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Feasibility of removal of dioxin and dioxin-like PCB's by intensive fishery of herring and sprat in the Baltic Sea

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Content

Preface

This report discusses the feasibility of removal of dioxin and dioxin-like PCB's by intensive fishery of herring and sprat in the Baltic Sea with the aim to assess and answer the following questions:

- Can intensified fisheries of herring and sprat in the Baltic Sea during a limited period be considered an effective way to remove dioxin and dioxin-like PCBs from the Baltic Sea environment?
- Is it relatively small amounts which can be removed compared to the existing pools in water, biota and sediment and are these pools in such conditions so they pose a lasting problem?
- How large are these amounts of dioxin and dioxin-like PCBs compared to the natural removal processes, the release from sediments, and new input to the Baltic Sea via atmosphere, rivers and other possible sources?
- How will an intensified fishery on herring and sprat affect the stocks of cod, salmon and other pelagic fish species in the Baltic Sea? Will there be other adverse environmental effects?
- Will intensive fishery on herring and sprat be ecologically sustainable in relation to other fish populations and the Baltic Sea ecosystem, in general?
- Is intensive fishery of herring and sprat a feasibly way for removal of dioxin and dioxin-like PCB's from the Baltic Sea?

The following institutions and persons have contributed to the present project:

- DHI Water Environment Health: Kim Gustavson and Morten Bjergstrøm
- Finnish Game and Fisheries Research Institute: Eero Aro
- Swedish Museum of Natural History: Jenny Hedman, Alma Strandmark and Anders Bignert
- DTU AQUA: Brian MacKenzie
- Water & Environment Consult: Claus Hagebro (untill 1/1 2009)

We should like to express our thanks to Working Group for Nordic Environment and Fisheries Strategy (MiFi) who have supported the project.

Summary

Recently, the idea about removing dioxins from the Baltic Sea by increased fisheries emerged during a Nordic Conference on Environmental Impacts and Fisheries Resources sponsored by the Nordic Council of Ministers. Based on the proposal from the conference the present project was formulated.

The background is the present problems complying with the European Commission limit values for dioxins and dioxin-like PCBs in Fish from the Baltic Sea. Also flame retardants and other hazardous substances present an increasing quality problem for the fisheries sector.

In the report it has been discussed and assessed whether it is feasible to reduce dioxin content of herring and sprat in the Baltic Sea by a period of intensified fishery in the region and if intensified fishery causes adverse environmental effects or affects the stocks of other species like cod, salmon and other pelagic species.

A decision to intensify fisheries on sprat and herring for the purpose of removing dioxin and dioxin-like PCBs must be based on a number of scientific considerations and criteria. Some of the issues arising are outlined below.

Such an action if implemented should be conducted in areas having the greatest impact on dioxin levels, but which have the least impacts on the populations themselves and on the rest of the Baltic ecosystem. There are, for instance, clear spatial variations in the concentrations of dioxin in herring and sprat in the Baltic Sea. Removing part of the biomass from some of these populations will therefore have a greater impact than removing similar biomass in other areas. Moreover, some of these areas are in the northerly areas of the Baltic where cod usually is very rare. Hence, possible detrimental or advantageous effects on the cod population would be relatively low in such areas. On the other hand, impacts on other sprat and herring predators (e. g., seabirds) may be larger here.

A further consideration is how much additional fishing mortality that herring and sprat populations can tolerate, and yet still continue to support sustainable fisheries. The International Council for the Exploration of the Sea (ICES) has already established recommendations for the maximum fishing mortality rates for several of the Baltic herring and sprat populations. Comparison of these rates with those observed during the last few years shows that exploitation rates are already near or exceed the recommended levels. This comparison suggests that additional exploitation to remove dioxin will increase the risk of long-term decline for these populations to, posing consequences for the ecosystem as outlined in earlier chapters. Hence, a decision to increase exploitation rates even

further should be made for those stocks only where there is a low exploitation presently. A decision to increase exploitation rates for stocks which are already fully exploited must carefully balance the ecological risks of a more vulnerable herring or sprat population against the benefits of a less polluted Baltic Sea.

Based on the most recent estimates of fishing mortality, the stock in The Bothnian Sea is being harvested sustainably. The spawning herring stock tripled in biomass in the late 1980s and has remained high since. In this stock there are possibilities to increase the fishery about two fold in the short term without excessive risk of stock depletion. This will mean catch rates between 110 000 – 150 000 tonnes annually in three successive years corresponding to removal of 0.6–0.8 g dioxin and dioxin like PCB's (TCDD-equivalents) in total over the three years.

The total amount of dioxins in the biomass of sprat and herring in the entire Baltic Sea is estimated to be about 4,4 grams (TCDD-equivalents). However, the uncertainty in this estimation is large and could be as large as 67 grams.

Considering the marine environment as a whole, i.e. water and sediment, the major external source of dioxins and dibenzofurans (PCDD/Fs) to the Baltic Sea is atmospheric deposition, though this result is obvious since direct emissions were not included in the POPCYCLING model used because of lack of estimates of direct emissions. The major sink for PCDD/Fs in the marine environment is sediment burial, while other sinks like volatilization and degradation are small. In comparison to the atmospheric deposition of 133g y^{-1} the amount of dioxin in herring and sprat corresponds to 6% to 50% of the yearly atmospheric deposition. With a 25% removal of fish biomass corresponding to the current fish mortality rate the removed amount of dioxin will correspond to 1.5% to 13% of the atmospheric deposition.

Finally, it must be considered how large the relative benefits on dioxin concentrations an increased herring and sprat fishery might have, seen in relation to the role of other processes that can lead to reduction in dioxin concentrations in the fish and the overall dioxin burden of the Baltic Sea. The dioxin budget and flux analysis presented earlier and the estimated dioxin removals via fishing shows that dioxin removals due to fishing are only a few % of the dioxin flux and burial rate to the sediments. Hence, if dioxin loadings to the Baltic could be reduced or stopped, sedimentation rates could achieve much higher rates of removal of dioxin from the food web than fishing. This action could lead to much more rapid declines (ca. 20%/year; Bignert et al., 1998a, 1998b) in dioxin concentrations in the biota than those that can be achieved by fisheries.

An increase in the fishery for herring and sprat to remove dioxin will have some consequences for the Baltic ecosystem. These could include reduced predation by these species on their zooplankton prey, which would benefit larval and pelagic 0–group cod, and other zooplanktivores such as sticklebacks and jellyfish. Removal of herring and sprat, if sufficiently large enough, may however lead to reduced growth and conditions in cod due to food limitation. Abundances of some seabird species may also decline because of a reduced food supply.

1. Introduction

Dioxins are possibly the most dangerous and toxic chemical substance known today. Due to the persistent, toxic and bio-accumulative properties dioxins are a major environmental concern and in particular the dioxin contamination of fatty fish in the Baltic Sea creates concern for the health of the population around the Baltic Sea. Some polychlorinated biphenyls have toxicological properties similar to dioxins ("dioxin-like PCB's") and add to the problems.

Recent studies of PCB's in undisturbed sediment cores from different basins in the Baltic Sea (Schneider and Leipe, 2007) demonstrate the historic development of this man-made pollution. These pollutants were mainly produced since the 1930'ies and 40'ies and were phased out in the 1970'ies, which is reflected in a clear increase of concentrations in sediments during the first 2/3 of the century with a maximum between the 1970'ies and 90'ies. Since then the upper parts of the sediments show decreasing trends apart from some places where smaller increases have been observed.

Fact sheet: Dioxins

Dioxins are a group of polychlorinated aromatic compounds with similar structure and physical-chemical properties. They are not produced intentionally but are formed as by-products from natural events or man-made processes such as pulp and paper bleaching and incineration of waste. Dioxins are colourless, odourless organic compounds and highly soluble in fat. This means that they bind to sediment and organic matter and are absorbed in animal and human tissue. They are persistent and not biodegradable and therefore accumulate in the food chain. Of the 210 different dioxin compounds (congeners) about 17 are of toxicological concern. The most toxic form is 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD).

PCB's or polychlorinated biphenyls are chlorinated aromatic hydrocarbons synthesized by direct chlorinating of biphenyls. Some PCB's have toxicological properties similar to dioxins ("dioxin-like PCB's"). They are still present today in some technical installations.

Dioxins are among the 12 chemicals which are banned by the Stockholm convention on Persistent Organic Pollutants ("the POP Convention").

The European Commissions policy and strategy to reduce exposure to dioxins has resulted in a range of Community legislation on dioxins in food and animal feed. Dioxins cannot be prohibited as they are not produced intentionally. Production and use of PCB's on the other hand has been discontinued in most industrialised countries. In the EU the use has been prohibited since 1978. Existing PCB-containing equipment should be taken out of service by the end of 2010.

Dioxins and dioxin-like PCB's create problems today even though the decreasing trends and the efforts to eliminate and reduce the polluting sources. Fish caught in the Baltic Sea and in particular fat-rich fish like salmon, herring and sprat exhibit high concentrations of these pollutants in their bodies. The health impact of eating food contaminated with dioxins encompasses several possible effects. Some dioxins are classified as known carcinogens but also developmental and neurobehavorial effects (learning disabilities), reproductive and immunotoxic effects are known from laboratory animals. Also the use of the contaminated fish for other purposes (e.g. fish feed) is a reason for serious concern.

The theoretical removal of PCBs during the 1970s and 1980s were estimated some years ago (MacKenzie et al. 2004). During that period the concentration of PCBs in cod and other fish were very high as well as the landings. The calculations which were possibly underestimates showed that fishing represented 3.5% of the total known PCB removal and that fish and fisheries are important for PCB dynamics in the Baltic Sea. It was proposed that banning the discard of cod liver (high fat and contaminant content) and other fish organs at sea should be considered.

Intensifying the artificial mortality on some components in the ecosystem may affect other components of the system. The relationship between cod, sprat, zooplankton and phytoplankton is well known. Since the 1990'ies the cod stock has been low mainly due to high fishing pressure. This has resulted in an increase of sprat which has decreased the zooplankton biomass again resulting in a higher phytoplankton biomass. During the preparation of the Baltic Sea Action Plan a proposal for increased quotas for the sprat fisheries was considered aiming towards reduction of the eutrophication problem of the Baltic Sea (HELCOM 2006). The removal and destruction of dioxins was also mentioned in the proposal. Another side-effect of increased fisheries quotas is the removal of nutrients. Hjerne and Hansson (2002) showed that fisheries annually remove 1.4% and 8% of the annual N and P loads, respectively.

The European Commission considers the possibility of landing certain categories of fish, which otherwise would be discarded, in a working document on environmental initiatives within the fishing sector aiming to stimulate the debate (EC working paper). Such landing could be taken as a direct removal of contaminating POPs and heavy metals. The Commission stresses, that special care should be taken to avoid the contaminants to reach the human or marine food chain. The idea may have important socio-economic impact in the fishing sector as well as environmental effects.

Recently, the idea about removing dioxins from the Baltic Sea by increased fisheries emerged again during a Nordic Conference on Environmental Impacts and Fisheries Resources sponsored by the Nordic Council of Ministers. Based on the proposal from the conference the present project was formulated.

The background is the present problems complying with the European Commission limit values for dioxins and dioxin-like PCBs in Fish from the Baltic Sea. Also flame retardants and other hazardous substances present an increasing quality problem for the fisheries sector.

The project aims as a first step to assess and answer the following questions:

- Can intensified fisheries of herring and sprat in the Baltic Sea during a limited period be considered an effective way to remove dioxin and dioxin-like PCBs from the Baltic Sea environment?
- Is it relatively small amounts which can be removed compared to the existing pools in water, biota and sediment and are these pools in such conditions so they pose a lasting problem?
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2. Dioxin and dioxin like PCBs in the Baltic Sea

2.1 Dioxin

’Dioxins’ are cyclic halogenated organic chemical compounds most commonly containing two benzene rings united by molecules in a third ring. Originally dioxins referred to a family of organic compounds, the polychlorinated dibenzo-para-dioxins (PCDDs). It has recently broadened its scope and also now encompasses the structurally related family of polychlorinated dibenzofurans (PCDFs). The PCDD group contains 75 different members and the PCDF group contains 135 members in total 210 different dioxins or congeners of which the most important are the 2,3,7,8 substituted ones (Assmuth, 2005; Environmental Agency, 2003).

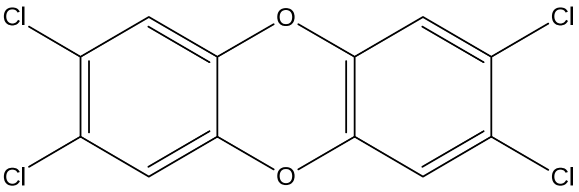

Figure 2.1: 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD, Seveso-dioxin)

Dioxins are solids with high melting and boiling points. There is some variation, however, between the volatility of individual congeners; for example, TCDD is considered to be significantly more volatile than octachlorodibenzo-p-dioxin (OCDD). Dioxins are almost insoluble in water (the solubility decreases with increasing chlorine content), but are quite soluble in organic solvents and fats. The solubility of TCDD is about 0.02 µg L–1 in water and about 0.5 g L–1 in benzene (Environmental Agency, 2003).

Dioxins have no known technical value and are not produced intentionally. While there are some natural sources, such as forest fires and volcanic eruptions, these are not significant contributors in industrialized countries. Two main categories of anthropogenic sources are recognized: (i) the production and use of organochlorine chemicals that are contaminated with dioxins, and (ii) the combustion of chemical, clinical and household waste, as well as fuels such as coal, wood, natural gas and oil (Environmental Agency, 2003).

Dioxins have gained much attention due to their toxicity and long-term health and environmental effects and risk. Dioxins have been associated in common awareness with contamination cases like the Agent Orange herbicide spreading during the Vietnam war, the Seveso industrial accident in Italy in 1976, and recent food contamination episodes, all of which were widely publicized and caused debates, controversies and conflicts, policy changes, actions and other societal responses. Through such cases dioxins have become a symbol of environmental contamination that is related to more general factors and concerns (Assmuth, 2005).

Dioxins are persistent and fat-soluble substances found everywhere in the environment with a tendency to accumulate in higher animals – including humans. Their very slow rate of degradation means that they may be transported over long distances and result in trans-national exchanges. In addition to these factors, dioxins that were released into the environment many years ago, are still contributing to current exposure. Even very small dioxin concentrations can have negative effects on the environment and on human health, in particular on more vulnerable groups such as children and pregnant women (HELCOM, 2004).

Specifically, the 17 dioxins with 2,3,7,8-chloro substitution are the most toxic and most prone to accumulating in living tissue over time; they are also most commonly found in animals and humans. The most toxic congener is 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). It is one of the most studied chemicals, and is used as a reference for all other related chemicals. The effects of some PCB-compounds are assumed to originate from chemical properties similar to those which cause the toxicity of dioxins (HELCOM, 2004).

To get an overview of the total effect of the dioxin content of a sample a Toxic Equivalents Scheme (TEQ) is introduced. TEQs are calculated values allowing comparison of the toxicity of different combinations of dioxins and dioxin-like compounds. The most toxic compound is the comparison point. For example, a mixture weighing 10g with a TEQ of 5g would be as toxic as 5g the most toxic compound.

In order to calculate a TEQ, a toxic equivalent factor (TEF) is assigned to each member of the dioxin and dioxin-like compounds category. The TEF is the ratio of the toxicity of one of the compounds in this category to the toxicity of the most toxic compound in the category, which is assigned a TEF of 1: 2,3,7,8-tetrachlorodibenzo-p-dioxin (commonly referred to as dioxin). TEFs that have been established through international agreements currently range from 1 to 0.0001.

A TEQ is calculated by multiplying the actual grams weight of each dioxin and dioxin-like compound by its corresponding TEF (e.g., 10 grams X 0.1 TEF = 1 gram TEQ) and then summing the results. The number that results from this calculation is referred to as grams TEQ.

2.2 Dioxin-Like PCBs

The criteria for identifying a compound as a dioxin-like-compound vary in time and depend on the context. Dioxins have been most commonly taken to include 2378-PCDD/Fs and certain PCBs, usually three 0-ortho and nine 1-ortho congeners. The criteria internationally agreed are structural similarity; binding to AhR; AhR-mediated dioxin-like toxicity; persistence and bioaccumulation. None of these are clear-cut, and such criteria may differ between regulation and research (Assmuth, 2005).

The PCBs assume a dioxin-like structure when chlorine atoms occupy:

- Usually no more than one of the ortho positions
- Both para positions
- At least two meta positions
- The structure is not hindered from assuming the preferred planar configuration

The dioxin-like PCBs have a geometric configuration like 2,3,7,8-TCDD.DlPCBs as other PCBs in the environment and also in the Baltic originated largely from the Aroclor, Clophen and similar Eastern European brands used mainly in electric appliances but also for many other purposes. There are data suggesting that primary sources contribute significantly to resent emissions, along with those from PCBs accumulated in the environment. In addition, dlPCBs originate from other products including pigments as well as combustion sources. The relative importance of such non-Aroclor and non-product sources is growing along with the progress in global and regional phase-out and stockpiles management for PCBs in Aroclors (US EPA; Assmuth, 2005).

2.3 Human risk

The issue of dioxins in human food led to the adoption by the European Council of a Regulation establishing maximum levels of dioxin and other contaminants in both human food and animal feed (COMMISSION REGULATION (EC) No 1881/2006 of 19 December 2006). Fish from the Baltic Sea generally seem to be twice as contaminated as fish from the North Sea. These vary geographically depending on their sources and data are not always available for different areas and species. Variations among species are another factor. Because dioxins accumulate in fatty tissues, fatty fish such as herring and salmon show higher levels of contamination. Farmed fish are assumed to be less exposed to dioxins than wild fish from the Baltic. Their feed can be controlled so dioxin ingestion can be minimized and the exposure time is briefer because the lifespan of farmed fish is generally shorter. However, a recent study has led to some discussion about the contamination of farmed fish and more investigations might be needed in this area (HELCOM, 2004) (TemaNord 2009:516). Feed for farmed salmon is primary meal and oil produced of so-called trash fish which among others include Herring, Sand Eel, Sprat, Blue Whiting. It is estimated that more than 20% of this trash fish in the EU exceed the limit values for content of Dioxin and dioxin-like PCB (dl- PCB) in fish (EU Parliament). Especially fish from The Baltic Sea and The North Sea have a high content of POPs and metals ().

