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The Potential to Target Smaller Sized Baltic Herring to Decrease the Dietary Exposure to Dioxins

- an Assessment Based on Dioxin Samples from the Southern Baltic

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Abstract

PCDD/Fs and dl-PCBs, or more commonly referred to as dioxin and dioxin like substances are compounds present in our surrounding environment. As some congeners of these have been shown to be toxic, they are regulated under the Stockholm Convention. As dioxins are persistent in biota and have lipophilic properties they are seen accumulating in lipid rich fish in the Baltic, one of the affected species being herring (*Clupea harengus*). The aim of this study was to assess if a fishery targeting smaller herring (length wise) could affect the expected dietary exposure to dioxins via herring and what efficiency and ecological effects such a measure could have. Herring is a key species for the commercial fisheries with regards on volume. The vast majority goes to industrial purposes but Baltic herring are also prepared for human consumption. The EU Regulation 2023/915 manage the allowable dioxin and dl-PCBs levels in wild caught fish that is put on the European market. Sweden and Finland are granted a derogation from these threshold values and only since 2018 the export ban, to EU, of herring (>17cm) caught in sub division 25 of the Baltic Sea were lifted. Eight pooled samples were sent to analysis and all samples had a dioxin content well below EUs threshold values. As no correlation could be seen for all samples between length and dioxin content, the correlation found for one site were used as a ”maximum” scenario in the model predicting dioxin content in the catches. A fishery targeting shorter herring could have positive effects on the dietary exposure to dioxins by approximately decreasing the TEQ with 0.8 pg/g w.w. if the target length of herring in the catches decreases from 26 to 16 cm. The variable weight-at-age had great impact on the results affecting the efficiency a targeted fishery actually would have. With the presumption that a targeted fishery on smaller herring only would be applied on the proportion of the catches that are allocated to human consumption the expected ecological effects were predicted to be low. Though as this thesis assessment included many assumptions and neglected parameters the results should be seen as highly approximate.

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Nomenclature

Biomass	In this report referring to the total amount of herring present in the sea
Catch	The retained fish
Catch composition	The composition of herring in the catch in relation to length or age composition
Fishing Mortality	Mortality from the fishery (related to the landed fish) does not include the mortality caused by injuries from escaping fishing gears
Landing/Landed fish	A landing is the transfer from the fishing vessel to the landing site on shore, the catch can then be referred to as ”landed”
Population	A subgroup of individuals from the stock
Quota	Amount given in tonnes of a managed fish stock that are allowed to catch
Spawning individual	Herring in breeding season
Stock	The herring present in a certain area, often comprised of multiple subgroups, e.g. populations
Yield	The total landed fish

Abbrevations

PCDDs	Polychlorinated dibenzodioxins
PCDFs	Polychlorinated dibenzofurans
dl-PCB	Dioxin like PCBs
ICES	International Council for the Exploration of the Sea
EFSA	European Food Safety Authority
TEQ	Toxic Equivalency
TEF	Toxic Equivalency Factor
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
SDXX	Subdivision XX, where XX is the number given to the certain sub division

Contents

1 Introduction

Dioxins are widely spread in the environment (Van den Berg et al., 2006) and are today banned under the Stockholm Convention (Stockholm Convention, 2019). The exposure of dioxins for humans comes predominantly from dietary intake and dioxins lipophilic properties enables them to bioaccumulate in biota (Knutsen et al., 2018). Lipid rich fish from the Baltic Sea have historically been shown to have high levels of dioxins (Parmanne et al., 2006). One of these fish species is herring, *Clupea harengus*.

Of the total Swedish fishery, 77% goes to feed (SCB, 2023). Out of the economic value of the landed fish, the feed fish only makes up 26%. The species making up the greatest part (weight wise) of the fish used for fodder is Sprat, *Sprattus sprattus* followed by herring, *Clupea harengus* (SCB, 2023). The herring proportion that goes to human consumption is regulated under EU Regulation 2023/915 regarding maximal allowable dioxin content in the fish (EU, 2023/915). The Swedish Food Agency provides dietary recommendations for lipid rich fish from the Baltic and for women of reproductive age the current recommendations are to not eat Baltic herring more than 2-3 times per year (Swedish Food Authority, 2023).

The greatest input of dioxins in the Baltic is from atmospheric sources. Atmospheric emissions of PCDD/Fs from industrial sectors have decreased since the 70s but there still remains unidentified fluxes from smaller sources that are thought to be a major contributor to the input of dioxins. As for PCBs, the greatest contributor to the atmospheric fluxes are secondary emissions (e.g. remobilization of PCBs already present in the environment) (McLachlan & Undeman, 2020).

As dioxins still are present in and introduced to the environment, even after decreased emissions from the industrial sector, other measures to mitigate the dioxin exposure to humans could be explored. As dioxins are seen to bioaccumulate, eating older herring would imply an increased dietary exposure for humans. A fishery targeting younger herring could thereby have potential to decrease the human exposure to dioxins. As today's fishery for herring mainly is conducted with pelagic trawls (ICES, 2023a) the catch is composed by a variety of sizes and ages. Other gears, such as gillnets, have a higher selectivity which enables a further discrete size range to be fished on (Jennings et al., 2001). To investigate how a gillnet fishery targeting smaller herring would influence the dioxin content in the catch, and in extension the dietary exposure to humans, are thus of interest.

1.1 Objectives

This thesis aims to give an updated overview of the dioxin content in southern Baltic herring. The aim is further to provide an analysis of measures to minimize the dietary intake via fish and what efficiency such measures would have. Lastly this report aims to explore the possibilities to decrease the dioxin content in the catch by changing the fishing methods and gears. The following research questions were composed in order to fulfill the aim.

- What is the total dioxin concentration of the Baltic Herring fished in Hanöbukten? How does the new results relate to previous temporal trends and legalized threshold levels?
- Can a positive correlation between length and dioxin content in the sampled fish be found?
- What are the possibilities to decrease the dietary intake of dioxin from Baltic caught herring via a fishery targeting smaller sized individuals?
- Which potential effects could a fishery targeting smaller sized herring have on the total stock biomass and the spawning stock biomass?

The listed research questions was answered using multiple methods. New samples was taken analyzing the dioxin content in herring where a total of 8 pooled samples were sent to analysis from three different fishing sites in the area (SD25). A literature review and search was conducted to assess previous dioxin levels and to gain more in depth knowledge in the field of fishery and ecotoxicology. Moreover, calculations on stock assessment and a further analysis of the sampled herring was conducted.

This thesis will predominately discuss and analyze the herring caught in the southern Baltic Sea and the ICES defined area subdivisions 25-27, 28.2, 29, 32 (see Figure 1). Further this thesis main scope is the herring fished for human consumption which will mainly be discussed. Though, as the herring fishery for industrial use also have a great effect on the herring stock and sales market those landings will also be taken into consideration in the analysis in order for the results to reflect on the current situation of herring fishery.

Note that, in this thesis the terms ”dioxins” and ”PCDD/Fs and dl-PCBs” will refer to the toxic congeners of the substances and will be used interchangeably.

1.2 Methodology

In this chapter the methodology used for the literature review is described. The more general searches, to gain insight and background information on the subject, is presented. Further a more in depth description of the methodology for some chapters will be described. These chapters were chosen on either a data scarcity basis or due to a more thorough search method.

The report consists of a analysis of received dioxin concentrations from a lab. This data was further used in a predictive model over expected dioxin content in a catch. Further the report will present a calculation example of an assessment of the herring stock exposed to different fishing efforts. The methods and calculations used for those analyses will be described in Chapter 4.

1.2.1 Overall methodology and literature review

For overall data collection, to gain an understanding of the herring fishery sector and present it in the background section through Chapters 2.1 to 2.5, databases were used to find relevant reports. Search strings such as Herring AND Baltic AND Dioxins were used. Backward reference searching were also utilized to find further relevant sources. To receive an up to date picture of the dioxin situation and herring fishery and stock as new as possible articles and reports were chosen. For some of the subjects, such as for fishing gear, older sources, as old as from 1990 had too be chosen due to a lack of newer and relevant data.

For the chapters containing a trend analysis from the literature as well as for the methodology assessment for the calculation/modelling parts a more thorough literature search was done.

1.2.2 Data scarcity

For some of the following chapters in the Background/Theory, data was difficult to find. When searching on engines for selectivity of gillnets, not a lot were found. Preforming a search on lubsearch the terms "Gillnets" AND "Herring" AND "Baltic" AND "Selectivity" only one article was found. When excluding "Baltic" from the search terms three additional results were given. When assessing these four articles, one did not cover herring (Direct and Indirect Estimation of Gillnet Selection Curves of Atlantic Herring (Clupea harengus harengus)), the second only included herring over 26 cm (Direct and indirect Estimation of Gill selection Curves of Atlantic Herring Clupea harengus harengus), the third ruled out as irrelevant as the catch rate only was look at against the assessed biomass (Estimation of roach (Rutilus rutilus (L.)) and smelt (Osmerus eperlanus (L.)) stocks with virtual population analysis, hydroacoustics and gillnet CPUE).

To find further information on gear selectivity, scientists within the fishery sector were contacted. This method yield some articles as result, though non of which actual selectivity were included. Backward referencing showed to be an efficient method for finding information and additional sources. Read further about this in the Chapter 4.

As described, there were some difficulties on finding relevant data, older literature were included as well. For some cases the information might still be valid but there could be potential cases of minor errors, e.g. if nets in previous literature were made of a different material than today's gears. Netting material is a variable that affects the visibility of the gear to fishes. Thus it could be more visible for older individuals, favoring a catch of younger ones, with that potentially not being a variable today.

1.2.3 Literature search for Chapter 2.3.4 Dietary exposure - Risk vs. benefit

For the studies chosen in Chapter 2.3.4 *Dietary exposure - Risk vs. benefit* the literature were searched with the aim to find up to date and well founded sources. The search terms "Herring" AND "Dioxin*" AND "Diet*" AND "Baltic" were typed into LUBsearch together with the requirement "peer-reviewed" as well as published from year 2000 or later. This yielded 23 results.

The titles of the 23 references found on LUBsearch were assessed and from this 11 references were chosen. The eliminated articles were found to be irrelevant as they did not cover a human intake of the herring but instead addressing e.g. rat being fed with herring oil or effects on predators such as seals or birds feeding on herring. The 11 remaining articles were then assessed on their abstract if they should be included in the analysis or not. This was also based on relevancy. Articles that were dismissed contained e.g. only a assessment of dioxins in blood plasma in humans and not a dietary exposure and/or benefit and risk assessment. After the abstract requirement 8 articles remained.

Another search string were used in LUBSearch with the search terms "Herring" AND "Dioxin*" AND "Baltic" AND "Risk*" AND "Benefit*". This gave two additional references, that were received in the first search, both of which were chosen to be included based on their abstract.

This yielded a total of 10 articles to be full-text screened. Out of these 10, only two were included in this report.

2 Background

2.1 Herring Fishery in the Baltic

To understand which possible measures that could be applied on the herring fishery a background on the stock dynamics and the current fishery is given below. Herring, *Clupea harengus*, is a species that is present in all sub basins of the Baltic Sea. There are both spring and autumn spawning populations, though spring spawning are the most dominant as for now (HELCOM, 2021). Herring feed on plankton of different sizes, with planktonic copoepods being an important food source. Further, herring is an important fish for predators in the Baltic, and is a valuable source for both cod and seal populations (HELCOM, 2013). Herring is mostly caught with pelagic trawls. The majority of these vessels catches both Herring and Sprat, *Sprattus sprattus*, simultaneously (ICES, 2023a). Herring is a key species for the commercial fisheries with regards on volume. However, the majority of the catch is not used for human consumption but instead for industrial purposes, such as fish meal and oil production that provides feed for other animals (e.g. fish and fur animals) (Sarkki & Pihlajamäki, 2019).

2.1.1 The Spatial Movement of Stocks

The spatial movements of the herring stock is important for understanding how to assess previous data from the literature as the exposure of toxicants differ at various sites. The migration patterns of stocks is further used as a basis for quotas assessment. The Herring stocks in the Baltic shows clear local populations and multiple populations return to the same spawning grounds each year. Spawning ground location is also affected by environmental conditions, such as currents and temperature (HELCOM, 2021). The stock in the Central Baltic (ICES's subdivisions 25-27, 28.2, 29 and 32, see Figure 1) are consisting of multiple different spawning populations. These are in some cases genetically separated, have different migration patterns and growth rates which in turn complicates the management of the stock (ICES, 2023b).

A study by Bekkevold et al., shed light on how Atlantic Herring populations are mixed within spawning areas and other basins in Skagerak, Kattegatt and the North Sea. The study estimated the composition of different populations in multiple areas, showing that not only one population is fished on within a given area. The authors further argues how this 'Mixed Stock Analysis', MSA, could be used when deciding on fishing quotas and for stock rebuilding (Bekkevold et al., 2023).

