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FOREWORD

The Bothnian Sea, as a shallow body of brackish water and part of the northern-most limb of the Baltic, is a unique environment differing from the rest of the Baltic. Due to this uniqueness it is a region which needs to be studied in itself, for example for the mitigation of climate change impacts and the effects of eutrophication, as research results from other parts of the Baltic may not be relevant here. In this study through reviewing the past 33 years of research on the Bothnian Sea, we have identified gaps in the current knowledge allowing us to provide recommendations for future research focus.

The Bothnian Sea has so far lacked a unified academic research strategy and mainly single research entities have been published over the years. What we now need is the big picture and a multidisciplinary research strategy to tackle problems such as eutrophication to ensure a sustainable future for the region and the people inhabiting its shores.

This study was conducted at the University of Turku Centre for Maritime Studies Pori Unit as part of the natural sciences environmental research development project of the coastal region of Satakunta (Luonnontieteellisen ympäristötutkimuksen kehittäminen Satakunnassa, LYKS). This project is funded by the Regional Council of Satakunta, the University of Turku and the City of Pori.

Turku 4th November, 2009

Anne Erkkilä
Director
Centre for Maritime Studies

SUMMARY

The Baltic Sea is one of the most studied areas in the world. However, parts of its northernmost reach, the Bothnian Sea, seem to be under represented in the natural scientific literature compared to other parts of the Baltic. The Bothnian Sea represents a unique inland sea environment for the scientific community to study due to its shallowness and low salinity. The natural sciences research carried out on the Bothnian Sea has been reviewed between 1975 and 2008. This time period was chosen to continue on from an earlier review paper ending in 1974. Along with the number of papers published the goal was also to review the content of the papers, indentifying dominating themes to evaluate gaps in the current knowledge on the Bothnian Sea and provide recommendations for topics of future research focus. In a classification into specific research topics biodiversity was the leading research focus followed by chemical and physical oceanography, pollution and toxins, and fish biology and fisheries. The current good condition of the Bothnian Sea is highly valued with its historically less eutrophic and clearer waters when compared to the Baltic. However, today the Bothnian Sea is facing eutrophication resulting from nutrient-rich water transported by the many rivers draining into it from Sweden and Finland making it an area in need of protection and preservation. More human activity will also concentrate on the Bothnian Sea in the future. Therefore the use of the sea and its coastal areas must be planned carefully to minimize the harmful effects of this increasing human activity. To achieve this more information is needed for the basis of Integrated Coastal Zone Management (ICZM) and maritime spatial planning (MSP). For example, for the Bothnian Sea the information on the underwater nature which is essential for ICZM is so far missing to a large extent. Specific biological, chemical and physical oceanographic information is needed to combine with economic analyses and environmental policies regarding this region. More research of a multidisciplinary nature is required on the unique Bothnian Sea environment and this we feel is best achieved through a joint Finnish-Swedish research strategy.

CONTENTS

1 INTRODUCTION

The Gulf of Bothnia is the northernmost section of the Baltic Sea. It is situated between the coast of Finland to the east and the coast of Sweden to the west. The Gulf of Bothnia is divided into two inland seas at the narrow passage of Kvarken. The Kvarken separates the inner (northernmost) part of the gulf, the Bothnian Bay, from the southern Bothnian Sea (see Figure 1).

The Bothnian Sea, with a mean depth of 60m, is a body of brackish water reaching south to the Archipelago Sea and Sea of Åland. It has a salinity averaging 5-6 per mille, a ragged coastline and a gradually deepening continental slope with slow sedimentation rates (Voipio, 1981, Granö et al, 1999). Due to the physical barriers set by the coastline, the groups of islands in the south as well as the shape of the seabed, the nutrient-rich bottom water from the Baltic cannot flow into the Bothnian Sea. This constitutes the main reason why eutrophication has not yet become for the Bothnian Sea the major problem which it is for the Baltic. However, the situation in the Bothnian Sea is now beginning to change as a result of the nutrient-rich water draining into the Bothnian Sea from the many Swedish and Finnish rivers (Lundberg et al, 2009, HELCOM, 2009).