The EU has set limits for the maximum dioxin content of various types of food. For fishery products the levels depend on whether the product is fresh fish, fish oil or fish meal. In the fisheries sector one consequence is that the fish oil producing industry might need to purify its product. Some of the Baltic fatty fish do not comply with the maximum level requirement, and would therefore be excluded from the diet, a measure which could have a negative health impact. Consequently, for a transitional period ending on 31 December 2006, Sweden and Finland have been authorized, to place on the domestic market fish from the Baltic region with higher dioxin levels. This allowance has been granted provided that a system is put in place to ensure that consumers are fully informed about the situation, and particularly about the risks associated with dioxin for identified vulnerable groups of the population. In Denmark problems with dioxins in fish caught in the Baltic Sea have arisen in 2004. Samples of salmon showed that the EU limit was exceeded by 5–85% and the Ministry of Food, Agriculture and Fisheries decided to stop salmon fishing immediately in the Danish waters of the Baltic Sea. In addition to this, a limited sample of herring indicated elevated dioxin content, prompting a more throughout investigation (HELCOM, 2004).

In Sweden, fish consumption accounts for as much as 33–38% of human dioxin exposure, and in Finland the figure is 63–83%. The corresponding numbers in other countries in the Baltic Region with a similar traditional influence, such as Estonia, Latvia, Lithuania and Poland, are not known at present. However, since these countries do fish from the same fish stocks as Sweden and Finland, the relationship between fish consumption and human dioxin exposure can be assumed to be within the same range, if the consumption patterns are similar. In Finland, herring alone accounts for 52% of the daily dioxin intake in humans, and in Sweden fatty fish from the Baltic Sea region contribute 19–22%.The influence of fish consumption on human dioxin exposure has been clearly demonstrated by some studies. In Finnish fishermen consuming high amounts of fish, dioxin concentrations in fat were 220 ng TEQ /kg (range 51–520). An even more conspicuous finding in the study was that in fishermen consuming predominantly one fish species, the dioxins spectrum clearly resembled that of the consumed fish, e.g. herring eaters could be differentiated from pike or bream eaters. In Finland, dioxin exposure from food items other than fish is very low – in 2000 the total intake was calculated to be 0.8 pg/kg/day on average. If dioxin-like PCBs are also included, intake in Finland rises to 1.45 pg/kg/day. The total Danish human dioxin intake including dioxin-like PCBs has been calculated at 1.7 pg TEQ/kg/day (2002 data). This is the same level as the previous year and corresponds to similar results in several neighbouring countries. The value corresponds to the tolerable weekly intake (TWI) of 14 pg TEQ/kg/week, which indicates that part of the population may exceed the limit regularly. This does not mean that there is a health risk for those persons but that the full safety factor included in the TWI is not applied. Against this background there is good reason and a need for sustained efforts to reduce the dioxin content in food (HELCOM, 2004).

2.4 Dioxins in the Baltic Sea

Dioxins enter the Baltic Sea as air fallout when transported from land-based sources and via the multitude of waterways. To a large extent in the past waterway pollution could be attributed to some chemical and forest industries, where chlorine was used in large amounts for pulp bleaching until the early 1990s. This has now stopped in Finland and Sweden but chlorine gas is still used in some Russian pulp and paper mills. Other water pollution sources include releases from coke plants and municipal waste waters. Natural events or processes such as forest or steppe fires and volcanic eruptions can also cause dioxin emissions. Apart from the current known sources and historical emissions there are also isolated incidents such as accidental emissions and building fires, which can release significant dioxin and furan emissions into the atmosphere (HELCOM, 2004).

Because of their emission routes dioxins are spread all over the Baltic Sea area. Since dioxins are persistent and bio-accumulative, they become more concentrated as they move up the food chain. Large quantities are stored in seabed sediments, accumulated over several decades. Releases from known sources have decreased during the last 10–20 years.

Little is known about the concentration of dioxins in the waters of the Baltic Sea. One investigation showed an average level of only 2.8 ng/m3 WHO-TEQ. Because dioxins have a very low solubility in water most dioxins settle in the sediments. Investigations of dioxins in surface sediments are available from Danish, Swedish, Finnish and German areas. The concentrations of dioxins are typically 500–1500 ng/kg dry weight; this corresponds to 10–30 ng WHO-TEQ/kg dry weight. Dioxins accumulate in sediments close to their main sources, such as old pulp and paper mills, chemical plants including vinyl chloride or biocide manufacturing, and harbours. Dioxins disintegrate very slowly. The half-lives of dioxin congeners in the Baltic have been estimated at between 20 and 275 years. Therefore, sediments serve as historical databases and analysis of dioxins in material from different depths in the sediments gives valuable information about how the pollution level in the Baltic Sea has varied over many decades. Over time small amounts of dioxin are released from the sediment reservoirs and become biologically available in the food web. The rate of release however, is estimated to be slower than the rate of deposition. Dioxins are released mainly from fresh surfaces and sediments which have been disturbed. It is unclear to what extent sediment storage of dioxins is responsible for the present levels of dioxins in biota such as fish, and to what extent more recent emissions or fallout influence these levels.

In the south western part of the Baltic and in Danish waters the average dioxin content in herring is 2–2.5 ng WHO-TEQ/kg fresh weight. In comparison, levels are approximately double this figure in the Baltic Proper and the Gulf of Finland and four times higher in the Bothnian Sea and the southern part of the Bothnian Bay. It is particularly in these areas that chemical plants producing biocides and pulp and paper industries emitted great amounts of dioxins for many years. Typically dioxin levels in Baltic wild salmon are currently 2–8 ng WHO-TEQ/kg fresh weight. Twenty years ago dioxin levels ten times higher than this were measured in wild salmon from the Umeå area. Figures on dioxin levels in herring do not provide enough data for reliable time-series analysis. Preliminary data from Finnish specimen bank samples at several locations indicate higher concentrations in herring during the late 1970's and early 1980's.

Fish-eating birds and other top predators also accumulate toxic substances. Data on guillemot eggs indicate a high level of contamination. The temporal trend in dioxin concentrations in the eggs corresponds to that found in sediments, i.e. high values in the 1970's followed by a significant decreasing trend until the mid–1980's. The decrease of dioxins in guillemot eggs has levelled out during the recent 25years.

Marine mammals living in the Baltic Sea, such as the ringed seal, grey seal, common seal and harbour porpoises, have a high intake of persistent organic pollutants including dioxins. Normally, adult females have lower dioxin residues as a result of the use of their fat deposits during lactation. In a Finnish study the TEQ of dioxins in seals varied between 7 and 150 pg/g lipid weight; this figure is lower than in Baltic Sea birds, but approximately the same as found in seals from other parts ofthe Baltic Sea and the west coast of Sweden. Nevertheless, the study found no relationship between the presence of dioxins and the high mortality rate among ringed seals of the Gulf of Finland (HELCOM, 2004).

3. Present stock and fishery on herring and sprat in the Baltic Sea

3.1 Baltic herring and sprat fishery by countries

In the Baltic herring and sprat fisheries, pelagic trawlers catching a mixture of herring and sprat dominate in the Baltic. In the mixed catches the proportions of herring and sprat varies according to area and season. Herring fishery is also carried out with trap-nets/pound-nets and gill nets in coastal areas as well as in some areas with bottom trawls. The catches of the pelagic species are used for human consumption, reduction to oil and meal and to animal fodder. The allocation of the catches into these categories differs not only by country, but also over time. The usage is to a large extent driven by the market conditions. Figure 3.1.1 shows the historical landings and TACs of Baltic herring and Figure 3.1.2 historical landings of both Baltic herring and sprat and sprat landings and TACs by sub-divisions 22–32.

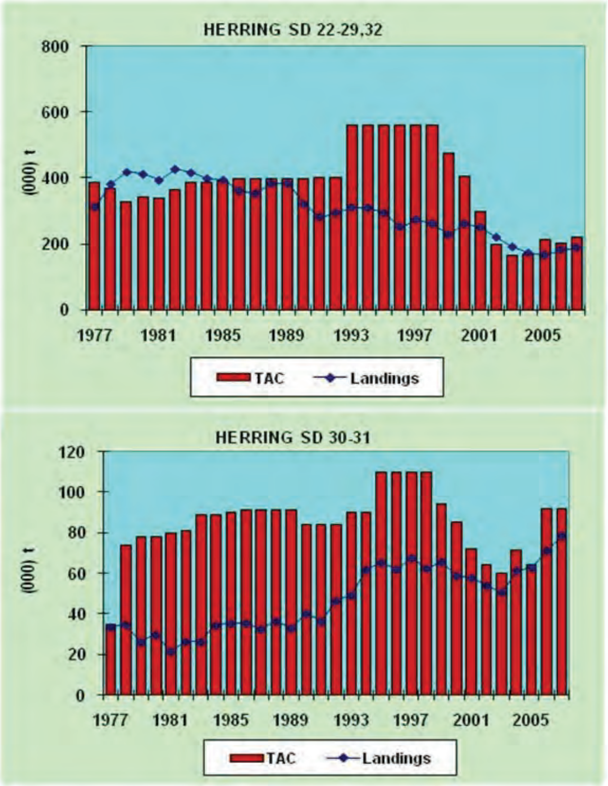

Figure 3.1.1 Reported landings of herring and agreed Total Allowable Chatch (TAC) by management units in the Baltic Sea (WGBFAS 2008)

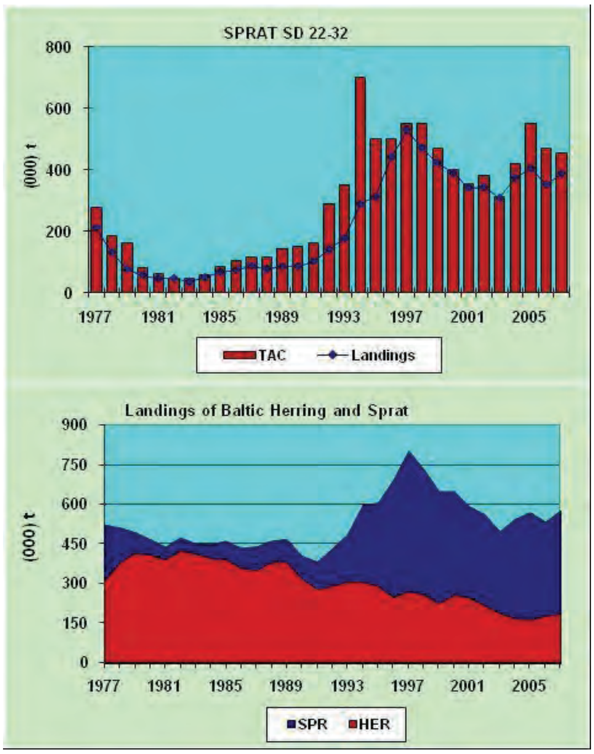

Figure 3.1.2. Reported historical landings of Baltic herring and sprat and reported landings of sprat agreed TACs by management unit in the Baltic Sea (WGBFAS 2008)

3.1.1 Danish herring and sprat fisheries

At present the Danish of herring and sprat from the Baltic area can be divided into the following two categories and fisheries:

Herring landings from a directed fishery for human consumption carried out by trawlers using a minimum mesh size of 32 mm.

Sprat landings from a directed fishery for industrial purposes using a mesh size of 16 mm.

3.1.2 Estonia

Estonian Baltic sea fishery is, in general, a trawl fishery and is directed mainly on herring and sprat. Pelagic trawls take, depending on the fishing area, from 40 to 99% of total landings. The rest part of catches is taken as trap net catch of herring at the spawning grounds of herring. The Estonian fishing fleet in the Baltic consists of 233 vessels: 119 vessels of >=300 HP, 101 vessels of 90–150 HP and 13 cod gill-netters of 150 HP and has been rather stable in recent years.

Most of the Estonian sprat catch is taken in the Subdivisions 28 and 29 in the 1st and 4th quarters. All sprat fisheries are pelagic trawl fisheries.

3.1.3 Finland

The total number of fishing vessels has been round 3500 in commercial fisheries in the Baltic in recent years. Most of the vessels are shorter than 12 meters and used in coastal fisheries. During the last decade, the total commercial Finnish catches in the Baltic has fluctuated between 60 000 and 100 000 tonnes.

Pelagic Trawls

Pelagic trawling is used to exploit Baltic herring stocks in the Baltic Main Basin, the Archipelago Sea, the Gulf of Bothnia and the Gulf of Finland. Only few vessels are exploiting directly sprat stock, and sprat is the main by-catch in Baltic herring fishery. Usually Baltic herring fishing is conducted as a single trawling. At certain times of the year, vessels may switch to demersal trawling. In autumn, early winter, and spring pelagic pair trawling is used for industrial purposes. Common to pelagic trawlers is that many vessels transfer between the Bothnian Bay (SD 31) and the Bothnian Sea (SD 30), the Bothnian Sea and the Åland Sea (SD 29), and between the Gulf of Finland (SD 32) and the Åland Sea depending on fishing possibilities and ice cover during the winter.

Demersal Trawls

Demersal trawls are used both for Baltic herring and cod. The main target is Baltic herring. There are some vessels using heavy ground gear but these have declined in numbers, and represent only a small part of the fleet. Similarly to pelagic trawlers, the demersal trawlers shift between fishing grounds, depending on fishing possibilities and ice cover.

Trap-nets

Trap-net fishery include a variety of trap-net types for Baltic herring, Baltic salmon and European whitefish (Coregonidae). Fishery is conducted near the coast and inside archipelagos. Trap-net fishery for Baltic herring is conducted mainly during the spawning season in spring and early summer (May-June), targeting spawning component of Baltic herring stock.

The gears used in Finnish herring and sprat fishery are as follows:

- herring trap nets
- big trap nets (for Baltic herring)
- pound nets (for Baltic herring)
- gill nets for herring and sprat
- pelagic trawls (single and pairs)
- demersal trawls (single and pairs)
- winter seine and beach seine.

3.1.4 Germany

Herring fleet

The German Baltic herring fishing fleet consists of two segments:

- coastal fleet with boats <12 m
- cutter fleet with vessels >= 12 m.

In 2007 the total German herring landings from the Baltic Sea in Subdivisions 22 and 24 amounted to about 24,583 t, which is about 12% higher than in 2006 (22,870 t). This increase was mainly caused by higher landings in the trawl fishery in Subdivision 24.

Only a small part of the total landing was taken in Subdivisions 25–29 (2007: 1,672 t; 2006: 3,234). As in last year almost all of these landings were landed in foreign ports (1,666 t of 1,672 t). The main part was caught in Subdivisions 25–29 in quarter IV (955 t).

The main fishing season was during spring time as in former years. About 60% of all herring was caught between March and May (2006: 77%). The dominant part of the German herring landings was taken in Subdivision 24 (2007: 86% and 2006: 75%). About 33% of the total landings are originating from waters around the Island of Rügen in Subdivision 24 (2006: 39%). Most of the herring was caught in this area in former years.

The decreased proportion of landings from waters around the Island of Rügen was caused by a overall change in fishing pattern in the last years. Until 2000 the dominant part of herring was caught in the passive fishery by gillnets and trapnets. Since 2001 the activities in the trawl fishery increased. The total amount of herring, which was caught by trawls, reached 62% in 2007 (2006. 67%, 2005: 62% and 2004: 61%). This significant change in fishing pattern was caused by the perspective of a new fish factory on the Island of Rügen, which finally started the production in autumn 2003. This factory intends to process 50,000 t fish per year.

Sprat fleet

The German sprat fishing fleet in the Baltic Sea mainly consists mainly of a:

- cutter fleet with vessels >= 12 m

Compared to last year, the total German sprat landings in the Baltic Sea kept the record high level and reached 30,778 t in 2007.

- As in last year’s most sprat:
- were landed in foreign ports
- were caught in the first quarter
- were caught in Subdivisions 25–29

3.1.5 Latvia

Herring fishery

About 85% of the total Latvian herring catches are taken by trawls and 15% by trap-nets. Latvian herring fleets are operating in the Gulf of Riga (eastern part of Subdivision 28) and in the Subdivisions 26 and 28 of the Baltic Main Proper.

In the Gulf of Riga there are two main kinds of fleets: trawl fleet and trap-net fleet. Trawl fleet is operating all year around except 30–day ban in May-June during the peak spawning of herring. Besides in cold winters fishery is stopped because of ice coverage of the Gulf of Riga. In the Gulf of Riga, herring is the dominating. The trawl fishery (mesh size 28 mm) is targeting herring. There is small amount by-catch of sprat in herring fishery. In Latvia the number of trawlers as well as the total engine power has not been allowed to increase since the end of 1990s. Each fishing company receives yearly catch quota. Recently the number of trawlers is gradually decreasing due to scrapping.

The trap-net fishery takes place during the spawning period from mid-April till July. The trap-net fishery is targeting on spawning fishes. The number of trap-nets has been limited and number of nets has been rather stable since the mid-1990s.

In the Baltic Main Proper herring fishery is trawl fishing. The number of trap-nets is minimal. Since 2002 herring targeted fishery has been forbidden and the by-catch of herring in the sprat-targeted fishery has been limited to 5%.

Sprat fishery

Latvian sprat fishing fleet is operating in Subdivisions 26 and 28 of the Baltic Sea Main Proper. In the Gulf of Riga sprat targeted fishery (mesh size 16 mm) is forbidden. Sprat is caught with pelagic trawls all year around with lower intensity during the summer months. Sprat is mainly fished for human consumption. Each fishing firm receives yearly catch quota of sprat and the corresponding herring catch quota.

3.1.6 Lithuania

Lithuanian Baltic Sea fishery by landings is a trawl fishery and it is directed mainly on cod and sprat. The all Lithuanian herring and sprat catches is taken in subdivision 26 and landed in Lithuania ports.

The Lithuanian fishing fleet in the Baltic consists of 267 vessels: 192 vessels of < 12 m long, 15 vessels 12 – 24 m long, 15 vessels gill-netters and 45 vessels trawlers of 24 – 40 m long (2004 year data). In pelagic trawl and demersal trawl categories, fishing vessels overlap. Many of the vessels use both pelagic trawl and demersal trawl or the same gear is used in both fisheries.

Pelagic trawl fishery

Some of the withdrawn vessels were involved in herring exploitation. Therefore, Lithuanian herring landings have been decreasing in most recent years. Most of the herring catches in 2005 were taken in the first two quarters of the year (80%) as well as sprat catches (96%).

