BIO-C3

Biodiversity changes: causes, consequences and management implications

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BIO-C3 overview

The importance of biodiversity for ecosystems on 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. 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

To assess the role of biodiversity in marine ecosystems, BIO-C3 uses a natural laboratory: the Baltic Sea. 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, and extinctions of residents or invasions of new species is therefore expected to have a more dramatic effect compared to species rich and presumably more stable ecosystems.

Moreover, human impacts on the Baltic ecosystem are larger than in most other sea regions, as this marginal sea is surrounded by densely populated areas. A further BIO-C3 focus is to predict and assess future anthropogenic impacts such as fishing and eutrophication, as well as changes related to global (climate) change using a suite of models.

If talking about biological variety, it is important to consider genetic diversity as well, a largely neglected issue. A central question is whether important organisms such as zooplankton and fish can cope or even adapt on contemporary time scales to changed environmental conditions anticipated under different global change scenarios.

BIO-C3 aims 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 are able to exploit 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 are 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.

From science to management

The ultimate BIO-C3 goal is to use understanding of what happened in the past to predict what will happen in the future, under different climate projections and management scenarios: essential information for resource managers and politicians to decide on the course of actions to maintain and improve the biodiversity status of the Baltic Sea for future generations.

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Executive Summary

The catchment area of the Baltic includes 14 countries, about 85 million people and around 200 rivers. Therefore it is not surprising that different drivers and pressures induced by human activities impact the Baltic ecosystem. Therefore the task is a mix between a review of important drivers and pressures and results from model runs to hind-cast and analyse different pressures.

At the beginning we present a review on the imprecise use of the ‘Driver’ and ‘Pressure’ terms and give a possible definition in line with the Driver-Pressure-State-Impact-Response (DPSIR) approach (Oesterwind et al, 2016). With the help of the whole consortium we produced a general table of potential important drivers and pressures of the Baltic Sea which will be used as a basis in task 5.1 (table is already discussed with task leader). In the following sections main pressures were reviewed concerning status, impact and outlook or model results were presented if available.

Introduction of non-Indigenous Species (NIS) is an important pressure in the Baltic Sea. We found out that 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. in prep.). 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 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 while fishing mortality for western Baltic cod is presently above the defined targets for maximum sustainable yield (ICES 2015b). For eastern Baltic cod the present exploitation status of the stock is unknown (ICES 2015a). The stock size of plaice in the Baltic Sea including the Kattegat has substantially increased in later years under stable or declining fishing pressure. Similarly, the stock size of flounders in the south-western Baltic Sea is increasing while the fishing pressure is estimate to be stable. However, an increasing fishing pressure and a declining stock size are identified for flounders in the eastern Baltic Sea. The harvest rate of salmon has decreased considerably since the beginning of the

1990s. Besides other factors, changes of fishing pressure depend on the fishing management and fishing policy. The Common Fisheries Policy has changed due to different reforms and regulations within the last decades. The last reform has been recently adopted and new regulations are implemented.

Climate change and oceanographic variables are important pressures in the Baltic as well. Beside the summary of current information we investigated the variability and dynamics of the abiotic parameters of temperature, salinity, oxygen and pH consisted in two main activities. One was aggregating and completing in vivo measurements from the ICES Oceanographic data base. The other was producing hydrodynamic model run outputs of the Ice Ocean model BSIOM. Those results will be used in models on habitat extension (Task 3.4).

In addition, nutrients were modeled as well. 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.

Beside those aspects we conducted a socio-economic analysis of different drivers and pressures and could show as example that although maritime transport in the Baltic was expected to increase greatly, it was affected by the economic crisis and consequent decline in international trade that reduced maritime transport globally. Nevertheless, maritime traffic in the Baltic has recovered to values around ten percent higher to those of 2005 (Eurostat), with big differences between countries. However, in the same period oil spills in the Baltic are reduced by around 40% (HELCOM 2015).

Introduction

The Baltic Sea is the world's largest semi-enclosed body of brackish water with a limited water exchange with the North Sea. It is located between Central and Northern Europe and is surrounded by nine countries (Denmark, Finland, Estonia, Germany, Latvia, Lithuania, Poland, Russia and Sweden) (HELCOM, 2010; Ojaveer et al, 2010). Its catchment area is about four times the size of the Baltic Sea (~1 720 000 km²) includes 14 countries, about 85 million people and 200 rivers (Ducrotoy & Elliot, 2008; Ojaveer et al, 2010; Helcom 2013a). Therefore it is not surprising that the Baltic Sea is vulnerable to different drivers and pressures induced by human activities (Ojaveer et al, 2010).

The Millennium Ecosystem Assessment (2005) gives a global overview about the most important drivers and pressures (Tab. 1) 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).

Table 1 Main direct drivers of change in biodiversity and ecosystems (modified after *Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.)*

	Habitat change	Climate change	Invasive species	overexploitation	pollution (nitrogen, phosphorus)
Inland water	very high very rapid increase	low very rapid increase	high very rapid increase	Moderate continuing	very high very rapid increase
Coastal	very high increasing	moderate very rapid increase	High ncrease	High increase	very high very rapid increase
Marine	moderate very rapid increase	Low very rapid increase	Low continuing	very high increasing	Low very rapid increase

As already described 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. In this report we reviewed the current information about selected drivers and pressures and try to give an overview about their recent and potential future impact.

Core Activity

High resolution hydrodynamic model runs for the whole Baltic Sea were conducted by **P1**. The resulting data base of hydrological data of the period between 1971 and 2014 provides a comprehensive foundation for the analysis of environmentally driven habitat dynamics. These will feed into Task 3.2 and 3.4. Data from the ICES oceanographic data base was aggregated on a basin scale and vertically halocline dependent. The resulting time series where converted into equidistant monthly resolved complete time series via an ARIMA time series modelling approach. These can function as basis for approximating the variability and range of the parameters temperature, salinity, oxygen and pH experienced by pelagic species in the Baltic Sea.

P2 reviewed and synthesised impacts of fisheries.

P6 reviewed and synthesised impacts of non-native species and summarised together with **P8** country-based information on the history and current status of bioinvasions and pathways responsible (based on information stored in AquaNIS).

P9 reviewed nutrient load and performed bio-geochemical models.

As a first step, **P11** reviewed the different usage of the terms Driver and Pressures and wrote a manuscript including a possible definition of those terminologies together with **P8**. As a second step, **P11** initiated a table of different drivers and send it to the consortium to be consistent within the project, merged the information and discussed the results with **P8** who leads task 5.1. Additionally **P11** delivered text about the fishing gear technology, relevant Fishery Policies and socio economics information in different sections.

Scientific highlights

1. What is a Driver

This paragraph is a summary of the open access publication: Oesterwind et al., 2016

More and more studies about environmental changes and their causes, as well as environmental assessments were published in the marine science. Thereby the different authors use non-uniform and often imprecise definitions of key terms like driver, threats, pressures etc.. In a lot of cases the causal dependencies between the interacting socio-economic and environmental systems are clear as described by the authors, but still an inconsequent definition of the terms could result in a misunderstanding in discussions between different policy makers, scientists and other stakeholders. Therefore we suggest using a consistent definition for a clear communication between science and management within environmental policies (e.g. the MSFD, BONUS Bio-C³-Project). In the following we recommend definitions in line with the driver-pressure-state-impact-response (DPSIR) approach and propose to use these definitions for a simplified and coherent knowledge transfer from science to management, since DPSIR model is already accepted as a framework for structuring and communicating ecosystem analyses and their results:

- A **DRIVER** is a superior complex phenomenon governing the direction of the ecosystem change, which could be both of human and nature origin.
- A **PRESSURE** is a result of a mechanism through which both natural and / or anthropogenic drivers have an effect on any part of an ecosystem that may alter the environmental state.
- A **STATE** is the actual condition of the ecosystem and its components established in a certain area at a specific time frame, that can be quantitatively-qualitatively described based on physical (e.g. temperature, light), biological (e.g. genetic-, species-, community-, habitat- levels), and chemical (e.g. nitrogen level, atmospheric gas concentration) characteristics.
- An **IMPACT** can be defined as consequences of environmental state change in terms of substantial environmental or socio-economic effects which can be both, positive or negative.
- A **RESPONSE** are all management actions seeking to reduce or prevent unwanted change in the ecosystem.

It is important to keep in mind that the framework is not two-dimensional. It is rather multi-dimensional since one driver can cause one or more pressures and one pressure can be based on one or more drivers as seen in Figure 2.1.2, for example.

2. Baltic Sea pressures

The most important drivers and pressures in the Baltic are listed in table 2.1. Although the table is rather comprehensive and based on the best available expertise within the consortium, it does not claim to be complete and might be revisited over time if the driver-pressure related status of the Baltic Sea changes. Following the definition from above (Oesterwind et al., 2016), pressures can be divided into natural and anthropogenic causes. Depending on the level of expertise and/or definition, the numbers of pressures could be clear if the level of known detail is very low and the definition is very general, but could increase dramatically with more detail and more precise definitions. For example constructions as a ‘pressure’ could be induced by building oil platforms, pipelines power plants, windfarms, harbours, coastal defence structures etc. Another example, extraction, could be originated by fishing, hunting and digging. But the level of detail could be even more improved for example if fishing and hunting will be divided into different metiers and fishing and hunting types. Therefore a kind of different levels exists (Fig. 2.1.2).

In addition, as described above a driver-pressure-impact matrix is multi-dimensional, and different drivers or pressures can cause one impact while different impacts could be caused by one or more drivers or pressures as example. But these complex interactions could not be illustrated in the table as well.

The most important mechanisms which results in pressures are based on:

constructions, pollutions, noise, introduction of non-indigenous species, disposition or removal of non-organic material or organic material, marine litter and climate change (Table 2.1).

In the following chapters we reviewed in detail the selected pressures of the Baltic justified by available scientific information and expert knowledge.

Table 2.1. Most important drivers and pressures within the Baltic based on the consortium expertise.

Driver origin	Driver	Pressure origin	pressure	Impact
Anthopogenic	Demand for energy	Pipelines	construct...	Physical loss, Habitat alteration
		Oil platforms	construct...	Physical loss, Habitat alteration
			pollute......	Contamination by non-synthetic substances and compounds
		Power plants	construct...	Physical loss, Habitat alteration
				Alteration of hydrological processes
		Windfarms	construct...	Physical loss, Habitat alteration
			make noise...	Other physical habitat disturbance
	Maritime transport	Harbours	construct...	Physical loss, Habitat alteration
			make noise...	Other physical habitat disturbance
			pollute...	Contamination by non-synthetic substances and compounds
				Contamination by synthetic substances and compounds
		Shipping	make noise...	Other physical habitat disturbance
			pollute...	Contamination by non-synthetic substances and compounds
				Contamination by synthetic substances and compounds
			Introduce non-indigenous species	Biological disturbance, Habitat alteration
			pollute (marine litter)…	Other physical habitat disturbance
		Dredging	remove dredged material	Physical loss, Habitat alteration
			dispose dredged material	Physical loss, Habitat alteration
			make noise...	Other physical habitat disturbance
			pollute...	Contamination by non-synthetic substances and compounds, by synthetic substances and compounds
	Increasing urbanisation, agriculture and industrialisation	Coastal defense structures	construct...	Physical loss, Habitat alteration, Alteration of hydrological processes
		Urban areas	pollute (marine litter)…	Other physical habitat disturbance
			pollute...	Contamination by non-synthetic substances and compounds, by synthetic substances and compounds, Nutrient and organic matter enrichment, Biological disturbance
		Bridges	construct...	Alteration of hydrological processes
				Physical loss
				Habitat alteration
		Dams	construct...	Alteration of hydrological processes, Physical loss, Habitat alteration
		Water treatment	construct...	Alteration of hydrological processes
			pollute...	Nutrient and organic matter enrichment
		Agriculture	Irrigation	Alteration of hydrological processes
			pollute...	Nutrient and organic matter enrichment
			producing marine litter	Other physical habitat disturbance

Continue Table 2.1.

Driver origin	Driver	origin	pressure	Impact
Anthropogenic	Demand for food	Mariculture	pollute...	Nutrient and organic matter enrichment
			Introduction of non-indigenous species	Biological disturbance, Habitat alteration
			construct...	Habitat alteration
		Fisheries	make noise...	Other physical habitat disturbance
			pollute (marine litter)…	Other physical habitat disturbance
			extraction (Bottom trawling)	Physical loss, Habitat alteration
			Selective extraction	Biological disturbance
		Hunting	Selective extraction	Biological disturbance
	Research and protection	Military activities	make noise...	Other physical habitat disturbance
		Seismic explorations		
	Tourism and recreation demand	Beach replenish	deposition of dredged material	Physical loss, Habitat alteration
		Recreational boating	make noise...	Other physical habitat disturbance
			pollute (marine litter)	Other physical habitat disturbance
			pollute...	Contamination by (non)-synthetic substances and compounds
			Introduction of non-indigenous species	Biological disturbance, Habitat alteration
		Recreational fishing	Selective extraction	Biological disturbance
			pollute (marine litter)	Other physical habitat disturbance
		Tourism	pollute (marine litter)	Other physical habitat disturbance
			pollute...	Nutrient and organic matter enrichment
	Total societal demands	Temperature	Climate change	Biological disturbance, Habitat alteration, Alteration of hydrological processes
		Ocean acidification		
		Sea level		
		Currents		
Natural		pollute...	Atmospheric transport	Nutrient and organic matter enrichment
		Changes in salinity	Riverine inputs	Biological disturbance, Nutrient and organic matter enrichment
		pollute...		
		Storms	Meteorological phenomena	Physical loss, Habitat alteration
		Currents	Oceanic transport	Habitat alteration
		Changes in oxygen distribution	Baltic Sea Inflow	Biological disturbance
		Changes in salinity		

2.1 Introduction of non-indigenous species

Introduction

Non-indigenous species (NIS) are recognized as one of the greatest threats to biodiversity worldwide (IUCN 2000). These are non-native species introduced from outside of their natural, past or present, distributional range deliberately or unintentionally by humans or other agents (Occhipinti-Ambrogi & Galil 2004). The importance of NIS introduction as a pressure to marine ecosystems is recognized through the international organizations (e.g. International Maritime Organization (IMO), International Council for the Exploration of the Sea (ICES), Helsinki Commission (HELCOM)), and is addressed in a number of recent legislative initiatives in Europe and worldwide (e.g. European Strategy on Invasive Alien Species and Marine Strategy Framework Directive (MSFD)).

Records of new observations and established NIS have increased steadily in marine ecosystems during the 19th-21st century. In European marine ecosystems, an average of two new annual records has occurred on average during the past decade (Olenin et al. 2013). Currently there are more than 130 non-indigenous species (NIS) introduced to the Baltic Sea area by human activities (AquaNIS 2016).

Most NIS arrived in recent decades due to intensification of global trade, human mobility and removal of former custom barriers, although first introductions are thought to take place centuries ago. Baltic NIS originate from coastal waters of three main donor regions the North American east coast, Ponto-Caspian region and East Asia. In the Baltic Sea, NIS are representing many taxonomic groups, from unicellular plankton organisms to crustaceans, molluscs, fish and mammals. Many of them increased functional diversity, bringing new and unusual functions into the species-poor Baltic Sea ecosystems. However, some NIS may spread, highly increase in abundance and cause an adverse impact on biological diversity, ecosystem functioning, socio-economic values and/or human health (Olenin et al. 2016).

The magnitude of the NIS introduction pressure is directly linked to the introduction pathways operating in the region. The main pathways to the Baltic Sea are shipping, canals and fisheries while aquaculture, so far, is of less importance in contrast to other European seas. In the Baltic Sea the ‘bioinvasion gradient’ varies between sub-regions due to the variability of the environmental conditions and natural constrains to NIS spread. The primary factor shaping the large-scale geographical distributions of NIS is salinity (Paavola et al. 2005). Temperature and oxygen regimes are additional significant factors for the spread of NIS, but their roles are less known than that of salinity. On a local scale, the distributions of NIS are, like those of native organisms, modified by factors like food supply, competition, predators, and availability of suitable substrates.

The lowest number of established NIS is found in the northernmost part of the Baltic Sea, the Bothnian Bay (19 species), where salinity is low and temperature conditions are sub-Arctic. The highest number (37 species) occurs in the high-salinity entrance area, the Kattegat and Belt Sea area, mainly because of the proximity to the North Sea and intensive ship traffic in combination with higher salinity and milder winters (Olenin et al. 2016).

Drivers & Impacts

So far the most important driver for NIS introductions in the Baltic Sea is maritime transport. Amongst the species invaded since 1900, the most important invasion pathways are vessels (37%), natural spread from the earlier invaded ecosystems (30%) and stocking (27%). While vessel and natural spread mediated invasions have been important by all four periods, the role of stocking clearly dominated during 1930-1989. Notably, the role of canals has always remained negligible (Figure 2.1.1). As most of the deliberate fish introductions have been unsuccessful, vessels and natural spread are far the most important invasion pathways for the currently established invasions.

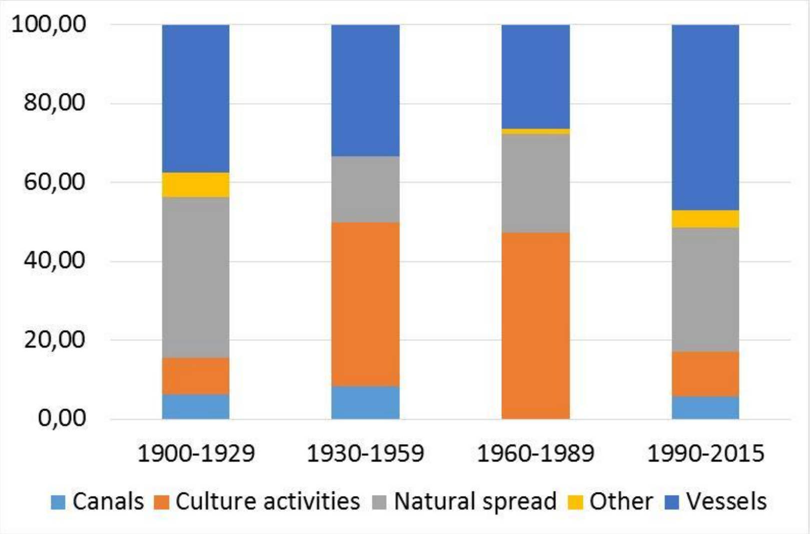


Figure 2.1.1. Relative importance of pathways (%) responsible for species invasions into the Baltic Sea over time (Ojaveer et al. in prep).

Evaluating magnitude and direction of NIS impacts in invaded ecosystems is an important research direction throughout the globe for both aquatic and terrestrial species. So far, all documented impacts are ecosystem and species-specific.

In the Baltic Sea impacts of 18 most widespread NIS have been investigated (Ojaveer & Kotta 2015). In the seven impact categories investigated, impacts were documented for 72% of the widespread species (Table 2.1.1). In terms of the different types of impact, the most impacting species are the benthic invertebrates *Marenzelleria* spp. and *Dreissena polymorpha*, followed by the predatory cladoceran *Cercopagis pengoi*, the round goby *Neogobius melanostomus* and the gammarid *Gammarus tigrinus*.

Table 2.1.1. Classification of impact type for the widespread established non-indigenous species in the Baltic Sea (from Ojaveer & Kotta 2015).

	Impact summary	Physical habitat	Nutrient and /or contaminant cycling	Predation/herbivory	Competition	Food-prey	Parasitism	Other
Acartia (Acanthacartia) tonsa	1					1		**
Anguillicoloides crassus	1						1	
Carassius gibelio	0							
Cercopagis (Cercopagis) pengoi	3			1	1	1		
Chara connivens	1	*	**	*	**	1		
Chelicorophium curvispinum	0					**		
Cyprinus carpio	0							
Dreissena polymorpha	4	1	1	1				1
Eriocheir sinensis	0							**
Evadne anonyx	0							
Gammarus tigrinus	3	*		1	1	1		
Hemimysis anomala	0							
***Marenzelleria* spp.**	5	1	1		1	1		1
Mnemiopsis leidyi	2			1	1			
Neogobius melanostomus	3			1	1	1		
Pontogammarus robustoides	2			1	1	**		
Potamopyrgus antipodarum	1			1				
Rhithropanopeus harrisii	2	1	**	1	**	**		
Total		**3**	**2**	**8**	**6**	**6**	**1**	**2**

1 = impact documented; *= impact investigated, but not detected; ** = impact highly likely, but formally not documented.

The effect magnitude and related confidence evaluation (Table 2.1.2) indicates effect magnitude to be the highest for benthic invertebrates *Marenzelleria* spp. and *D. polymorpha*, due to their nutrient and/or contaminant cycling effects, which likely impact the whole ecosystem. The planktonic *C. pengoi* ranked third in this list (Table 2.1.2). Overall, considering both effects magnitude and confidence, the three invertebrates listed above exhibit the highest impact in the Baltic Sea.

Table 2.1.2. Classification of the effect magnitude and related confidence (and their joint estimate) for the widespread established non-indigenous species in the Baltic Sea (from Ojaveer & Kotta 2015).

	Impact summary	Physical habitat	Nutrient and/or contaminant cycling	Predation/herbivoory	Competition	Food-prey	Parasitism	Other	Confidence
Acartia (Acanthacartia) tonsa	3					3		0	1
Anguillicoloides crassus	4						4		1
Carassius gibelio	0								0
Cercopagis (Cercopagis) pengoi	6			3	0	3			3
Chara connivens	1		0		0	1			1
Chelicorophium curvispinum	0					0			0
Cyprinus carpio	0								0
Dreissena polymorpha	10	2	4	0				4	2
Eriocheir sinensis	0							0	1
Evadne anonyx	0								0
Gammarus tigrinus	5			2	3	0			2
Hemimysis anomala	0								0
***Marenzelleria* spp.**	9	1	4		3	1		0	3
Mnemiopsis leidyi	1			1	0				2
Neogobius melanostomus	4			0	0	4			2
Pontogammarus robustoides	5			2	3	0			2
Potamopyrgus antipodarum	0			0					0
Rhithropanopeus harrisii	5	2	0	3	0	0			1

The scale for evaluation of the effect magnitude: 0 = impact undescribed or unassessed; 1 = an effect of >10% change; 2 = an effect of 10-50% change, 3 = an effect of 50-75% change; 4 = an effect of >75% change. Confidence of the summary impact estimate was evaluated at the following three-level scale: 1 = low (≤ 3 observations/experiments); 2 = medium (4...9 observations/experiments); 3 = high (≥ 10 observations/ evidences)

Although for 72% of the widespread NIS in the Baltic Sea measurable ecological impacts are investigated and reported in literature, no published evidence is available for the rest.

Current studies lack spatial range and temporal extent and there has been no attempt to consider the cumulative impact of NIS, although many invasive species are likely having strong synergistic effects.

Impacts caused by NIS have been and remain one of the major concerns associated with bioinvasions. Unfortunately, our knowledge on bioinvasion impacts is very limited and insufficient for management actions. Therefore, impact of bioinvasions should stand as one of the major research fields in future, the outcomes of which should not only contribute to the advanced understanding of ecosystem structure and dynamics, but also be utilised in EAM decisions. As the benthic invertebrates strongly dominate amongst the NIS/CS community (see below), they should be the primary targets for investigation and assessment of ecosystem impacts.

NIS and environmental status of the Baltic Sea

Non-indigenous species may cause environmental and economic effects if attaining a critical level of abundance and occupying a sufficiently large area. In fact, even a single NIS introduction may affect the state of native communities, habitats, and alter the overall marine ecosystem functioning (Fig. 2.1.2). The most adverse impacts imply loss of naturalness, biodiversity, ecosystem goods and services, etc. On the other hand, the value of some indicators used for the ecological status assessment of coastal waters could be compromised due to the impact of invasive NIS. For example, the ability of the zebra mussel to modify bottom habitats and form local patches of elevated biological diversity biases the results of benthic quality assessment by showing false improvement of ecological status. It was concluded, that if not considered in the course of the assessment, any species richness-based index may reflect the invasive NIS impact rather than anthropogenic pressure effects (Zaiko & Daunys 2015).

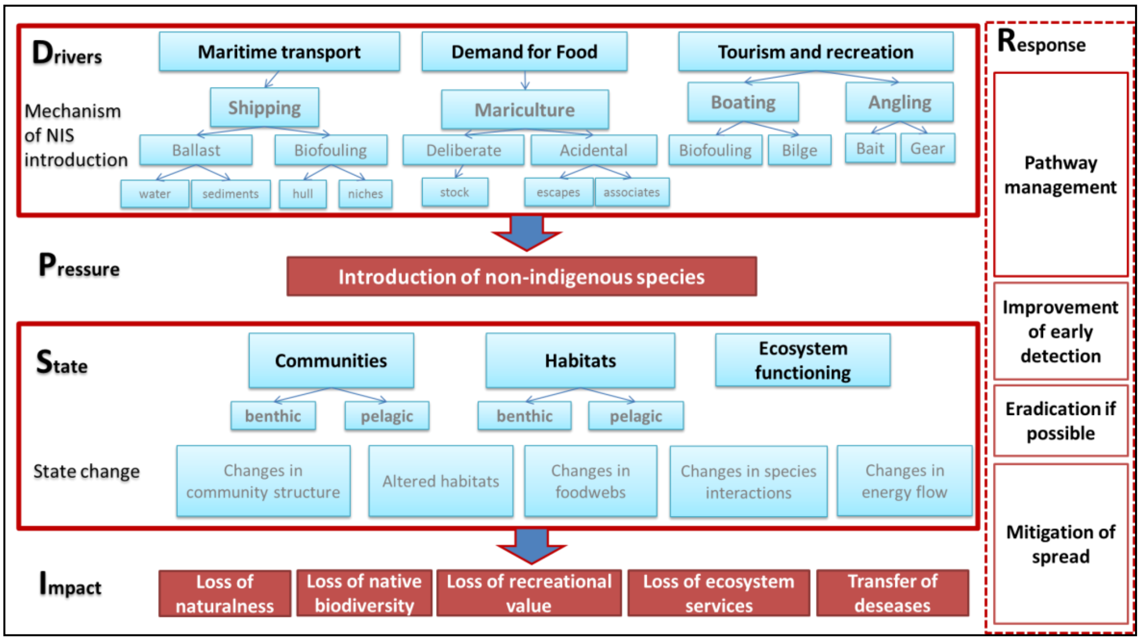


Figure 2.1.2. Theoretical example of DPSIR-based split-out for non-indigenous species related drivers, pressures, state changes and impacts (Oesterwind et al., 2016).

Status & Outlook

In total, findings of 132 NIS and cryptogenic species (CS), with in total of 440 introduction events have been documented in the Baltic Sea. Germany has the highest (66) and Lithuania the lowest (33) number of recorded introductions. On average, 27 NIS/CS are currently established (with min/max of 20 and 42 species in Latvia and Germany, respectively) while 13 species have been unable to establish self-sustaining population per country (Table 2.1.3).

Table 2.1.3. Status of non-indigenous and cryptogenic species in the Baltic Sea by countries until the end of 2015 (Ojaveer et al. in prep.).

