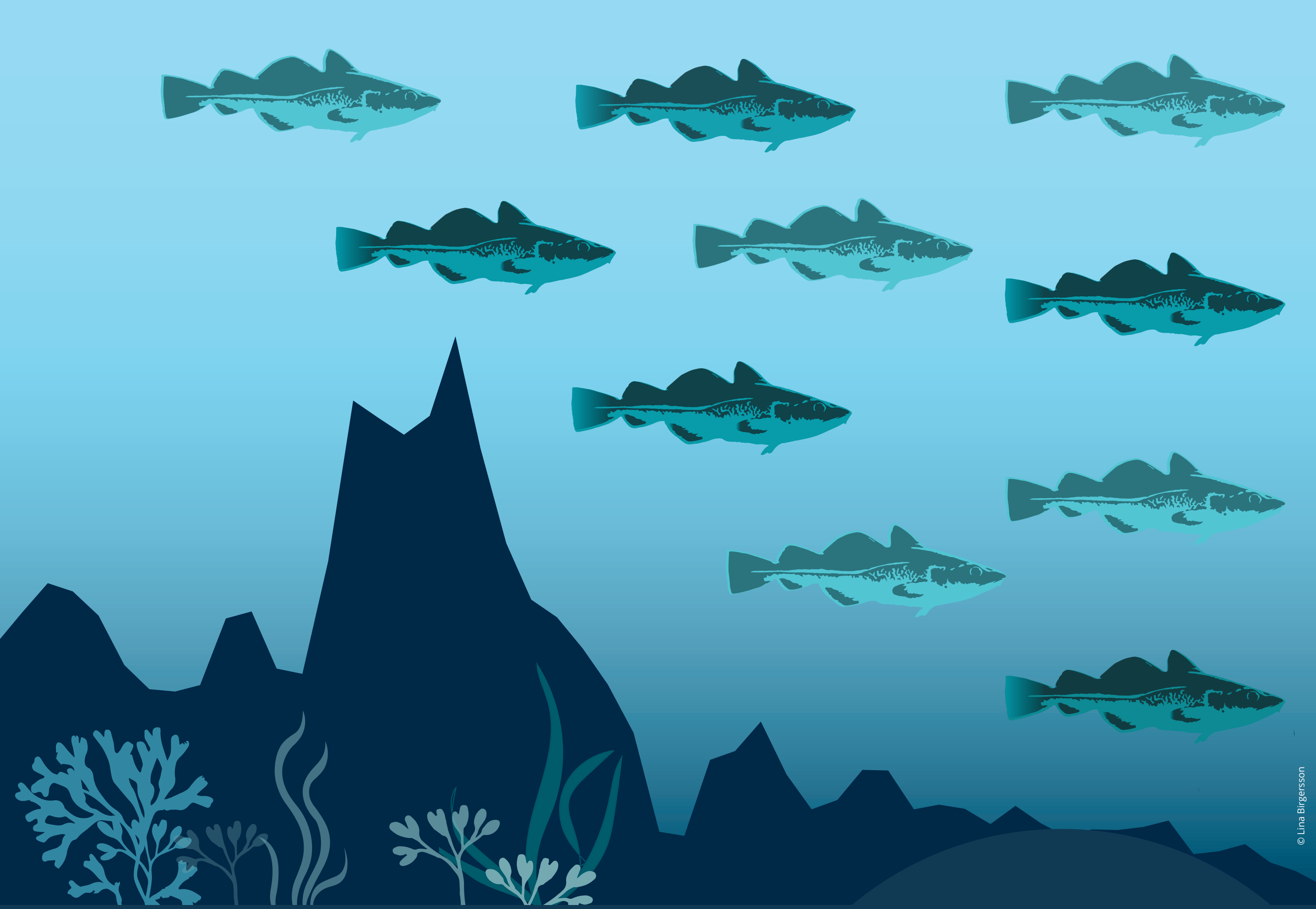
The Decline of Cod in the Baltic Sea

A review of biology, fisheries and management, including recommendations for cod recovery



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Authors:

Chapter 1 – **Literature review of Baltic cod**
Lina Birgersson, PhD. Researcher, Department of Biological and Environmental Sciences, University of Gothenburg, Sweden

Chapter 2 – **Socio-economic impact assessment**
Mohammed Belhaj, PhD. Research advisor, University of Gothenburg, Sweden

Chapter 3 – **Policy and management**
Mohammed Belhaj, PhD. Research advisor, University of Gothenburg, Sweden
Sara Söderström, PhD. Policy officer, the Fisheries Secretariat.

Chapter 4 – **Conclusions and recommendations**
Sara Söderström, PhD. Policy Officer, the Fisheries Secretariat.

Editorial reviewers:

Jan Isakson, Niki Sporrong, Irene Kingma – Fisheries Secretariat

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The Fisheries Secretariat (FishSec)
Tegelviksgatan 40, SE-116 41 Stockholm, Sweden
+46 8 25 07 90 | e-mail: info(at)fishsec.org | www.fishsec.org

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Abbreviations / acronyms

BAT	Best Available Technology
BSAP	Baltic Sea Action Plan
CAC	Command and Control
CFP	EU Common Fisheries Policy
CBA	Cost benefit analysis
CBD	Convention of Biological Diversity
CVM	Contingent Valuation Method
DE	Germany
DK	Denmark
EBC	Eastern Baltic cod
EE	Estonia
EFCA	European Fisheries Control Agency
EMFF	European Maritime and Fisheries Fund
FAO	UN Food and Agriculture Organisation
FI	Finland
GC	Grand Coalitions
GDP	Gross Domestic Product
GES	Good Environmental Status
I	Information Instrument
ICES	International Council for the Exploration of the Sea
IUU	Illegal Unreported Unregulated Fishing
LO	Landing Obligation
LT	Lithuania
LV	Latvia
M	Market approach
MAP	Multiannual management plan
MSC	Marine Stewardship Council
MSC	Monitoring, control and surveillance
MSFD	Marine Strategy Framework Directive
MSY	Maximum Sustainable Yield
NC	Non-cooperation interactions
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Development
PL	Poland
PPP	Purchasing Power Parity
PSU	Practical salinity unit
PV	Present Value
RU	Russia
SD	Subdivision
SEIA	Socio-Economic Impact Assessment
SE	Sweden
SSB	Spawning stock biomass
TAC	Total Allowable Catch
UNEP	United Nations Environmental Programme
WBC	Western Baltic cod
WTP	Willingness to pay

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Executive summary – the road to recovery for Baltic cod

Baltic cod is in crisis. The two main populations (Eastern and Western Baltic cod) are in a critical state after a massive decline over the past two decades, with no recovery in sight. As a result, the International Council for the Exploration of the Sea (ICES) has recommended a zero fishing quota for the Eastern Baltic cod population for the last three years. The trajectory for the Western Baltic cod is not far behind. In a last attempt to reverse the decline, targeted fishing for both cod stocks was prohibited in December 2021 and a limited bycatch quota agreed, but this is unlikely to rebuild the populations.

The collapse of the Baltic cod populations was not a sudden event, but an on going process driven by overfishing and environmental degradation. This comes at a crucial time for the planet, when we need our seas in prime condition and more resilient to the threats posed by climate change.

Aim of the study and methodological underpinning

The aim of the report is to collate current knowledge and research concerning the state of Baltic cod. Based on a scientific literature review of both academic studies and other literature, the report provides an overview of the situation of cod in the Baltic Sea today, including:

- the current features and the changes that have occurred in Baltic cod;
- factors/problems that are assumed to have contributed to the changes;
- suggested measures that may counteract these issues.

The report also describes European Union fisheries management in the Baltic Sea, and provides recommendations based on the current state of both the ecosystem and the legal framework.

Cod biology and stressors

Atlantic cod (*Gadus morhua*) is a top predator that plays an essential role in the Baltic Sea ecosystem. The two cod populations in the Baltic Sea are adapted to the challenging conditions of low salinity and low but variable oxygen concentration in the water that characterise this sea. However, both populations have declined dramatically in recent decades, and are now suffering from poor health, a reduced size distribution with few large individuals, and low productivity.

Cod has been an important food source for humans in the Baltic region for centuries. In more recent times, this popularity fed a profitable industry but unsustainable catch levels caused the fishing pressure outpaced the cod's reproductive ability to replenish the population by the end of the 1980's, resulting in the gradual collapse. This has resulted in a regime shift, where the cod fishery from the past (with a limited bycatch of flatfish) has now become a fishery targeting flatfish where cod is now just bycatch.

Decades of high fishing pressure are undoubtedly one of the main causes of cod decline in the Baltic but many other anthropogenic environmental stressors have played a role too. Eutrophication and chemical pollution have changed the marine environment, resulting in large areas of low levels of oxygen and dead zones where hardly any life is possible. In addition to the targeted cod fishery, other fishing practises have had great impact. For example, the large-scale fishing for small fish like sprat and young herring that provide essential food for cod leads to starvation. Also, the bycatches of cod in all life stages in demersal fisheries remove many juveniles and adults from the populations.

Climate change

Climate change is causing sea temperature to rise, impacting the resilience of the ocean and the species within it. As the Baltic Sea is a shallow sea basin, almost completely enclosed by land, effects of climate change will likely be severe. The feeding patterns, reproduction and spawning times of cod are all linked to temperature. Essentially, the effects of climate change adds further burdens to the Baltic cod populations, making it even more important to limit the direct human impacts on the species in any way we can.

Fisheries management in the Baltic Sea

Despite the clear evidence of the perilous state of Baltic cod, Baltic EU Member States have set fishing limits above the sustainable levels advised by scientists every year since 2013. In July 2019, the impending collapse of the Eastern Baltic cod population led the European Commission to announce emergency measures to save this stock. This resulted in the introduction of an immediate ban on all targeted commercial cod fishing in most of the Baltic Sea. Yet, despite this drastic step and against the advice of scientists, fishers were allowed to catch cod again in 2020. That year, 2,000 tonnes of Eastern Baltic cod landings were permitted, provided it was classed as 'bycatch', leading to a further decline of the populations. This led to the decision in October 2021 to ban all targeted fishing for cod (both the Eastern and Western stock) and to significantly reduce the amount of unavoidable bycatch allowed.

However, only part of the problem is addressed by the new restrictions. Since most of the cod are now bycatch in demersal fisheries for other species – fisheries, predominantly with trawl gear, that catch a variety of species throughout the year. To manage all stocks sustainably, fishing should be limited by the needs of the most vulnerable species and therefore halted once that populations is depleted, even if it means that 'available' quota from other stocks goes unexploited.

Since 2015, there is an EU policy – the landing obligation – which makes it illegal to discard cod above quota. But a lack of effective control mechanisms means that unwanted cod continue to be thrown back dead into the sea. This does nothing for the recovery of the populations and seriously undermines scientists' ability to monitor the stocks, since illegal discards do not appear in the catch and landings data they use in their calculations.

Recommended actions

To help cod recover in the Baltic Sea, an ecosystem-based approach must be implemented that recognizes the interactions among species in food webs, crucial habitats for all life stages of cod and the importance of predatory fish to a healthy ecosystem. On all management levels, concrete steps must be taken toward low-impact fisheries in the Baltic Sea, safeguarding essential habitats, as well as combatting pollution and eutrophication.

We propose these steps to aid the recovery of cod in the Baltic Sea.

Implement an ecosystem-based approach to fisheries management

1) Implement multi-species management in demersal fisheries

Today, most of the cod is taken as bycatch in demersal fisheries for flatfish and other fish species. Setting catch limits individually for each stock – so-called Total Allowable Catches (TACs) - do not reflect the reality in the fisheries, as catches of one species results in the bycatch of others. As a first step, Baltic Sea Member States and the European Commission need to request that ICES provides real multispecies advice on fishing opportunities.

2) Add a sufficient precautionary buffer to the fishing quotas/catch limits

A combination of multiple anthropogenic stressors make fish stocks in the Baltic more vulnerable to overexploitation and less likely to recover. This should be taken into account in the discussion on fishing limits. TAC proposals from the European Commission shall incorporate a sufficiently large buffer to be precautionary and in line with Common Fisheries Policy (CFP) objectives. We propose that the European Commission makes a Special Advice Request to ICES to calculate how large this buffer needs to be.

3) Set industrial fisheries limits based on the precautionary approach and ecosystem-based approach to fisheries management

Forage fish like sprat and small herring are an essential source of food for predatory fish, mammals and seabirds. These populations are also targeted by very large-scale pelagic trawlers and, when landed, mainly used in fish meal production feeding other fish in aquaculture or livestock. When setting the catch limits for these so-called industrial fisheries, the fish's role as food for other species should be taken into account, as well as the spatial distribution of the stocks and their predators. Fishing effort should not be too concentrated.

Make fisheries sustainable

1) Prioritise low impact fishing

The current management system and the setting of fishing limits/catch quotas do not take the ecosystem effects or bycatches of fisheries sufficiently into account. A system that favours low impact fishing by providing priority access to fishing opportunities for the vessels that do the least damage, or fish in the most sustainable manner, would benefit both the fishing industry and the ecosystem.

Such a principle is already outlined in Article 17 of the CFP; Member States should implement this by allocating fishing opportunities to vessels with the lowest cod bycatch. Our analysis shows that this policy is still not fully implemented, even though the CFP regulation was adopted in 2013. It is important that the Baltic Member States make more use of this obligation, to the benefit of all Baltic fish populations.

2) Make Remote Electronic Monitoring mandatory in fisheries

Sustainable management is only possible if catch data is reliable and there is an appropriate level of control and enforcement. Remote Electronic Monitoring (REM) provides a cost effective way to address all of the above. Particularly considering the documented continued illegal discarding of unwanted cod, it is time to make REM mandatory in fisheries interacting with cod in the Baltic Sea.

3) Mandatory selectivity measures to reduce bycatch

Over the past years, advances have been made in alternative gears development which would help prevent bycatches of cod, but very few of these improvements are currently used by the fishing sector. To decrease cod mortality, making the use of best available selective gear mandatory in fisheries with bycatch of cod, would be an effective way to reduce/minimise cod mortality.

Improve environmental protection

1) Implement the HELCOM Baltic Sea Action Plan

The Baltic Sea marine environment is in a dire state due to several reasons, foremost eutrophication and hypoxia caused by agricultural run-off and pollutants from human activities. These wide-ranging problems are best addressed through coordinated action among all nations around the Baltic Sea. The Baltic Marine Environment Protection Commission also known as the - Helsinki Commission (HELCOM) - provides a framework for this regional coordination and joint actions are agreed and implemented under a Baltic Sea Action Plan (BSAP), which was updated in 2021. Full implementation of the HELCOM BSAP will lead to meaningful improvement of the state of the Baltic Sea.

2) Actively work to restore damaged ecosystems & minimize bottom trawling

Humans have greatly damaged essential habitats in the Baltic Sea for decades. Bottom trawling is one of the especially harmful activities that are allowed to continue – even in protected areas. The new EU restoration law will provide an opportunity to make binding agreements on ecosystem restoration. Such efforts should be combined with a removal of the most destructive fishing gears from the Baltic Sea in a just and progressive manner.

3) Connect fisheries and environment in legislation, policy and implementation

Even though strong links between fisheries and environmental law exist through several EU laws and directives, there are only a few examples of Member States actually combining them in their national management. However, as they are legally obliged to follow EU law, delaying and avoiding the implementation of an Ecosystem-Based Approach to Fisheries Management at a national level is no longer an option. To do this, full integration of fisheries and environmental policies is needed at national level, as well as in inter-governmental organisations (IGO;s) like HELCOM and BALTFISH.

Cod has an essential role in the Baltic ecosystem and plays a key part in the recovery of the Baltic Sea. Even though the current state of Baltic cod is the worst it has ever been, recovery is possible if steps are taken now to turn the downwards trend. It is the responsibility of Baltic countries, the European Commission and all stakeholders to support these efforts and bring around the return of the cod.

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Disposition of report

Chapter 1 is a literature review summarising the current situation for Baltic cod including changes in stock status, factors that have led to the decline in stock and the proposed measures that could be taken to improve its status. Since the late 1980s, two of three main spawning sites have no longer been in use, which has led to a decrease in distribution area and reproduction of Baltic cod. In addition to this change, a number of factors are suggested as potential drivers of the decline in cod status. These include unsustainable fishing pressure, a lack of oxygen due to eutrophication, a lack of food as the geographical overlap with prey species has declined, climate change, predation, increased incidence of parasite infestation, pollution and thiamine deficiency.

Chapter 2 is a socioeconomic impact assessment estimating and discussing cod recovery through a cost benefit analysis of different scenarios including various measures to establish sustainable cod stocks.

Chapter 3 describes the basics of the Common Fisheries Policy in the European Union, with the emphasis on ecosystem-based management. Other subjects discussed include TACs, fishing fleet capacity, bycatch, discards, the precautionary approach and Article 17 of the CFP.

Chapter 4 links the biological features of cod to the environmental conditions and legal outlook though policy and political commitments, and presents practical recommendations

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Chapter 1
Literature review of Baltic cod

1.1. Introduction

The Atlantic cod (*Gadus morhua*, referred to as "cod" throughout this report), is one of the top predators in the Baltic Sea and has historically been a key species and an important component of the ecosystem. As a top predator, it has been involved in the control of the food web, but it has also been of economic and cultural importance as a target species for fisheries in the countries surrounding the Baltic Sea. However, Baltic cod stocks have been in decline for decades, and low quotas or no fishing at all are currently recommended by the International Council for the Exploration of the Sea (ICES). The main changes in the state of the cod stock, especially for the eastern cod, over recent decades are a decline in individual growth, the reduced number of large cod individuals, a decline in body condition or length-weight factor (which is used to give a general indication of wellbeing in fish) and low productivity. This has caused a large proportion of the current stock to consist of small, skinny cod with reduced commercial value and limited ability to sustain the fishing industry. These developments indicate that the stock is severely affected (Eero et al., 2015). As there are relatively few species inhabiting the Baltic Sea, and there is consequently a simpler food web, the loss of a top predator such as cod has consequences for the entire ecosystem.

Baltic cod is split into two separate stocks, Eastern and Western Baltic cod (abbreviated as EBC and WBC), neither of which are doing well from a biological perspective. The stocks are genetically distinct; the smaller WBC stock is located to the west/east of the Danish island of Bornholm, in SDs 22-24, and the larger EBC stock is located in SDs 24-32. This report has a somewhat greater focus on Eastern Baltic cod, which is the larger of the two stocks and more severely affected. A third stock of importance in the study is the Kattegat cod in SD 21. In SD 24 the Western Baltic stock is mixed with the Eastern Baltic stock (Hüssy, 2011). Nevertheless, the complexity of the stock dynamics is far more intricate than this, according to the scientific literature (Hüssy, 2011). Due to unsustainable fishing levels, the WBC has now passed a tipping point, according to a recent study of ecosystem dynamics (Möllmann et al., 2021).