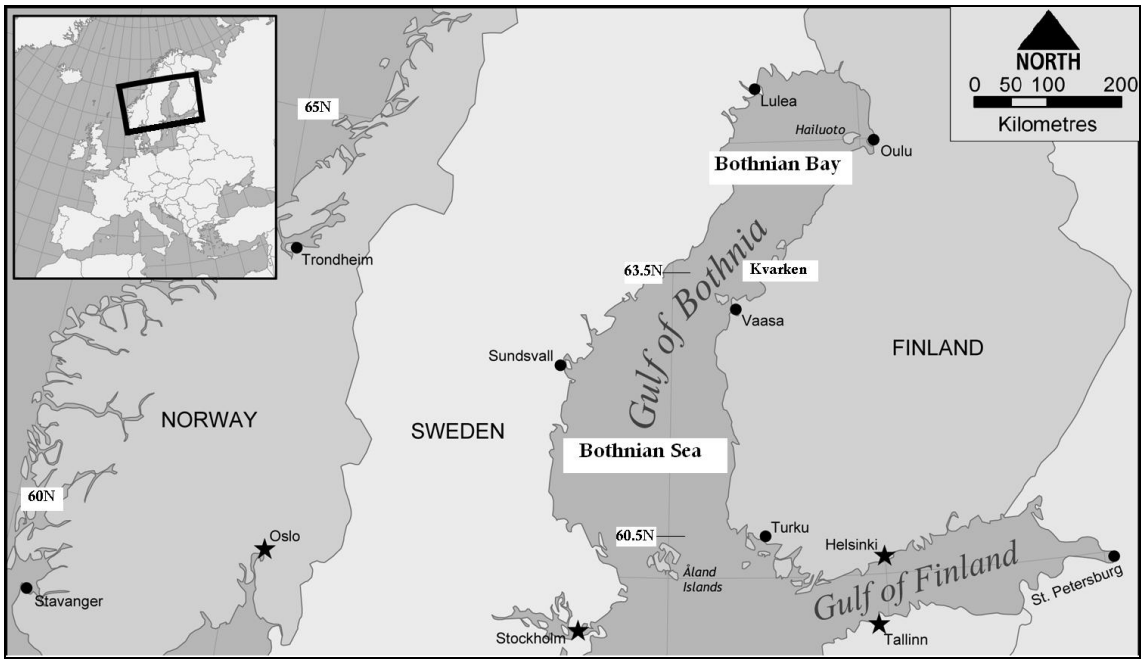

Figure 1.1 Map of the Bothnian Sea and the Bothnian Bay (together making up the Gulf of Bothnia) divided by the Kvarken. The study area of this review paper is defined by the coastlines and the 60.5°N and 63.5°N lines of latitude.

While the Bothnian Sea is an economically important region with the majority of herring in the Baltic being caught in the Bothnian Sea (Lehtonen, 2005, Parmanne, 1998), it has generally not been the focus of much scientific effort. The reason for this could be its rather good condition. The same is true for monitoring efforts as there are fewer monitoring sites, temporally and spatially, in the Bothnian Sea than in the smaller Archipelago Sea (HELCOM, 2009). This has made it difficult to conduct spatially

representative surveys of the Bothnian Sea when the spatial distribution of sites is not sufficient (Erkkilä & Kalliola, 2007).

With this paper we will review the past 33 years of research on the Bothnian Sea. While this publication is not intended to be an exhaustive list of all Bothnian Sea research articles, we will be reviewing the number of research articles found and their content, indentifying dominating themes and extensive research programs to evaluate how research themes have changed over the decades. This process will then allow us to identify gaps in the current knowledge on the Bothnian Sea and provide recommendations for topics and methods of future research focus.

2 METHODOLOGY

2.1 Territorial definition

There are several territorial definitions for the Bothnian Sea which vary depending on the source used. The most common definition of the area, which is adopted for the present study, is the latitudes of 60.5ºN and 63.5ºN, and the coasts of Finland and Sweden (see Figure 1). This above defined area will from now on be referred to in the text as the 'Bothnian Sea'. Research work with a focus outside of this region, and not including any research carried out within the designated Bothnian Sea area, have not been taken into consideration.

2.2 ISI Web of Knowledge

The Institute of Scientific Information (ISI, http://www.isiwebofknowledge.com/) was used for the study. It provides a large selection of bibliometric information incorporating various searchable databases and also going back an extensive period of time.

The ISI Web of Knowledge and the Science Citation Index Expanded database (covering journal articles from 1900-present) was searched with the keywords 'Bothnian Sea' (in title or topic) to find articles related to the study area. A keyword search was also performed with 'Gulf of Bothnia' as a check for articles which, while mainly dealing with the Gulf, also included research carried out in the Bothnian Sea area. All articles which came up in the searches were manually checked.