Country/region	Total/established
Denmark	39/25
Estonia	34/25
Finland	45/24
Germany	66/42
Latvia	40/20
Lithuania	33/22
Poland	56/32
Russia/Kaliningrad	43/26
Russia/St. Petersbourg	38/21
Sweden	49/31
Average	**44/27**

Zoobenthic invertebrates strongly dominate both in terms of introductions recorded as well as established (63 and 46 species, respectively). Despite of relatively high introduction records of fish (32 species), only five of them have been able to form self-sustaining population in at least one country. The number of invaded species by all other organism groups (i.e., phytoplankton, phytobenthos, zooplankton, parasites) remains below ten species (Table 2.1.4).

Table 2.1.4. Population status of non-indigenous and cryptogenic species in the Baltic Sea by life form (as per adult stage, Ojaveer et al. in prep.).

Population status	Endoparasite	Phytoplankton	Phytobenthos	Zooplankton	Benthopelagos	Zoobenthos	Nekton
Established	4	5	7	6	5	46	5
Not established	0	1	1	3	1	8	27
Unknown	0	3	1	0	0	9	0
Total	4	9	9	9	6	63	32

Benthic lifestyle dominates with 60% amongst the 20 most widespread species defined as being currently established in at least 50% countries/country areas. Species invaded prior to 1900 prevail with 35%. Four species, three of them being pelagic/benthopelagic invertebrates, invaded after 1990 have achieved the widespread status (Table 2.1.5).

Table 2.1.5. Summary information on primary invasions of the most widespread non-indigenous and cryptogenic species currently established in at least 50% countries / country regions in the Baltic Sea (Ojaveer et al. in prep.)

No.	Species	Life form	Time period	Number of countries/areas	Pathway
1	*Acartia (Acanthacartia) tonsa*	zooplankton	1900-1929	10	Vessels, natural spread
2	*Amphibalanus improvisus*	zoobenthos	<1900	10	Vessels, natural spread
3	*Cordylophora caspia*	zoobenthos	<1900	10	Vessels
4	*Potamopyrgus antipodarum*	zoobenthos	<1900	10	Vessels, natural spread
5	*Prorocentrum cordatum*	phytoplankton	1960-1989	10	Vessels, natural spread
6	*Marenzelleria neglecta*	zoobenthos	1960-1989	9	Vessels, natural spread
7	*Neogobius melanostomus*	fish	1990-2015	9	Vessels
8	*Anguilliculoides crassus*	parasite	1960-1989	9	Culture activities
9	*Gammarus tigrinus*	zoobenthos	1960-1989	9	Natural spread
10	*Mya arenaria*	zoobenthos	<1900	9	Vessels, leisure activities, natural spread
11	*Cercopagis pengoi*	zooplankton	1990-2015	8	Vessels
12	*Dreissena polymorpha*	zoobenthos	<1900	8	Canals, vessels
13	*Elodea canadensis*	phytobenthos	<1900	7	Aquarium trade, Culture and leisure activities, natural spread, vessels

No.	Species	Life form	Time period	Number of countries/areas	Pathway
14	*Pontogammarus robustoides*	zoobenthos	1960-1989	7	Culture activities
15	*Rhithropanopeus harrisii*	zoobenthos	1930-1959	6	Vessels
16	*Evadne anonyx*	zooplankton	1990-2015	6	Vessels
17	*Carassius gibelio*	fish	<1900	6	Culture activities
18	*Chelicorophium curvispinum*	zoobenthos	1900-1929	6	Vessels, canals, natural spread
19	*Palaemon elegans*	benthopelagos	1990-2015	5	Vessels, natural spread
20	*Hemimysis anomala*	benthopelagos	1960-1989	5	Culture activities

Invasion dynamics are a shifting landscape, where the past may not predict the future, especially with emerging trade patterns and global to local environmental changes. However, and based on the historical evidences, vessels and natural spread from the adjacent North Sea will very likely remain as very important pathways for future invasions. This should be the case even in the situation of intensified cross-regional cooperation and Ballast International Convention for the Control and Management of Ship's Ballast Water and Sediments (BWMC) entering into force, considering that only three countries in the Baltic Sea coast have ratified it so far.

Additional information

Information on the invasion events is freely accessible from the Information system on aquatic non-indigenous and cryptogenic species, AquaNIS (http://www.corpi.ku.lt/databases/index.php/aquanis).
Continuous information flow into the database has been essentially achieved through activities of the Working Group on Introductions and Transfers of Marine Organisms of the International Council for the Exploration of the Sea, ICES WGITMO.

2.2 Extraction - Fishing

Introduction

Fishing in the Baltic Sea has a long history dating back thousands of years (Hammer et al. 2008). Landings of most species were generally relatively low until the 20th century. In first half of the 20th century, fishing technology went through major developments (e.g.

motorization of vessels, increase in horse power, gear developments) and the fishery increased catchability and got access to new fishing grounds expanding spatially from coastal to offshore areas that intensified the exploitation (Bagge et al. 1994; Eero et al. 2007). The trawl fisheries developed further after World War II, with consequences for fish stocks, benthic fauna and habitats. As a result, physically undisturbed seabeds have become rare in areas where bottom trawl fishery is taking place. An attempt to quantify the magnitude and distribution of cumulative impacts of anthropogenic pressures for an entire Baltic Sea in 2000s, taking into account the sensitivity of different ecosystem components concluded that fishing exerts a high pressure on the Baltic Sea ecosystem in all areas of the Baltic Sea (Korpinen et al.2012).

Fishing contributes substantially to the economy of the Baltic region and has a central role in the cultural heritage. The main target species in commercial fisheries in the Baltic Sea are cod, herring and sprat. These constitute about 95% of the total catch. In recent years, the catch biomass in the Baltic Sea is dominated by sprat and herring (ICES 2015). The major fisheries in the Baltic Sea can be divided into demersal and pelagic fisheries. Pelagic trawlers catch a mixture of herring and sprat. To a minor extent, a predominantly herring fishery is carried out with trap-nets/pound-nets and gill nets in coastal areas as well as with bottom trawls. The catches of the pelagic species are used for human consumption, reduction to oil and meal and to animal fodder. Cod is mainly caught in demersal fisheries using trawls and gill-nets. Other target fish species in the Baltic region having local economic importance include salmon, plaice, flounder, dab, brill, turbot, pike-perch, pike, perch, vendace, whitefish, turbot, eel and sea-trout. Many of these species are caught in coastal fisheries conducted along the entire Baltic coastline, using a variety of gears (e.g. gill, pound and trap nets, weirs, and Danish seines).

Drivers & Impacts

Fishing activities affect marine ecosystems, including the Baltic Sea in various ways (ICES 2000, Hopkins 2003), including:
i) Causing mortality on the target fish and shellfish populations, affecting their abundance, size structure and genetic diversity;

ii) Causing mortality via by-catch and discards affecting under-sized individuals of target species, and non-target species including non-commercial fish, benthic invertebrates, seabirds, and marine mammals;
iii) Alternating seabed and associated habitats of benthic fish and invertebrates;
iv) Changing the structure, functioning and integrity of ecosystems and food webs.

Fisheries management is traditionally mainly focusing on fishing impacts related to mortality and abundance of target species, while the other impacts are considered as integral part of the ecosystem based fisheries management and EU MSFD. Expected effects of fishing on mortality rate and size structure of fish populations are generally well understood, which explains the relatively wider use of related indicators in practical management. The more ecosystem based impacts of fishing, e.g. on species compositions and biological diversity are difficult to interpret and often not easily predictable (Rochet and Trenkel 2011).

Impact on target species and food web structure and functioning

In the Baltic Sea, fishing effects act in combination with hydrographic and climatic conditions, including temperature, salinity and oxygen having large impacts on individual species and overall biodiversity of the Baltic Sea (e.g., Köster et al. 2005; MacKenzie et al. 2007). Furthermore, the ecosystem structure and functioning is additionally influenced by predator-prey interactions (Sparholt 1994) and other anthropogenic influences such as eutrophication. Moreover, at lower stock sizes, for example due to high fishing pressure, fish are thought to be more vulnerable to environmental stress (Brander 2007). Thus, the fishing impacts on individual species and on the ecosystem as a whole are complex, and act in combination with other pressures, which makes disentangling fishing impacts from other influences difficult (e.g. MacKenzie et al. 2002). A combination of drivers have shaped the biodiversity including the fish community in the Baltic Sea and caused major fluctuation in biomasses and catches of for example cod, sprat and herring (Figure 2.2.1).

Cod is the main predator species in the central Baltic Sea. Despite the low fishing pressure on cod until World War II (Eero et al. 2008), the stock was not very abundant, likely due to a combination of lower nutritional status of the Baltic Sea and high abundance of seals (Eero et al. 2011). In the 1950-1970s, the eastern Baltic cod was intensively exploited, with a reduction in fishing pressure in the late 1970s that, under favorable state of other pressures, contributed to building up a largest biomasses recorded for this stock in the earlier 1980s (Eero et al. 2011). From the late 1980s to 2000s, fishing pressure on eastern Baltic cod has been high, which together with unfavorable conditions for recruitment maintained the stock at a very low level for several decades. In the late 2000s, the fishing pressure was estimated to have declined substantially, partly due to effective fisheries management measures, which contributed to an increase in stock size (Eero et al. 2012).

The decline in top-predator, i.e. cod in late 1980s, partly due to intensive fishing, resulted in released predation pressure on sprat (Sparholt, 1994), and in combination with high reproductive success and relatively low fishing pressure caused a pronounced increase in sprat stock in the mid-1990s (Parmanne et al. 1994; Köster et al. 2003). In 2000s, the sprat stock has reduced again, concurrent with increased fishing mortality (ICES, 2015a). The major shift in cod and sprat biomass observed in the late 1980s-early 1990s, with a major decline in cod and an increase in sprat, where differences in fishing pressure on these species was one of the responsible factors, contributed to substantial changes in the entire central Baltic food web and ecosystem functioning (Möllmann et al. 2009; Casini et al. 2009).

The stock size of central Baltic herring continuously declined from the late 1970s to early 2000s. Increasing fishing pressure in parallel with diminishing stock size until the 2000s and a lower fishing pressure in later years concurrent with improving stock suggest that fishing is beside the environmental conditions a major driver regulating the stock size of central Baltic herring. Major changes in flatfish dynamics in the Baltic Sea have taken place in early decades of the 20th century, i.e. before the beginning of modern stock assessments with quantitative estimates for fishing mortality. However, fishing is hypothesized to have contributed to major declines in fisheries catches of plaice and flounder in the 1920s-1940s, though hydrographic conditions probably contributed to these developments as well (Hammer et al. 2008).

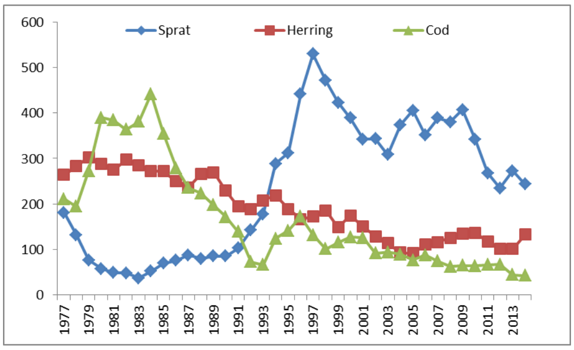


Figure 2.2.1. Landings of the major commercial fish species in the Baltic Sea, i.e. sprat, central Baltic herring and cod (eastern plus western) (data from ICES 2015).

Impact on benthic ecosystems and habitats

A major impact of fishing on biodiversity, especially concerning benthic ecosystems is associated with the effects of bottom trawling (Jennings et al. 2001; Kaiser et al. 2002). Short-term impacts of bottom trawling are associated with mortality of benthic organisms (Kaiser et al. 2006), resuspension of sediments (O'Neill and Summerbell 2011; Bradshaw al. 2012; Martin et al. 2014), and physical disturbance of habitats (Kaiser et al. 2006; Cook et al. 2013). Longer-term impacts may also include changes in species compositions (Kaiser et al. 2006) and reduction in habitat types and complexity (Kaiser et al. 2002). Besides these effects, bottom trawling in the Baltic Sea can remobilize substantial amounts of nutrients and contaminants (e.g. heavy metals), smothering some filter-feeders, and thereby add to the pollution load and biological oxygen demand (Caddy 2000). Furthermore, bottom trawling may produce simultaneously above-water and underwater noise and increased siltation (Korpinen et al.2012). Abrasion and resuspension by bottom-trawling have been estimated as particularly destructive in the Baltic Sea (Riemann and Hoffmann 1991; Tjensvoll et al. 2009).

The footprint of a trawl is a combination of different gear elements such as otter boards, twin trawl clump, groundrope, and sweeps that herd the fish. The physical impact of these elements on the seabed, comprising scraping of the seabed, sediment mobilization, and penetration, therefore depend on the mass, size, and speed of the individual elements (Eigaard et al. 2015; Rijnsdorp et al 2016). Estimation of the biological impact on benthic community on the other hand needs to consider the vulnerability of the benthic community to trawl impact (e.g. sediment position, morphology), the recovery rate (e.g. longevity, maturation age, reproductive characteristics, dispersal), and ecological role (Rijnsdorp et al. 2016). This type of studies are scarce for the Baltic Sea, though there are activities currently ongoing in e.g. EU BENTHIS project (http://www.benthis.eu) estimating fishing impact on benthic habitat in the Baltic Sea. An investigation assessing the seabed pressure of towed fishing gears and physical interactions with the seabed at the level of the individual fishing operation has also included gears used in the Baltic Sea (Eigaard et al. 2015). Further, spatially highly resolved models of fishing activities are available for the Baltic Sea (e.g. DISPLACE) that amongst other have been applied to test management scenarios and their effects in terms of location of fishing effort in relation to sensitive benthic habitats (Fig. 2.2.1.2; Bastardie et al. 2015).

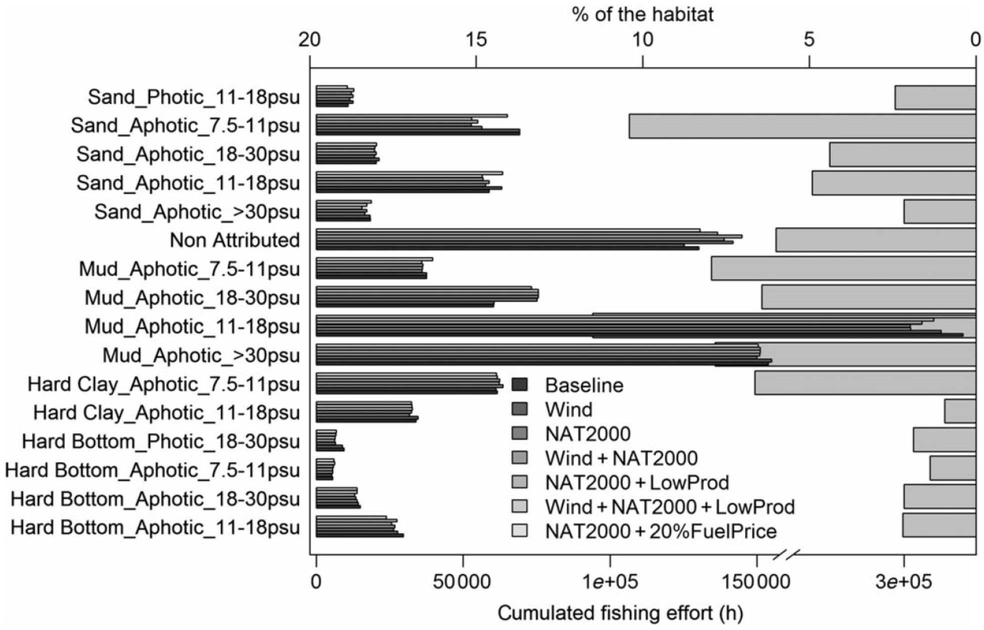


Fig. 2.2.2. Cumulated fishing effort over the western Baltic area and Kattegat simulated over the 5-year projection, which applies on the underlying benthic marine habitats (landscapes) defined within the Baltic Sea (Al-Hamdani et al., 2007; BALANCE, 2007). Habitats (in rows) with at least 5000 cumulated hours displaced have been selected. (From Bastardie et al. 2015).

Impact on non-target species, by-catch of marine mammals and seabirds

Fishing impacts on marine mammals and seabirds mainly through bycatch in fishing gear, which can be substantial in some areas and for some species (Korpinen and Braeger 2013). Harbour porpoise, grey seal, ringed seal, harbour seal and seabirds have been found drowned throughout the Baltic Sea in drift nets, gillnets and trawls (Lunneryd et al. 2004; ICES 2015c; ASCOBANS 2011). Fishery bycatch is a pressure on seabird species like long-tailed duck and scoters. According to HELCOM estimates, the bycatch rate of seabirds has decreased during the last two decades, which is likely a result of declined abundance of wintering waterbirds (Korpinen and Braeger 2013). Bycatch of harbor porpoises and seals in fisheries is difficult to estimate and reliable studies are scarce, however the bycatch of harbour porpoise in fishing gears is considered to be an issue (Korpinen and Braeger 2013). In general, bycatch data on marine mammals and seabirds are insufficient (ICES 2013b, ICES 2015d) and monitoring should be more intensified.

Concerning other non-target species, for example bottom trawling by the *Nephrops* fishery in the Kattegat and Skagerrak has been shown to possibly amount to a by-catch which is 50% of the biomass of the *Nephrops* catch and can include up to 24 non-target species in one catch (Ottosson 2008).

Gear selectivity & discards

The following section will give a brief overview about the recent changes in fishing gear technology with a main focus on gear selectivity.

In contrast to other areas, e.g. the North Sea where pulse trawl was introduced recently, the main fishing techniques used in the Baltic Sea did not changed significantly over the last few decades (active gears, like demersal and pelagic trawls; passive gears, such as gill nets, longlines, pound nets).

Presumably the most important technological changes were implemented by fisheries management related to the selectivity of trawl fishery targeting the demersal fish assemblage (cod, flat fish). In the western Baltic Sea, this fishery is typically a bottom trawl fishery, whereas due to oxygen limitation at the bottom in the deeper basins this fishery is in some cases pelagic. Since the type of fishery is not consistent within the fleet discussed below (demersal vs. bottom), nor all fishermen use cod as main target species, it is not easy to find a consistent wording for this fishery. Therefore, this fishery will be called mixed demersal fishery in the following.

As for many other mixed fisheries around the world, fisheries management (and gear technology research) mostly focused on the improvement of selectivity for a given target species and almost exclusively focused on the selective properties of codends (the final collecting bags in trawls) (Feekings et al., 2013; Madsen, 2007; Stepputtis and Wienbeck, 2010). This approach can be referred to a 'single-species approach'. As shown in Figure 2.2.3, Tables 2.2.1, 2.2.2, the fisheries management introduced a variety of different codends for the Baltic mixed fishery over the past 15 years.

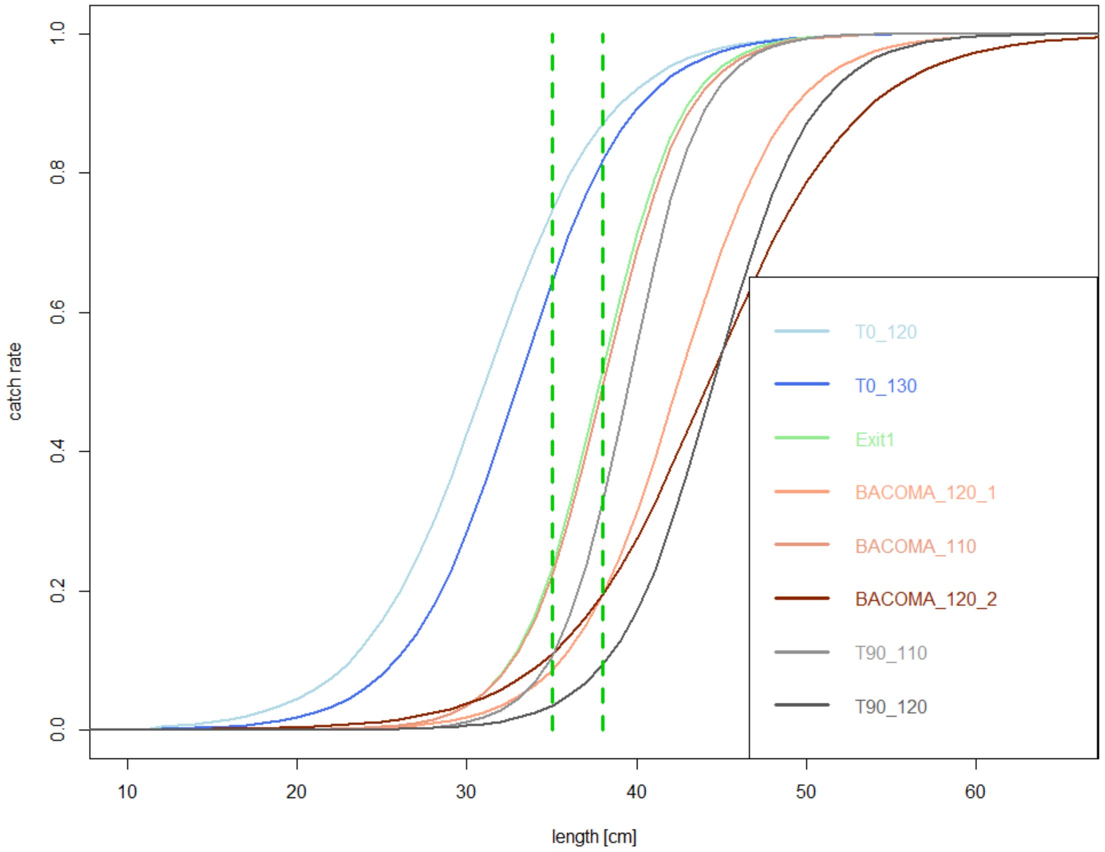


Figure 2.2.3. Example for selectivity curves for cod (*Gadus morhua*) of different codends, which were legal in the past two decades. Y-axis: Likelood that a fish of a given length is retained in the codend. Description of codends (including period when legal): a) T0_120=T0 120mm (1999-2001); b) T0_130=T0 130mm (2002-2003); c) Exit1= Exit Window Model 1 (1999-2001); d) Bacoma_120_1=Bacoma Window 120mm (2001-2003); e) Bacoma_110=Bacoma Window 110mm (2003-2009); f) Bacoma_120_2=Bacoma Window 120mm (2010-recent); g) T90_110=T90 110mm (2006-2009); h) T90_120=T90 120mm (2010-recent). Curves obtained from German selectivity trials / German selectivity database. Green vertical lines indicate the minimum landing sizes (35cm until 2001, 38 cm 2002 until 2014) and minimum reference size (35cm since 2015).

The aim of the fisheries management was to reduce the capture of juvenile cod, and subsequently discards through trawl selectivity by introducing new gear measures (Feekings et al., 2013). On a first view, over the last two decades the general trend of discard rates seems to show the success of this approach (Feekings et al., 2013). Nevertheless, the last change in gear specification in 2010, which was the introduction of the Bacoma 120 mm codend (a codend made of 105 mm T0 netting and a 120 mm square mesh escapement panel) and the T90 120mm codend (a codend made of 120mm netting, where the netting orientation is turned 90°) has shown the limitations of such an approach. Recent analyses (Stepputtis et al. in prep.) have shown that the change from 110 mm netting to 120 mm (i.e. using larger meshes) can increase the discard rate. The actual discard rate depends on a variety of parameters, such as

- gear selectivity: defines the escapement probability / catch probability of specific length classes
- population structure: as example, if there are no undersized individuals available, the discard rate of undersized fish will be zero – independent of gear selectivity
- a number of other parameters, which are difficult to use for a standardized analysis, such as towing speed, catch volume, water temperature, specific rigging of the gear, haup back procedure etc.

Consequently, investigations on the effect of the gear change in 2010 on the discard rate were performed by using a theoretical simulation (i.e. in the year when the new codends were introduced). By using the length distribution of a population (e.g. length estimates from Baltic International Trawl Survey BITS for a given area and season), the known selectivity curves (see Figure 2.2.3 and Table 2.2.1) can be applied to see which fraction of the population would be retained in the trawl (assuming that the entered population in the trawl has a similar length distribution as the population in the field) (Figure 2.2.4).

Table 2.2.1. Selectivity parameters for cod (*Gadus morhua*) of different codends, which were legal in the mixed demersal fishery over the past two decades. Given are the L50 and the Selection Range (SR) values, which well describe the selectivity of a specific gear. L50 is defined as the length, where the likelood that a fish of a given length is retained in the codend is 50% (i.e. chance to escape is 1:1, see also Figure 2.2.3. for illustration). The Selection range is defined as the length range between L25 (25% rentention probability) and L75 (75% rentention probability). The smaller the selection range, the steeper the selection curve and hence 'sharper' the selection

Type	nominal mesh opening [mm]	period in use	L50 [cm]	SR [cm]
T0	120	01/1999-12/2001	31.10	7.96
T0	130	01/2002-08/2003	33.05	7.25
Exit Window Model 1		01/1999-12/2001	37.84	5.23
BACOMA	120	01/2001-08/2003	42.48	6.95
BACOMA	110	09/2003-12/2009	38.06	5.36
BACOMA	120	SD22-24: 01/2010 - recent SD25-32: 03/2010 - recent	44.25	9.68
T90	110	01/2006-12/2009	39.54	4.69
T90	120	SD22-24: 01/2010 - recent SD25-32: 03/2010 - recent	44.53	6.32

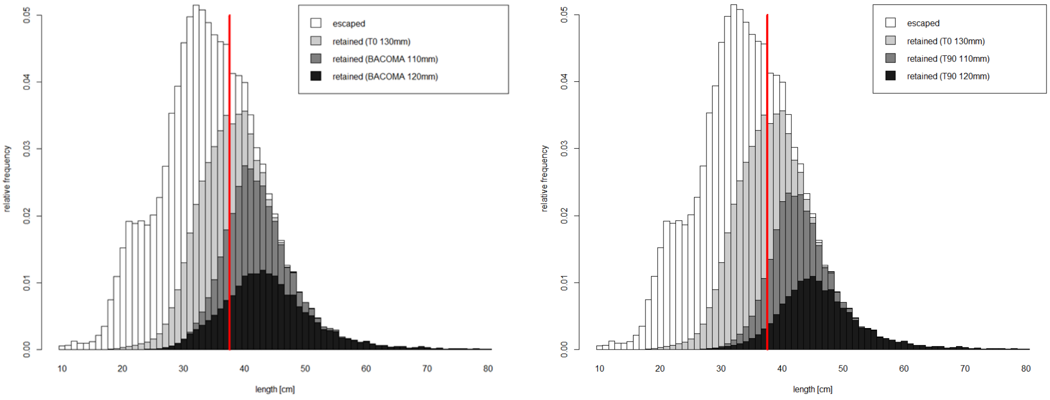


Figure 2.2.4. Theoretical catch of cod assuming 2010 population, using selection curves of different codends. Selection curves are applied on population structure derived from Baltic International Trawl Survey (BITS Q1 2010, SD25; data extracted from DATRAS-database http://datras.ices.dk). Left figure: comparison of catch of BACOMA-cod ends (Bacoma 110mm and Bacoma 120mm); Right figure: comparison T90 cod ends (T90 110mm and Bacoma 120mm). Theoretical catch using a T0 130mm (legal 2002-2003) is shown for reference. Red vertical lines shows the 38cm minimum landing size (legal 2002-2014) to indicate which part of the catch would lead to discards (assuming all undersized fish are discarded and no highgrading occurs). Corresponding discard rates are given in table 2.2.3)

Table 2.2.2. Technical regulations and changes related to the codends, used in the Baltic mixed demersal fishery in the Baltic Sea. Regulations give the reference/number of specific EU regulations, which define the codends to be used in this specific year. Technical details about gear codend specifications can be found for each codend.