3.1.7 Poland

Since the end of 2004 Polish fisheries has undergone significant changes resulting from capacity reduction programme co-funded by EU. Within the framework of fleet scrapping programme, in 2004–2007, 405 fishing vessels (57 thousand kW and 19.6 thousand GT) has been reduced by the end of 2007. As compared with May 2004 number of fishing vessels was reduced by 32%, fishing power by 38% and tonnage by 41%.

Pelagic trawlers over 24 m in length account for the highest share (36%) in terms of tonnage and power of engines. These vessels mainly catch for sprat and herring. An important fleet segment is also a group of fishing vessels of 24–40 m fishing mainly with bottom trawls. At the end of 2007, 31 vessels of that segment were registered and their share in total tonnage accounted for 16%. These vessels specialize mainly in cod and flatfishes catches but sprat catches also play an important role.

Sprat landings have indicated declining trend in recent years. In 2004, 97 000 tonnes of sprat was caught (15% less than in proceeding year). In 2005 sprat catches decreased by 23% and in 2006 decreased by 42% in comparison with 2004. Sprat catches reduction was mainly the result of scrapping vessels.

Over 90% of sprat is fished by pelagic trawlers exceeding 24 m. The same fleet segment of pelagic trawlers specializes also in herring catches. In years 2004–2007 pelagic trawlers 24–40 m shared 80% in Polish herring landings. The rest of the catches were mainly carried out by small fishing boats using set nets.

Vessels belonging to pelagic segment specialize in industrial and consumption catches of sprat and also in herring catches. Sprat catches are typically seasonal being concentrated in first half of the year. In June–November these vessels carry out directed herring catches. Trawlers belonging to pelagic segment in 2005–2007 fished on average for 156 days a year.

3.1.8 Russia

Pelagic fleet

This fleet, targeting sprat for the human consumption, during I-IV quarters, has by-catches of herring between 4–25%. During summer and fall this fleet targets sprat for the animal food and by-catches of small herring is increased. The small vessels fleet (up to 29 vessels) operates mainly within 12–NM limit, targeting herring in the period from October to

March. Mesh size in the trawl cod-end is 20 mm opening. The by-catches of sprat in quarter I can reach 60–91%, in quarter II – 78–96%, in quarter III – 75–83%, in quarter IV – 80–90%.

Pound net fleet

This type of fishery exists in the Vistula Lagoon and Eastern part of Gulf of Finland. This fishery is targeting herring.

3.1.9 Sweden

Baltic herring and sprat fishery

The Swedish fishery for herring and sprat in the Baltic is carried out by four fleet categories:

- Trawlers catching herring with a minimum mesh size of 32 mm. This fishery is for human consumption and for meal/oil.
- Trawlers catching sprat with a minimum mesh size of 16 mm. A part of the landings is used for human consumption. Most of the landings are used for industrial purposes. Herring is caught as by-catches in this fishery.
- Coastal fishery for herring with gillnets. This fishery is for human consumption.
- Purse seine fishery near the coast for spawning herring in the second quarter of the year. This fishery is also for human consumption.

Most of the Swedish landings of herring and sprat from the Baltic are from pelagic trawls and also with bottom trawls for herring. Fishing with gillnets for herring is of local importance in the coastal fisheries, especially in the northern Baltic.

3.2 The management and the state of herring and sprat stocks

3.2.1 Background

Both Baltic herring and sprat stocks are managed by annual total allowable catches (TACs) and various fishing rules set by European Commission and bilateral agreements between Russia and European Union. The European Union has implemented now a precautionary approach when proposing the TACs for 2009 in the Baltic Sea. TACs have largely been set in accordance with ICES and STECF (Scientific, Technical and Economical Committee for Fisheries) latest advice to ensure that Baltic Sea fishery resources are exploited in a sustainable manner and it is aiming at long-term resource utilisation. Consequently, there has been a development of management plans for all commercial species in the Baltic Sea and it is important that the rules and guidelines given by existing plans are followed.

3.2.2 The assessment and management units for Baltic herring and sprat

The ICES assessment units for herring stocks are presently as follows:

- The herring in the Central Baltic Sea is assessed as two units:
- Herring in SD 25–27, 28.2, 29 and 32 and
- Gulf of Riga herring (SD 28.1)

The herring in the Gulf of Bothnia are assessed as two stocks:

- Herring in SD 30
- Herring in SD 31

The herring stock in southwestern Baltic (SD 22–24) is assessed together with the spring spawners in Kattegatt and Skagerrak (Division IIIa) within HAWG (Herring Assessment Working Group).

Sprat is assessed as a one unit stock for the whole Baltic (SD 22–32).

Herring has in former time been managed by three TAC:s:

- SD 22–29S and 32 (excl. Gulf of Riga),
- Gulf of Riga (SD 28.1),
- SD 29N, 30, 31 (Management unit 3)

These units were changed in 2005 to be:

- SD 22–24
- SD 25–27, 28.2, 29 and 32
- Gulf of Riga (SD 28.1)
- SD 30, 31

Sprat is managed by one TAC agreed for the whole Baltic (Sub-divisions 22–32).

The historical development of agreed TAC:s and reported landings for these management units are shown in Figures 3.1.1 and 3.1.2.

3.3 Baltic herring and sprat management in 2008 and 2009

The stock status, recommendations from ICES and the TAC decided are presented in the following text table for the pelagic stocks. The stock status is expressed in relation to the precautionary reference levels proposed by ICES.

State of the stocks:

Stock	Stock status 2008		ICES Advice 2009	TAC 2009
	in relation to SSB	in relation to F		
Herring				
SD 25-29&32 (excl. GOR)	undefined	Harvested sustainably	< 147 000 t (< F_{pa})	* 143 609 t
SD 28.1 (Gulf of Riga)	Full reproductive capacity	Harvested sustainably	< 31 500 t (< F_{pa})	34 892 t
SD 30 (Bothnian Sea)	Full reproductive capacity	Harvested sustainably	67 300 t (< Fpa)	82 669 t
SD 31 (Bothnian Bay)	undefined	undefined	< 3 000 t (no increase in catch)	
Sprat				
SD 22–32	Full reproductive capacity	Harvested sustainably	< 291 000 t (= F_{pa})	* 399 953 t

* EC quotas

3.4 Biological reference points

For some stocks (Baltic herring in the Gulf of Riga) an estimation of MBAL and Study Group on Management Strategies for Baltic Fish Stocks (ICES CM 1998/ACFM:11) approach has been applied. The approach recommended by the authors consists in fitting a stock-recruitment relationship and defining the MBAL value as the SSB producing 50% of maximum recruitment from the fitted relationship. To obtain Precautionary Approach Reference Points the Working Group applied the PA software developed by CEFAS, Lowestoft. Presently defined reference points for Baltic herring and sprat stocks has been taken from the ACOM Report, 2008 and summarized in table below.

Stock	**Limit Reference Points**	**Pa Reference Points**
Herring in SD 25-29&32 excluding Gulf of Riga	B_{lim} not defined F_{lim} not defined	B_{pa} not defined F_{pa} 0.19 Technical basis: F_{med}
Herring in the Gulf of Riga	B_{lim} 36 500 t Technical basis: B_{pa}/exp (1.65*0.2) F_{lim} not defined	B_{pa} 50 000 t Technical basis: = MBAL=50 000 t F_{pa} 0.4 Technical basis: from medium-term projections
Herring in SD 30	B_{lim} 145 000 t Technical basis: spawning stock biomass, where probability of lower recruitment increases F_{lim} 0.30 Technical basis: F_{loss}	B_{pa} 200 000 t Technical basis: B_{lim} *exp(1.645*0.2) F_{pa} 0.21 Technical basis: F_{med}
Herring in SD 31	Not defined	Not defined
Sprat in SD 22–32	B_{lim} is 200 000 t Technical basis: MBAL F_{lim} is not yet defined	B_{pa} 275 000 t Technical basis: B_{lim}*1.38; some sources of uncertainty in assessment taken into account F_{pa} 0.40 Technical basis: ~ average F_{med} in recent years, **allowing for variable natural mortality**

3.5 Multispecies interactions and the effect of predator – prey relationships on stock abundance and fisheries

Background

In the Baltic Sea, the interacting fish community in the open sea is dominated by three species: Cod, herring, and sprat. The abundance of cod stock in the Main Basin is currently rather low, herring stocks are slightly increasing, and the sprat stock is at high level. The effect of cod on prey species (herring and sprat) is now low level. Multispecies interactions are present and they will become important, when predator population recovers. While cod biomass is low, there is the potential for herring and sprat to have an adverse effect on cod recruitment, through consumption of eggs and larvae.

The multispecies interactions in the Baltic are rather clear and strong, Thus it is relative easy to demonstrate how species interactions effect our assessments of the state of the stocks and our perception of the interactions. Presently the following multispecies assessments and data are available for the Baltic Sea according to ICES sub-divisions (Figure 3.5.1):

Baltic Main Basin: Years 1974–2005:

- cod in Sub-divisions 25–29+32
- sprat in Sub-divisions 25–32,
- herring in Sub-divisions 25–29+32 including Gulf of Riga,
- Western Baltic: Years 1977–1999
- cod in Sub-divisions 22+24 (sub-division 23 included in 1996–1999),
- sprat in Sub-divisions 22–24,
- herring in Sub-divisions 22–24 including Division IIIa.

Baltic Main Basin: Years 1976–2005, area dis-aggregated MSVPA by Sub-divisions:

- cod in Sub-divisions 25, 26 and 28
- sprat in Sub-divisions 25, 26 and 28
- herring in Sub-divisions 25, 26 and 28

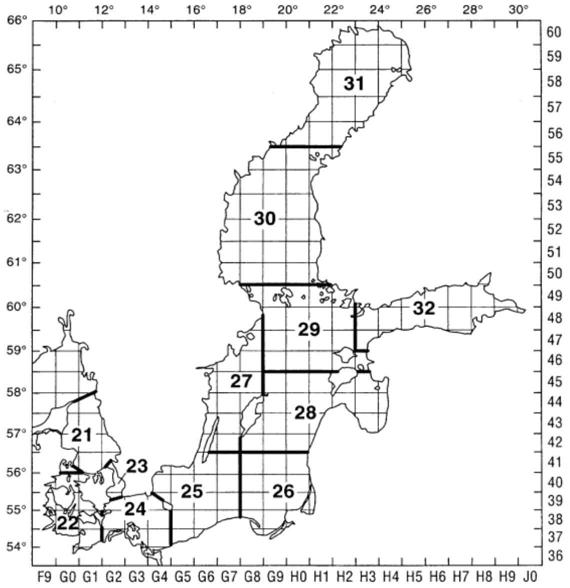

Figure 3.5.1 ICES Sub-divisions in the Baltic

In the Baltic Sea the spatial and temporal suitability of the spawning habitats of cod (*Gadus morhua*) vary dramatically with the oxygen conditions at the depth of incubation of the eggs (e.g., Wieland *et al.,* 1994). As a consequence, the population dynamics of cod exhibit distinct trends in different areas of the Central Baltic (Sparholt and Tomkiewicz 2000), with a corresponding variation in predation pressure on its major prey species, sprat (*Sprattus sprattus*) and herring (*Clupea harengus*) (Sparholt 1994). In turn the population development of these planktivores determines the predation intensity on early life stages of cod (Köster and Möllmann 2000). Hence in order to develop sustainable management strategies for the Central Baltic stocks, assessments and stock projections should resolve and incorporate the effects of environmental variability and species interactions on reproductive success, in particular the potential for different spawning localities to contribute to recruitment success.

3.6 Multispecies assessment

At present MSVPAs are run for two areas in the Baltic, a Western and Central Baltic component to match the stock units used in the regular stock assessments, with the Central Baltic component dominating in terms of biomass and abundance (ICES 1998/ACFM:16). Within these two regions, the abundance and biological characteristics of the three species are heterogeneous both spatially (between subdivisions) and temporally (inter and intra annually). For example, population sizes of Central Baltic cod, as resolved by international bottom trawl (Sparholt and Tomkiewicz 2000) and ichthyoplankton surveys (Köster *et al.,* 2001a), have revealed distinct distributional trends. Furthermore, for cod substantial differences in weight-at-age and maturity ogives have been reported for different subdivisions (ICES 1997/Assess:12, Tomkiewicz *et al.*, 1997). The abundance and characteristics of herring and sprat have also been observed to vary spatially and temporally in the different subdivisions of the Central Baltic (e.g., Ojaveer 1989). The herring stock in the Central Baltic is comprised of a number of different spawning components exhibiting variations in spawning period and growth rates as well as meristic, morphometric and otolith characteristics (e.g., Parmanne *et al.*, 1994). For sprat the existence of distinct populations is controversial as deviations in growth rates observed between subareas have been explained by immigration from the western Baltic and by migration between different basins (Parmanne *et al.*, 1994). However, other authors state that sprat in the eastern Central Baltic form local populations (Ojaveer 1989), which can be separated, primarily by otolith characteristics (Aps 1981).

Disaggregated MSVPAs were conducted in Subdivisions 25, 26 and 28; here all species were assumed to be unit stock components:

Cod composed of age-groups 0–8 with oldest age-group handled as plus group, preying on herring and sprat. Last-mentioned species were defined as prey in the age-groups 0–8 (oldest age-group handled as plus group) for herring and age-groups 0–7 for sprat. Exhibiting cannibalistic behaviour, cod was also considered as prey in the MSVPA of the Baltic.

Input Data for the disaggregated MSVPA

Weight at age and catch in numbers

Quarterly catch-at-age in numbers and weight-at-age in the catch according to Subdivisions were revised and updated for years 1976–2003 following the compilation scheme presented in ICES (1997b). Input for 2004 and 2005 was based on national data reported to WGBFAS (ICES 2004 and 2005). Missing data on weight-in-the-catch of cod for age-classes 0 and 1 were substituted in the 3rd quarter by a value of 0.028 in Subdivision 25 and 0.005 in Subdivision 26 and 28. In the 4th quarter a value of 0.028 was used for all Subdivisions.

Any other missing values on weight-in-the-catch were substituted by a mean of neighbouring years for herring and sprat and by a weighted mean of the sub-divisions for cod. Weight-at-age in the catch was assumed to be equal to weight-at-age in the sea, exceptions being weight-at-age for cod age-groups 0–2.

Here, due to size selection by commercial gear, mean values for two time periods (1977–1989 and 1990–2005) were used.

For the time period 1990 to 1997 a multiplicative regression ($Y = a*X^b$) of weight over age was performed and this analysis yielded an estimation of mean weights at age-groups 0–2 in the stock for all quarters

(ICES, 1999a) in the considered time period. For the years from 1998 up to 2005 the same values were used (Table 3.6.1)

Table. 3.6.1. Values for cod weight – at – age in the stock used in all SDs

All SDs	Time period 1977 – 1989			Time period 1990 – 2005		
	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2
1st Quarter		0.065	0.206		0.052	0.226
2nd Quarter		0.073	0.242		0.090	0.339
3rd Quarter	0.005	0.089	0.310	0.005	0.138	0.425
4th Quarter	0.028	0.125	0.460	0.024	0.195	0.520

Maturity ogives

Maturity ogives for cod in different Subdivisions represent averages over 5 years periods available from 1980 (applied also before 1980) onwards for combined sexes as presented in ICES (1998/ACFM:16), updated with data for 1998 and 1999 presented in ICES (1999b) and ICES (2000/ACFM:14) and 2000 to 2003 as presented in the last SGMAB-Report (ICES, 2005). For the years 2004 and 2005 the values of the last year were used. According to ICES (1998) the maturity ogives for herring and sprat stocks were assumed to be constant over time.

Stomach content data

Quarterly cod stomach content data according to Subdivision as revised in ICES (1997/J:2) were utilized as input. Intra-cohort cannibalism in cod was excluded by changing prey age to predator age minus 1 and omitting 0-group cod in 0-group cod stomachs.

Quarterly Food Intake by Cod

Quarterly, age-specific consumption rates of cod were estimated as described in Temming (1996) and ICES (1997a) for each sub-division (see chapter 5). Also alternative (consumption rates with effect of oxygen on evacuation) quarterly, age-specific consumption rates of Baltic cod were calculated.

Other input data

The residual natural mortality (M1) was assumed to be 0.2 year^{-1} equally distributed over quarters corresponding to standard MSVPA runs in the Baltic (Sparholt, 1991). The Suitability coefficients were estimated according to standard suitability submodel implemented in the Baltic MSVPA (ICES, 1997b). The constant biomass of “other food” assumed to be 1 million tons, similar to ICES (1996/Assess:2).

Results of dis-aggregated MSVPA run and discussion of the results

Population biomass

The time trend in stock biomass for cod, herring and sprat in the different Sub-divisions (SD) as determined by the three MSVPA runs are displayed in Figure 3.6.1. For cod a substantial decrease in the biomass is obvious in all three areas from 1983 onwards (Figure 3.6.1; upper panel). In SD 28 the stock biomass declined from 186.000 – 135.000 t in the early time period to less than 10000 t from 1990 onward, with no subsequent sign of recovery. In both other areas stock biomass was in general higher, i.e. for Subdivision 25 the biomass declined from values of about 375.000–383.000 t in the early 1980s to low values of about 89.000 t in 1992. For SD 26 highest values of 362.000 – 371.000 t became apparent in 1982/83, the lowest values of biomass appear in 1991/92 with values around 47000 – 70000 t. After a slightly enhanced reproductive success and a reduction in fishing mortality in the early 1990s, the biomass increased again in both area to maximum levels of about 175000 t in SD 25 and 107000 t in SD 26 in the 1994/95. After these years the biomass declined continuously to values of about 30.000 t in SD 26 and 70.000 t in SD 25 in the end of the investigated period.

The corresponding developments of the herring biomass estimates are presented in Figure 3.6.1, middle panel. For SD 25 a more or less continuous decline from the beginning of the time series of about 800.000 t to approximately 142.000 t in 1999 is indicated, with a slight increase afterwards. In SD 26 the herring biomass shows an obvious decrease from values over 500.000 t at the beginning of the time period to values of about 193.000 t in the year 19810.5. Since 1988, biomass values were significantly lower, i.e. around 175.000 t, with a slight declining trend. Contrary to the other SD, the herring biomass in SD 28 showed a slight positive development up to the year 1993, i.e. an increase in biomass from 243.000 to 434000 t, afterwards a continuous decrease in biomass was apparent to values below 80.000 t in the last two years of the time period.