2.3 Time period/scale

The time period from 1975 to the end of 2008 will be reviewed. 1975 was chosen as the start as an earlier review paper 'Literature on the Gulf of Bothnia' (Armelius et al. 1977) covers the earlier years of 1950-1974. This bibliography was compiled by the Finnish-Swedish Committee for the Gulf of Bothnia. Their definition differs slightly as the publication lists articles referring to the Gulf of Bothnia (consisting of the Bothnian Bay in the far North, the Gulf of Bothnia and the Bothnian Sea to the south, see Figure 1) as a whole whereas our study focuses on articles concerning only the Bothnian Sea.

The search was also expanded to cover the years 1974-2009 as a check for potential input errors in the search engine data itself with regard to the publication year, with some papers found listed the year before or after the true publication date.

2.4 Other definitions

The focus of this review is on research into the natural environment and the human impact on this environment. Therefore research into the potential human health issues resulting from environmental degradation (such as pollution) was not considered.

Today English is the dominant language of published science. Our focus will be on peer-reviewed international and ISI-recognized scientific journal articles published in English. This may therefore exclude articles published particularly in the 1970s and 1980s.

2.5 Division into themes

In the **scientific disciplines** the research papers are classified according to lead keywords given in the ISI Web of Knowledge resulting in a total of 18 categories.

Due to the large number of scientific disciplines and the low number of articles categorized in those disciplines a second, simpler classification is carried out dividing the papers under 7 main **thematic research topics**. These research topics were chosen in such a way as to describe the natural sciences research done in the Bothnian Sea area. 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.

2.6 Review database

The website ISI Web of Knowledge was searched for articles related to the Bothnian Sea on 8th September 2009. The search was done with a keyword ‘Bothnian Sea’, which resulted in 227 references. A further search was carried out with the keyword ‘Gulf of Bothnia’ to make sure all research carried out within the Bothnian Sea area was taken into account. All references were manually checked for duplicate listings and any errors in the listing details (such as an incorrect year of publication). As a result 10 articles were excluded. The remaining 217 papers were checked for the actual study region as defined previously. As a consequence another 85 papers were excluded because they were outside the territorial definition used in the study (see Figure 1). Therefore a final dataset of 132 articles referring to the Bothnian Sea are reviewed and summarized.

3 RESULTS

3.1 List of journals

Bothnian Sea research was published in a total of 62 different journals between 1975 and 2008. 55% of these journals included only one paper concerning Bothnian Sea research. Most often papers appeared in Ambio (8 papers), Marine Ecology-Progress Series (8), Continental Shelf Research (6) and Estuarine Coastal and Shelf Science (6) (see Table 3.1). Of the 132 articles 130 were original research carried out in the Bothnian Sea region. The remaining two were review papers on mysids and eutrophication (Salemaa et al, 1990 and Bonsdorff et al, 2002 respectively).

Table 3.1 Journal titles where two or more papers of Bothnian Sea research were published

Journal	Number of papers 1975-2008
AMBIO	8
MARINE ECOLOGY-PROGRESS SERIES	8
CONTINENTAL SHELF RESEARCH	6
ESTUARINE COASTAL AND SHELF SCIENCE	6
CHEMOSPHERE	5
ENVIRONMENTAL SCIENCE & TECHNOLOGY	5
ICES JOURNAL OF MARINE SCIENCE	5
MARINE POLLUTION BULLETIN	5
JOURNAL OF MARINE SYSTEMS	4
MARINE BIOLOGY	4
TECTONOPHYSICS	4
BOREAL ENVIRONMENT RESEARCH	3
ENVIRONMENTAL POLLUTION	3
HYDROBIOLOGIA	3
LIMNOLOGY AND OCEANOGRAPHY	3
ANNALES ZOOLOGICI FENNICI	2
AQUACULTURE	2
AQUATIC ECOLOGY	2
ARCHIV FUR HYDROBIOLOGIE	2
CANADIAN JOURNAL OF FISHERIES AND AQUATIC SCIENCES	2
ENVIRONMENTAL MONITORING AND ASSESSMENT	2
FISHERIES RESEARCH	2
JOURNAL OF ENVIRONMENTAL RADIOACTIVITY	2
JOURNAL OF FISH BIOLOGY	2
NORDIC JOURNAL OF BOTANY	2
OECOLOGIA	2
OPHELIA	2
SCIENCE OF THE TOTAL ENVIRONMENT	2

