Reviewing the History of Natural Sciences Research on the Bothnian Sea, 1975–2008

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The Bothnian Sea is a shallow body of brackish water and part of the northern-most limb of the Baltic (Fig. 1). With salinity averaging 5–6 per mille, a ragged coastline, and slow sedimentation rates (Voipio 1981; Granö et al. 1999), it forms its own unique environment. The Åland Islands and the shape of the seabed prevent the nutrient-rich bottom water from Baltic proper from flowing into the Bothnian Sea. This constitutes the main reason why eutrophication has not yet become a major problem here. However, the situation is now beginning to change as a result of nutrient-rich water draining into the Bothnian Sea from the many Swedish and Finnish rivers (Lundberg et al. 2009). While the Bothnian Sea is an economically important region with the majority of herring in the Baltic being caught here (Parmanne 1998), it has generally not been the focus of much scientific effort and the reason for this could be its rather good condition. The same is true for monitoring as there are fewer sites, temporally and spatially, in the Bothnian Sea than in the smaller Archipelago Sea (HELCOM 2009). Consequently it is difficult to conduct spatially representative surveys with an insufficient spatial distribution of sites (Erkkilä and Kalliola 2007). Through reviewing the past 33 years of research on the Bothnian Sea (1975–2008) (Saikku et al. 2009), we have identified gaps in the current knowledge allowing us to provide recommendations for future research focus.

The website ISI Web of Knowledge and the Science Citation Index Expanded database was searched for articles relating to the Bothnian Sea (defined by the latitudes of 60.5°N and 63.5°N, and the coasts of Finland and Sweden, Fig. 1). Research work with a focus outside of this region,

with no research carried out within the designated Bothnian Sea area, has not been taken into consideration. The focus of the review is on research into the natural environment and the human impact on this environment published in English peer-reviewed international and ISI-recognized scientific journals. This may, therefore, exclude articles published particularly in the 1970s and 1980s. A keyword search was also performed with “Gulf of Bothnia” as a check for articles which, while mainly dealing with the Gulf, included research carried out in the Bothnian Sea region as well. All articles which came up in the searches were manually checked. A final dataset of 132 articles referring to the Bothnian Sea were reviewed and summarized and these articles were divided under 7 main thematic research topics (Fig. 2; Table 1). These research topics were chosen to describe the natural sciences research done in the Bothnian Sea area, and an article was categorized into a research topic based on its major research theme also giving potential information on past and future directions of research.

RESEARCH VOLUME AND QUANTITY

Bothnian Sea research was carried out in small groups of scientists with the publications most commonly authored by 1–3 people. A total of 327 different scientists carried out research over the past 33 years, but 80% of them published only one article on the Bothnian Sea during this time. Many scientists are, therefore, not continuously researching or at least not continuously publishing research relating to the Bothnian Sea. This would mean that the Bothnian Sea region was not a constant and career-spanning topic of research. However, instead of suggesting a lack of interest,

Fig. 1 Map of the Bothnian Sea and the Bothnian Bay (together making up the Gulf of Bothnia) divided by the Kvarken. The study area is defined by the coastlines and the 60.5°N and 63.5°N lines of latitude

Fig. 2 Number of publications per year between 1975 and 2008

Table 1 Classification of publications according to main thematic research focus

Thematic research topics	Number of publications	%
Biology, biodiversity	37	28
Chemical and physical oceanography	32	24
Fish biology and fisheries	26	20
Pollution and toxins	18	14
Eutrophication and nutrients	8	6
Geological sciences	8	6
Climate change	3	2

this may be a lack of opportunity as it may also be a question of funds available to scientists to carry out Bothnian Sea-related study over the years. The 1990s were productive years with regard to publishing which may have been contributed to by the exposure given by the large integrated research program, the Gulf of Bothnia Year

1991 (Ambio Special Report number 1996). This is suggested especially by the peak in the number of articles from 1995 to 1999 (Fig. 2), allowing some years for the normal time-lag between initiating a natural science project and then publishing its results. Therefore, such thematic events appear to have an impact spurring on research.

REGIONAL COMPARISON

The volume of research on the Bothnian Sea is far less than for regions such as Baltic proper. However, the size or the deemed urgency in the deteriorating condition of a study region does not explain all the differences in the number of articles published. Bonsdorff et al. (2002) reviewed eutrophication studies done on the Baltic since 1970 with the Archipelago Sea and the Gulf of Finland receiving the most attention, followed by the Gulf of Bothnia. They

concluded that this did not reflect the amount of eutrophication, rather the awareness of the problem and the distribution of the researchers. These conclusions, along with our study, highlight the need for joint management of scientific research in a region to make the most of the funds and expertise available.