		T0 without window	exit window model 1 and 2				BACOMA window				T90 without window	
			cod end		window		cod end		window			
year	regulation	mesh opening [mm]	mesh opening [mm]	number of meshes around	mesh opening [mm]	length of window (% of codend)	mesh opening	number of meshes around	mesh opening [mm]	length of window [m]	mesh opening [mm]	number of meshes around
1999	0088/1998; 0048/1999	120	105	100	105	80%						
2000	0088/1998; 2742/1999	120	105	100	105	80%						
2001	0088/1998; 2848/2000	120	105	100	105	80%	105	100	120	3.5		
2002	0088/1998; 2555/2001; 1811/2002	130					105	100	120	3.5		
2003a*	0088/1998; 2341/2002	130					105	100	120	3.5		
2003b*	0088/1998; 2341/2002; 1754/2003						105	100	110	3.5		
2004	0088/1998; 2287/2003						105	100	110	3.5		
2005	0088/1998; 0027/2005						105	100	110	3.5		
2006	2187/2005; 0052/2006						105	max. 100	110	3.5	110	50
2007	2187/2005; 1941/2006						105	max. 100	110	3.5	110	50
2008	2187/2005; 1098/2007; 1404/2007						105	max. 100	110	3.5	110	50
2009	2187/2005; 1098/2007; 1322/2008						105	max. 100	110	3.5	110	50
2010	2187/2005; 1098/2007; 1266/2009						105	max.100	120*	5.5/6**	120	50
2011	2187/2005; 1098/2007; 0686/2010; 1124/2010						105	max.100	120	5.5/6*	120	50
2012	2187/2005; 1098/2007; 0686/2010; 1124/2011						105	max.100	120	5.5/6*	120	50
2013	2187/2005; 1098/2007; 0686/2010; 1124/2012						105	max.100	120	5.5/6*	120	50
2014	2187/2005; 1098/2007; 0686/2010; 1124/2013						105	max.100	120	5.5/6*	120	50

Table 2.2.3 supports the general trend of improved selectivity over the years, as found by Feekings (2013), but also reveal, that the introduction of (at least) the Bacoma 120mm in 2010 has not shown the desired effect in all sub divisions.

Table 2.2.3. Theoretical discard rates of cod for 2010, assuming a population structure as derived from Baltic International Trawl Survey (BITS Q1 2010, SD24-SD26; data extracted from DATRAS-database http://datras.ices.dk) and selectivity curves for different codends used in the Baltic Sea over the past years (see also Table 2.2.1, Table 2.2.2 and Figure 2.2.3.

codend	SD24	SD25	SD26
T0 120mm	60.25%		37.85%
T0 130mm	54.38%		32.29%
Exit window	28.93%		13.45%
Bacoma 110mm	29.04%	19.52%	13.15%
Bacoma 120mm	30.77%	20.23%	12.86%
T90 110mm	18.40%	11.60%	7.38%
T90 120mm	13.16%	7.67%	4.32%

Additionally, Figure 2.2.4 shows impressively that the increase in mesh size in 2010 has resulted for Bacoma, as well as for the T90-codend in a significantly reduced catchability of sized/marketable fish, which will have economic implications for this fishery.

As mentioned before, the theoretical catch profile and hence the discard rates depend on the specific population structure, which is typical e.g. for year, season and location. Repeating the same exercise as done for Q1 2010 with population data for 2014, the adverse effects of the increased mesh size can be seen even more dramatically (Figure 2.2.5 and Table 2.2.4).

Figure 2.2.5 shows a dramatically change in the length distribution of the population. Whereas in 2010, quite a number of fish was found larger than 50cm, this part of the population is almost absent in 2014. This can also be seen in a long term perspective (Figure 2.2.6). Whereas the analysis and modeling approaches to investigate the effect of changed selectivity on discard rates, efficiency and the population structure (with focus on the decrease in large length classes) are still ongoing and will be likely published in 2016, it is also clear that if the catchability for mid-sized fish is significantly reduced – and the catchability for the larger length classes stay relatively stable (see catchability of different gears for lengths larger 50cm in Figure 2.2.3), the fishing pressure on large length classes increases.

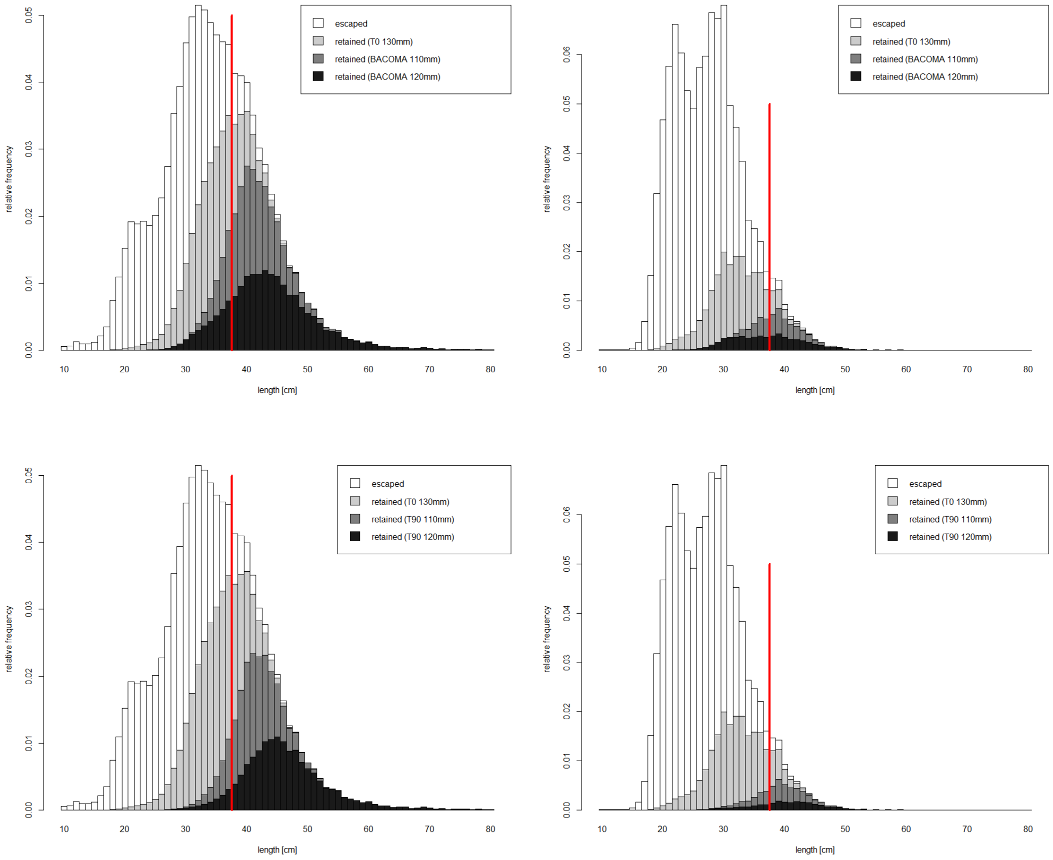


Figure 2.2.5. Comparison of theoretical catch of cod between different years (left column 2010, right column 2014) and different gear (top row: Bacoma 110mm vs. Bacoma 120mm; bottom row: T90 110mm vs. T90 120mm), using selection curves of the different codends. Selection curves are applied on population structure derived from Baltic International Trawl Survey (BITS Q1 2010 and 2014, SD25; data extracted from DATRAS-database http://datras.ices.dk). Theoretical catch using a T0 130mm (legal 2002-2003) is shown for reference. Red vertical lines shows the 38cm minimum landing size (legal 2002-2014) to indicate which part of the catch would lead to discards (assuming all undersized fish are discarded and no highgrading occurs). Corresponding discard rates are given in table 2.2.4)

Table 2.2.4. Comparison of theoretical discard rates of cod for different years (2010 vs. 2014) and different gears, assuming a population structure as derived from Baltic International Trawl Survey (BITS Q1 2010 and 2014, SD24 and SD25; data extracted from DATRAS-database http://datras.ices.dk) and selectivity curves for the different codends.

	SD24		**SD25**	
codend	**2010**	**2014**	**2010**	**2014**
Bacoma 110mm	29.04%	35.70%	19.52%	46.14%
Bacoma 120mm	30.77%	40.74%	20.23%	57.62%
T90 110mm	18.40%	23.73%	11.60%	31.06%
T90 120mm	13.16%	19.11%	7.67%	29.18%

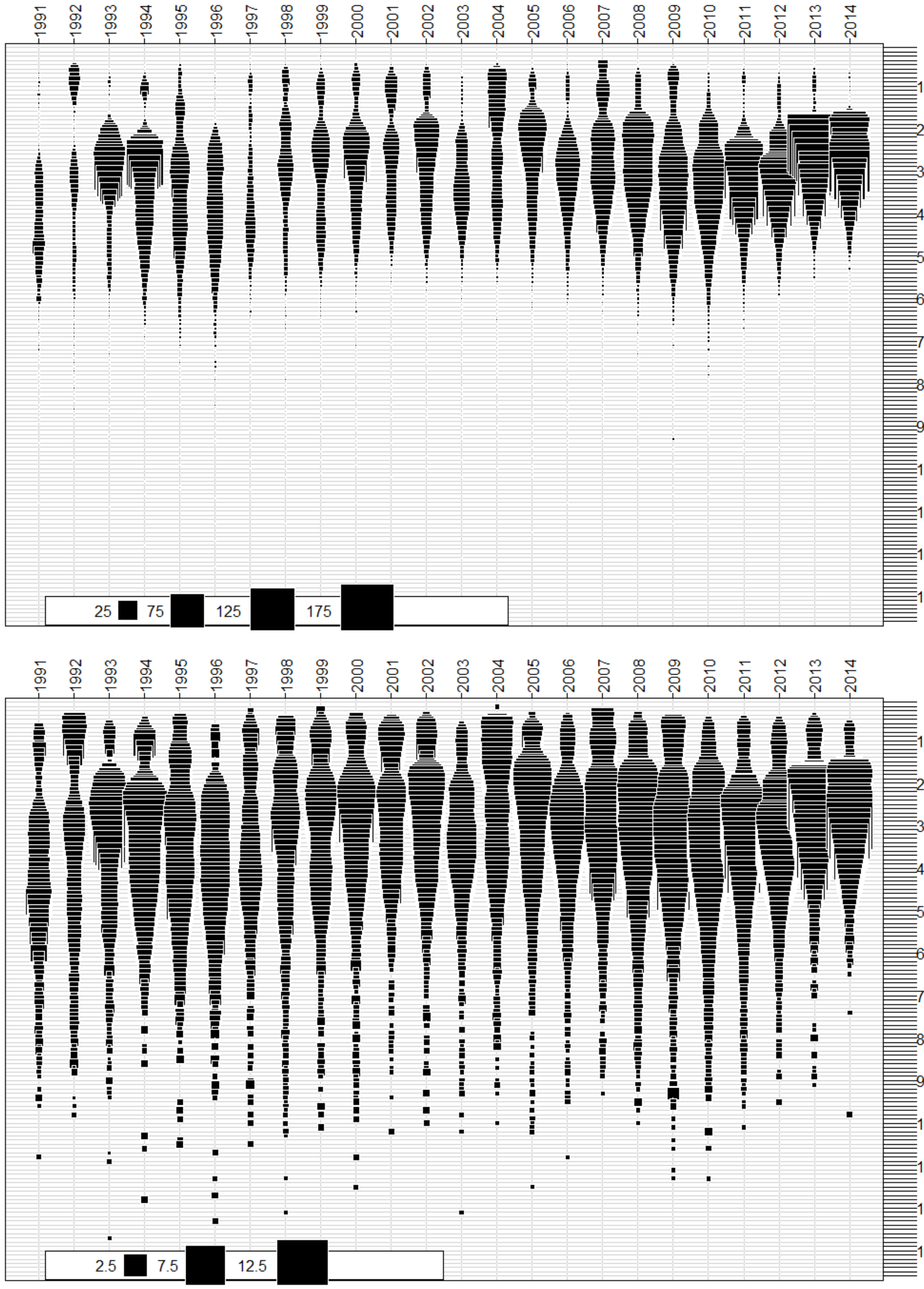


Figure 2.2.6. Length composition of Baltic cod over the years (in SD25, Q1). Length distribution in the population of Baltic cod is derived from Baltic International Trawl Survey (BITS Q1 SD25; data extracted from DATRAS-database http://datras.ices.dk). Top figure: raw data; Bottom figure data square rooted for better recognition of reduction of larger length classes in recent years.

In summary, the changes in gear selectivity for the Baltic mixed demersal fishery resulted in most cases in a reduction in discards of cod. Nevertheless, the most recent change in codend specifications (in 2010 from Bacoma 110mm and T90 110mm towards Bacoma 120mm and T90 120mm) had some adverse effects, which most likely are key factors to explain some recent observations, which lead to scientific discussions (e.g. during WKBALTCOD 2015) about:

a) Unexpected high discard rates
b) Low fishing effiency / not full use of TAC
c) Decline of abundance of large length classes

So far, this paragraph only discussed the catch of cod. As mentioned above, the mesh size and mesh geometry of the codend meshes in the mixed demersal fishery in the Baltic were solely optimized for cod, whereas other species beside cod are also caught. Especially flatfish species, such as flounder (*Plathychtes flesus*), plaice (*Pleuronectes platessa*) and turbot (*Psetta maxima*) have a morphology (body shape) which does not fit to the codend meshes, optimized for cod. This resulted in high discard rates of flatfish species in this fishery. Whereas the high discard rates of flatfish species in the mixed demersal fishery were already problematic in the past – at least from an ethical point of view - in the light of the new fisheries policy in Europe, including a landing obligation and under increased ecological/ethical demands from consumers this single-species-approach is not suitable.

Therefore, the scientific questions of gear technology research in the Baltic area changed to include how to develop the fishing process towards improved ecological and economic sustainability (incl. improved energy efficiency, reduced gear impact on the marine environment, reduction of unwanted bycatches). A main topic of the current research is the “multi-species-approach” of gear selectivity.

Since different species often have different selective properties (e.g. flatfish vs. roundfish), it is difficult to optimize selectivity for both types of fish solely within the codend. Consequently, new concepts for multispecies selectivity have to be developed and tested, whereas different fisheries can have different challenges to cope with /problems to solve and even the challenges in one fleet might change between areas and seasons.

Several new concepts were already developed over the past few years, with the aim to establish a toolbox containing several tools to obtain multi-species selectivity in mixed fisheries and hence to give opportunities to fishery and fishery management to cope with the current challenges in fisheries. Such developments include devices to reduce the unwanted bycatch of flatfish in roundfish fisheries, such as FRESWIND-device (Santos in press) and FLEX (Santos in prep.).

Status & Outlook

In the last decade, fishing effort in all major fleet segments in the Baltic Sea has generally substantially declined (Figure 2.2.7; EU STECF 2014). According to available effort data in units of fished hours, the spatial distribution of deployed otter trawl effort did not show any particular trend in the over the time series since mid-2000s. In recent years, the effort of demersal trawls seems relatively evenly distributed in the Baltic Sea, though with highest concentrations in areas of Bornholm and Gdansk Deep (Figure 2.2.8). Similarly, the gill-net fishery is relatively evenly distributed, though with the biggest fishing effort concentration in the Polish coastal areas. The distribution pattern of pelagic trawls indicates a high concentration of effort in the areas of Bornholm and Gdansk Deep as well as in the Sub-division 28.2 in 2003-2007. The pelagic trawl effort was distributed rather evenly in the most recent years. This can be explained with northward distribution of sprat stock in recent years (ICES 2015a).

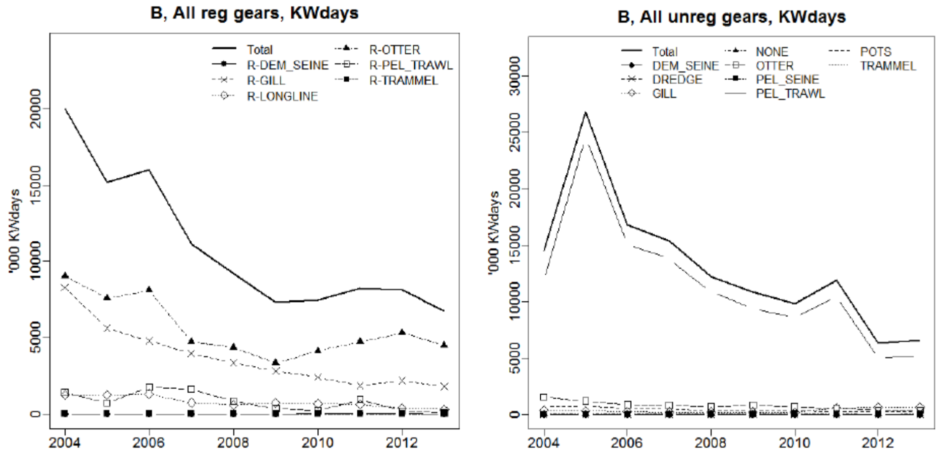


Figure 2.2.7. Trend in nominal effort by gear types 2004-2013 (kW *days at sea) in the Baltic Sea in SD 25-28. Left: Regulated gears. Right: Unregulated gears. No data from Finland (from STECF 2014).

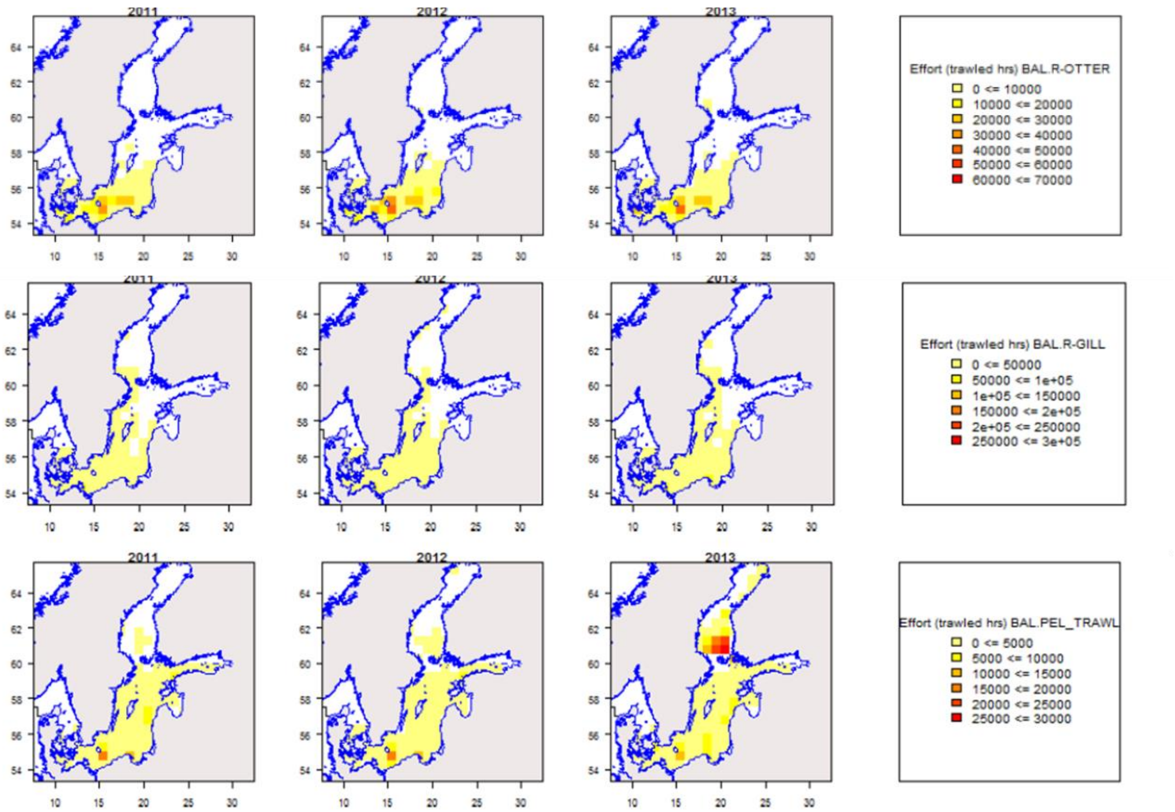


Figure 2.2.8. Spatial distribution of effective effort (fishing hours) of demersal trawls, r-OTTER (upper panels), gill-netters (r-GILL; middle panels) and pelagic trawls (lower panels) in 2011-2013. There was no data reported on the spatial distribution from Finland (from STECF 2014).

The fishing pressure measured in terms of fishing mortality has been reduced for several target species in the Baltic Sea in later years compared to historical levels. 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. For central Baltic herring, fishing mortality increased until 2000 and then decreased, remaining below the level corresponding to maximum sustainable yield in later years (Figure. 2.2.9). From the other herring stocks in the Baltic Sea, also herring in Gulf of Riga, western Baltic Sea and Bothnian Sea are harvested in accordance with or close to the defined targets for sustainable fisheries (ICES 2015a). The spawning-stock biomass of sprat has been declining from a historical high in the late 1990s, but remains above the reference points, with the fishing mortality being currently slightly above the precautionary targets. For cod, the fishing mortality of western Baltic cod is presently above the defined targets for maximum sustainable yield. For eastern Baltic cod, a substantial reduction in fishing mortality from historical high levels was recorded in the late 2000s (ICES 2013), while the present exploitation status of the stock is unknown (ICES 2015a). For flatfishes, the stock size of plaice in the Baltic Sea including the Kattegat has substantially increased in later years under stable or declining fishing pressure. Similarly, the stock size of flounders in the south-western Baltic Sea is increasing while the fishing pressure is estimate to be stable (SDs 22-25). However, an increasing fishing pressure and a declining stock size are identified for flounders in the eastern Baltic Sea (SD 26&28). The harvest rate of salmon has decreased considerably since the beginning of the 1990s.

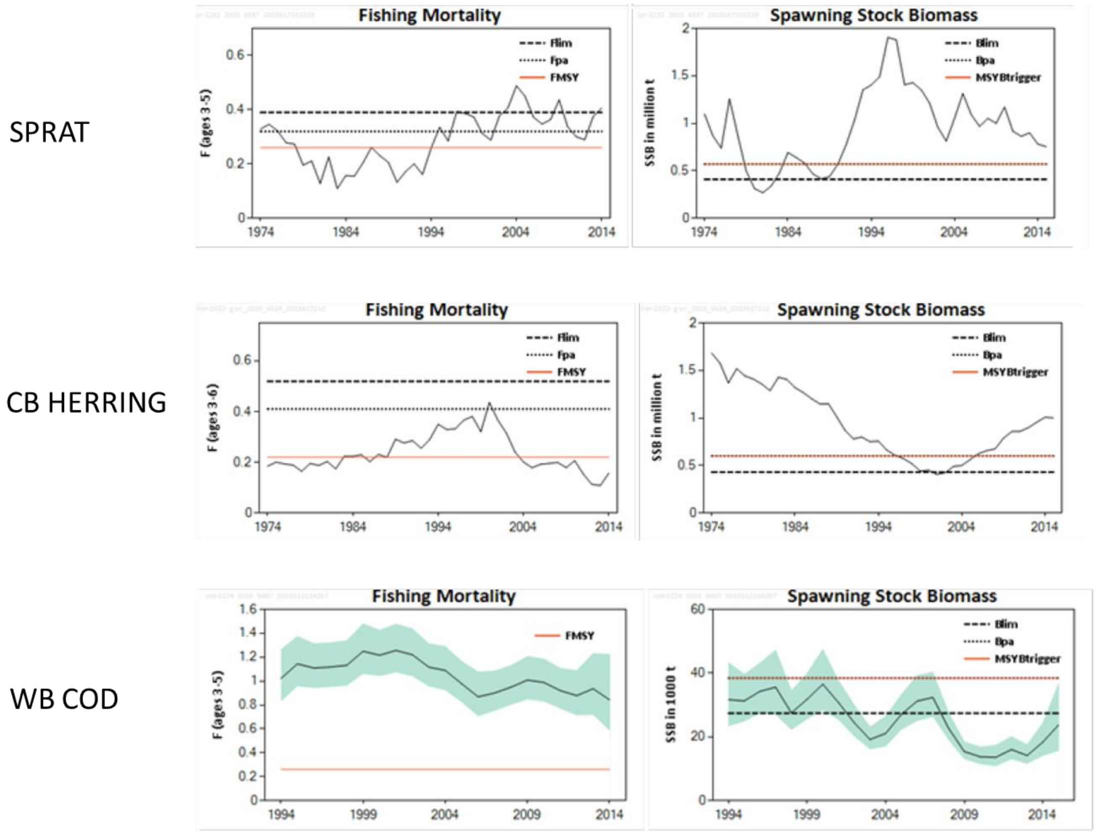


Figure 2.2.9. Developments in fishing mortality and spawning stock biomass of some major fish stocks in the Baltic Sea, i.e. sprat, central Baltic herring and western Baltic cod (ICES 2015b).

It is impossible to make a relevant statement about the future fishing pressure and its consequences especially in a wider context of biodiversity of the Baltic Sea, where the developments also depend on other drivers. Concerning fisheries developments, on one hand human population size is increasing and people depend on marine resources to satisfy the demand for food, on the other hand the EU Common Fisheries Policy and other relevant policy frameworks as well as the development of fishing technology become more important as a tool to manage the marine resources sustainable and to reduce the impact of fisheries on the environment.

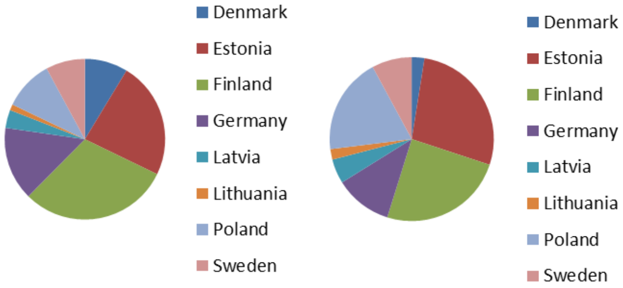
Socio-economic view

The fisheries in the Baltic Sea are exploited by all the coastal states, which include eight EU member states (Denmark, Germany, Poland, Lithuania, Latvia, Estonia, Finland and Sweden) which have their economic activity regulated centrally by the Common Fisheries Policy. This implies many restrictions both on input and outputs, as well as public support for sustainable management through the European Maritime and Fisheries Fund (EMFF, regulation 508/2014).

The structure of the EU fishing sector in the Baltic can be first defined by its division into small scale fisheries and large scale or industrial fisheries. Each of this subsectors has different profiles with respect to social and economic characteristics. In the small scale sectors the most important players in terms of size of the fleet (number of vessels) and employment are Finland and Estonia, with Finland leading in the number of vessels but Estonia providing more employment in the area (see Figure2.2.10 a-b below).

With respect to the large scale fisheries, Poland is the member state with more vessls, followed by Denmark. The importance of the Polish large scale fleet is even larger if we consider employment, with 923 people employed, three times more than Latvia and any other country in the Baltic area (see Figure 2.2.10 c and d below).