There are still uncertainties with regard to the main factors leading to the current state of cod (Eero et al., 2020; Eero et al., 2015), and there is no scientific consensus as to whether the main drivers are any of a range of unfavourable environmental conditions or unsustainable fishing pressure. It is most likely that a combination of several factors is contributing simultaneously.

1.1.1. Aim

This report aims to collate current knowledge and scientific research concerning the state of Baltic cod, including the factors that are responsible for the decline and possible measures that can be taken to counteract the adverse effects caused by these factors.

1.2. Method

Based on a literature review of academic studies and reports published up to February 2022, the following review aims to give an overview of the current situation of Atlantic cod in the Baltic Sea, including:

- the current features and the changes that have occurred in Baltic cod;
- factors/problems that are assumed to contribute to the changes;
- suggested measures that may counteract these issues.

We did not produce novel data or perform an analysis of the extent to which the challenges/factors listed in Section 1.5 affect Baltic cod. The order of appearance and length of sub-sections in Section 1.5 is not an indication of the importance of the challenge.

A systematic search of peer-reviewed material was performed using predefined criteria. The search was performed using the Scopus literature database on 25 February 2021 and returned 869 results. This included published scientific papers, scientific reviews, short communications, books and conference abstracts (not peer reviewed and considered as grey literature[1]). The material was then treated in three steps, starting with initial identification through the Scopus database search, followed by screening of abstracts to select relevant materials where they were sorted according to relevance (the list of search results was placed in an Excel file and colour coded using a stop-light system for relevant (green), possibly relevant (yellow) and non-relevant (red) sources) and finally extraction of information through deeper examination of the relevant sources which were used for the final review. In addition, recent grey-literature reports and papers published after February 2021 were also scanned for relevance and included in the overview.

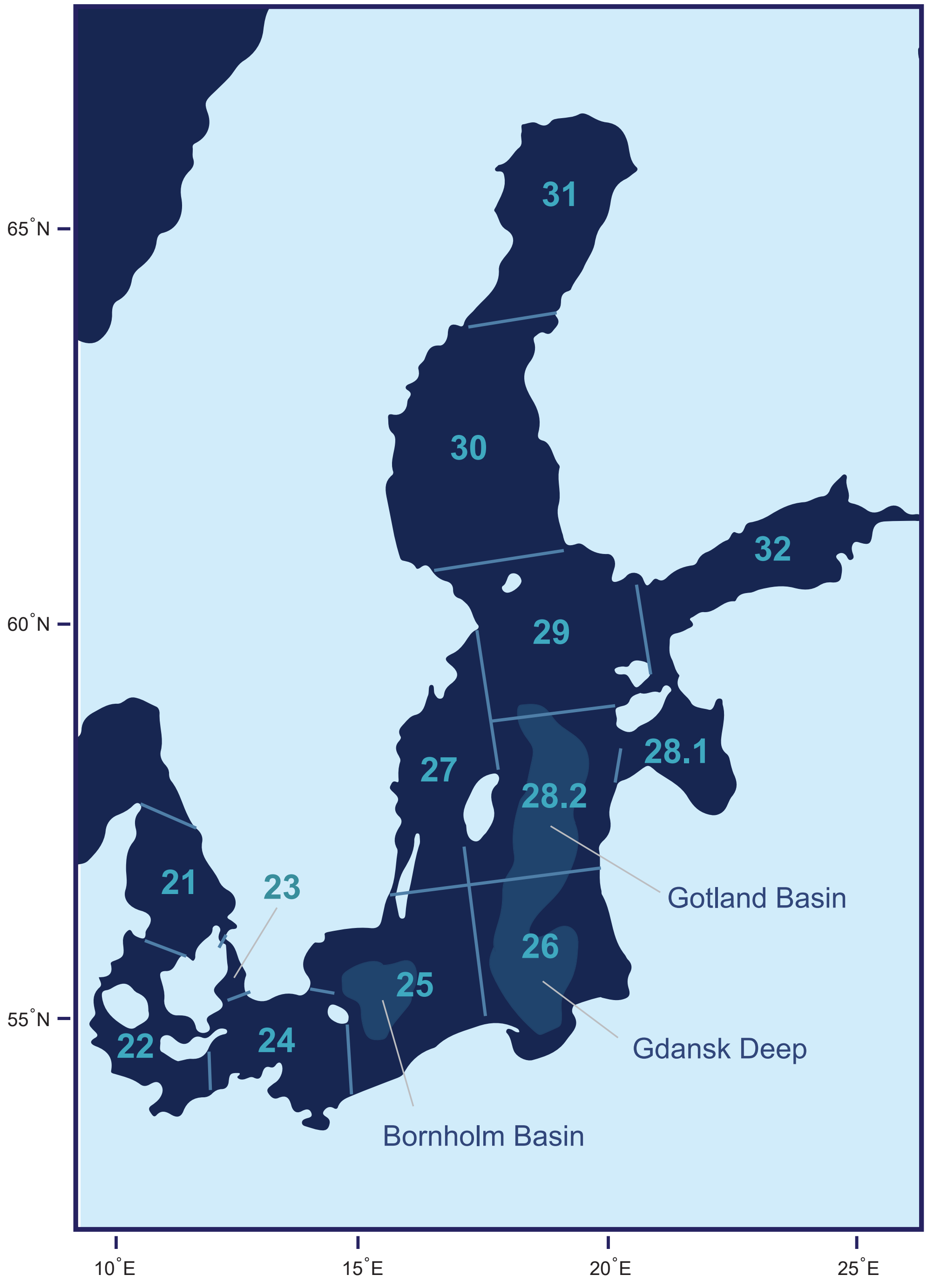
Papers were placed in the non-relevant category and excluded if they were focused on a different species than cod, if they were outside the geographic scope of the review (i.e. focused on a different location than the Baltic Sea), if they were focused on cod as a food product, if they were inaccessible due to language barriers, or if the full paper was not retrievable. Only materials written in English or Swedish were included in the review, which is a limitation of the study.

1.3. Background

Baltic cod and the situation in the Baltic Sea is well studied, researchers have investigated it for decades and there are hundreds of scientific papers published on the topic. This illustrates the importance of cod as a species from both a commercial and ecological point of view. The adverse changes to Baltic cod which are described in this report are extensive and have occurred over the last few decades, i.e. a relatively short period of time. This situation has also affected the role of cod in the ecosystem and disrupted the Baltic Sea ecosystem as a whole.

1 Grey literature is a term used for scientific material that is not formally published, such as reports or governmental papers. https://kib.ki.se/en/search-evaluate/grey-literature

Figure 1. ICES Subdivisions in the Baltic Sea ecoregion



Cod has a range of different values for humans. It is a well-liked, local food source, a recreational fishing target, and is of importance to biodiversity, but is also linked to our cultural and natural heritage. Other large predators such as flounder, plaice and salmon in the Baltic Sea make up a small part of the commercial annual catch, while cod, together with herring and sprat, has accounted for the majority of the catch. The Baltic Sea is divided into subdivisions (SDs) by ICES, which are used for management (Figure 1). SDs 25-32 are the Eastern Baltic Sea, SDs 22-24 are the Western Baltic Sea and SD 21 is the Kattegat. SD 23 Öresund/The Sound is managed together with the Western Baltic cod, and the Kattegat contains a cod population that will not be the focus of this report.

1.3.1. The Baltic Sea is a unique and challenging environment to live in

The Baltic Sea is a shallow, semi-enclosed inland sea that is one of the largest brackish areas in the world, covering 420 000 km². The sea itself is young in geological terms, and its ecosystem is young from an evolutionary perspective (Bonsdorff, 2006). It is considered species-poor and contains a relatively small number of plant and animal species which often have unique adaptations to this environment (Johannesson et al., 2011). One reason for the low number of species is the hydrological characteristics of the area. As described by Bonsdorff, species that live in the Baltic Sea are facing several challenges, including varying temperature that changes depending on the depth, location, and time of year with a climate gradient in a north-south and east-west direction. The water also has varying oxygen concentrations, and low salinity that varies with depth and location. Water with higher salinity and higher oxygen content enters through the Belt Sea and the Sound and spreads to the deeper layers, while freshwater enters the top layer from the surrounding rivers and through precipitation (Carstensen et al., 2014; Bonsdorff, 2006). This contributes to a salinity gradient from the southern to the northern parts of the Baltic Sea, and marine species are predominantly found in the southwestern parts of the Baltic Sea while freshwater species inhabit the northern and eastern parts (Walday & Kroglund, 2002).

In addition to the environmental conditions, predation by mammals and birds, parasitic infestations and different human activities are putting pressure on fish living in the Baltic Sea. The fish stocks are/have been under intense targeted fishing pressure from both commercial and recreational fishing; eutrophication and hypoxia/oxygen deficiency due to high nutrient levels affect the ecosystem (see Section 5.2.1), and the Baltic Sea is also known to be contaminated with pollutants such as heavy metals (e.g. mercury, lead and cadmium), organochlorines such as DDTs and PCBs, brominated flame retardants, and perfluorinated substances including PFOS (Danielsson et al., 2020; Bignert et al., 2017). Additionally, the introduction of invasive species such as the round goby may affect the structure of the food web (Kotta et al., 2016; Almqvist et al., 2010). Taking salinity levels, variations in temperature and oxygen levels combined with these factors into account, it is obvious that the Baltic Sea is a demanding environment for fish to live in.

1.3.2. Salinity is an important factor in the Baltic Sea

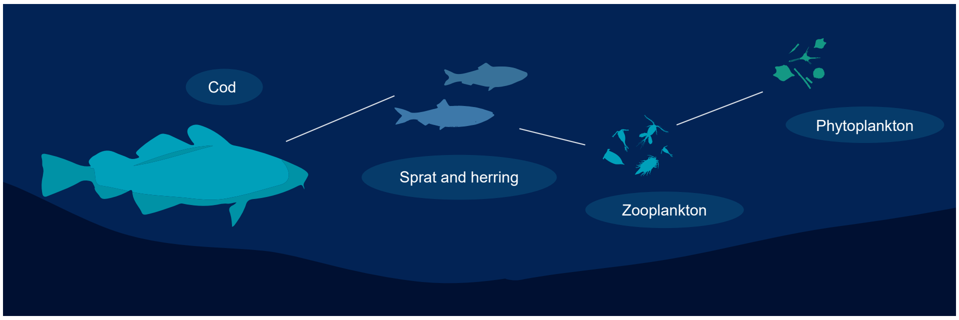
As previously mentioned, one important characteristic of the Baltic Sea environment is the large variations in salinity throughout the sea. The water gradually becomes more saline from north to south and, in addition, a vertical salinity gradient exists and the water is vertically stratified, meaning that it is divided into layers where the one at the surface has more oxygenated water but lower salinity while the deeper layer is less oxygenated (sometimes completely deoxygenated) and more saline. In the deeper parts of the sea, a permanent halocline is present, preventing water mixing, with higher salinity in the deeper parts (Bonsdorff, 2006). The total oxygen content in the bottom water layer depends on the inflow of saline water and on the rate of oxygen consumption in the water as the stratification of the Baltic Sea water stops oxygenated water from the surface level from mixing with the deeper layer (Carstensen et al., 2014; Walday & Kroglund, 2002).

The salinity level is a demanding challenge for life in brackish environments as it is normally too high for freshwater species and too low for marine species, and the environment is not truly optimal for either group (Svedäng & Humborg, 2020). As described by Berg et al (2015), adaptation to brackish water requires effort. Fish species are able to adapt and live in a range of different salinities, but in order for them to do so the water and salt balance inside the fish needs to be maintained. This regulation is called osmoregulation and includes uptake of salt in freshwater environments and active excretion in sea water. Adaptation to environments with different salinity requires changes in molecular and physiological processes throughout the lifecycle, from egg to adult fish (Berg et al., 2015). Baltic cod have adapted to life in the brackish water and are able to reproduce at much lower salinity than their neighbours in the Northeast Atlantic. Egg buoyancy (ability to float in water that is less saline and therefore less dense than the normal environment for cod eggs) and sperm motility (capability of movement or swimming in the water) are some of the factors that need to be adapted for a marine species like Atlantic cod to be able to live in the Baltic Sea. Baltic cod, particularly the EBC stock, are also able to cope with rapid changes in salinity when they move to spawning areas and during vertical movements in the water column (Svedäng & Humborg, 2020; Neuenfeldt et al., 2007). However, there is a limit to how low the salinity can be for successful reproduction. Eastern Baltic cod fertilization and egg development is most suited to water with an oxygen content above 2 mL/L and salinity above 11-12 PSU (PSU = practical salinity unit) (Köster et al., 2003; Westin & Nissling, 1991). These adaptations can act as a barrier, stopping adjacent cod populations from moving into the area and reproducing or mixing with the Baltic cod stocks. Salinity also acts as a barrier between the two Baltic stocks and maintains the differences in genetics and physiology of Baltic cod. The EBC and WBC stock have proved to cope with changes in salinity differently, as the EBC stock is more adapted to quick variations than the WBC stock (Kijewska et al., 2016).

1.3.3. Importance of cod in the ecosystem

Cod is one of the key predatory fish species living in the Baltic Sea and one of the best studied marine fishes. While a healthy stock of cod consists of a range of different sizes and ages, the current stocks are uniform in size, and the regulatory role that cod as a predator plays in the whole system is affected. Cod diets change with age and size. At younger life stages, cod feed on zooplankton, while juveniles eat invertebrates, including crustaceans. Large cod still eat invertebrates but also act as a top predator and eat other fish, including other species and smaller cod (Neuenfeldt et al., 2020; Funk et al., 2020; Neuenfeldt & Köster, 2000; Niiranen et al., 2019) (Figure 2). Predators are important for balance in the entire ecosystem. When the numbers of cod and other large predators decline due to high fishing pressures and/or environmental factors, smaller fish are being eaten less and therefore become more abundant. As an example, the decline in cod in the Baltic Sea has reduced the predation of sprat, one of the main prey species that cod feed on, the released predation pressure having led to higher sprat biomass after the 1980s (ICES, 2020b). This leads to reduced populations of zooplankton and other grazers as these are eaten more by the larger number of small fish. In turn, the phytoplankton that would normally be eaten by grazers can grow stronger and form algal blooms. This increase in phytoplankton contributes further to the eutrophication problem, and leads to even lower oxygen levels, in turn leading to less favourable conditions for cod reproduction. Hence, the lack of top predators can be linked to algal growth and algal blooms (Casini et al., 2008; Eriksson et al., 2009).

Figure 2. Simplified overview of the food web in the Baltic Sea ecosystem. Large cod eat sprat and herring, which in turn feed on zooplankton, and zooplankton eat phytoplankton. A decrease in the number of large cod has led to an increase in the numbers of sprat, a decrease in zooplankton and an increase in phytoplankton



As previously stated, large cod individuals have become very rare in the Baltic Sea, and the current cod population mainly consists of small and skinny individuals that are competing for the same food sources (Eero et al., 2015). This is in contrast to healthy diverse populations, including the earlier situation in the Baltic Sea where the size distribution was more diverse, which fed on more diverse prey. Furthermore, larger individuals are more responsible for reproduction. Fecundity (reproductive capacity) is usually higher with age, and condition, i.e. older fish and fish with better body condition are able to produce a higher number of eggs. In addition, the eggs from larger females are able to float at lower salinity levels than eggs from smaller females. The lack of large individuals and poor condition of the Baltic cod stock thus has a negative impact on reproduction (Mion et al., 2018; Vallin & Nissling, 2000).

1.3.4. Cod stocks in the Baltic Sea

After a peak in productivity in the early 1980s, the cod stock has steadily declined to the point of collapse for the eastern stock, and the western stock is also greatly diminished (Eero et al., 2011; Lade et al., 2015). A fishing ban for targeted fishing of the eastern stock in ICES Subdivisions 24, 25 and 26 was introduced by the European Commission in 2019 as an emergency measure. The western stock was given only a bycatch quota in the 2021 negotiations, after a sharp decline of fishing opportunities in the ICES advice. Hence, all targeted fishing for both the western and eastern cod socks is prohibited from 2022. According to ICES recommendations, there should be zero catch of EBC in 2020 (ICES, 2019c) and in 2021 (ICES, 2020d), and also for 2022 (ICES, 2021a). For the latest advice, ICES also states that it is possible that the low quotas and disruptions caused by COVID-19 have caused some misreporting when it comes to landings for 2020 (ICES, 2021a). For WBC, a reduced catch was recommended for 2020 (ICES, 2019b) and 2021 (ICES, 2020c) while the advice for 2022 allows for a historically low figure of 698 tonnes, which was lowered to 489 tonnes after the TAC negotiations in the Council. This applies to both commercial and recreational fisheries (ICES, 2021d).

1.4. Current situation of Baltic cod

Unless otherwise stated, the following section is focused on the state of the EBC, while WBC indicates the western stock excluding the Öresund area.

Over recent decades large changes have happened to Baltic cod. Firstly, the distribution range has been greatly reduced. Three main spawning sites were once used by the EBC: the Gdansk Deep and Gotland Basin in SD 28 and 26 (Bagge & Thurow, 1994) at this point are hardly used and make a negligible contribution to reproduction (Cardinale & Svedäng, 2011), which is mainly done in the third area, Bornholm Basin, which is located to the south-west in SD 25. This loss of spawning sites led to reduced reproduction/productivity and a reduced distribution range. Next, the following adverse effects have been observed in scientific literature used in the current literature study:

- the condition (weight-at-length) of Baltic cod has decreased;
- the range of sizes has become much smaller, meaning that individuals are now more similar in size and the number of large individuals has greatly declined, either because individual growth is lower or because of higher mortality in older cod (natural mortality or mortality caused by fishing);
- cod are becoming sexually mature at smaller sizes than previously;
- cod have higher natural mortality;
- there is a higher number of parasite-infested cod;
- the reproduction/productivity of Baltic cod has decreased;
- cod live in a more limited distribution range.

1.4.1. Stock trends/fluctuations over time

Increasing amounts of nutrients during the 1900s led to higher production overall in the Baltic Sea (See Section 1.5.2.1). The spawning stock biomass (SSB) (Figure 3A) and catch of Baltic cod increased until the mid-1980s, with a peak in 1984 when the total EBC catch was over 400,000 tonnes (Figure 3B) but it was also heavily fished during this time and the peak was followed by a steep decline. At the end of the 1980s, the number of spawning sites was reduced, and conditions became less favourable for cod, partially due to the increased occurrence of hypoxia in the deeper areas as well as high fishing pressure. In the following years the stock declined more than tenfold (see SSB in Figure 3A). The catch of EBC has decreased steadily since the late 1990s, after the initial sharp decline, which was caused by a combination of low recruitment due to unfavourable hydrological conditions, and high fishing pressure (Köster et al., 2005, and references therein). Similarly, the SSB and total catch of WBC has been declining since the mid 1990s (Figure 4).