In the beginning of the time period the sprat biomass in SD 25 decreased from 195.000 to 50.000 t in the year 1980 (Figure 3.6.1; below). Afterwards a strong increase in biomass is obvious to maximum values of about 960.000 t in 1995. This increase is followed by a substantial decrease in the biomass, i.e. to values of about 340.000 t. The biomass of sprat in SDs 26 and 28 showed a rather similar time trend, but not in the same order of magnitude. In the beginning of the investigated time period both biomasses showed a slight decrease. Afterwards both biomass estimates increased in the beginning of the 1980s to 275.000 and 127.000 t, respectively. In the beginning of the 1990s a further increase to 487.000 and 363.000 t was calculated. To the end of the regarded time period the biomass in both SDs decreased slightly to values of about 350.000 and 330.000 t respectively in the year 2003. Only in SD 28 a strong increase in biomass from 2003 onwards to values higher than 800.000 t in 2004 and 2005 was obvious.

Fishing mortality rates

Determined fishing mortality rates (for simplicity summed over quarters) of cod and herring (average over age-groups 3–6) as well as sprat (average over age-group 3–5) are displayed in Figure 3.6.2. Fishing mortalities of cod in Sub-division 25 were in general higher than in SDs 26 and 210.5. They were fluctuating between 0.4–1.66 without any clear time trend (Figure 3.6.2), with the exception that since 1997 the F-values were always at approx. 1.2, i.e. above the long-term average. For both other Sub-divisions, fishing mortality was most of the time lower but again no clear time-trend was obvious. Within the 1990s, even at low biomass values, no substantial decrease in mortality rates is obvious.

For herring, an increase in fishing mortalities from the beginning of the time series until the mid 1980s is estimated for all Sub-divisions (Figure 3.6.2). In Sub-divisions 25 and 26, this level (approx. 0.2) was kept throughout the remaining time period covered, while for Sub-division 28 this was followed by an increase to relatively high levels in most recent years.

The fishing mortalities determined for sprat were much more variable, than those determined for both other species (Figure 3.6.2), with maximum changes from 0.94 to 0.11 in successive years. Although the variability makes it difficult to detect any consistent time trends, an increase in fishing mortality since 1992 from 0.04–0.13 in 1993 to 0.34–0.58 in 1997 is obvious for all areas.

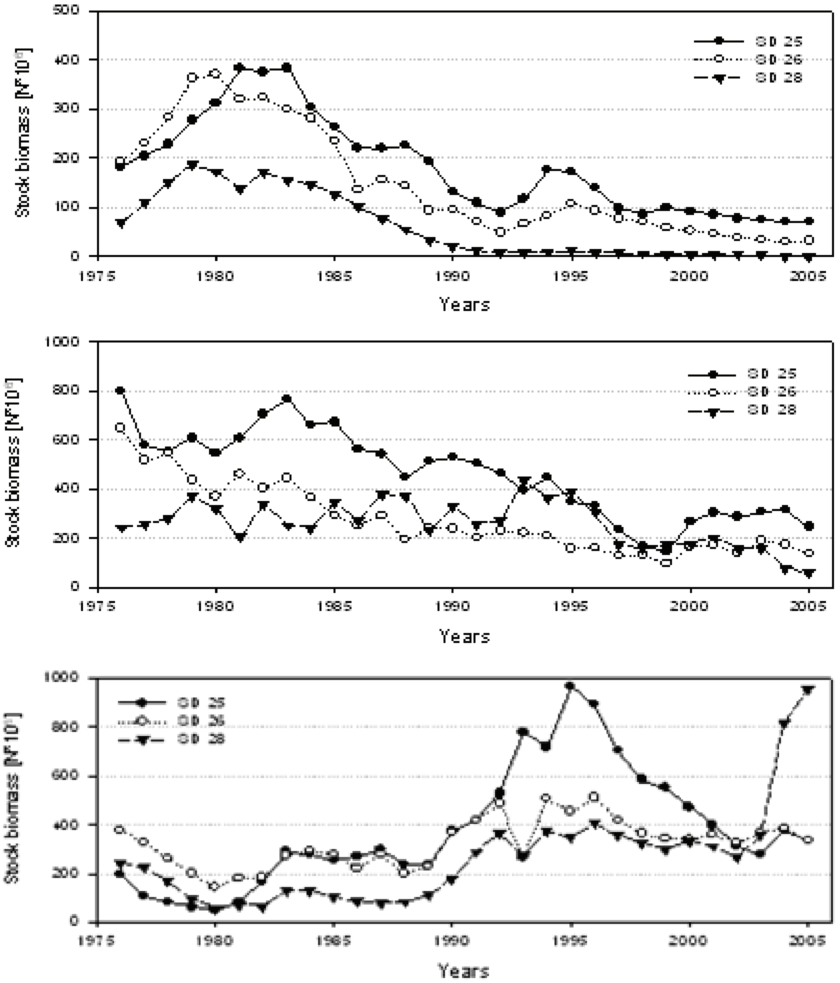

Figure 3.6.1: Stock biomass for cod (above), herring (middle) and sprat (below) in the 1st quarter of each year summarized over age-group 1–8 for cod and herring and age-group 1–7 for sprat.

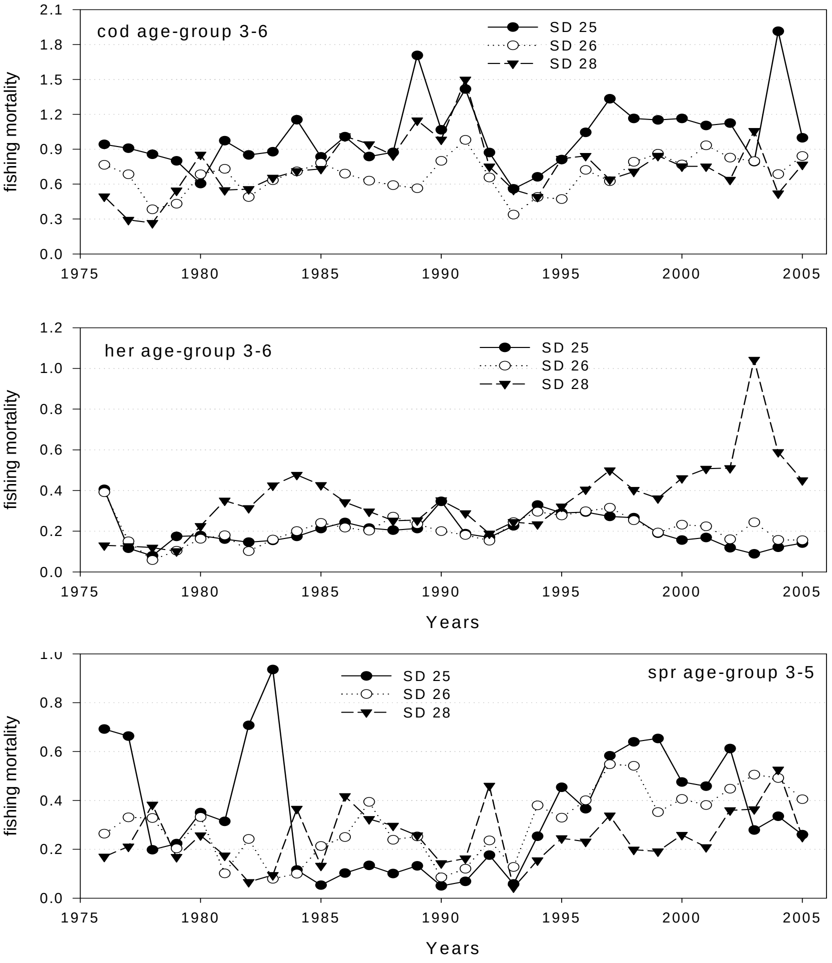

Figure 3.6.2: Fishing mortality rates per year of cod age-groups 3–6 (as arithmetic averages; above), of herring age-groups 3–6 (as arithmetic averages; middle) and of sprat age-groups 3–5 (as arithmetic averages; below) in different Subdivisions (SD) of the Central Baltic Sea

3.7 The management considerations and possibilities to increase catches in the medium term

Herring in IIIa and western Baltic:

North Sea Autumn-Spawning and the Western Baltic Spring-Spawning herring stocks are exploited and managed simultaneously in Division IIIa (ICES 2009). Hence, the management of the herring fisheries in Division IIIa influences both stocks. Recruitment of Western Baltic herring has been reduced by 15–35% annually from 2004 onwards. The estimated strength of the 2008 year class is the lowest of the whole times series, and amounts to only a quarter of the average. There is no indication that recruitment would return to the previous level in the near future. The poor year classes have not yet fully contributed to the SSB but will increasingly do so in the near future. In this situation, there is no alternative to reduce F significantly to avoid a drastic decline of the SSB. ICES has used the mean recruitment from 2003–2007 (year classes) for the short-term prediction which might be overly optimistic in the present situation.

In the absence of agreed reference points, the state of the stock cannot be evaluated. SSB has been stable in recent years but is expected to decline rapidly due to poor recruitment. Fishing mortality has been stable and is estimated at 0.37, well above the candidate for Fmsy. From 2004 onwards, recruitment has been declining and is now at a record-low. Thus on the basis of exploitation boundaries in relation to long-term yield that fishing at the candidate Fmsy fishing mortality (0.25) implies catches in 2010 not larger than 39 800 t in the entire distribution area. In the medium term (3–5 years period) there is very little room for increasing the fishery and catches.

Herring in SD 25–27, 28.2, 29 and 32

Herring fishery in SD 25–27, 28.2, 29 and 32, as most of the pelagic fisheries in the Baltic, take a mixture of herring and sprat and this contributes to uncertainties in the actual catch levels (ICES 2009). The reported landings have been well below the TAC in the period 1992–2002; since then the reported catches have been closer to the TAC, which may have resulted in an incentive for misreporting of herring as sprat. However, the extent to which species misreporting has occurred is not well known. From 2005 onwards, EC vessels operating in the sprat and herring fishery have not been allowed to land unsorted catches, unless there is a proper sampling scheme to monitor species composition. This is thought to have led to a reduction of the amount of species misreporting.

The slight increase in SSB after 2001 was mainly driven by the reduction in F and to some extent by the strong 2002 year class. However, fishing mortality had increased by 25% since 2005. The impact of the 2002 year class on the stock will further diminish during the next several years. No stronger year class has been observed since 2002. In the absence of defined biomass reference points (BRPs), the state of the stock cannot be evaluated with regard to such BRPs. SSB markedly declined between the mid–1970s (1 770 000 t) and 2001 (357 000 t), increased between 2002 and 2006 (526 000 t), and has since been relatively stable (between 525 000– 537 000 t). SSB in 2008 (535 000 t) was 59% of the long-term (1974–2008) average. F has increased by 25% in the past three years. In 2008, F was estimated to be 0.251, above Fpa (0.19). The last strong year class for this stock was the 2002 year class. The possibilities to intensify fishery on this stock are rather limited just because the current fishing mortality, estimated at 0.25, is above the candidate target F.

Gulf of Riga herring (SD 28.1)

A mixture of Central Baltic herring (Subdivisions 25–27, 28.2, 29, and 32) and the Gulf of Riga (Subdivision 28.1) herring is caught in Subdivisions 28.1 and 28.2. The assessment and the advice consider the Gulf of Riga herring stock taken both in and outside the Gulf (ICES 2009). The TAC is set for herring caught in the Gulf of Riga, which includes a percentage of central Baltic herring caught in the Gulf of Riga but does not include Gulf of Riga herring taken outside the Gulf of Riga. The fraction of herring caught outside the stock area should be taken into account when setting the TAC. The variability of the fraction of open water herring caught in the Gulf of Riga has increased markedly; while the catch of this stock was at the lowest level since 1986 in 2007 (1500 t), it increased 4fold in 2008 (to 6100 t, highest catch since 1995, 16% of total catch in Gulf of Riga). This makes a prediction of the fraction of the different stocks caught in the Gulf of Riga very uncertain.

Precautionary reference points for this stock have been established in 1998. The recent integrated ecosystem assessment indicates a major shift in food web composition and abiotic drivers. This indicates that the reference points are not applicable under the current environmental regime. In 2008, ICES therefore removed the biomass reference points. Fpa will need to be revised in the near future. This could have an impact on the future classification of the exploitation of this stock.

In the absence of applicable biomass reference points, the state of the stock cannot be evaluated with regard to these. Following high recruitment, SSB increased in the late–1980s and is currently estimated to be at the long-term average. The fishing mortality has been above Fpa for the past 12 years, but was below Fpa in 2008. The year classes of 2005, 2007, and 2008 are strong, while the 2006 year class is poor. Based on the information above there are some possibilities to increase the fishery on this stock although rather limited.

Herring in SD 30 (The Bothnia Sea)

Catches from this stock comprise the major fraction of the TAC set for the Management Unit, consisting of Subdivisions 30 and 31. Most herring is taken in trawl fisheries. The sprat bycatches in herring fisheries are low in ICES Subdivisions 30 and 31. The TAC has not been limiting since 2006 (ICES 2009). Last two decades The Bothnian Sea has undergone changes in the food web composition. The most obvious primary driving forces on the food web changes have been decreasing salinity, increasing temperature and increasing eutrophication. In the current period (1989–2008), the Bothnian Sea is less saline, warmer and more eutrophicated compared to two decades ago. The decreased mean weights-at-age in the stock are caused most likely by climate induced changes in the food web as well as stock density dependent effects, which have impacted the age and size composition of the stock.

In the absence of applicable biomass reference points, the state of the stock cannot be evaluated with regard to these. Based on the most recent estimates of fishing mortality, the stock is being harvested sustainably.

The spawning stock tripled in biomass in the late 1980s and has remained high since. The fishing mortality has been below Fpa since the beginning of the time series (1973), fluctuating between 0.1 and 0.2. Recruitment seems to be stable over the last 20 years with the exception of two very rich year classes, those of 2002 and 2006. In this stock there are possibilities to increase the fishery about two fold in the short term without excessive risk of stock depletion. This would mean catch rates between 110 000–150 000 tonnes annually in three successive years.

Herring in SD 31

The available information on this stock is inadequate to evaluate stock trends. Therefore the state of the stock is unknown and there is no basis for an advice. However, based on past knowledge the catches and fishery on this stock should not allowed to increase and thus, there is no room to intensify the fishery.

Sprat stock in the whole Baltic (SD 22–32).

Sprat is taken with a bycatch of herring to an extent that depends on season and area. This means that the fishing options for sprat should take account of the state of Baltic herring stocks, especially the Central Baltic herring stock, as they overlap in distribution and fishing area (ICES 2009). From 2005 EC vessels operating in the sprat and herring fishery are no longer allowed to land unsorted catches, unless there is a proper sampling scheme to monitor species composition. This is thought to have led to a reduction of the amount of species misreporting. The highest yield which this stock can sustain in the long term depends on natural mortality, which is linked to the abundance of cod. Strong recruitment of sprat and low predation in recent years contributed to the high SSB in the mid–1990s and 2000s. The exploitation of sprat may have to be reduced if the cod stock recovers. Precautionary reference points for this stock have been established in 1998. The recent integrated ecosystem assessment indicates a major shift in food web composition and abiotic drivers in the Central Baltic sea. This indicates that the biomass reference points are not applicable under the current environmental regime. In 2008, ICES therefore removed the biomass reference points. In the absence of applicable biomass reference points (BRPs), the state of the stock cannot be evaluated with regards to such BRPs. SSB has declined from a historic high level in the late 1990s. SSB is in 2008 estimated to be around 20% above the long term average. Based on the most recent estimates of fishing mortality (in 2008), ICES classifies the stock at risk of being harvested unsustainably. Of the recent year-classes, the 2006 year-class is estimated to be above average, and the 2008 year-class is predicted to be strong. The future catch opportunities will very much depend on the strength of the 2009–2010 year classes. 17% of predicted yield for 2010 and 45% of the 2011 SSB result from the assumption of average recruitment (1991–2008).

4. Potential effects of intensive fishery on other fish stocks, seals and the ecosystem in general

4.1 General

Herring and sprat are zooplanktivorous fish species which occupy an intermediate level in the trophic food web of the Baltic Sea. An intensive fishery for these species could potentially have impacts on other food web components and the ecosystem in general. In this section, we identify some of the impacts that a targeted fishery on herring and sprat could have for these components.

4.2 Other fish stocks

The main fish species that could be impacted by an intensive fishery for sprat and herring would be direct predators and prey of sprat and herring. One of the most directly impacted species would be cod.

Adult cod is an important predator of sprat and herring and its consumption rates have been quantified on the basis of extensive stomach sampling and predator-prey modelling (Sparholt 1994; Uzars and Pliksh 2000; Aro 2000, ICES 2007). A large fishery-induced reduction in the biomass of sprat and herring could potentially have and effect on cod growth and condition. For example, the growth of cod has been shown to depend on biomass of clupeids in the Baltic (Gislason 1999),when the abundance of cod was very high, but on the other hand cod is an omnivorous species and Baltic herring and sprat may easily be replaced by other food items. However the sensitivity of cod bioenergetics (ingestion, growth, condition, reproduction) to variations in sprat and herring abundance is poorly understood and is likely complicated by spatial and temporal variations in hydrographic conditions that affect the encounter probability of cod with these prey species (Neuenfeldt and Beyer 2003; Neuenfeldt and Beyer 2006). Reductions in growth rate or condition could have consequences for reproductive output as growth rates and condition are coupled to rates of maturation in juvenile cod and to relative fecundity and atresia (Marshall et al 1999; Kraus et al 2002).

Alternatively, an intensified fishery for herring and sprat could have potential positive impacts on cod. This situation could arise in at least two ways.

First, sprat and herring are predators of cod eggs, in at least one of the main cod spawning areas in the eastern Baltic (Bornholm Basin, subdivision 25; (Köster and Möllmann 2000; Köster et al 2003)). Levels of predation on cod eggs vary between seasons and years, and are influenced by the seasonal spawning and feeding migrations of sprat and herring to and from the Bornholm Basin, as well as the vertical variations in temperature, salinity and oxygen concentration. The extent of sprat and herring predation on cod eggs in other subdivisions has not been investigated. However predation by sprat on cod eggs is sufficient to explain some of the inter-annual variation in cod recruitment in subdivisions 25–32 (Sparholt 1996; Köster et al 2003).