3.2 Authors

Publications were most often co-authored by 1-3 scientists (see Table 3.2). A total of 327 different scientists are named on the 132 research articles. The great majority of them, up to 80%, only published one Bothnian Sea paper between 1975 and 2008. 39 scientists contributed to two papers within this time period. The highest number of publications contributed to by a single author was 8 (Table 3.2). When classifying the publications by first authorship only most of the articles are written by different authors with 91 scientists listed as first author on a single paper (Table 3.3).

Table 3.2 Number of papers per author

Number of papers per author	Number of authors
1	261
2	39
3	13
4	4
5	6
6	3
8	1

Table 3.3 Number of first author papers per author

First author on	Number of authors
1 article	91
2 articles	11
3 articles	5
4 articles	1

3.3 Distribution of articles between 1975-2008

According to the dataset the first peer-reviewed publications in English on the Bothnian Sea were published in 1977. Between 1970 and 1980, there were 0-2 articles published annually (Figure 3.1). However, this small number of publication from these two decades is most likely the result of the absence of the publications from the database rather than their absence completely. In fact, there were several non-peer-reviewed papers on the Bothnian Sea published during this time by the Finnish Environmental Administration and the Helsinki Commission Baltic Marine Environment Protection Commission (HELCOM). The 1990s were more productive in peer-reviewed publications. 1991 was selected as the Gulf of Bothnia Year (Johansson, 1996), resulting in a peak of six articles. The most active period was between 1995 and 1999: up to 8-13 scientific articles concerning the Bothnian Sea were published. During 2000s the amount of published scientific articles varied from four to six articles with the exception of 2007 when 12 articles were published. See Figure 3.1 below.

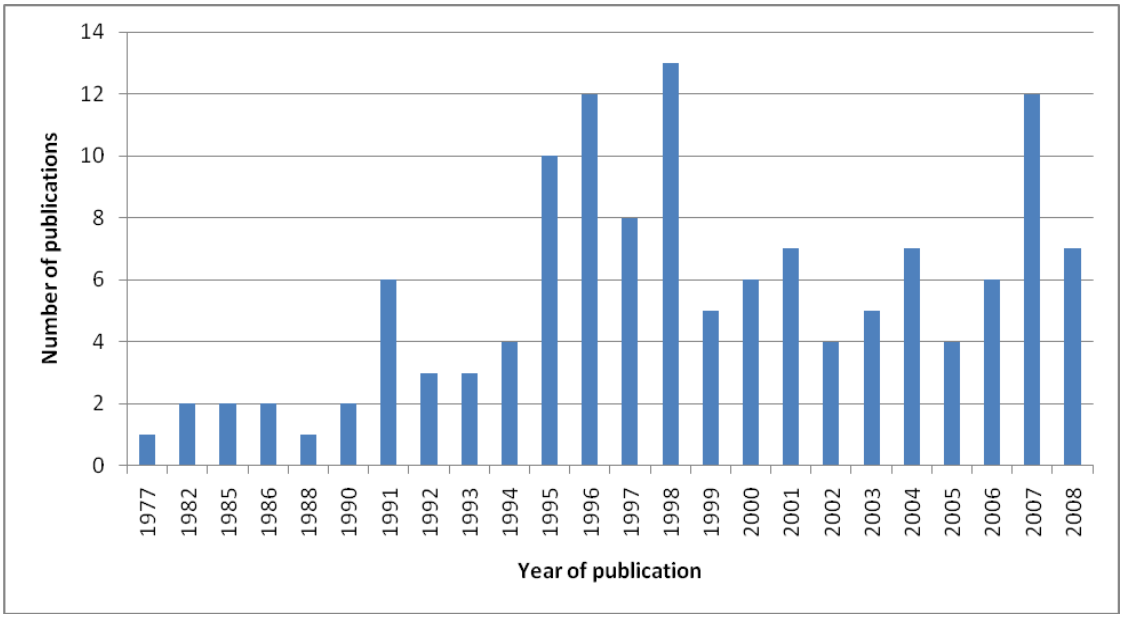

Figure 3.1 Number of publications per year between 1975 and 2008

3.4 Times cited

The papers were categorized according to the number of times they were cited and grouped as shown in Table 3.4. Approximately 15% (20 of the 132 publications) had not been cited by the date this study was conducted. The publications were most often cited between 1 to 5 times and rarely more than 20 times. The most cited paper of Bothnian Sea research was a toxin study on marine mammals by Kannan et al (2001) which, to date, had been cited 211 times.