The state of Baltic cod has been critical in recent decades. This is reflected in lower condition (weight-at-length), with condition declining since the 1990s (Eero et al., 2012a), a smaller range of sizes (Svedäng & Hornborg, 2017), fish being younger and smaller at the onset of sexual maturation (ICES, 2021a; Köster et al., 2016), and lack of large individuals as important characteristics. According to the ICES summary of stock development, recruitment is assessed as having declined since 2012, while the spawning stock biomass has been in decline since 2015 and the total quota set for targeted fishing of the EBC in all countries has not been landed since 2007 (ICES, 2019c). The ban on targeted EBC fishing was introduced in the summer of 2019 and was extended in the following years as a result of these declines. The stock is currently at its lowest point yet, based on the biomass estimates that are available from ICES from 1966 onwards (e.g. ICES, 2021a). Assessments are made more difficult as the imprecise age information for Baltic cod (see Section 1.4.2) means that there is also some uncertainty in the growth estimations.

Figure 3. Overview of the A) spawning stock biomass of EBC cod in SD 24-32 based on ICES data for the period 1946-2021 and B) annual Total Catch of EBC in SD 24-32 based on ICES data for the period 1966-2020 (ICES, 2021a)

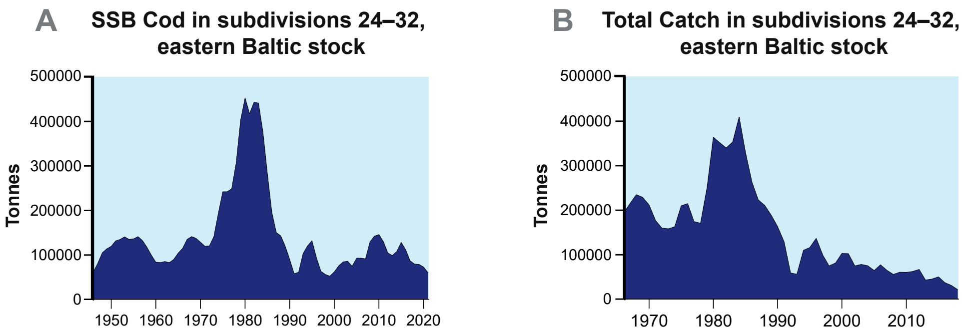
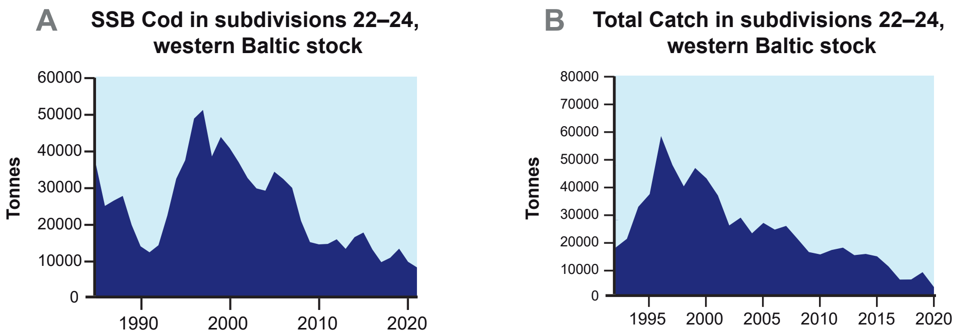
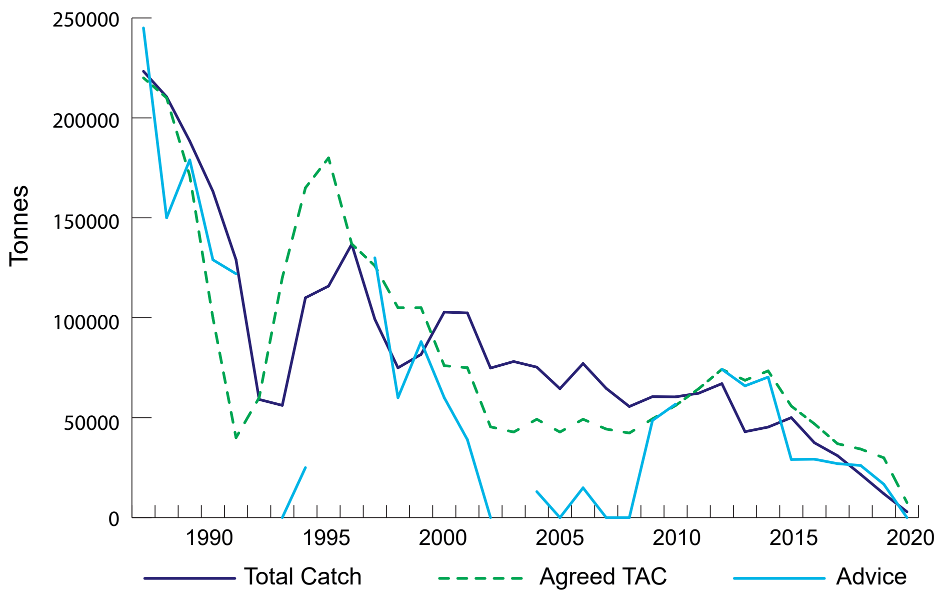


Figure 4. Overview of the A) spawning stock biomass of WBC cod in SD 22-24 based on ICES data for the period 1985-2021 and B) annual Total Catch of WBC in SD 22-24 based on ICES data for the period 1992-2020 (ICES, 2021d)



The biomass of small EBC cod increased during the late 2000s and early 2010s after two decades of severe depletion (Eero et al., 2015; Köster et al., 2016). The improvement could be attributed to an increase in recruitment and a decrease in fishing mortality (Eero, et al., 2012a; Köster et al., 2016). This perceived stock recovery was seen as good news for the status of Baltic cod, which is reflected in the publications appearing around this time (e.g. Eero et al., 2012a) as well as more optimistic scientific advice from ICES and TACs (illustrated in Figure 5) and in the fact that Baltic cod was MSC certified in 2011-2015. However, this improvement was not followed by an increase in biomass of cod over 35 cm (commercial-sized cod) or improved catch during the same period, and MSC certification was suspended in 2015 when the stock was found to have declined further (ICES, 2021a).

Figure 5. Total Catch of Eastern Baltic cod compared to the TAC quota and the levels that should be landed according to ICES advice during the period 1987-2020 based on data from (ICES, 2021a). Agreed TAC was given for the total Baltic Sea until 2003



1.4.2. Age determination and growth estimation in Baltic cod

Accurate estimations of growth, mortality as well as age is very important for fish stock assessments. The age information is used to determine age at reproduction, to determine whether the growth rate is reduced and whether mortality is increased, and to estimate the number of individuals belonging to a certain age group, which can give an indication of whether the abundance changes over time (Hüssy et al., 2020). Otoliths or "earstones" are involved in hearing, orientation and balance in cod as well as in other bony fish. These are calcified structures that are found in the heads of bony fish and that keep growing as the fish grows. Otoliths are traditionally used for age determination as distinct growth zones of different translucency, where one opaque and one translucent zone are formed each year. These rings can be counted to interpret the age of the fish, similarly to the way growth rings are counted to determine the age of trees. Age rings in fish from areas with clear seasonal differences in temperature are normally easy to distinguish. Furthermore, otoliths can be used to assess periods of hypoxia during the life of a fish, since manganese accumulates in the otoliths during these periods (Limburg & Casini, 2018; Limburg & Casini, 2019). Size and protein content has also been used to assess metabolic status in EBC cod (Svedäng et al., 2020).

Unfortunately, the age assessment of Baltic cod is known to be especially difficult because the annual rings in the otoliths are not very distinct, leading to errors in interpretation and inconsistent results from the traditional age readings (Hüssy, 2010; Hüssy, et al., 2016b). Since growth is one of the factors that have been severely altered in the Baltic cod, reliable age determination methods are very important for correct stock assessments and management decisions. For instance, the lack of large individuals could be either a result of lower individual growth or due to higher mortality in older cod (caused by increased natural mortality or mortality caused by fishing) (Hüssy et al., 2020). A reliable age determination method is needed to determine which cause is the main driver. The uncertainties for EBC age determination and on growth and natural mortality resulted in a lack of analytical quantitative assessments after 2014 (ICES, 2014, 2019a). The traditional otolith method for estimation of age in WBC is also unreliable (McQueen et al., 2018). Several scientific studies have been focused on addressing the ageing problem by finding alternative methods for age determination. Alternative options for age determination include microchemistry-based methods that can consist for instance of measuring trace elements with seasonal pattern formation in the otoliths (Heimbrand et al., 2020; Hüssy et al., 2015). Cod tagging data from projects for tagging and recapture of Baltic cod from previous decades can be used to determine historical growth and to confirm the accuracy of new age determination methods being developed (Mion et al., 2020).

1.4.3. Stock mixing and stock assessment uncertainties

The EBC and WBC stocks are well separated from a genetic point of view (Hemmer-Hansen et al., 2019; Poćwierz-Kotus et al., 2015). The stocks maintain their separation by spawning at different times and locations. EBC cod spawns further east where the salinity is lower, between April and August, while WBC cod spawns from January to April (Wieland et al., 2000). However, they live adjacent to each other and overlap in the Arkona Basin (SD 24). The two stocks are assessed and managed separately, and individuals are assigned to the stock depending on the management area they were caught in. However, the overlap in location means that there is considerable mixing of the stocks in the SD 24 area (Hüssy et al., 2016a), which needs to be taken into account for management, as Eastern Baltic cod is caught in mixed fisheries with WBC there. If the stock mixing is not taken into account in this area of distribution overlap, there is a risk of under- or overestimating size and possibly affecting the exploitation level (Bastardie et al., 2017). Stock assignment of cod landed in the overlapping area is done through analysis of otolith shape as well as based on genetics (Hüssy et al., 2016a; ICES, 2020a; Poćwierz-Kotus et al., 2015). Genetics-based methods are still expensive and require fresh tissue samples, which it is not feasible to use at a larger scale. Analysis of stable isotopes and analysis of the shape of the otolith (for instance the ratio between length and width) has been shown to be more reliable (Schade et al., 2019). As well as improved stock assessment, the distinction between EBC and WBC is important for our biological understanding of the two stocks.

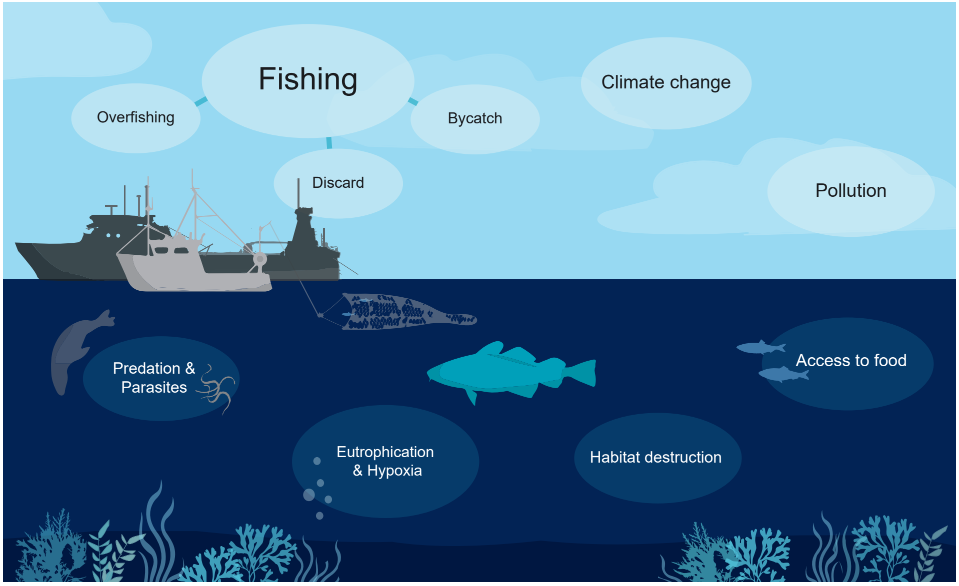
1.4.4. Cod in Öresund, a positive exception

The Öresund cod in the eastern North Sea (SD23) is located adjacent to the collapsed Kattegat population (SD 21). It is managed together with the WBC stock in SD 22 and 24 but differs from the EBC stock, the Kattegat and the rest of the WBC stock. The Öresund contains the only healthy cod stock in the eastern North Sea and is distinct from the EBC and the rest of the WBC stock. Genetically, the cod in SD23 belong to WBC (Weist et al., 2019) but can be considered to be a subpopulation of the WBC stock, and it has been suggested that it should be managed separately (Lindegren et al., 2013). In contrast to the rest of the WBC stock and the EBC stock, there is no trend towards smaller size variation in the Öresund, and the abundance of large individuals is higher (Svedäng & Hornborg, 2017). One reason for this difference is the long-term local trawling ban in the Öresund area that has been in place since 1932 (Anonymous, 1932). This was not intentionally put in place for the benefit of cod or other fish stocks at the time but instead was aimed at facilitating shipping. The use of gillnets instead of trawls in this area might affect fish growth as size selectivity is lower, possibly combined with higher ecosystem productivity than EBC and WBC (Svedäng & Hornborg, 2017).

1.5. Possible causes of the poor state of Baltic cod

Direct and indirect effects of human activities including unsustainable fishing, pollution with toxic substances and excessive input of nutrients leading to eutrophication, in combination with ongoing climate change, is a challenging stressor for biodiversity and integrity of aquatic ecosystems all over the world. According to ICES, the most important factors pressuring the Baltic Sea ecoregion as a whole are "*nutrient and organic enrichment, selective extraction of species, introduction of contaminating compounds, introduction of non-indigenous species, and abrasion and substrate loss*" (ICES, 2020e). Unsurprisingly, these pressures are also to some extent represented in the scientific literature focused on Baltic cod. Decades of human activities have had an effect on the size and state of fish stocks in the Baltic Sea. However, due to the fact that several changes have happened simultaneously the cause of the deterioration is becoming more complex, making it hard to pinpoint the exact root of the problem (Eero et al., 2015). It is likely to be a synergistic effect of multiple factors. This complexity has also made management of the stocks more difficult. The factors suggested to be involved in the poor status of Baltic cod according to scientific papers (summarised in Figure 6) and the potential effects of these factors are listed below.

Figure 6. Overview of the multiple different factors that can affect the status of Baltic cod according to current scientific literature used in the literature study and described further in Section 1.5.1-1.5.2. Several of these factors are linked together; the lack of oxygen can, for example, reduce access to food for young cod, and fishing of cod prey, including sprat, can reduce food availability for older cod. The fishing category includes both targeted fishing (prior to summer 2019 for EBC), bycatch of cod in other fisheries, discard and fishing of prey species that are important for cod



1.5.1. Fisheries-related factors

Based on condition and growth changes, it can be concluded that the EBC stock is severely depleted. In consideration of ongoing climate change, fishing pressure that was sustainable in the past may no longer be possible to maintain, and management decisions need to be made based on the new state. As illustrated in Figure 5, there has periodically been inconsistency between the advice on quotas given by ICES, the TACs and the total landings for EBC. For instance, during the period 2010-2014 the scientific advice from ICES and the TAC quota were increased compared to previous years, but the total catch was still decreasing. At other times, the catch and TAC have been higher than the levels recommended in scientific advice, which is not likely to have a beneficial effect on the stock. The EU Fisheries Council's decisions on Total Allowable Catches for Eastern Baltic cod stock have exceeded scientifically advised levels each year since 2013 (www.fishfix.eu).

1.5.1.1. Overfishing

Overfishing is a problem worldwide, and this trend has not yet been reversed, even though efforts and progress have been made in some areas (FAO, 2020). This is in spite of the EU's Common Fisheries Policy (CFP), stating that stocks should be managed to maintain MSY (maintained at sustainable exploitation rates) by 2020 (CFP, 2013). Overfishing has been identified as a main driver in the decline of some fish stocks. For instance, the decline of cod in Newfoundland during the 1960s was shown to be caused by fishing pressure which greatly exceeded the productivity of the stock, based on studies of historical stock development (Rose, 2004). The overfishing of Baltic cod during the 1980s led to a decline in cod abundance and a transformation into a system dominated by sprat (Möllmann et al., 2009). At the time of the highest catch levels in the 1980s, the cod stock was unusually large (as illustrated in Figure 3A, the spawning stock biomass for EBC was very high during this time compared to both the previous and following timepoints). In order to establish a baseline for the biomass of the cod stock, one might instead need to look further back, possibly to the levels the stock was at before the Second World War (Eero et al., 2008). Fishing pressure that was sustainable in the past might become too high if circumstances for the fish stock changes, such as changes in environmental conditions or increased occurrence of pathogens, and the fishing pressure would need to be adapted to this new state to maintain the fishery at a sustainable level (Bastardie et al., 2021). Both the EBC and WBC stocks are currently too small to reproduce in a stable manner and should not be weakened further by fishing at this point. This is in line with the scientific advice stating that there should be zero catch for EBC and a small catch of a maximum of 689 tonnes for the WBC (ICES, 2021a, ICES 2021d).

1.5.1.2. Discards

Discard is an unwanted catch, which is not kept, and instead thrown back into the sea. This is done, for example, with damaged individuals, individuals that are too small (below the minimum allowed size for landing), individuals belonging to an unwanted species of low commercial value or fish that the fishers are not allowed to land as they do not have a quota for them. Discarding practice is a waste of resources and not a part of sustainable fishing, as the catch that is returned is often already dead or is in bad shape and will not survive after re-entering the water (Catchpole et al., 2005). The EU's Landing Obligation (LO) has been introduced to eliminate discards and states that all catches must be landed and be included in the fisher's quotas (EU, 2013). Baltic fisheries were among the first to fully implement this ban on discards as of 2015. Before this, undersized and unwanted catches were required to be discarded. The introduction of the landing obligation means that there is no longer a minimum landing size for cod, all caught cod has to be landed, and the previous minimum landing size of 38 cm has been replaced by a "*minimum conservation reference size*" of 35 cm. Below the total size of 35 cm, cod can no longer be sold as a food product for human consumption (ICES, 2020a). However, the introduction of the LO has not put a complete end to the practice of discards in Baltic cod fisheries after 2015. In 2019, discards were estimated to account for 14% of the total catch weight for cod from SD 25-32, and this figure might be underestimated (ICES, 2020a). Keeping track of discards is important for stock assessments and work towards reducing waste. Removing substantial numbers of a species without registering the amount or species of fish that is being removed can affect stock viability (Uhlmann et al., 2013). It is especially harmful when the status of a stock is already weakened, as is the case for Baltic cod. The monitoring of discards in the field, improved documentation/ reporting and data quality are important for assessment of both Baltic cod stocks.