2.1.2 Fishing Quotas and Stock Assessment

The total biomass of herring is dependent on the fishing pressure. The herring fishery in the Baltic Sea is regulated by the European Union. The quotas are divided among the subdivisions shown in Figure 1. The herring in the central Baltic is managed as two units, one within the subdivisions 25-27, 28.2, 29, 32 and the second in subdivision 28.1 which is referred to as the Gulf of Riga (GoR) Herring. The herring in the northern Baltic is assessed as one unit in subdivision 30-31. Lastly the herring in the western Baltic is assessed as one unit (subdivision 22-24 and is managed together with spring spawning herring in Kattegat and Skagerrak. (ICES, 2023a) The 2023 quotas are showcased in Table 1 for each region the stock are managed within. (Swedish Agency for Marine and Water Management, 2023)

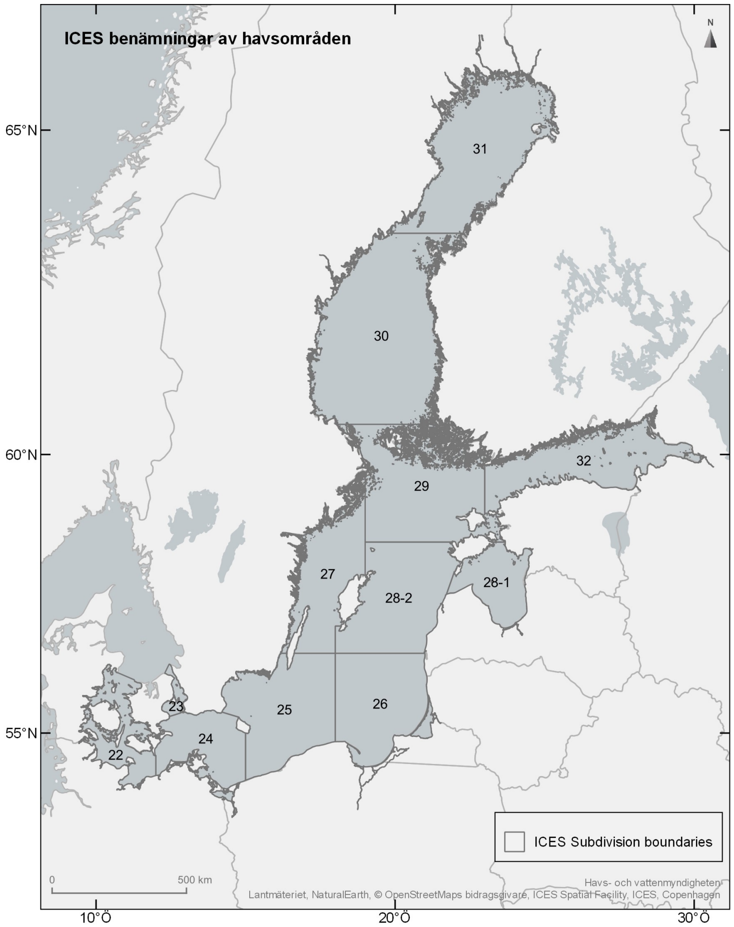


Figure 1: Shows the ICES subdivisions boundaries for the Baltic Sea. Figure retrieved from Swedish Agency for Marine and Water Management, 2023 (see list of references)

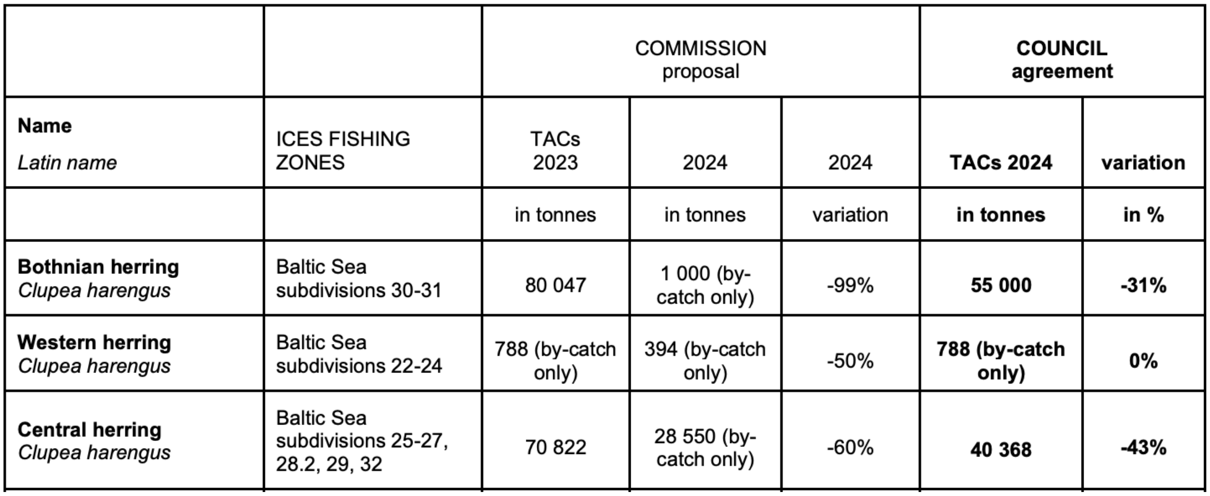
Table 1: Shows the quotas in tonnes for herring in each subregion of the Baltic Sea for year 2023. Swedish and total quotas are showcased as well as the change from previous year in percent. Data retrieved from: (Swedish Agency for Marine and Water Management, 2023).

Region with subdivisions	Swedish quota	EU quota	Change in %
Gulf of Bothnia (30-31)	14 420	80 047	-28
Central Baltic (25-27, 28.2, 29, 32)	23 686	70 822	+32
Western Baltic (22-24)	140	788	0

ICES provides advice on total allowable catches (TACs) to EU to use as a basis when deciding on fishing opportunities (e.e the quotas). These TACs are based on stock assessment done with a Maximum Sustainable Yield (MSY) approach. The MSY objectives are to achieve and sustain a maximal yield each year, e.g. maximal fishing quota, without affecting the stock's productivity. The stocks productivity can be evaluated by the assessment the spawning stock biomass (SSB). ICES also uses precautionary reference points, such as certain thresholds for SSB, for stock assessment to ensure that a stocks biomass or productivity are not at a alarmingly low level (ICES, 2023c). In June 2023, ICES published a report on the herring in the Central Baltic (subregions 25-27, 28.2, 29, 32). The central Baltic herring were seen at low levels and the suggested quotas were set to be for by-catches only (ICES, 2023b). The status for the spawning stock biomass (SSB) of Herring in the central Baltic have been under the precautionary reference point (B_{lim}) since 2019. Further it is stated that even with a scenario with zero catches the SSB would still not be over B_{lim} in 2025 with a 95% probability (ICES, 2023a).

On October 26th the council of the European Union agreed on 2024 years quotas. The quotas are shown in Table 2 as well as the commissions proposal (EU, 2023). As can be seen the commission proposed, in accordance with ICES advice, that only by-catches of herring should be granted for 2024. The quotas decided by the council was lower than for year 2023 but not dropped to ”by-catch only” as proposed.

Table 2: Shows the agreed quotas for 2024 by the EU council. The table is taken from the press release. (EU, 2023)



		COMMISSION proposal			**COUNCIL agreement**	
Name *Latin name*	ICES FISHING ZONES	TACs 2023	2024	2024	**TACs 2024**	**variation**
		in tonnes	in tonnes	variation	**in tonnes**	**in %**
Bothnian herring *Clupea harengus*	Baltic Sea subdivisions 30-31	80 047	1 000 (by-catch only)	-99%	**55 000**	**-31%**
Western herring *Clupea harengus*	Baltic Sea subdivisions 22-24	788 (by-catch only)	394 (by-catch only)	-50%	**788 (by-catch only)**	**0%**
Central herring *Clupea harengus*	Baltic Sea subdivisions 25-27, 28.2, 29, 32	70 822	28 550 (by-catch only)	-60%	**40 368**	**-43%**

2.1.3 Further regulations for Herring Fishery in the Baltic

In accordance with (EU) 2019/1241 there is no minimum conservation reference size for Herring in the Baltic Sea. Thus, all sizes of the specie can be fished on and landed.

Though there are mesh size regulations for fisheries targeted on herring with a minimum mesh size of 32 mm (for trawls) (EU, 2019/1241).

Exceptions to the minimum mesh size are however given. Along the Swedish coast line in the Baltic a trawl limit is set. Within the area of this limit, eight trawl-fishing areas are established. Within one of these (in sub division 27) a permit can be applied for in order to be allowed to use a 16 mm mesh (Swedish Agency for Marine and Water Management, 2020).

2.1.4 Fishing methods and equipment

Fishing gear can be classified as active or passive. Trawls and purse seines are examples of active gears and nets, longlines and traps are passive. In ICES report *Baltic Fisheries Assessment Working Group (WGBFAS)*, the percentage of fish landed from each gear is presented from catch area SD 32 (no information about catch-percentage for each gear was given for any other subdivision in the Baltic). For Swedish catches of herring in 2022 (SD 32) 99% were caught with trawls, 1% with gillnets and 0,03% with other gears (ICES, 2023a).

The selectivity of a gear can be described by the retention rate (e.g. the catch) of different sizes. A high selectivity corresponds with a narrow and more discrete selection of sizes, often expressed in length (Jennings et al., 2001). Gillnets have a high selectivity and many of the selectivity curves for herring caught with gillnets are seen as normalized or having bell-shaped curves (Winters and Wheeler, 1990; Hubert et al., 2012, Jennings et al., 2001). One problem that is stated is the predation from seals on the catch in the net (Lundin et al., 2012).

Pontoon traps or push-up traps are a stationary gear which fish can swim into and be trapped inside. These traps enables a stationary fishing of herring in the Baltic with a lower risk of seal predation on the catch (Lundin et al., 2012).

2.2 Dioxins and Dioxin like Substances

Dioxin is a term used for polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). These two groups are also commonly referred to as PCDD/Fs. When discussing dioxins, dioxin-like substances are also brought to attention, such as dioxin like polychlorinated biphenyls (dl-PCBs) (Knutsen et al., 2018). As the PCDD/Fs and the dl-PCBs often have similar toxicity mechanisms they are handled as one group when setting guidelines (WHO, 2019). The PCDD/Fs and dl-PCBs have different *congeners*, depending on number and position of the chloral atoms. These varieties also results in the toxicity changing (Knutsen et al., 2018). In this thesis the terms ”dioxins” and ”PCDD/Fs and dl-PCBs” will refer to the toxic congeners of the substances.

PCDD/Fs and dl-PCBs are present in all of the global environment (Van den Berg et al., 2006). PCDD/Fs can occur naturally from e.g. vulcanic eruptions, but are mainly formed unintentionally from combustion (WHO, 2019). PCBs were manufactured and widely used in electrical equipment, flame retardants for building materials but its use has decreased since the 70s (McLachlan & Undeman, 2020). Now PCBs are banned and managed under the Stockholm Convention. However, PCBs are still introduced to the environment from the disposal and waste handling of these electrical and electronic equipment (WHO, 2019).

2.2.1 Origin and Sources of Dioxins in the Baltic Sea

Sediments are a common source to assess the origin of dioxins as their lipophilic and persistent nature make them stay in the sediments. When assessing the origin of PCDD/Fs research showed that most of the PCDD/Fs came from atmospheric sources (over 80% in the Baltic Proper and 50% further north in the Gulf of Bothnia). For the PCBs, atmospheric sources have also shown to be the most dominant source in the Baltic. The source of the atmospheric PCDD/Fs are not well known as it is difficult to identify them. In the industrial sector emissions have been seen to decrease from the 1990 to 2017, e.g. a decrease of 83% in the public electricity and heat production. Another source of PCDD/Fs to the Baltic descend from the chlorine bleaching in pulp and paper mills. These emissions were grater in the past, when an intensive chlorine bleaching were taking place throughout the 50s to the 80s, but have decreased since then. At some coastal sites, PCDD/Fs originating from pulp and paper mills still showed to be a major contributor to the total dioxin concentrations found at the sites. Moreover, there are still unidentified fluxes from sources such as back yard barrel burning, domestic combustion etc. for which the quantities are unknown but believed to be a major source of input to the Baltic Sea. As for PCBs in the atmosphere, reemission or secondary emission (remobilization of previous emitted PCBs) are thought to be the greatest source (McLachlan & Undeman, 2020).

2.2.2 Toxicity of the PCDD/Fs and dl-PCBs Congeners

For PCDD/Fs, 210 congeners can occure where of 17 are classified relevant due to their persistence in biota. For PCBs, 12 are considered *dioxin like* with a similar toxicity mechanism as the most toxic dioxin congener 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) (Knutsen et al., 2018). The PCDD/Fs and dl-PCBs are bioaccumulative due to their lipophilic properties as well as resistance against being metabolized in vertebrates. Hence, biomagnification is seen in food webs (Van den Berg et al., 2006).

The toxic equivalency (TEQ) is used for PCDD/Fs and dl-PCBs in order to aid the determination of the total toxicity. Toxic equivalency factors (TEF) are used for each congener to relate them to one another in terms of toxicity. The TEFs are stated in relation to the most toxic congener, TCDD, which is given the value 1. A TEF value of

0.1 then indicates that the congener only is a tenth as toxic as TCDD (Knutsen et al., 2018). The World Health Organisation (WHO) reevaluated the TEFs in 2005 which is the current values used in legal practices (EU, 2023/915; Van den Berg et al., 2006). In Table 3 the 29 PCDD/F and dl-PCB congeners and their respective TEF value are given.

Table 3: Table over the 29 PCDD/Fs and PCBs and their respective TEF value. Data retrieved from Van den Berg et al., 2006

Congener	TEF
PCDD/Fs	
2,3,7,8-TCDD	1
1,2,3,7,8-PeCDD	1
1,2,3,4,7,8-HxCDD	0.1
1,2,3,6,7,8-HxCDD	0.1
1,2,3,7,8,9-HxCDD	0.1
1,2,3,4,6,7,8-HpCDD	0.01
OCDD	0.0003
2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDF	0.03
2,3,4,7,8-PeCDF	0.3
1,2,3,4,7,8-HxCDF	0.1
1,2,3,6,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDF	0.1
2,3,4,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,4,7,8,9-HpCDF	0.01
OCDF	0.0003
dl-PCBs	
3,3,4,4-tetraCB (PCB 77)	0.0001
3,4,4,5-tetraCB (PCB 81)	0.0003
3,3,4,4,5-pentaCB (PCB 126)	0.1
3,3,4,4,5,5-hexaCB (PCB 169)	0.03
2,3,3,4,4-pentaCB (PCB 105)	0.00003
2,3,4,4,5-pentaCB (PCB 114)	0.00003
2,3,4,4,5-pentaCB (PCB 118)	0.00003
2,3,4,4,5-pentaCB (PCB 123)	0.00003
2,3,3,4,4,5-hexaCB (PCB 156)	0.00003
2,3,3,4,4,5-hexaCB (PCB 157)	0.00003
2,3,4,4,5,5-hexaCB (PCB 167)	0.00003
2,3,3,4,4,5,5-heptaCB (PCB 189)	0.00003

2.2.3 Toxicity for humans

Both PCDD/Fs and PCBs are seen as potential human carcinogens (Stockholm Convention, 2019). Dioxins bioaccumulate in humans due to their lipophilic structure and as the metabolic ability of these compounds are low in humans. The half-lives of most of these compounds are thus several years in the human body. The toxic effects of exposure have been assessed both from incidents when dioxins have spread in the environment, such as the Seveso incident, or occupational exposure and further been compared to animal studies to conclude casualties. Some causal effects found were impaired semen quality and lower sex ratio in birth (more females to males) (Knutsen et al., 2018).

EFSA further states that for many end points the number of available studies in humans are too few in order to make any conclusions or proceed to do a risk assessment (Knutsen et al., 2018).

2.3 Dioxins in Herring

2.3.1 EU regulations on dioxins in Baltic Herring

The EU Regulation 2023/915 *on maximum levels for certain contaminants in food*, manage the allowable dioxin and dl-PCBs levels in wild caught fish that is put on the European market. Table 4 shows the limits set by the European Union. The limits are set for concentrations in muscle tissue but for cases when the whole fish are intended to be consumed, the limit refers to the whole fish. All measured concentrations of the congeners that are under the limit of quantification should be set equal to the limit of quantification (EU, 2023/915). As can be seen the sum of dioxins should be stated as TEQ and not as (quantitative) concentration.

Table 4: The limits of dioxins for wild caught fish expressed as sum of PCDD/Fs and sum of PCDD/Fs & dl-PCBs. The limits are stated in pg/g wet weight (w.w.) (EU, 2023/915).