Table 3.4 Number of citations

Grouping	Times cited
0	20
1 to 5	32
6 to 10	23
11 to 15	18
16 to 20	17
21-30	8
31+	14

3.5 International collaboration

The publications were also categorized by country of origin of the research institute participating in the study (Table 3.5). Collaboration between different international institutes was not common; in 79% of the publications research was carried out at one or more research institutes located within a single country. In 23 publications (17% of

total) collaboration occurred between two international institutes. Larger international groupings were rare.

Table 3.5 Number of different countries collaborating on a publication

Number of international participant organizations	Number of publications out of 132	% of total
1	104	79
2	23	17
3	3	2
5	2	2

Sweden and Finland, the countries bordering Bothnian Sea, participated in the highest number of the 132 publications on the Bothnian Sea region, 84 and 53 respectively. However although Finland and Sweden carry out the great majority of Bothnian Sea research there were only 10 publications where Finland and Sweden collaborated. This collaboration included one publication in 1993 (with partner institutes also from Denmark, Germany and England), 5 in 1996 (including one article with a partner institute from Canada), one article during 2001 and 2004, and finally 2 articles published in 2007. Among the total 132 publications some collaboration occurred between institutions in a total of 19 different countries.

3.6 Themes

3.6.1 Scientific disciplines

The publications were divided into 18 major scientific disciplines based on the lead keyword used in the ISI Web of Knowledge keyword classification (Table 3.6). 25 and 20 papers fell under the category of environmental sciences and ecology respectively, making up the two leading categories. Over 10 papers were also published under the themes of marine and freshwater biology, fisheries and environmental engineering.

Table 3.6 Number of publications associated with each scientific discipline

Scientific discipline	Number of publications	%
Environmental Sciences	25	19
Ecology	20	15
Marine & Freshwater Biology	17	13
Fisheries	15	11
Engineering, Environmental	14	11
Geochemistry & Geophysics	8	6

Oceanography	8	6
Geosciences, Multidisciplinary	6	5
Limnology	5	4
Plant Sciences	4	3
Chemistry	3	2
Behavioral Sciences	1	<1
Biotechnology & Applied Microbiology	1	<1
Computer Science, Interdisciplinary Applications	1	<1
Genetics & Heredity	1	<1
Microbiology	1	<1
Multidisciplinary Sciences	1	<1
Pharmacology & Pharmacy; Toxicology	1	<1

3.6.2 Thematic research focus

A second classification into 7 more specific research topics was also done as shown in Table 3.7. Most of the natural sciences research carried out in the Bothnian Sea came under the biodiversity (28%), chemical and physical oceanography (24%) and fish biology and fisheries (20%) themes.

Table 3.7 Classification according to main thematic research focus

Thematic research topics	Number of publications	%	Publications
Biology, biodiversity	37	28	Albertson, 2004, Albertson & Leonardson, 2001, Aljetlawi et al, 2004, Andersson et al, 1996, Audzijonyte et al, 2008, Bergstrom & Bergstrom, 1999, Bianchi et al, 1997, Busse & Snoejis, 2003, Duplisea, 2000, Eriksson et al, 1998, Eriksson et al, 1977, Gustavson & Jonsson, 1999, Haahtela, 1990, Hagner & Wennstrom, 1997, Hagstrom et al, 2001, Heinänen, 1992, Ikavalko & Thomsen, 1997, Kuparinen et al, 1996, Lehtonen, 1995, Lehtonen & Andersin, 1998, Leonardsson, 1986,1991, Mullerhaeckel, 1985, Nilsson, 1985, Nygard & Ekelund, 2006, Ojaveer & Kalejs, 2008, Raberg & Kautsky, 2007, Rumohr et al, 1996, Ruuskanen & Back, 1999, Salemaa et al, 1990, Sandberg, 2007, Sandberg et al, 2004, Snowjis, 1995, Sparrevik & Leonardsson, 1998, 1999, Sundelin & Eriksson, 1998, Väinölä & Vainio, 1998
Chemical and physical oceanography	32	24	Algesten et al, 2004, Alling et al, 2008, Bergstrom & Carlsson, 1994, Carlsson, 1998, Conley et al, 2008, Drott et al, 2007, Hakansson et al, 1996, Hietala et al, 2007, Holby & Evans, 1996, Jonsson et al, 2005,