Number of vessels vs. number of employees for the small scale fisheries



Number of vessels vs number of employees for the large scale fisheries

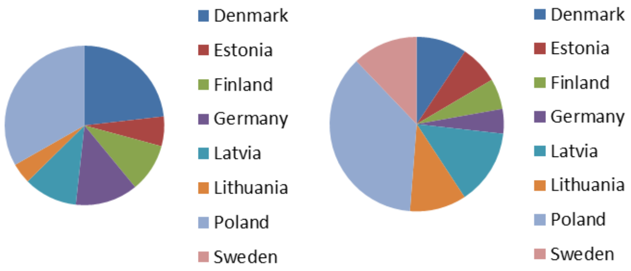


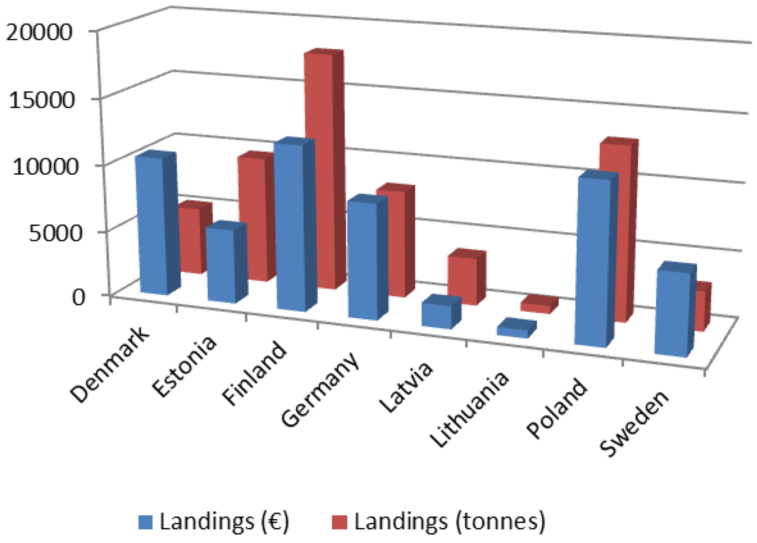
Figure 2.2.10 a, b, c, and d. Comparison between the number of vessels and the peopke employed in the small scale fishery and in the large scale fisheries in the Baltic Sea.

Estimates for the EU Baltic Sea SSF excludes two Estonian coastal fleet segments PG VL0010 and PG VL1012. German pelagic trawlers and Dutch large scale fisheries are excluded.

Source: AER 2015

The volume of fish that is landed from the small scale fisheries in the Baltic (60894tonnes) is only 10% of the total volume of landings, however its value amounts to 23% of the total value of landings from the EU Baltic fleets. A comparison between the member states is illustrated in Figure 2.2.11 below.

Comparison between volume and value of landings in the small scale and large scale fisheries



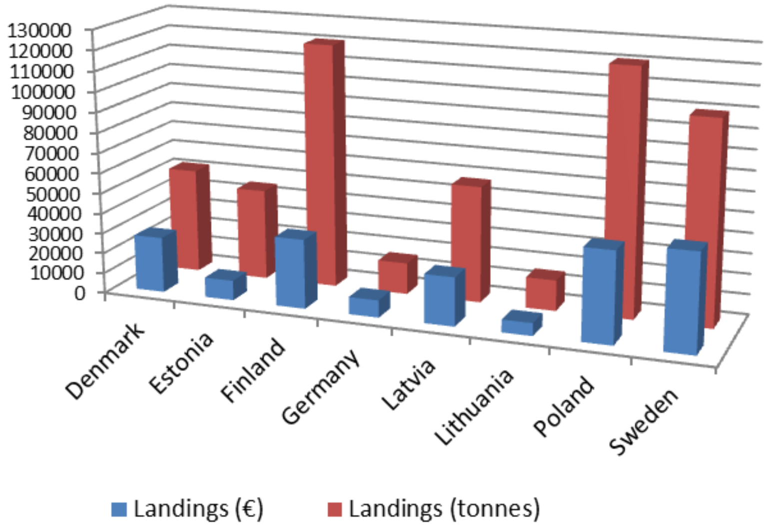


Figure 2.2.11 Comparison between volume and value of landings in the small scale and large scale fisheries in the Baltic Sea

In addition to the revenue indicator, the gross value added shows the contribution of the fishing sector to society, as it includes among others components the part of the revenue that is distributed through wages (AER 2015). For example, the Finnish small scale fisheries have the highest revenues of this type of fishing fleet in the Baltic, but it is the Polish that distribute more resources, through a higher GVA (see Table 2.2.5).

Table 2.2.5 Revenue and Gross Value Added of Baltic Sea fisheries, small and large scale fisheries

	Estimated revenue SSF	Estimated revenue LSF	Estimated GVA SSF	Estimated GVA LSF
Denmark	11866	27503	4680	11885
Estonia	5781	9782	3353	5794
Finland	12482	30558	6134	11734
Germany	8975	9602	2838	3315
Latvia	1734	25514	1681	9841
Lithuania	582	6754	375	1674
Poland	11914	44718	7190	20961
Sweden	8090	51621	2228	26959

Source: AER 2015

As we have shown, there are important social and economic differences between the large and small sectors in the Baltic, the technical distinction between this two group is however difficult to establish and has been subject to analysis in the Baltic as in other EU fishing areas (e.g. Natale et al. 2015). The social and economic importance of some small scale fisheries in the Baltic has been analysed through social impact assessment (Delaney 2007, 2010). The link between the economic dependence of some fleet segments and the Baltic Sea ecosystem,is difficult to establish due to the complexity of both the national fleet segments (some of them fishing in different seas) and the fish stocks. Some attempts have been made e.g. by Gascuel et al.

Policy

The European Common Fisheries Policy (CFP) is one of the few common policies of the European Union. Already in the Treaties of Rome for the foundation of the European Community the fisheries policy, as the agricultural policy, was foreseen as a common policy. Until the end of the 1970ies, however, only a common market organization was adopted. This was due to the very limited necessity to regulate fisheries as until then coastal states had exclusive fishing rights only up to 12 nm.

With the expansion following the adoption of the Economic Exclusive Zone in the United Nations Convention on the Law of the Sea (UNCLOS) large marine areas came under the jurisdiction of the European Union. Additionally, countries with large coastlines, Denmark, Ireland and the UK, joined the European Community (EC) (PECH, 2009). Now the EC member states decided to implement a Common Policy for fisheries and the member states decided to give up their rights in favor of a joined management. The EC (later the EU when the European Community changes to the European Union) negotiates for its members in Regional Management Authorities. In the Baltic Sea this was until 2004 the International Baltic Sea Fisheries Commission.

From the start the CFP was criticized for being a top down command and control fisheries management instrument (Sissenwine & Symes, 2007).

Since the first agreements, the CFP has changed due to different reforms and regulations: After years of negotiation the regulation (EEC) No 170/83 came into force in 1983. Within the regulation the EEZ was accepted and total allowable catches (TACs) and quotas were established (Marti Dominguez, 2011). All Common Policies are going through a regular reform process every 10 years. In 1992 the Council adopted the next basic regulation (EEC) No 3760/92. The new regulation focused on the imbalance between the fleet capacity in the Community and catch potential and introduced the approach of ‘fishing effort’. In parallel measures to mitigate the social implications were defined. But this regulation was not adequate effective to stop the overfishing in Europe resulting in a reform of the Common Fishery Policy (Marti Dominguez, 2011). In December 2002 three new regulations were accepted by the Council; EC No 2369/2002, EC no 2370/2002, EC No 2371/2002. The new regulations focused on the conservation and sustainable use of fisheries resources, on arrangements concerning assistance in the fisheries sector and on establishment an emergency Community measure for scrapping fishing vessels. But the new regulations were not successful in the short term again and a new reform of the CFP began in 2009 (Marti Dominguez, 2011). Again three new regulations were adopted; Regulation No 1379/2013, Regulation No 1380/2013, Regulation No 508/2014. The new regulations include a mixture of different tools e.g. multiannual plans with an ecosystem approach, Maximum sustainable Yield (MSY), discard ban, adjustment of the fishing capacity (Marti Dominguez, 2011). For example, Bicknell et al. (2013) consider the current reform as the biggest change in European fisheries management for decades and concentrate on the aspect of the discard ban and its consequences for seabird communities. They conclude that the reform of the discard may have positive and negative impacts on seabird communities and that more research is needed to increase the knowledge about the nature of these impacts.

It could be assumed that the results and the implementation of the current CFP reform will have a significant influence on the fish stocks and the biodiversity in European Waters and hence in the Baltic as well. Furthermore it may be expected that the new regulations led to a more sustainable exploitation of marine resources with less impacts on the Baltic ecosystem, and will therefore promote the natural Baltic biodiversity.

Another important framework, regarding biodiversity in the Baltic, is the Marine Strategy Framework Directive (MSFD). The EU's MSFD requires Member States to develop marine strategies for the marine areas under their jurisdiction. The main target of the MSFD is to achieve a Good Environmental Status (GES) of EU marine waters by 2020. These strategies include a detailed assessment of the state of the environment and a definition of the GES, and they should establish clear environmental targets and related monitoring programmes. In a guidance document (EU-COM, 2010), the European Commission published several criteria and methodological standards on how to define GES in marine waters, including a hierarchical system in which 11 so-called descriptors of the MSFD are grouped into indicators and criteria. The first descriptor addresses the marine biodiversity while descriptor 3 focuses on commercially exploited fish and shellfish. Even if descriptor 3 is covered by the CFP and the MSFD is implemented in coherence with the existing regulations, it could be assumed that the directive will also promote the biodiversity in European waters and therefore in the Baltic as well.

Even if both policy examples will promote the biodiversity and ensure that the impact of fisheries on the environmental decreases, a scientific outlook about the consequences of those changes are unscientifically.

2.3 Climate change & Oceanography

Work for investigating the variability and dynamics of the abiotic parameters of temperature, salinity, oxygen and pH consisted in two main activities. One was aggregating and completing in vivo measurements from the ICES Oceanographic data base. The other was producing hydrodynamic model run output of the Ice Ocean model BSIOM. These were aggregated horizontally on a basin scale (see Figure 2.3.1) and vertically depending on the position of the permanent halocline into the water layers above within and below the halocline. In case of the ICES data base resulting time series needed to be completed to provide equidistant monthly resolved complete time series. This was accomplished by an ARIMA time series modelling approach (Figure 2.3.2). The script language SAS for statistical analysis was used to realize this algorithm. Central approach was to fill the missing values with and overall mean and fit an ARIMA model to the resulting time series. This model was used to replace the inserted means with the forecasted value given by it. With the resulting new time series the ARIMA model fitting process was repeated and the goodness of fit criteria AIC was used to decide if the newly fitted model resulted in an increase of fit to the data. Only if the fit was 0.01% better than the previous fitted ARIMA model the sequence of steps was repeated. In Case of pH below the halocline oxygen could be used as correlated parameter to increase the model accuracy.

Reviewing activities were focused on the drivers salinity, oxygen and acidification. But ICES data and modeling included temperature. All resulting data will feed into tasks of habitat modeling including task 3.2 for further investigating the impact of climate change to species available habitat and in some cases their reproductive potential.

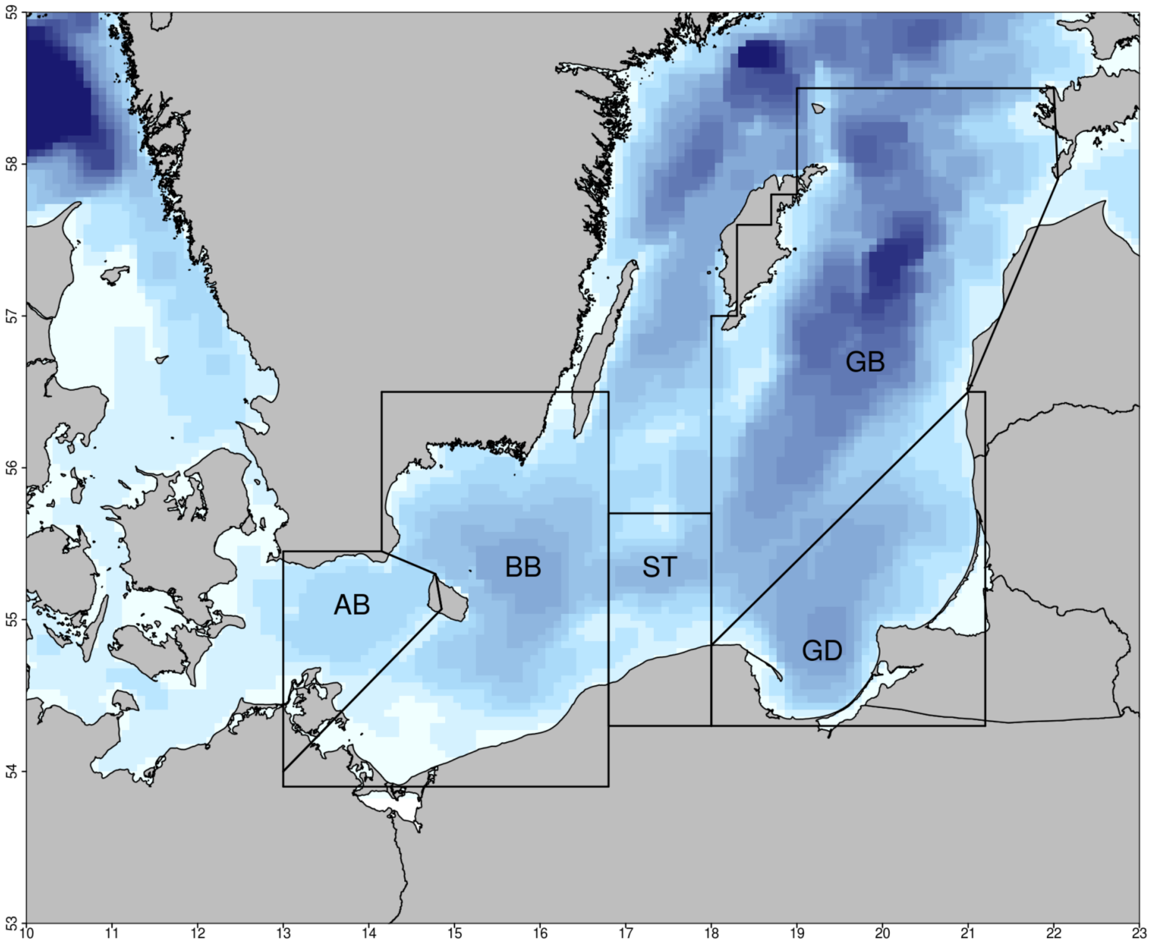


Figure 2.3.1: Horizontal classification of the main Basins of the Baltic Proper. Used in aggregating ICES Oceanographic data base data and BSIOM model data. Abbreviations: AB= Arkona Basin, BB = Bornholm Basin, ST = Stolpe Trench, GD= Gdansk Deep, GB = Gotland Basin.

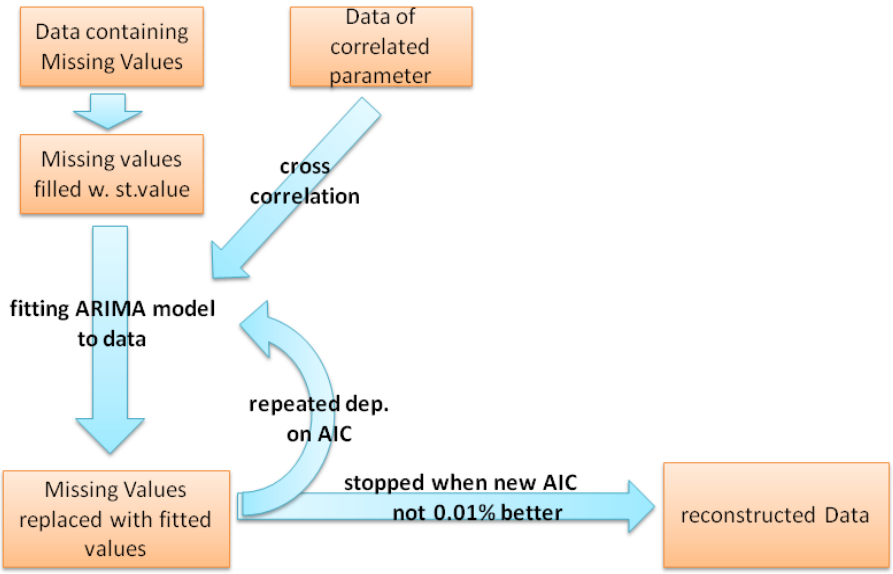


Figure 2.3.2: schematic representation of the ARIMA missing value replacement algorithm. All steps were realized in scripts for the statistics software SAS.

2.3.1 Temperature

ICES time series of main Basins and high resolution BSIOM model data of temperature is available for habitat modeling. Work was not focused on reviewing the impact of temperature on Baltic Sea species. In general modeling and in vivo measurements analysis done in this task are consistent to findings of previous consortiums. Sea surface temperatures in the Baltic Sea do 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 since. For more details please go to reports of HELCOM (2013b) and the IPCC (2014).

2.3.2 Salinity

Short introduction on the topic

The Baltic Sea is one of the largest semi-enclosed brackish waters in the world with a water surface area of 377,400 km2 (Sjoeberg, 1992). The topography features a series of basins separated by sills (Kullenberg & Jacobsen, 1981) The Gulf of Bothnia and the Gulf of Riga can be seen as internal fjords, while the Baltic Proper and the Gulf of Finland consists of several deep basins with open connections. The oceanography of the Baltic Sea is mainly determined by the North Atlantic and European continental large scale climatic conditions. The topographical and meteorological factors (e.g. wind, precipitation and temperature) influence the ratio of the two main water sources of the Baltic Sea (river runoff and saline water inflows from the North Sea) and their interactions.

Because the inflow of water trough rivers with origins in the 1 745 000 km2 of drainage area sums up to a mean of 15 130 m3/s-1 (Bergström & Carlsson, 1994) and the shallow and narrow Danish straits hinder water exchange with the North Sea, a large surface layer of low saline water is maintained. Additionally, the net effect of precipitation and evaporation contributes to the freshwater input into the low saline surface layer (70% of the total Baltic Sea volume, Hinrichsen et al., 2002). The large amount of inflowing water from rivers and precipitation in contrast to low evaporation rates forces the Baltic Sea Basin to drain into the North Sea producing a net flux outward through the Danish straits. This causes a countercurrent of high saline water at the sea floor from the North Sea into the Baltic Sea. Hence a steady, small amount of saline water is mixed into the deeper but still intermediate layers of Baltic Sea water maintaining a vertical and horizontal salinity gradient (Reissmann et al., 2009; Burchard et al., 2009). Under special oceanographic conditions the net flux through the Danish straits gets reversed forcing large amounts of high saline water from the North Sea through the Danish straits; termed major Baltic inflow events (MBI) (Matthäus & Frank, 1992). Only these major inflow events provide water masses of sufficiently high salinity to be mixed with the bottom water of deep basins, replenishing them with oxygen and salinity (e.g. Bornholm Basin, Gotland Basin or Gdansk Deep). In the period between 1920 and 1977 these MBIs occurred sporadically but often enough to withhold the strong vertical stratification within the larger Basins. After the inflow in the winter 1976/77 there was an exceptionally long stagnation period during which the vertical stratification weakened dramatically. Within the Gulf of Finland the permanent halocline effectively disappeared. This period was stopped by MBIs in the year 1993 and 1994 and the stratification was returned to pre 1976 levels. Since then besides the winter MBIs e.g in recent years 2014 and 2015 there were also MBIs recorded in the summer months bringing warm oxygen poor water masses to the intermediate depths of the major basins adding to the overall warming of the Baltic Sea area and with it sea surface. Besides through the MBIs in winter and summer conditions within and below the halocline are to a lesser degree also affected by variations in winter sea surface temperatures (Hinrichsen et al., 2002), wind mixing effects (e.g. Stigebrandt & Wulff, 1987), up- and downwelling, and the breaking of internal waves (Krauss & Brugge, 1991). The most influential process remains however, a major Baltic inflow event.

Schinke and Matthäus (1998) state that these major Baltic inflow events are only possible if at least one of the following two phases is well developed: (1) high pressure fields over the Baltic region with easterly winds or (2) several weeks of strong zonal wind and pressure fields over the North Atlantic and Europe. They explained however, that the increased zonal circulation linked with intensified precipitation in the Baltic region followed by a substantial increase of river runoff (see also Stalnacke et al., 1999), did strongly reduce the probability of major inflow events after the mid-1970's. In fact periods of up to almost 20 years with a total absence of major inflow events were observed after 1976. Only a very small number of exceptional conditions triggered a substantial inflow in 1993, 2003, 2010 and 2014.

Drivers & Impacts

Due to the interactions between climate driven Major Baltic Inflows and precipitation the salinity gradient makes the Baltic Sea a highly stratified habitat. There are almost freshwater conditions in the north and an increase in salinity to the south west. Therefore, inflow events play a very important role in the oceanographic conditions of the Baltic Sea and consequently also have a strong influence on all biological and biogeochemical levels (Schulz et al., 2007; Hannig et al., 2007; Hinrichsen et al., 2007; Schneider et al., 2010; Yakushev et al., 2011). One important aspect of the separation between high saline water in deeper basins and low saline water in the mixed layer at the surface with the permanent halocline in between is that it limits the transport of oxygen and heat from the surface to deep waters. As a result the oxygen in the deep layers can become depleted by respiration of organisms breaking down organic matter. The depletion can result in anoxic conditions within a substantial part of the bottom layer (Neuenfeldt & Beyer, 2003). Therefore Salinity conditions also impact all other abiotic drivers in the deeper layers in the Baltic with Inflow events causing an increase in oxygen, a decrease or increase in temperature and usually an decrease in acidification. Although some evidence shows, that the stronger vertical stratification caused by inflow events do firstly increase the oxygen content but also favor a faster oxygen decrease in the subsequent months.

The salinity conditions within the Basins of the Baltic with vertical stratification have various impacts on the reproduction of marine fish populations. All pelagic spawning species like Cod, Sprat and Flounder need certain salinities for their buoyant eggs to stay above the sea floor.

Same as in the case of oxygen and temperature BSIOM model data was generated and is now available for habitat modeling. Data is not shown here.

Status & Outlook

Climate change will impact the patterns of precipitation on a global scale. For the Baltic a reduction of salinity is predicted for the next century caused by these 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).

2.3.3 Oxygen

Short introduction on the topic

Compared to larger oceans the Baltic Sea is in terms of the Oxygen conditions an extreme habitat. From fully saturated waters on the Sea surface to anoxic conditions in the deep Basins often lay only 30 to 50 meters depth. For all Biological processes these conditions are challenging. Due to climate change and the prognoses of the impact on the Baltic Sea the oxygen depletion in the Baltic is most likely to increase impacting many ecosystem aspects like species composition and ecosystem functioning.

Drivers & Impacts

The Oxygen content of the Baltic Sea is primarily driven by the vertical segregation through the salinity gradient (see section Salinity). Therefore oxygen content in the upper mixed layer follows the seasonal trends introduced by changes in temperature, wind and primary production (see e.g. Panel A Figure 2.3.3.1). With increasing temperatures of the SS resulting in a reduced oxygen solubility and a reduced oxygen content. Intensified primary production leads to higher oxygen saturation. Through the permanent perturbation of the upper 40 to 50 m of the water column through wind forcing the depletion of oxygen by biological metabolic machinery is compensated and oxygen levels of the Sea Surface of all major Basins range in the same window (see Panels A of Figures 2.3.3.1, 2.3.3.2 and 2.3.3.3).

In the Arkona Basin and western Baltic Sea bottom near waters regularly show hyperoxic conditions during summer months but get reoxygenated during winter and spring months by regular small amounts of high saline water entering the Baltic Proper form the west.

In Basins east of the Island Bornholm bottom Waters are stronger separated from the Sea surface and inflowing water from the west has in the last 2 decades less and less often sufficient volumes to increase the oxygen content of these areas like the Bornholm Basin or Gotland Basin sufficiently. Therefore hyperoxic or anoxic conditions are prevailing over the last 2 decades in the Gotland Basin (see Figure 2.3.3.3).

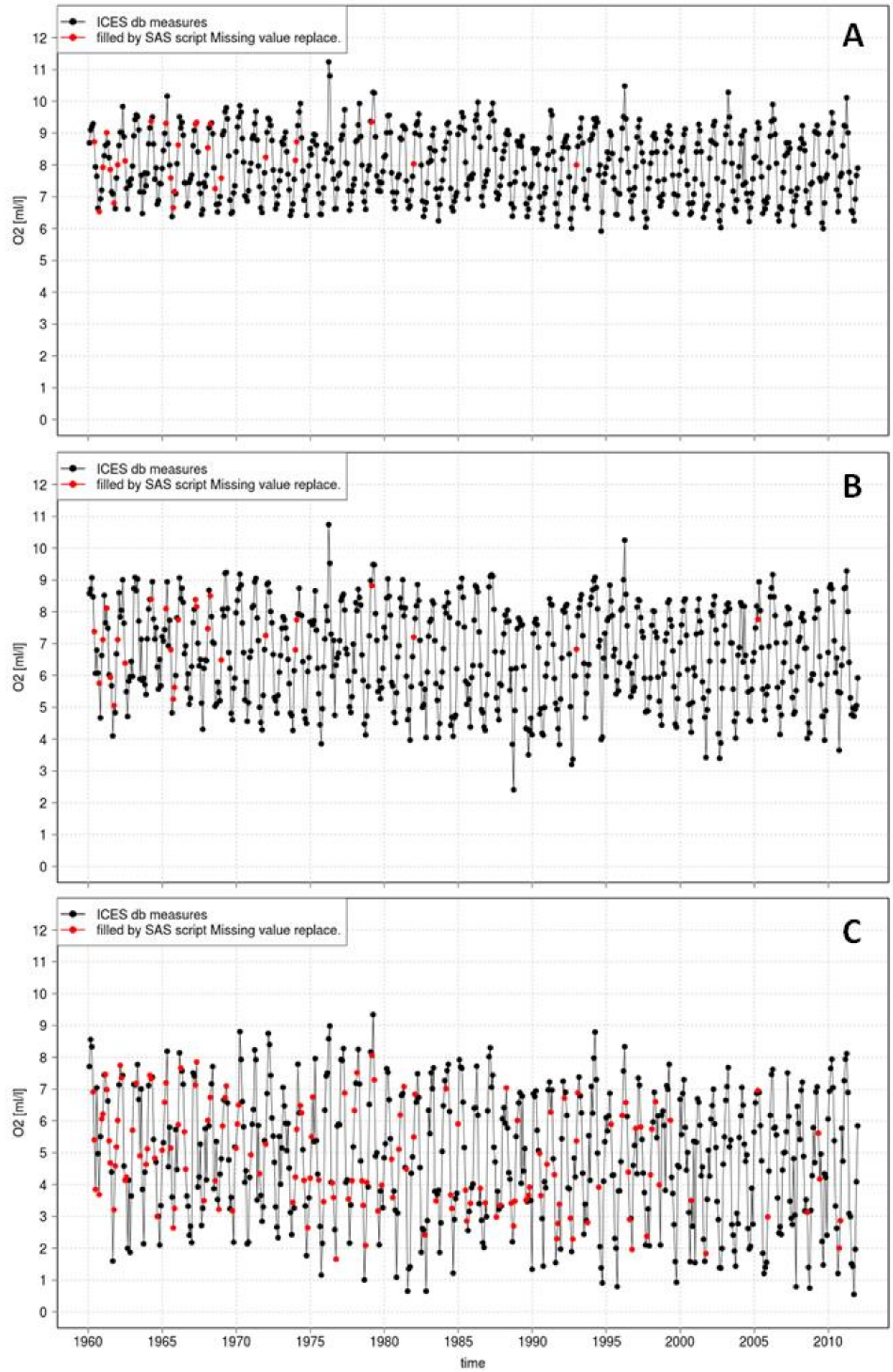


Figure 2.3.3.1: Time series of oxygen content in the Akrona Basin. Aggregated Data from ICES Oceanographic data base. Missing values filled by ARIMA fitting method indicated in red. Panels A, B and C represent vertical aggregation of measurements above, within and below the permanent halocline, respectively.

