Expert group viewpoint

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1. Why do we need to strengthen the science base?

The Baltic Sea is currently undergoing fundamental changes regarding both its environmental drivers and the ecosystem responses. This is closely coupled to the way society utilizes the sea and its living resources. In order to strengthen an integrated management of the Baltic Sea, there is a need to redefine and develop multidisciplinary and holistic research efforts and monitoring for the coming decades.

The following brief Expert-group assessment of knowledge gaps and challenges for a science-based assessment and management of the Baltic Sea summarizes the discussions held during a workshop at the Swedish Environmental Protection Agency in Stockholm on the 18/19 Nov. 2013.

Our group concluded that there are at least five broad arguments for continuing and/or even stepping up monitoring efforts and research in the Baltic Sea:

1. Science is already helping to understand ***today's problems*** and find solutions to them. However, today's problems are a result of yesterday's causality and knowledge of the causal links depends to a good extent on information gathered in the past, which may be incomplete.
2. Science can help to avoid ***tomorrow's problems*** by understanding the causal chain of events affecting the system now and understanding how these may change in the future. Thus science can help society in being pro-active rather than reactive on environmental issues, such as climate change scenarios or the development of novel chemicals with improved environmental properties.
3. We have to service the ***statutory and voluntary obligations*** that Sweden and its neighbours are committed to such as the HELCOM Baltic Sea Action Plan, the EU Water Framework Directive, the Common Fishery Policy, and the Marine Strategy Framework Directive (which is involving a lot of input from scientists to help define and reach Good Environmental Status).
4. Scientific knowledge is essential to enhance the ***sustainable use of ecosystem services*** that the Baltic is providing, and to avoid seemingly effective short-term solutions that might not be adequate to solve long-term problems.
5. ***Discovery,*** based on curiosity-driven science, of how the Baltic ecosystem and its components operate and of the emergent issues affecting it (many of the great discoveries have happened this way).

In each of these areas there are gaps in knowledge and sometimes in the skills required to generate the necessary knowledge. We will describe and discuss our perception of these gaps in the following section of the overall report.

2. The Baltic Sea as a temporal and spatial continuum

The Baltic Sea is a “young” ecosystem; the topographical, hydrographical and ecological framework is defined by the last glaciation, and the succession that has taken place during the last 10.000-8.000 years, and the current regime is less than 3.000 years old. The environmental gradients are steep, ranging from the fully marine conditions in the Skagerrak-Kattegat region to the semi-limnetic conditions in the inner reaches of the Gulf of Bothnia and Gulf of Finland. The water exchange is driven by both the irregular inflows of saline Atlantic water and the fresh water inflows from land (the drainage area being roughly 4 times the surface area of the Baltic Sea). Thus the gradients in salinity (E<->W and S<->N) and temperature (S<->N) form the environmental continuum to which all organisms in the ecosystem must adapt. These gradients affect the outcome of e.g. production-rates and -levels, and impact levels of oxygen saturation (with hypoxia/anoxia currently being one of the main threats to the structure and functioning of the ecosystems both below the halocline and in the coastal waters in some regions). This spatial continuum further changes over time (seasonal and long-term; decadal and beyond), currently being emphasized by the impacts of climate change (increasing temperature, decreasing salinity, decreasing oxygen saturation, increasing acidity i.e. reduced pH-conditions). These macro-ecological drivers to a large extent govern the presence/absence of species (significant shifts in species composition have been reported for e.g. zooplankton, zoobenthos and fish during the last 40-50 years), and thus potentially affect the functional properties of the entire sea and/or its sub-systems.

With this setting in mind, it is important to acknowledge that change is inevitable and natural, and that return to what has been described as “pristine conditions” in the past is neither likely nor desired. Hence, setting realistic targets for the ecosystem is important, keeping in mind both the overriding and more specific threats/drivers for the system. We may need to view such things as invasive, non-native species in a different way than has so far been customary. This could be to regard the ecosystem in terms of functionality along the spatio-temporal continuum, where the “memory” of the system (e.g. hazardous substances currently buried in the sediments may have an impact long after the input of them to the sea has ended) and the outcome of the succession (resilience) is in part unpredictable and in part manageable by people. ***This highly dynamic nature of the Baltic Sea as a whole and of its individual compartments underlines the need for long-term and holistic approaches to monitor and manage the Baltic Sea ecosystem.*** Research and monitoring cannot be de-coupled, and the commitments to environmental monitoring must be long-term ones. Another aspect of this is the continuum from land to the open sea, i.e. the “interface ecosystem”, the coastal fringes and zones, where diversity is often at its highest, and where human impacts are first seen (both negative and positive). Thus, in order to manage the state of the Baltic Sea, we must understand the linkages between land and sea, and in order to do so, we must understand the intricate ecological linkages in the coastal environment.