Contaminant	TEQ limit (pg/g w.w.)
Sum of PCDD/Fs (TEQ)	3.5
Sum of PCDD/Fs and dl-PCBs (TEQ)	6.5

Sweden and Finland are both granted a derogation from the maximum levels of dioxins and dl-PCBs in Herring caught in the Baltic region larger than 17 cm (EU, 2023/915). This derogation allows Herring, larger than 17 cm, to be put on their respective market despite dioxin content. Note that Baltic caught herring under the length of 17 cm is approved for export to the EU market. With this derogation, the countries are obliged to inform consumers of dietary recommendations and identify risk groups in regards to potential health risks. The countries are also responsible of keeping the products on the domestic market (EU, 2023/915). Since the 1st of October 2018, herring caught in the ICES subdivision 24-27 (all sizes) and 28.2 (individuals under 21 cm) are also allowed for export onto the EU market (Swedish Food Authority, 2019).

2.3.2 Dietary recommendations - Sweden and Finland

The Swedish Food Authority (Livsmedelsverket) provides dietary advice for consumption of herring as demanded by the derogation from the EU thresholds for dioxins and dl-PCBs in Herring. The dietary advice from the Swedish food authority are formulated to cover all sizes of Herring. Children, youths, pregnant or breastfeeding women or women wanting to become pregnant in the future are advised not to eat the fish more than 2-3 times per year. Others are advised not to eat the fish more than once a week (Swedish Food Authority, 2023). The fish included are listed below.

- Herring caught in the Batic Sea
- Salmon and Trout (wild) caught in the Baltic Sea, Lake Vättern or Lake Vänern
- Freshwater whitefish (*Coregonus lavaretus*) caught in Lake Vättern or Lake Vänern
- Char caught in Lake Vättern
- Eel

(Swedish Food Authority, 2023)

The Finnish Food Authority's dietary advise departs from the Swedish recommendations. The advice given from the Finnish Food Authority, to children, youths and persons of fertile age, is not to eat Herring larger than 17 cm, Salmon or Trout that origins from the Baltic Sea more then once or twice per month. Herring smaller than 17 cm are not included in the dietary advice and can be eaten as any other fish (Finnish Food Authority, 2019).

In addition to EUs threshold values for dioxin content in food and the dietary recommendations from national food authorities, EFSA have set a Tolerable Weekly Intake, TWI, for dioxins. In 2018 EFSA reassessed previous guidelines and set the TWI to 2 pg/kg, bw (body weight) (Knutsen et al., 2018). In Sweden the average weekly intake of dioxins is 3.4 pg/kg, bw for persons aged 18-80 (Swedish Food Authority, 2023). As EFSA provides impartial scientific advice on risks with regards on food, the TWI given by EFSA is not legislative (EFSA, n.d.).

2.3.3 Size range of herring that goes to human consumption

The sizes that goes to human consumption in Finland are usually in the range of 23-85g (Parmanne et al., 2006). The same size selection is said to go to human consumption for the Northern Baltic herring fishery (Peltonen et al., 2007).

2.3.4 Dietary exposure - Risk vs. benefit

The human exposure of PCDD/Fs and dl-PCBs come predominantly from dietary exposure (Knutsen et al., 2018). The following paragraphs highlights the conclusions given from the articles found from the literature search described in Chapter 1.2.3 with their respective title given as heading.

Health effects of nutrients and environmental pollutants in Baltic herring and salmon: a quantitative benefit-risk assessment

A study by Toumisto et al. stated that the health benefits out weighted the risks of consumption of Baltic Herring for age groups over 45 years. For the group stated as the most vulnerable, women of child bearing age, the risks were at comparable levels as the benefits. TEQ values included in the assessment ranged from 1.95-3.08. (Tuomisto et al., 2020).

Marine and farmed fish on the Polish market: Comparison of the nutritive value and human exposure to PCDD/Fs and other contaminants

This article stated that herring had high nutritional values such as of omega fatty acids and vitamin D. Though these species also have high dioxin content and further states that studies should be done in order to assess the, cite, "balance between being beneficial and detrimental to human health". The values found in that article was 1.2 PCDD/Fs and 2.5 PCDD/Fs and PCBs (their own values) (Szlinder-Richert et al., 2011).

2.3.5 Historical Trends and Present Data of Dioxin Concentration in Herring

In a report published by IVL (Swedish Environmental Research Institute) long term data over the dioxin content in herring are presented (Hållén et al., 2020). The dioxin content in herring have decreased since the late 1970s for sites in the Stockholm archipelago and up to the Bothnian Bay. A more slight decrease is seen in the more Southern basins such as at the site Utlängan (located in SD25). The presented long term concentrations in the report by IVL are stated in pg/g l.p. (lipid weight) which complicates the comparison to the limits set by EU which are stated as pg/g w.w. (wet weight). In an article by Miller et al., 2012, the concentrations are partially presented on a wet weight basis. The measured PCDD/Fs in Utlängan since the first presented data (from 1986) have been seen to decrease since then. The presented measured values have been around 1 pg/g w.w. (TEQ PCDD/Fs) in Utlängan since the 1990s and been decreasing to below 0.5 pg/g w.w. in 2009. These TEQ values are from samples of the muscle tissue only, hence no skin or subcutaneous fat was included (Miller et al., 2012). The concentration found in the southern sites are lower than what is found in the Bothnian Bay. The gradient of the decrease in dioxins over time is steeper for the more northern sites than the southern (Hållén et al., 2020; Miller et al., 2012).

Further, in the previous mentioned report by Hållén et al., 2020, data from samples collected within the period 2015-2019 are presented. The report also presents data over dioxin content for the additional fish species included under the same dietary advice (given from the Swedish Food Agency) as herring. The levels of dioxins for all species are seen varying dependent on site and with variations within the sites as well. The dioxin content (TEQ PCDD/Fs & dl-PCBs) for herring ranged between around 15 pg/g w.w. and down to just above 0 with mean values for each basin varying from around 3 to 7.5 pg/g w.w.. Skin and subcutaneous fat were included for the herring samples. The range of dioxin content for the other species (salmon, trout, and whitefish) were seen at similar levels as for herring with ranges between around 1-15 and 0-20 pg/g w.w. Trout had a TEQ range within, approximately, 1-6.5 pg/g w.w. but only 8 individual samples was taken for trout whereas for herring 103 individual samples were taken. The mean TEQ values (pg/g w.w.) for salmon, trout, and whitefish varied between approximately 6.5, 4, and 1-6.5 (for three basins) respectively (Hållén et al., 2020).

3 Suggested measures from the assessed literature

When assessing the literature for the background and theory chapter, some suggesting measures on minimizing the dietary intake of dioxins via herring were found. They will be presented below in order to be used as a further comparison to this reports research question regarding an increased fishing pressure on smaller sized herring.

Multiple reports suggested an increased fishing pressure in order to decrease the dioxin content in the catches (Parmanne et al., 2006; Lundstedt-Enkel et al., 2010; Kiviranta et al., 2007). In the report by Parmanne et al., 2006, regarding herring in the Bothnian Bay, a positive correlation between the dioxin content and age were found (Parmanne et al., 2006). The authors then argues that an increased fishing pressure on the stock would lead to a younger age composition in the stock and thus in turn a lower dioxin content in the future catches (Parmanne et al., 2006). The same measure is presented in Lundstedt-Enkel et al., 2010 were the authors further states that the accumulation also is seen having a steeper gradient in older herring due too a shift in diet. Further in the article by Kiviranta et al., the same measure is again presented. They further argue that an increased fishing pressure could also lead to a higher growth rate among the herring since competition of food hence will decrease. The last statement is thus only valid if plankton abundance is a limitation for growth of the stock. The authors stated that to mitigate the dietary intake of dioxins via herring, an increase in fishing pressure would not be as efficient as dietary recommendations of herring (Kiviranta et al., 2007).

A fourth article by Peltonen et al., 2007 more thoroughly examines the potential decrease of dioxin content by increasing the fishing mortality (in the Northern Baltic). Their results shows that with an 50% increase of fishing mortality, there could be an 20% decrease of the TEQ in the catch. Though the authors further states that if the increased catches are assumed to go to human consumption the exposure to dioxins would be seen as increasing. The herring stock in the northern Baltic is seen to be density-dependent, hence growth rate is regulated by the total stock biomass (Peltonen et al., 2007). Moreover the authors writes that fishing alone are not enough to solve the problem as the found mean concentrations in the catch were higher than the, by EU stated, thresholds for dioxins.

In a report published by IVL, suggestions are given to the commercial fishery sector to target as small herring as possible in order to minimize the dioxin content in the catch (Hållén et al., 2020). This as accumulation for herring have been observed and seen correlating with length. For herring with in the length interval of 15-20 cm the dioxn content (expressed as TEQ) is decreased by 1 pg/g w.w. for each cm (Hållén et al., 2020).

4 Methodology of the Analyses

In the following chapters the methodologies for the Dioxin Analysis, the Prediction of Dioxin Content in the Yield and the Stock Assessment will be presented. Each chapter will begin with the aim of the calculations as well as certain assumptions and prerequisites.

In Appendix A all input data used in the calculations of the following chapters are included as well as their respective sources.

4.1 Dioxin Analysis

In the following chapter, the methodology of the dioxin analysis of the herring is explained. To gain information about the sampling methods preformed within the research field, the literature was searched. Articles found in previously searches for the background chapter was used as well as new searches. This was done in order to assess the sampling methods used in the field, e.g. if only the muscle or fillet of the fish should be analyzed and how to decide on what parameter to pool the fish after. Marint centrum and IVL further assessed in how to make the pools and the amount of herring needed for each pooled sample which further set some limitations for the pooling.

4.1.1 Preparations of the samples

Herring samples was prepared at Marint centrum in Simrishamn and sent to IVL to be further prepared for the dioxin concentration quantification. A total of 80 herrings were prepared from three different locations, Hanöbukten, Skillinge and Flatskär. These herrings were yielded from commercial catches in the area which is the reason for the three locations. The length, weight and sex was noted for each individual. Length was rounded to closest half centimeter and weight given by scale in grams with one decimal. The sex was determined by assessing the gonad of the fish, though this determination includes great uncertainty for the fish that was not in spawning season. For the majority of the spawning individuals the weight was noted for both the whole fish as well as gutted (since the gonads are of substantial weight in terms of total gutt content).

IVL requested a sample weight of approximately 1 kg, thus requiring pooled samples to be made. When deciding on which parameter to use to pool the fish, e.g. weight or length, the literature were searched to assess if one parameter was more suitable than the other. An article based on 60 herrings in the Baltic proper was assessed to determine correlation with age for the two parameters (Lundstedt-Enkel et al., 2010). Both variables showed a positive correlation with age, with a R^2 value slightly above 0,60 (0,64 and 0,61 for length-age and weight-age respectively) (Lundstedt-Enkel et al., 2010). A sorting after length was decided on as the correlation with age showed similar goodness as for weight-age and also due to the fact that gear selectivity often is described with length as parameter (Jennings et al., 2001). Before settling on sorting the pooled samples by length, a sorting by weight was also done. This showed some variations in the individuals included in each pool when keeping groups with. The fish was then pooled by length within each fishing area and 8 pooled samples was sent to analysis. The pooled samples contained between 7-12 individuals. Both skin, subcutaneous fat and muscle tissue was included in the dioxin analysis. In an report published by the Swedish Environmental Protection Agency samples including skin and subcutaneous fat have a higher concentration of fat than a sample of pure muscle. The fat content is stated to be at least 1,5 times higher. (Soerensen & Faxneld, 2020)

The final eight pooled samples are given below described by site and length interval. HB, FS and SK refers to Hanöbukten, Flatskär and Skillinge respectively and the numbers to 1-3 refers to the length group, 1 consisting of the shortest individuals at the site and 3 the longest. See figure 2 for a visualisation of the overlapping in lengths of the samples. All the included herring for each pool are shown in Table 5 as well as the determined sex and measured weight.

- Hanöbukten: HB1 (18-20cm) HB2 (20,5-21,5cm) HB3 (22-23cm)
- Flatskär: FS1 (19-20,5cm) FS2 (21cm) FS3(21,5-24cm)
- Skillinge: SK1 (14-21cm) SK2 (22-26cm)

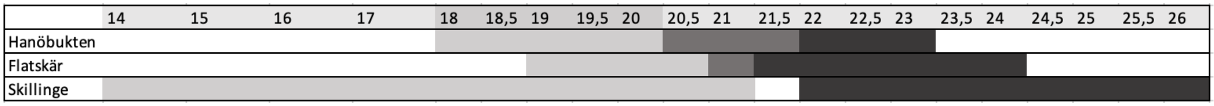


Figure 2: Shows the included sizes (length, cm) for each pooled sample and location.

Table 5: Shows data for all 80 herring included in the analysis. Included parameters are length, weight, (gutted weight) and sex. Pooled sample shows which pool the herring belong to, denoted as site abbreviation with a number. HB, FS and SK refers to Hanöbukten, Flatskär and Skillinge respectively.

Pooled Sample	Length (cm)	Weight (g)	Sex
HB1	18	26,2	M
HB1	19	33,4	M
HB1	19,5	32,5	F
HB1	20	50	F
HB1	20	34	M
HB1	20	34,5	M
HB1	20	43,7	F
HB1	20	39,4	M
HB1	20	48,1	M
HB1	20	33,6	F
HB1	20	37,4	M
HB2	20,5	37,5	M
HB2	20,5	42,2	M
HB2	21	52,5	M
HB2	21	39,8	M
HB2	21	44,6	M
HB2	21	43,5	M
HB2	21,5	61,8	F
HB3	22	51	?
HB3	22	50,7	F
HB3	22	47,5	F
HB3	22	44,5	F
HB3	22	51,4	F
HB3	22	67,6	F
HB3	22,5	46,1	F
HB3	22,5	60	F
HB3	23	54,9	F
HB3	23	49	M
HB3	23	64,6	M
HB3	23	83,4	F

Pooled Sample	Length (cm)	Weight (g)	Sex	Gutted weight (g)
FS1	19	55,9	M	
FS1	19	56,4	M	
FS1	19	54,4	F	
FS1	19	48	F	38,3
FS1	19	47,8	M	40,4
FS1	20	60	M	
FS1	20	47,4	M	
FS1	20	63,6	F	38
FS1	20	62,2	F	35
FS1	20,5	73	F	
FS1	20,5	60	M	
FS2	21	68,9	F	
FS2	21	62,2	F	
FS2	21	62,7	M	50,4
FS2	21	60,8	F	41
FS2	21	54,9	F	42,4
FS2	21	69,9	F	36,5
FS2	21	67,7	F	41,2
FS2	21	63,7	F	48
FS2	21	74	F	57,1
FS2	21	70,6	F	53,3
FS3	21,5	82,2	F	
FS3	21,5	66,3	M	58
FS3	21,5	63,3	F	46,8
FS3	21,5	76,6	F	58,1
FS3	22	83,7	M	68,7
FS3	23	81,4	M	
FS3	23	78	F	
FS3	24	94,2	M	50,7
FS3	24	96,8	F	87,7