			Kahma & Calkoen, 1992, Kahru et al, 1995, Kaikkonen et al, 1996, Koistinen et al, 2008, Kuparinen et al, 2007, Malkki, 2001, Marmefelt & Omstedt, 1993, Meier, 2007, Myrberg & Andrejev, 2006, Omstedt & Axell, 2003, Pettersson et al, 1997, Rahm et al, 1995, Riahi & Juhlin, 1996, Riahi & Lund, 1994, Ribbe et al, 1991, Rolff & Elmgren, 2000, Samuelsson, 1996, Sandberg et al, 2000, Sanden & Danielsson, 1995, Stockenberg & Johnstone, 1997, Wulff et al, 1996, Zweifel et al, 1995
Fish biology and fisheries	26	20	Bignert et al, 2007, Ericson & Larsson, 2000, Eriksson & Eriksson, 1991, Flinkman et al, 1992, Jurvelius et al, 1996, Kallio-Nyberg et al, 1999, 2000, Kauppinen et al, 2005, Koljonen & McKinnell, 1996, Koljonen & Pella, 1997, Leonardsson, 1994, Merivirta et al, 2001, Muller, 1982, 1986, Muller & Berge, 1982, Nissling et al, 2002, Parmanne et al, 2006, Peltonen & Balk, 2005, Peltonen et al, 2002, 2007, Rahkonen et al, 1997, Salminen, 1997, Salminen & Erkamo, 1998, Salminen et al, 2001, Sandtrom & Neuman, 2003, Vuori et al, 2008,
Pollution and toxins	18	14	Balk et al, 1993, Borg & Jonsson, 1996, Broman et al, 1991, Haglund et al, 2007, Hakansson et al, 1991, Heinänen, 1991, Ilus, 2007, Kannan et al, 2001, Leivuori, 1998, Leivuori & Niemistö, 1995, Olsson & Bergman, 1995, Pikkarainen & Lemponen, 2005, Soderlund, 1988, Strandberg et al, 1998(a,b,c), 2000, van Bavel et al, 1996
Eutrophication and nutrients	8	6	Bonsdorff et al, 2002, Fleming-Lehtinen et al, 2008, Helminen et al, 1998, Humborg et al, 2003, Jonsson & Carman, 1994, Nilsoon & Jansson, 2002, Rahm & Danielsson, 2007, Tamminen & Andersen, 2007
Geological sciences	8	6	Hobbs et al, 1993, Huigen & Andriessen, 2004, Korja et al, 2001, Korja & Heikkinen, 1995, Mattila et al, 2006, Nielsen & Schovsbo, 2006, van Balen & Heeremans, 1998, Widerlund & Andersson, 2006
Climate change	3	2	Meier et al, 2004, Gustaffsoon, 2004, Stigebrandt & Gustafsson, 2003

4 DISCUSSION

4.1 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. It is of course possible that this low number of collaborators is common in the specific research fields. However, it may also be a reflection of the lack of international collaboration and the lack of a multidisciplinary nature in the research, which usually increases the number of participants. A total of 327 different scientists carried out research over the past 33 years, but 80% of them published only one paper 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, 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 work. There are potentially large changes and fluctuations over the years in the funding made available, in this case mainly in Sweden and Finland, for natural sciences research encompassing the Bothnian Sea region.

The 1990s were productive years with regards to publishing which may have been contributed to by the exposure given in 1991 as the Gulf of Bothnia Year. This is suggested especially by the peak in the number of articles from 1995 to 1999, allowing some years for the normal time-lag between initiating a natural sciences project and then publishing its results. Therefore, such thematic events appear to have an impact spurring on research. Summer 2008 to summer 2009 was a Bothnian Sea theme year in Finland. It remains to be seen if a peak in Bothnian Sea publications also results from this focus on the region as well.

