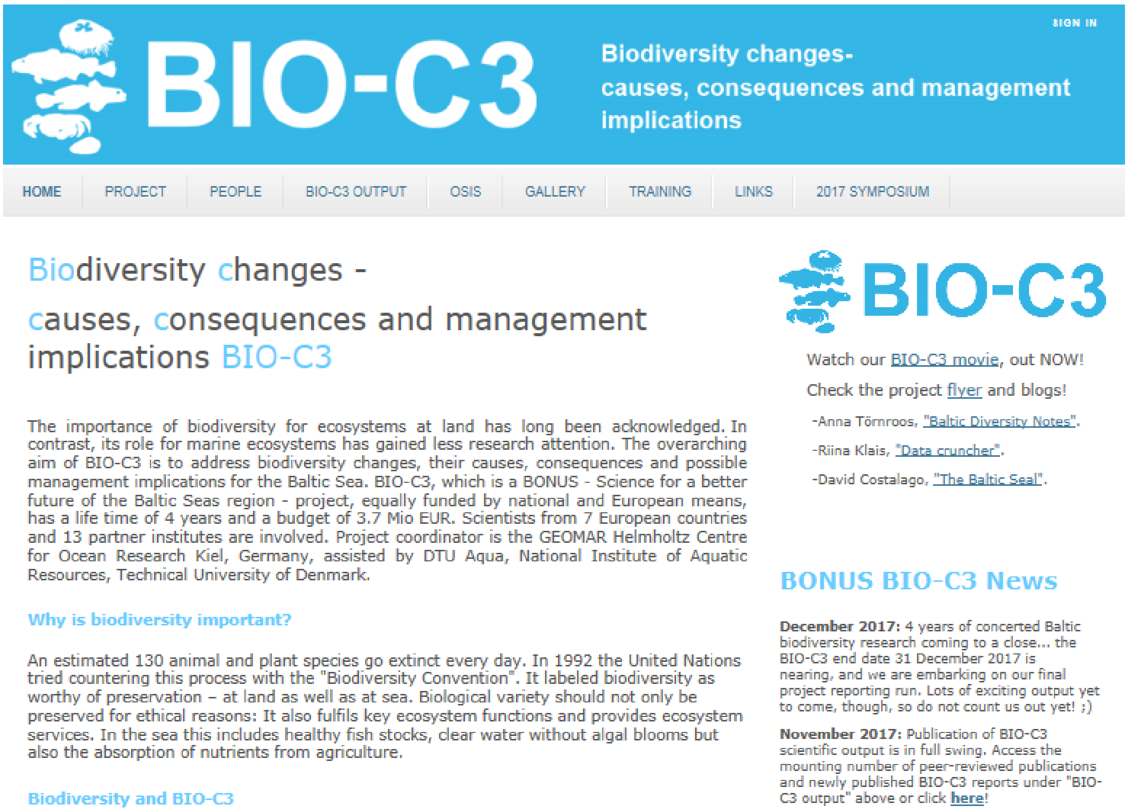
InnovationsFonden
Research Council of Lithuania
Academy of Finland
The National Centre for Research and Development
Federal Ministry of Education and Research
The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning
Eesti Teadusagentuur Estonian Research Council
BONUS

BIO-C3

Biodiversity changes - causes, consequences and management implications

GEOMAR DTU BONUS

2. Start page of the public website of BIO-C3 (www.bio-c3.eu, accessed 01.03.2018)



SIGN IN

BIO-C3

Biodiversity changes- causes, consequences and management implications

HOME | PROJECT | PEOPLE | BIO-C3 OUTPUT | OSIS | GALLERY | TRAINING | LINKS | 2017 SYMPOSIUM

Biodiversity changes - causes, consequences and management implications BIO-C3

The importance of biodiversity for ecosystems at 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. BIO-C3, which is a BONUS - Science for a better future of the Baltic Seas region - project, equally funded by national and European means, has a life time of 4 years and a budget of 3.7 Mio EUR. 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

BIO-C3

Watch our BIO-C3 movie, out NOW!

Check the project flyer and blogs!

-Anna Törnroos, "Baltic Diversity Notes".

-Riina Klais, "Data cruncher".

-David Costalago, "The Baltic Seal".