Pooled sam	ength (cm)	Weight (g)	Sex
SK1	14	15,5	?
SK1	18,5	25,3	F
SK1	18,5	26	F
SK1	19	26,3	?
SK1	19	27,8	F
SK1	20	30,7	M
SK1	21	23	F
SK1	21	29	?
SK1	21	35,5	?
SK1	21	46,5	M
SK2	22	39	F
SK2	22	53,6	M
SK2	22	70	?
SK2	22,5	91	F
SK2	23	90,8	F
SK2	23	95,9	F
SK2	23,5	90,4	?
SK2	24	61,9	M
SK2	24	79,6	?
SK2	26	129	M

4.1.2 Calculations

The results from the lab were given as concentration expressed as pg/g w.w. (wet weight or sometimes referred to as f.w., fresh weight) of each screened congener. The analytical method used by the laboratory was HR-GC/MS (High Resolution Gas Chromatography/Mass Spectrometry). The TEFs presented in Table 3, Chapter 2.2.2, were then used to evaluate the total toxicity (Eq. 1) in order to compare it to the threshold values given in the regulation (EU) 2023/915. The total toxicity is calculated as shown in Equation 1 where the sum of toxicity of all 29 congeners are calculated letting c_x be the concentration of a congener and TEF_x its respective TEF value. The concentrations that were under the limit of detection were set to the limit of quantification, in accordance with the EU regulation (EU, 2023/915). The limit of quantification is two times the limit of detection as stated in the received lab results.

$$total\ TEQ = \sum_{x=1}^{29} c_x \cdot TEF_x \tag{1}$$

Further, by utilizing the TEFs it is possible to identify how much each congener contribute to the total toxicity of the sample. A percentage of this can be given by multiplying the concentration of a congener with its respective TEF value and dividing it with the TEQ of all congeners in the sample, Eq. (2).

$$\text{Contribution to toxicity from congener x } = \frac{c_x \cdot TEF_x}{total\, TEQ} \tag{2}$$

Lastly, a correlation of dioxin content and length were needed which would be used for predicting dioxin content in the catch. For the three pooled samples from Hanöbukten a positive correlation were seen. A exponential trend line were fitted to these three TEQ values plotted against the length. This correlation between length and dioxin content will be used as a "maximum" scenario for predicting dioxin content with varying catch compositions in Chapter 4.2. The correlation is shown in Equation (3) where Y is the dioxin content (pg/g w.w.) and X is the length (cm) and e is the base of the natural logarithm.

$$Y = 0,2048 \cdot e^{0,118 \cdot X} \tag{3}$$

4.2 Methodology for Predicting the Dioxin Content in the Yield

The following calculations were done to predict how the dioxin content in the catch vary with gillnets retaining different sizes of herring. This was conducted based on the prediction that the dioxin content should be higher in larger (length wise) herrings due to bioaccumulation and thus a fishery targeting smaller individuals would have a lower dioxin content. Predictive models for fisheries includes various parameters and many will be disregarded in the scope of this thesis. Thus, the following calculations does not aim to produce quantitative numbers as a certain result but rather a more qualitative assessment on the subject.

The model used in this assessment is modified from the stock assessment model given in the course *BIOR87 Limnology and Marine Ecology - Concepts and Processes* with supervising from Anders Persson. The data used was retrieved from ICESs report *Baltic Fisheries Assessment Working Group (WGBFAS)* from 2023 and 2022 where all relevant data from the Baltic in regards to this modelling exercise was found. It should be noted that no official numbers of landed herring was received from Russia and hence these numbers were approximated by ICES from limited data from regional resources (ICES, 2023a). To give more depth to the model, a second relationship for weight-at-age were included from a study by Lundstedt-Enkel et al., 2010.

When conducting this estimation, many variables and states had to be assumed constant or overruled in order to make the analysis possible within this time frame. In the *Manual on Estimation of Selectivity for Gillnet and Longline Gears in Abundance Surveys* variables affecting the "catching" of fish are described (Hovgard & Lassen, 2000). Some main parameters mentioned were hanging ratio, netting material, color of netting that all affects the retention probability of fish. These parameters will not be included in this thesis.

The following calculations does not include the probability of the fish encountering the equipment but only the probability of being retained.

4.2.1 Calculations

The yield can be calculated by multiplying the catch (expressed as caught individuals of each age class), C_X with the weight-at-age as shown in Equation (4).

$$Y = \sum C_X \cdot W_X \tag{4}$$

The catch at time t for a year class, C_t can be expressed as shown in Equation (5) (Jennings et al., 2001). N_t is the amount of individuals alive at time t. The fishing mortality and natural mortality is denoted as F and M and are together being expressed as Z. Further e is the base of the natural logarithm. The mortality variables, F and M, are found in ICES report (ICES, 2023a) for each age of herring up to 8 years.

$$C_t = \frac{F}{F+M} \cdot N_t(1 - e^{-(F+M)}) = \frac{F}{Z} \cdot N_t(1 - e^{-Z}) \tag{5}$$

The amount of alive individuals is given in Equation (6) (Jennings et al., 2001). Where N_{t+1} is the amount of individuals alive at time t+1 and correspondingly N_t the amount alive at time t. Time t can be seen as given in years as depicted in Equation (6) where the number alive at year one, N_t, is set equal to number alive aged one, N_X.

$$N_{t+1} = N_t \cdot e^{-Z} \longrightarrow N_{X+1} = N_X \cdot e^{-Z} \tag{6}$$

The parameters N_{t+1} and C_t are then calculated for each age class.

To examine how the catch composition changes with fishing gears and their selectivity, the fishing mortality F will be varied with each age group. The variable, F, given from ICES is altered, denoted F_{alt}, as described in Equation (7) for each year class. The lowercase f is a factor that is simply scaling the fishing pressure up or down, e.g. how much is fished. In this model f is held constant at 0.1 as the retrieved F from the literature are "set" after the trawl fisheries. Thus the gillnet fishery modelled in this thesis is assumed to be 10% of the current fishing mortality. The proportion reduction P is the relative change in retention probability of different sized fishing gear, in this case gillnets.

$$F_{alt} = F \cdot f \cdot P \tag{7}$$

P varies with the retention of different sizes of herring which then is dependent on length. Thus, a relationship between the length and age is needed. As ICES provides data of weight-at-age for SD25 a relationship between how weight and length correlates was needed.

From the literature an exponential relationship between length and weight have been shown, presented in Equation (8), where W is the weight (gram), L the length (cm) and a and b are constants (Lundstedt-Enkel et al., 2010).

$$W = a \cdot e^{(b \cdot L)} \tag{8}$$

From the 80 sampled herrings 67 was scatterplotted and a exponential equation was fitted for them. From this equation the a and b value was retrieved. For the herring in spawning season, the weight is given as gutted weight (as gonads can have a substantial effect on the total weight). The reason that only 67 fishes were included out of the sampled 80 was that only the total weight noted at first and not the gutted weight as that was something thought of later.

By using the rules of logarithms and rewriting Equation (8), the length L, can be expressed as shown in Equation (9). For both a and b, a higher value gives a lower length.

$$L = \frac{ln\frac{W}{a}}{b} \tag{9}$$

The weight-at-age retrieved from ICES report (ICES, 2023a) were then used in Equation (9) together with the a and b values given from the correlation from the 67 samples. This then yielded lengths for each age (1-8yrs).

To assess how the assessed weight-at-age influence the results from the model, two correlations for weight-at-age were included in the calculations. The second weight-at-age relationship, retrieved from Lundstedt-Enkel et al., 2010, is shown in Equation (10) where W_X is weight-at-age and X is age. These weight-at-age were then also used in Equation (9) to retrieve a second result for the length-at-age.

$$W_X = 29,61 + (-8,319) \cdot X + 2,898 \cdot X^2 + (-0,1131) \cdot X^3 \tag{10}$$

The selectivity for the gillnets have been assumed to follow a normal distribution. The standard deviation have been chosen to a number similar to what have been found in the literature and the mean value have been varied and represents the target length of a certain mesh sized gillnet. Retention probabilities for each year class, with length-at-age received from Equation (9) as parameter, were then calculated utilizing excel's NORM.DIST function. The standard deviation were set to 4, 4,5 and 5 after assessing the literature (Hansson and Rudstam, 1995). The reason for three values being chosen were to assess the impact the standard deviation had on result as this was a parameter that was estimated and further assumed to be constant over all mesh sizes.

The predicted total dioxin content in the yield, Equation (11), can be calculated by simply multiplying the expected dioxin content per year class, c_X, to Equation (4). The expected dioxin content per year class, c_x, were calculated from the correlation between length and dioxin. The length-at-age was based on the weight-at-age and thus the dioxin content-at-age could be calculated. Two weight-at-age were used, both from ICES (ICES, 2023a) as well as the weight-at-age stated in Equation (10).

$$\text{total Dioxin content in catch } = \sum C_X \cdot W_X \cdot c_X \tag{11}$$

By utilizing the function "data table" in excel, multiple yields and thus dioxin contents in the catch were calculated with the variable of the "target length" in the gillnets varying. Two cases were done for these calculations, one based on ICES presented weight-at-age and the second with the weight-at-age correlation found in Lundstedt-Enkel et al., 2010.

To receive a scenario the reflects the current fishery, the fishing mortality at age, today dependent on the trawling, were kept in the model as a "background" fishery at 90% of its current value. Another fishing mortality were then added to this which then represented the yield from a gillnet fishery. This was included in the model by adding variables to the Z (total mortality) variable. Equation (12) shows the altered total mortality Z as the sum of the natural mortality, the trawl fishery mortality and a gillnet fishery mortality set to 0,1 of the trawled mortality and scaled by P (relative change in retention probability for gillnets).

$$Z = M + 0,9 \cdot F + 0,1 \cdot F \cdot P = M + 0,9 \cdot F + F_{alt} \tag{12}$$

4.2.2 Deciding on which Fishing Gear to Include

To assess if the catch composition, e.g. the different sized herring included in a catch, affects the mean dioxin content per kg of the catch, selectivity curves/parameters for the specific equipment is needed. The catch composition from an equipment can be given via retention rate, which describes the probability of a certain size of the fish to be retain and thus caught with the equipment. When deciding on which equipments that were assessed in this report, trawl was considered an option. This was due to the fact that most of the landed herring from the Baltic is fished with trawls compared to other methods such as gillnets. When exploring the possibilities further, Vesa Tschernij, working on Marint centrum in Simrishamn (personal communication, January 9th, 2024) stated some of the problems with the selectivity for trawls targeting herring. Firstly the survival rate for smaller herring that escape a trawl with a larger mesh size is very low (approximately 10%). Therefore a smaller mesh could be used to retain and then land those individuals as well so that they can be counted for against the quota. Inclusion of other selectivity measures, such as a sorting grid that will let larger fish escape, has not been shown efficient for herring. The catch composition of trawled herring have a large spectra of sizes and as selectivity measures such as mesh size and sorting grid does not prove efficient for optimizing the retention of a certain size span of herring other fishing gears were examined. Gillnets for example, have a more narrow selectivity curve over retained sizes (Jennings et al., 2001). Though, Tschernij stated that the predation from seals on the retained herring complicates the fishery making it more difficult for fishers to achieve a sustainable revenue.

4.3 Methodology for Stock Assessment

The modelling in this chapter is done to further evaluate the effects of a fishery targeting younger herring. This is to find out if there is potential to fish on smaller sizes, to decrease the dietary intake of dioxins, without disturbing the population dynamics or size. This will be done by assessing how many more individuals that is needed to receive the same yield with a shift in fishing mortality towards smaller sized herring, e.g. here seen as younger herring. Three scenarios will be used in this assessment: 1) a 30% increase in ages 2-3 in the catches (weight wise), 2) a 50% increase in ages 2-3 in the catches (weight wise) and 3) only ages 2-3 in the catches. The scenarios were chosen by assessing the literature, e.g. in a article by Peltonen et al., 2007 the impact of a 50% increase in fishing mortality were assessed. Thus, scenarios with numbers within a similar interval were chosen. The third scenario were included to visualize the trend of the model when scaling up the fishery pressure on 2-3 year old herring. Hence, this is not seen as a likely scenario but were included for further understanding of the impact on the stock.

As the statistics presented in ICES report ICES, 2023a often only assesses ages up to 8 years the following assessment will be covering herring up to 8 years. In some data points herring at the age of eight or older will be referred to as 8+ years as this is commonly how it is presented in records from ICES.

4.3.1 Calculations

To analyze what impact a fishery targeting younger individuals would have on the population the current catch composition was used as reference point. ICES have data over estimated caught herring (number individuals per age) in subdivision 25. This was used together with the weight-at-age from ICES as well as the weight-at-age from Lundstedt-Enkel et al., 2010 to determine how different assessments of weight-at-age affects the fishery.

The fishing mortality per age group (expressed in number individuals) by ICES is assumed to be based on their given weight-at-age relationship. The contributing weight of each year class were then calculated to get the yield (in tonnes). Further the contribution by weight (in percentage) from each year class, $\%_X$, were calculated. To maintain the same yield but changing the catch composition, i.e. $\%_X$, Equation (13) were set up. The yield on the left hand side is expressed as a weight and the yield on the right hand side is expressed in number individuals.

$$Yield = \sum(W_X \cdot \%_X \cdot Yield) = \sum e_X \tag{13}$$

To change the catch composition a correction factor were added to Equation (13) as demonstrated in Equation (14). The e will be held constant and a be the varying variable. An increase of catch with 30 percent for the year classes of 2 and 3 years will thus be equivalent to a a value of 1,3. In order to maintain the same yield the a values for the remaining ages needs to be decreased. For simplicity, the a value will be set to the same for age classes 1 and 4-8. By then isolating a from Equation (14) and letting a_2 and a_3 be set to 1,3 Equation (15) is given.

$$Yield = \sum(e_X \cdot a_X) \tag{14}$$

$$a = \frac{Yield - (e_2 + e_3)1,3}{e_1 + e_4 + e_5 + e_6 + e_7 + e_8} \tag{15}$$

With the calculated a value, a new e_X (tonnes) could be calculated for each age and transformed to number individuals. The total amount of number individuals caught with the targeting-scenario can then be compared to the number individuals with the previous catch composition. By this comparison, a percentage can be derived for how many more fishes that will die, with an increased fishing pressure on age groups 2-3 year olds, than with today's catch composition (Eq. (16)). The yield, Y, is expressed as catch in numbers.

$$\% = \frac{Y_{new} - Y_{present}}{Y_{present}} \tag{16}$$

Another weight-at-age relationship was included in the analysis. This was done due to the fact that the weight-at-age have great influence on how much a number of individuals contribute to the total yield in tonnes. The weight-age relationship were chosen to be included from the beginning of the calculations, e.g. from Equation (13). A further discussion on these calculations is held in Chapter 6.

5 Results

5.1 Weight-Length Relationship

A positive correlation was seen between the length and weight for the sampled herring (Fig. 3). The equation of the fitted exponential trend line and its R^2 are included in the figure.