3. The need to manage the Baltic Sea: role of science in management successes and failures

The impacts of human-induced pressures, both those on the sea and those on land, are multifaceted and need to be minimized in order to restore and maintain good environmental status of the Baltic

Sea and use its resources sustainably. This is not possible without understanding the complex processes as well as causes and consequences, and transforming this knowledge to scientific advice for environmental policy makers.

The landscape of management policies and regulations relevant to the Baltic Sea is broad and multileveled – a recent analysis revealed over 80 international, European and regional policy regulations and action plans, which have a direct relevance to the Baltic Sea. Despite this multiplicity the Baltic Marine Environment Protection Commission, HELCOM and more recently the spatial planning organization VASAB, offer a channel for mediating the science contribution to management activities.

Baltic Sea science has contributed in many ways to creating the knowledge base for the development of HELCOM's action plans. ***The lesson learned is the need for adaptive management. In such a management approach, the decision-making is based on progressively increasing scientific knowledge and the related action plans on iterative adjustments, taking into account spatial and temporal scales and differences, the level of uncertainty as well as socio-economic developments***.

An appropriate structure for science governance and funding, such as the policy driven joint Baltic Sea Research programme BONUS, is necessary for fostering the development of effective, knowledge-based 'fit-for-purpose' regulations and management practices as well as for facilitating the science – policy communication based on multidisciplinary and visionary research.

4. Setting new objectives: Maintenance of functional diversity, food webs and ecosystem services

In the past, monitoring and basic research has been focussed on specific compartments of the ecosystem, ranging from the physical and chemical drivers to specific units, such as commercial fish, macroalgal communities or specific heavy metals. Currently, however, we are becoming increasingly aware that these units are linked, and cannot be comprehensively understood or managed without profound knowledge of these linkages. The utilization of designated ecosystem services cannot be sustainable unless we take into account the cascading impacts on all levels of the ecosystem. As the species composition inevitably changes over time and in space (as explained in (2) above), and empty/available niches are increasingly occupied by non-native species (or by species of currently low commercial value), one way forward is to look beyond the species-composition (which is not the same as neglecting the taxonomy and biology of the organisms), and focus on the functional properties and aspects of diversity. Biodiversity in itself (ranging from molecular levels to species to functional levels) is valuable, but the current concept of conserving species and habitats may be of limited value unless we (a) acknowledge that natural change will transform them over time, and (b) understand their inherent functional properties. ***Linking the functional traits and their categories of the entire range of organisms in the Baltic Sea to the food web-concept is a major challenge for future research efforts***: Although species-richness in itself is valuable, ultimately it will be the **functions** the organisms (species) perform that will sustain the ecosystem, and thus there is an acute need to understand these properties. From a management-perspective it is not trivial to understand that although species compositions may be different in defined sub-habitats, the functional linkages and the food-web properties may in fact require a broader understanding. It has been suggested that ecosystems that are rich in species will also be rich in functions, and *vice-versa*. Currently, however, there is accumulating evidence that the functional properties may in fact be surprisingly robust throughout the Baltic Sea gradient, potentially offering unifying links for the ways we manage the sea. From a resilience-perspective this is also intriguing, as the number of species fulfilling certain food-web linkages and/or functional properties/pathways will still vary along the gradient. How these properties and characteristics respond to large-scale environmental change is one of the main challenges for future research, which may ultimately help in setting environmental targets for the ecosystem.

The concept of ecosystem services emerged from the Millennium Ecosystem Assessment. One way of thinking about this concept is to regard it as the amount of 'interest' that can be drawn down from natural capital (the ecosystem) without undermining the natural capital itself. The types of services may be classified into: *supporting* services (e.g. nutrient cycling, soil formation, primary production), *regulating* services (e.g. climate regulation, flood regulation, water purification), *provisioning* services (e.g. food, fresh water), and *cultural* services (e.g. aesthetic, spiritual, recreational and other non-material benefits). Ecosystem services may be used to produce benefits (such as material goods, work and leisure opportunities etc) and these stem from a chain of events that connect the ecosystem to human beneficiaries.