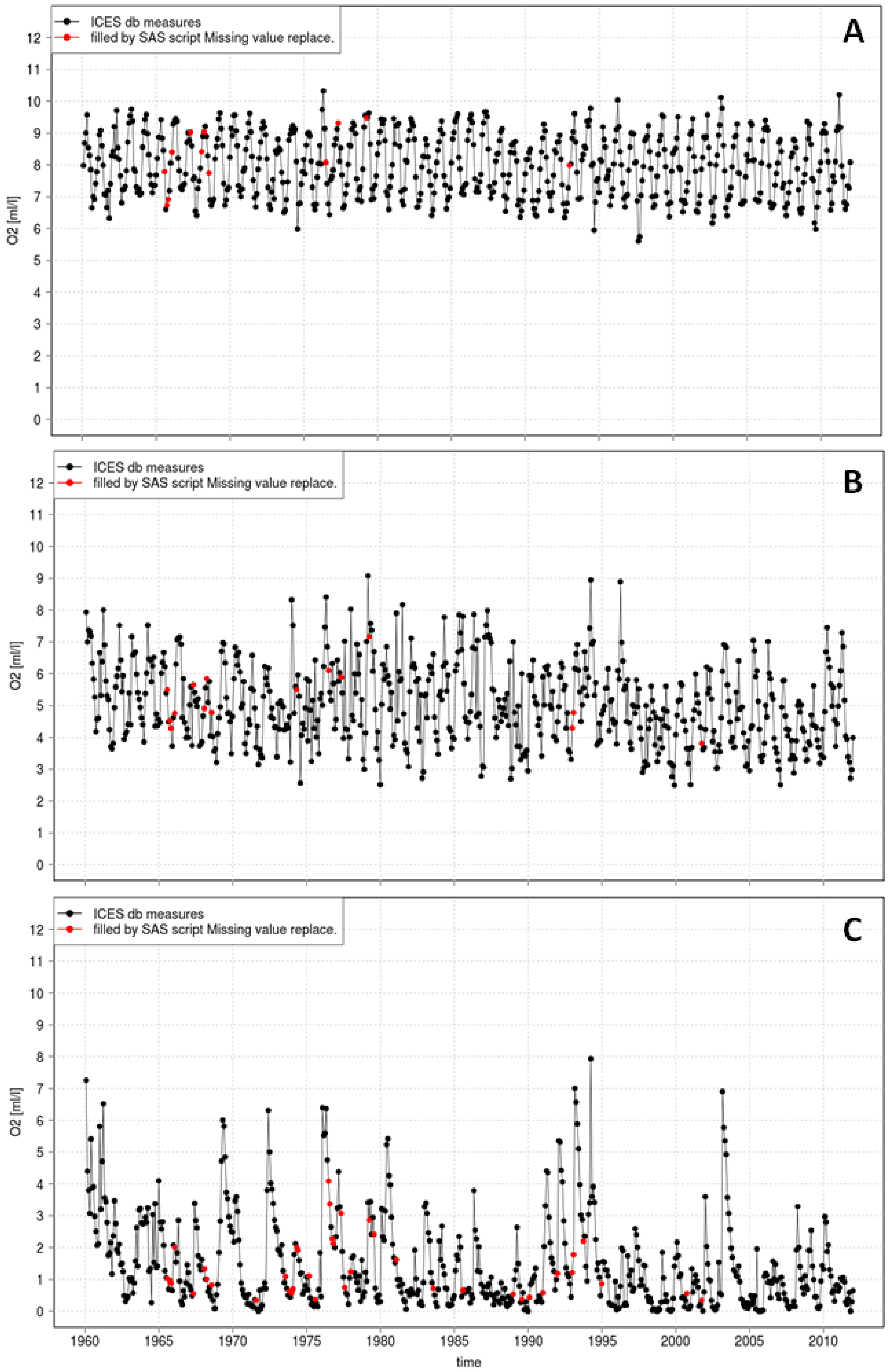


Figure 2.3.3.2: Time series of oxygen content in the Bornholm Basin. Aggregated Data from ICES Oceanographic data base. Missing values filled by ARIMA fitting method indicated in red. Panels A, B and C represent vertical aggregation of measurements above, within and below the permanent halocline, respectively.

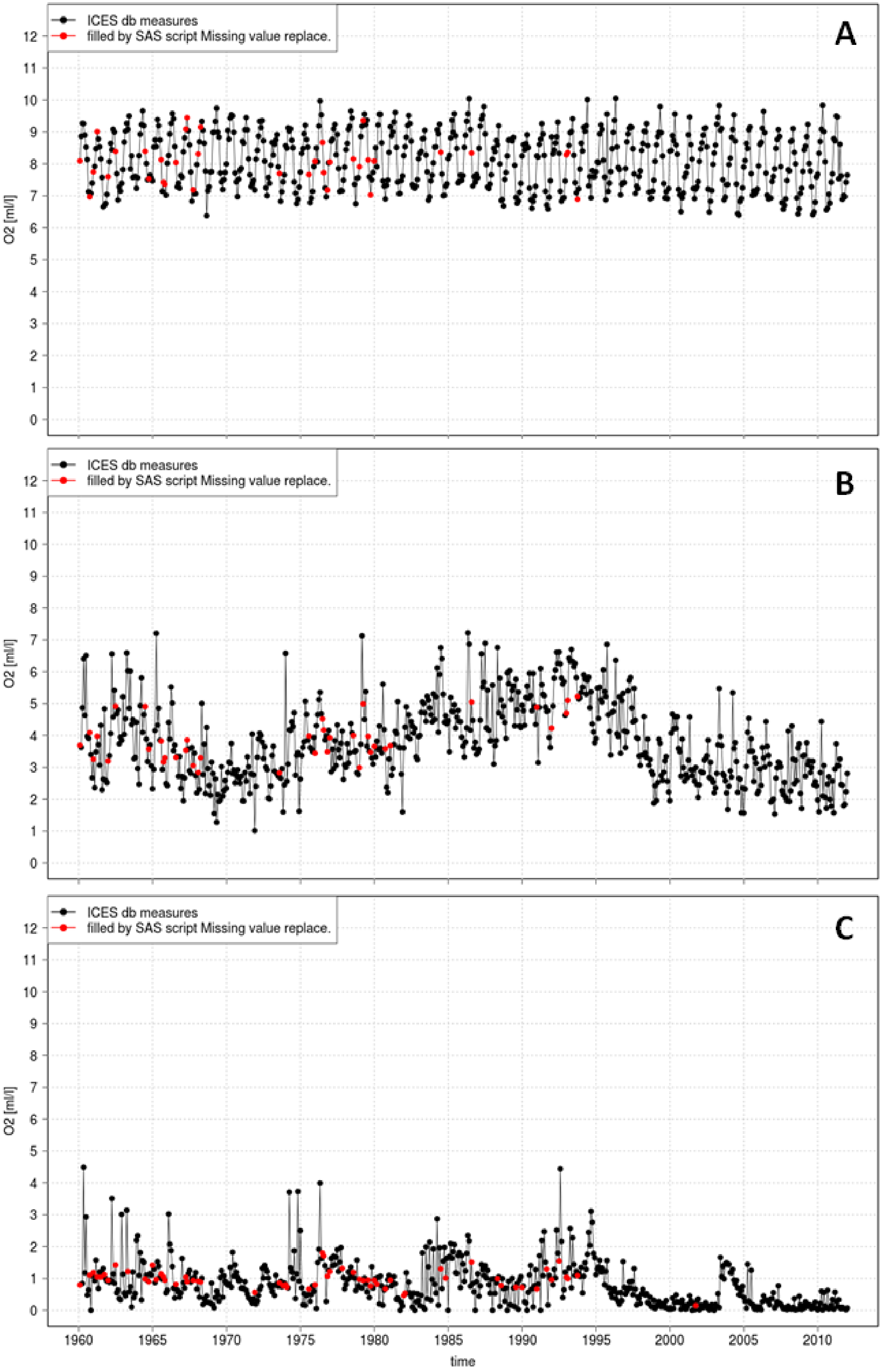
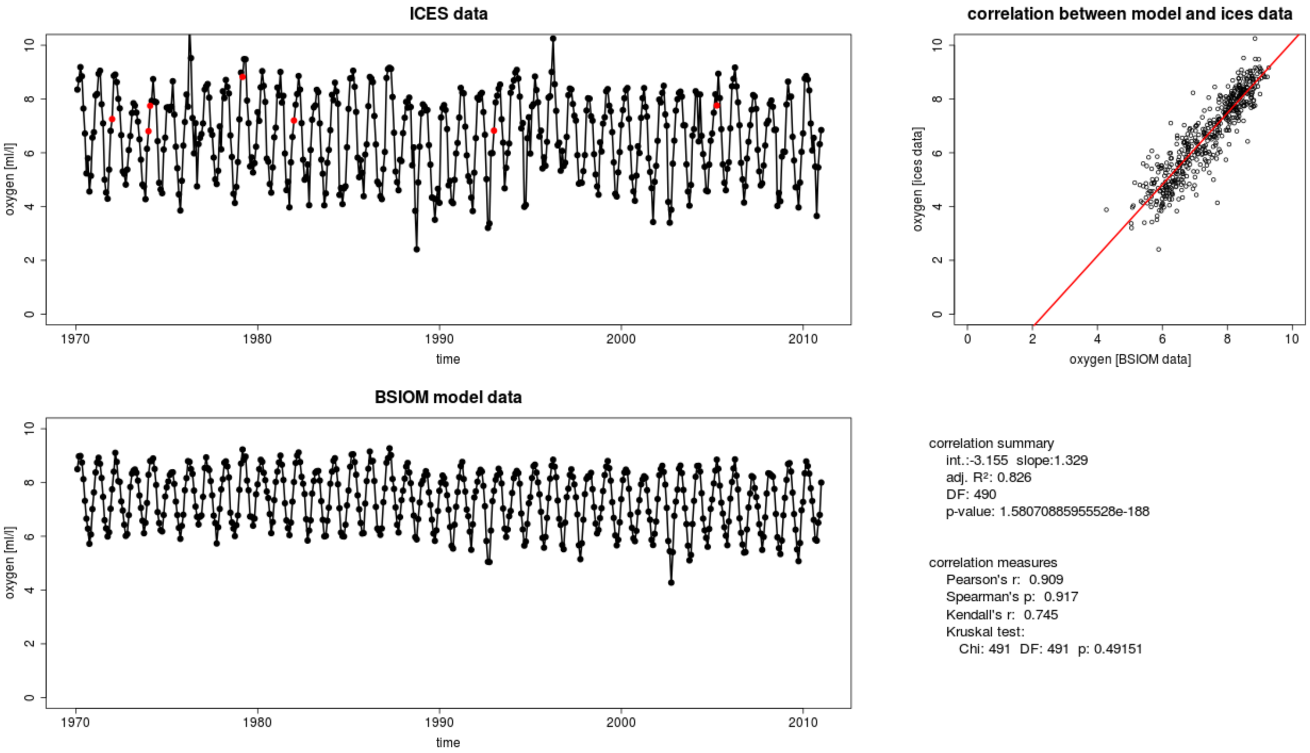


Figure 2.3.3.3: Time series of oxygen content in the Eastern Gotland Basin. Aggregated Data from ICES Oceanographic data base. Missing values filled by ARIMA fitting method indicated in red. Panels A, B and C represent vertical aggregation of measurements above, within and below the permanent halocline, respectively.

Depending on the localization of Baltic Sea species and their environmental preferences these oxygen conditions will have severe impacts on habitat availability and characteristics. The ICES data base for Oceanographic data is a very good basis to analyze oceanographic processes on a meta-scale of basins. For a horizontal expansion analyzes however the aggregation level needed to perform meaningful calculations and produce useful results is much too high. Therefore only a hydrographical model like the BSIOM (Lehmann and Hinrichsen, 2000; Lehmann et al., 2002) gives sufficient resolved data to calculate habitat expansions and abiotic characteristics within these habitats.

When aggregated over the same horizontal segmentation (see Figure 2.3.1) the BSIOM model data is found to be in good agreement with the ICES data for the upper mixed layer of the water column (see Figure 2.3.3.4 & 2.3.3.5). Also below the permanent halocline (in depths >60-70 m) trends and large scale changes in the oxygen content are reasonably modeled supporting findings by Lehman et al. (2014). Due to the nature of large scale modeling of oceanographic parameters with climate forcing the aggregated time series shown have a smoothened character compared to the in vivo measurements. Heterogenic cover of the area under investigation by the research cruises performed every year can in the case of large Basins like the eastern Gotland Basin result in distorted aggregated means. To some extend the larger variability of the in vivo time series is owed to this fact.

Overall the BSIOM data is a good basis for future habitat investigations.



```
correlation summary
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   adj. R²: 0.826
   DF: 490
   p-value: 1.58070885955528e-188

correlation measures
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   Spearman's p:  0.917
   Kendall's r:  0.745
   Kruskal test:
      Chi: 491  DF: 491  p: 0.49151
```
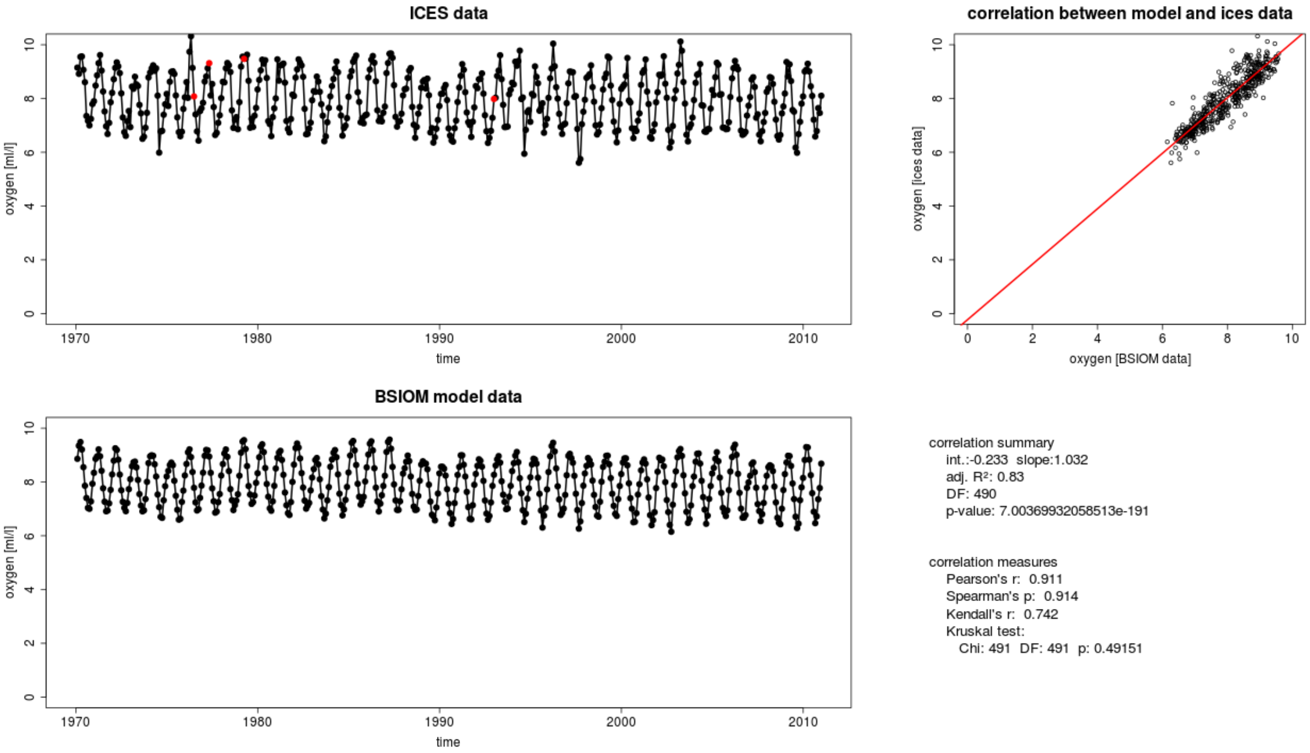

Figure 2.3.3.4: Time Series comparison between ICES Oceanographic db and BSIOM model data. Time series for the water layer above the halocline in the Arkona Basin. Upper left panel: time series aggregated from ICES data base data. Reconstructed data points indicated in red. Lower left panel: time series aggregated from BSIOM model data. Upper right panel: correlation graph between the two time series. Lower right panel: correlation parameters.



```
correlation summary
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   DF: 490
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correlation measures
   Pearson's r:  0.911
   Spearman's p:  0.914
   Kendall's r:  0.742
   Kruskal test:
      Chi: 491  DF: 491  p: 0.49151
```
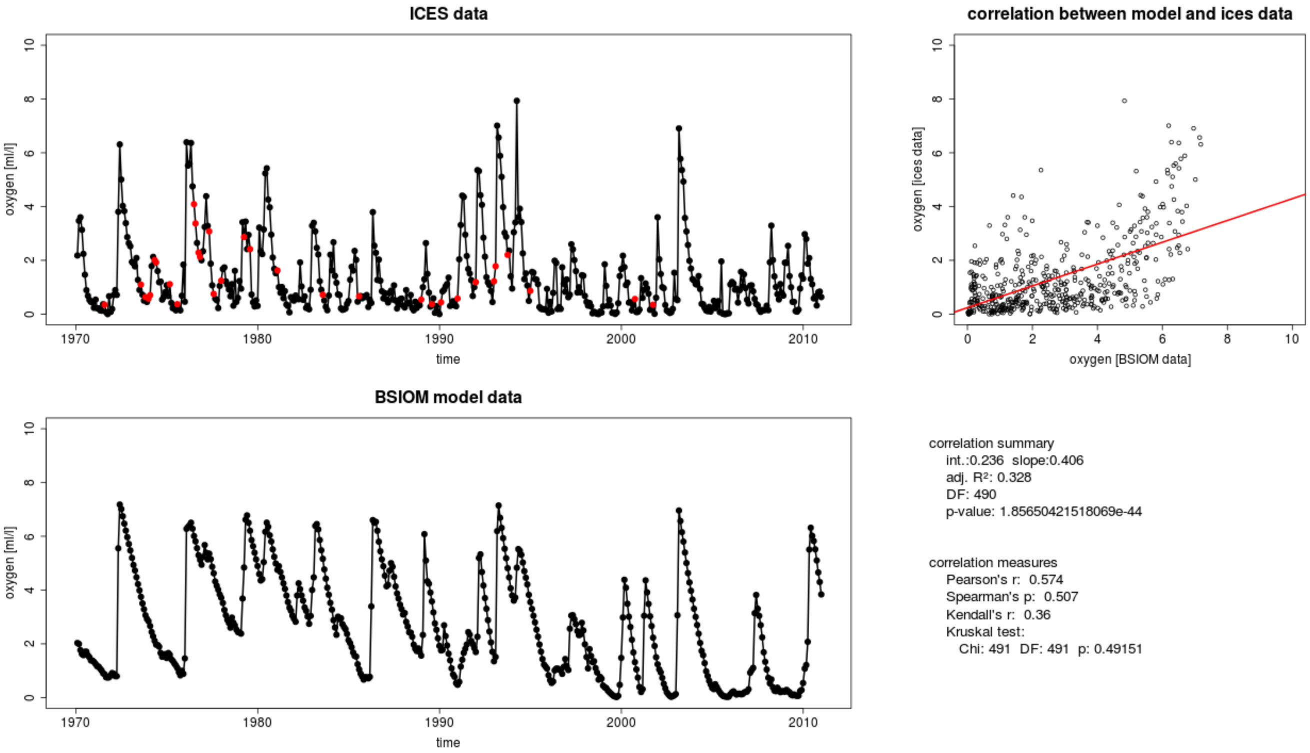
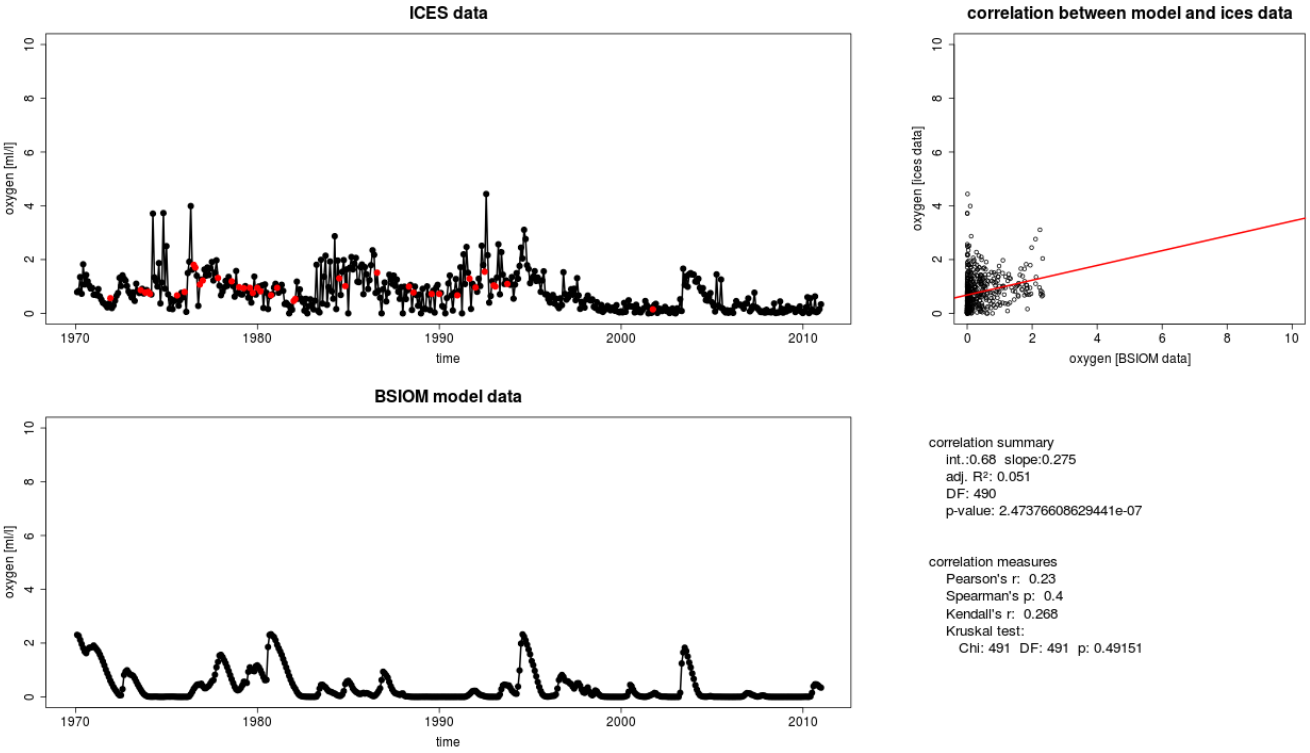

Figure 2.3.3.5: Time Series comparison between ICES Oceanographic db and BSIOM model data. Time series for the water layer above the halocline in the Bornholm Basin. Upper left panel: time series aggregated from ICES data base data. Reconstructed data points indicated in red. Lower left panel: time series aggregated from BSIOM model data. Upper right panel: correlation graph between the two time series. Lower right panel: correlation parameters.



correlation summary
int.:0.236 slope:0.406
adj. R²: 0.328
DF: 490
p-value: 1.85650421518069e-44

correlation measures
Pearson's r: 0.574
Spearman's p: 0.507
Kendall's r: 0.36
Kruskal test:
Chi: 491 DF: 491 p: 0.49151

Figure 2.3.3.6: Time Series comparison between ICES Oceanographic db and BSIOM model data. Time series for the water layer below the halocline in the Bornholm Basin. Upper left panel: time series aggregated from ICES data base data. Reconstructed data points indicated in red. Lower left panel: time series aggregated from BSIOM model data. Upper right panel: correlation graph between the two time series. Lower right panel: correlation parameters.



correlation summary
int.:0.68 slope:0.275
adj. R²: 0.051
DF: 490
p-value: 2.47376608629441e-07

correlation measures
Pearson's r: 0.23
Spearman's p: 0.4
Kendall's r: 0.268
Kruskal test:
Chi: 491 DF: 491 p: 0.49151

Figure 2.3.3.7: Time Series comparison between ICES Oceanographic db and BSIOM model data. Time series for the water layer below the halocline in the Eastern Gotland Basin. Upper left panel: time series aggregated from ICES data base data. Reconstructed data points indicated in red. Lower left panel: time series aggregated from BSIOM model data. Upper right panel: correlation graph between the two time series. Lower right panel: correlation parameters.

2.3.4 Acidification

Short introduction on the topic

Due to the increasing amount of diluted anthropologic CO2 in the world’s oceans, the carbonate system and its equilibria are changing. One of the main consequences is a higher concentration of hydrogen ions measured by a decrease of pH, known as ocean acidification. In open ocean environments this process is causing a measurable decrease in pH in surface waters over the last 20 years of around 0.05 units (Doney et al. 2009).

Closer to shore, ocean acidification is interacting with processes induced by river runoff, eutrophication, upwelling, atmospheric deposition and mineralization (Doney et al., 2007; Omstedt et al., 2009; Melzner et al., 2012). Due to the characteristics of the Baltic Sea all these factors are influencing its carbonate system to a high extent as, for example, in the Kiel fjord (Thomsen et al., 2010). Additionally, these factors are closely linked to biological processes acting, for example, as vectors for carbonate transportation or CO2 producers and consumers. In comparison with highsaline oceans around the world the Baltic Sea has due to its reduced salt content also a reduced buffering capacity to acidification (Hjalmarsson et al, 2008). Therefore, the Baltic Sea has in general a higher variability in pH (Thomas & Schneider, 1999; Melzner et al., 2012).

Therefore, the pH-environment is expected to be extremely diverse and the impact of ocean acidification could be superimposed.

Drivers & Impacts

Impacts of ocean acidification on marine species do vary extensively between different classes of organisms, between closely related species and between life stages within the same species (Doney et al., 2009, 2012; Byrne, 2011). One of the first effects being investigated was the impact on calcifying invertebrate organisms. In theory, lowered pH-levels would inhibit the formation of important structures for these taxa, like shells or exoskeletons. Numerous studies have been conducted revealing potentially dramatic changes in coral reefs, juvenile pteropods, larval echinoderms or single celled planktonic organisms (Langdon et al., 2000; Lischka et al., 2011; Stumpp et al., 2011, 2012; Riebesell et al., 2000). Recently however, evidence was given by Iglesias-Rodriguez and colleagues (2008) that ocean acidification can also lead to an increase of calcification by a certain

Emiliana huxleyi strain. Studies on *Mytilus edulis* from Thomsen et al. (2010) also suggested that calcifying organisms are not generally negatively impacted. This reflects the highly varying responses to an elevated pCO2 found in many different species, most likely due to differences in their acid-base regulation machinery. Furthermore, the elevated pCO2 levels in the oceans which induce ocean acidification were shown to possibly increase rates of photosynthetic activity and growth in planktonic primary producers (Rost et al., 2003; Martin & Tortell, 2006; Riebesell et al., 2007) and even eelgrass (Zimmerman et al., 1997).