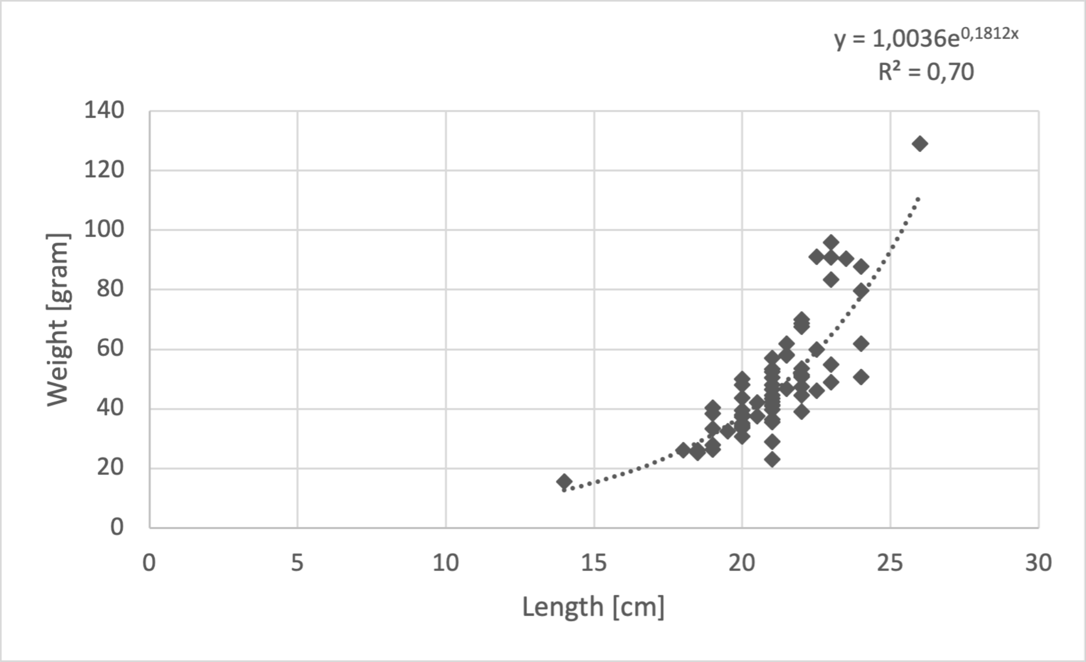


Figure 3: A scatterplot over 67 measured samples, plotted as weight against length. A exponential trendline have been fitted to the measurements in Excel and its equation as well as R^2 value are included in the image.

The retrieved a, b and R^2 values are also given in Table 6 as well as the corresponding values found in the report *The dependence of organohalogen compound concentrations on herring age and size in the Bothnian Sea, northern Baltic* by Lundstedt-Enkel et al., 2010 for comparison.

Table 6: The retrieved a, b and R^2 values from the 67 herrings. The corresponding values from the litterature is also shown for comparison (Lundstedt-Enkel et al., 2010).

	Samples	Lundstedt-Enkel et al., 2010
a	1.0036	3.193
b	0.1812	0.1430
R^2	0.70	0.9568

5.2 Dioxin Analysis

No correlation between length and dioxin content were found for the eight pooled samples (Fig. 4). The mean TEQ value of all eight samples were 1.03 and 1.19 pg/g w.w. for PCDD/Fs and dl-PCBs respectively. The mean TEQ for PCDD/Fs and dl-PCBs were 2.22 pg/g w.w.. The threshold values given from (EU) 2023/915 are 3.5 and 6.5 pg/g w.w. for PCDD/Fs and PCDD/Fs & dl-PCBs respectively. See Appendix B for all calculated TEQ values for each congener and site.

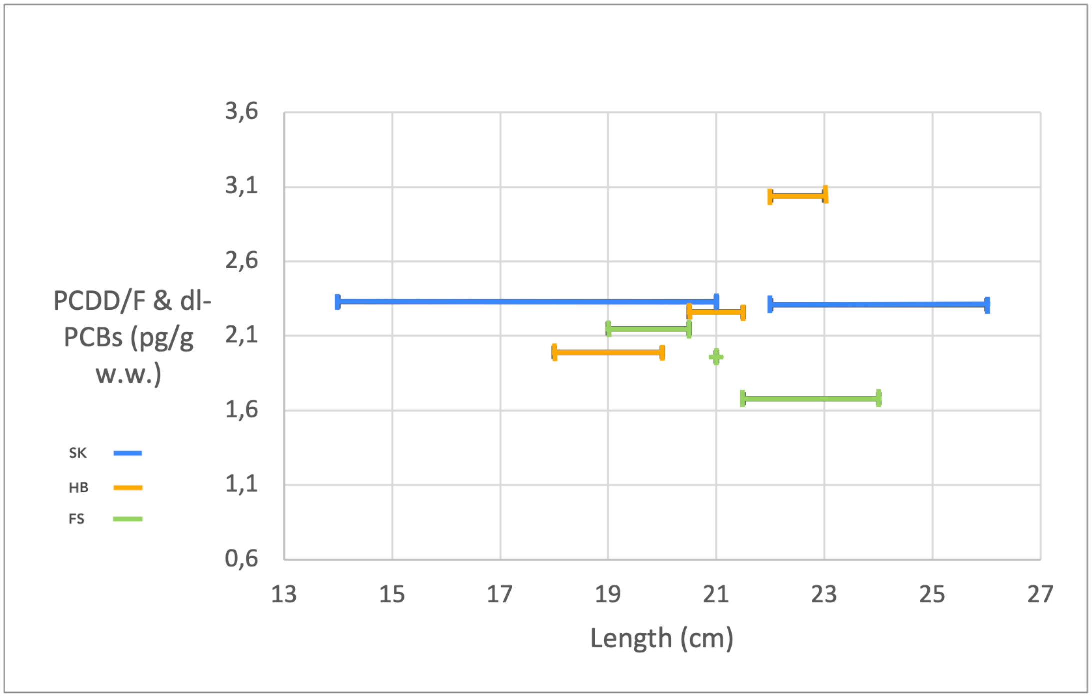


Figure 4: The dioxin content for the 8 pooled samples are plotted against the length. The length-interval of each pooled sample is showcased in the graph. The dioxin content in pg/g w.w. (expressed as TEQ) is seen on the y-axis and the length of the herring is seen on the x-axis. The three colors blue, orange and green represent the sites Skillinge, Hanöbukten and Flatskär respectively.

However, a positive correlation was seen for the three samples in Hanöbukten (isolated and plotted in Fig. 5). This correlation were further used as the ”maximum correlation” for the calculations generating Table 7 in Chapter 5.3 *Predicted Dioxin Content in the Yield*.

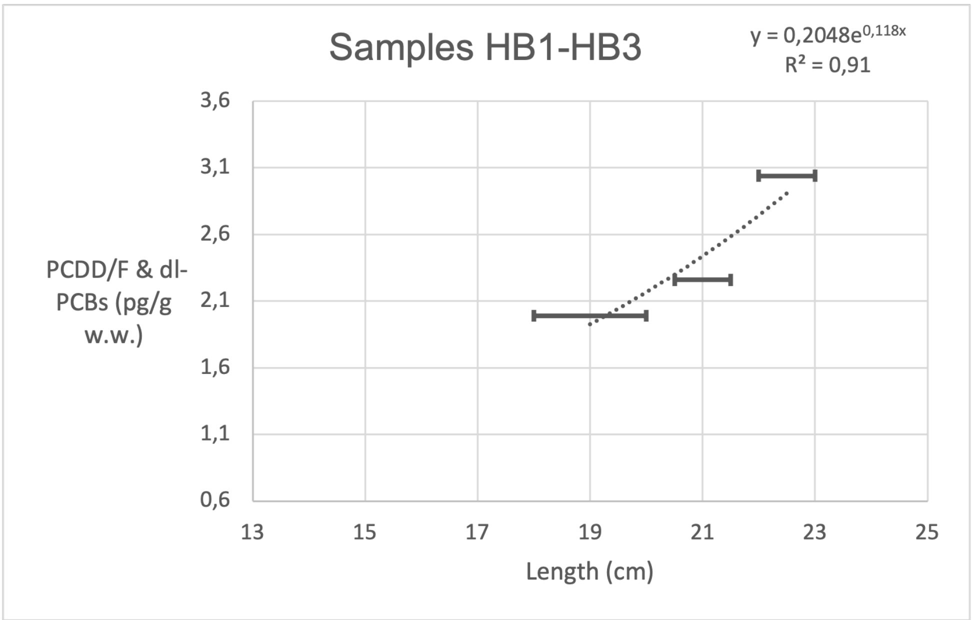


Figure 5: The correlation between dioxin content (expressed as TEQ) and length for the three pooled samples from Hanöbukten. A fitted trend line is included in the figure and its corresponding equation and R^2 value.

The congeners contributing the most to the TEQ for all 8 samples was PCB 126 followed by 2,3,4,7,8-PeCDF. These two made up 58-65% of the total toxicity. PCB 126 alone made up 35-49% of the total toxicity. For all samples PCB 126, 2,3,4,7,8-PeCDF, together with 2,3,7,8-TCDF, 1,2,3,7,8-PeCDD and PCB-169 were the top five most contributing congeners. These five contributed to 89-90% of the total toxicity in the samples.

In terms of the quantitative concentration, the dl-PCBs made up the greatest amount of the total dioxin content with PCB 118 being the largest contributor for all samples.

The PCDD/Fs and dl-PCBs had a similar contribution to the total toxicity (Fig. 6).

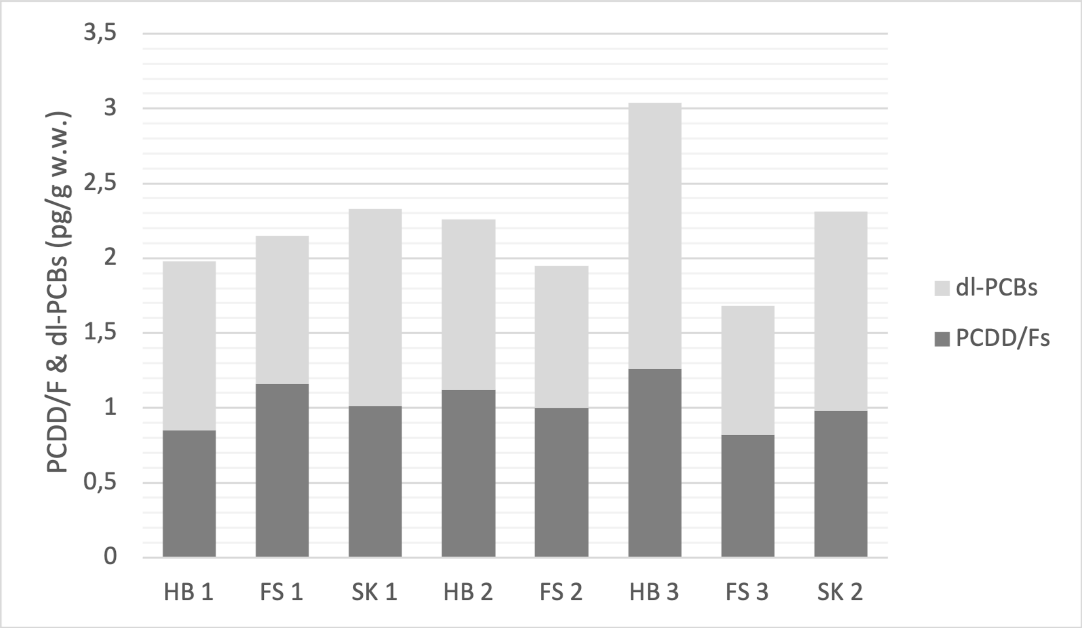


Figure 6: The total dioxin content for each sample and the fractions of PCDD/Fs and dl-PCBs.

The contribution of a congener can be expressed as the contribution to the total quantitative concentration or the contribution to the total toxicity (TEQ). The congeners that are the top contributers to quantitative concentration departs from the congeners contributes the most to the toxicity (Fig. 7). The contribution-pattern (HB1 showed in Fig. 7) was similar for all eight samples.

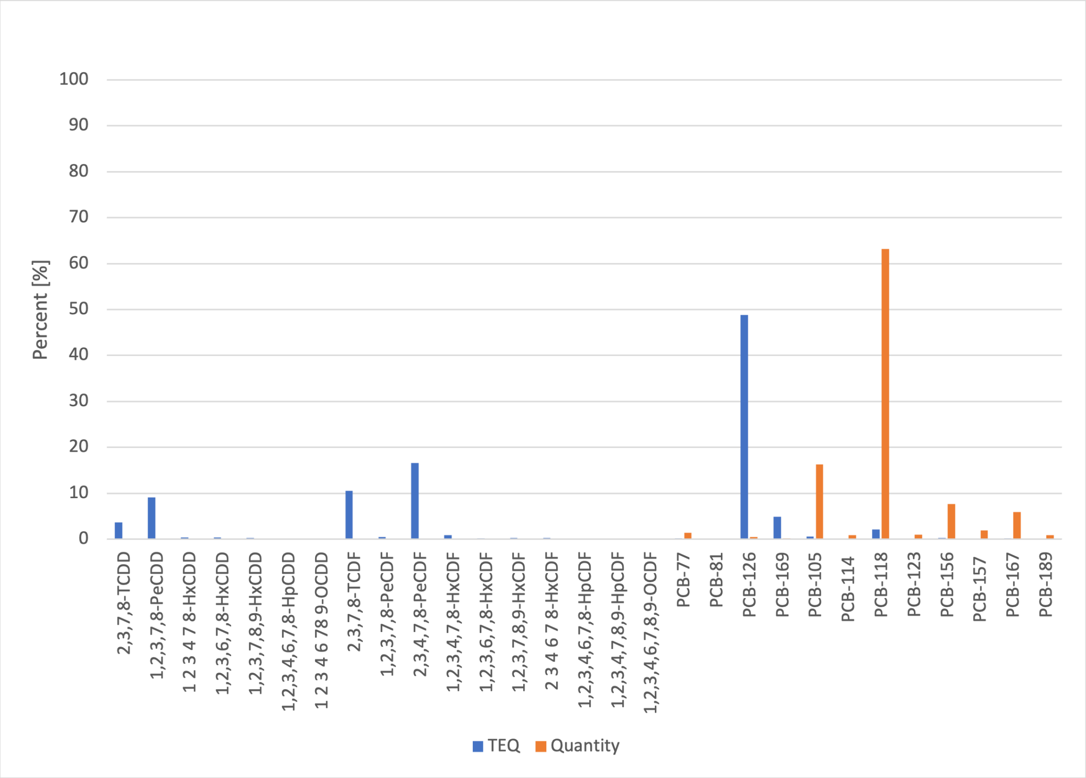


Figure 7: The percentage contribution to toxicity (blue) and quantitative concentration (orange) for each of the congeners for one of the eight samples (HB1).

A positive correlation is seen for the dioxin content (expressed in TEQ) and the lipid content (in weight percent) (Fig. 8).