Understanding this chain of events, the value of the services and the factors that limit them is crucial when deciding how the system can be exploited (or conserved). Not all of the services can be drawn down at the same time; the Baltic cannot have crystal clear water and be teaming with fish at the same time and there are inevitable trade-offs. This way of looking at ecosystems is relatively new and requires considerable interdisciplinary science. So far, ***there are few studies of the ecosystem service concept and its application to resource use in the region and this is a clear area for accelerated future development***.

5. Tackling multiple stressors and cumulative impacts

Marine life in a water body such as the Baltic Sea, with a dense population and heavy economic activities, is obviously rarely, if ever, exposed to one particular stressor. Instead, marine life is exposed simultaneously to a variety of stressors, comprising either large-scale unmanaged ones (e.g. ocean acidification), and/or site-specific managed ones (e.g. noise from underwater installations and shipping). It can be expected *a priori* (and the few case studies available support the notion), that the joint action of several stressors is quantitatively and qualitatively different from the action of each individual stressor (often higher). This implies the need for developing appropriate assessment and management approaches considering multiple stressors and their potential cumulative impacts on the ecosystem and the services the ecosystem provides human society. ***Ecosystem diagnosis is one particular challenge, i.e. the retrospective identification and quantification of cause-effect relationships between an observed ecological impact and the set of biotic, chemical and physical drivers that act in concert and jointly push the system away from good environmental status***.

In order to account for multiple stressors we need

1) conceptually sound approaches on how to model and predict the joint action of multiple stressors, for which it will be critical to agree on a consistent nomenclature;
2) the corresponding model-validation studies;
3) agreed approaches on how to rescale different stressors into one (or a few) holistic descriptors for "good environmental status of the Baltic Sea";
4) the means to rank and prioritize the stressors present at a site or an area, in order to provide options for management.

The initial holistic assessment of the Baltic Sea that was recently published under the auspice of HELCOM is a first substantial step to describe the status of the Baltic Sea ecosystem in relation to the presence of multiple stressors. Much progress has also been made during recent years in developing approaches for predicting and assessing the joint toxicity of complex chemical cocktails, tools that might serve as templates for similar approaches that enable multiple stressor assessment. Finally, it should be stressed that ***the optimization and integration of biological, chemical and physical monitoring programs as well as adequate data storage and documentation will be critical to manage and act on the cumulative impacts of multiple stressors***.

6. Legacy issues, delayed responses and unpredicted change

The Baltic Sea experiences many different perturbations, both natural and human-induced (e. g., eutrophication, climate variability and change, exploitation of fish and marine mammals, contamination, invasion of non-native species). The responses to these perturbations occur at different time scales, depending for example on which part of the food web is impacted, on the structure of the food web itself, and on the current state ("initial" conditions) of the system immediately prior to perturbation. Smaller biota (i.e. organisms with a rapid turnover and large recruitment potential) with short lifespans are likely to respond quicker to perturbations than larger biota with longer times to maturity and slower population growth rates. Perturbations therefore may not affect (or be detectable in) some biota until several years or even decades after their initiation. For example, 20th century eutrophication impacted lower trophic levels, including creation of larger and more frequent anoxia events, earlier than higher trophic levels such as piscivorous fish. Moreover responses of biota to perturbations can be delayed because of reservoir effects: a reduction in nutrient loading may not have detectable effects on food webs for many years because reservoirs of nutrients may continue to supply nutrients to primary producers. Likewise future impacts of climate change or an invasive species on specific biota or the Baltic food web could be minimal, until certain threshold conditions (e. g., temperatures that ensure or prevent high reproductive success; abundances of a predatory invader) are surpassed, thereby altering population demographics. Moreover biotic and food web responses to perturbations may not necessarily be reversible following changes in intensity or direction of the drivers. This suggests that biotic responses to perturbations, and higher-order food web properties such as resilience and recovery potential, depend on species and trait assemblages of communities.