4.2 Regional comparison

In comparison to the 227 articles found with the ‘Bothnian Sea’ keyword, searching for ‘Baltic Sea’ (in topic or title), one of the most studied areas of the world, resulted in 6914 references between the years 1975 and the end of the year 2008. However, the size or the deemed urgency in the deteriorating condition of the 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. In their case, they reviewed Gulf of Bothnia studies as a whole without dividing it into the Bothnian Sea and the Bothnian Bay. The authors conclude that out of the defined sub-regions of the Baltic the Archipelago Sea (119 out of 1170) and the Gulf of Finland (103) had received the most attention, followed by the Gulf of Bothnia (96). According to Bonsdorff et al (2002) this does not reflect the amount of eutrophication, rather the awareness of the problem and the distribution of the researchers. This means that although the Archipelago Sea is smaller, it has at least in the past received more attention than the adjacent larger Gulf of Bothnia. The Bonsdorff et al (2002) conclusions, along with the

present study, highlight the need for joint management of scientific research in a region to make the most of the funds and expertise available.
The results of our review show that Bothnian Sea research has 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, Finnish-Swedish collaboration has been very low over the past 33 years, producing only 10 studies. Again a peak in publications occurred in 1996, which could be the result of the Gulf of Bothnia Year. Instead of collaborating, it is likely that each country has over the years published its own research. In the case of Finland, the Finnish Game and Fisheries Research Institute published its own 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 53 publications dealt with fish biology and fisheries, and 25% on biodiversity. In Sweden 32% out of a total 84 studies focused on chemical and physical oceanography and 30% also on 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.

4.3 Research themes

The 132 publication on the Bothnian Sea were divided into seven major themes to give an idea of the focus of the research. 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 Baltic. The Bothnian Sea can therefore provide a region to contrast with heavily polluted areas such as the Baltic.

As a specialty topic in **chemical and physical oceanography**, there were numerous papers 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 papers were published on isostatic rebound and the resulting geology. Isostatic rebound is especially rapid in the Bothnian Sea coastlines, making this region ideal for future research on this topic.

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. This may be due to the fact that there are still naturally reproducing salmon in the Bothnian Sea. Examples of research on the environmental aspects of fisheries were studies on parasites in fish and seals.

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 research themes that together contribute to the current situation of the Bothnian Sea. The study of 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 is 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. A Bothnian Sea National Park, which is currently being planned, would provide a unique site for climate change research.

The Bothnian Sea is an inland sea with a unique and species rich flora and fauna community. It is also important for the reproduction of a number of fish species and provides the foundation to entire food webs. The area with its characteristic nature gives refreshment for visitors and income for inhabitants with human activity focused in the shallow basin. The area is therefore also under strong land use pressure and is in need of preservation as its previously heralded pristine environment is now beginning to be affected by eutrophication. A prerequisite for sustainable planning of a marine area, through Integrated Coastal Zone Management (ICZM) and maritime spatial planning (MSP), is to know the special characteristics of its underwater nature. Due to the uniqueness 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 the policy-makers is missing in the Bothnian Sea. Sustainable management and use of the marine area is impeded because information about underwater habitats and species is so far missing 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 socio-economic and environmental policy aspects as the challenges and research needs facing the Bothnian Sea 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 international and 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 socio-economic, 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 Gulf of Bothnia as a whole depends on the future decisions and actions of Finland and Sweden.

5 CONCLUSIONS

Natural sciences research on the Bothnian Sea was reviewed between 1975 and 2008. This time period was chosen to continue on from an earlier review paper ending in 1974. Along with the number of papers published the goal was also to review the content of the papers, indentifying dominating themes to evaluate gaps in the current knowledge on the Bothnian Sea and provide recommendations for topics of future research focus. In a classification into specific research topics biodiversity was the leading research focus followed by chemical and physical oceanography, pollution and toxins and fish biology and fisheries. Natural values in the Bothnian Sea are highly appreciated due to its historically less eutrophic and clearer waters when compared to the Baltic. Today the Bothnian Sea is facing eutrophication resulting from nutrient-rich water transported by the many rivers draining into the Bothnian Sea making the area a unique inland sea environment in need of protection and preservation. More human activity will concentrate on Bothnian Sea in the future. Therefore the use of sea and coastal areas must be planned carefully to minimize the harmful effects of this increasing human activity. To do this requires specific biological, chemical and physical oceanographic information to feed into the economic analyses and environmental policies regarding this region. Therefore more research and especially that of a multidisciplinary nature is needed on the unique Bothnian Sea environment and this we feel is best carried out through a joint Finnish-Swedish research strategy.

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