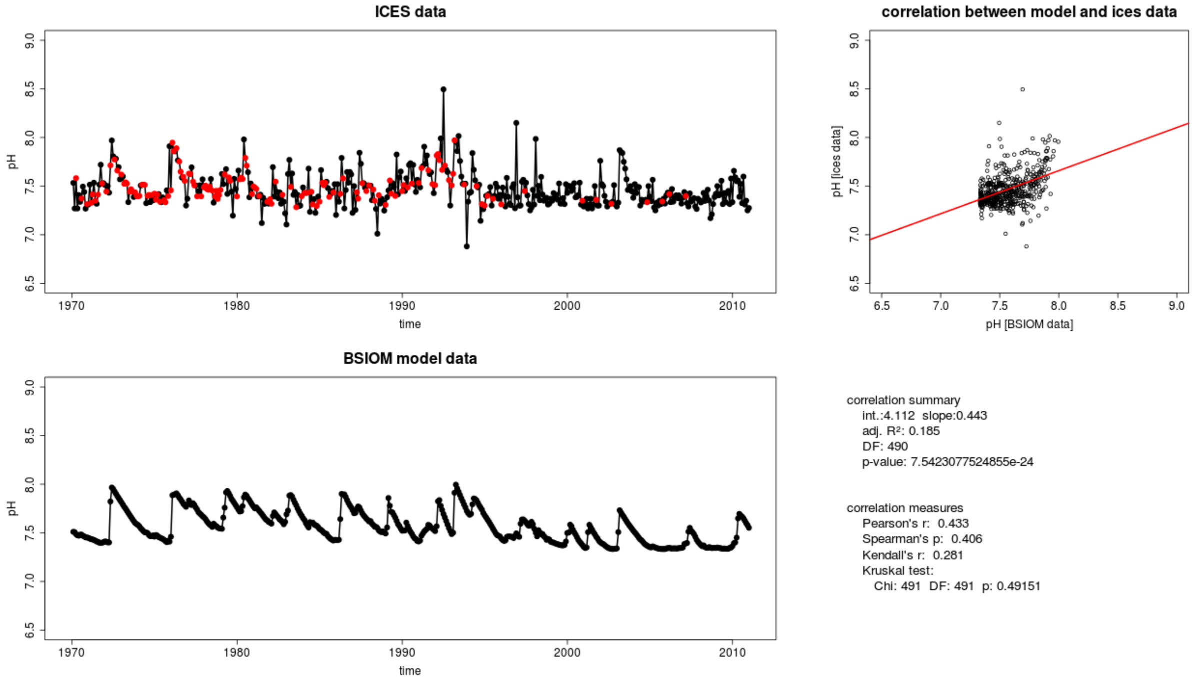
Recently, the additional impacts of hypercapnia on vertebrates like marine fish were brought into focus. Baumann et al. (2012) revealed reduced survival and growth rates of early life stages of the estuarine fish Menidia beryllina which is common in the USA. Negative impacts were also found for several species of coral reef fish by Munday and his group though also in larvae and adult fish (Munday et al., 2009; Donelson et al., 2012a, 2012b; Devine et al, 2012). Here primarily the olfactory ability was found to be disturbed, impairing homing capacity and predator avoidance. Conversely, in studies investigating the physiological impacts of ocean acidification on fish compensatory mechanisms controlling the pH buffer system in the blood were found to prevent acidosis to a certain degree (Claiborne et al., 2002). Melzner et al. (2009) revised all knowledge of acid induced stress on marine organisms and concluded that ectothermic metazoans with an extensive extracellular fluid volume, like adult fish, would be quite robust to moderate acid induced stress by ocean acidification (Cecchini & Caputo, 2001; Michaelidis et al., 2007). These organisms possess strong CO2 excretion and acid-base regulation machinery to tolerate short anaerobic metabolic processes while exercising (Claiborne et al., 2002).

The single cell phases before fertilization and first phases of the ontogeny however are expected to be vulnerable to acid induced stress. Adaptation to hypercapnia and acidic stress could be possible, but only few studies focusing on this aspect have been conducted at this point and used only species other than fish (sediment worm Sipunculus nudus, Langenbuch & Portner, 2004; Bryozoa, Pistevos et al., 2011; Fungi, Ravindran & Naveendan, 2011; Sea urchins, Foo et al., 2012). 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, 2011a; 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).

The impact on species inhabiting the highly diverse pH-environment of the Baltic Sea is as yet only poorly understood. Impacts on primary producers, like the eelgrass Zostera marina and the planktonic community dominated by diatoms and cyanobacteria, 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).

There are no publications available to date investigating the impact of ocean acidification on zooplankton in the Baltic Sea by exposure to elevated pCO2 pressures in an experimental setup. Studies from other parts of the world however, suggest that pCO2 concentrations of 2000-2300 µatm had no significant impact on survival, size and development of Acartia steueri (Kurihara et al., 2004) and Acartia tsuensis (Kurihara & Ishimatsu, 2008). Vehmaa et al. (2012) showed also an hampered decrease in egg production for Arcatia spp. when exposes simultaneously to higher temperatures and elevated pCO2, but suggested that maternal effects could be an important mechanism to cope with ocean acidification and that Arcatia spp. has the potential to adapt. The genus of Acartia is among the four most important genera of calanoid copepods for the whole Baltic Sea (Acartia, Pseudocalanus, Centropages and Temora; Hansen et al., 2004, 2006; Ojaveer et al., 2010). Although the Baltic Sea is habitat for a variety of other copepod species (Ojaveer et al, 2010), it can be speculated that due to the already variable and relatively low pH levels existing in the Baltic (Thomsen et al., 2010) and the diurnal vertical migrations performed by most copepod species (Schmidt 2006) resulting in experienced changes in pH of e.g. 0.5 units (Almen et al. 2014), a significant impact on Baltic Sea copepod species is unlikely. Nonetheless, the zooplankton community in the Baltic Sea is diverse and in addition to copepods, includes fore most appendicularians, polychaete larvae and cladocerans. Before the physical impacts of ocean acidification on these different families and the following interactions between these groups are investigated, no prognosis can be made.

Impacts of ocean acidification on Baltic fish species has been investigated in recent years only by groups from the GEOMAR institute in Kiel. The fish community of the Baltic Sea is dominated by cod, herring and sprat (Sparholt, 1994). Results from experimental data showed that sperm motility in Baltic Cod were not affected by moderate levels of CO2 induced acidification (1360 pCO2 and pH of approximately 7.55; Frommel et al., 2010). For the larval stage of the Baltic cod however, indications of hypercalcification in otoliths and changes in swimming behavior were found (Maneja et al., 2012a, 2012b). Unfortunately, no further published information is available for Baltic Cod populations at this point. Fertilization, embryogenesis, hatching success and larval growth of Baltic Sea herring was investigated by Franke and Clemmesen (2011). After analyzing their data, all parameters of the embryonic development of herring, beside some indications for lowered RNA/DNA ratios, were shown to be unaffected by pCO2 levels of 4600 µatm. Additionally, impacts of ocean acidification on Baltic sprat are yet unknown. In conclusion, although the information is scarce, Baltic fish species are expected to be relatively tolerant to effects of ocean acidification. Furthermore, early life stages, especially the early larval phase are, in general, identified as the most vulnerable stage in the ontogeny.



```
correlation summary
   int.:4.112  slope:0.443
   adj. R²: 0.185
   DF: 490
   p-value: 7.5423077524855e-24

correlation measures
   Pearson's r:  0.433
   Spearman's p:  0.406
   Kendall's r:  0.281
   Kruskal test:
      Chi: 491  DF: 491  p: 0.49151
```

Figure 2.3.4.1: Time Series comparison between ICES Oceanographic db and BSIOM model data. Time series for the water layer below the halocline in the Bornholm Basin. Upper left panel: time series aggregated from ICES data base data. Reconstructed data points indicated in red. Lower left panel: time series aggregated from BSIOM model data. Upper right panel: correlation graph between the two time series. Lower right panel: correlation parameters.

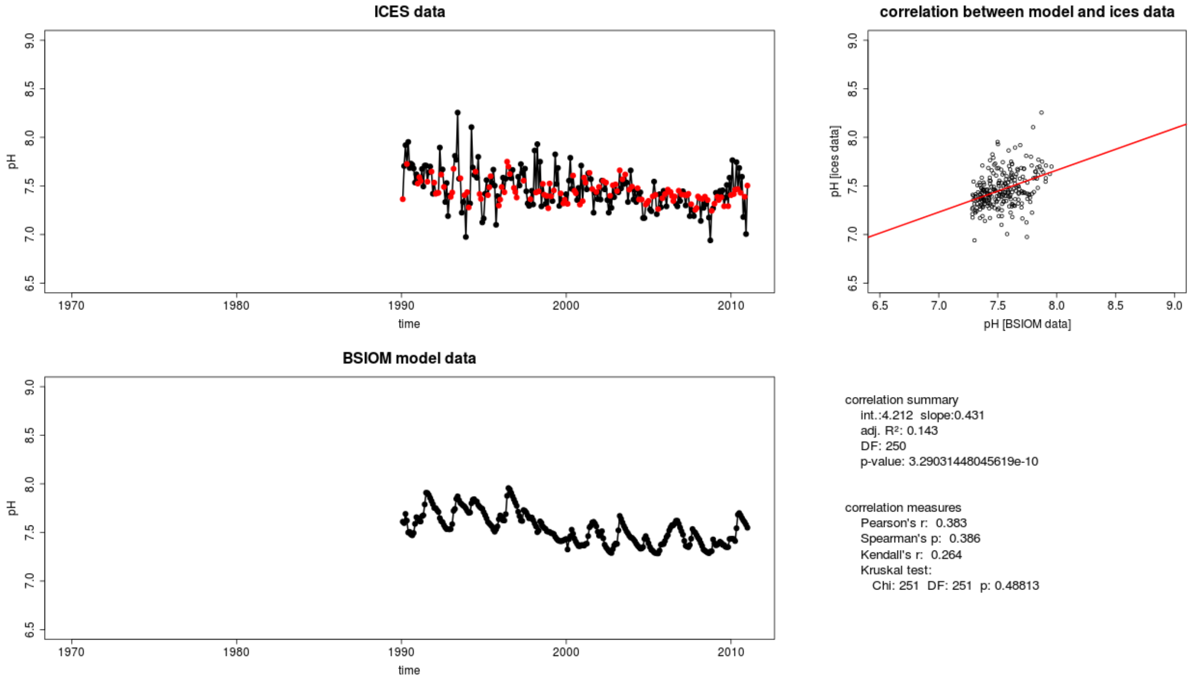
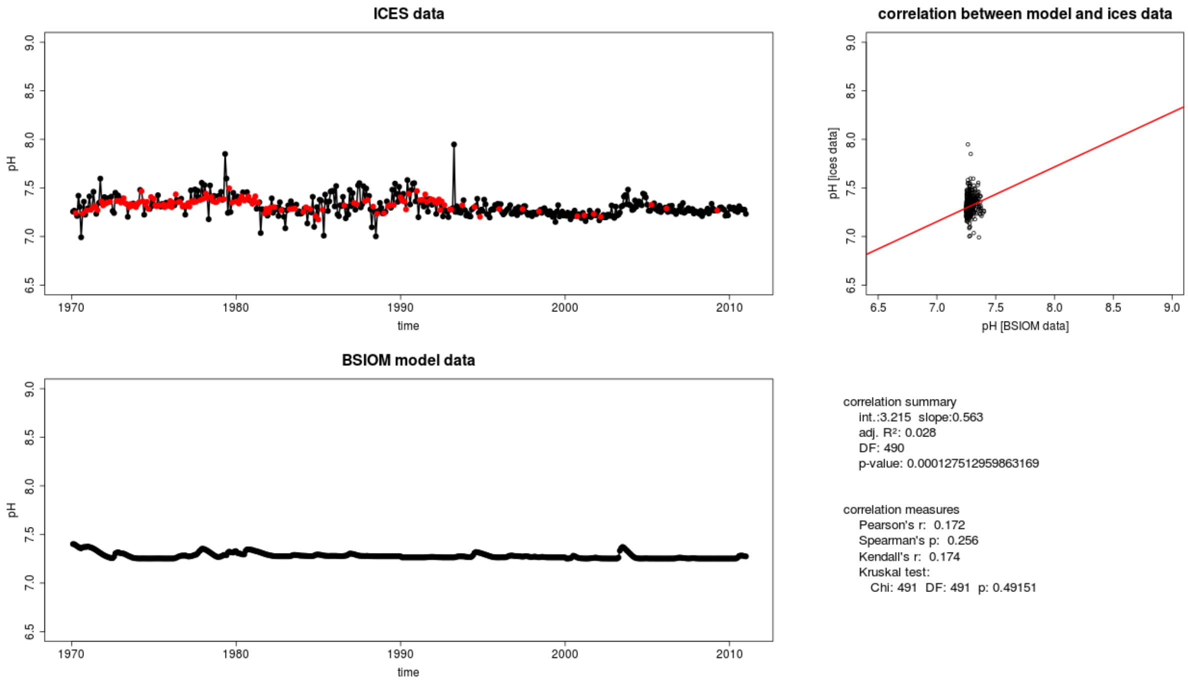


Figure 2.3.4.2: Time Series comparison between ICES Oceanographic db and BSIOM model data. Time series for the water layer below the halocline in the Gdansk Deep. Upper left panel: time series aggregated from ICES data base data. Reconstructed data points indicated in red. Lower left panel: time series aggregated from BSIOM model data. Upper right panel: correlation graph between the two time series. Lower right panel: correlation parameters.

The available ICES pH data was aggregated through the same Basin like approach as for oxygen and temperature. In case of pH the availability of in vivo measurements was found to be very heterogeneous. Relatively good coverage was found in regularly assessed areas like the Bornholm Basin or the Gotland Basin but data for the Gdansk Deep for example showed substantial gaps with missing data. For the period before 1990 the temporal data coverage was so poor that the missing value reconstruction procedure was not applicable (Figure 2.3.4.2). The Aggregation process was completed for all areas shown in Figure 2.3.1 with the same water layer separation as for other parameters depending on the permanent halocline to examine the variability and trends of the physically separated water bodies. Shown are here as examples the comparisons between ICES data and the BSIOM model data for the water bodies below the halocline in the Bornholm Basin (Figure 2.3.4.1), the Gdansk Deep (Figure 2.3.4.2) and the Gotland Basin (Figure 2.3.4.3).

In case of the BSIOM model data for pH a correlation between the oxygen content and the pH value in a water body found in the ICES data was used to approximate pH values to model outcome of oxygen content. These correlations between oxygen and pH were produced and applied in a decadal resolution.

Large variation processes like major Baltic inflows and stagnation periods were in quite good agreement between both data sources but small scale developments and variations with a very short amplitude were not realized with the model. Therefore the used large scale physical process oriented model BSIOM is not equipped to depict the highly complex carbonate system of the Baltic Sea. But for general trends and approximations of experienced pH of certain taxa the produced data is sufficient.



```
correlation summary
   int.:3.215  slope:0.563
   adj. R²: 0.028
   DF: 490
   p-value: 0.000127512959863169

correlation measures
   Pearson's r:  0.172
   Spearman's p:  0.256
   Kendall's r:  0.174
   Kruskal test:
     Chi: 491  DF: 491  p: 0.49151
```

Figure 2.3.4.3: Time Series comparison between ICES Oceanographic db and BSIOM model data. Time series for the water layer below the halocline in the Gdansk Deep. Upper left panel: time series aggregated from ICES data base data. Reconstructed data points indicated in red. Lower left panel: time series aggregated from BSIOM model data. Upper right panel: correlation graph between the two time series. Lower right panel: correlation parameters.

Status & Outlook

Nevertheless, in models investigating the development of surface pH in the Baltic Sea, a decrease due to increasing CO2 levels in the atmosphere is obtained (Omstedt et al., 2009). Impacts of the continuously rising CO2 concentrations on seasonal changes in pH and the different chemical regimes in the Baltic Sea, induced by the vertical and horizontal salinity gradient, is uncertain.. Modeling approaches however indicate that an 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, due to the nature of climate models and their uncertainty together with the complex set of conditions triggering major Baltic sea inflows which then induce drastic changes to the water chemistry and characteristics of below halocline water and the mineralization and remineralization processes within unoxic or hypoxic waters which influences to the carbonate chemistry are poorly understood, the forecasting of the below halocline or near bottom acdidification reaching further than a couple of years is uncertain to say the least.

2.4 Pollution - Nutrients

Short introduction on the topic

Nutrients play a pivotal role for marine bio-productivity. In general, phytoplankton production is limited by either light, carbon or nutrients. With respect to the Baltic Sea the most important nutrients are nitrogen (NO3, NO2, NH4) and phosphorus (PO4), with silica (SiO2) playing a secondary role. The importance of nitrogen and phosphorus varies between basins and seasons, and both nutrients are found naturally in organisms, dissolved and dispersed gases, and minerals. Nutrient loads to the coastal waters of the Baltic Sea have significantly increased in recent decades, mostly because of population growth and changes in agricultural practices in catchment areas. The supply of large quantities of nutrients to the coastal regions of the Baltic Sea has no doubt caused an increase in phytoplankton growth with cascading positive effects on benthos productivity (Cederwall & Elmgren 1990). However, due to its unique characteristics, the Baltic Sea is unusually sensitive to high concentrations of nutrients, which has also lead to a series of undesired side effects and impacts on the health of the ecosystem such as eutrophication and oxygen depletion. This sensitivity is specifically driven by the following three characteristics:

- Limited water exchange between the basin and the North Sea;
- Extensive stratification created by persistent thermocline and/or halocline;
- High residence time of nutrients due to transformations and releases from sediments coupled to hypoxia and anoxia.

Since the 1970’es the majority of areas in the Baltic Sea have been assessed as areas affected by eutrophication (Andersen et al. 2015), and a number of international management actions and measures have been implemented to prevent further degradation like the HELCOM Baltic Sea Action Plan, the WFD and MSFD. Yet, due to the considerable resilience in especially the phosphorus cycles (Gustavsson et al. 2012) and large-scale shifts in the relationship between chlorophyll *a* and nitrogen (Carstensen et al.

2011) a delayed response is observed and the reversal to a pre-eutrophication or oligotrophic state will be long-term.

Impacts

In coastal ecosystems nutrient enrichment will generally cause an increase in phytoplankton primary production and growth and the growth of short-lived macroalgae (Cederwall & Elmgren 1990). The increased biomass of phytoplankton will generate a growth in benthos (Josefson and Rasmussen 2000), not least in filter-feeding benthos (Kiørboe et al. 1981) which again may provide food for an increased abundance of benthivorous predators . Negative side effects of an increase in phytoplankton biomass includes a decrease in light penetration through the water column, which may reduce the colonization depth of macroalgae and seagrasses. This effect has lead to reductions in benthic primary productivity (Duarte 1995). An increase in phytoplankton biomass and ultimately an increase in sedimentation and decomposition of organic matter at the seafloor may increase oxygen consumption and create the basis for hypoxic and anoxic conditions. Both conditions are classified as major threats to coastal ecosystems (Diaz & Rosenberg 1995), and may affect both productivity and diversity of benthic invertebrate and vertebrate communities (Conley et al. 2007). The impact on invertebrates differs between species, as a function of different tolerance to extreme oxygen conditions (Bonsdorff & Pearson 1999). Currently, the anoxic area is 100 000 km2 (~25% of the total area of the Baltic Sea, Jansson 1980), concentrated to the Gulf of Finland, the Baltic proper, the Belt Sea and the Kattegat. Large inter-annual variations occur, and the present development is towards a decreased volume of hypoxia, but with more pronounced anoxia and increased amounts of hydrogen sulphide released into the system (Unverzagt 2001).

In the pelagic ecosystems increased concentrations of nutrient may cause similar undesirable effects as in coastal ecosystems like increased planktonic primary production (Cederwall & Elmgren 1990) and increased sedimentation of organic matter to the seafloor and associated hypoxia or anoxia and loss of sensitive benthic fauna. In addition, important negative impacts on the pelagic ecosystems include a change towards dominance of microbial food webs over the ‘classic’ planktonic food chain and a dominance of non-siliceous phytoplankton species over diatoms, and gelatinous zooplankton over crustacean zooplankton (Suikkanen et al. 2013). Despite the implementation of recent measures to control eutrophication the status of the pelagic ecosystem of the Baltic Sea have remained. The reason for this is the high phosphorus availability in the system due to the large sediment outflux and an increasing mismatch between external nitrogen and phosphorus sources with decreasing N/P ratios. As a result, more phosphorus is available for summer production, which favours the growth of blue-green algae.

Spatio-temporal changes

In order to resolve spatio-temporal changes in the concentration of nutrients in the Baltic Sea measurements and modeled time series were analyzed for the eastern and southern parts of the Baltic Sea between 1970 and 2010. The concentration of winter dissolved inorganic nitrogen (DIN) and phosphorus (DIP) was assessed for surface waters (0-10 m) for the winter period (November-March), when biological activity is lowest. The measured data were extracted from the Baltic Nest Institute Data Assimilation System (DAS) database http://www.balticnest.org/balticnest/thenestsystem/dasdataassimilationsystem.4.74cf9d0413b817d9359ed.html, and the data were aggregated for coastal and open waters for the Gulf of Riga, eastern part of Baltic Proper, Arkona - Bornholm Basins, Kiel Bay - Fehmarn Belt and Kattegat (Figure 2.4.1).

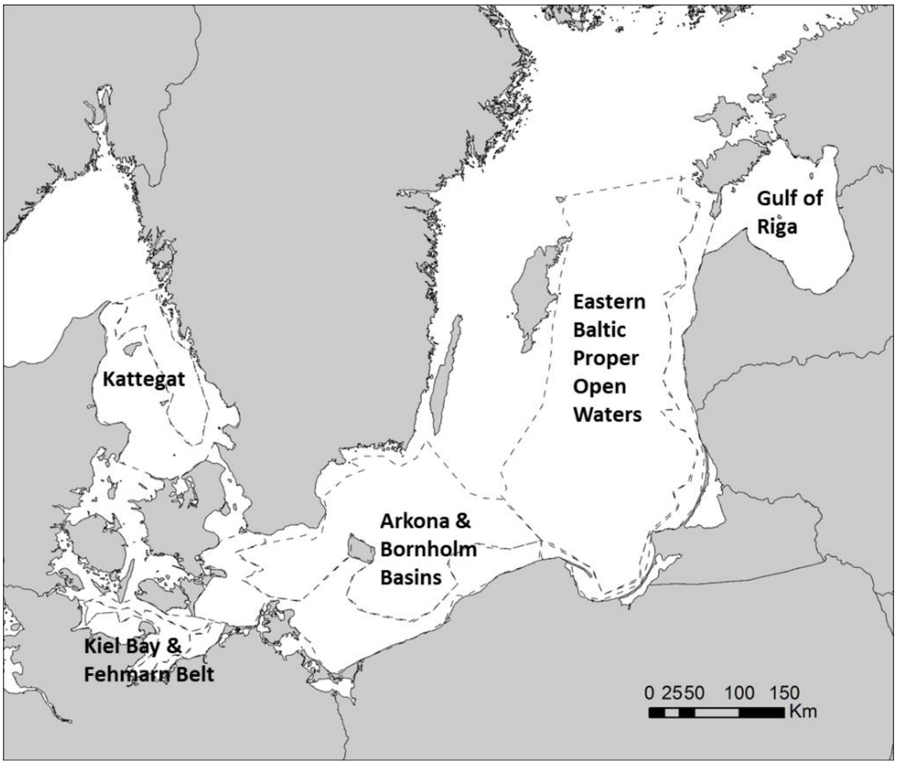
Although a lot of chemical measurements have been made on a large number of monitoring stations in the Baltic Sea over the analysed period, they have to be interpolated both in space and time in order to describe large-scale seasonal and regional distribution pattern. This can be done by simple linear interpolations, however, the uneven sampling regimes and the long residence time of the surface water and rapidly changing currents and oxygen conditions make it difficult to statistically characterize distribution patterns. Therefore, hydrodynamic models can provide improved means for calculating nutrient concentrations based on the quantification of flow patterns and mixing processes. Gustavsson et al. (2012) described a reconstruction of nutrient levels in the Baltic Sea based on the large-scale BALTSEM model. In order to resolve nutrient concentrations at a higher spatial resolution as required in this assessment we used the dedicated bio-geochemical BIO C3 Baltic Sea model set-up by DHI (Rasmussen 2015) to extract DIN and DIP concentrations for selected stations along depth gradients in the eastern and southern Baltic Sea (Figure 2.4.1). The results for locations with the following depths were selected:

- Irbe Strait: coastal (10 m), open waters (100 m)
- Lithuania: coastal (10 m), open waters (100 m)
- Kaliningrad: coastal (10 m), open waters (100 m)
- Central Polish coast: coastal (10 m), open waters (100 m)
- Arkona and Bornholm Basins: coastal (10 m), open waters (100 m)
- Kiel Bay: coastal (20 m)
- Kattegat: coastal (10 m), open waters 30 m

Modelled DIN concentrations show long-term declines in the coastal areas of both Irbe Strait, Lithuania and Kaliningrad waters since 1993, while the decline off the central Polish coast, in Kiel Bay and Kattegat started already in 1985 (Figure 2.4.2). The decline in DIN concentrations off the Central Polish Coast and in Kattegat involved both coastal and open waters, while the decline in the open waters to the north was less evident. In general, DIN levels in coastal waters were almost twice as high as levels in the open sea, indicating strong N gradients towards land. The declines in DIN concentrations in all coastal areas and in open waters south of Kaliningrad were as strong as 50 %. No decline is evident in modelled DIN concentrations in Arkona and Bornholm basins.

Measured DIN concentrations showed a decline in most areas since mid 1980’es, in Kattegat since mid 1990’es and in coastal areas of Arkona and Bornholm Basins since 2001 (Figure 2.4.3). No declines were seen in the Gulf of Riga.

Modelled DIP concentrations revealed general increases up to the mid 1980’es, followed by stabilization (Figure 2.4.4). Concentrations in Irbe Strait were, however, stable throughout. In most areas a second peak is indicated in mid-late 2000’s. Measured DIP concentrations were similar showing two peaks with one in mid 1980’es and one mid-late 2000’es (Figure 2.4.5).