Improved gear selectivity in demersal trawling, which lets young, small individuals escape, is one of the measures that can be taken to reduce discards of undersized fish as a step towards fulfilling the LO. However, currently no targeted fishing for cod is allowed in the Baltic Sea, so the discussion on selective gear is now focusing on flatfish gear that lets the cod escape. Different designs used to improve size selectivity have been used for over 25 years in the Baltic cod trawl fishery, but discard rates are still relatively high (Feekings et al., 2013; Madsen, 2007; Madsen et al., 2021; Valentinsson et al., 2019). The use of new codend designs in commercial fishery could be a more sustainable option and could reduce discards (Madsen et al., 2021).

In a review of the Landing Obligation using the Baltic cod trawl fishery as a case study, Valentinsson et al. found that the LO has not so far led to successful results for cod. The following main problems were identified: i) The practice of discard had not stopped since the introduction of the LO. ii) The depletion of both cod stocks has forced fishers to target sizes closer to the minimum size which have led to large numbers of unwanted, small individuals in catches and inevitably had a negative economic impact on the fishers. iii) Scientific data quality has not improved, as underreporting is consistent and uncertainty of observer data has increased. iv) Gear selectivity had not increased (Valentinsson et al., 2019).

1.5.1.3. Bycatch

Besides this, bycatch of the EBC stock in fishing targeting the Western stock (when this practice was allowed) is difficult to avoid in SD24 (See section 1.4.3). Bycatch is defined by FAO as "*part of a catch of a fishing unit taken incidentally in addition to the target species towards which fishing effort is directed. Some or all of it may be returned to the sea as discards, usually dead or dying.*" (FAO, n.d.a). Baltic cod is no longer the main target for commercial fishing, and targeted fishing of the EBC stock is not allowed, but cod is still caught as bycatch in the fishing of other species. Cod are, for instance, caught as bycatch in demersal trawling for flounder and plaice. These species used to be caught together as a mixed fishery. The EBC stock overlaps in location with plaice in SD 24-25 and flounder in the entire area that EBC inhabits, which makes it impossible to completely exclude cod in trawling for flatfish in the SD 24-26 area by only trawling for flatfish in certain areas or during a certain time period (ICES, 2020f). It can, however, be reduced by improved gear selectivity. Due to the difference in body shape between cod and flatfish, it is possible to adjust the selectivity of trawls by, for instance, increasing the mesh size or reduction of the top panel of the trawl which allows the cod to escape while the flatfish stay.

Besides this, bycatch of the EBC stock in fishing targeting the Western stock is difficult to avoid in SD24 (See section 1.4.3). Any fishing of cod in SD24 will lead to some cod from the eastern stock being caught.

1.5.1.4. Bottom trawling

Bottom trawling can be done with heavy nets and gear which are dragged along the seabed behind the fishing vessel. This efficiently catches large numbers of organisms but also disturbs non-target species and the seabed itself by "ploughing" the sea floor, making it flatter and less complex (Puig et al., 2012). Bottom trawling has been linked to decreased diversity and lower abundance of benthic invertebrates, limiting or changing the food availability for fish (Hiddink et al., 2016), as well as reducing the amounts of the fish themselves. Non-target species are frequently caught or relocated. Additionally, the interaction between the gear and the seabed resuspends the sediment into the water, leading to increased turbidity and relocation of the sediment. This can negatively impact eggs and larvae, which are less mobile than adults and depend on specific areas to grow up in (Sköld et al., 2018). However, few studies of the effects of bottom trawling on fish in the Baltic Sea have been done so far.

As mentioned previously, nursery habitats of the Eastern Baltic cod are found in deep areas where salinity is higher and are limited by the oxygen deficiency in the Baltic Sea. Bottom trawling can interfere with the nursery areas and could negatively impact the cod population if fewer larvae are allowed to grow into adulthood. A recent report on the state of Swedish cod suggested that an important measure for recovery of the EBC stock would be to protect nursery habitats in specific areas from trawling (Bryhn et al., 2020). The fact that Öresund cod does not have a truncated size structure and is seemingly healthier than the rest of the WBC stock and the EBC stock might indicate that the lack of trawling is positive for cod stock. As mentioned in Section 1.4.4, a local trawling ban has been in place in the area since the 1930s (Anonymous, 1932; Svedäng & Hornborg, 2017).

Bottom trawling also adds to the already severe environmental status of the Baltic sea when it comes to eutrophication. Bottom trawling is the greatest source of disturbance to the seabed on a global basis, and it is critically coupled with eutrophication (Ferguson et al., 2020). In short, bottom trawling disturbs the denitrification process which buffers against eutrophication, i.e. areas where bottom trawling occurs have lower resilience to eutrophication (Ferguson et al., 2020). As the Baltic Sea suffers from heavy eutrophication, adversely affecting cod, bottom trawling adds to both the disturbance of cod nursery habitats and also lowers resilience to nutrient enrichment in the system, so that there is a double negative effect on cod. Furthermore, bottom trawling affects the carbon cycle and disturbs carbon sinks when the demersal trawls creates resuspension of the sediment, hence counteracting the sinking carbon (Cavan and Hill, 2020), and also adds to ocean acidification and potentially atmospheric CO_2 (Sala et al., 2021). Marine sediment can store organic carbon for a very long time if left undisturbed, and the protection of carbon-rich seabeds has thus been suggested as one way to combat climate change (Sala et al., 2021).

A recent special request from ICES has led to the analysis of different management scenarios to reduce seafloor disturbance by bottom trawling. It is shown that a 10% reduction in bottom trawling efforts from peripheral fishing grounds will induce a 40% increase of untrawled areas, collectively in the Baltic Sea, the Greater North Sea, the Celtic Seas, and the Bay of Biscay and the Iberian Coast (ICES, 2021c).

1.5.1.5. Management and management problems

There are a number of identified difficulties when it comes to management of the Baltic cod stocks, some of which are listed below:

- As mentioned in Section 1.4.2, age determination for EBC is uncertain, making stock assessments more difficult. Furthermore, SD 24 contains both WBC and EBC stocks (Section 1.4.3). Similarly, the WBC and Öresund stocks are managed together (SD22-24), which can lead to over- or underestimations in stock assessments. Inaccurate data due to misreporting also makes stock assessment more difficult.
- With the EBC productivity as low as it currently is, the stock is likely to stay at low levels even though no cod is removed by targeted fishing. Any fishing of the EBC stock at present would catch fish of commercial size, and these large individuals are needed for new reproduction (ICES, 2020f).
- In order to reach the zero catch level, the discard of cod, bycatch of cod in flatfish trawling and catch of EBC in WBC fisheries in SD24 would need to be zero as well. It is currently not possible to completely avoid cod as a bycatch in trawling for flatfish. The gear used for catching flatfish normally has the same mesh sizes as that used for cod, and demersal trawls would normally catch both cod and flatfish (species differ depending on location) as a mixed fishery, while targeted cod fishing of the EBC was still allowed (ICES, 2020f). Development of more species selective gear for flatfish is ongoing but the actual use and control of the new gear would also need to be taken into consideration.
- In spite of the Landing Obligation, the practice of discard is still ongoing. There are not enough control measures in place ensuring that the LO is being followed/complied with (Valentinsson et al., 2019).

1.5.2. Non-fisheries related factors

Apart from the measures that can be taken to reduce fishing or fish more sustainably, a number of environmental factors are also likely contributors to current cod status and may need to be addressed. The factors that are most frequently discussed in the scientific literature on Baltic cod are listed below. Please note that the order of the factors in the text does not reflect their level of importance. No new analysis of the impact of each factor was done in this report.

1.5.2.1. Eutrophication and lack of oxygen

Eutrophication

Eutrophication is a process of nutrient enrichment, where excessive input of nutrients including nitrogen and phosphorus to a water body leads to an increased supply of organic matter. While natural eutrophication is slow, the process is sped up considerably as a result of human activities such as runoff from agriculture and sewage disposal. The Baltic Sea started out as a nutrient-poor sea, and rapidly became more nutrient-rich during the 1900s as a result of increased emissions from agriculture

and from the cities surrounding it. Nutrient input was especially high between the 1950s and 1980s (Gustafsson et al., 2012), and the Baltic Sea currently contains the largest deoxygenated area in the world, caused by human (anthropogenic) activities (Carstensen et al., 2014; Limburg & Casini, 2018).

Eutrophication leads to a chain reaction where excessive primary production through increased growth of phytoplankton in turn reduces water quality and makes the water less favourable for fish and other organisms to live in. The reduced water quality also includes lower visibility and affects light conditions as clarity is decreased when water becomes more turbid, causing fish to find it harder to catch prey. The water quality changes can alter the species composition and interactions between species, depending on which animals are favoured by the conditions. Some species have moved to new areas, and the new overlaps or lack of overlaps can affect prey availability for predators like cod. Eutrophication also leads to oxygen deficiency in the water, a decrease in the amount of available oxygen in deeper water as increasing amounts of oxygen are consumed at the sea floors where more organic material is deposited. Oxygen is entirely depleted in some local areas, leading to what are known as dead zones. This is particularly harmful for species which use these areas for spawning and reproduction (Carstensen et al., 2014; Casini et al., 2016).

Effects of oxygen deficiency

As mentioned above, the oxygen deficiency is a problem for cod spawning in the Baltic Sea. Cod need deeper areas with higher salinity for egg survival in order to reproduce successfully, and a loss of spawning sites due to hypoxia has caused a reduction in stock productivity as reproduction has declined, and a reduction in the distribution of cod. Cod eggs are directly affected by the lower oxygen content; at least 2 mL oxygen per L water is needed at the correct salinity (over 11 PSU) (Köster et al., 2003; Westin & Nissling, 1991). Furthermore, the increased occurrence of hypoxia in the Baltic Sea has led to a decrease in the habitats that are suitable for juvenile and older cod but also to a decrease in the benthic fauna that is important for the food web (Conley et al., 2009). Since these benthic communities are already limited by the low salinity in the Baltic Sea, hypoxia makes the situation even more challenging. Low oxygen conditions have thereby been linked to reduced benthic food availability and in turn to decreased growth of young Baltic cod, especially in combination with the reduced sprat availability (Casini et al., 2016; Neuenfeldt et al., 2020). The growth and body condition of cod could also be adversely affected by hypoxia (Limburg & Casini, 2018; Limburg & Casini, 2019). However, a new study by Svedäng et al (2022) gives new insights regarding the connections between the decline of cod and hypoxia. In the Gotland Deep the deterioration of the spawning conditions for cod originated already in the 1950s due to oxygen depletion. However, the research also shows that there is no clear connection between hypoxia and the condition and productivity of EBC in SD 25, where the stock productivity has been declining even though hydrographic conditions have remained unchanged over the last 60 years and no change in benthos over the last 30 years. It is thus unlikely that hypoxia is the driver of the decline of cod in the Bornholm basin. (Svedäng et al., 2022).

Management of eutrophication

It has been well known for decades that eutrophication is a major issue contributing to the deteriorating condition of the Baltic Sea, and in the late 1980s it was agreed by the HELCOM Ministerial Declaration that action needed to be taken (HELCOM, 1988). Monitoring, research and considerable efforts to reduce nutrient loads have been undertaken. Trends towards improvement are seen in some areas, but the nutrient loads have accumulated over long periods of time and the Baltic Sea is still very much affected by eutrophication, and recovery will take a long time. Efforts to reduce the nutrient loading still need to be made continuously (Andersen et al., 2017; HELCOM, 2018).

HELCOM has been important for management of eutrophication and for international efforts to reduce nutrient loads and counteract eutrophication in the Baltic Sea, and the Baltic Sea Action Plan (BSAP) includes management advice for improved conditions (HELCOM, 2007). While it will take a long time to achieve a state where the Baltic Sea is unaffected by eutrophication, modelling predicts that following the BSAP can lead to good eutrophication status in the long term in most parts of the Baltic Sea (Murray et al., 2019). However, this change is slow and climate change is likely to make improvement more challenging.

1.5.2.2. Lack of food and fishing for prey species

Food deprivation and starvation is connected to reduced growth in fish (e.g. references in Neuenfeldt et al., 2020). As previously stated, the smaller range of sizes in the current population of cod could be explained by reduced growth, but this has not yet been proven for certain. Some uncertainty is caused by the lack of reliable age determination for EBC (see Section 1.4.2), but individual growth of Baltic cod could be affected. Growth is affected by several different factors, starvation and limited food availability being one possible explanation (Casini et al., 2016). As well as affecting growth, lower food availability can have an impact on the reproductive success of cod (Mion et al., 2018).

Sprat and herring are important as prey species for larger cod. The distribution of Baltic sprat has shifted to locations further to the north over recent decades, while cod has stayed in the south where the salinity is higher. This has led to a situation where the spatial overlap with the main areas that cod live in has decreased (Casini et al., 2011; Casini et al., 2016), reducing the availability of food for the larger, fish-eating cod. Fishing for sprat in the area where the sprat stock overlaps with cod, mainly in SD 25-26, could affect food availability for cod and increase food deprivation (Casini et al., 2016). Ensuring increased availability of prey by reduced fishing of these species in selected areas is one suggested measure that could benefit cod stock recovery. SD 25 and 26 are populated by more cod than the other areas and might be especially sensitive to limitations in the abundance of food. The overlap in spatial distribution is smaller than previously due to the location shift for sprat stocks which are now living further north in the Baltic Sea (Casini et al., 2016; Eero et al., 2012b; ICES, 2020b; Neuenfeldt et al., 2020). Additionally, similarity in diets between cod and flatfish could also affect the food availability, particularly for small and intermediate cod. The competition overlap between Baltic cod and flounder was found to have increased over recent decades (Orio et al., 2020). However, by studying metabolic status using otoliths, others have found that the EBC cod's intake of food has increased rather than decreased in recent decades, which might suggest that lower feeding rates or limited access to food is not the cause of their poor condition. Instead, changes in the quality of the food could be a contributing factor (Svedäng et al., 2020).

1.5.2.3. Climate change

The abiotic (non-living) factors driving changes in the Baltic Sea vary somewhat with location, but some main contributors related to climate change are reduced salinity, increased ocean acidification and increased temperature. Lower salinity has a negative impact on Baltic cod habitat and reproduction (see section 1.3.2). Lower salinity and oxygen levels have already been linked to the initial cod decline after the peak in the 1980s (Köster et al., 2005). Changes in the inflow of saltwater in combination with eutrophication that is still ongoing could affect the structure and function of the Baltic ecosystem. Since the end of the 1980s only two major inflows that transfer large volumes of saline water into the Baltic Sea have been detected, including a particularly large one in 2014. Despite the reduction in inflow events, it has been suggested that there is no long-term trend for mean salinity in the Baltic Sea. Morholz proposes that the increase in oxygen-depleted bottoms and stagnation in deep water areas cannot so far be explained by a reduced inflow due to climate change, but is instead mainly driven by the eutrophication during the last century (Mohrholz, 2018).

Ocean acidification is the decrease in pH in the water as a result of carbon dioxide (CO_2) uptake. Acidification is known to have a detrimental effect on aquatic ecosystems globally. While increased temperatures can be avoided to some extent by shifting location, acidification is more difficult to avoid. Cod at early life stages are more sensitive to decreases in pH. Cod larval mortality (WBC and Barents sea cod) was, for instance, affected by scenarios simulating the predicted ocean acidification at the end of the century (Stiasny et al., 2016).

Higher temperatures are also expected to have a negative impact on Baltic cod. With increasing temperature, improved management of the WBC stock is predicted to be needed in order to maintain the stock at a level that can be fished, and a precautionary approach is even more important (Voss et al., 2019).

1.5.2.4. Seal predation

Over the last few decades there has been increasing concern that predators have a negative impact on Baltic cod. Among marine mammals, the grey seal (*Halichoerus grypus*) is considered a main contributor and is often brought up as a problem by fishermen (Svels et al., 2019). Historically, human influence led to a substantial reduction in marine mammals (seals and harbour porpoises) during the 20th century through hunting and pollution, which is likely to have had a positive impact on the size of the cod stock (Eero et al., 2011). The grey seal has since recovered, leading to increased concerns about competition with fisheries. Seals are top predators which eat a varied diet of different fish. In the southwestern Baltic, a substantial proportion of the diet has been reported to be made up of cod (Eero, 2019). Overall knowledge of the seal diet is limited, but some research has shown that seals north of Kalmarsund mainly eat herring, while the amount of cod in the diet increases in the central Baltic Sea and is substantial in the southern parts. The proportion of cod in the seal (and cormorant) diet has been shown to vary between a few percent and a third of the stomach content (Bryhn et al., 2020).

MacKenzie et al. found predation by grey seals to have a relatively low impact on the recovery of cod compared to salinity and human exploitation in the form of fishing (MacKenzie et al., 2011) while Hansson et al. found that the effects of seals on commercial species including cod were likely limited compared to the substantial pressure from fisheries (Hansson et al., 2018). Similarly, Costalago et al. found that the impact of seals was not the main threat to Baltic cod and is unlikely to affect the preservation of fish stocks when compared to other factors (Costalago et al., 2019). The decline of Baltic cod cannot be explained by predation from seals alone but the recovery of the already depleted Baltic stock under continuing environmental change may be made worse by any stressor, including the increase in predation (MacKenzie et al., 2011).

Local effects of seals could lead to increasing cod mortality (Eero, 2019). Direct effects of seals on cod fishing include gear damage and catch losses as a result of seals eating entire fish (hidden losses) or damaging the caught fish, in turn leading to economic loss (Königson et al., 2009; Waldo et al., 2020). The presence of seals is commonly identified as a large problem by fishermen, and a threat to their livelihood which can cause them to leave the fishery (Svels et al., 2019). Small-scale fisheries are particularly vulnerable. Alternative gear can be used in order to reduce the damage caused by seals (Königson et al., 2015; Stavenow et al., 2016). Other suggested solutions include reduction in seal numbers through hunting, which was the preferred method according to fishers in a survey investigating impacts on coastal small-scale fisheries, or protective measures that drive away the predators from the local area, or monetary compensation for the economic loss (Svels et al., 2019). In the large study by Bryhn et al. (2020) it is shown that scientific studies both support and dismiss seal predation as contributing to cod mortality to a large extent. Hence, the results are inconclusive.