BONUS BIO-C3 News

December 2017: 4 years of concerted Baltic biodiversity research coming to a close... the BIO-C3 end date 31 December 2017 is nearing, and we are embarking on our final project reporting run. Lots of exciting output yet to come, though, so do not count us out yet! ;)

November 2017: Publication of BIO-C3 scientific output is in full swing. Access the mounting number of peer-reviewed publications and newly published BIO-C3 reports under "BIO-C3 output" above or click **here**!

Appendix 4: BIO-C3 scientist memberships and participations in stakeholder committees in 2017 (n = 103 in total)

Partner	Institute	Last name	First name	Working group (ICES, HELCOM, OSPAR etc.)
P01	GEOMAR	Clemmesen-Bockelmann	Catriona	ICES WGRP (Working Group on Recruitment Processes)
P01	GEOMAR	Dewitz	Burkhard	ICES/HELCOM WGIAB (Working Group on Integrated Assessments of the Baltic Sea)
P01	GEOMAR	Dierking	Jan	ICES/HELCOM WGIAB (Working Group on Integrated Assessments of the Baltic Sea)
P01	GEOMAR	Petereit	Christoph	ICES WGBAST (Working Group on Salmon and Seatrout Assessment in the Baltic Sea)
P01	GEOMAR	Petereit	Christoph	ICES WGTRUTTA (Working Group with the Aim to Develop Assessment Models and Establish Biological Ref. Points for Sea Trout pops.
P01	GEOMAR	Petereit	Christoph	ICES WGDAM (Working Group on Data Poor Diadromous Fish)
P02	DTU Aqua	Andersen	Ken Haste	ICES WKSPATIAL
P02	DTU Aqua	Behrens	Jane	ICES WKSIBCA
P02	DTU Aqua	Behrens	Jane	ICES WKBEBCA
P02	DTU Aqua	Bekkevold	Dorte	ICES WGAGFM
P02	DTU Aqua	Bekkevold	Dorte	ICES WGIMT
P02	DTU/IOW	Dutz	Jörg	ICES WGZE
P02	DTU/IOW	Dutz	Jörg	HELCOM ZEN-ZIIM
P02	DTU Aqua	Eero	Margit	ICES WGSPATIAL
P02	DTU Aqua	Eero	Margit	ICES WGBFAS
P02	DTU Aqua	Eero	Margit	ICES WGHIST
P02	DTU Aqua	Eero	Margit	ICES/HELCOM WGIAB (Working Group on Integrated Assessments of the Baltic Sea)
P02	DTU Aqua	Eero	Margit	ICES WKBEBCA
P02	DTU Aqua	Hemmer Hansen	Jakob	ICES WGAGFM
P02	DTU Aqua	Hemmer Hansen	Jakob	ICES WGNSSK
P02	DTU Aqua	Huwer	Bastian	ICES WGALES
P02	DTU Aqua	Huwer	Bastian	ICES IBTSWG
P02	DTU Aqua	Huwer	Bastian	ICES WGEGGS2
P02	DTU Aqua	Huwer	Bastian	ICES WKHERLARS2
P02	DTU Aqua	Huwer	Bastian	ICES WGBIFS
P02	DTU Aqua	Jaspers	Cornelia	ICES WGNEW
P02	DTU Aqua	Köster	Fritz	ICES Bureau
P02	DTU Aqua	Köster	Fritz	ICES Council
P02	DTU Aqua	Köster	Fritz	ICES CSIMTC
P02	DTU Aqua	Lindegren	Martin	ICES WGCOMEDA
P02	DTU Aqua	Lindegren	Martin	ICES/HELCOM WGIAB (Working Group on Integrated Assessments of the Baltic Sea)
P02	DTU Aqua	MacKenzie	Brian	ICES Science Committee
P02	DTU Aqua	MacKenzie	Brian	ICES SCCIME (Strategic Initiative on Climate Change Effects on Marine Ecosystems)