Second, a reduction in sprat and herring biomass will reduce their consumption of zooplankton prey in the Baltic Sea. Herring in particular are important consumers of a key prey item of the diets of larval and pelagic 0-group cod, *Pseudocalanus* spp. (Hussy et al 1997; Voss et al 2003; Möllmann et al 2004; Möllmann et al 2005). This copepod species is presently relatively rare in the Baltic sea due to both a multi-annual change in hydrographic conditions (i. e., lower salinity; (Möllmann et al 2008) and predation by herring [Casini, 2008 3715 /id;Möllmann, 2008 3716 /id; Casini et al. 2009]. The reduced consumption of the remaining *Pseudocalanus* in the Baltic by a smaller clupeid population could allow *Pseudocalanus* to increase when hydrographic conditions improve, thereby leading to an increase in the prey for cod larvae. This situation assumes that no other zooplanktivorous predator (either presently inhabitating or potentially invading the Baltic Sea) increases its own consumption of *Pseudocalanus* due to reduced competition.

The dual roles of sprat and herring as both prey for and predators of cod, and the functional role of herring as a competitor with cod larvae/0-groups for the same prey species (*Pseudocalanus*), therefore complicates attempts to estimate the overall consequences of a reduction in sprat and herring abundance on cod. Existing modelling approaches such as the MSVPA and SMS multi-species models include cod predation on sprat and herring but not clupeid predation on cod or cod larval prey. The exclusion of clupeid predation on cod eggs and zooplankton from these models is partly due to lack of field data for parameterizing the clupeid predation process. The issue requires development of new modelling approaches which in turn require new knowledge of interactions between the clupeids and cod, and between herring and its prey. Some newer approaches for doing this are being developed and have been used in some preliminary analyses of how an intensive fishery for sprat might affect the cod population and parts of the Baltic ecosystem [ICES 2009]. Results of those analyses are summarized by ICES and reproduced in a later section of this chapter (see below).

The effects on cod of an intensive fishery for herring and sprat outlined above are mainly via the foodweb and species interactions. The intensive fishery could however have direct impacts on cod, i. e., cod could be caught as bycatch in some pelagic fisheries to some extent. In general, cod bycatch in clupeid fisheries in the Baltic is low (ICES 2004). However some bycatch of cod (e. g., 0-groups) does occur in some seasons and areas (ICES 2004). Bycatches in Latvian and Russian fisheries were equivalent to ca. 20–500 kg cod per 100 to 200 t sprat catches in the Gdansk Deep and 20–50 kg cod per 50 to 100 t sprat in Subdivision 28 in May 2002–2003 (ICES 2004). Similar levels were reported for Danish sprat fisheries in May 2003 (ICES 2004). Bycatch of cod is probably potentially highest when oxygen conditions in the deep layer are too low, so that sub-adult and adult cod occupy higher levels in the water column or shallow areas (Tomkiewicz et al 1998). In both cases, their overlap of these size groups with sprat and herring could increase (Neuenfeldt papers), thereby increasing the potential for cod to be captured as bycatch in intensive clupeid fisheries.

4.3 Seals and harbour porpoises

There are three seal species in the Baltic Sea: grey seals (*Halichoerus grypus*), ringed seals (*Phoca hispida*), and harbour seals (*Phoca vitulina*). One species of harbour porpoise inhabits the Baltic Sea (Helcom 2002). The grey seal is the most common of the 3 seal species and occurs over the whole Baltic Sea, however the majority of the seals occur north of latitude 58°.

In the early 20th century the populations of grey and ringed seals were estimated to be around 100,000 and 200,000 individuals, respectively, whereas by the late 1970s both populations had declined to only a few thousands of animals (Harding and Härkönen 1999). In recent years, grey seal population has recovered to approximately 21,000 individuals in 2004 (Hiby et al 2007).

Comprehensive studies of seal diets in the Baltic Sea are limited to the materials collected in the 1960s–1970s (e.g. (Söderberg 1972; Söderberg 1975) and subsequently in recent years (Lundström et al 2007).

In both periods, the estimated diet composition of grey seals was dominated by herring and in the samples from the 1960s–1970s herring constituted the main prey of ringed seals as well (Söderberg 1972; Söderberg 1975; Lundström et al 2007). Herring is therefore considered to be the most important type of food for both the grey and ringed seals, especially during their first year of life (Söderberg 1975). Herring dominated the diet composition of grey seals throughout the Baltic Sea, both by numbers and weight; in recent studies it occurred in 81 percent of stomachs of the examined seals (Lundström et al 2007). In addition to herring, sprat and common whitefish (*Coregonus lavaretus*) were found to be important prey items for grey seals, occurring in 27 and 20 percent of stomachs, respectively (Lundström et al 2007).

The periods where some information on seal diets is available (late 1960s–early 1970s and 2000s) represent different fish community composition in the Baltic Sea, thereby providing some indication of potential changes in the seal diet composition following changes in fish populations. Comparison of the materials collected during the two periods suggests that the importance of herring in the diet of grey seals has increased during the last decades (Lundström et al 2007), even though the herring biomass in the entire Baltic was likely larger in the earlier period than it is now (Thurow 1997; ICES 2008). The increased incidence of herring in seal diets in the recent period may be due to the recent increase in herring biomass in areas where seal biomass has been increasing and thus where the two species' distributions overlap (e. g., Archipelago Sea and Bothnian Sea). The occurrence of sprat in the diet of grey seals has also increased in the recent period, which is in accordance with the increase in the sprat biomass (ICES 2008). Similarly, the decreased stock size of cod during the 1980s–early 2000s is reflected in a significant reduction in the importance of cod in the grey seal diet. In recent years, only 1% of the consumed prey individuals were cod (due also partly to a reduction in the spatial overlap of seals and cod), whereas the importance of cod in grey seal diet in the 1960s–1970s was estimated to have been about 19% and cod was considered as one of the major prey species for grey seals in this period (Söderberg 1972; Söderberg 1975; Lundström et al 2007).

Quantities of different species consumed by seals are at present unclear, hence the effect of intensified clupeid fisheries on seal or porpoise food consumption and related variables (growth, pup production) can not be quantified. At the present population levels of seals and clupeids, the predation rate by seals on the total herring and sprat populations in the Baltic is likely relatively low compared to levels in the early 1900s when seals were more abundant. However, the situation could change if herring and sprat populations were drastically reduced by dioxin-related fishery removals, especially if grey seals simultaneously continue to increase in abundance and expand their spatial distribution, This may lead to increased seal predation on other fish species, including cod, and increase food competition between predator fish (e.g. cod) and seals for clupeids.

All four marine mammal species are occasionally caught as bycatch in clupeid fisheries, although such bycatches are higher in gillnet fisheries for demersal species than in pelagic and demersal trawl fisheries for clupeid. Since abundances of harbour porpoise are lowest among the four marine mammal species and this species is possibly facing extinction (Helcom 2002), intensified fisheries for clupeids would need to ensure that the total bycatch of marine mammals does not further increase extinction risk.

4.4 Consequences for the general ecosystem

Some of the ecosystem consequences of an intensified clupeid fishery are summarized in other sections of this chapter.

Additional ecosystem effects could involve impacts on trophic levels below herring and sprat in the food web (zooplankton and phytoplankton). Statistical analyses of multi-annual abundances of cod, clupeids, zooplankton, and chlorophyll concentration (as indicator of phytoplankton biomass) in the central Baltic Sea show that concentrations of some zooplankton species have decreased and chlorophyll concentrations have increased following an increase in sprat biomass throughout the 1990s and early 2000s [Casini, 2008 3715 /id;Möllmann, 2008 3716 /id; Casini et al. 2009]. Similar cascading consequences of changes in abundance of upper trophic level species have been detected in some other large marine ecosystems (Canadian Scotian Shelf: (Frank et al 2005); southeast coast of USA: [Myers et al. 2007];Black Sea: (Daskalov et al 2007)).

Reducing the abundance of sprat and herring in the Baltic by fishing could therefore lead to an increase in the abundance of zooplankton and a decrease in probability of harmful algal blooms (Casini et al 2008). These ecological changes could occur because predation rates on the zooplankton would be reduced by the increased fishery on clupeids. However, as noted in an earlier section, such an increase in zooplankton abundance assumes that no other zooplanktivore increases its abundance. In the time period covered by the statistical analyses, this did not happen.

Another zooplanktivorous fish which occasionally has an important functional role in the Baltic Sea is three-spined sticklebacks, *Gasterosteus aculeatus*. Abundances of this species are not known precisely but do fluctuate widely, and have supported directed fisheries in the past for example in the Gulf of Finland, where production of three-spined-stickleback oil was common in late 1950’s. The causes of these fluctuations are not known, but presumably an increase would be promoted by an increase in abundance of zooplankton prey. Hence an additional consequence of a fishery-induced reduction of sprat and/or herring could be an increase in stickleback abundance. How the rest of the Baltic foodweb would respond to such an event is unclear.

A fishing-induced removal of sprat and herring could have ecological consequences for other clupeid predators, such as seabirds. For example, abundance of three seabird species (guillemots, razorbills and lesser black-backed gulls) is positively correlated with the biomass of sprat in the Baltic Sea [Hjernquist and Hjernquist 2009]. A reduction in sprat biomass due to increased exploitation may therefore have some negative impacts on these bird species.

The question of how an increased fishing effort on one clupeid species might affect the Baltic ecosystem has been considered recently by the

ICES/HELCOM Working Group on Integrated Assessment of the Baltic Sea [ICES 2009]. Their consideration of the issue is relevant to the topic of this section and is included in its entirety here. The following in grey is extracted from the working groups' answers**:**

8.3.3.1.d Answer to ToR(d) concerning ecosystem effects of a reduction of the size of the sprat stock

EC has requested ICES to

> "Evaluate the ecosystem effects (including the size of the [Eastern Baltic] cod stock) of a reduction of the size of the sprat stock through an increased fishing mortality for sprat"

ICES Response

ICES addressed this request by (i) conducting a literature review on Baltic ecosystem functioning and (ii) a modelling study investigating the effect of increased sprat fishing on the ecosystem.

In conclusion, the present knowledge on Central Baltic ecosystem functioning suggests the following ecosystem effects of a sprat stock reduction:

1) weakening of the trophic cascades leading in spring to increased P. acuspes and in summer to increased total zooplankton as well as decreased phytoplankton biomass;
2) reduced control of cod recruitment by sprat due to lower predation on eggs and P. acuspes;
3) increased growth and improved condition and subsequently an increase in biomass of herring due to reduced competition with sprat;
4) increased growth and condition of sprat due to reduced intra-specific competition and hence a higher quality food supply for seabirds.

In summary the literature review and the performed modelling study indicate a clear positive response by herring on reduced sprat stock, potentially induced by lower competition and an improved zooplankton food supply. Generally the modelling of the lower trophic levels in food-web models needs to be improved. The modelling results with respect to the importance of the indirect effects of species interaction for the recovery of the cod stock are less clear, as all of these interactions could not be included in the models. However, it seems clear from all sources that fishing down the sprat stock or improved abiotic conditions will only lead to a cod recovery if the fishing pressure on the cod stock is significantly reduced compared to previous years.

Technical background

Literature review on mechanisms mediating ecosystem effects of a potential sprat stock reduction

The Central Baltic ecosystem underwent a drastic shift in composition in the late 1980s due to climate change and overfishing (Möllmann et al. 2008, 2009). A major component of this regime shift was a change from a cod (Gadus morhua) dominated to a sprat (Sprattus sprattus) dominated ecosystem state (Köster et al. 2003). This remarkable shift in the fish community was triggered by coinciding overfishing and climate change, the latter causing high cod egg and larval mortalities and eventually recruitment failure due to low salinity and low oxygen concentrations (Köster et al. 2005). Following the collapse of the cod stock, sprat was released from predation (Köster et al. 2003, Möllmann et al. 2008, Casini et al. 2008), and in combination with temperature-driven high recruitment success, the sprat stock rose to unprecedented levels (MacKenzie & Köster 2004).

The increased sprat stock affected lower-trophic levels with a “spring trophic cascade” on a species-level reducing the biomass of the copepod P. acuspes (Möllmann et al. 2008), and a “summer cascade” reducing total zooplankton and increasing phytoplankton biomass (Casini et al. 2008). In summer, moreover, the effects of the large sprat stock have been also evident in other features of the zooplankton community; i.e. species and stage composition as well as vertical distribution (Casini et al. 2009). Additionally, the increased sprat abundance led to strong intra- and inter-specific competition with herring (Möllmann et al. 2005, Casini et al. 2006), which resulted in poor condition of clupeides and hence less energy content of fish prey for sea-birds (Österblom et al. 2006).

The large sprat stock may now impose a key feedback on cod recruitment by reducing the main food for cod larvae, the copepod P. acuspes and directly preying on cod eggs (Köster & Möllmann 2000, Möllmann & Köster 2002, Casini et al. 2004). The effect of the egg predation has however to be taken with caution, as it (i) has been demonstrated only for one spawning area (Bornholm Basin), (ii) has limited importance during the present peak summer spawning of cod reducing the temporal overlap with the sprat stock, and (iii) is mediated by the physical environment making it difficult to disentangle the effect from a direct effect of low oxygen on cod egg mortality (Köster & Möllmann 2000, Köster et al. 2005, Andersen et al. 2008).

Nevertheless, these newly established feedback loops in the ecosystem possibly delay cod stock recovery and maintain the food-web in a new stable state which may be difficult to reverse (Casini et al. 2009, Möllmann et al. 2009). A further mechanism potentially contributing to a difficult to reverse low cod stable state has been revealed using a stage-structured biomass model for the cod–sprat interaction (van Leeuwen et al. 2008). These preliminary modeling results indicate that a lack of cod recovery could be explained by a stunted growth of sprat offering insufficient food for cod to grow and reproduce. This mechanism, referred to as an emergent Allee effect (De Roos and Persson 2002) has been shown to occur in predator–prey–resource systems when predators forage exploitatively on selective size ranges of prey only.

In conclusion, the present knowledge on Central Baltic ecosystem functioning suggests the following ecosystem effects of a sprat stock reduction:

1) weakening of the trophic cascades leading in spring to increased P. acuspes and in summer to increased total zooplankton as well as decreased phytoplankton biomass;
2) reduced control of cod recruitment by sprat due to lower predation on eggs and P. acuspes;
3) increased growth and improved condition and subsequently an increase in biomass of herring due to reduced competition with sprat;
4) increased growth and condition of sprat due to reduced intra-specific competition and hence a higher quality food supply for seabirds.

With respect to the top-predator cod, the presence of the 2 key feedback loops, i.e. sprat predation on cod eggs and P. acuspes (Möllmann et al. 2008, 2009) suggests that a reduction in the sprat stock may cut off these processes which potentially hinder or retard a cod stock recovery. However, for a significant increase in the cod stock and a resulting reversal of the trophic cascade to occur, fishing mortality on cod needs to be reduced, and most likely also the physical oceanographic conditions, i.e. deepwater salinity and oxygen conditions, would need improvement as these are a prerequisite for cod egg survival (Köster et al. 2005) and an increase in P. acuspes biomass (Möllmann et a. 2003).

Testing the effect of reducing the sprat stock using Baltic Sea food web models

The relative importance of the different bottom-up and top-down processes involved in modulating the ecosystem effects of a potential reduction in the sprat stock can eventually only be resolved by using suited food-web or ecosystem models. Hence, the ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB) used 3 different models to explore the ecosystem effects of increasing the fishing pressure on sprat with a special focus on the fish community (ICES 2009). Effects on lower trophic levels have not been considered due to an insufficient development of these components in the models.

The models used by WGIAB included

1) a first order multivariate autoregressive model (BALMAR) simulating the dynamics of cod, herring and sprat under different fishing and climate scenarios (Lindegren et al. submitted);

2) a Stochastic Multi-Species model (SMS) that represents a stochastic version of the traditional Multispecies Virtual Population Analysis (MSVPA) estimating stock sizes as well as fishing and predation mortalities for cod and its prey species herring and sprat (Lewy and Vinther 2004);
3) a full food-web model (including all trophic levels) using the ECOSIM-model, the dynamic implementation of the ECOPATH approach (Pauly et al. 2000).

A fourth food-web model, structurally different from models 1–3 above, was used to test whether their qualitative results were affected by processes omitted from models 1–3: size-selective predation combined with density-dependent body growth (ICES 2009). Models 1–3 were fitted to a reference period (1974–2006) and then projected into the future. Projections were made using 2 different "climate scenarios", i.e. assuming 1) no change in climate, or 2) changes in temperature and salinity, by forcing different components of the models by temperature and salinity. The climate change scenario is based on the International Panel on Climate Change (IPCC) emission scenario A2 and predicted using coupled regional atmospheric and hydrodynamic circulation models (BACC 2008, Meier 2006). Here we present only runs assuming no climate change as climate effects are visible only on a time-scale > 50 years. Runs assuming climate change can be found in ICES (2009).

The management scenarios to simulate an increased fishing pressure on the sprat stock included (i) moderately intensified sprat fishing (Fsprat=0.6) and (ii) strongly intensified sprat fishing (Fsprat=0.8). Detailed descriptions of the models, the modelling strategy and model forcing as well as a discussion of the results are given in ICES (2009).

Figure 8.3.3.1.1 presents historic and the future developments of the 3 fish stocks until 2025 for the 3 management scenarios. The major trends from this exercise are that in comparison with business-as-usual, BAU (Fcod, Fsprat, Fherring all means of the last 10 years), increased fishing pressure on the sprat stock will result in:

1) a decrease in sprat SSB to an on average stable level;
2) a slight increase in cod SSB;
3) an increase in herring SSB.