Worthy of note, however, is a historical perspective on seals and fishing in the Baltic Sea. In a recent study by Svedäng and Rolff (2021), the history of fishing in the Baltic, focusing on the Stockholm archipelago, reveals that there were already complaints of seals eating out of the nets in the 19th century. Fishermen developed their own strategies to avoid seal damage. The herring stock did fluctuate then, as it does now, but no connections were made between the size of the herring stock and the seal population (Svedäng & Rolff, 2021). In addition, the cod stock did fluctuate and sometimes vanish (and then return). Nevertheless, the fishery for both cod and herring flourished during the 19th century, protecting the people living in the archipelago from starvation due to crop failure. Although seals caused local problems, the fishery as such was prosperous despite the seal population at that time being much larger than today in the Stockholm archipelago (comprising grey seal, harbour seal and ringed seal) (Svedäng & Rolff, 2021).

It is difficult to estimate scientifically how much the status of the cod stock might improve at a lower seal abundance. Studies of the economic effects of the predation on Baltic cod are still limited, and further studies of the scale of the impact of seal predation are needed to increase knowledge about the effects of seals on Baltic cod.

1.5.2.5. Seal parasites

Another factor that could affect the condition and health of Baltic cod is the increasing occurrence of seal parasites which could affect both the stock itself and the quality of cod as a food product for human consumption. The increase in seal parasites in the Baltic Sea is connected to the increased numbers of seals which act as their final host. Scientific studies of seal parasites in cod have become more frequent over recent decades. These parasites are nematodes (roundworms), and the most common ones in Baltic cod are the seal worm (*Pseudoterranova decipiens*), which is found in muscle tissue, and the liver worms (*Contracaecum osculatum*), which are found in cod livers. Levels of *Pseudoterranova decipiens* nematodes in cod muscle tissue have been shown to be negatively linked to the condition factor of cod (Mehrdana et al., 2014). In the most heavily infected fish, the nematodes could be lethal for the cod (Horbowy et al., 2016). Effects on cod larvae have also been documented and may affect growth and immune function (Marnis et al., 2019). Ryberg et al. found that the condition factor as well as metabolic rate and physiology were affected in fish with high *Contracaecum osculatum* levels. This might affect the cod's ability to swim, hunt for prey and escape predators (Ryberg et al., 2020). Svedäng et al., stated that the metabolic effects seen in Baltic cod are unlikely to be caused entirely by parasites as the changes in cod metabolism occurred before seal parasites became more prevalent (Svedäng et al., 2020). It is possible that the lower condition and immunosuppression are not caused by the nematodes but are instead caused by lack of nutrients, weakening the fish and making them more susceptible to parasite infestation, which would explain why unhealthy cod contain higher levels of nematodes (Ryberg et al., 2020). A recent study performed by the Luke, the natural resource institute Finland, investigated the occurrence of *Contracaecum* larvae in cod livers in the Sea of Åland as well as food availability. The results showed that when food availability is high the effects of the liver worm infection are small or insignificant, looking at the condition and growth of the cod. The cod in the waters surrounding Åland has increased in recent years and the cod is reported to be in good condition despite a high abundance of grey seals (Raitaniemi & Leskel, 2021).

1.5.2.6. Cormorants

Cormorants are seabirds with a diet entirely consisting of fish. They are often perceived as threats to the livelihood of fishermen, and conflicts with these birds were given as one factor impacting job satisfaction in Swedish fishermen (Schreiber & Gillette, 2021). In another study of the impact on Baltic fishermen from several countries, seals and cormorants were identified as obstacles potentially preventing fishermen from continuing with their livelihood (Svels et al., 2019). There are few published papers on the biological impact of cormorants on Baltic cod and knowledge of their threat to cod stocks is quite limited. Cormorants have been shown to have a local impact on catches of species such as perch, pikeperch and eel in the Baltic Sea, while the impact on cod was found to be limited (Östman et al., 2013). However, a report by Ovegård et al., found that in the Blekinge archipelago (southern Sweden), cod was a common prey for cormorants (Ovegård et al., 2016). Habitats are of importance for the impact that cormorants have on fish stocks and the proportion of catch by seals and seabirds tends to be higher for coastal species. In order to fully assess the impact of cormorants on Baltic cod status, further studies are needed.

1.5.2.7. Thiamine deficiency

A recent paper by Engelhardt et al., has suggested that thiamine deficiency in EBC cod explain the decline in condition, reproduction, growth and increased mortality as the tested cod were found to be thiamine deficient (Engelhardt et al., 2020). Thiamine, or Vitamin B1, is produced by bacteria, fungi and plants and is important for many cellular processes. Deficiency leads to disrupted metabolism and adverse effects have been seen in many different species of wildlife (Balk et al., 2016). It is associated with health effects and energy deficiency and can be lethal to the organism. Thiamine deficiency has been shown to cause a reproductive disorder in Baltic salmon (Åkerman & Balk, 1998). Engelhardt et al., also suggest that the increased parasite infestation in EBC cod can be a side effect of thiamine deficiency, as it may lead to immunosuppression (Engelhardt et al., 2020). Studies of thiamine in Baltic cod are limited to date, and more research is needed to determine if there is a link to the poor status of EBC cod.

1.5.2.8. Chemical pollution

The Baltic Sea contains thousands of chemicals that have been produced and used by humans and then ended up in the sea. The contaminants in the Baltic Sea belong to a range of different chemical groups and include legacy contaminants such as PCBs, DDT and dioxins, heavy metals, flame retardants and perfluorinated compounds (PFASs). The effects and mechanisms of the pollutants differ depending on which chemical group they belong to. Sublethal effects may, for instance, include disruption of neurodevelopment, reproduction, metabolism or behaviour. In addition, drugs from human and veterinary use also enter the water and can affect the fish. Contaminants can have an effect on fish at the individual level or even affect entire populations. Persistent chemicals are able to stay in the environment for a long time, and can be stored in sediments and bioaccumulate in fauna, leading to higher contaminant levels in predators. Cod tissues (apart from the liver) have a lower fat content than those of salmon and herring and will therefore accumulate less of the fat-soluble compounds even though the cod is a top predator. Even though some older contaminants like PCBs are no longer in use they can still be found in the Baltic Sea due to their persistence (Asker, 2019; Danielsson et al., 2020).

Traditional pollutants including PCBs, pesticides and heavy metals (mercury, lead and cadmium), have been regularly monitored and seen as large threats to the environment in the Baltic Sea for some time (Korpinen et al., 2010; Schnell et al., 2008). They have also been the focus of many ecotoxicological studies in Baltic cod, both for the sake of fish health but also to assess possible risks for human consumption. Newer studies have focused on emerging pollutants including PFASs, HBCDD (Danielsson et al., 2020) and chemicals related to chemical munitions dump sites (see Section 1.5.2.9). Continued monitoring to assess the risk of these exposures is recommended.

1.5.2.9. Chemical Warfare Agents

Chemical warfare agents (CWAs) that were dumped in the Baltic Sea after World War II can still be found in the deeper areas in several regions, including the Bornholm Basin which EBC cod use for spawning, as well as the Gotland Basin and the Little Belt. The main groups dumped in the Baltic Sea and the Skagerrak are sulfur mustard and phenylarsenic CWAs. Some of the canisters containing these agents are corroding and leaking, which may pollute the sediment and the water around them. These compounds are designed to act against humans through chemical or biological activity, and they could also negatively affect the environment and animals around the leaking containers (Szarejko & Namieśnik, 2009). Some assessments of CWA impact on cod have been made. This includes measurements of the changes in biomarkers which could indicate that cod health is affected, but the effects are not yet fully elucidated (Bełdowski et al., 2016). A recent study by Niemikoski et al. found that 14% of the cod collected from the Bornholm Basin contained CWA-related phenylarsenic chemicals in their muscle tissue (Niemikoski et al., 2020). The toxicity of CWA-related products on fish should be studied further.

1.5.2.10. Other factors

A number of other factors could also contribute to the status of cod in the Baltic Sea. These will not be discussed at length here, but it is important to keep in mind the complexity of the situation in the Baltic Sea and the fact that the combination of multiple additional stressors can make the situation more difficult to manage:

- Debris in the water including plastics, microplastics and ghost nets could, for instance, affect fish by entanglement, physically damage fish, cause suffocation after ingestion or lead to leakage of chemicals with adverse effects.
- Non-indigenous species in the Baltic Sea could affect interactions in the food web. The invasive round goby (*Neogobius melanostomus*) has, for instance, become more common as prey for cod compared to earlier studies (Almqvist et al., 2010).
- Cod is also likely to be exposed to algal toxins that are present in the Baltic Sea, including natural brominated chemicals and nodularin (Sipiä et al.,

2001). However, further assessments of the impact of algal toxins on cod health and Baltic fish health in general is recommended as the knowledge in this field is still limited.

- The destruction of natural habitats, for example the removal of stones and boulders from coastal reefs, has had a local negative effect on cod and other fish. The restoration of such habitats, especially cave formations, have been proven to be positive for cod recovery, according to Danish research from the Læsø Trindel in the Kattegatt (Støttrup et al., 2014).

1.5.3. Factors of importance for rebuilding the cod population

As listed in the previous sections, there are a range of different challenges that could be driving the decline of Baltic cod. In order for management to be successful, natural and human-induced processes need to be considered together (e.g. Eero et al., 2011). The simultaneous pressure from several factors means that it is difficult to select one simple solution to solve the problem. The 2020 Baltic Fisheries Assessment Working Group (WGBFAS) report states that the current poor state of cod is associated with the following changes to the ecosystem: i) lack of oxygen, ii) reduced prey availability for older cod due to the decreased spatial overlap with sprat and herring iii) increased parasite infestation, linked to the rebounding population of grey seals. The relative impact of each of these was stated to be unclear (ICES, 2020a). According to a report by Bryhn et al. based on a literature review of the situation for Swedish cod, the most beneficial efforts for the EBC stock would be to i) improve the availability of food by reducing fishing of sprat and herring in areas overlapping with cod, ii) reduce or control the levels of predation by grey seals and iii) protect habitats that the cod grow up in, possibly by a trawling ban (Bryhn et al., 2020). For the WBC stock where targeted cod fishing is still going on (which was the case when the report was written), a decrease in bycatch of cod in flatfish fisheries and a precautionary approach in the targeted fishery, as well as a reduced predation and protection of nursery areas were assessed to be the most important measures (Bryhn et al., 2020). In addition, the report stresses the importance of ecosystem-based management.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Chapter 2
Socio-economic impact assessment

The following chapter discusses cod from a socio-economic perspective, where different scenarios are explored to aid rebuilding of the cod stock.

2.1. Background, rationale and objectives

The cod in the Baltic Sea is considered one of the most important fish species in European waters, with high socioeconomic value for both commercial and recreational fishing. Until the 1980s, cod was abundant in the Baltic Sea, but stocks have declined dramatically since then and remain at historically low levels (ICES 2021a; ICES 2021b; Lindgren et al., 2009). The decline emanates largely from two different sources; (i) overfishing, driven by overcapacity in the fishing fleet and by political decisions taken without respecting scientific advice and (ii) environmental factors, including eutrophication and climate impact on cod stocks generally through changes in the physical environment (e.g., temperature and salinity), but also through altered food supply for early life-history stages, eventually affecting recruitment and declines in productivity (Köster et al., 2005).

In this chapter, the socio-economic impact assessments focus on fisheries as the source of the stock decline. For environmental factors affecting the cod stock, please see Chapter 1. In order to rebuild the cod stocks in the Baltic Sea, various strategies and measures have been used in recent decades to ensure efficient cost-effective socio-economic services and resourceful ecosystem functions. The overarching objective of this chapter is a socio-economic impact assessment with the following aims: (i) to investigate different prospects for socio-economic development under changing environmental-social and economic conditions, and (ii) to evaluate the consequences of different fishing methods and strategies.

2.1.1. Methods and delimitations

The socio-economic impact assessment is limited to the impacts of the potential measures to be taken on the commercial small-scale fisheries, where the recreational fisheries include direct and indirect impacts and the linkages that exist between these groups. To estimate the different effects as well as their values, *the benefit/value transfer method* is used: a method developed to estimate economic values for ecosystem services by transferring available information from studies already completed in another location and/or context. For example, values for recreational fishing in a particular country or region may be estimated by applying measures of recreational fishing values from a study conducted in another country or region (Bureau of Rural Sciences, SEIA Toolkit, 2005).

The following preconditions are applied to the socio-economic impact assessment:

- *Geographical scope*: the Baltic Sea and the eight EU countries and Russia;
- *Time scale*: the scenarios are set for the period 2022-2042;
- *Considered costs and effects*: the considered effects are on the cod fish stock, especially eastern Baltic cod, along with the related socio-economic activities, implying non-beneficial business for commercial fishing as well as decreased opportunities for recreational fishing, recreation and tourism.

The data are to be used for the assessment of the impacts consisting of:

- *Economic impacts*: cover both the small-scale commercial fishermen and their community. In this case the economic impact equals the income of the fishermen.
- *Tourism*: many of the cultural environments that attract tourists are based on a local fishing port. The fact that fishing attracts tourists to an area by keeping ports open is a positive external effect. These ports are often associated with small-scale and local fishing activities (Waldo et al., 2009).
- *Environmental impacts*: as discussed above, the environmental impacts on the decline of the cod stock are extensive. However, a full assessment of these factors is not possible within the scope of this study and is thus only discussed briefly.

2.1.2. The Baltic Sea Region

Approximately 90 million people live within the Baltic drainage basin. The Baltic Sea region has for generations been the centre of several socio-economic activities. The maritime heritage is the most preeminent element connecting the Baltic Sea Region, carrying a whole set of history, culture, know-how and traditions (Council of Europe, n.d.). The countries situated on the Baltic Sea coast are dependent on the sea for its resources, thus relying on the state of the marine environment and coastal areas for their economic, social and leisure activities (HELCOM, 2010). The Baltic Sea is one of the largest brackish bodies of water in the world, receiving both ocean and river water. The sea is impacted by natural occurrences such as environmental factor fluctuations, and anthropogenic effects.

The marine environment makes a positive contribution economically, socially and culturally to the people in the Baltic Sea region. Human activities that depend on the sea bring significant economic benefits, both in terms of their impact on the national economy and more generally on the well-being of citizens (Council of Europe, n.d.). Coastal areas are among the most productive environments worldwide, supplying a large number of ecosystem services of environmental, economic, social, cultural, existence and recreational value for many stakeholders. In fact, all the ecosystem services together are important for the well-being of humans. Commercial fisheries and sport fisheries are highly dependent on well-functioning marine ecosystems where economic and leisure activities are dependent on the state of the marine environment in these areas (HELCOM, 2010).

2.2. Socio-economic impact assessment

Socio-Economic Impact Assessment (SEIA) based on a cost benefit analysis (CBA) is a well-used tool that helps to study, assess and rank the effects of proposed projects or scenarios. CBA has long been a core tool of public policy[2]. The systematic process of calculating the benefits and costs of policy options and projects is widely regarded as an essential step in the policy process. This is particularly the case for the development of environmental policy, where CBA is central to the design and implementation of policies in many countries (OECD, 2018).

In general, a CBA consists of different steps to assess mitigation scenarios. The major steps of CBA are (i) definition of project, (ii) identification of project impacts, (iii) economically relevant impacts, and (iv) present value. In the case of cod recovery, the following parameters have been taken into consideration:

- *Definition of project:* the overarching objective of this study is a socio-economic impact assessment related to aid restoring the Baltic cod with associated socio-economic benefits.
- *Identification of project impacts*: the severe decline of the cod stock, the main reason for which has been overfishing and overcapacity of fishing fleet in the Baltic Sea, implying non-beneficial business for commercial fishing, less fish to catch by recreational fishers and a less attractive environment for recreation, e.g., tourism. Other impacts are social and cultural losses such as reduced market value for summer cottages when the surrounding environment became less attractive (Blenckner et al., 2013).
- *Identification and quantification of the economically relevant impacts.* All impacts above are relevant and different methods are used to estimate the value of their costs and/or benefits.
- *Present value* (PV) calculation of discounted cost and benefit flows using the formula:

$$PV\ (X_t) = X_t\ /\ (1+r)^t$$

X is the value to be discounted, *t* represents the time span for the analysis and *r* is the discount rate. Different discount rates as well as different populations and different years and quantities, e.g., cod stock level may be used while assessing sensitivity of the results to changes regarding these elements.

Other impacts of interest are reduced eutrophication and noxious gases to the Baltic Sea. However, based on the limited scope of this study, the impacts of these negative externalities are discussed only briefly.

2 In general, there are at least three methods to accomplish this task. The most widely used is cost-benefit analysis (CBA). The other methods are multicriteria analysis (MCA) and cost-effectiveness analysis (CEA). For more details on each of these see MCA: European Commission, EC (2021). 'Better regulation' toolbox. TOOL #63. MULTI-CRITERIA ANALYSIS. PAGE 516-520. https://ec.europa.eu/info/sites/default/files/file_import/better-regulation-toolbox-63_en_0.pdf. CEA: https://europa.eu/capacity4dev/evaluation_guidelines/wiki/cost-effectiveness-analysis-0

2.2.1. Externalities

One of the most basic concepts in environmental economics is that of externalities. There are both positive and negative externalities in the case of fisheries in the Baltic Sea Region. The positive externalities may take the form of economic development; coastal area management and ecosystem monitoring and rehabilitation (FAO, n.d.b).

Table 1 displays the results of a study done in the Baltic Sea region in 2008 (Hasselström, 2008). As shown, beach tourism and recreational fishing are sectors experiencing negative externalities of the prevailing problems which originate from the activities that create imbalances around the Baltic Sea. The decline in cod stock, for instance, has negatively affected recreational fishing.

Table 1. Is the industry sector (in general) affected (Yes) or not affected (No) by current marine environment problems? Per country (Hasselström., 2008).

	DK	EE	FI	DE	LV	LT	PL	SE	RU
Beach tourism	Yes	No	Yes	Yes	No	No	Yes	Yes	No
Recreational fishing	Yes	Yes	Yes	Yes	n.a	No	No	Yes	n.a

2.2.2. WTP case studies in the Baltic Sea area

There has been a great interest in valuing the benefits of recreational fishing (and related biodiversity and environment) both in Nordic/Baltic countries and elsewhere in the world (e.g. Blenckner et al., 2011). In the case of the Nordic countries many studies have been conducted in the area with the aim of evaluating the socio-economic and environmental benefits that the inhabitants not only on the Baltic coast but all populations on the Baltic Sea benefit from. The results of the studies are characterized by a high willingness to pay to preserve or restore the various services provided by the Baltic Sea. The large values that have been calculated indicate that there are major socio-economic values in the preservation of a functioning ecosystem in the Baltic Sea. Common to these studies is the estimation of willingness to pay to calculate total or marginal values of the benefits enjoyed by use or non-use values of the subject studied.