Bothnian Sea research has so far not been an international effort. Research work has been focused in the Nordic countries with some input from North America. Studies have, therefore, been carried out by local experts and the results distributed globally. Although the majority of the publications had either a Finnish or a Swedish participant, surprisingly Finnish–Swedish collaboration has been very low over the past 33 years, producing only 10 studies. A peak in publications occurred in 1996, which could again be the result of the Gulf of Bothnia Year 1991 program. Instead of collaboration, it is likely that each country has over the years published its own body of research. In the case of Finland, the Finnish Game and Fisheries Research Institute published a research series on the Gulf of Bothnia during this time. Although the total number of Finnish–Swedish collaboration pieces is very low, many different themes were covered including biology and biodiversity, chemical and physical oceanography, climate change, eutrophication and nutrients, and geological sciences. As a country-specific focus, both had two clear major themes. In Finland 32% of the publications dealt with fish biology and fisheries, and 25% on biology and biodiversity. In Sweden 32% focused on chemical and physical oceanography, and 30% also on biology and biodiversity. Not only in biology and biodiversity but also in the other themes, natural sciences research in Finland and Sweden would greatly benefit from pooling together funds and expertise via a joint research plan.

RESEARCH THEMES

The publications were divided into seven major themes to give an idea of the focus of the research (Table 1). Although biology and biodiversity was the leading research theme, key areas of biodiversity research were found missing. For example, only a few studies on bottom fauna were carried out. This lack of emphasis and focus on bottom fauna is unfortunate since bottom fauna will have a central role as an indicator of ecological status in the EU Water Framework Directive (Perus et al. 2007). The Bothnian Sea provides an ideal study location for bottom fauna as currently the bottom fauna are healthier here than, for example, in the Archipelago Sea or the Gulf of Finland, providing a contrast with more polluted areas. As a specialty topic in chemical and physical oceanography, there were numerous articles on the study of sea ice. Together

with the northern Bothnian Bay the inland seas appear to provide a good study area for winter sea ice formation. In the future, topics such as the impact of climate change on the length of the winter sea ice season and following from there, the potentially detrimental impact of this on the biodiversity of the region will be an important research focus. In the geological sciences theme articles were published on isostatic rebound and the resulting geology spurred on by the especially rapid isostatic rebound occurring in the Bothnian Sea coastlines. Fish biology and fisheries research is significant not only for environmental but also economic reasons. Fisheries research in the Bothnian Sea serves as an important comparison study to local as well as international fisheries, such as those in Canada. Studies on the relationship between stocked and natural salmon have been a common topic as there is still naturally reproducing salmon in the Bothnian Sea. Many publications on pollution and toxins served as conservation work monitoring and attempting to reverse the pollution of the environment and the biota. Pollution and toxins together with eutrophication and nutrients are themes that together contribute to the current situation of the Bothnian Sea. Both of these themes would be greatly assisted by an increase in the monitoring efforts in the Bothnian Sea. It is extremely difficult to make any firm conclusions when dealing with data that are not spatially or temporally representative. Such data or conclusions, therefore, do not provide the support to policy making which scientific research should. The effects of climate change on the Bothnian Sea have also not received much study. This theme is now very central and inherently multi-disciplinary and would work well in a future joint research strategy. Furthermore, the Bothnian Sea, as it extends across several degrees latitude, includes fauna and flora living at their most northern exposure and extent. Therefore, any changes to such habitat boundaries as a result of climate change would be clearly visible and easily studied in the Bothnian Sea region.

The Bothnian Sea is an inland sea with a unique flora and fauna community giving refreshment for visitors and income for inhabitants. The area is, therefore, also under strong land use pressure and in need of preservation as it is now beginning to be affected by eutrophication. A prerequisite for sustainable planning of a marine area is to know the special characteristics of its underwater nature and take into account the three-dimensional nature of the sea. Due to the unique nature of the Bothnian Sea region, research results from other parts of the Baltic Sea may not be relevant here. For example the Bothnian Sea appears to have a unique P:N ratio which varies over temporal and spatial scales with conditions sometimes forming an N-limited environment (Johansson 1996). However, there is little research available on the topic preventing any final

conclusions and highlighting the need for further research and monitoring. The link between the scientists and policy-makers is missing. Sustainable management and use of the marine area is impeded because information on the functioning of the ecosystem, the underwater habitats, and species is so far absent to a large extent. The Bothnian Sea region is especially lacking permanent monitoring sites. The aim of EU policy is to standardize environmental sampling procedures and sites. Therefore, hopefully the future will see an increase in the number of such sites within the Bothnian Sea.

The future of Bothnian Sea research needs to be multidisciplinary, not merely focusing on natural sciences but also on the socioeconomic and environmental policy aspects as the challenges and research needs require data and information on many sectors. The Bothnian Sea region would, therefore, greatly benefit from a joint research strategy of a multidisciplinary nature with Sweden. Careful planning concerning the use of land and natural resources is one of the most important methods in achieving a sustainable infrastructure in coastal areas. This could potentially take place within an extensive multidisciplinary project and, in line with the EU Water Framework Directive and the Marine Strategy Directive, execute a strategy of scientific research specific to Bothnian Sea. Increasing the interest in Bothnian Sea research for socioeconomic, environmental, and conservation reasons will be driven by the two countries which have regulatory power over the Bothnian Sea area, Finland and Sweden. The threats on the Bothnian Sea are common for both countries, and it is more cost-effective finding the solutions to these problems together. The condition of the Bothnian Sea as well as the whole Gulf of Bothnia as a whole depends on the future decisions and actions of Finland and Sweden.

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