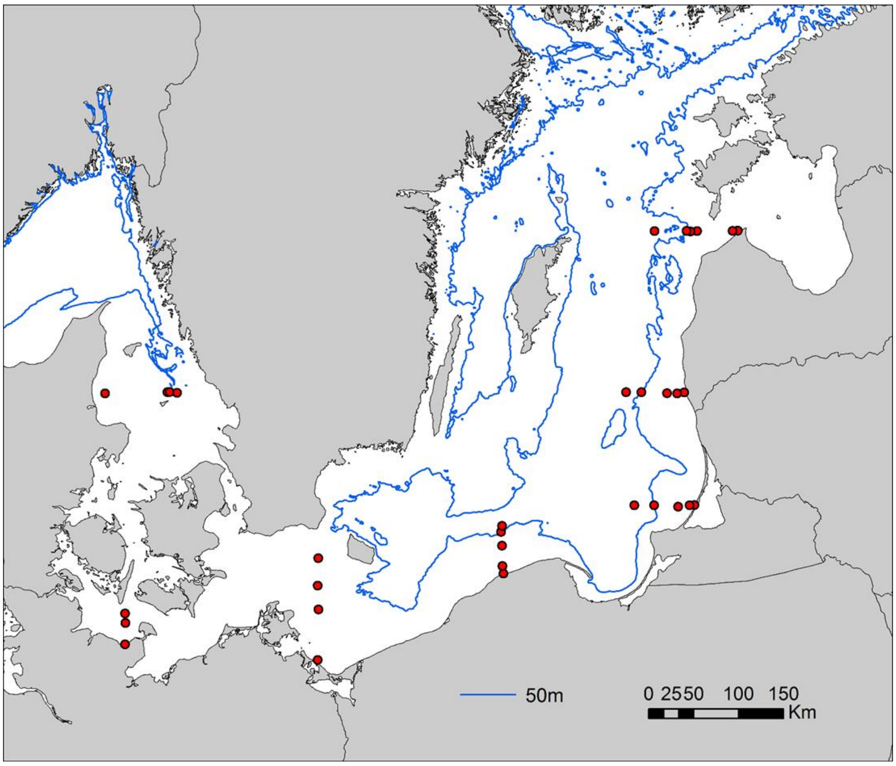
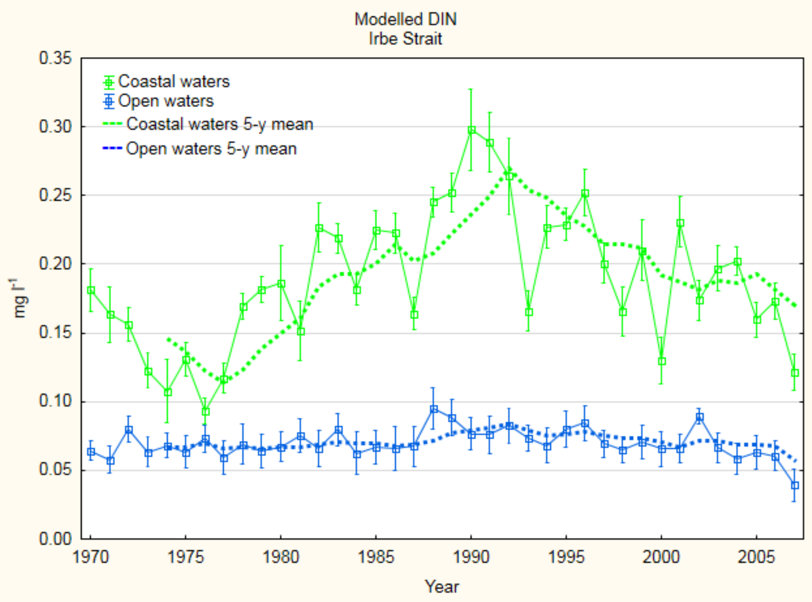
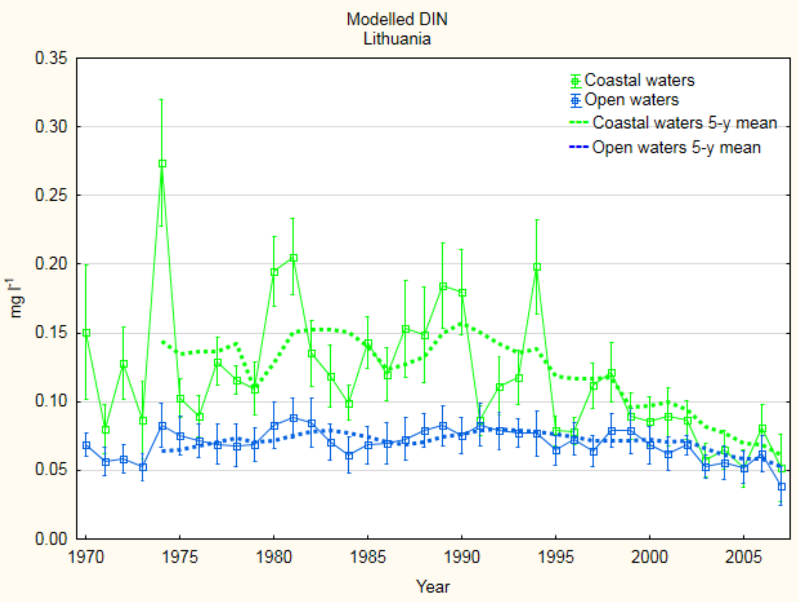
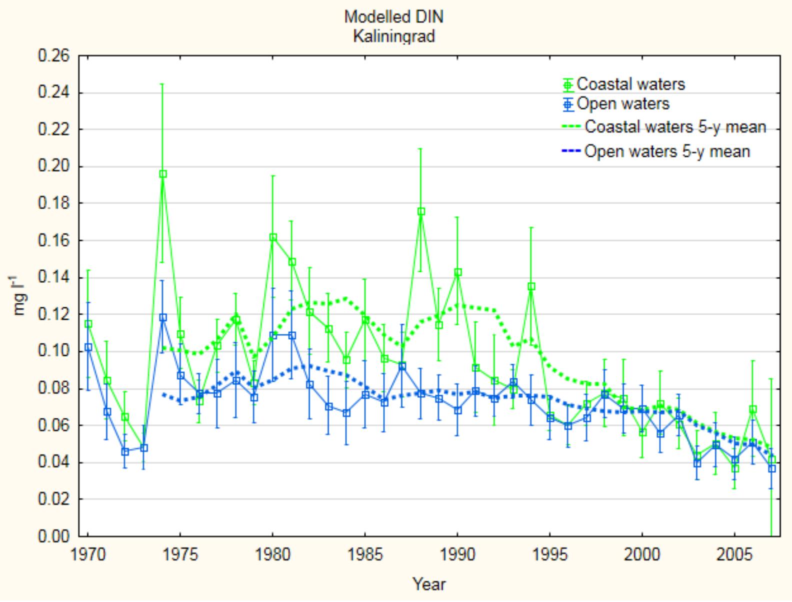
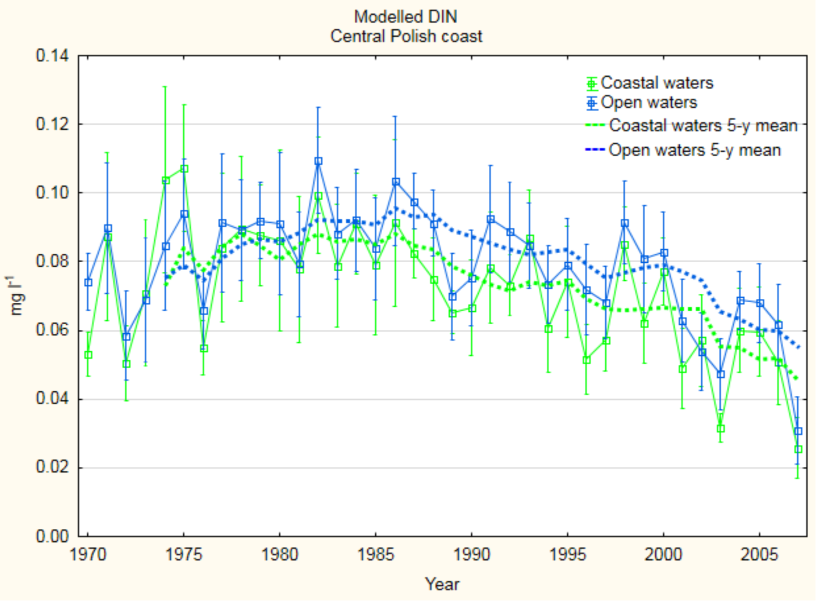


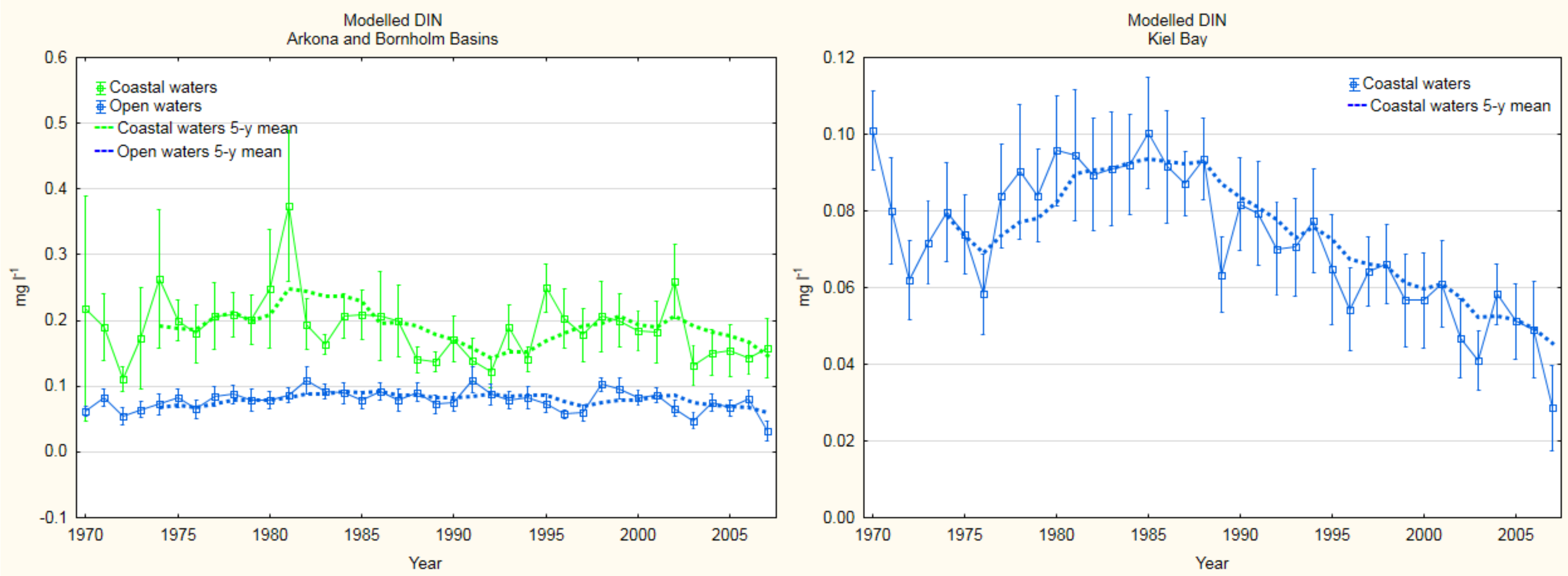
Figure 2.4.1. Location of zones used for extraction of nutrient measurements from the DAS database, and stations used for extraction of modelled nutrient concentrations from DHI's Baltic Sea Model.


Modelled DIN
Irbe Strait
Coastal waters
Open waters
Coastal waters 5-y mean
Open waters 5-y mean
mg l^{-1}
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1970
1975
1980
1985
1990
1995
2000
2005
Year


Modelled DIN
Lithuania
Coastal waters
Open waters
Coastal waters 5-y mean
Open waters 5-y mean
mg l^{-1}
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1970
1975
1980
1985
1990
1995
2000
2005
Year


Modelled DIN
Kaliningrad
Coastal waters
Open waters
Coastal waters 5-y mean
Open waters 5-y mean
mg l^{-1}
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1970
1975
1980
1985
1990
1995
2000
2005
Year


Modelled DIN
Central Polish coast
Coastal waters
Open waters
Coastal waters 5-y mean
Open waters 5-y mean
mg l^{-1}
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1970
1975
1980
1985
1990
1995
2000
2005
Year



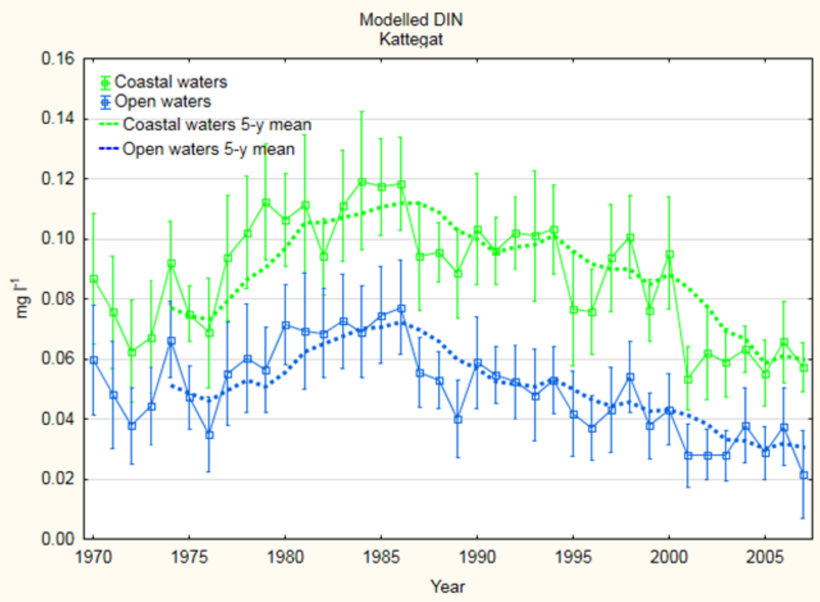
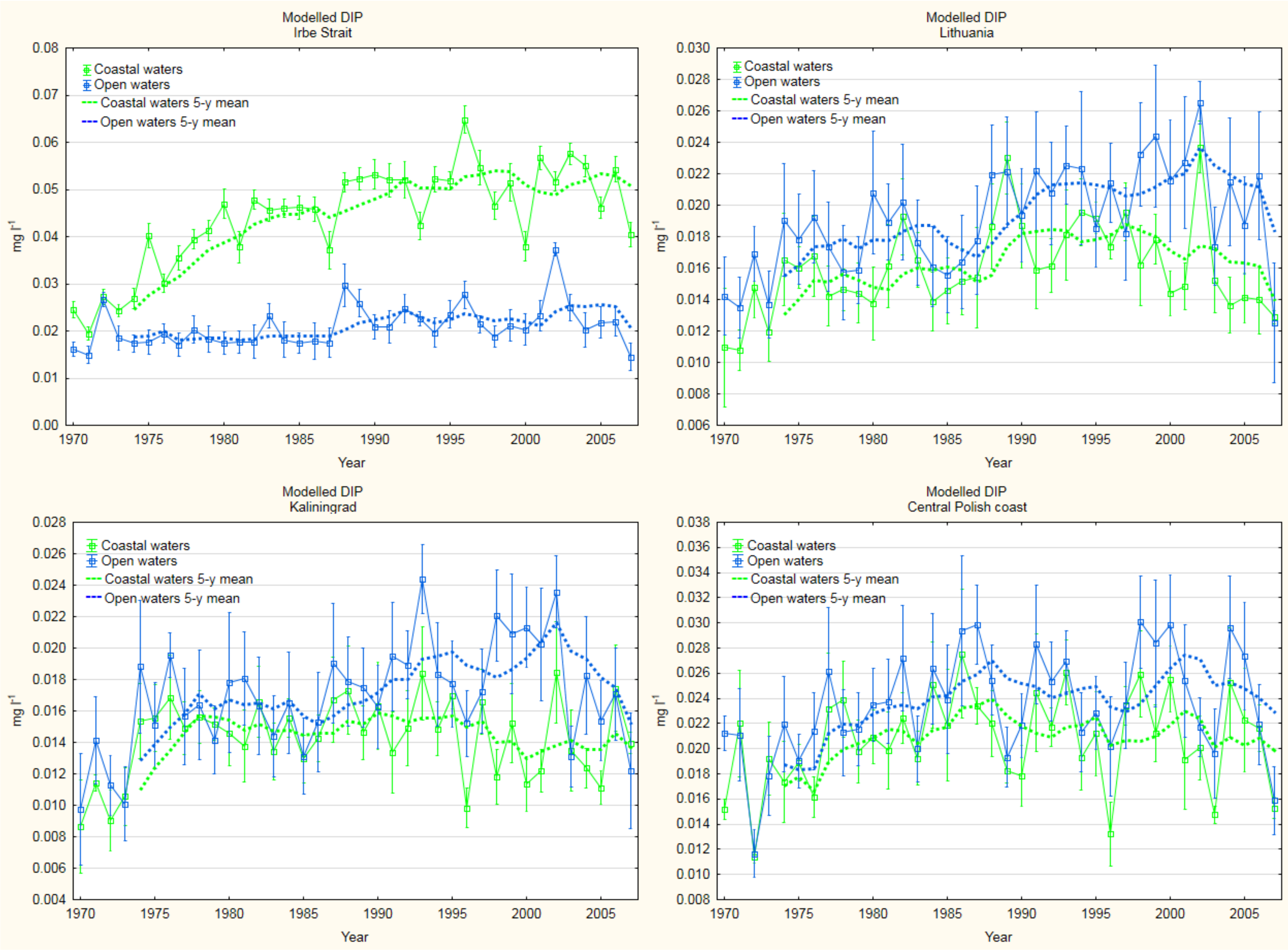
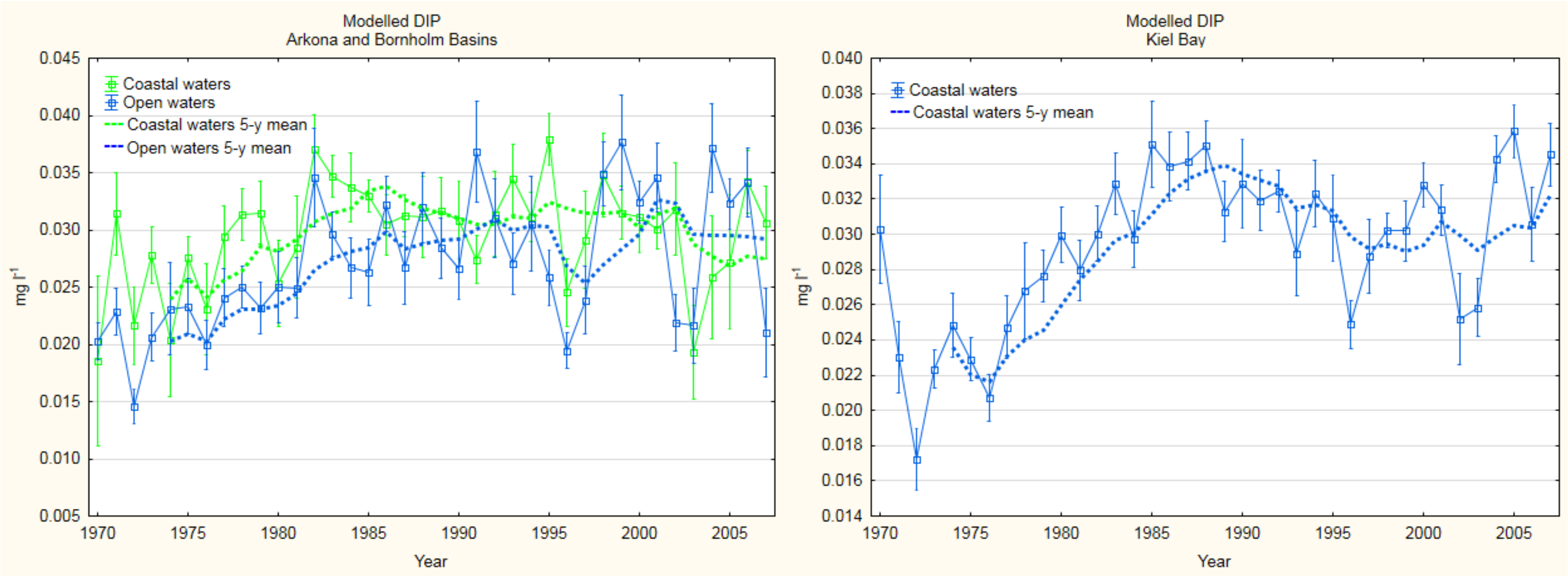


Figure 2.4.2. Trends in modelled concentrations of dissolved inorganic nitrogen (DIN) in surface waters (0-10 m) during the winter months (November-March) 1970-2007. Error bars show 95% confidence limits of the means of modelled hourly values. Dotted curves are 5-year moving averages.


Modelled DIP
Irbe Strait
Coastal waters
Open waters
Coastal waters 5-y mean
Open waters 5-y mean
mg l-1
Year
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
1970
1975
1980
1985
1990
1995
2000
2005
Modelled DIP
Lithuania
Coastal waters
Open waters
Coastal waters 5-y mean
Open waters 5-y mean
mg l-1
Year
0.006
0.008
0.010
0.012
0.014
0.016
0.018
0.020
0.022
0.024
0.026
0.028
0.030
1970
1975
1980
1985
1990
1995
2000
2005
Modelled DIP
Kaliningrad
Coastal waters
Open waters
Coastal waters 5-y mean
Open waters 5-y mean
mg l-1
Year
0.004
0.006
0.008
0.010
0.012
0.014
0.016
0.018
0.020
0.022
0.024
0.026
0.028
1970
1975
1980
1985
1990
1995
2000
2005
Modelled DIP
Central Polish coast
Coastal waters
Open waters
Coastal waters 5-y mean
Open waters 5-y mean
mg l-1
Year
0.008
0.010
0.012
0.014
0.016
0.018
0.020
0.022
0.024
0.026
0.028
0.030
0.032
0.034
0.036
0.038
1970
1975
1980
1985
1990
1995
2000
2005



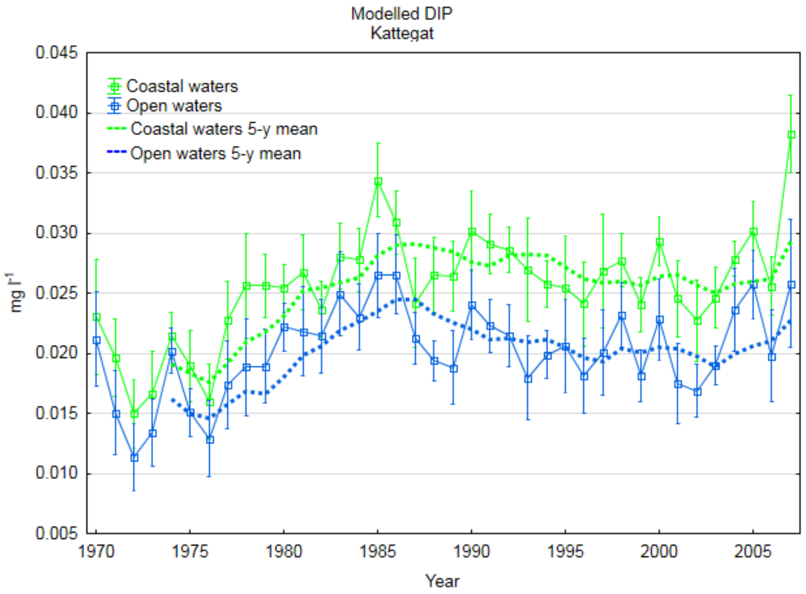
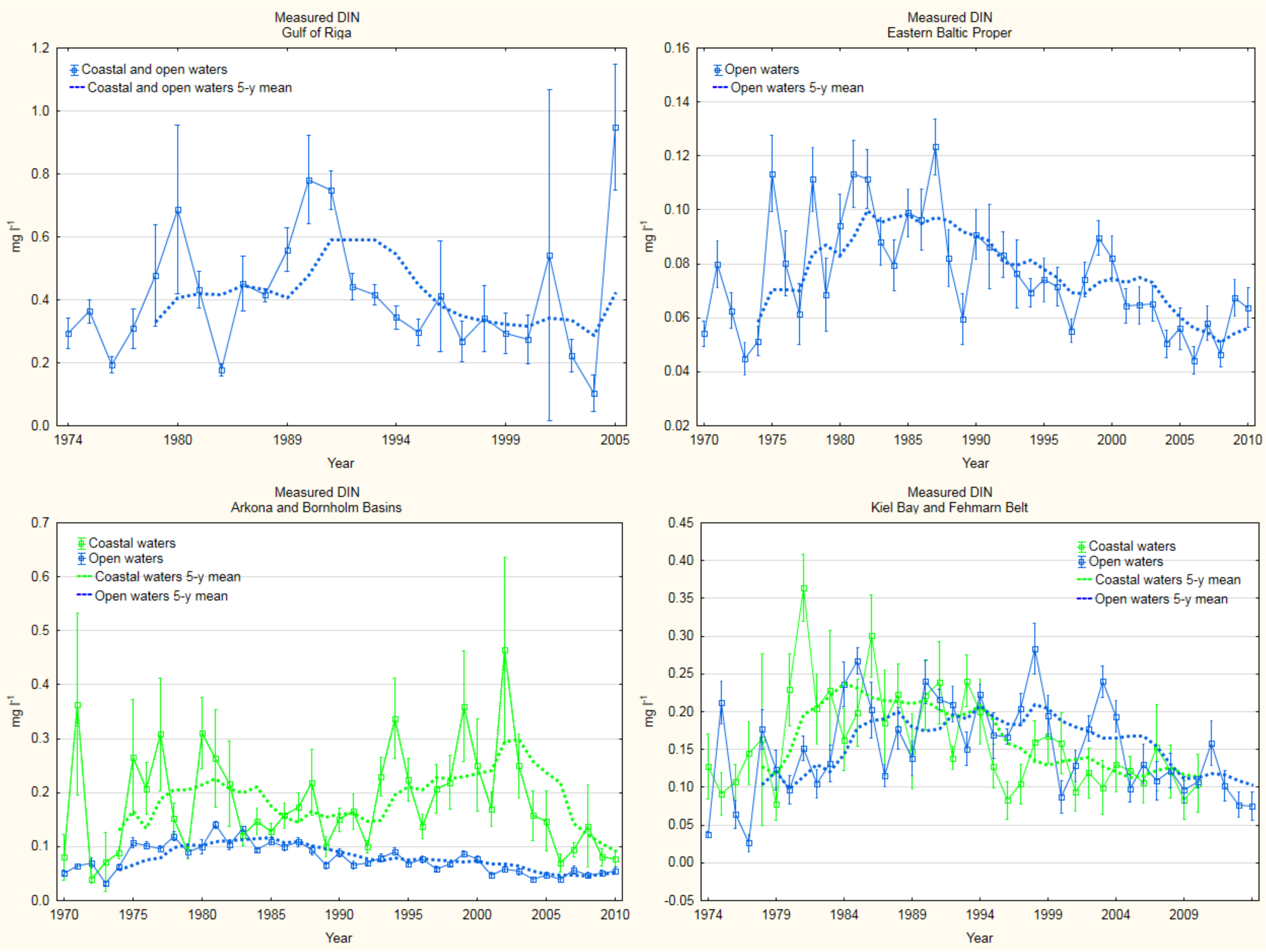


Figure 2.4.3. Trends in modelled concentrations of dissolved inorganic phosphorus (DIP) in surface waters (0-10 m) during the winter months (November-March) 1970-2007. Error bars show 95% confidence limits of the means of modelled hourly values. Dotted curves are 5-year moving averages.