Eggert and Olsson (2009) estimate the relative benefits of improving coastal water quality with respect to fishing opportunities, bathing water quality and biodiversity levels for a random sample of individuals in the southwestern parts of Sweden. The estimated mean marginal willingness to pay (WTP) for improved bathing water, cod stock, high biodiversity, and avoiding lower biodiversity is €63.9, 13.30, 66.7, and 13.48, respectively. The highest average marginal WTP values, around €13.00, are found for avoiding a reduction in biodiversity level and for an improved cod stock (2007 prices). The studied area has roughly one million inhabitants aged 20–64, and overall hosts about 20% of the total Swedish population. Assuming zero WTP from all non-respondents implies that the respondents represent 40% of the sample area population, which leads to an aggregate estimate of € 50 million for improving the cod stock to the 1970s level.

Kataria & Lampi (2008) estimated that willingness to pay to increase the number of cod in the seas by 1 percent was less than €0.8 per household per year, or approximately € 4 million per year, in total, for Swedish households. The willingness to pay to increase cod stocks by 70 percent was approximately €50 per household per year – a total of approximately €0.25 billion per year. Willingness to pay to enable 1 percent of commercial fishermen to keep their jobs was €0.07. For all Swedish households, willingness to pay was approximately € 0.3 million a year. Willingness to pay to enable 1,500 fishermen to remain in their profession instead of 900 fishermen, as forecast, was approximately €40 per household per year. Some of the studies are listed in Table 2.

Table 2. Studies of the economic value of ecosystem services provided by the Baltic Sea and Skagerrak with focus on fisheries, adapted from Swedish EPA (Söderqvist & Hasselström, 2008).

Country	Reference
Denmark, Finland, Iceland, Norway, Sweden	Toivonen et al (2000)
Denmark	Roth & Jensen (2003)
Estonia	Vetemaa et al (2003)
Finland	NOA (2007), Olkio (2005), Parkkila (2005), Valkeajärvi & Salo (2000)
Germany	Bundesforschungsanstalt für Fischerei (2007)
Sweden	Fiskeriverket (2008) Olsson (2004), Paulrud (2004), Soutukorva et al (2005)

2.2.3. Baltic Sea fisheries

2.2.3.1. Commercial fisheries

Fisheries include the production of food, livelihood improvement, nutrition and health as well as several social, physiological and psychological benefits. Fisheries in the Baltic Sea consist of industrial/commercial and small-scale fishing, as well as recreational fishing. Both small-scale, commercial fisheries and recreational fisheries target coastal fish populations, but patterns differ between regions. For coastal species such as perch, pikeperch, pike and whitefish, which are mainly targeted in the eastern and northern parts of the Baltic Sea, the outtake from the recreational fisheries sector greatly outnumbers that of the small-scale commercial fishery in many countries (HELCOM, 2015).

Commercial fishing vessels from the nine nations comprise vessels of different sizes ranging from large ships to small ones used for offshore or coastal fisheries that target different fish species such as cod, eel and flatfish. Below is a short description of the coastal fleet devoted to cod fishing in the studied countries in 2019 where the vessels using passive gear are small-scale vessels not larger than 12 metres. There are, however, exceptions where some smaller vessels with powerful engines being smaller than 12 m use active gear, as in the case of Denmark. Vessels using active gear are in general larger than 12 metres (ICES, 2019e).

- **Denmark**: The Danish fleet comprised approximately 150 vessels. The coastal fisheries target species such as eel, flatfish and cod using mainly trapnets, poundnets, and gillnets, and occur off all coasts and in the Belt area.
- **Estonia**: The coastal fishery consisted of several hundred small vessels of < 12 m.
- **Finland**: The fleet comprised around 3,200 vessels, of which almost 1 500 vessels are actively used in the fishery. The vast majority of the vessels are < 12 m and operate in coastal fisheries. The coastal fisheries occur from all parts of the coast, using trapnets, fykenets, and gillnets.
- **The German** commercial fleet in the Baltic Sea consisted of about 60 trawlers and larger (>10 m total length) multi-purpose vessels, and about 650 vessels using exclusively passive gear (< 12 m total length). The major targeted fisheries are cod and flounder.
- **Latvia**: The fleet comprised around 610 coastal vessels (< 12 m).
- **Lithuania**: The Lithuanian fishing fleet in 2018 comprised 59 coastal vessels (< 12 m).
- **Poland**: The fishing fleet consisted of around 150 active offshore vessels (12–35 m) and approximately 500 coastal vessels (< 12 m). Smaller offshore vessels (12–18.5 m) target cod, flounder and sandeel using bottom trawls. Fishing occurs mainly in subdivisions 24, 25, and 26 and these species account for about 97% of the total annual landings.
- **Russia**: The Russian coastal fishing fleet in the Baltic Sea region was composed of coastal fisheries (nine vessels in the 15–25 m size class).
- **Sweden**: The fleet comprised around 550 coastal vessels (the vast majority < 12 m). The coastal fisheries use a mix of gillnets, longlines and fish traps to catch flatfish and cod. A coastal fishery using fykenets targets eel and other species along the south-eastern coast.

(ICES, 2019e)

As discussed in the previous section, landings of eastern cod have decreased since the 1980s, for all the Baltic Sea countries and in all the subdivisions. Table 3 shows the distribution of total landings of cod in the Baltic countries for the period 1988-2018. As shown, Denmark, Poland, Sweden and Russia were the countries that landed the most cod in 1988. Danish landings of cod were higher than landings in these other countries. In 2018, however, Poland and Russia's landings of cod were highest. During this period the decrease in landings of cod ranges between 83 and 100%, the main reason being overcapacity in the region leading to overfishing.

Table 3. History of ICES estimates of landings of cod caught in the eastern Baltic management area (SDs 25–32) by country. Weights are in tonnes (ICES 2019c).

Year	DK	EE	FI	DE	LV	LT	PL	SE	USSR Russia*	Total
1988	60 436	—	2 904	14 078	—	—	33 351	48 964	28 137	194 787
1998	7 818	1 188	1 026	1 270	7 765	4 176	25 155	14 431	4 599	67 428
2008	7 374	841	670	2 341	3 990	2 835	8 721	8 901	3 888	42 235
2018	2 684	1	53	241	1 253	694	5 695	1 912	3 376	15 907

* Until 1990 USSR, then Russia

In general, as opposed to large, commercial fisheries that usually involve industrial, energy-intensive vessels and long trips, small-scale fisheries are characterised by smaller vessels, low mobility, highly reliant on coastal areas, smaller crews, multi-purpose seasonal fishing approaches, low extraction rates, low capital investments and turnover, low fuel consumption and low dependence on subsidies and use of fish mainly for local consumption or trade (Guyader et al., 2013; OHIS, n.d.). Passive gear is typical fishing gear used by small-scale vessels below 12 metres, where fishing areas are located less than 12 nautical miles from the coast. The fisheries are performed locally, geographically bound to rural areas and often combined with other types of fishing or other occupational activities (Björkvik, 2013). The annual financial gain of these segments, i.e., vessels 10-12 m, is often not positive as fishing constitutes only part of the activities of most of the fishermen (European Commission, 2018). Yet, this segment is very important in socio-cultural aspects as traditional activities for the population of coastal settlements such as in the case of Finland (Salmi et al., 2020). Regarding Poland, for instance, the future of the sector depends primarily on the availability of resources in the Baltic Sea. If these allow for a balance between operating costs with revenues from fish sales and subsidies for administrative suspensions of fishing, income from other economic activities should be sufficient for fishers to continue their profession (Rakowski et al., 2020).

2.2.3.2. Recreational fisheries

Recreational fishing, also called sport fishing, is an activity done for pleasure or competition where the practice of catching or attempting to catch fish usually is by angling. Recreational fishing can be seen as a competitor to commercial fishing depending on the region, the country of the fishing area in question and the catch[3]. If recreational catches in coastal areas are large, these may be seen as competitors and may contribute to unsustainable fishing, especially if these catches, although they may be regulated, are not reported at all or not reported in a credible way, which may be the case in the Baltic Sea (Waldo et al., 2009). In the south-western Baltic Sea, however, proportionally large recreational catches in coastal areas are also seen for species such as cod, flounder and eel (Ferter et al., 2013).

Estimations from Hyder et al (2017) count approximately 8.7 million marine recreational fishers in Europe, who fish for 77.6 million days annually, with a direct expenditure equal to €5.9 billion (Hyder et al., 2017). According to a study on Baltic Sea recreational fishing, the number of participants, including both sea and lakes is shown in Table 4. Anglers have been estimated to make up 10%, around 10 million of the population in these areas. Recreational fisheries take place in all parts of the Baltic Sea, using a variety of gear including rod and line, longline, gillnets, traps and spearfishing. Recreational fisheries catch the same species as the commercial fisheries but also several other species (Sporrong, 2017). Recreational catches of eastern cod are neither evaluated nor included in ICES stock assessments (ICES, 2021a). In the Baltic Sea, recreational catches of salmon and cod are accounting for the largest landings (ICES, 2019c).

Table 4. Distribution of recreational fishers in the Baltic Sea region. Table adapted from Sporrong, 2017.

	DK	EE	FI	DE	LV	LT	PL	SE	RU
Recreational fishermen	500 000	149 000	1.495 mill.	3.4 mill.	120 000	200 000	1.5 - 2 mill.	1.4 mill.	>100 000
Anglers	191 940*		1.4 mill.	163 000	100 000-120 000	200 000	37 000 (2014)	++	-

* Angling licences: 191 940 in 2016, of which 14 022 annual angling licences. Recreational licence (including angling): 31 502 in 2016

Similar to commercial fishing, sport fishing contributes to environmental externalities, where the negative ones on the marine environment may in a wider context include overfishing, noise (sonars and engines), CO_2 emissions, lost gear, lures, sinkers as well as littering and overfishing (Sporrong, 2017). The positive externalities of recreational fishing which could be practised by all ages are its contribution to several social physiological and psychological benefits, where this activity is suited to people of almost any age, for example being outdoors, socialising and enjoying the

3 Analysis of the development in fishing in Sweden in 2008 shows that from the commercial fishing side, recreational fishing is generally not seen as a competitor for the fish resource. The report is based on a number of interviews with fishermen from different coastal stretches, and most of the fishermen interviewed do not consider themselves to have any problems with recreational fishermen. In some fishing and areas, however, there are contradictions. One example is lobster fishing on the west coast, another is salmon fishing in the Baltic Sea (Waldo et al., 2009).

maritime environment. Its economic benefits are large, for example creating work opportunities along the coastline.

Almost without exception, many rules and regulations surround the recreational fishing sector as well (Sporrong, 2017). Yet policy has focused on regulation, without integrating recreational fisheries within fisheries management as a sector. One reason for this is concern about the burden of reporting and enforcement. A second reason is that management objectives for commercial fisheries and recreational fisheries are not always compatible, due to different motivations, leading to conflict (Eggert and Langlet, 2020). Recreational fisheries have been defined in some EU legislation, although not in the Common Fisheries Policy. For example, Regulation (EU) 2017/1004 on data collection gives the following definition: "*'recreational fisheries' means non-commercial fishing activities exploiting marine biological resources for recreation, tourism or sport*" (European Anglers Alliance, n.d.).

2.3. Evaluation of different socio-economic scenarios through scenario analysis

In general, scenario analysis is a process for evaluating and examining possible alternative projects or scenarios that may take place in the future and for estimating the different or possible results that the scenarios give rise to.

Reference Scenario: The zero scenario, or 'reference alternative', means that no measures are taken during the current time horizon, which is 20 years in this study. The implication of this scenario based on business as usual may lead to different impacts on cod and its socio-economic environment. However, in this study we assume that the costs in this case would be equivalent to all forgone benefits estimated in Scenario 1.

2.3.1. Scenario 1: Fishing limitations and MPAs

This scenario is based on various measures that would enable eastern cod to re-establish to sustainable levels in 2040, i.e., within 20 years. The proposed measures are:

- **dedicate 25% of the total Baltic Sea** to demersal and pelagic trawls, and other active gear;
- **dedicate 35% of the total Baltic Sea** to small-scale passive gear fishing;
- **40% of the total Baltic Sea** is protected as no-take marine protected areas, where no fishing is permitted, except for recreational fishing after receiving a permit based on an environmental impact assessment that has proven that the fishery does not harm the conservation values set out in the MPA management plan (Tunca et al., 2019).

In the 25% of the total Baltic Sea designated for trawling and other active gear only, selective gear allows very low bycatch of cod. Research is underway to develop a tool that could target flatfish but avoid cod as bycatch. Together with the fishing industry, the Secretariat for Selective Fishing at the Swedish University of Agricultural Sciences (SLU) has developed several types of selective gear that will promote long-term sustainable fishing. An example is a two-part trawl that separates flatfish from cod. By using a two-part trawl with two sorting grids, the flatfish ends up in the lower trawl bag and round fish such as cod in the upper one. *"If the quotas for any of the species were to run out, you could simply open one trawl bag and continue fishing with the other"*, says a project manager within the Secretariat for Selective Fishing and researcher at the Department of Aquatic Resources at SLU (SLU, 2020).

According to personal contact with Fiskereturen (2021), a highly adapted selective tool that both leads to very low bycatch and is gentle on the seabed would cost in the range of €7,500. This value has been used to estimate the extra cost incurred at the 25% of Baltic Sea where trawling would be possible only if the condition with the selective tool is met. The number of vessels used for the estimations are those larger than using active gear (see Table 5 for the number of vessels in the Baltic nations using active or passive gear).

Table 5. Baltic Sea vessels using passive or active gear in 2019 (European Commission, 2020b).

Countries	Vessels using passive gear	Vessels using active gear
Denmark	862	441
Finland	3 170	42
Estonia	1 784	33
Germany	1 028	53
Latvia	236	51
Lithuania	103	35
Poland	636	189
Sweden	640	213
Russia*	9	44
Total	**8 468**	**1101**

* Data for Russia is adapted from ICES (2019e)


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Table 6 shows the number of vessels used in the analysis to estimate compensation for vessels not allowed to fish i.e. 75% of total (100-25% of vessels using active gear) and 65% (100-35% of small-scale fishing using passive gear).

Table 6. Number of vessels used in the analysis (based on Table 5).

Countries	Vessels with passive gear to be compensated (65% of total)	Vessels with active gear to be compensated (75% of total)
Denmark	560	331
Finland	2 061	21
Germany	1 160	25
Estonia	668	40
Latvia	153	38
Lithuania	67	26
Poland	413	142
Sweden	416	160
Russia	6	32
Total	**5 504**	**825**

Table 7 presents the results of a scenario where the net present value, being a difference between net benefits and net costs, is positive and equivalent to more than €51 billion. This finding is in line with other studies such as BalticStern (in HELCOM, 2013; Döring and Egelkraut, 2008; Blenckner et al., 2011).

Table 7. Net present value of Scenario 1 (PPP, € million).

PV of benefits	+ 55,030
PV of compensation	- 2,875
PV of costs of selective gear	- 32
PV of management cost	- 925
Net present value	+ 51,198

Premises for the CVM calculation:

- **Calculated WTP:** The contingent valuation method (CVM) and the derived willingness to pay (WTP) of the respondents are in general used to estimate both use values and non-use values. The estimated CVM value from Eggert and Olsson (2009) is used to estimate the marginal WTP for an improvement in the cod stock. The benefit transfer method is used for all values in order to consider the differences in income in the studied countries, i.e., based on the Swedish contingent valuation study results for another country are obtained by way of extrapolation, e.g., the Swedish marginal WTP was multiplied by the ratio between the other countries' GDP per capita at purchasing power parity (PPP) and Swedish's GDP per capita at PPP. Hence, the value used is €130.
- **Time period:** The study period is 2021-2040. This relatively long period is assumed to enable the return of cod in an environment corresponding to the conditions under the 1970s.
- **Discount rate:** 2% is the discount rate used to calculate the net present value (NPV). 2% is equal to the market interest rate that has been in place for some time and will, we assume, apply for many years to come.
- **Income compensation:** The loss of income used to estimate the costs of the losses i.e., compensation to fishermen not allowed to fish is based on an average salary for fishermen in this area equal to €1915/month. This value is in line with the values estimated for employment and salary of Nordic coastal fishermen (Nielsen et al., 2017, Shivarov, 2005). To estimate compensation, it is assumed that the average crew of a trawling vessel, in general meaning large vessels in the range of 12 m – 40 m, is three persons, and for small-scale vessels is limited to one person.
- **Other costs:** Managing this alternative implies costs. These costs are assumed to be 36% of the average value of the eastern cod catch in SD 24, 25-32 during the period 2010-2020 (ICES, 2021a) assuming 1.5 €/kg is paid to the fishermen. The management cost is based on the requirements to provide for optimal economic performance and to meet environmental objectives. Management authorities therefore devote considerable funds to conducting stock research, making decisions and enforcing those decisions. It is estimated that 36% of all government financial transfers associated with fishery policies in OECD countries are for research, management and enforcement services

(Wallis et al., 2020).

2.3.1.1. In case of eutrophication measures

As has been discussed above other factors besides overfishing together with eutrophication and climate change are the predominant sources of reduced fish stocks (see also Section 5 of Chapter 1). The results of this scenario would have been more consistent if action costs to reduce eutrophication and the effect of climate change had been included. With regard to eutrophication, costs were estimated for achieving load reduction targets for each sea region and country according to the schemes specified in the HELCOM Baltic Sea Action Plan, BSAP (HELCOM, 2013). The total costs of achieving the remaining targets of the BSAP were estimated to be between €1,400 and €2,800 million annually. Hence, while the annual benefits in Scenario 1 are estimated at around €3,400 million annually, adding eutrophication costs to the costs of Scenario 1 being equal to €240 million annually would still lead to a net present value.

2.3.1.2. Sensitivity analysis

Since the estimated benefits are much larger than the considered costs, using different discount rates would not imply consistent change in the outcomes of Scenario 1. However, this does not mean that the results are insensitive to assumptions made with regard the period studied and also to the variables that are included, such as other costs. Using the benefit transfer method, i.e. applying data that other researchers have collected, although the method is increasingly used due to its time-effectiveness and inexpensiveness to accomplish a project, is another factor correlated with approximation of the results. Furthermore, the studied period is assumed to be 20 years for eastern cod. However, the success of the measures to avoid overfishing by reducing the capacity of the Baltic Sea fleet alone may not be enough. As discussed above, in addition to eutrophication the collapse of cod is a result of other covariates.

