

# Scenario simulations of future salinity and ecological consequences in the Baltic Sea and adjacent North Sea areas—implications for environmental monitoring



Ilppo Vuorinen<sup>a,\*</sup>, Jari Hänninen<sup>a</sup>, Marjut Rajasilta<sup>a</sup>, Päivi Laine<sup>a</sup>, Jan Eklund<sup>a</sup>, Federico Montesino-Pouzols<sup>b</sup>, Francesco Corona<sup>c</sup>, Karin Junker<sup>d</sup>, H.E. Markus Meier<sup>e,f</sup>, Joachim W. Dippner<sup>d</sup>

<sup>a</sup> Archipelago Research Institute of University of Turku, Turku, Finland

<sup>b</sup> Center of Excellence in Metapopulation Biology, Dept. of Biosciences, University of Helsinki, Helsinki, Finland

<sup>c</sup> School of Science, Faculty of Information and Computer Science, Aalto University, Helsinki, Finland

<sup>d</sup> Leibniz Institute for Baltic Sea Research, Rostock, Germany

<sup>e</sup> Swedish Meteorological and Hydrological Institute, Norrköping, Sweden

<sup>f</sup> Department of Meteorology, Stockholm University, Stockholm, Sweden

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## ABSTRACT

Substantial ecological changes occurred in the 1970s in the Northern Baltic during a temporary period of low salinity (S). This period was preceded by an episodic increase in the rainfall over the Baltic Sea watershed area. Several climate models, both global and regional, project an increase in the runoff of the Northern latitudes due to proceeding climate change. The aim of this study is to model, firstly, the effects on Baltic Sea salinity of increased runoff due to projected global change and, secondly, the effects of salinity change on the distribution of marine species. The results suggest a critical shift in the S range 5–7, which is a threshold for both freshwater and marine species distributions and diversity. We discuss several topics emphasizing future monitoring, modelling, and fisheries research. Environmental monitoring and modelling are investigated because the developing alternative ecosystems do not necessarily show the same relations to environment quality factors as the retiring ones. An important corollary is that the observed and modelled S changes considered together with species' ranges indicate what may appear under a future climate. Consequences could include a shift in distribution areas of marine benthic foundation species and some 40–50 other species, affiliated to these. This change would extend over hundreds of kilometres, in the Baltic Sea and the adjacent North Sea areas. Potential cascading effects, in coastal ecology, fish ecology and fisheries would be extensive, and point out the necessity to develop further the “ecosystem approach in the environmental monitoring”.

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## 1. Introduction

Low salinity (S) forms a threshold for marine and freshwater species distributions in river mouths, estuaries, fjords, lagoons, and coastal seas. A direct control of marine species distributions, through osmoregulation, was earlier focused on in marine biological research, which included seminal studies in the Baltic Sea area dating back to the 1930s. This issue was later updated by [Remane and Schlieper \(1971\)](#). The regulating effect of S on invertebrates is summarized by [Kinne \(1964, 1971\)](#). The

anticipated climate change in the northern coastal areas brings S back into focus. Regional projections concerning global change concentrate on the effects of increased temperature and eutrophication ([BACC, 2008](#); [Neumann, 2010](#); [Philippart et al., 2011](#)), however, they also point out a decrease of S in northern coastal areas ([Meier et al., 2006](#)). [BACC \(2008\)](#) reviews pelagic fish, deep water benthos, and plankton populations in relation to recent S and demonstrate the profound effect of S changes in the Baltic Sea pelagic and deep water biota. However, there are several reasons to focus on the sea surface S (SSS). The shallow bottom and littoral habitats are directly affected by changes in surface S. The surface layer is ecologically and economically crucial since all primary production takes place there and the secondary production also is greatly dependent of this zone.

\* Corresponding author. Tel.: +358 405560668.

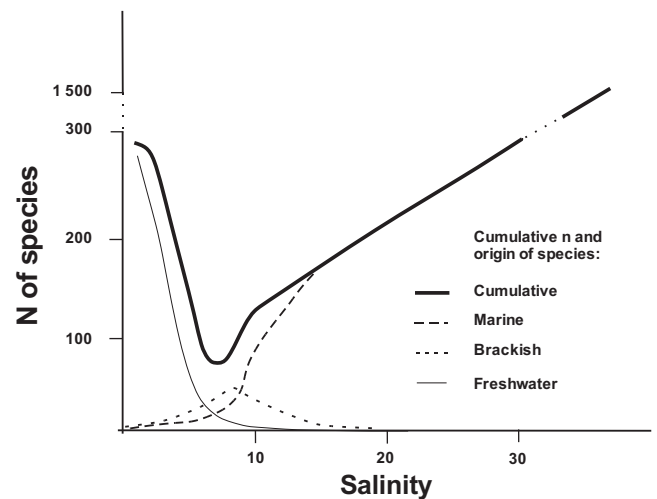
E-mail address: [Ilppo.Vuorinen@utu.fi](mailto:Ilppo.Vuorinen@utu.fi) (I. Vuorinen).