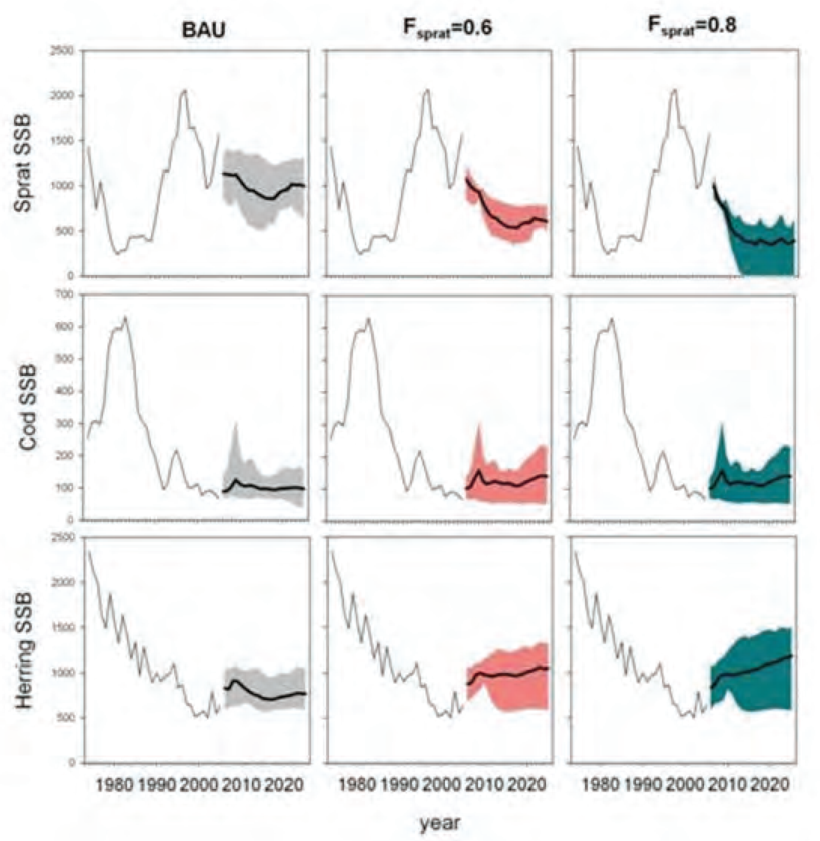

Figure 8.3.3.1.1.Historical and simulated future development of spawning stock biomass (SSB) in Central Baltic sprat, cod and herring stocks: Thin lines in all plots represent the historic data reconstructed by MSVPA (ICES, 2006). Results of the future simulations for the 3 stocks under business as usual (BAU) and 2 levels of increased sprat fishing mortality (Fsprat = 0.6, 0.8) are represented by bold lines and coloured areas – bold lines are the means of the 3 models used, coloured areas are confined by lowest and highest estimates among the 3 models. The shaded areas hence give an estimate of the uncertainty in the future simulations due to model structure. All simulations presented here assume no climate change.

By nature, these future projections incorporate many sources of uncertainty as partly represented in the given projection envelopes (coloured areas around the means in Fig. 1). Uncertainties are beside the model structure due to the used abiotic forcing time-series (salinity and temperature) and the applied forcing functions (ICES 2009). The projection envelopes indicate the highest uncertainties to exist in (i) the risk inherent in a higher fishing mortality for sprat which might result in strong overfishing of the stock, and (ii) the level of recovery of the herring stock. The latter is clearly a result of reduced competition with sprat captured by models 1 and 3, but due to model set-up not by model 2 (the SMS).

Uncertainty exists also in the reaction of the cod stock on the sprat reduction. The future SSB trajectory is largely independent on the level of sprat stock reduction which points towards other factors being important for cod SSB in these models. As fishing mortality of cod is kept at BAU-levels in these simulations, this high fishing mortality and recruitment driven by abiotic conditions are the most likely factors.

The question if with the decreased sprat stock the above described feedback loops are weakened can only to a limited degree be answered by the applied models. Egg predation is included implicitly but not mechanistically in models 1 and 3, and P. acuspes availability only in model 3. However, the parameterization especially in model 3 needs further improvement. The results of these three models so far suggest that cod fishing mortality is the limiting factor of cod SSB, which does not preclude that weakening the feed back loops caused by species interactions can be a prerequisite for cod stock recovery when abiotic conditions improve and cod fishing mortality decreases.

The question if reducing the sprat stock can result in a recovery of the cod stock alone was addressed additionally with a stage-structured multispecies biomass model of cod, sprat and their zooplankton resources, which mechanistically includes size-dependent predation and resource-dependent body growth (van Leeuwen et al. 2008). Similar to models 1–3, this model predicts that increased sprat fishing alone is not sufficient to shift the food-web from the current cod depleted state, because the fishing mortality on cod is still too high (ICES 2009). These simulations show that only if the increased sprat fishing is combined with a reduced cod fishing mortality, the cod stock can recover.

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5. Dioxin and dioxin like PCBs in herring and sprat

The concentrations of dioxins and dioxin-like PCBs (dlPCBs) in herring and sprat in the Baltic Sea are generally high compared to other nearby seas, e.g. the North Sea (Karl & Ruoff, 2007). In addition, there are large and distinct spatial differences within the Baltic Sea (Bignert et al., 2007). The underlying causes of these differences in dioxin levels in fish are currently unknown, however, likely explanations are differences in exposure from local sources and/or ecological factors, such as fish growth rate and prey availability (Peltonen et al., 2007). Dioxins and dl-PCBs are highly bioaccumulative and there is a strong correlation between dioxin levels in fish and age.

5.1 Concentrations in Baltic herring and sprat

5.1.1 Herring

In Sweden, herring is one of the main species in the national environmental monitoring programme for contaminants. Long time-series of dioxin levels in herring along the Swedish coast show that, despite probable large reductions in the input of dioxins to the Baltic Sea, no significant change in dioxin levels in Baltic herring has been detected in the last 20 years (Figure 5.1.1). The average concentration decreases from ca. 0.9 PCDD/F-TEQ[1] pg/g ww in the northern Baltic to ca. 0.7 in the south, and 0.4 on the Swedish west-coast (Bignert et al., 2008a). dl-PCBs are not included in the calculated TEQ values. The fish used in the Swedish monitoring programme are collected in the autumn at reference sites (far from known local sources), small and generally young (2–5 years). Only the muscle tissue is analyzed for dioxins. Other studies on dioxin levels in herring along the Swedish coast have shown considerably higher TEQ-values, e.g. 4.0–6.4 PCDD/F-TEQ pg/g ww and 2.1–3.2 dlPCB-TEQ pg/g ww in herring muscle from the Bothnian Sea (Bignert et al., 2007, Bignert et al., 2008b). In both studies, the fish were generally of the size used for human consumption (ca. 20 cm) and therefore older (5–10 years) than the fish in the monitoring programme, which could explain the higher concentrations.

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[1] Based on WHO TEF (toxic equivalence factors) values (van der Berg et al., 1998).

Reported dioxin levels in herring from the Finnish coast varies between a mean of generally less than 4.0 PCDD/F and 2.0 dl-PCB-TEQ pg/g ww in fish 1–5 years, and up to 5.5–27.0 PCDD/F and 3.0–25.0 dl-PCB-TEQ pg/g ww in herring older than 6 years (Kiviranta et al., 2003). Isosaari et al. (2006) found similar concentrations in young herring from the Finnish coast, ca. 2.5 PCDD/F and 1.6 dl-PCB-TEQ pg/g ww. Both studies analyzed the whole fish as intended for cooking, i.e. head and gut removed. Both studies also indicated generally higher values in the Bothnian Bay than in the Gulf of Finland. Along the Estonian coast, whole fish (as above), 1–5 years old, were shown to have concentrations in the range of 0.6–3.1 PCDD/F and 0.7–2.5 dl-PCB-TEQ pg/g ww (Pandelova et al., 2008). In the southern Baltic Sea, Szlinder-Richert et al. (2009) reported 1.6–3.0 PCDD/F and 1.8–2.5 dl-PCB-TEQ pg/g ww in herring muscle, and Karl & Ruoff (2007) ca. 3.8–11 total-TEQ (PCDD/F and dl-PCB) pg/g ww.

All literature values come from analyses of fish caught either in single years (between 1993 and 2006) or a time-series of up to 4 years (2002–2006).

5.1.2 Sprat

There are no long time-series on the concentration of dioxins in sprat in the Baltic Sea. The Swedish monitoring programme does not include sprat.

Literature values of the dioxin levels in sprat from the Gulf of Finland and Central Baltic are reported by Pandelova et al. (2008) to 1.0–4.5 PCDD/F and 1.1–4.2 dl-PCB-TEQ pg/g ww, and by Roots & Simm (2007) to 1.8–2.0 PCDD/F and 3.6–4.0 dl-PCB-TEQ pg/g ww. In the southern Baltic Sea, Szlinder-Richert et al. (2009) reported ca. 2.5–3.5 PCDD/F and 3.5–4.1 dlPCB-TEQ pg/g ww.

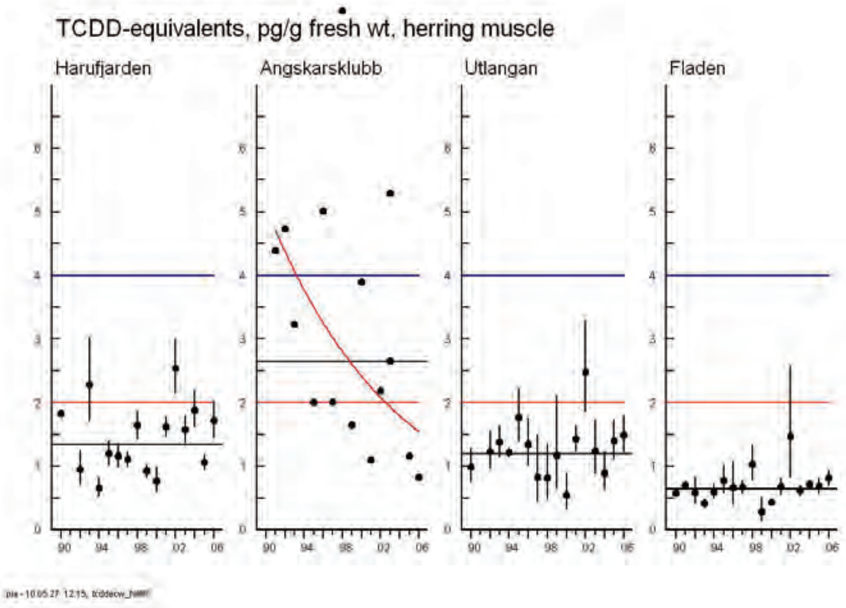


Figure 5.1.1. Concentrations of dioxin and dlPCBs (PCDD/F-TEQ ng/g ww) in herring around the Swedish coast (muscle with skin, data from the Swedish monitoring programme for contaminants). Harufjärden = Bothnian Bay, Ängskärsklubb = Southern Bothnian Sea, Utlängan = Southern Baltic Sea, Fladen = Swedish west coast. The red line indicates the EU regulated limit for fish used for animal fodder (2 pg/g ww) and the blue line for fish used for human consumption (4 pg/g ww).

5.2 Concentrations in relation to EU regulations

Dioxins are included in the Stockholm Convention on POPs. Concerns regarding the impact of dioxins on human health have led to an EU directive (EC 1881/2006) on maximum allowable levels in food (4 PCDD/F and 4 dl-PCB-TEQ pg/g ww, or 8 total-TEQ pg/g ww) and feed (2 PCDD/F pg/g ww). Sweden and Finland have been authorized derogations from this for a transitional period until 2011. Dioxin levels in fat fish, such as herring, sprat and salmon, from the Baltic Sea frequently exceed the limit set by the EU for food and feed.

5.3 Calculations of dioxins in herring and sprat biomass

5.3.1 Herring and sprat

In this study, only data on the PCDD/F-TEQ values in herring from the Swedish monitoring program was used, due to the availability of long and reliable time-series data. Considering that the fish in the monitoring program comes from reference areas only and are relatively young (1–5 years), the PCDD/F-TEQ values used for the calculations can be considered low. Therefore, the resulting calculated average total TEQ in spawning biomass in the Baltic Sea and landings should be considered low. To estimate maximum loads, concentrations adjusted for seasonal variation and age were used.

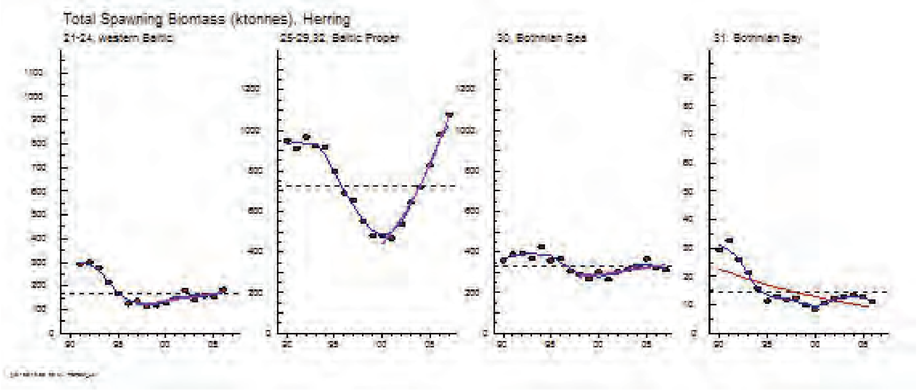
Concentrations in herring muscle was adjusted to represent the concentration in the whole fish (including sub-cutaneous fat and skin) by multiplying with 1.66, according to previous calibration studies (Bignert et al., 2005). Dioxin levels in sprat are estimated based on the concentrations in herring. Generally, sprat has a higher fat percentage (around 8%) than herring (around 4%), which can contribute to a higher bioaccumulation of dioxins by sprat. Based on this relationship, and on the relative concentrations in herring and sprat reported in the literature (ca. 1.5 times higher in sprat than in herring, see references above), the concentration in sprat (whole fish) was calculated by multiplying the concentration in herring muscle with 2.5. Obviously, this is a rough estimate and should be considered uncertain. All values used for further calculations are presented in Table 5.3.1.

Table 5.3.1. Mean PCDD/F-TEQ values (pg/g ww) used for calculations.

	Bothnian Bay (Harufjärden)	Bothnian Sea (Ängskärs-klubb)	Baltic Proper (Utlängan)	Kattegat (Fladen)
Mean PCDD/F-TEQ pg/g ww in herring muscle	0.86	1.09	0.72	0.58
Mean PCDD/F-TEQ pg/g ww in whole fish – herring	1.43	1.81	1.20	0.96
Mean PCDD/F-TEQ pg/g ww in whole fish – sprat	2.15	2.73	1.80	1.45

5.3.2 Biomass and landings

Data on biomass and landings was provided by E. Aro (Finnish Game and Fisheries Research Institute). Figure 5.3.1 shows the total spawning biomass of herring between 1991–2006 in various HELCOM fishing areas (see Figure 5.4.2 for areas). For sprat, data was only available for total spawning biomass in the whole Baltic Sea area. Total biomass of herring, sprat and herring + sprat between 1990–2006 in the Baltic Sea is shown in Figure 5.3.1.



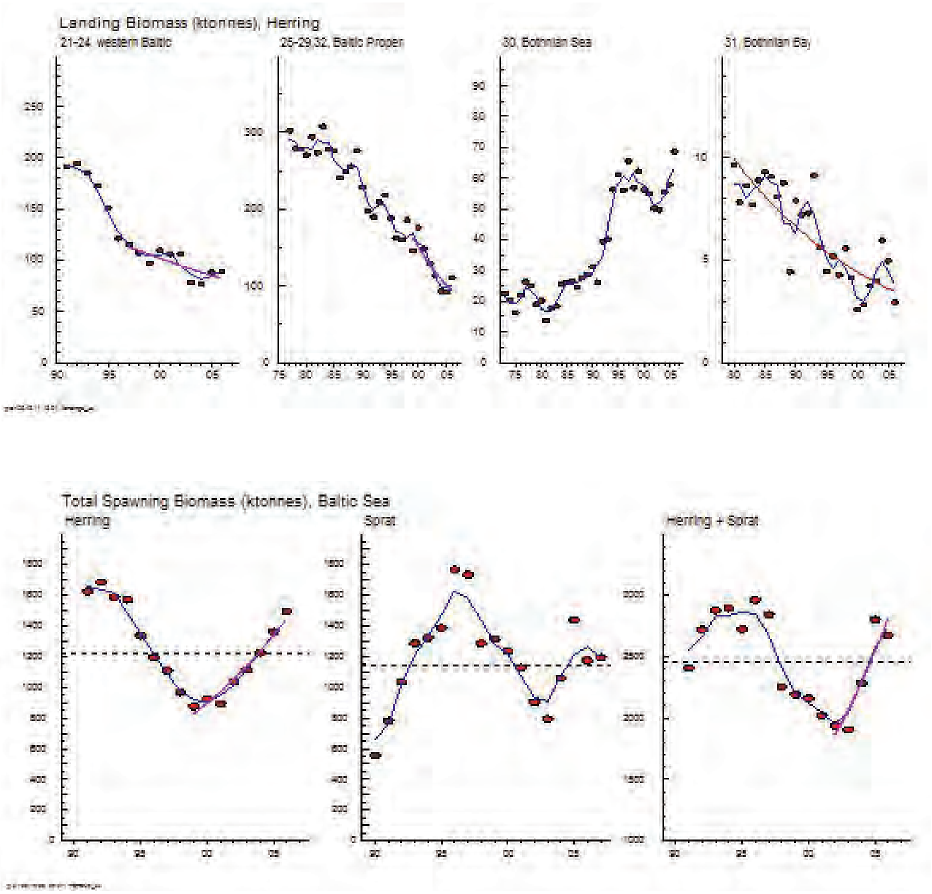


Figure 5.3.1. A) Total spawning biomass and B) landings of herring 1990–2006 divided into ICES areas C) Total spawning biomass of herring, sprat and herring + sprat 1991–2006 in the whole Baltic Sea.

5.3.3 Total PCDD/F in biomass and landings in herring and sprat

Mean total PCDD/F-TEQ (g) bound in herring and sprat biomass in the Baltic Sea was simply calculated by multiplying the various mean concentrations (pg/g ww) with biomass (ktonnes) or landings (ktonnes).

To get a range of minimum and maximum amount PCDD/F-TEQ (g) potentially bound in the fish biomass, the lowest/highest concentrations in each area was multiplied with the lowest/highest estimated total spawning biomass. In addition, there are seasonal and age related variances in the dioxin level of herring. For example, studies have shown a higher concentration in the spring than in the autumn (Bignert et al., 2009). Therefore, as an additional estimate of maximum levels in the Baltic Sea, the calculated total amount of PCDD/F-TEQ (g) in herring and sprat was multiplied with 1.85 to represent fish caught in the spring (Bignert et al., 2009), and further with 4.6 to represent older fish (Kiviranta et al., 2003).