2.3.2. Scenario 2: Regulatory difficulties and cooperation

The Baltic Sea is surrounded by nine countries with historical differences regarding dependence on cod for the fishing community, but which also exhibit socio-economic differences. Baltic Sea fisheries management is governed by the CFP, which has the aim of sustainable fishing practices in all European waters. Nevertheless, this does not seem to be the case in the Baltic Sea, with a history of overfishing and contamination of the marine environment. The Baltic Sea is even considered to be one of the most polluted sea areas in the world (Vlasov, 2010). The poor condition of the sea contributes to the reduction in fish stocks and catches. This scenario explores the regulatory difficulties regarding overexploitation of Baltic sea fish stocks.

According to Aps et al. (2012), the sources of regulatory overfishing include (i) the scientific uncertainty/error related to what can be termed 'scientific overfishing', (ii) when managers deliberately disregard scientific advice, 'decision overfishing'[4], (iii) 'implementation overfishing' when managers fail to ensure that the fishing quotas are respected, and (iv) 'illegal overfishing', which occurs where fishers make illegal or unreported catches (IUU), which result in illegal fishing above the legal quota (Aps et al., 2012).

Scenario 2 is about cooperation, namely (i) cooperation to abide by the laws and regulations that countries have agreed upon and (ii) cooperation that can lead to more efficient use of Baltic Sea resources to, among other things, avoid overfishing. Management here is about collective management in which all Baltic Sea countries participate in an effective way.

2.3.2.1. Cooperation to apply the laws and regulations

According to Ostrom, a couple of the rules with the aim of managing the commons include that Commons must be monitored and that those who abuse them should be sanctioned (Wall, 2017). In the case of the Baltic Sea, some of the reasons for its dire state are the lack of respect for and violation of the regulations that apply as well as inefficiency to monitor and control the catches, the landings, the bycatch and the discards.

In general, fisheries control is governed by annual inspection plans that cover all efforts in the area of fisheries control. Inspections are carried out within the EU by all countries together i.e., Joint Deployment Plans. The inspections are carried out in collaboration with the European Fisheries Control Agency (EFCA). The countries cooperate nationally with various fisheries-related authorities and organizations, for better control of marine resources. Internationally, there are also commitments to effective oversight of fishing vessels stemming from international agreements.

But all this does not help to reduce or remove overfishing and the associated fleet overcapacity where a large part is Unreported and Unregulated (IUU) fishing, which is a significant threat to achieving biologically sustainable fisheries and a serious management problem for a large number of the fisheries on which these industries and coastal communities depend, particularly in the Eastern Baltic Sea (Aps et al., 2012).

One of the major reasons for IUU is the national and international inability to effectively monitor and control the fisheries. Even though modern technology is increasingly used to ease the monitoring of fishing vessels, the monitoring, control and surveillance (MCS) systems are generally not keeping up with fleet capacity and its harvesting capabilities. However, the development of next-generation enforcement, such as drone patrols, use of on-board cameras and real-time satellite monitoring, is helping to ensure that the wild-caught seafood that reaches consumers' plates has been harvested legally (Toonen and Bush, 2018; De Souza et al., 2016). Further, for

4 Information on stock depletion is available but goes unheeded and is counteracted by fishermen who want to fish more and who are routinely supported by the 'political establishment' who appear to be most concerned about (short-term) employment, Sterner & Svedäng (2005).

MCS systems to be successful in practice, they need competent staff responsible for their coordination, maintenance and regular updating.

Environmental, economic and social costs of Illegal, Unreported and Unregulated (IUU) fishing to EU Member States are large and represent a significant proportion of fishing value. It is further stated that the cost estimates for selected fish groups across the five large marine ecosystems sum to 1) over €10 billion in lost catch by 2020, 2) over €8 billion in lost stock value in 2020, and 3) over 27,000 lost jobs in fishing and processing industries (Aps et al., 2012).

2.3.2.2. Cooperation, management and efficient use of Baltic Sea resources

As described in Chapter 1, eutrophication and algal blooms affect both wildlife and tourism and dilute the problem of dead sea-beds in the Baltic Sea. Furthermore, in the Baltic Sea, worldwide ongoing climate change is causing a decrease in salinity, an increase in water temperature, and more carbon dioxide to be absorbed in the water, causing ocean acidification. All these negative externalities, in addition to overfishing, contribute to collapse of the cod stock. This part of Scenario 2 is a brief discussion of cooperation that can lead to more efficient use of Baltic Sea resources in general and cod in particular.

Game theory has been used to analyse the impact of collaborative or non-collaborative management related to fisheries (Nieminen et al., 2016). Game theory is an appropriate tool for analysing the strategic interactions of more than one rational decision maker. Game theory has been an effective tool to generate solutions for decision making in many fields (e.g., policy making, environmental and natural resource economics and management) (Eatwell et al., 1989 in Tunca et al., 2019). In general, the nature of game theory is highly suited to management problems in fisheries, as the fishers want to increase their economic profit from their activity (Bailey et al., 2010 in Tunka et al., 2019).

Sumaila (1997), conducted one of the first multispecies studies to apply game theory (Nieminen et al., 2016). With regard to the Baltic Sea, game theory has been used to examine the impact of different coalitions between the littoral countries of the Baltic Sea to mitigate eutrophication. The research shows that a treaty with modest abatement targets between all the littoral countries would be more efficient than a coalition between fewer countries, but littoral countries would be more efficient than a coalition between fewer countries but with more ambitious targets (Ahlvik et al., 2013).

Other studies such as Tunca et al. (2019) associated with the Baltic Sea have used game theory to study the effect of two strategic interactions between players, represented here by different fishing fleets (rather than individual vessels) as agents in Denmark, Poland and Sweden. The first interaction is a non-cooperation interaction (NC) where each fleet takes its fishing decision by itself, and the second is a fully cooperative interaction (grand coalition: GC) where all fleets cooperate through a binding agreement using different climate change scenarios associated with dynamic single or multispecies fisheries, i.e. cod, herring and sprat (Tunca et al., 2019). The study focuses on the effects of climate variations on the biological, harvesting and economic results of game models, where the first scenario is characterised by low temperature and high salinity and a second scenario has high temperature and low salinity as the prevailing backgrounds on the Baltic Sea. The base scenario is about existing climate conditions.

Table 8 shows the payoffs of the different scenarios. Cooperative management is shown to be fundamental in defining economically optimal use strategies for shared fish resources. In view of the multispecies and multi-fleet nature of the fisheries, the effectiveness of the cooperative approach would be essential in the decision-making process. Furthermore, this effectiveness of the cooperation is not only limited with the existing climate conditions but also under changing climatic conditions that would be mitigated by the cooperative agreements (Tunca et al., 2019).

Table 8. Country level aggregated net present values (€ millions) for non-cooperative (NC) and the grand coalition (GC) games under three climate scenarios (Tunca et al., 2019).

	Base scenario		Scenario 1		Scenario 2	
Country	**NC**	**GC**	**NC**	**GC**	**NC**	**GC**
Denmark	2 444	2 684	2 358	2 985	1 955	1 955
Poland	747	735	903	889	646	663
Sweden	1 399	1 730	1 652	1 878	1 246	1 378
Total	**4 590**	**5 139**	**4 913**	**5 753**	**3 847**	**3 998**

Chapter 3
Policy and management

As outlined in the previous chapters the management of cod is complex and multi-faceted. This is also reflected in the policies and management bodies that are of influence on the Baltic cod populations. All elements relating to the extraction of fish from the ocean are regulated through fisheries policy where environmental legislation regulates ecosystem considerations and aspects relating to pollution and eutrophication.

3.1. The EU Common Fisheries Policy (CFP) and related fisheries laws

The principles for management and regulation of fishing, resource policy, or the regulation of the fishing activity itself, have from the outset comprised three main parts (Eggert and Langlet, 2020):

1. **regulation of fishing capacity**, i.e., regulation of the number of, size (gross tonnage) and engine power (kW) of the fishing vessels operating in the Union;
2. **technical regulation of the way in which fishing is conducted**, including provisions on permitted gear, mesh sizes and areas where certain fishing activities are prohibited or restricted;
3. **limits on the number of fish that may be caught or landed.**

The Common Fisheries Policy (CFP) which was first established in 1983 as an overarching fisheries policy instrument. This law includes all agreements and guidelines with regard to commercial fishing. The first iteration of the CFP mainly focussed on setting catch limits for commercial fish species and the division of these fishing opportunities between member states. Subsequent reviews in 2002 and 2013 have added additional environmental and sustainability safeguards.

There are a number of regulations related to the CFP that further flesh out the policy prescribed by the CFP. These include the Technical Measures Regulation, the Data Collection Regulation and the Control Regulation. Underpinning financial programs (research, support, etc) arising from the CFP and related legislation is financed through the European Maritime and Fisheries Fund (EMFF). Furthermore, Regional Fisheries Management Organisations (RFMOs) are important in managing fishing on the high seas, often with a focus on migratory species such as herring, mackerel and tuna (www.ec.europa.eu[1]). Bilateral or trilateral quota agreements are also made with non-EU countries for stocks that are shared and jointly managed, such as Russia in the case of the Baltic Sea.

The purpose of fish policies in general and the EU Common Fisheries Policy (CFP) in particular is to regulate both the technical part of fisheries i.e. vessels and the gear being used for fishing, as well as setting limits for the amount of fish that may be caught. With the latest reform in 2013, several new elements were introduced that greatly altered the way fisheries are managed in the the EU (EU, 2013; European Commission, 2020):

- Setting Total Allowable Catches (TACs) in line with the Maximum Sustainable Yield (MSY) by 2020 at the latest for all managed stocks.
- The introduction of Multiannual plans (MAPs) to manage fisheries in different sea basins.
- Regionalisation to allow EU countries with a management interest to propose detailed measures which the Commission can then adopt as delegated or implementing acts and transpose into EU law.
- The obligation to land all catches (Landing Obligation) starting in 2015 and by 2017 at the latest in the Baltic Sea, and by 2019 at the latest for the whole of the EU.[5]
- Explicitly linking fisheries management to the EU's environmental legislation through Ecosystem-Based Management (EBM).

(EU, 2013; European Commission, 2020)

The 2013 reform also gave a central role to scientific advice to underpin all management decisions taken within the realm of the CFP. This advice is provided by two independent scientific bodies. Fisheries stock assessments and other biological evaluations are carried out by the International Council for the Exploration of the Sea (ICES) and the European Commission's Scientific Technical and Economic Committee for Fisheries (STECF) is responsible for providing scientific advice on policy and evaluating management processes.

3.1.1. Total Allowable Catch (TAC) – limits on the number of fish that may be caught

Total allowable catches (TACs), or fishing opportunities, are catch limits (expressed in tonnes or numbers) that are set for most commercial fish stocks. TACs should be based on scientific advice on stock status from the advisory bodies ICES and STECF, and follow the rules of the EU Common Fisheries Policy to achieve sustainable fisheries. Article 2.2 of the CFP gives a clear definition of the maximum TAC level and the timeline towards achieving it:

> *"2. The CFP shall apply the precautionary approach to fisheries management, and shall aim to ensure that exploitation of living marine biological resources restores and maintains populations of harvested species above levels which can produce the maximum sustainable yield.*

5 CFP Basic Regulation Art. 15 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R1380&from=EN

In order to reach the objective of progressively restoring and maintaining populations of fish stocks above biomass levels capable of producing maximum sustainable yield, the maximum sustainable yield exploitation rate shall be achieved by 2015 where possible and, on a progressive, incremental basis at the latest by 2020 for all stocks."

(EU, 2013, p 29)

However, the scientific monitoring and evaluation of the Common Fisheries Policy (CFP) show that TACs are still not set by the politicians so that they meet the legal requirements in the regulation, as shown in Table 9 and 10.

"Regarding the progress made in the achievement of FMSY in line with the CFP, STECF notes that the latest results confirm a reduction in the overall exploitation rate and increases in biomass for the NE Atlantic over the long time period. However, when considering stocks in the Baltic Sea, North Sea and outside EU waters, this has recently stabilised (Baltic Sea) or has even been reversed. Furthermore, STECF notes that many stocks remain overfished and/or outside safe biological limits, and that progress achieved until 2019 is obviously too slow to ensure that all stocks are fished at or below FMSY in 2020. /…/

STECF notes that only few stocks have estimates or even proxies of BMSY available. This restricts considerably the ability to monitor the performance of the CFP. STECF therefore identifies the need to increase the numbers of stocks for which a BMSY estimate is available.

STECF recognises the need to broaden the scope of the monitoring to cover additional aspects of the CFP not currently dealt with."

(STECF, 2021, p 14)

Table 9. Number of stocks by ecoregion for which fishing mortality (F) exceeded FMSY.
Source: STECF, 2021, p 33.

Eco Region	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
ALL	45	47	49	49	49	47	43	38	38
Baltic Sea	**7**	**7**	**7**	**7**	**7**	**6**	**7**	**6**	**6**
BoBiscay & Iberia	7	7	7	7	7	7	6	5	5
Celtic Seas	12	12	13	13	15	15	13	11	11
Greater North Sea	13	16	17	18	17	15	14	13	13
Widely	6	5	5	4	3	4	3	3	3

Eco Region	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
ALL	36	35	36	33	33	33	27	28
Baltic Sea	**4**	**4**	**4**	**5**	**5**	**6**	**5**	**5**
BoBiscay & Iberia	5	6	6	5	5	4	3	1
Celtic Seas	13	9	10	9	10	9	8	7
Greater North Sea	11	13	13	11	10	11	8	13
Widely	3	3	3	3	3	3	3	2

Table 10. Number of stocks outside safe biological limits by ecoregion. Source: STECF, 2021, p 37.

	2003	2004	2005	2006	2007	2008	2009	2010	2011
ALL	31	32	32	27	26	23	21	20	19
Baltic Sea	**5**	**6**	**6**	**3**	**3**	**4**	**5**	**4**	**4**
BoBiscay & Iberia	5	4	5	5	5	3	3	2	1
Celtic Seas	10	10	10	8	8	8	6	7	6
Greater North Sea	7	7	7	7	7	5	5	5	6
Widely	4	5	4	4	3	3	2	2	2

Eco Region	2012	2013	2014	2015	2016	2017	2018	2019
ALL	16	17	20	19	14	15	13	17
Baltic Sea	**3**	**3**	**3**	**4**	**3**	**3**	**2**	**4**
BoBiscay & Iberia	2	3	3	3	0	0	0	0
Celtic Seas	5	5	7	6	6	6	6	6
Greater North Sea	5	5	6	5	4	5	4	6
Widely	1	1	1	1	1	1	1	1

3.1.2. Regionalisation and the Baltic Sea multiannual plan

The process of regionalisation was introduced to allow EU member states to suggest actions and implement measures that are of relevance to the sea basin in their region. Before the 2013 CFP reform there was no formal EU process at a regional level to take decisions on fisheries measures. The Regional Baltic Sea Fisheries Forum (BALTFISH), which was already in place in 2009 as a formal place for member state interaction on Baltic fisheries, formed as a model for the regionalisation of the whole EU. Where BALTFISH members can only be representative of EU member state governments, the fisheries stakeholders can participate in the regional process through the Baltic Sea Advisory Council (BSAC). Through which they can provide input to the European Commission on the management of EU fisheries as well as directly to the BALTFISH Forum.

On 6 July 2016, the Council adopted the Multiannual Management Plan for cod, herring and sprat in the Baltic Sea, *REGULATION (EU) 2016/1139 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 6 July 2016 establishing a multiannual plan for the stocks of cod, herring and sprat in the Baltic Sea and the fisheries exploiting those stocks, amending Council Regulation (EC) No 2187/2005 and repealing Council Regulation (EC) No 1098/2007*. The regulation is often referred to as the 'Baltic MAP'. It came into force on the 1st January 2017 and MAPs for the North Sea, the Western Waters and the Western Mediterranean have since followed, drawing lessons from the first MAP (EU, 2020). This highlights the obligation of sustainable fisheries already set out in UNCLOS (1982), the World Summit on Sustainable Development at Johannesburg (2002), the GES objective of MSFD (2008) and the CFP (2013), where the main target is worded as follows:

> *"(4) The objectives of the CFP are, inter alia, to ensure that fishing and aquaculture are environmentally sustainable in the long term, to apply the precautionary approach to fisheries management, and to implement the ecosystem-based approach to fisheries management."*

Baltic MAP, introduction (4), p 1

The Baltic MAP should be considered a tool to aid management and the CFP to reach MSY for cod, herring and sprat. In the legal text, in preamble 5, concern is expressed regarding the exploitation rate of certain of these stocks, which is deemed too high, according to figures from both ICES and STECF. Also, the by-catch species plaice, flounder, turbot and brill should be taken into account in the fisheries and the MAP should contribute to the implementation of the Landing Obligation (LO). Safeguard measures for threatened stocks mentioned include reduction of fishing opportunities or specific conservation measures (EU, 2016). Two years later, in 2018, an addition to the Baltic MAP was launched after the decision of ICES to combine the stocks of herring in the Bothnian Bay and Bothnian Sea, namely REGULATION (EU) 2018/976 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 4 July 2018 amending Regulation (EU) 2016/1139 as regards fishing mortality ranges and safeguard levels for certain herring stocks in the Baltic Sea (EU, 2018).

The MAP already emphasises on its first page the necessity of EBM. Further on, under 'objectives' it is stated:

> *"(3) The plan shall implement the ecosystem-based approach to fisheries management in order to ensure that negative impacts of fishing activities on the marine ecosystem are minimised. It shall be coherent with Union environmental legislation, in particular with the objective of achieving good environmental status by 2020 as set out in Article 1(1) of Directive 2008/56/EC."*

Baltic MAP, CHAPTER 11,Article 3 Objectives (3), p 5

The main objective of the whole Baltic MAP is to establish proper management of the three species of cod, herring and sprat altogether, since the interaction between those species is important to ecosystem functioning and the status of each of the populations. As pointed out:

> *"(6) Since strong biological interactions exist between the cod and pelagic stocks, the size of the cod stock can affect that of the herring and sprat stocks and vice versa."*

Baltic MAP, introduction (6), p 2

This is also reflected in the ICES advice on sprat (2021), where the importance of the interaction is stated in the 'Issues relevant for the advice':

> *"Sprat are an important forage species for Baltic cod, and multispecies interactions should be considered when managing the sprat fishery."*

ICES, 2021b, p 3

In 2020 the European Commission released its first report on the performance of the Baltic MAP, *the REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL First report on the implementation of the Multiannual Plan for the stocks of cod, herring and sprat in the Baltic Sea and the fisheries exploiting those stocks*. It concludes that the imminent collapse of the Eastern Baltic cod, and other environmental and fish-related factors, is a result of long-term occurrences from long before the Baltic MAP, but the MAP is considered to have reduced overall fishing pressure (EU, 2020). The report also highlights EBM and Article 3(3)of the MAP[6] which require coherence with the MSFD and GES, especially Descriptor 3 in the MSFD stating *"the populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock"*. Furthermore, the report on several occasions stresses the dire condition of the Baltic Sea as a root of the poor condition of several fish stocks, as well as too high fishing pressure (EU, 2020). Overall, the Commission is pleased with the performance of the MAP, although environmental degradation and unsustainable fishing practices are still causing concern.