P02	DTU Aqua	MacKenzie	Brian	ICES WGHIST
P02	DTU Aqua	MacKenzie	Brian	ICES WGRFE
P02	DTU Aqua	MacKenzie	Brian	ICES WKSPATIAL
P02	DTU Aqua	Neuenfeldt	Stefan	ICES WKSPATIAL
P02	DTU Aqua	Neuenfeldt	Stefan	ICES WGBFAS
P02	DTU Aqua	Neuenfeldt	Stefan	ICES WGBIODIV
P02	DTU Aqua	Neuenfeldt	Stefan	ICES/HELCOM WGIAB (Working Group on Integrated Assessments of the Baltic Sea)
P02	DTU Aqua	Krüger-Johnsen	Maria	ICES WGALES
P03	UHAM-IHF	Temming	Axel	MSC steering committee of Dutch, Danish, German MSC certification of Crangon fishery
P03	UHAM-IHF	Temming	Axel	ICES WGCRAN
P03	UHAM-IHF	Herrmann	Jens-Peter	ICES WKBEBCA
P04	SU	Winder	Monika	SCOR WG137 (Global Phytoplankton Group)
P05	NMFRI	Calkiewicz	Joanna	HELCOM ZEN (Zooplankton Expert Network)
P05	NMFRI	Fey	Dariusz	ICES PUBCOM (Publications and Communications Group)
P05	NMFRI	Margonski	Piotr	ICES Council
P05	NMFRI	Margonski	Piotr	ICES WGZE (Working Group on Zooplankton Ecology)
P05	NMFRI	Margonski	Piotr	ICES WGIMT (Working Group on Integrated Morphological and Molecular Taxonomy)
P05	NMFRI	Margonski	Piotr	HELCOM ZEN (Zooplankton Expert Network)
P05	NMFRI	Radtke	Krzysztof	ICES WGBFAS (Baltic Fisheries Assessment Working Group)
P05	NMFRI	Radtke	Krzysztof	ICES WGBIFS (Baltic International Fish Survey Working Group)
P05	NMFRI	Radtke	Krzysztof	ICES WGBIOP (Working Group on Biological Parameters)
P05	NMFRI	Radtke	Krzysztof	ICES WGRFS (Working Group on Recreational Fisheries Surveys)
P05	NMFRI	Smolinski	Szymon	ICES WGBFAS (Baltic Fisheries Assessment Working Group)
P05	NMFRI	Smolinski	Szymon	ICES WGBIOP (Working Group on Biological Parameters)
P05	NMFRI	Smolinski	Szymon	HELCOM FISH-PRO II (Project for Baltic-wide assessment of coastal fish communities in support of an ecosystem-based management)
P05	NMFRI	Warzocha	Jan	ICES BEWG (Benthos Ecology Working Group)
P05	NMFRI	Woźniczka	Adam	ICES WGBYC (Working Group on Bycatch of Protected Species)
P06	UT-EMI	Klais	Riina	SCOR WG137 (Global Phytoplankton Group)
P06	UT-EMI	Klais	Riina	IOC WG TrendsPO (Working Group to Investigate Climate Change and Global Trends of Phytoplankton in the Oceans)
P06	UT-EMI	Ojaveer	Henn	OPI (Global network on Oceans Past Initiative, executive committee member)
P06	UT-EMI	Ojaveer	Henn	ICES HAPISG (Human Activities, Pressures and Impacts Steering Group, chair)
P06	UT-EMI	Ojaveer	Henn	ICES SCICOM (Science Committee, member)
P06	UT-EMI	Ojaveer	Henn	ICES WGBOSV (Working Group on Ballast and Other Ship Vectors, member)
P06	UT-EMI	Ojaveer	Henn	ICES WGITMO (Working Group on Introductions and Transfers of Marine Organisms, chair)
P06	UT-EMI	Ojaveer	Henn	ICES WGHIST (Working Group on History of Fish and Fisheries)
P06	UT-EMI	Ojaveer	Henn	ICES Awards Committee, member