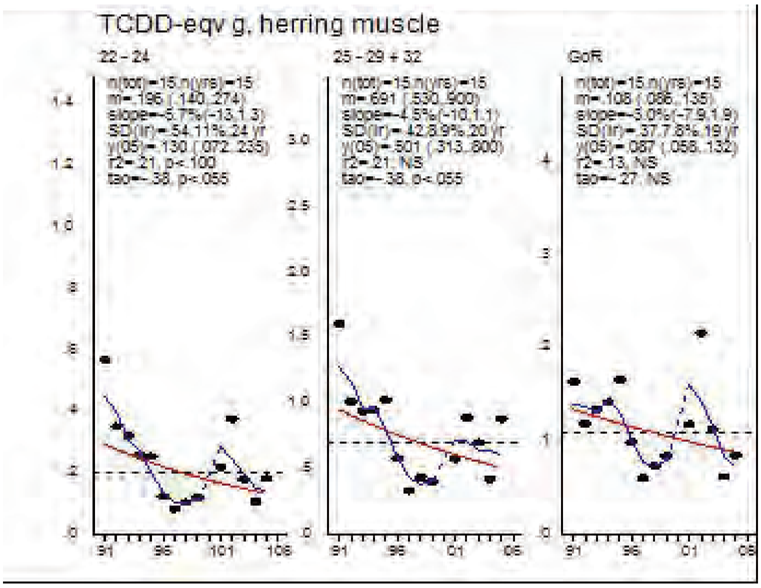
To divide the biomass and landings reported for ICES areas 25–29 + 32 (Figure 5.3.1) and make a rough estimate of the biomass in single areas, the total biomass was divided by weighted surface extrapolation.

5.4 Total amount of dioxins in herring and sprat biomass in the Baltic Sea

Figure 5.4.1 shows the total amount of PCDD/F-TEQ (g) bound in the herring and sprat biomass in the Baltic Sea 1991–2005. Since the concentrations in the fish have been relatively stable during these years, the fluctuations of the total amount of dioxin reflect the fluctuations of the fish biomass.

In 2005, the calculated mean total amount of PCDD/F-TEQs bound in the biomass of herring and sprat in the Baltic Sea was 4.4 g (Table 5.4.1). Generally, the contribution from sprat was somewhat higher. Figure 5.4.2 shows an estimate of how the total amount of dioxins in herring biomass is divided geographically in the Baltic Sea. The Baltic Proper holds the highest total amount (1.1 g, ICES 25–29), largely due to the concentration of biomass in that basin. Second is the Bothnian Sea (0.6 g, ICES 30), where the concentrations in herring are relatively high compared to other areas in the Baltic Sea. This region is considered to contain hot-spot areas for dioxins. The total load in sprat is not covered in these maps since the biomass data for sprat was only available for the whole Baltic Sea.

The mean total amount increased from 4.4 g to 8.2 g when using data for spring caught fish, and to 37 g when also calculating with a higher age (Table 5.4.1). The calculated maximum total amount of dioxins bound to fish biomass in the Baltic Sea was estimated to 67 g.



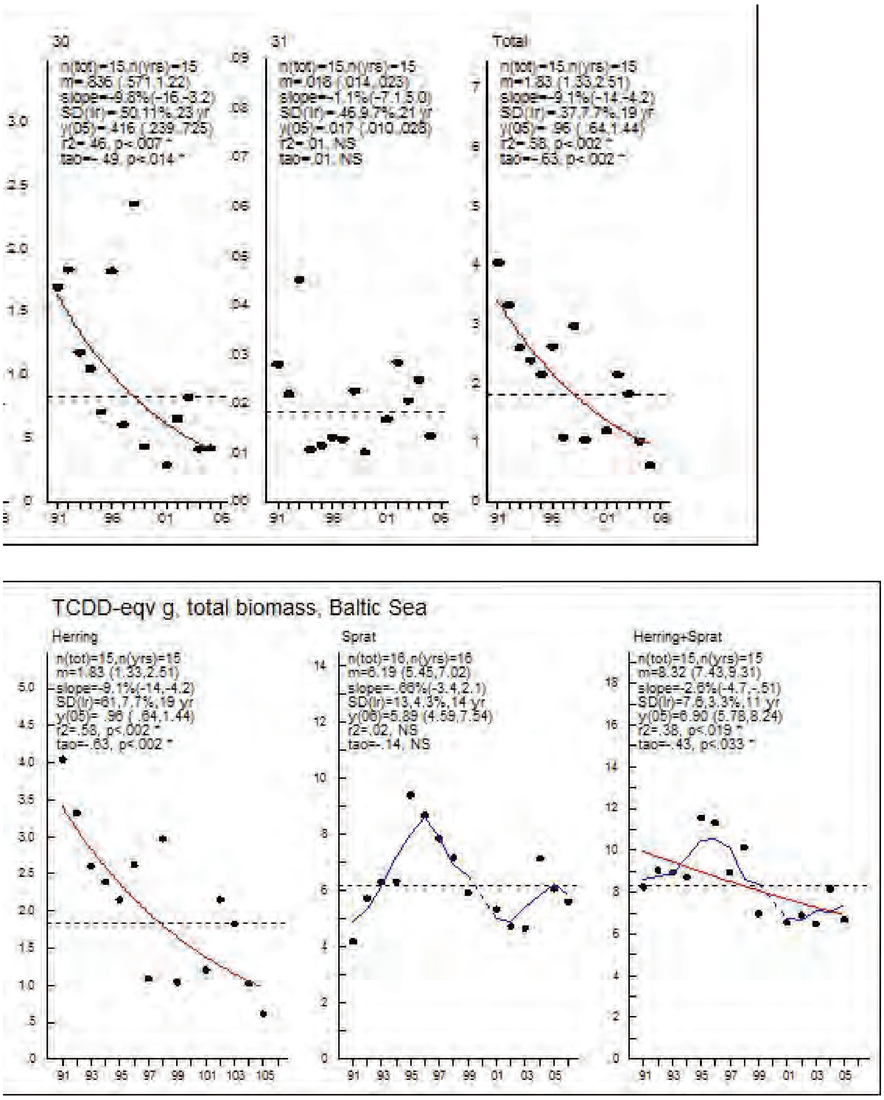


Figure 5.4.1. A) Total amount of PCDD/F-TEQ (g) bound in the herring biomass in different sectors of the Baltic Sea B) Total amount of PCDD/F-TEQ (g) bound in the herring, sprat and herring + sprat biomass in the whole Baltic Sea

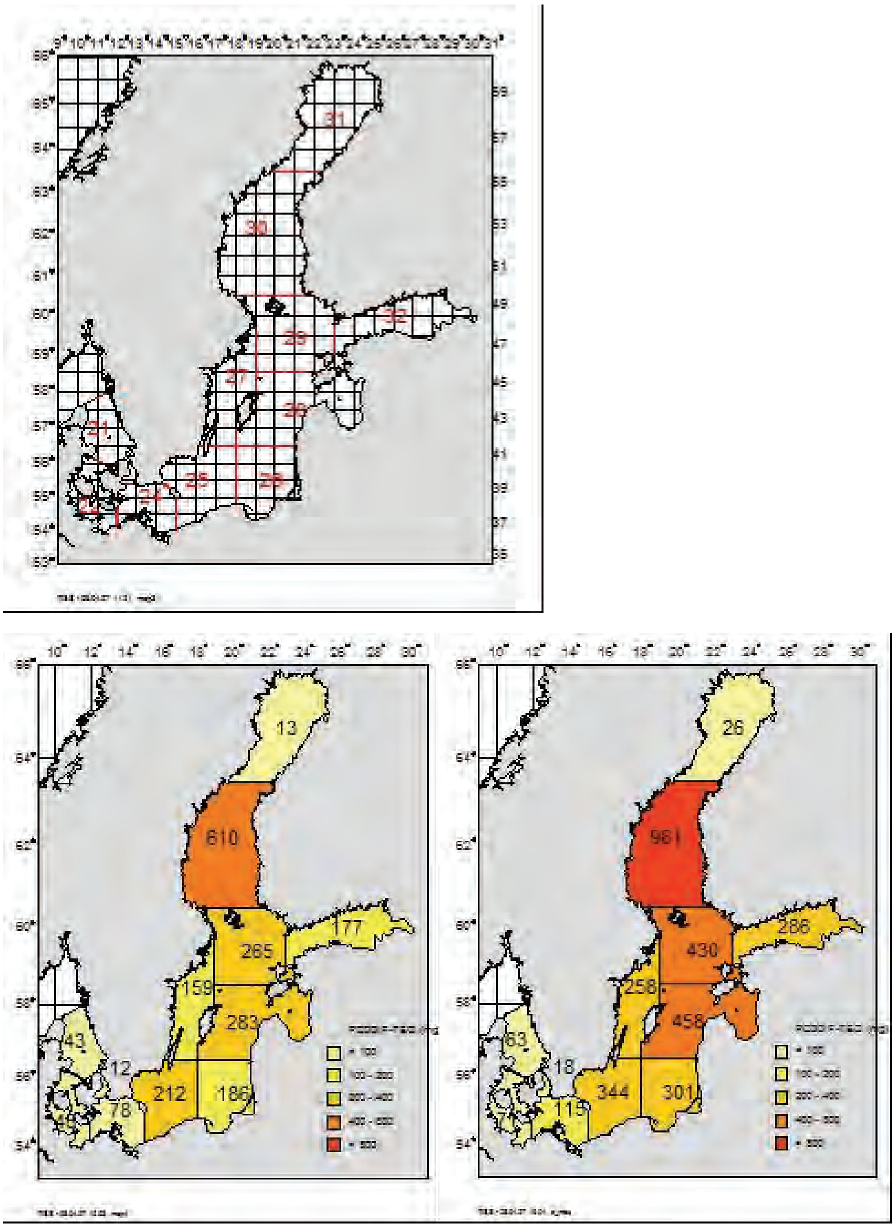


Figure 5.4.2. Top: ICES sub-divisions. Bottom left: Estimated mean total amount of PCDD/F-TEQ (mg) in various geographic areas of the Baltic Sea in 2005. Bottom right: Estimated maximum total amount of PCDD/F-TEQ (mg) in various geographic areas of the Baltic Sea in 2005.

5.5 Total amount of dioxins in herring and sprat landings

The landings of herring and sprat could represent an annual out-take of PCDD/F-TEQ of about 0.35 and 1.15 respectively, in total about 1.5 g as a low estimate based on concentrations in young herring (Figure 5.5.1 & 5.5.2).

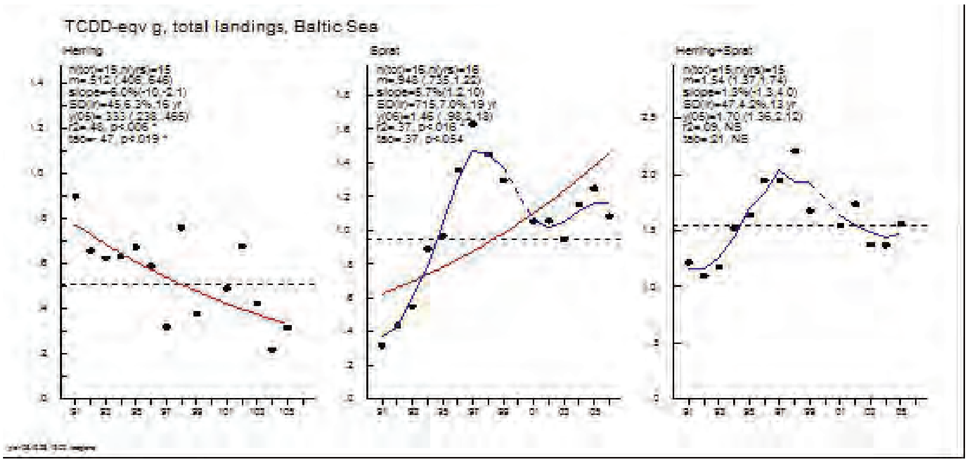


Figure 5.5.1. The total amount of PCDD/F-TEQ in the landings of herring and sprat in the Baltic Sea between 1991 and 2005.

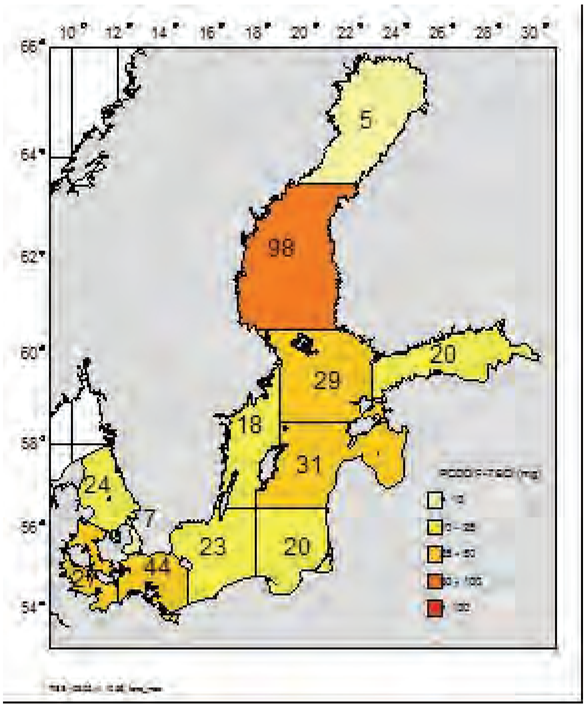


Figure 5.5.2. Estimated average PCDD-TEQ mass removed by landings of herring based on concentrations in young herring caught in autumn at reference sites and landing biomass from year 2005 was about 0.35 g

Table 5.4.1. Estimated total amount PCDD/F-TEQ (g) bound in the biomass of herring and sprat in the Baltic Sea 2005.

	Mean	Min.	Max.
Young, autumn, ref. sites			
Herring	2.1	1.3	3.4
Sprat	2.3	1.2	4.5
SUM	4.4	2.5	7.9
Young, spring, ref. sites			
Herring	3.8	2.4	6.2
Sprat	4.3	2.3	8.3
SUM	8.2	4.7	15
Older, spring, ordinary fishing			
Herring	18	11	29
Sprat	20	10	38
Sum	37	21	67

Young, autumn, reference site = dioxin levels in herring from the Swedish contaminant monitoring program. Young, spring = x 1.85 to adjust for higher levels in the spring. Older, spring = young, spring x 4.6 to represent amount in commercial fish.

6. Budget for dioxin and dioxin like PCBs in the Baltic Sea

6.1 Emission and deposition

Dioxins enter the Baltic Sea as air fallout when transported from land-based sources and via the multitude of waterways. To a large extent in the past waterway pollution could be attributed to some chemical and forest industries, where chlorine was used in large amounts for pulp bleaching until the early 1990s. This has now stopped in Finland and Sweden but chlorine gas is still used in some Russian pulp and paper mills. Other water pollution sources include releases from coke plants and municipal waste waters. Natural events or processes such as forest or steppe fires and volcanic eruptions can also cause dioxin emissions. Apart from the current known sources and historical emissions there are also isolated incidents such as accidental emissions and building fires, which can release significant dioxin or furan emissions into the atmosphere (HELCOM, 2004).

Because of their emission routes dioxins are spread all over the Baltic Sea area. Since dioxins are persistent and bio-accumulative, they become more concentrated as they move up the food chain. Large quantities are stored in seabed sediments, accumulated over several decades. Releases from known sources have decreased during the last 10–20 years (HELCOM, 2004).

The total atmospheric deposition to the Baltic Sea has however decreased between 1990 and 2004 with 33%. The deposition was 117 g TCDD-equivalents/ year in 1990 and had dropped to 78 g TCDD-equivalents/ year in 2004 (Gusev, 2006 b).

Concentrations of dioxins in water are low, because of the very low water-solubility. Measurements in water are also scarce but could be as low as 2.8 ng/m^3 WHO-TEQ (Helcom, 2004).

Because of the low water solubility of dioxins the largest part will be associated with organic materials and stored in the sediments. Concentrations of dioxins (TCDD-equivalents) are typically about 10 to 30 ng/ kg dry weight in surface sediments (Helcom, 2004) even though there are large differences because of regional output. Investigations of dioxins in surface sediments are available from Danish, Swedish, Finnish and German areas. The concentrations of dioxins are typically 500–1500 ng/kg dry weight; this corresponds to 10–30 ng WHO-TEQ/kg dry weight. Dioxins accumulate in sediments close to their main sources, such as old pulp and paper mills, chemical plants including vinyl chloride or biocide manufacturing, and harbours. Dioxins disintegrate very slowly. The half-lives of dioxin congeners in the Baltic have been estimated at between 20 and 275 years (ref). Therefore, sediments serve as historical databases and analysis of dioxins in material from different depths in the sediments gives valuable information about how the pollution level in the Baltic Sea has varied over many decades. Over time small amounts of dioxin are released from the sediment reservoirs and become biologically available in the food web. The rate of release however, is estimated to be slower than the rate of deposition. Dioxins are released mainly from fresh surfaces and sediments which have been disturbed. It is unclear to what extent sediment storage of dioxins is responsible for the present levels of dioxins in biota such as fish, and to what extent more recent emissions or fallout influence these levels.

Mussels have an important role in the circulation of dioxins since they filter large amounts of particles in the water and also process the surface sediments. Mussels increase the deposition rate of these substances on the seabed and make them more easily available to organisms living on the sea floor. In addition to this, mussels increase the residence time of substances in the water, and accumulate and excrete them.

The fat-soluble properties of dioxins cause them to accumulate in fatty tissues. Herring and salmon are fatty fish, and contain the highest dioxin concentrations when calculated by fresh weight. The degree of contamination varies geographically, from year to year and according to the season (highest in the spring), the fat content, and also the size and age of the fish.

Dioxins are known to bioaccumulate and biomagnify through the food chain. Herring and sprat in the Baltic Sea are probably exposed to dioxins via food (zooplankton, small crustaceans and small fish). The total amount of dioxins in the biomass of sprat and herring in the Baltic Sea is estimated in this report to be about 4,4 grams (TCDD-equivalents). However the uncertainty of this estimation is large and as shown in Table 6.5.1 the total load could be as large as 67 grams.

In the south western part of the Baltic and in Danish waters the average dioxin content in herring is 2–2.5 ng WHO-TEQ/kg fresh weight. In comparison, levels are approximately double this figure in the Baltic Proper and the Gulf of Finland and four times higher in the Bothnian Sea and the southern part of the Bothnian Bay. It is particularly in these areas that chemical plants producing biocides and pulp and paper industries emitted great amounts of dioxins for many years. Typically dioxin levels in Baltic wild salmon are currently 2–8 ng WHO-TEQ/kg fresh weight. Twenty years ago dioxin levels ten times higher than this were measured in wild salmon from the Umeå area. Figures on dioxin levels in herring do not provide enough data for reliable time-series analysis. Preliminary data from Finnish specimen bank samples at several locations indicate higher concentrations in herring during the late 1970’s and early 1980’s.

According to Swedish investigations, no trends can be observed in the 1990’s.