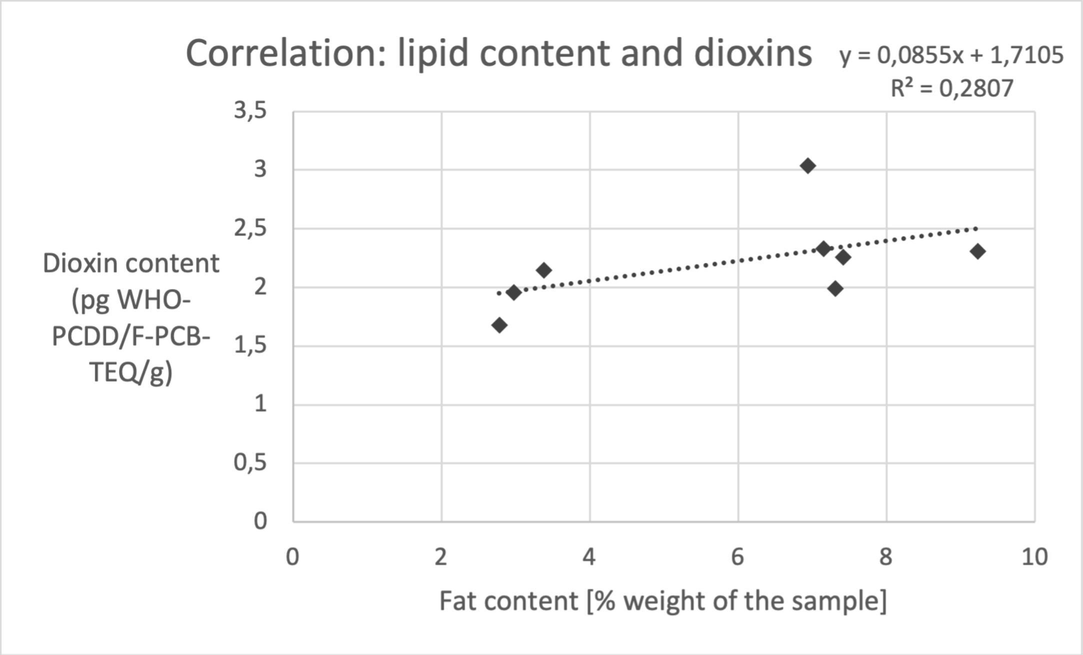


Figure 8: The dioxin content (expressed as TEQ) for the eight samples are plotted against the lipid content of the samples. A linear trend line were fitted in excel with its corresponding equation and R^2 value included in the figure.

5.3 Predicted Dioxin Content in the Yield

Table 7 contains the results generated in Chapter 4.2 *Methodology for Predicting the Dioxin Content in the Yield*. The dioxin-length correlation presented in Figure 5 was used in the calculations. The mean expected dioxin content in the catch (expressed in TEQ) are shown for 6 different target lengths of herring, each representing the mean value of the normal distribution. The expected dioxin content are meant to represent the dioxin content given from a gillnet fishery.

Table 7: The predicted dioxin content in the expected catch (PCDD/Fs and dl-PCBs TEQ pg/g) and how it changes with different sizes of retained herring. The values are shown for three varying standard deviations and two varying weight-at-age.

Mean value (target length, cm)	16	18	20	22	24	26
ICES weight-at-age, σ=4	2,47	2,49	2,51	2,53	2,57	2,61
Literature weight-at-age, σ=4	2,52	2,72	2,89	3,04	3,18	3,31
ICES weight-at-age, σ=4,5	2,47	2,49	2,50	2,52	2,55	2,58
Literature weight-at-age, σ=4,5	2,52	2,68	2,83	2,97	3,10	3,22
ICES weight-at-age, σ=5	2,47	2,48	2,50	2,51	2,53	2,56
Literature weight-at-age, σ=5	2,52	2,65	2,78	2,90	3,02	3,13

5.4 Stock Assessment

Table 8 shows the results from Chapter 4.3. Three different targeting scenarios are calculated and for each two weight-at-age correlations are used. The output is presented as increase in percentage of mortality on a number-individual basis. Hence, if the fishery were shifted towards smaller sized herring, with a 30% increase in retention of ages 2-3 year olds, would result in 0.7% or 1.2% more herring (in terms of number individuals) needed for the same yield as the current catch composition.

Table 8: The increase in mortality, in terms of number individuals, with a change in catch composition while keeping the yield (in tonnes) constant. Scenario ↗ 30% correlates to an increase in retention rate of 30% for ages 2-3 and Scenario ↗ 50% for a 50% increase.

	ICES weight-at-age	Litterature weight-at-age
Scenario ↗ 30%	0.7%	1.2%
Scenario ↗ 50%	4.5%	7.6%
Scenario only 2-3 yr olds in catch	4,6%	46,5%

6 Discussion

6.1 Dioxin analysis

As can be seen from the results (Fig. 4) from the dioxin content in terms of toxicity (TEQ) all eight samples contained less dioxin than the EU threshold values (EU, 2023/915) for PCDD/Fs and dl-PCBs. The TEQ-values for the eight samples were between 26 and 47% of EUs threshold for PCDD/Fs & dl-PCBs. With the samples also containing skin and subcutaneous fat the expected dioxin content could be higher than in what would be found in muscle tissue only as literature point towards a higher dioxin content when samples are done including skin and subcutaneous fat (Miller et al., 2012). For human consumption the subcutaneous fat and skin of herring can be eaten, thus an analysis containing skin could be seen as more suitable but it could be argued for to not include skin and subcutaneous fat as the fish sold also could be skinned. When comparing the dioxin content in this thesis to previously measurements taken around the same area (Miller et al., 2012), this thesis number are higher which most likely would depend on the inclusion of skin and subcutaneous fat in the samples.

All samples showed similar patters for the congeners (though individual differences are cancelled out by the pooled samples). All three sites had the same five most contributing congeners (to toxicity). These five congeners also showed to make up between 89-90% of the total toxicity thus the congeners that might be of most concern and thus could be further assessed in regards to dietary exposure via herring and/or origin. Although, as the origin of PCDD/Fs in the Baltic mainly comes from atmospheric sources and are formed unintentionally it poses a challenge track them.

There was no clear relationship between length and dioxin content (Fig. 4). However, as only eight datasets are used, a correlation of any kind would come with great uncertainties. When adding the lipid content in relation to length and dioxin content (Fig. 8) a slight positive correlation were observed. This could be part of the explanation of the variation in dioxin content over length as both high and low lipid contents were found for all length groups. Moreover, a correlation between length and dioxin content have been found in literature, as well as a correlation with age and dioxin content (and age in turn correlates with length) (Hållén et al., 2020). The assumption that a correlation exist, but with great individual deviations, is considered reasonable for the following calculations that were done.

The pooled samples eliminates the individual variation for dioxin content. Though in a sense on dietary exposure the individual variation in herring might be less interesting to follow. The pools also comes with uncertainty when drawing conclusions between length and dioxin content. E.g. the length group from Skillinge including 14-21 cm, only had one individual at 14 cm and the second smallest at 18,5 cm. In hind sight, the smallest individual at 14 cm could have been excluded from the pool as it's contributing weight also is very small to the total sample to obtain a more discrete length interval.

6.1.1 Dietary Exposure from the Current Herring Fishery

With EFSAs stated TWI as 2 pg/kg b.w (Knutsen et al., 2018) (note that this value is given for all genders), a woman of 60 kg could ingest 120 pg/week. As fish and other seafood make up approximately 60% of a woman's exposure to dioxins (Swedish Food Authority, 2023), 72 pg/week could then be seen as 'allocated' to fish. Relating this to the mean dioxin content found in the catch, 2.22 pg/g, a total of 32 g/week could be eaten in order to stay within the TWI given from EFSA.

From both the literature review on risk-benefit on herring consumption in regards to dioxin a gap in research was found. Some of the articles stated that further assessments on risk-benefit had to be done and many of the assessed articles did not include a risk assessment of herring. As the data on dietary habits and dioxin exposure were from 2010 that the Swedish Food Agency seemed to use, higher levels of dioxin might have been used in the assessment. This further argues for, as previously suggested, a more updated assessment of risks versus benefits and total dietary exposure if dioxins from Baltic herring.

6.2 Predicted Dioxin Content in the Yield

For the research question if a targeted fishery can be done on one size group in the stock to minimize dioxin content in the catch, no clear answer can be given. As no correlation between length and dioxin content was seen, a targeted fishery on smaller sizes might not result in a lower dioxin intake for humans. However, there are a lot of uncertainties involved in the dioxin analysis compared to sizes as previously mentioned. Some included are the size variation within each pooled sample, morphological differences such as length-at-age and few datasets. It should further be stated that a correlation between length an dioxin content found in the literature, mainly as dioxins are shown to correlate with age which in turn correlates with length.

The positive correlation for length and dioxins from the samples from Hanöbukten were used as a "maximum scenario" to yield the results presented in Table 7. It is seen that there might be a small profit in terms of minimizing the dioxin content in the catch when fishing on smaller individuals. The chosen standard deviation on the selectivity showed to have a lower impact on the results compared to the chosen weight-at-age. Using ICES weight-at-age the difference would be so small that a targeted fishing after length would not necessarily show to be efficient. This is due to the fact that the growth rate for ICES weight-at-age is very low hence the length are very similar resulting in a more "mixed" catch in terms of the different age classes included in the catch. If the weigth-at-age and thus corresponding length in SD25 were to follow the weight-at-age found in Lundstedt-

Enkel et al., 2010 a fishery targeting smaller sized herring could potentially decrease the dioxin content in the catch by approximately 0,8 pg/g if shifting the targeted length of herring from 26 to 16 cm (Tab. 7). Though these results are highly uncertain and based on the "maximum scenario" found from the samples. Further more, the selectivity of gillnets are often assumed to have a normal distribution which is what is included in this thesis model as well. In reality the catches would be more varied in terms of catch composition and thus dioxin content. When comparing the values given from the model (Tab. 7) with the dioxin content of the eight samples (Fig. 4) the predicted content for the 16 cm target length catches is higher than the TEQ values calculated for 7 out of the 8 samples.

As a sorting after length might show to have a potentially positive effect on dioxin content other variables that affects the dioxin content are "lost" when sorting after length. Lipid content, spawning season, gender and age can all influence the dioxin content.

6.3 Stock Assessment

If catches were to premiere smaller individuals, increasing retention in 2-3 year-old herring with 50 percent, the quotas could be compared to rising with 4.5 to 7.6 percent. Putting these numbers in comparison with the yearly quotas, a 32% increase of the quotas (in SD 25-27,28.2, 29, 32) were seen from 2022 to 2023. An increase of the quotas of 4.5% would affect the stock, but are not a very large number in comparison to how quotas can change on a year-to-year basis. With the included "extreme" scenario of only fishing on herring aged 2-3, one can more clearly see the effects that the weight at age assessment have on the results, with an increase of 4,6 versus 46,5% in mortality (in terms of number individuals per set yield) when compared to today's catch composition.

These number are dependent on which weight-at-age is used for the assessment. The increase in catches (expressed as total number individuals) is due to the fact that younger individuals weight less and thus more individuals is "needed" to get the same yield. Though, as a shift in catch composition, premiering smaller individuals, could potentially be seen as a problem due to increased mortality there are other aspect of the problem as well. Depending on fishing gear a fishery that increases catches of smaller individuals might not have an as large impact of total deaths as anticipated. With trawl as an example, the escaped fish (fish that encounter but escapes the gear) could be fewer by retaining smaller sizes in the catch. As the survival rate of these "escapies" are shown to be low, by retaining them we can count them towards the quotas. Thus Premiering catches on smaller sizes might not increase the mortality of herrings as much as a model predicts when accounting for the potential of less fish escaping the gear.

One important flaw of the model for stock assessment is the weight and length correlation. As the R^2 value for the length-weight relationship is 0,70, implies causality to 70%. In the model of the catch, the length is seen as only dependent of the weight (at age) which causes some errors due to a low R^2. Hence, other variables affect the length-at-age than just the weight which the model presumes.

When doing calculations on the stock assessment, it became transparent how different methods of calculations affected the result. It showed to be challenging to back-track ICES calculations and numbers, as e.g. when transforming the caught herring (in numbers) to catch in weight the received number did not add up to the quotas of that year. As for the stock assessment many assumptions had to be made and thus the results given from this could be seen as what a change in targeting ages in herring fishery might result in. This further shows the in depth knowledge needed when doing analyses like this as well as transparency needed of larger institutions like ICES in order for their data to be assessed further in analyses. It shall be stated that with a longer time frame, it might have been possible to receive more information from ICES on how their calculations are made and the assumptions used. Though what is presented in their annual reports are the most in depth data there is on the Baltic fishery in numbers.

6.4 Potential use with Regards to the Current Herring Fishery

Targeting smaller herring could be preferred for human consumption as there might be a slight decrease in dioxin content. All sizes of herring are allowed to land (EU 2019/1241) which thus enables such a fishery. To get a catch with a majority of smaller sized herring, a selective fishing gear is needed. Gillnets have a more narrow selectivity curve than the trawls and would in that respect be suitable. However, seals have become a great concern for the gillnet fishery in the Baltic Sea (Lundin et al., 2012) and such a fishery might not be profitable at all sites. Though new fishing gears which are striving to be ”seal-proof” such as pontoon traps could be an alternative to further explore and put more research on to support the local small scale fishers. As the majority of the herring fishery today is conducted with trawl a sorting after landing might be more likely than to fish for smaller sizes.

The majority of today’s catches are used for industrial purposes (e.g. fish meal and oil), thus a shift towards catch smaller sizes are not likely for the whole herring fishery sector. If a shift would be realized for the fish that goes to human consumption the effect on the stock are predicted to not be that intrusive (in terms of amount of individuals caught). However, more research would be needed before realizing such a suggestion as herring also plays a role in the Baltic ecosystem as an important prey fish for predators such as cod, birds and seals (HELCOM, 2013). Multiple of the assessed articles argued for an increase in fishing pressure as a measure to reduce the dioxin levels in the catches. Today, this does not align with ICES advice on quotas nor the set quotas from EU for 2024. As the stock today already is very fished on an increase in fishing pressure today would not be probable nor ”safe” in terms of the stock abundance. As the references suggesting this measure were from 2006-2010, the conditions of the stock and dioxin content were different from today as the dioxin content have been seen to decrease since then. The increased fishing pressure might have shown to be efficient for a stock with measured higher dioxin content.

As it may sound straight forward to fish on smaller individuals and thus getting a lower dioxin content in the catches the reality holds many more difficulties in front of such an idea. Mainly due to the many parameters affecting dioxin content in Herring.

6.5 Improvements of analysis

For future assessments on herring size (length) and dioxin content some improvement to the study could be made. Firstly an age assessment could be done for each fish in order to see the age that are included in each length group. As this research aim to understand evaluate if a sorting by size will be beneficial to the dioxin content (in a dietary sense), it mirrors what could be done in reality as the fish that goes to human consumption not will be sorted by age (due to cost and the profitability). Though, a age determination in the study would however give the analysis more depth as an additional variable affecting the dioxin content would be included minimizing the uncertainties as one more variable is explained/measured. Secondly, the selection of the sampled fish could be improved. As all fish assessed also had to be included in a length group the possibilities to sort by length was limited to a certain degree. By assessing more fishes, more discrete length groups could be done and fishes ”in between” length groups could be excluded. Thirdly, a more reliable result would be yielded with more data sets and a larger difference in length for the samples. This to further assess the variations between the samples and to find of there are clearer correlations between dioxin content and length.