P06	UT-EMI	Ojaveer	Henn	UN Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects (nominated expert)
P06	UT-EMI	Ojaveer	Henn	Joint HELCOM/OSPAR Task Group on Ballast Water Management Convention Exemptions, member
P06	UT-EMI	Ojaveer	Henn	HELCOM MARITIME ad hoc Correspondence Group on Ballast Water Management, member
P06	UT-EMI	Orav-Kotta	Helen	BMB member
P07	SYKE	Kuosa	Harri	SCAR Life Sciences Group (LSG)
P07	SYKE	Kuosa	Harri	ICES/PAME Working Group on Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean
P07	SYKE	Kuosa	Harri	UN Regular Process (State of marine environment)
P07	SYKE	Lehtiniemi	Maiju	HELCOM/Ospar TG Ballast
P07	SYKE	Lehtiniemi	Maiju	ICES/IOC/IMO WGBOSV (Working Group on Ballast and Other Ship Vectors)
P07	SYKE	Lehtiniemi	Maiju	ICES WGITMO (Working Group on Introductions and Transfers of Marine Organisms)
P07	SYKE	Lehtiniemi	Maiju	ICES WGZE (Working Group on Zooplankton Ecology, member)
P07	SYKE	Lehtiniemi	Maiju	National committee to implement the EU regulation on invasive species
P07	SYKE	Lehtiniemi	Maiju	National committee to implement the Finnish alien species strategy
P07	SYKE	Lehtiniemi	Maiju	National committee on Ballast Water Convention led by Traffic and Safety Agency
P07	SYKE	Puntila	Riikka	National ad hoc committee on Ballast Water Convention led by Traffic and Safety Agency
P09	DHI	Middelboe	Anne Lise	Chair for CEDA WG on Sea floor Integrity, 2 meetings in 2017
P09	DHI	Middelboe	Anne Lise	Member of DG ENV WG on GES, 1 meeting in 2017
P10	UGOT	Jonsson	Per	PAME (Protection of the Arctic Marine Environment) scientific advisor
P10	UGOT	Jonsson	Per	Biodiversity working group at Swedish Agency for Marine and Water Management
P11	TI-OF	Oesterwind	Daniel	ICES Review Group on Bycatch of cetaceans and other protected species (RGBYC)
P11	TI-OF	Oesterwind	Daniel	ICES Advice Drafting Group on Bycatch of cetaceans and other protected species (ADGBYC)
P11	TI-OF	Oesterwind	Daniel	ICES Working Group on Cephalopod Fisheries and Life History (WGCEPH)
P11	TI-OF	Rau	Andrea	ICES Workshop on providing a method to aggregate species within species groups for the assessment of GES for MSFD D1 (WKD1Agg)
P11	TI-OF	Rau	Andrea	ICES Working Group on the Ecosystem Effects of Fishing Activities (WGECO)
P11	TI-OF	Rau	Andrea	National MSFD Expert Group: Fach-AG “Fisch und Fischerei” (AG FiFi)
P12	SMHI	Andersson	Helen	ICES WGIPEM (Working Group on Integrated Physical-biogeochemical and Ecosystem Modelling)
P12	SMHI	Andersson	Helen	OSPAR ICG-EMO
P12	SMHI	Gröger	Matthias	OSPAR ICG-EMO
P12	SMHI	Eilola	Kari	OSPAR ICG-EMO
P12	SMHI	Hordoir	Robinson	ICES Working Group on Seasonal-to-decadal Prediction of Marine Ecosystems (WGS2D)
P13	ÅAU	Törnroos	Anna	ICES/HELCOM WGIAB (Working Group on Integrated Assessments of the Baltic Sea)
P13	ÅAU	Törnroos	Anna	ICES WGCOMEDA (Working group on Comparative Analysis between European Atlantic and Meditteranean marine ecosystems)
P13	ÅAU	Törnroos	Anna	ICES Workshop to evaluate regional benthic pressure and impact indicator(s) from bottom fishing (WKBENTH)
P13	ÅAU	Törnroos	Anna	HELCOM SPICE Workshop on Cumulative Impacts and Maximum Allowable Pressures on Habitats

Appendix 5: BIO-C3 meta-data summary (75 datasets available as of 1st of March 2018; only the first 6 datasets shown as example); up-to-date version accessible via our website www.bio-c3.eu, or by contacting Jan Dierking at jdierking@geomar.de