Freshwater runoff and inflows of North Sea water through the Danish Straits control the S levels and biodiversity of the Baltic Sea (Segerstråle, 1957; Järvekülg, 1979; Hänninen et al., 2000; a recent review by BACC, 2008) rendering it a suitable environment for demonstrating the biogeographic aspects of S regulation. The importance of the regulation may be exemplified by its large taxonomic coverage. For each S isoline value may a distinct natural community be defined due to species specific S preferences (Segerstråle, 1957; Järvekülg, 1979; Furman et al., 2001). Thus, the Baltic Sea S gradient limits the distribution of marine species towards the Bothnian Bay in the north and the Gulf of Finland in the east. S of less than three in the northernmost Bay of Bothnia is too low for most marine species, of which reproducing populations are found only of: one Lamellibranchiate, the Baltic tellin (*Macoma balthica*); one barnacle (*Balanus improvisus*); and one macroscopic alga, the wrack (*Fucus radicans*) (Järvekülg, 1979; Bergström et al., 2005). Further south in the Bothnian Sea the Decapods, *Palaemon adspersus*, *Crangon crangon*, and the Polychaete *Fabricia sabella*, are found above salinities of five to six (Järvekülg, 1979). In the Kattegat with S above 25, more marine species start to occur, such as Echinodermata (the starfish, *Asterias rubens*) and the shore crab (*Carcinus moenas*). The lowest number of species is found in the S range between five and seven. This range is often called the range of critical S, “horohaliticum” (Kinne, 1971). Next to the lower end of this range, the decrease in the number of fresh water species is highest, while in its upper end, around a S of seven, the decrease of marine species is steepest (Fig. 1).

In this study, we firstly examine the hydrographic and biological data, reviewing a selected period (from 1960s up to present) when the S of the Baltic Sea was temporarily dropped due to increased runoff (Hänninen and Vuorinen, 2011). Secondly, model projections for future surface water S are presented. Thirdly, possible consequences of S changes are projected in terms of distribution areas of shallow water plant and animal species. Finally, we discuss environmental monitoring, modelling, and fisheries in relation to our projections in order to propose research areas and topics that deserve more attention. As the littoral area is a central environment in harboring species diversity in the Baltic Sea we focus our discussion only on selected, predominant, littoral species. For practical reasons, we focus on distribution of marine species.

## 2. Review of changes in hydrography and their ecological consequences in the 1970s

Since the 1950s there have been periods of high and low S and precipitation as well as episodic inflows of North Sea water into the Baltic Sea. The observation that species may change their distribution, in concert with S fluctuations, was discussed after a large inflow of highly saline North Sea water into the Baltic Sea in 1951 (Segerstråle, 1969), and again together with decreasing

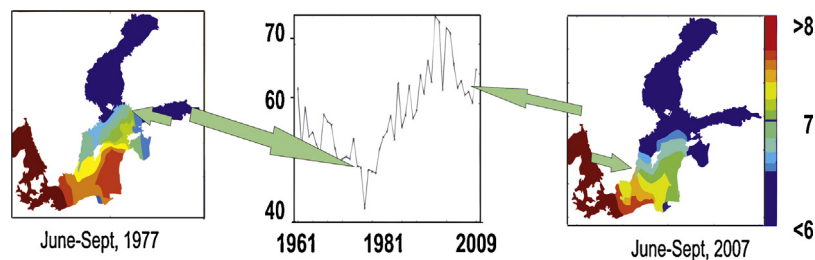


**Fig. 1.** Critical salinity, “horohaliticum” (modified after Remane and Schlieper, 1971), is the range of salinity from approximately 5–7, where both the freshwater (on the left) and marine species (on the right) number declines the steepest in the Baltic Sea. Currently, a total of 6065 species exist in the Baltic Sea (incl. Kattegat). The most numerous are phytoplankton, macrozoobenthos, and zooplankton (at least 1700, 1476, and 1190 species, respectively) (Ojaveer et al., 2010).

salinities in the 1980s (Vuorinen et al., 1998 Leppäkoski et al., 1999).

For this study, a period with increased precipitation and decreased S, from 1960 up to the present day, was selected. Yearly isohalines of the layer from 0 to 25 m and the percentage of surface area of the Baltic Sea with a S of less than seven, were constructed. In the 1970’s, S was high, with 7 psu on the S coast of Finland (60° N). Since then S has decreased and the 7 psu isopleth lies now between 56 and 58° N. During late 1970s, the area with S of less than seven thus increased in a considerable way in the northern Baltic proper (Fig. 2).

A profound change of SSS can be traced down to increased precipitation and runoff (Hänninen et al., 2000; Hänninen et al., 2000). Using NCEP/NCAR reanalysis data (Kalnay et al., 1996), composites of annual mean anomalies of precipitation rate were constructed for the periods 1960–1975 and 1976–1990. The first period (1960–1975) was characterized by two positive anomalies in precipitation in the Baltic Sea catchment. These occurred between 60° and 70° N and around 50°–56° N (Fig. 3, upper panel). During this period, a stronger than normal runoff prevailed in relatively small northern pristine rivers (The Nordic rivers: Tornionjoki and Kemijoki) and in the, southern Baltic rivers (rivers: Oder and Vistula) (Fig. 4). The two positive anomalies were separated by a band of approximately zero anomalies, which also covered the single largest source of freshwater to the Baltic Sea the Neva runoff area (see Fig. 4). During the period from 1976 to 1990,



**Fig. 2.** Percentage of area with sea surface salinity less than 7 in the Baltic Sea during the years 1961–2009 (middle panel) and the Baltic Sea surface water (0–25 m) salinities during the years 1977 (left panel) and 2007 (right panel). Source of data: ICES Dataset on Ocean Hydrography (The International Council for the Exploration of the Sea Copenhagen, 2011). SSS of 7 marked with arrows. Salinity gradients above 8 in the Danish Sounds and below 6 in the Bay of Bothnia and Gulf of Finland are not shown.

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