6.6 Future Research

For future research a more in depth analysis of ICES data and calculations would be interesting. As could be seen in the result, the weight-at-age approximation have great influence on the results. ICES numbers shows larger weights-at-age in the southern SDs than the northern which correlates with the literature. Though, ICES weight-at-age is seen to follow a very low growth rate from age 2 and older. Thus for individuals to reach a weight of over 60 grams they would need to be over 9 years of age (speaking in terms of mean). The values found in the literature (Lundstedt-Enkel et al., 2010) rather suggest that a weight of 60 g is the mean for a 6 year old herring.

As five congeners showed to make up for up to 90% of the total toxicity further future research on these would be interesting in terms on mitigating the dioxin problem in the Baltic. Though, as stated in Chapter 2.2 dioxins occur spontaneously via e.g. combustion, which perhaps complicates a mitigation of certain congeners rather than mitigation of all. As the congeners contributing the most to quantitative concentration versus toxicity didn't overlap (Fig. 7) a mitigation of all dioxins might not have an as large effect on the toxicity as the most recurrent congeners are not the top contributors to toxicity.

As the Baltic herring fishery today mainly are conducted with trawls, there were a lot of data scarcity for other gear types both regarding selectivity and management. If one aims to further explore in smaller scaled fisheries it would be suggested to preform interviews with local fishers handling these gears.

7 Conclusions

The total dioxin content for all eight samples are well below EUs threshold on the allowable content in herring. To improve the methodology used for the pooling of samples, more specimens should be assessed for making the samples in order to be able to compose more discrete groups on length. As for the dietary recommendations given from the Swedish Food Authority, they are inline with the TWI given from EFSA. Though a new consumers survey could be done to assess the current dietary habits to get a more updated assessment of allocating the current sources of dietary intake of dioxins.

Fishing on smaller sized herring gaining the same yield as with the catch composition that are seen today would increase the yield in terms of number individuals. How much this would increase is highly dependent on which weight-at-age relationship that is included in the analysis. The long term ecological consequences on e.g. the population dynamics from a fishery targeting smaller individuals should be examined further if a measure like that would be included in the herring fishery. Thus, as the vast majority of today's catches goes to the "industrial sector" for which the dioxins can be removed, a shift in targeting effort would be more likely to only affect the catches that goes to human consumption and thereby only affect a smaller fraction of the total quotas. With the presented numbers in this report on the increase in total numbers of individuals needed with a fishery targeting smaller herring shows on a low increase and thus the consequences from this might not be as intrusive as anticipated when formulating the research questions. The efficiency of this measure to reduce the dioxin content is however questioned in this report as only a decrease of 0,8 pg/g w.w. were seen with a 10cm down shift in target size of herring. As there will always be individual variations, a certain sized herring can never be ensured to never have a higher dioxin content than expected from a model. Individual variations can be due to feeding sites or growth rate of a certain individual. Models on herring stocks and fishery includes many parameters. As many were neglected in the scope of this thesis the results come with uncertainties.

References

Bekkevold, D., Berg, F., Polte, P., Bartolino, V., Ojaveer, H., Mosegaard, H., Farrell, E. D., Fedotova, J., Hemmer-Hansen, J., Huwer, B., Trijoulet, V., Albertsen, C. M., Fuentes-Pardo, A. P., Gröhsler, T., Pettersson, M., Jansen, T., Folkvord, A., & Andersson, L. (2023). Mixed-stock analysis of Atlantic herring (Clupea harengus): a tool for identifying management units and complex migration dynamics. *ICES Journal of Marine Science*, *80*(1), 173–184. Retrieved October 26, 2023, from https://doi.org/10.1093/icesjms/fsac223

EFSA. (n.d.). *About us.* Retrieved March 6, 2024, from https://www.efsa.europa.eu/en/about/about-efsa

EU. (2023). Council agreement on 2024 catch limits in the baltic sea [press release]. Retrieved October 30, 2023, from https://www.consilium.europa.eu/media/67495/table-council-agreement-on-2024-catch-limits-in-the-baltic-sea-draft-002.pdf

EU. (2023/915). On maximum levels for certain contaminants in food and repealing regulation (ec) no 1881/2006. https://eur-lex.europa.eu/legal-content/ENG/TXT/HTML/?uri=CELEX:02023R0915-20230810#tocId9

EU. (2019/1241). On the conservation of fisheries resources and the protection of marine ecosystems through technical measures. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:02019R1241-20230107#tocId109

Finnish Food Authority. (2019). *Safe use of fish.* Retrieved November 1, 2023, from https://www.ruokavirasto.fi/en/foodstuffs/instructions-for-consumers/safe-use-of-foodstuffs/safe-use-of-fish/

Hållén, J., Waldetoft, H., Viktor, T., & Karlsson, M. (2020). Dioxiner i fet fisk från östersjön, vänern och vättern. Retrieved February 13, 2024, from https://urn.kb.se/resolve?urn=urn:nbn:se:ivl:diva-2777

Hansson, S., & Rudstam, L. G. (1995). Gillnet catches as an estimate of fish abundance: A comparison between vertical gillnet catches and hydroacoustic abundances of baltic sea herring (clupea harengus) and sprat (sprattus sprattus). *Canadian Journal of Fisheries and Aquatic Sciences*, *52*(1), 75–83. https://doi.org/10.1139/f95-007

HELCOM. (2013). *Species information sheet - clupea harengus.* Retrieved January 12, 2024, from https://helcom.fi/wp-content/uploads/2019/08/HELCOM-Red-List-Clupea-harengus.pdf

HELCOM. (2021). *Essential fish habitats in the baltic sea – identification of potential spawning, recruitment and nursery areas.* Retrieved October 19, 2023, from https://helcom.fi/wp-content/uploads/2021/09/Essential-fish-habitats-in-the-Baltic-Sea.pdf

Hovgard, H., & Lassen, H. (2000). Manual on estimation of selectivity for gillnet and longline gears in abundance surveys. *FAO Fish. Tech. Pap*, *397*, 1–84.

Hubert, W. A., Pope, K. L., & Dettmers, J. M. (2012). Passive capture techniques. *Fisheries techniques, 3rd edition*, 223–265. Retrieved January 18, 2024, from https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1110&context=ncfwrustaff

ICES. (2022). Baltic Fisheries Assessment Working Group (WGBFAS). https://doi.org/10.17895/ices.pub.19793014.v1

ICES. (2023a). Baltic Fisheries Assessment Working Group (WGBFAS). https://doi.org/10.17895/ices.pub.23123768.v3

ICES. (2023b). Herring (clupea harengus) in subdivisions 25–29 and 32, excluding the gulf of riga (central baltic sea). replacing advice provided in may 2023. *ICES Advice: Recurrent Advice. Report.* Retrieved October 26, 2023, from https://doi.org/10.17895/ices.advice.23310368.v1

ICES. (2023c). Advice on fishing opportunities (2023). https://doi.org/10.17895/ices.advice.22240624.v1

Jennings, S., Kaiser, M. J., & Reynolds, J. D. (2001). *Marine fisheries ecology*. Blackwell Sciences.

Kiviranta, H., Tuomisto, J. T., & Jones, R. I. (2007). Human dietary intake of organochlorines from baltic herring: Implications of individual fish variability and fisheries management. *Ambio*, *36*(2/3), 257–264. Retrieved January 31, 2024, from https://eds-p-ebscohost-com.ludwig.lub.lu.se/eds/detail/detail?vid=4&sid=c1903ec5-9b78-4e71-85be-ba7c067871fc%40redis&bdata=JkF1dGhUeXBlPWlwLHVpZCZzaXRlPWVkcy1saXZlJnNjb3BlPXNpdGU%3d#AN=edsjsr.10.2307.4315822&db=edsjsr

Knutsen, H., Alexander, J., Barregård, L., Bignami, M., Brüschweiler, B., Ceccatelli, S., Cottrill, B., Dinovi, M., Edler, L., Grasl-Kraupp, B., Hogstrand, C., Nebbia, C., Oswald, I., Petersen, A., Rose, M., Roudot, A.-C., Schwerdtle, T., Vleminckx, C., Vollmer, G., & Hoogenboom, L. (2018). Risk for animal and human health related to the presence of dioxins and dioxin-like pcbs in feed and food. *EFSA Journal*, *16*(11). https://doi.org/https://doi.org/10.2903/j.efsa.2018.5333

Lundin, M., Calamnius, L., & Lunneryd, S.-G. (2012). Survival of juvenile herring (clupea harengas membras) after passing through a selection grid in a pontoon trap. *Fisheries Research*, *127-128*, 83–87. Retrieved January 18, 2024, from https://www.sciencedirect.com/science/article/pii/S0165783612001658

Lundstedt-Enkel, K., Bjerselius, R., Asplund, L., Nylund, K., Liu, Y., & Södervall, M. (2010). Supporting information to modeling relationships between baltic sea herring (clupea harengus) biology and contaminant concentrations using multivariate data analysis. *Environmental science & technology*, *44*(23), 9018–9023. Retrieved January 24, 2024, from https://doi.org/10.1021/es102448b

McLachlan, M., & Undeman, E. (2020). Dioxins and pcbs in the baltic sea. Retrieved November 2, 2023, from https://urn.kb.se/resolve?urn=urn:nbn:se:su:diva-189380

Miller, A., Hedman, J., & Bignert, A. (2012). Temporal, seasonal and spatial variation in dioxins and dioxin-like PCBs from Baltic herring (Clupea harengus) in the Baltic Sea. Retrieved January 7, 2024, from https://www.nrm.se/download/18.5d34f45c13c8cffc9a0cf7/15_2012+Dioxins+in+herring+in+the+Baltic+Sea.pdf

Parmanne, R., Hallikainen, A., Isosaari, P., Kiviranta, H., Koistinen, J., Laine, O., Rantakokko, P., Vuorinen, P. J., & Vartiainen, T. (2006). The dependence of organohalogen compound concentrations on herring age and size in the bothnian sea, northern baltic. *Marine Pollution Bulletin*, *52*(2), 149–161. Retrieved January 31, 2024, from https://www.sciencedirect.com/science/article/pii/S0025326X05003693

Peltonen, H., Kiljunen, M., Kiviranta, H., Vuorinen, P. J., Verta, M., & Karjalainen, J. (2007). Predicting effects of exploitation rate on weight-at-age, population dynamics, and bioaccumulation of pcdd/fs and pcbs in herring (clupea harengus l.) in the northern baltic sea. *Environmental science technology*, *41*, 1849–55. https://doi.org/10.1021/es0618346

Sarkki, S., & Pihlajamäki, M. (2019). Baltic herring for food: Shades of grey in how backcasting recommendations work across exploratory scenarios. *Technological Forecasting and Social Change*, *139*, 200–209. https://doi.org/https://doi.org/10.1016/j.techfore.2018.11.001

SCB. (2023). Swedish sea-fisheries during 2022. definitive data. Retrieved January 15, 2024, from https://www.scb.se/contentassets/8521b21a462d439f91e91d9874c81b67/jo1101_2022a01_sm_jo55sm2301.pdf

Soerensen, A. L., & Faxneld, S. (2020). The swedish national monitoring programme for contaminants in marine biota (until 2019 year's data)-temporal trends and spatial variations. Retrieved January 12, 2024, from https://naturvardsverket.diva-portal.org/smash/record.jsf?pid=diva2%3A1515030&dswid=1912

Stockholm Convention. (2019). Retrieved February 12, 2024, from https://www.pops.int/TheConvention/ThePOPs/AllPOPs/tabid/2509/Default.aspx

Swedish Agency for Marine and Water Management. (2020). N2020/00130/fjr. uppdrag om generellt stopp för bottentrålning i skyddade områden. Retrieved January 12, 2024, from https://regeringen.se/contentassets/ef118139d00b4f52b1ba8793585cab69/redovisning_ru_bottentralning.pdf

Swedish Agency for Marine and Water Management. (2023). *Kvoter i östersjön*. Retrieved October 18, 2023, from https://www.havochvatten.se/fiske-och-handel/kvoter-uppfoljning-och-fiskestopp/kvoter-i-ostersjon.html

Swedish Food Authority. (2019). *Livsfs 2014:22*. Retrieved November 23, 2023, from https://www.livsmedelsverket.se/om-oss/lagstiftning1/gallande-lagstiftning/livsfs-201422

Swedish Food Authority. (2023). *Dioxins and pcbs in swedish food*. Retrieved November 1, 2023, from https://www.livsmedelsverket.se/en/food-and-content/oonskade-amnen/miljogifter/dioxiner-och-pcb

Szlinder-Richert, J., Usydus, Z., Malesa-Ciećwierz, M., Polak-Juszczak, L., & Ruczyńska, W. (2011). Marine and farmed fish on the polish market: Comparison of the nutritive value and human exposure to pcdd/fs and other contaminants. *Chemosphere*, *85*(11), 1725–1733. https://doi.org/https://doi.org/10.1016/j.chemosphere.2011.09.019

Tuomisto, J. T., Asikainen, A., Meriläinen, P., & Haapasaari, P. (2020). Health effects of nutrients and environmental pollutants in baltic herring and salmon: A quantitative benefit-risk assessment. *BMC Public Health*, *20*, 1–18. Retrieved November 8, 2023, from https://link.springer.com/content/pdf/10.1186/s12889-019-8094-1.pdf

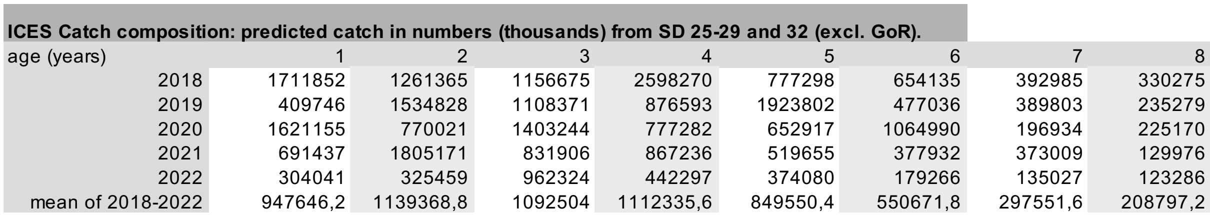
Van den Berg, M., Birnbaum, L. S., Denison, M., De Vito, M., Farland, W., Feeley, M., Fiedler, H., Hakansson, H., Hanberg, A., Haws, L., Rose, M., Safe, S., Schrenk, D., Tohyama, C., Tritscher, A., Tuomisto, J., Tysklind, M., Walker, N., & Peterson, R. E. (2006). The 2005 World Health Organization Reevaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-Like Compounds. *Toxicological Sciences*, *93*(2), 223–241. https://doi.org/10.1093/toxsci/kfl055

WHO. (2019). Exposure to dioxins and dioxin-like substances: A major public health concern. *WHO reference number: WHO/CED/PHE/EPE/19.4.4*. Retrieved October 24, 2023, from https://www.who.int/publications/i/item/WHO-CED-PHE-EPE-19.4.4

Winters, G., & Wheeler, J. (1990). Direct and indirect estimation of gillnet selection curves of atlantic herring (clupea harengus harengus). *Canadian Journal of Fisheries and Aquatic Sciences*, *47*, 460–470. Retrieved January 18, 2024, from https://cdnsciencepub.com/doi/pdf/10.1139/f90-050

A Appendix

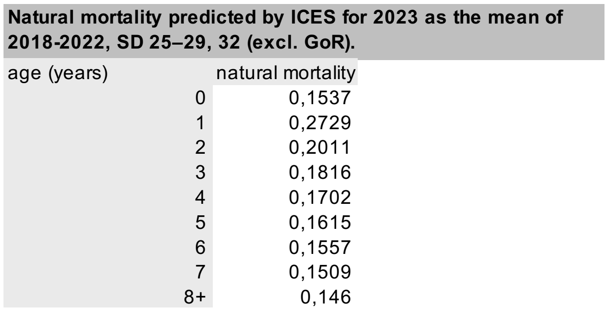
Table A1: Data retrieved from ICES, 2023a.