Many "legacy" contaminants still exist in the Baltic environment due to their large historical use and extreme persistence. Once generated, they can persist in soils, sediments and waste depositories for periods extending from decades to centuries. Transport mechanisms such as discharge and evaporation from land areas and transport from contaminated soils and sediments result in long residence times before entering the Baltic food chain and this sometimes causes delayed responses even centuries after banning their use. Accordingly, effects may emerge in regions that are not the most exposed to these contaminants but may be more vulnerable (for example dioxins that are highest in the northern Baltic despite lower loadings than in the southern Baltic). Similarly, environmental response to any mitigation efforts will often also take a long time to become visible.

Understanding the occurrence and consequences of legacy issues, delayed responses and unpredicted changes therefore requires both regular system monitoring and data collection about the state of the system, increased knowledge of species and functional group responses to perturbations and interactions among species and functional groups within food webs. The current absence of such knowledge means that forecasts of how Baltic ecosystems, biodiversity, species and populations will react to its multiple, cumulative and interacting drivers will remain uncertain.

7. Invasive species and ecosystem restructuring

The Baltic has been subjected to the arrival and 'outbursts' of invasive species as a natural process since it was established in its current form after the Holocene. Humans have accelerated this process and provided vectors for species to be introduced from all over the planet and the rate of invasions has accelerated from the 'natural' rate as a consequence. Invasive species often occupy available niches that result from human damage to habitats. Currently, there are some 120 known invasions to the Baltic Sea marine ecosystem, but many of them have remained at low abundance and/or local (e.g. harbours and river mouths)/regional (e.g. coastal lagoons, archipelago areas etc) distributions. The EU Habitats- and Biodiversity Directives stipulate that biodiversity shall not be altered or reduced, and invasive species are oftentimes considered as threats, *a priori*, to the ecosystem, but in a changing environment, the role of species invasions must be judged in a nuanced manner.

Invasions can trigger major functional changes to ecosystems, potentially resulting in shifts in food webs or even the remobilisation of contaminants and nutrients previously trapped in sediments (e.g. the arrival of the polychaete worm *Marenzellaria* spp in the 1980s, which has also proven to be potentially beneficial for hypoxic areas, i.e. potentially also providing positive ecosystem service in the coastal regions of the Baltic Sea). Some species, such as the ctenophore (comb jelly) *Mnemiopsis leidyi* have arrived but not resulted in the huge devastation they caused to the Black Sea or Caspian systems, perhaps as a result of lower temperatures in the Baltic – but this could change as the climate gets warmer. Several species are also known to have an impact on human use of the ecosystem, thus directly affecting our use of the natural resources provided by the marine environment. ***It is important to understand the role of invasive species, not only as negative factors but also of their functional role in the system and the likely change in their abundance as a result of new human vectors or by climate change.*** There are major gaps in our knowledge in this area (taxonomy, function, distribution, behaviour, risk of arrival).

8. Difficulty to understand causality with the currently available data and information

The Baltic Sea is considered to be one of the best studied marine systems on earth, with detailed information on a variety of factors within natural sciences going back to the late 1800's. There is a considerable amount of information about many aspects of human impact on the coast and the open sea. Despite the large amount of data, and that many of the key pressures influencing the Baltic Sea environment have been described, their relative impact is described only in approximate terms, sometimes only qualitatively and without a holistic approach. The level of uncertainty with regard to the system's responses to pressures and mitigation measures still needs to be reduced.

There is a need for interdisciplinary studies on the socio-economic and ecological systems that interact and develop jointly. One of the key problems is that results from biogeochemical models, food-web models and economics cannot be easily combined. Furthermore, there is a gap between the scientific research and integrated management, including, for example, fisheries management, spatial planning, impact analyses and regulations concerning economic activities.

So far, most studies have addressed current or past situations, and only one or a few drivers of change. ***New knowledge is needed to explore alternative scenarios for future options for sustainable development and predict their effects on ecosystem functions and services, taking into account the global change and changing societies***.

9. Uncertainty and precaution

Epistemic uncertainty must not be confused with biological variability. The former results when a lack of data (i.e. incomplete information) is available to the risk assessor or manager. Uncertainty can hence be lowered by recording and evaluating additional data. Variability, on the other hand, can be increasingly well described by generating more data, but is of constant size. Uncertainty also needs to be distinguished from simple ignorance and bias, i.e. the systematic deviation of a measurement or model from reality.

Despite the fact that the Baltic Sea is one of the best researched sea regions in the world, considerable uncertainties remain that hamper integrative ecological monitoring and management. This includes for example incomplete information on the loads of nutrients and hazardous substances entering the system, their fate and temporal trends in the various compartments of the Baltic Sea and the hazards they might pose to marine life.