No	Insti.	Title of dataset	General description	Keywords	Data type[6]	Parameters	Area	Spatial reso-lution	Time span	Temporal resolution	Originator; contact	Publication where data used	Location of dataset	Availa-bility
1	GEO MAR	Bornholm Basin cod spawning datast	Oxygen related Baltic cod egg survival	cod female age structure, egg size, SR relationship	O	Habitat size and oxygen-related Baltic cod egg survival	Bornholm Basin	a few km	1993 – 2010	April, May, July	H.H.Hinrichsen; hhinrichsen@gemoar.de	Hinrichsen, H. H., von Dewitz, B., Dierking, J., Haslob, H., Makarchouk, A., Petereit, C. and Voss, R. (2016) Oxygen depletion in coastal seas and the effective spawning stock biomass of an exploited fish species Royal Society Open Science, 3 (1). p. 150338. DOI 10.1098/rsos.150338.	Dryd repository: http://dx.doi.org/10.5061/dryad.2pm6f	Open
2	GEO MAR	Distribution and connectivity of Eastern Baltic cod eggs	Connectivity and distribution based on biophysical modelling	Habitat, dispersal, mortality	O and M	Habitat size and oxygen-related Baltic cod egg survival	ICES SD 24, 25, 26 and 28	2.5 km	1971-2010	daily	H.H.Hinrichsen; hhinrichsen@gemoar.de	Hinrichsen, H. H., Lehmann, A., Petereit, C., Nissling, A., Ustups, D., Bergström, U. and Hüssy, K. (2016) Spawning areas of eastern Baltic cod revisited: Using hydrodynamic modelling to reveal spawning habitat suitability, egg survival probability, and connectivity patterns Progress in Oceanography, 143 . pp. 13-25. DOI 10.1016/j.pocean.2016.02.004.	Pangaea repository: doi:10.1594/PANGAEA.859993	Open
3	GEO MAR	Distribution and connectivity of Eastern Baltic flounder eggs	Connectivity and distribution based on biophysical modelling	Habitat, dispersal, mortality	O and M	Habitat size and oxygen-related Baltic flounder egg survival	ICES SD 24, 25, 26 and 28		1971-2010	daily	H.H.Hinrichsen; Hhinrichsen@gemoar.de	Hinrichsen, H. H., Petereit, C., Nissing, A., Wallin, I., Ustups, D. and Florin, A. B. (2017) Survival and dispersal variability of pelagic eggs and yolk-sac larvae of central and eastern Baltic flounder (Platichthys flesus): application of biophysical models ICES Journal of Marine Science . DOI 10.1093/icesjms/fsw163.	Pangaea repository: doi:10.1594/PANGAEA.869896	Open
4	GEO MAR	Larvae mortality and Recruitment of Cod under OA	Mortatlity data of larval cod from Western Baltic and Barents Sea ages 1 to 25 days post hatching	Cod, Baltic Sea, Barents Sea, Recruitment, Ocean Acidification	E and M	Mortality data, Carbon Chemistry, modeled Recruitment	Western Baltic, Barents Sea	none	2013-2014	daily	Catriona Clemmese; cclemmesen@geomar.de	Martina H. Stiasny,Felix H. Mittermayer, Michael Sswat, Rüdiger Voss, Fredrik Jutfelt, Melissa Chierici, Velmurugu Puvanendran, Atle Mortensen, Thorsten B. H. Reusch, and Catriona Clemmesen* Ocean Acidification Effects on Atlantic Cod Larval Survival and Recruitment to the Fished Population, PLoS One. 2016; 11(8): e0155448.	Pangaea repository: doi:10.1594/PANGAEA.858618	Open
5	GEO MAR	Seasonal stable isotope data of Kiel Fjord jellyfish	Carbon, Nitrogen and Sulfur stable isotope values for Aurelia aurita and Cyanea capillata	Baltic Sea, Kiel Fjord, jellyfish, stable isotopes, feeding ecolgy, temporal changes	O	Size dependant, temporally resolved stable isotope values (C, N, S) for two jellyfish speices	Western Baltic, SD 22, Kiel Fjord	one location only	2011	June - October, bi-weekly	Jamileh Javidpour; jjavid@geomar.de	Javidpour, J., Cipriano-Maack, A. N., Mittermayr, A. and Dierking, J. (2016) Temporal dietary shift in jellyfish revealed by stable isotope analysis Marine Biology, 163 (5, 112). pp. 1-9. DOI 10.1007/s00227-016-2892-0.	Pangaea repository: doi:10.1594/PANGAEA.858057	Open
6	DTU-Aqua	Distribution and connectivity of Baltic cod eggs originated in the Arkona Basin	Connectivity and distribution based on biophysical modelling	Habitat, dispersal, mortality	O and M	Habitat size and oxygen-related Baltic cod egg survival	ICES SD 22, 24 and 25	2.5 km	1990-2010	daily	F.W. Köster; fwk@aqua.dtu.dk	Hüssy, K.; Hinrichsen, H.-H.; Eero, M.; Mosegaard, H.; Hansen, J.H.; Lehmann, A.; Lundgaard, L.S. (2016) Spatio-temporal trends in stock mixing of eastern and western Baltic cod in the Arkona Basin and the implications for recruitment. ICES Journal of Marine Science 73 (2): 293-303. DOI 10.1093/icesjms/fsv227.	Contact originator Fritz Köster	On request

…continuing to dataset No. 75 as of 1st of March 2018

[6] O – Observational; M – Model; E - Experimental