ICES Catch composition: predicted catch in numbers (thousands) from SD 25-29 and 32 (excl. GoR).

age (years)	1	2	3	4	5	6	7	8
2018	1711852	1261365	1156675	2598270	777298	654135	392985	330275
2019	409746	1534828	1108371	876593	1923802	477036	389803	235279
2020	1621155	770021	1403244	777282	652917	1064990	196934	225170
2021	691437	1805171	831906	867236	519655	377932	373009	129976
2022	304041	325459	962324	442297	374080	179266	135027	123286
mean of 2018-2022	947646,2	1139368,8	1092504	1112335,6	849550,4	550671,8	297551,6	208797,2

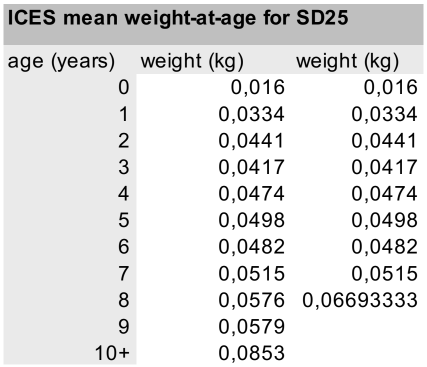
Table A2: Data retrieved from ICES, 2023a.



Natural mortality predicted by ICES for 2023 as the mean of 2018-2022, SD 25–29, 32 (excl. GoR).

age (years)	natural mortality
0	0,1537
1	0,2729
2	0,2011
3	0,1816
4	0,1702
5	0,1615
6	0,1557
7	0,1509
8+	0,146

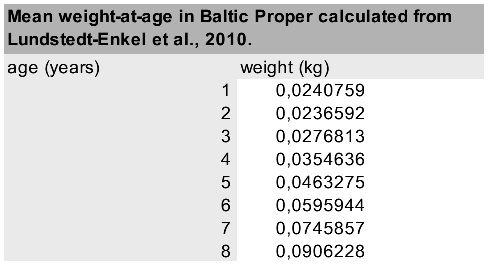
Table A3: Data retrieved from ICES, 2023a.



ICES mean weight-at-age for SD25

age (years)	weight (kg)	weight (kg)
0	0,016	0,016
1	0,0334	0,0334
2	0,0441	0,0441
3	0,0417	0,0417
4	0,0474	0,0474
5	0,0498	0,0498
6	0,0482	0,0482
7	0,0515	0,0515
8	0,0576	0,06693333
9	0,0579	
10+	0,0853	

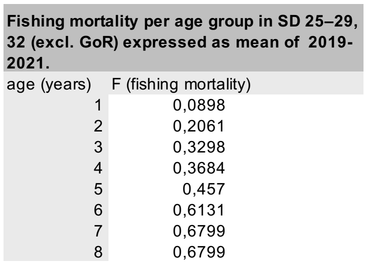
Table A4: Data retrieved from Lundstedt-Enkel et al., 2010.



Mean weight-at-age in Baltic Proper calculated from Lundstedt-Enkel et al., 2010.

age (years)	weight (kg)
1	0,0240759
2	0,0236592
3	0,0276813
4	0,0354636
5	0,0463275
6	0,0595944
7	0,0745857
8	0,0906228

Table A5: Data retrieved from ICES, 2022.

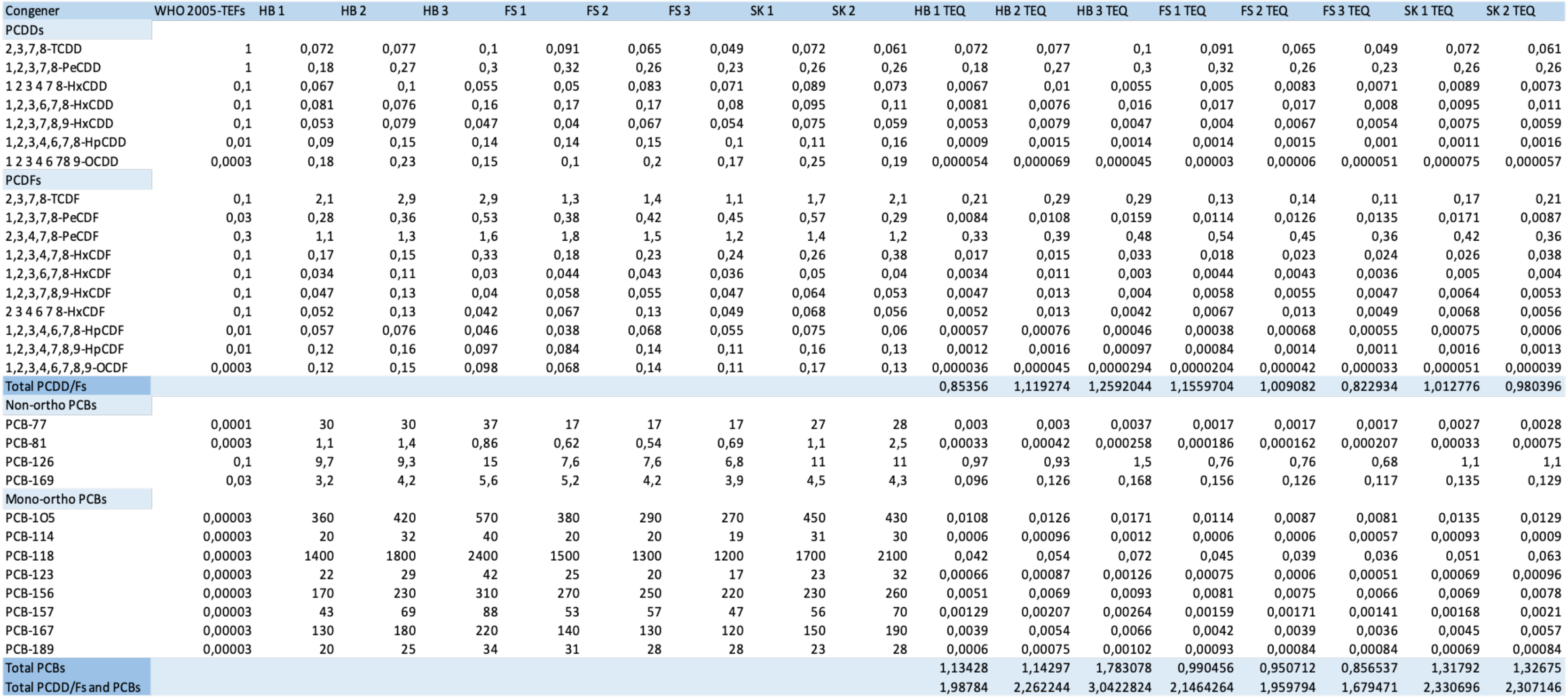


Fishing mortality per age group in SD 25–29, 32 (excl. GoR) expressed as mean of 2019-2021.

age (years)	F (fishing mortality)
1	0,0898
2	0,2061
3	0,3298
4	0,3684
5	0,457
6	0,6131
7	0,6799
8	0,6799

B Appendix

Table B1: Table over the calculated TEQs for each cnogener and site as well as total TEQ over PCDD/Fs and PCBs.



Congener	WHO 2005-TEFs	HB 1	HB 2	HB 3	FS 1	FS 2	FS 3	SK 1	SK 2	HB 1 TEQ	HB 2 TEQ	HB 3 TEQ	FS 1 TEQ	FS 2 TEQ	FS 3 TEQ	SK 1 TEQ	SK 2 TEQ
PCDDs																	
2,3,7,8-TCDD	1	0,072	0,077	0,1	0,091	0,065	0,049	0,072	0,061	0,072	0,077	0,1	0,091	0,065	0,049	0,072	0,061
1,2,3,7,8-PeCDD	1	0,18	0,27	0,3	0,32	0,26	0,23	0,26	0,26	0,18	0,27	0,3	0,32	0,26	0,23	0,26	0,26
1 2 3 4 7 8-HxCDD	0,1	0,067	0,1	0,055	0,05	0,083	0,071	0,089	0,073	0,0067	0,01	0,0055	0,005	0,0083	0,0071	0,0089	0,0073
1,2,3,6,7,8-HxCDD	0,1	0,081	0,076	0,16	0,17	0,17	0,08	0,095	0,11	0,0081	0,0076	0,016	0,017	0,017	0,008	0,0095	0,011
1,2,3,7,8,9-HxCDD	0,1	0,053	0,079	0,047	0,04	0,067	0,054	0,075	0,059	0,0053	0,0079	0,0047	0,004	0,0067	0,0054	0,0075	0,0059
1,2,3,4,6,7,8-HpCDD	0,01	0,09	0,15	0,14	0,14	0,15	0,1	0,11	0,16	0,0009	0,0015	0,0014	0,0014	0,0015	0,001	0,0011	0,0016
1 2 3 4 6 78 9-OCDD	0,0003	0,18	0,23	0,15	0,1	0,2	0,17	0,25	0,19	0,000054	0,000069	0,000045	0,00003	0,00006	0,000051	0,000075	0,000057
PCDFs																	
2,3,7,8-TCDF	0,1	2,1	2,9	2,9	1,3	1,4	1,1	1,7	2,1	0,21	0,29	0,29	0,13	0,14	0,11	0,17	0,21
1,2,3,7,8-PeCDF	0,03	0,28	0,36	0,53	0,38	0,42	0,45	0,57	0,29	0,0084	0,0108	0,0159	0,0114	0,0126	0,0135	0,0171	0,0087
2,3,4,7,8-PeCDF	0,3	1,1	1,3	1,6	1,8	1,5	1,2	1,4	1,2	0,33	0,39	0,48	0,54	0,45	0,36	0,42	0,36
1,2,3,4,7,8-HxCDF	0,1	0,17	0,15	0,33	0,18	0,23	0,24	0,26	0,38	0,017	0,015	0,033	0,018	0,023	0,024	0,026	0,038
1,2,3,6,7,8-HxCDF	0,1	0,034	0,11	0,03	0,044	0,043	0,036	0,05	0,04	0,0034	0,011	0,003	0,0044	0,0043	0,0036	0,005	0,004
1,2,3,7,8,9-HxCDF	0,1	0,047	0,13	0,04	0,058	0,055	0,047	0,064	0,053	0,0047	0,013	0,004	0,0058	0,0055	0,0047	0,0064	0,0053
2 3 4 6 7 8-HxCDF	0,1	0,052	0,13	0,042	0,067	0,13	0,049	0,068	0,056	0,0052	0,013	0,0042	0,0067	0,013	0,0049	0,0068	0,0056
1,2,3,4,6,7,8-HpCDF	0,01	0,057	0,076	0,046	0,038	0,068	0,055	0,075	0,06	0,00057	0,00076	0,00046	0,00038	0,00068	0,00055	0,00075	0,0006
1,2,3,4,7,8,9-HpCDF	0,01	0,12	0,16	0,097	0,084	0,14	0,11	0,16	0,13	0,0012	0,0016	0,00097	0,00084	0,0014	0,0011	0,0016	0,0013
1,2,3,4,6,7,8,9-OCDF	0,0003	0,12	0,15	0,098	0,068	0,14	0,11	0,17	0,13	0,000036	0,000045	0,0000294	0,0000204	0,000042	0,000033	0,000051	0,000039
Total PCDD/Fs										0,85356	1,119274	1,2592044	1,1559704	1,009082	0,822934	1,012776	0,980396
Non-ortho PCBs																	
PCB-77	0,0001	30	30	37	17	17	17	27	28	0,003	0,003	0,0037	0,0017	0,0017	0,0017	0,0027	0,0028
PCB-81	0,0003	1,1	1,4	0,86	0,62	0,54	0,69	1,1	2,5	0,00033	0,00042	0,000258	0,000186	0,000162	0,000207	0,00033	0,00075
PCB-126	0,1	9,7	9,3	15	7,6	7,6	6,8	11	11	0,97	0,93	1,5	0,76	0,76	0,68	1,1	1,1
PCB-169	0,03	3,2	4,2	5,6	5,2	4,2	3,9	4,5	4,3	0,096	0,126	0,168	0,156	0,126	0,117	0,135	0,129
Mono-ortho PCBs																	
PCB-1O5	0,00003	360	420	570	380	290	270	450	430	0,0108	0,0126	0,0171	0,0114	0,0087	0,0081	0,0135	0,0129
PCB-114	0,00003	20	32	40	20	20	19	31	30	0,0006	0,00096	0,0012	0,0006	0,0006	0,00057	0,00093	0,0009
PCB-118	0,00003	1400	1800	2400	1500	1300	1200	1700	2100	0,042	0,054	0,072	0,045	0,039	0,036	0,051	0,063
PCB-123	0,00003	22	29	42	25	20	17	23	32	0,00066	0,00087	0,00126	0,00075	0,0006	0,00051	0,00069	0,00096
PCB-156	0,00003	170	230	310	270	250	220	230	260	0,0051	0,0069	0,0093	0,0081	0,0075	0,0066	0,0069	0,0078
PCB-157	0,00003	43	69	88	53	57	47	56	70	0,00129	0,00207	0,00264	0,00159	0,00171	0,00141	0,00168	0,0021
PCB-167	0,00003	130	180	220	140	130	120	150	190	0,0039	0,0054	0,0066	0,0042	0,0039	0,0036	0,0045	0,0057
PCB-189	0,00003	20	25	34	31	28	28	23	28	0,0006	0,00075	0,00102	0,00093	0,00084	0,00084	0,00069	0,00084
Total PCBs										1,13428	1,14297	1,783078	0,990456	0,950712	0,856537	1,31792	1,32675
Total PCDD/Fs and PCBs										1,98784	2,262244	3,0422824	2,1464264	1,959794	1,679471	2,330696	2,307146