Marine management cannot be postponed until all knowledge gaps are closed – which might be an unattainable goal for many sources of uncertainty, as the Baltic Sea is a highly dynamic, constantly evolving system. Management decisions therefore often have to be taken under conditions of considerable uncertainty. Employing adaptive management, multi-criteria decision making, participatory governance, and the precautionary principle provide formalized or at least semi-formalized approaches that enable action under conditions of uncertainty.

Characterizing the uncertainty and variability of pressures, stressors, their impacts and interactions is critical, in particular to prioritize future monitoring and research. Unfortunately, ***despite a growing body of academic literature, formal guidance for uncertainty description and quantification in marine risk assessment and management is largely missing, and the current practice of science-based advice often does not adequately addresses the issue.*** The aim to achieve and maintain good environmental status might be particularly challenging in this context. It is currently absolutely unknown, how the necessary holistic integration of a broad range of descriptors, each one based on a unique set of criteria, indicators and hence uncertainties, affects the overall uncertainty of the assessment.

10. How many levers can managers pull?

There are a limited number of practical measures that can be taken to improve the state of the Baltic and optimise its ability to generate ecosystem services. The use of these 'levers' is associated with research gaps (on their effectiveness, the way they are employed and the collateral effects), data availability and monitoring gaps (where there is insufficient information for a management decision). The effectiveness of each 'lever' is also different. The expert group has made a preliminary attempt to illustrate the magnitude of the gaps as well as the potential impact of the 'lever' for improving the Baltic. This does not examine the political, economic or technical factors involved in deciding how each of these measures is employed and to what extent.

Table 1. Examples of measures that can potentially be used for the benefit of the ecosystem, the gaps in current knowledge associated which these measures, and the potential leverage that can be obtained for optimising sustainable use of ecosystem services. Number of stars indicates the size of the research gap, the size of the data/monitoring gap and the leverage that the corresponding measure provides for a sustainable use of ecosystem services, respectively. * = small gap; ***** = large gap; * = low leverage; ***** = high potential leverage.

Measure	Research gap	Data/monitoring gap	Leverage for optimising sustainable use of ecosystem services
Control of nutrient loads	*	*	*****
Land use	***	**	*****
Coastal engineering	***	***	**
Disposal of hazardous substances (air, land and sea) and sewage	****	****	*****
Fishing (manage effort and selectivity	*** (i. e., ecosystem effects poorly understood)	*(i. e., fish & stocks relatively well understood) **** (i. e., ecosystem effects poorly understood)	*****
Shipping (including ballast water)	*	***	***
Removal of top predators	*	*	**
Drilling and dredging	*	*	**

Renewable energy	**	****	*
Artificial reefs	*	*	*
Aquaculture	**	*	***
Protected areas	*****	****	*****
Marine spatial planning	***** (cumulative impacts)	***	*****

Currently, there is nothing in place in the Baltic that can address all of these levers simultaneously in an integrated, holistic fashion, and which can predict the overall consequence of their use. This is a particularly important shortcoming for marine spatial planning where the trade-offs need to be explicit. We reiterate the huge uncertainties associated with cumulative impacts from different stressors (five stars).

Not everything can be managed (on the scale of the Baltic) and some of the unmanageable issues are also major system drivers that need to be monitored and understood. Key problems are

- Legacy hazardous substances and nutrients
- Climate change (including increased precipitation) and acidification
- Water exchange with the Atlantic (including long-term large-scale variability)

11. Delivering reasonable science-based advice

In presenting our findings, we do not want to give the impression that there is a general deficiency in research and monitoring on the Baltic; there is a huge wealth of knowledge and expertise. Our discussions did reveal a number of critical gaps however and these make it sometimes difficult to give useful and consistent advice to policy makers who are faced with difficult decisions involving trade-offs, while pursuing a stated intention to restore and maintain the Baltic Sea in a 'Good Environmental Status'. The existing knowledge gaps currently hamper our ability to select an optimum science-based management approach for the various pressures in the Baltic Sea. At worst, unrealistic or even fundamentally wrong long-term goals might be pursued, based on a faulty assessment of the prevalence, spatio-temporal dynamics and interactions of the various pressures and impacts. To a large extent, this can be avoided by addressing the gaps we have highlighted and by conducting scenario analyses, all in the context of adaptive management.