Measured DIN
Gulf of Riga
Coastal and open waters
Coastal and open waters 5-y mean
mg l⁻¹
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1974
1980
1989
1994
1999
2005
Year
Measured DIN
Eastern Baltic Proper
Open waters
Open waters 5-y mean
mg l⁻¹
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year
Measured DIN
Arkona and Bornholm Basins
Coastal waters
Open waters
Coastal waters 5-y mean
Open waters 5-y mean
mg l⁻¹
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year
Measured DIN
Kiel Bay and Fehmarn Belt
Coastal waters
Open waters
Coastal waters 5-y mean
Open waters 5-y mean
mg l⁻¹
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
1974
1979
1984
1989
1994
1999
2004
2009
Year

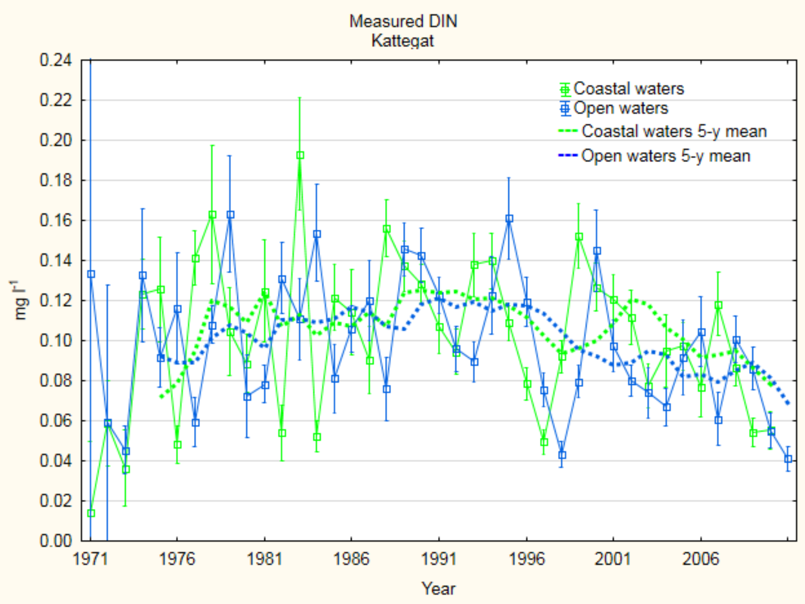
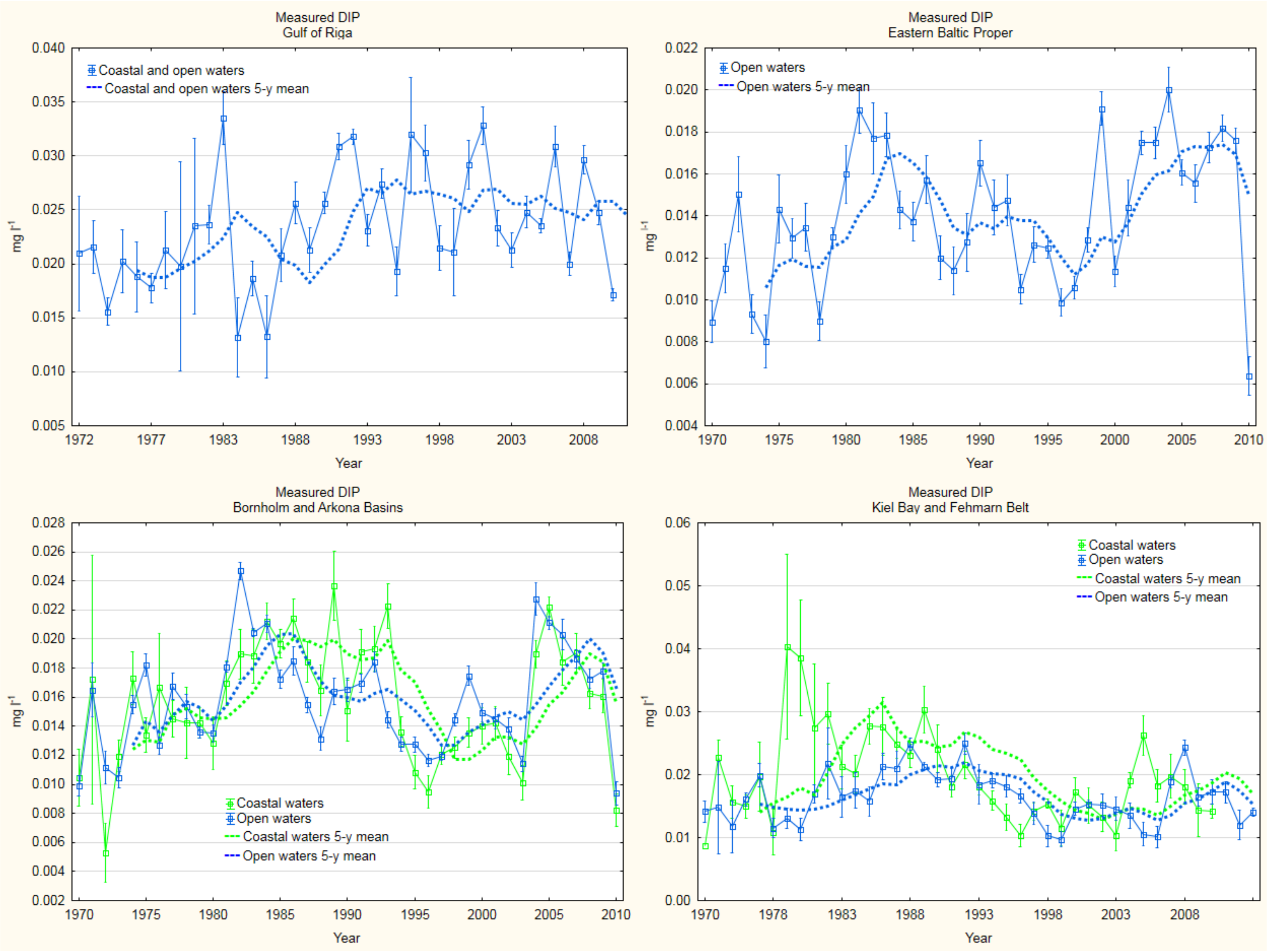


Figure 2.4.4. Trends in measured concentrations of dissolved inorganic nitrogen (DIN) in surface waters (0-10 m) during the winter months (November – March) 1970-2010. Error bars show the 95% confidence limits of the means. Dotted curves are 5-year moving averages.


Measured DIP
Gulf of Riga
Coastal and open waters
Coastal and open waters 5-y mean
mg l-1
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
1972
1977
1983
1988
1993
1998
2003
2008
Year
Measured DIP
Eastern Baltic Proper
Open waters
Open waters 5-y mean
mg l-1
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year
Measured DIP
Bornholm and Arkona Basins
Coastal waters
Open waters
Coastal waters 5-y mean
Open waters 5-y mean
mg l-1
0.028
0.026
0.024
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year
Measured DIP
Kiel Bay and Fehmarn Belt
Coastal waters
Open waters
Coastal waters 5-y mean
Open waters 5-y mean
mg l-1
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1970
1978
1983
1988
1993
1998
2003
2008
Year

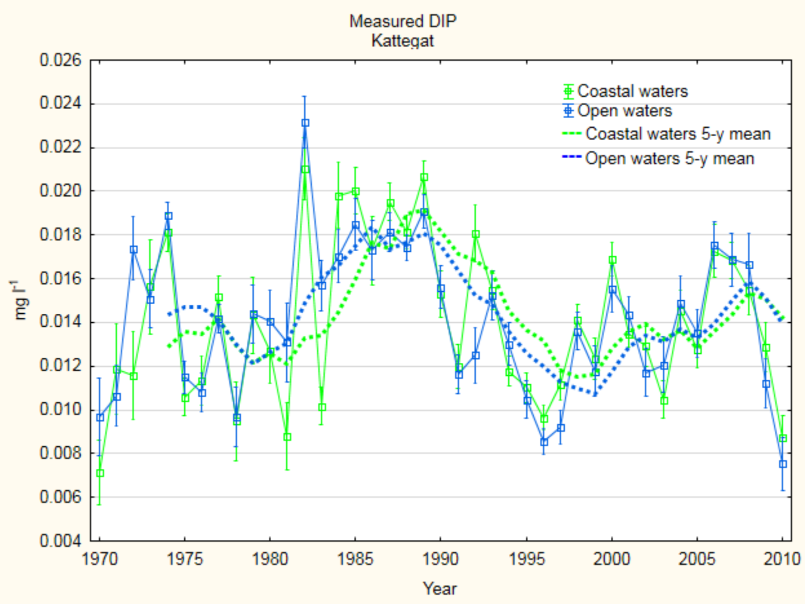


Figure 2.4.5. Trends in measured concentrations of dissolved inorganic phosphorus (DIP) in surface waters (0-10 m) during the winter months (November – March) 1970-2010. Error bars show the 95% confidence limits of the means. Dotted curves are 5-year moving averages.

Status & Outlook

Both measured and modeled nutrient concentrations document overall declines in nitrogen concentrations, especially in the coastal areas of the Baltic Sea, while phosphorus concentrations due to release from sediments coupled to mixing processes are at the same level as during the period of excessive nutrient inputs in the 1980'es. The spatio-temporal dynamics of phosphorus correspond to the dynamics of the deep water renewal in the Baltic Proper (Conley et al. 2002). The major inflows to the Baltic Proper in 1993 and 2003 caused a halocline uplift, increasing the potential for entraining large pools of DIP into the surface layer. Action plans to reduce nutrient loads (Carstensen et al. 2006) have contributed to reduce nitrogen levels to levels comparable to those in the 1970s. The relationship between loading and concentrations of nitrogen in the coastal waters and in the whole southern Baltic indicates a strong link to land-based loads on a year-to-year basis.

With the large-scale decrease in concentrations of nitrogen ubiquitous changes in the distribution and biomass of submerged vegetation and benthic macrofauna are currently observed. According to the Danish national monitoring program signs of increased cover of macroalgae in deeper waters and a drastic decline in the biomass of filter-feeding macrofauna are among the most significant recent changes (Riemann et al. 2015). Concurrently with the decline in the stocks of benthic filter-feeding macrofauna large-scale declines in benthic feeding waterbirds have been reported since the early 1990'es (Skov et al. 2011).

The degree to which increased control of eutrophication in the Baltic Sea will have cascading effects on the bio-productivity in the coastal ecosystems is one of the focal research areas in BIO C3 with ecosystem modelling and assessments undertaken in WP 2, WP 3, WP 4 and WP 5. As documented by this assessment, modelling the effect of changing nutrient loads on bio-productivity in the Baltic Sea will require the application of bio-geochemical models at a relatively high spatial resolution.

Socio-economic view

There are various economic sectors that contribute to the eutrophication in the Baltic Sea, including agriculture and industry (through discharges). Though not an economic sector, sewage is also an important contributor that depends on social factors (concentration of population and leisure options) and economic development (advances in sewage processing technology and its diffusion). Agriculture is acknowledged to be the main source of nutrient inputs to the Baltic Sea (HELCOM 2007).

From the main components of eutrophication, in the case of nitrogen the most important sources are diffuse, with a 71% of the load in surface waters From this, agriculture contributes with an 80% (HELCOM 2009b). There are two main phenomena related to agriculture that affect the load of nutrients that end up in the sea: the loss of agricultural land and the intensification of agriculture. Agricultural land is lost to abandonment, but even more to artificial uses (urbanization, infrastructures etc.) that can also contribute with other sources of pollution. This contrast with other economic uses that would have less environmental impact and possibly serve as buffer zones, as semi-natural grasslands or set-aside land (EEA 2003).

As to intensification, there is a growing trend in the use of organic agriculture (Eurostat 2016, EEA 2009), with most countries in the Baltic area over the EU average on land dedicated to organic agriculture (5.91% in 2014 according to Eurostat). However, the proportion of agricultural land with this lower eutrophication potential is less than 10% in most cases. There are several studies on the use of ecological recycling agriculture (ERA) in the Baltic area, with data showing much lower outputs of nitrogen and phosphorus than conventional agriculture (Larsson and Granstedt, 2010, Seppänen, 2003, Granstedt 2000).

Percentage of organic agricultural land vs total agricultural land in the Baltic area

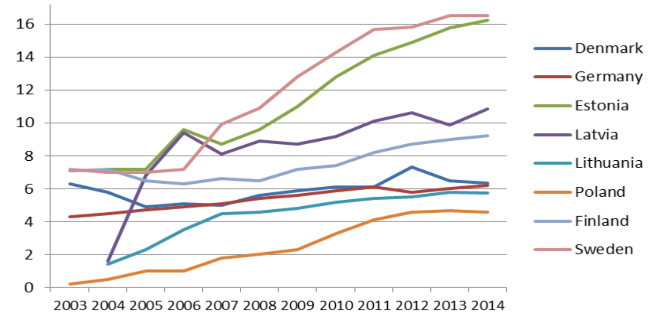


Figure 2.4.6. There is a strong increase in the surface dedicated to organic agriculture in the Baltic area, with some countries doubling the share in the last decade. (Data for Estonia 2004, Denmark 2007 and values for 2014 are estimates estimates, Gemany has a break in the time series in 2012). Source: Eurostat 2016

In total, agricultural nitrogen surpluses have decreased, but they continue existing in all EU countries and in the Baltic are higher in Germany and Denmark (DG ENVIRON, 2012). Some policy instruments that have influenced this decrease, and that allow us to think of further decreases in the future are the nutrient management plans and environmental farm plans included in the Common Agricultural Policy (CAP, EEA 2007), the nitrates directive under the Water Framework Directive (including all catchment areas up to the coastal waters).

2.5 Tourism

Tourism affects biodiversity through marine litter, and to a lesser extent through hazardous substances pollution (ETC 2015). An even broader influence of tourism on biodiversity has been highlighted by HELCOM (2009).

The evolution of tourism in the Baltic can be measured through the number of hotel nights spent by tourists (see fig. 2.5.1 below). The evolution of residents stays in hotels start decreasing in 2006 already, while the stays by non residents seem to be only affectd by the economic crisis in 2009.

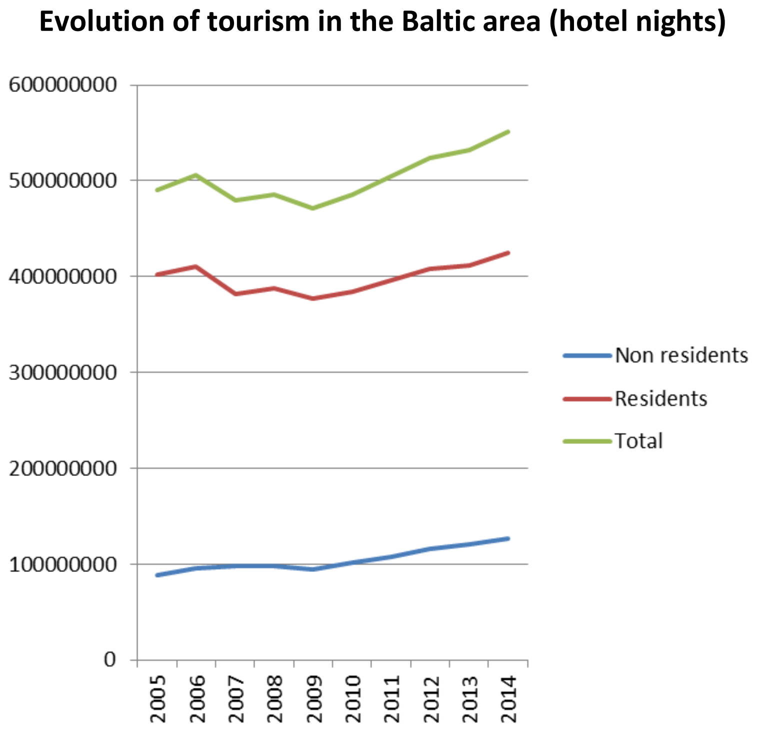


Fig. 2.5.1 The number of hotel nights by non residents has increased steadily in the last decade, with the exception of 2009, possibly due to the economic crisis.

The impact of tourism on biodiversity in the Baltic is sometimes measured by selecting geographic areas that are identified as touristic, called gradients of tourism intensity, accessibility or distance to the shoreline (e.g. Schierding et al.2011; Seer et al. 2016). Then an analysis of the effect of tourism on biodiversity is performed in biological terms focusing in one or a group of species.

However economic statistics have a much lower spatial definition, being measured at country level or NUTS 2statistical region at the most. Depending on the definition of regions by the Member State, some of these statistical regions can comprise large areas that englobe different coastal regions. In the Baltic that is the case specially for Denmark, Germany and Sweden, when trying to distinguish between the Baltic and the North Sea. A standard statistical criterion is used to separate coastal areas, including seaside and in the proximity and inland areas (Eurostat 2013). The distinction between the Baltic and the North Sea coasts is only available at local administrative unit (LAU) level and there are no Eurostat tourism statistics at that level.

As stated in Seer et al. “beach access is essential to coastal tourism and is a prime factor in beach vacation destinations (Haller et al. 2011”. The distinction between coastal and non coastal areas is therefore important to measure the influence of tourism on biodiversity. At disaggregated level we can get an impression of the spatial importance at national level of coastal tourism by observing the proportion of coastal LAU in the region (see table. 2.5.1 below).

Table 2.5.1 Percentage of coastal municipalities in the Baltic area

Member state	Total of municipalities	All coastal	Seaside	50% area on 10km buffer	%coastal	%seaside (of total)
Denmark	99	85	77	8	86%	78%
Germany	11255	595	302	297	5%	3%
Estonia	226	65	56	9	29%	25%
Latvia	119	19	17	2	16%	14%
Lithuania	540	8	7	1	1%	1%
Polan	2479	55	40	7	2%	2%
Finland	336	82	81	1	24%	24%
Sweden	290	94	87	7	32%	30%
EU-28	*113102*	*12090*	*6011*	*6046*	*11%*	*5%*

Source: Eurostat, 2013

An approximation to the social and economic importance of this sector for the countries in the Baltic area can be achieved using the number of hotel nights consumed by non residents (see Fig. 2.5.2 below)

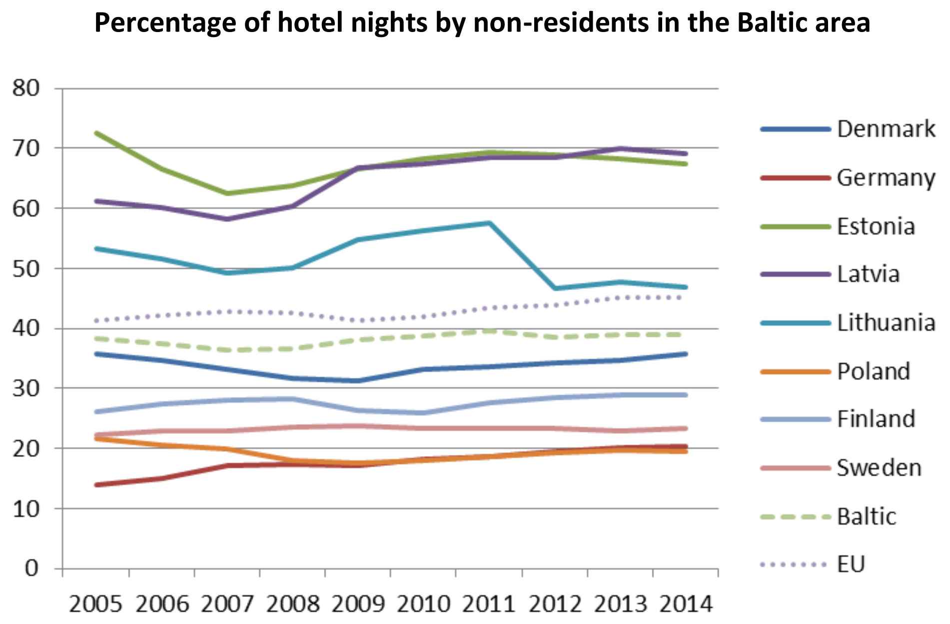


Figure 2.5.2 The Baltic states have the highest proportion of non-resident tourists in the area, which has remained fairly stable with the exception of Lithuania.

When looking at pollution from sewage, the risk from touristic accommodation is higher when they are not permanent edifications, as the sewage systems are less developed in those cases and there is a higher risk of waste being discharged unprocessed. This would be the case with camping grounds, recreational vehicle parks and trailer parks (see table 2.5.2 below)

Table 2.5.2 Proportion of night stays in campings, recreational vehicles and trailers over total night stays in coastal areas

	2014
EU 28	*25%*
Denmark	46%
Germany	13%
Estonia	0%
Latvia	8%
Lithuania	0%
Poland	3%
Finland	12%
Sweden	28%

Source: Eurostat Tourism statistics 2016

The trend seems to point at more disperse (and more polluting) holiday dwellings In the Baltic states, with waste regulation trying to limit their impact.

2.6 Noise - Shipping

A socio-economic analysis of different drivers and pressures related to shipping is limited by the disaggregation of data, as mentioned in the tourism section. The impacts of this sector on biodiversity are nevertheless wide, and, in addition to noise include also CO_2, NOx and oil spills as well as marine litter, alien species through ballast water and direct impacts with marine mammals (HELCOM 2009a).

The countries in the area contribute with almost four thousand firms and over sixty thousand jobs to the European economy. As can be seen in fig. 2.6.1 below, there is a clear specialisation among countries, with most cargo firms being located in Germany while passenger transportation firms are more frequent in Sweden.

Figure.2.6.1 There is a clear specialization in maritime transport in the Baltic area, with Germany having the most enterprises in freight transport and Sweden in the passenger transport. Source: Structural Business Statistics, 2016.

Germany is the country with most people employed in maritime transportaion among Member States, though there has been a strong decrease in 2012 that brings it close or even below the second country in the area, Denmark. Sweden and Finland are the other major employers, though slowly decreasing. The Baltic countries and Poland play a minor role with around or less than 2000 employed people.

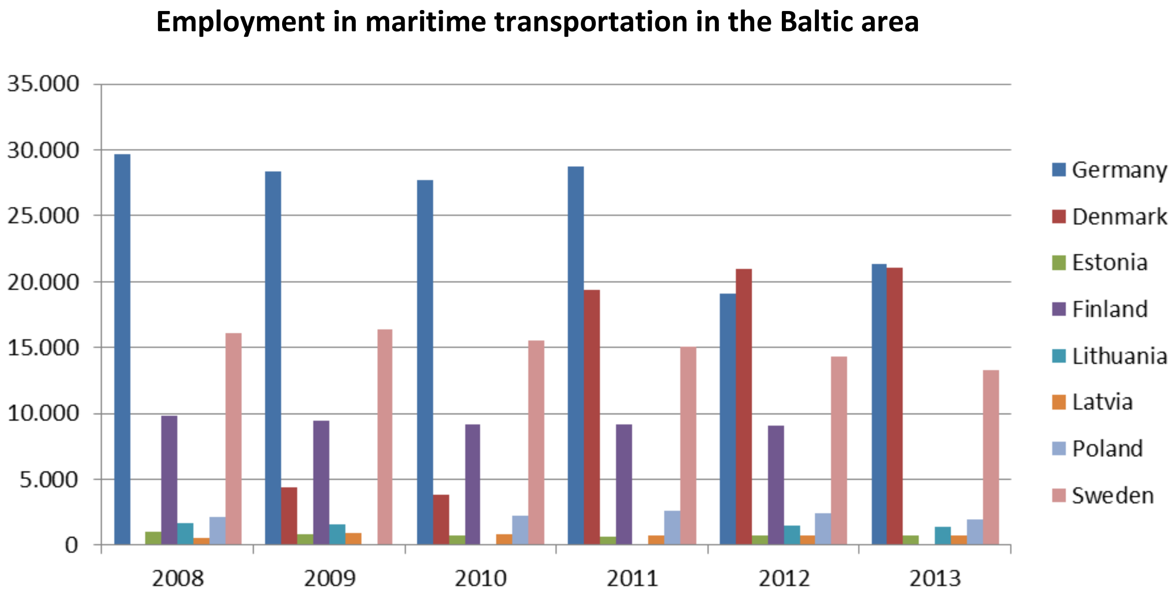


Figure 2.6.2 Employment in the maritime transpor in the Baltic area remains stable or decreasing. Source: Structural Business Statistics, 2016. Danish freight transport data missing until 2011

Although maritime transport in the Baltic was expected to increase greatly (Anonymous 2006), it was affected by the economic crisis and consequent decline in international trade that reduced maritime transport globally. Nevertheless, maritime traffic in the Baltic has recovered to values around a ten percent higher to those of 2005 (Eurostat 2016), though big differences between countries exist. However, in the same period oil spills in the Baltic reduced in around 40% (HELCOM, 2015)

Maritime transportation vs. oil spills in the Baltic (2005-2013)

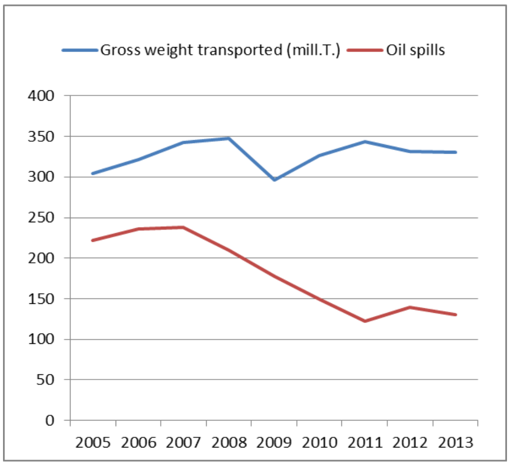


Figure 2.6 .3 Maritime transportation vs oil spills in the Baltic (2005-2013). The graph shows the fall and recovery of maritime transportation due to the economic crisis together with the reduction of oil spills

In addition to the noise problematic, there are initiative from the shipping sector to reduce other impact on biodiversity, as the fostering innovative, less polluting solution as the use of liquefied natural gas (e.g. Wurster et al. 2014), with pressure from the European directive on sulphur on ship fuels.

Progress

The review process is completed. Appendix 1 lists all BONUS Bio-C³ publications regarding Task 3.1. In addition submitted manuscripts or manuscripts in preparation are mentioned as well in the reference list or at least in the text. Furthermore it is planned to summarize the task report for an additional publication.

Deviations from the work-plan

The Advisory Board suggested to take the national initial assessments (IA) from the Marine Strategy Framework Directive into account. This was only partly possible because the initial assessments were published in native language and different approaches within the assessment make a coherent statement very ambitious. However a summary about the national initial assessments from the MSFD already exists and is published in English by Dupont et al. (2014). In addition, the inconsistency between and fragmented sources used for the non-indigenous species chapters in national IA's pose difficulties to provide reliable summary for this topic. Therefore, the current report provides yet unpublished, but scientifically validated and the most up-to-date overview on NIS introductions by all Baltic countries.

P1 promised only analysis from the BSIOM model and has additionally kindly included some review work on abiotic and oceanographic factors.

P11 promised a contribution about the Common Fisheries Policy (CFP) reform, but when the problem of the definition of drivers and pressures came up; it was decided to start a review about that topic and to propose a definition in order to use the same wording within the whole project. Therefore the review about the CFP is shorter than expected.

Recommendations

Two recommendations can be suggested for the introduction of non-indigenous species:

1. Research on ecological effects should be intensified. As per now, the relevant knowledge is very fragmentary and we lack critical information on even the most widespread (and potentially highly impacting) NIS in the Baltic Sea
2. Common, validated, routinely updated and free-access underlying information source (such as AquaNIS or similar) should be maintained. Amongst others, such an information source will serve both scientists, policymakers and managers.

Appendices overview

Appendix I: List of dissemination

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Appendix I

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Per reviewed paper

In prep

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