Fish-eating birds and other top predators also accumulate toxic substances. Data on guillemot eggs indicate a high level of contamination. The temporal trend in dioxin concentrations in the eggs corresponds to that found in sediments, i.e. high values in the 1970’s followed by a significant decreasing trend mainly in the 1980’s. The decrease of dioxins in guillemot eggs has levelled out during the recent 10 years.

Marine mammals living in the Baltic Sea, such as the ringed seal, grey seal, common seal and harbour porpoises, have a high intake of persistent organic pollutants including dioxins. Normally, adult females have lower dioxin residues as a result of the use of their fat deposits during lactation. In a Finnish study the TEQ of dioxins in seals varied between 7 and 150 pg/g lipid weight; this figure is lower than in Baltic Sea birds, but approximately the same as found in seals from other parts of the Baltic Sea and the west coast of Sweden. Nevertheless, the study found no relationship between the presence of dioxins and the high mortality rate among ringed seals of the Gulf of Finland.

6.2 POPCYCLING-Baltic model

To estimate the flows, concentrations and future trends of dioxins and dioxin-like PCBs in the Bothnian Sea and the Baltic Proper the POPCYCLING-Baltic model has been used by Naturvårdsverket. (2009).

The POPCYCLING-Baltic model is a multimedia fate and transport model integrating informations on chemical emission levels, reservoirs and mass flows. Such a model gives an overview of the chemical fate in the environment and makes it possible to identify key factors controlling the levels in the environment and to evaluate the impact of management scenarios.

Simulations were conducted separately for the seven 2,3,7,8-substituted dibenzo-p-dioxins and the ten 2,3,7,8-substituted dibenzofurans. The predicted concentrations and mass flows were summed after adjusting the predicted values with the appropriate toxic equivalency factors (TEQs).

6.3 PCDD/F inventories

The total PCDD/F inventory in Baltic Sea surface sediments was estimated to be 10 kg TEQ. The water column contained 4% of this quantity (0.4 kg TEQ). Because of the large size of the inventory in surface sediments compared with water this indicates that the surface sediments might be a potential major source of PCDD/Fs to the water column and thus potentially buffering the concentrations in the water column. (Naturvårdsverket, 2009)

6.4 PCDD/F-flows

The current mass flows of PCDD/F in the Baltic Sea have been estimated with the POPCYCLING model. Considering the marine environment as a whole i.e. both water and sediment the major external source of PCDD/F to the Baltic Sea is atmospheric deposition though this result is obvious since direct emissions were not included in the model because of lack of estimates of direct emissions. To evaluate the importance of other sources they can be compared with the total atmospheric deposition to the Baltic Sea. The major sink for PCDD/Fs in the marine environment is sediment burial while other sinks like volatilization and degradation are small. The sediment burial occurs on a time scale of decades meaning that once PCDD/Fs enter the Baltic Sea they will remain in the marine environment for a long time with a residence time of 11 years indicating a slow response to changes in inputs of PCDD/F to the Baltic Sea. The current mass flows are summed in Table 6.4.1 below. (Naturvårdsverket, 2009)

Table 6.4.1 Mass flows of PCDD/Fs in the Baltic Sea

Mass flows	g TEQ yr^{-1}
Atmospheric deposition	133
Volatilization	42
Degradation	27
Burial	73

Other sources of dioxins to the Baltic Sea than atmospheric deposition exist. One example is the Kymijoki River in Finland with an emission of 44 g I-TEQ yr^{-1} to the Gulf of Finland in 2001 which is greater that the atmospheric deposition to the Gulf of Finland indicating that this river is an important source of PCDD/Fs in this particular part of the Baltic Sea and it is not possible to rule out other important riverine or direct inputs in less well studied regions of the Baltic Sea (Naturvårdsverket, 2009).

6.5 Removal of fish biomass

The current understanding of dioxin and dioxlin-like PCB bioaccumulation in pelagic fish indicates that the concentrations in fish are linearly proportional to the freely dissolved concentrations in the water column.

According to Naturvårdsverket (2009) atmospheric emissions at the current level results in a slow decrease in dioxin concentrations to a level about 60% below current levels. The concentrations in the Baltic Proper surface water stabilize most rapidly – by about 2015 – while the decrease in the Baltic Proper deep water and in the Bothnian Sea is more gradual, continuing over at least 40 years.

In a scenario with unchanged atmospheric deposition the dioxin concentration in water decreases to about 40% of the current level in 2045 i.e. the inventory of dioxins in water decreases from 400g to 160g. Assuming a linear relationship between water concentration and concentration in fish biomass the amounts of dioxins in fish biomass in 2045 is shown in the Table 6.5.1.

Table 6.5.1 Dioxin amounts in fish in a scenario assuming unchanged atmospheric deposition resulting in a decrease in water concentrations to 40% of the current level in 2045

Young, autumn, ref. sites	**Mean**	**Min.**	**Max.**
Herring	0.8	0.5	1.4
Sprat	0.9	0.5	1.8
SUM	1.8	1.0	3.2
Young, January, ref. sites			
Herring	1.5	1.0	2.5
Sprat	1.7	0.9	3.3
SUM	3.3	1.9	6.0
Older, January, ordinary fishing			
Herring	7.2	4.4	11.6
Sprat	8.0	4.0	15.2
Sum	14.8	8.4	26.8

To evaluate the effect of fish biomass removal to decrease the dioxin content in fish from the Baltic Sea several assumptions has to be made. In the calculations used in this report a 400g inventory of dioxin in 2005 was used as established by the POPCycling Baltic model. To account for the decrease in the concentration of dioxin in water due to the current atmospheric concentration as simulated by the model POPCycling-Baltic a exponential relationship of the decrease in the water concentration was assumed – calculations based on a decrease in water content of dioxins from 400g to 160g over a period of 40 years ($M(t)=400 \cdot e^{-0.023 \cdot t}$; t=0 equals year 2005). Obviously the estimates are very uncertain. The results from these calculations are found in the graphs below.

Figure 6.5.1 represents a scenario using an initial dioxin content of fish of 67g in total for the Baltic Sea. Under the assumption that there is no removal of fish biomass in the Baltic Sea the dioxin level in fish will decrease from the initial 67g in 2005 to less than 30g in 2045 due to a lower water concentration of dioxins in the Baltic Sea caused by the current level of atmospheric emissions of dioxins, which is lower than former emissions responsible for the current water concentration of dioxins.

The current mortality rate of sprat and hering is about 0.2 – 0.4 corresponding to an annual removal of 25% of fish biomass. This removal of fish biomass results in a further decrease in dioxin content in fish compared to the decrease caused by lower water concentrations. In 2043 the dioxin content in fish approaches zero.

Similar results are obtained with fish content of dioxins of 15g and 7.9 in 2005 Figure 6.5.2 and Figure 6.5.3 though the content of dioxin in fish in 2045 is somewhat higher than in Figure 6.5.1 caused by the fact that less dioxin will be removed with biomass.

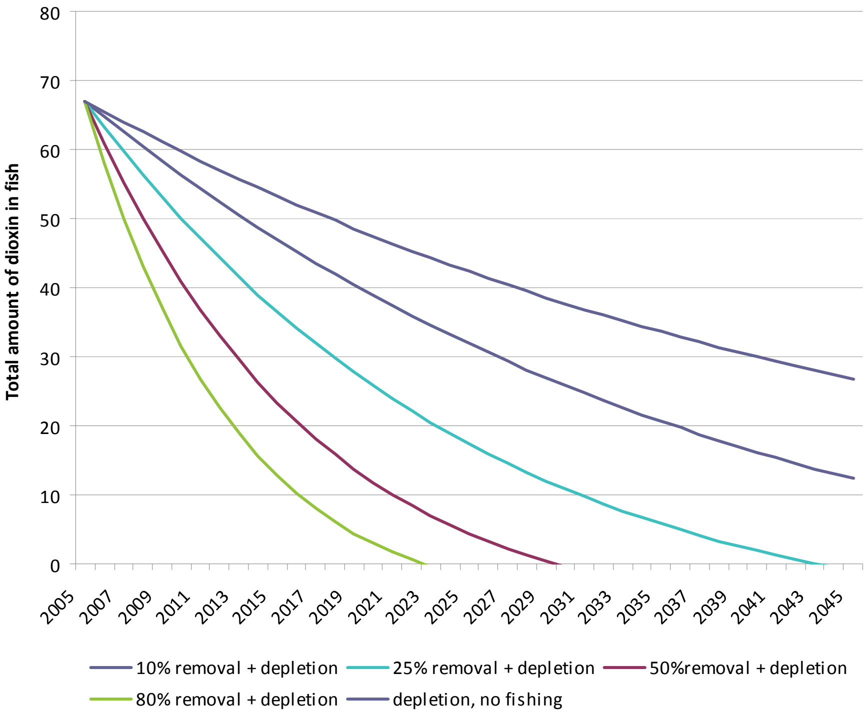


Figure 6.5.1: These graphs shows the time trend of the total dioxin content in fish in five different scenarios based on maximum dioxin content in older January hering and sprat:

1) No fishing; 2) Removal of 10% of fish biomass; 3) Removal of 25% of fish biomass corresponding to the current fish mortality rate; 4) Removal of 50% of fish biomass; 5) Removal of 80% of fish biomass

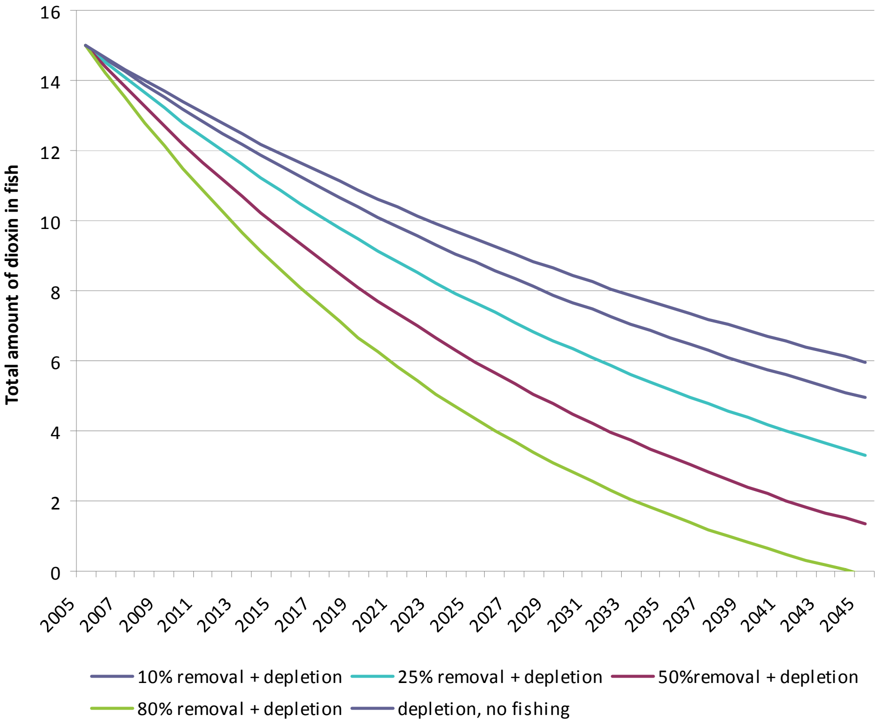


Figure 6.5.2: These graphs shows the time trend of the total dioxin content in fish in five different scenarios based on maximum dioxin content in young January hering and sprat:

1) No fishing; 2) Removal of 10% of fish biomass; 3) Removal of 25% of fish biomass corresponding to the current fish mortality rate; 4) Removal of 50% of fish biomass; 5) Removal of 80% of fish biomass

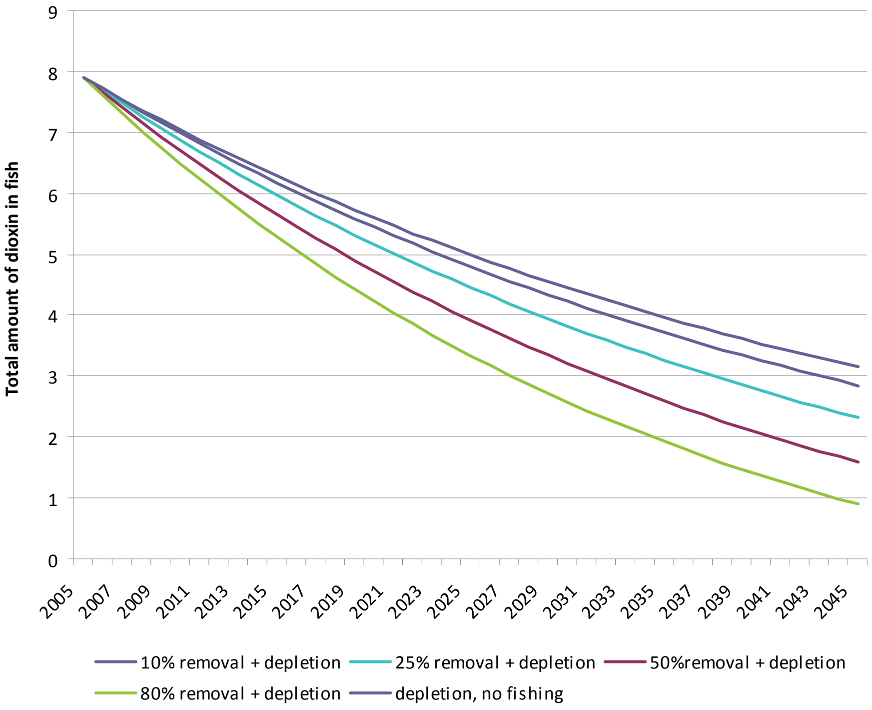


Figure 6.5.3: These graphs shows the time trend of the total dioxin content in fish in five different scenarios based on maximum dioxin content in young autumn hering and sprat:

1) No fishing; 2) Removal of 10% of fish biomass; 3) Removal of 25% of fish biomass corresponding to the current fish mortality rate; 4) Removal of 50% of fish biomass; 5) Removal of 80% of fish biomass

In addition to evaluating the effects of fish biomass removal to reduce dioxin content in fish with the model above depicted in Figure 6.5.1 – 6.5.3 the dioxin content can be compared to the atmospheric deposition of 133g y^1. If the total fish biomass were to be removed the removed amount of dioxin would correspond to 6% to 50% of the atmospheric deposition. With a 25% removal of fish biomass corresponding to the current fish mortality rate the removed amount of dioxin would correspond to 1.5% to 13% of the atmospheric deposition.

7. Conclusion and Feasibility of removing dioxin and dioxin like PCBs by intensive fishery of herring and sprat

A decision to intensify fisheries on sprat and herring for the purpose of removing dioxin and dioxin-like PCBs must be based on a number of scientific considerations and criteria. Some of the issues arising are outlined below.

Such an action if implemented should be conducted in areas having the greatest impact on dioxin levels, but which have the least impacts on the populations themselves and on the rest of the Baltic ecosystem. There are, for instance, clear spatial variations in the concentrations of dioxin in herring and sprat in the Baltic Sea. Removing part of the biomass from some of these populations will therefore have a greater impact than removing similar biomass in other areas. Moreover, some of these areas are in the northerly areas of the Baltic where cod usually is very rare. Hence, possible detrimental or advantageous effects on the cod population would be relatively low in such areas. On the other hand, impacts on other sprat and herring predators (e. g., seabirds) may be larger here.

A further consideration is how much additional fishing mortality that herring and sprat populations can tolerate, and yet still continue to support sustainable fisheries. ICES has already established recommendations for the maximum fishing mortality rates for several of the Baltic herring and sprat populations. Comparison of these rates with those observed during the last few years shows that exploitation rates are already near or exceed the recommended levels. This comparison suggests that additional exploitation to remove dioxin will increase the risk of long-term decline for these populations to, posing consequences for the ecosystem as outlined in earlier chapters. Hence, a decision to increase exploitation rates even further should be made for those stocks only where there is a low exploitation presently. A decision to increase exploitation rates for stocks which are already fully exploited must carefully balance the ecological risks of a more vulnerable herring or sprat population against the benefits of a less polluted Baltic Sea.

Based on the most recent estimates of fishing mortality, the stock in The Bothnia Sea is being harvested sustainably. The spawning herring stock tripled in biomass in the late 1980s and has remained high since. In this stock there are possibilities to increase the fishery about two fold in the short term without excessive risk of stock depletion. This will mean catch rates between 110 000–150 000 tonnes annually in three successive years corresponding to removal of 0.6–0.8 g dioxin and dlPCBs (PCDD/F-TEQ) in total over the three years.

The total amount of dioxins in the biomass of sprat and herring in the entire Baltic Sea is estimated in this report to be about 4,4 grams (TCDD-equivalents). However, the uncertainty in this estimation is large and could be as large as 67 grams.

The current mass flows of dioxin and dlPCBs PCDD/F in the Baltic Sea have been estimated with the POPCYCLING model. Considering the marine environment as a whole, i.e. both water and sediment, the major external source of PCDD/F to the Baltic Sea is atmospheric deposition, though this result is obvious since direct emissions were not included in the model because of lack of estimates of direct emissions. The major sink for PCDD/Fs in the marine environment is sediment burial, while other sinks like volatilization and degradation are small. In comparison to the atmospheric deposition of 133g y-1 the amount of dioxin in herring and sprat corresponds to 6% to 50% of the yearly atmospheric deposition. With a 25% removal of fish biomass corresponding to the current fish mortality rate the removed amount of dioxin will correspond to 1.5% to 13% of the atmospheric deposition.

Finally, it must be considered how large the relative benefits on dioxin concentrations an increased herring and sprat fishery might have, seen in relation to the role of other processes that can lead to reduction in dioxin concentrations in the fish and the overall dioxin burden of the Baltic Sea. The dioxin budget and flux analysis presented earlier and the estimated dioxin removals via fishing shows that dioxin removals due to fishing are only a few % of the dioxin flux and burial rate to the sediments. Hence, if dioxin loadings to the Baltic could be reduced or stopped, sedimentation rates could achieve much higher rates of removal of dioxin from the foodweb than fishing. This action could lead to much more rapid declines (ca. 20%/year; Bignert et al., 1998a, 1998b) in dioxin concentrations in the biota than those that can be achieved by fisheries.

An increase in the fishery for herring and sprat to remove dioxin will have some consequences for the Baltic ecosystem. These could include reduced predation by these species on their zooplankton prey, which would benefit larval and pelagic 0-group cod, and other zooplanktivores such as sticklebacks and jellyfish. Removal of herring and sprat, if sufficiently large enough, may however lead to reduced growth and conditions in cod due to food limitation. Abundances of some searbird species may also decline because of a reduced food supply.

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