Although the European Commission reviewed its own plan as a success, another assessment of the effectiveness of the Baltic MAP was performed by the Pew Charitable Trust in cooperation with Birdlife International, WWF, FishSec and Oceana, in 2019. In this report the performance of the MAP was criticized from several perspectives, amongst them the introduction of MSY ranges, i.e. a span of fishing exploitation rates exceeding the MSY reference point and consequently higher fishing pressure. In addition the authors note that after the introduction of the MAP, over the period 2016-2019, the number of stocks with catch limits set above MSY $B_{trigger}$ has been consistent – there has been no improvement since the MAP came into force (Pew Charitable Trusts, 2019).

3.1.3. Regulation of fishing capacity

Overcapacity in the fishing fleet is a sign of market failure within the fishery industry, and has been addressed globally as a matter of high priority by the FAO since the late 1990s (Vestergaard, 2005). In a recent report by Berkow (2018) the overcapacity in the EU fleet is analysed in detail. To sum up, the capacity balance concerns the fishing fleet capacity in relation to the size of the resource, in this case the number of fish at sea that are allowed to be caught – known as fishing opportunity. European fisheries have a record of overfishing which the reform of the CFP in 2013 addresses, amongst other ways, through mechanisms where the Member States are obliged to identify overcapacity (stated in Article 22). In practice, all MS must submit a capacity balance report to the Commission every year to state the balance between fishing fleet capacity and fishing opportunities. These reports are to be based on certain guidelines stipulated by the Commission, and if overcapacity is identified the report should be followed by an action plan on how to attain balance. Subsequently, the Commission informs the European Parliament and the Council regarding the overall MS fleet capacity and fishing opportunities (Berkow, 2018).

The guidelines mentioned above includes six basic indicators, addressing i) two biological indicators aiming at the impact on depleted fish stocks (sustainable harvest indicator and stocks at risk indicator), ii) two economic indicators concerning fleet viability (return on investment indicator and current revenue/break-even revenue indicator), and iii) two technical/vessel use indicators (inactive fleet indicator and vessel utilisation indicator). If any of these indicators are exceeded, this implies

6 The plan shall implement the ecosystem-based approach to fisheries management in order to ensure that negative impacts of fishing activities on the marine ecosystem are minimised. It shall be coherent with Union environmental legislation, in particular with the objective of achieving good environmental status by 2020 as set out in Article 1(1) of Directive 2008/56/EC.

a capacity imbalance. However, there is doubt that adequate information is provided by the MS to the Commission and decision-makers to fully comprehend the requirements in the CP regarding MS overcapacity. This has been criticized by STECF (Berkow, 2018).

Nevertheless, it has been shown that the current procedures of annual reporting to the Commission do not reflect the reality of occurrences in many member states. Instead, socio-economic considerations are often claimed as a reason to uphold overcapacity in a certain fishing fleet, which, as a consequence, should induce the Commission to notify closer consideration of the actual capacity in the concerned fleet (Berkow, 2018).

3.1.4. Landing Obligation and measures to prevent bycatch, discards and IUU

Since the Landing Obligation (LO) was introduced, it has no longer been legal to discard catch. Fish smaller than the 'minimum conservation reference size' must still be landed, but not sold for human consumption (ICES, 2020a), and thus, at a lower price. The rationale is to provide incentives to choose selective gear that lets the small fish escape and keep the large individuals which have a higher price in the market. Nonetheless, there are no allowed targeted fisheries for Baltic cod, either EBC or WBC, only a small bycatch TAC is allowed, so selective gear is now being discussed at length in flatfish fishery where cod is caught as a bycatch species. Although different selective gear has been operational in the Baltic Sea for over 25 years, the discard rates have been, and are still, high (Feekings et al., 2013; Madsen, 2007; Madsen et al., 2021; Valentinsson et al., 2019). In a recent publication from Valentinsson et al. (2019) it is stated that discards have not stopped since the introduction of the LO, where underreporting is continuing and gear selectivity has not increased. According to ICES (2020a) discards were estimated to comprise 14% of the total catches of EBC in 2019, a practice which can severely threaten stock health (Uhlmann et al., 2013).

Apart from reduced bycatch of unwanted sizes and of non-target species, gear development can help improve the discard situation, since the smaller fish would obviously not need to be thrown away if they had never been caught. However, implementation needs to be enforced. There are not enough control measures in place today to ensure that discard is stopped and the LO is being fully complied with. In general, encouraging the use of gear with higher selectivity could, for instance, be done by rewarding the users of selective gear with exclusive access fishing during selected times or in selected areas (Condie et al., 2014; Valentinsson et al., 2019). Different incentives to use gear with higher selectivity could help reduce discards, keeping in mind that it is difficult to motivate investment in and use of new gear when stock status is still declining and fishing quotas are becoming lower.

The reduction of discards through gear development should be combined with increased monitoring and regulation of unwanted catches. Methods of monitoring include observers onboard, surveillance with patrol vessels (air or sea), self-sampling, vessel-transmitted information and electronic monitoring. All of these options have pros and cons when it comes to factors including cost, level and time scale of deterrent, precision and reliability, but improved monitoring can be achieved by combining existing methods. However, coverage needs to be high and support from the fishing industry is important in order to implement improved monitoring in a successful way (James et al., 2019). Electronic monitoring, EM, has been suggested to play a vital part in at-sea monitoring to ensure good fishing management and better protection of marine resources and ecosystems (Ewell, et al., 2020). It is described as a game changer for the demand of transparency and accountability, and thus to provide reliable data for a more effective management (Michelin et al., 2018). Trials from different parts of the world have shown EM to be a time and cost effective way to monitor catch, and overcome difficulties with observer reports (Bartholomew et al., 2018; Evans & Molony, 2011; Ruiz et al., 2015). Also, EM has been discussed in the light of human rights as it complements on board observers, who have been reported to experience safety risks and violations such as intimidation and assault (Ewell, et al., 2020; Michelin et al., 2018).

Bastardie et al. have suggested that one of the management actions dealing with the multiple ecosystem challenges in European waters should be a regional approach and building of trust with local fishers. As an example, collaboration between scientists and fishermen with local knowledge is valuable for the development of improved gear (Bastardie et al., 2021). Incorporation of ecological knowledge from fishers is still limited but can be valuable for research as well as policymaking. This has also been shown to improve compliance with regulations (Figus & Carothers, 2017). Similarly, compliance with new gear regulations is likely to be more successful when the fishers themselves are involved in the decision-making process. Suuronen et al. (2007) found that the introduction of new gear regulations in the Baltic cod trawl fishery was more successful when they were carefully planned and gradually introduced in smaller steps. A sudden, substantial increase in selectivity introduced as a single step was less likely to be complied with by fishers as the short-term catch losses were large in such cases (Suuronen et al., 2007).

For sustainable fish stocks in general and a healthy cod stock in particular different measures can be used to manage bycatch, discards, IUU and control of fish catch. Some of these measures are more adapted for commercial fishing including both industrial and small-scale ones. Recreational fishing has been defined in some EU legislation, although not in the Common Fisheries Policy (European Anglers Alliance, n.d.).

It is, however, undoubtedly very important that these measures have to be complemented by efficient national ones in the countries bordering the Baltic Sea[7]. The national regulations are better adapted, both nationally and regionally, and these policies should therefore be taken into consideration because they are a prerequisite for a sustainable fishery policy in the region.

7 The Technical Measures Regulation came into force in 2019. EU countries with a fisheries interest in a given sea basin can agree on regional technical measures, adapted to the specific regional circumstances. Such measures can then be adopted as EU secondary legislation, if confirmed by scientists to be consistent with the objectives of the common fisheries policy. The Technical Measures Regulation aims to de-centralise the management of technical features to the regional level. It is therefore important to measure progress regularly. The regulation states that the Commission should carry out such assessments every 3 years. https://ec.europa.eu/oceans-and-fisheries/fisheries/rules/technical-measures_en

3.1.5. Technical measures and Article 17 – where, when and how fishing can be done

Technical measures are used to regulate the taking and landing of marine biological resources, the operation of fishing gear and the interaction of fishing activities with marine ecosystems, i.e. where, when and how you are allowed to fish. Fisheries managers and responsible politicians in EU Member States across the Baltic region have failed to use technical measures successfully to conserve fishing resources and the marine ecosystem, including through cod gear regulations.

According to Suuronen et al. (2007) legal and illegal manipulation of stipulated cod gear have been widespread among trawl fishermen targeting cod in the Baltic Sea. Scientists also found that, generally, the fishing industry did not tolerate large short-term economic losses due to any technical measure (Suuronen et al., 2007). Studies show that there has been no measurable positive development following the introduction of more selective trawls in Baltic Cod fishery (ICES, 2005). Further, fishermen have been generally negative towards any kind of restrictions on fishing in marine protected areas (MPAs), not least in the Baltic Sea cod fishery.

MPAs were seen as an inefficient conservation tool to preserve the cod stock (Suuronen et al., 2010). On 14 August 2019, EU amended technical measures, Regulation (EU) 2019/1241 of the European Parliament and of the Council ('the Regulation') entered into force (EU, 2019). The new Regulation, looking at more results-based approaches to the definition of measures, includes targets for technical measures to: reduce unwanted catches (especially of sensitive species); optimise exploitation patterns; contribute to improved yields; and ensure impacts of fishing on seabed habitats are in line with EU environmental legislation.

The European Commission (European Commission, 2019) has evaluated the implementation of the new technical measures in a report to the European Parliament. It concludes that there are still no reliable methods that are available to monitor selectivity and more accurately measure the quantities of small fish or of sensitive species that are caught. Current monitoring methods only provided data adequate for STECF to evaluate broad trends in size selectivity in large fleet segments. The Regulation does provide the legislative instruments for Member States to address EU environmental and sustainable fisheries management objectives, such as the protection of sensitive species and sensitive habitats, with some species close to extinction. EU Member States, on a regional basis, have a duty to raise both ambition and speed in the implementation of necessary technical measures in order to meet the legal obligations under EU environmental and fisheries law to conserve and restore marine resources and habitats. However, efforts to monitor the effects of fishing on ecosystems need substantial improvements.

3.1.5.1. Measures to aid recovery of cod

Table 11 below shows various measures that would aid the recovery of the cod population, focusing on overfishing, eutrophication and implied effects of climate change.

Table 11. Examples of measures with potential to contribute to cod recovery in Swedish waters (beyond regulation of cod fishing), as suggested in HaV 2020, p 54-55. SU – Skagerrak - open sea spawning stock, SK – Skagerrak coastal spawning stock, K – Kattegatt cod, WB – Western Baltic cod, EB – Eastern Baltic cod.

	Significance for the recovery of the cod							
Measure	**SU**	**SK**	**K**	**WB**	**EB**	**Timeframe for effect**	**Ecological risk**	**Scale**
Trials with local reduction of seals and cormorants	No	Unclear	Unclear	Unclear	Unclear	Short	Yes	Local
More selective and low-impact fisheries	High	High	High	High	High	Short	No	Large
Prevent and reduce ghost fishing	Unclear	Unclear	Unclear	Unclear	Unclear	Short	No	Local/Large
Protect and restore cod habitats	High	High	High	High	High	Short-Long	No	Local/Large
Trials to improve food web conditions	No	No	No	No	High/ Unclear	Short-Medium	Yes	Large
Trials with feeding of cod	No	No	No	No	Unclear	Short	Yes	Local
Trials with releases of cod	No	Unclear	Unclear	No	No	Medium	Yes	Local
Trials with artificial reefs	No	Unclear	Unclear	Unclear	Unclear	Medium	Yes	Local
Accelerate the reduction of carbon dioxide emissions	High	High	High	High	High	Long	No	Large
Accelerate action to prevent eutrophication	High	High	High	High	High	Long	No	Large
Trials to locally mitigate the effects of eutrophication	No	Unclear	No	No	Unclear	Medium	Yes	Local
Investigate the effects of environmental toxins on cod	Unclear	Unclear	Unclear	Unclear	Unclear	Medium	No	Large
Investigate the effects of pharmaceutical residues on cod	Unclear	Unclear	Unclear	Unclear	Unclear	Medium	No	Large

3.1.5.2. Article 17 of the CFP: support low impact fisheries

Article 17 of the CFP is a short paragraph with great implications, if implemented correctly. It stipulates how the Member States are to allocate the fishing opportunities domestically, stating that the allocation criteria should be i) transparent, and ii) objective, among other things including the impact of fishing on the environment. Furthermore Member States are to provide incentives for the use of selective gear or low-impact techniques (EU, 2013). The full Article reads as follows:

> *When allocating the fishing opportunities available to them, as referred to in Article 16, Member States shall use transparent and objective criteria including those of an environmental, social and economic nature. The criteria to be used may include, inter alia, the impact of fishing on the environment, the history of compliance, the contribution to the local economy and historic catch levels. Within the fishing opportunities allocated to them, Member States shall endeavour to provide incentives to fishing vessels deploying selective fishing gear or using fishing techniques with reduced environmental impact, such as reduced energy consumption or habitat damage.*
>
> EU, 2013, p 38

A working document from the European Parliament (2021) examines the use of Article 17. Regarding *transparency* in the allocation of fishing opportunities to fishers and producer organisations, there is generally low compliance since many Member States do not provide data on the domestic quota share, despite this being a requirement. Furthermore, there is a demand for the allocation to be *objective*, while it is shown that historical catches are the most common method of quota allocation, thus promoting large commercial fisheries rather than local and low impact fishing. All MS are obliged to report to the Commission on the basis of allocations and the implementation of Article 17. However, not all MS adhere to this obligation. Article 17 furthermore provides for optional use of economic, social and environmental criteria when allocating fishing opportunities. Currently few MS have used these criteria. Consequently, insufficient implementation of Article 17 hampers the goals of both the CFP and the MSFD/GES. Article 17 leads the way in encouraging MS to support fishing practices less harmful to the environment, economically efficient and societal and culturally valuable to local societies (European Parliament, 2021).

The implementation of Article 17 was examined in an evaluation of the CFP made by WWF in 2018. Since data availability in MS is low, national experts have been consulted, as well as WWF officers. The following questions were asked:

> *"Article 17:*
> *Are the criteria for the allocation of fishing opportunities publicly available in your MS? (Yes or No) If yes, are the criteria favouring low impact fishers? (Yes or No) Are you aware of changes to come in the allocation system? (Yes or No)"*

The results can be seen in the table 12. As is clearly shown, low-impact fisheries are not subject to support.

Table 12. Summary of answers in a survey targeting fisheries experts in EU MS, asking about fishing restrictions on the basis of Article 17. Source: WWF, 2018, p 24.

	PT	LT	DK	LV	IE	CY	EE	ES	FI	FR	GR
Perceived as transparent?	no		yes	yes	yes	yes	yes	yes	yes	yes	yes
Favouring low- impact fishers?	no		yes	yes	yes	no	no	no	no	no	no
Changes to come in the system?	yes	yes	yes					yes			
Group of MS	About to change		Implementation under way	Starting implementation		No implementation yet					

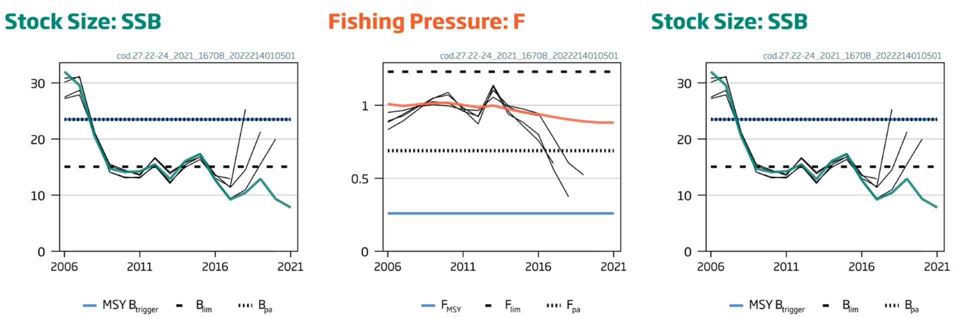
	IT	MT	RO	HR	SE	BE	DE	NL	PL	SI	BG
Perceived as transparent?	yes	yes	yes		no	no	no	no	no		
Favouring low- impact fishers?	no	no	no	no	no	no	no	no	no		
Changes to come in the system?											
Group of MS	No implementation yet									No info	

Depending on the answers to the question, the MS belong to one of the five groups, "about to change", "implementation underway", "starting implementing", "no implementation yet", and "no information".

3.2. Cod landings and fishing management

Since the new Common Fisheries Policy came into effect on 1 January 2014, fisheries management has aimed at maximum sustainable yield (MSY), and a deadline for achieving sustainable fisheries within the EU was set for the year 2020. The deadline has passed and sustainability has not yet been achieved.

Figure 7. ICES SSB assessment and fishing pressure for WBC. It is clearly shown that the predicted SSB has been much larger than actual stock development. Source: ICES, 2021d



The MSY for a given fish stock means the highest possible annual catch which is considered to be sustainable over time, by keeping the stock at the level producing maximum growth (Blenckner et al., 2011). The MSY is in general not equal to the Total Allowable Catch (TAC), which is the catch quota decided by the Council of the EU after a political process of scientific advice and recommendations from the European Commission. Each year the European Commission uses scientific advice to propose total allowable catch (TAC), however this is often ignored by the Agriculture and Fisheries Council (AGRIFISH) and does not ensure sustainability (social, economic and environmental) in the long term.

Table 13. History of the advice, catch and manangement. From ICES 2021a.

Cod in subdivisions 25–32, eastern Baltic stock. ICES advice and official landings. All weights are in tonnes.

Year	ICES Advice	Catches corresp. to advice	Landings corresp. to advice	Agreed TAC	ICES landings (SDs 25–32)	ICES EBC stock catches (SDs 24 and 25–32)
2007	No fishing		0	44 300	50 843**	64 656
2008	No fishing		0	42 300***	42 235**	55 578
2009	Limit (total) landings to 48 600 tonnes		≤ 48 600	49 380***	48 439**	60 513
2010	Follow management plan		56 800	56 100***	50 277	60 400
2011	See scenarios		-	64 500***	50 368	62 245
2012	Follow management plan		74 200	74 200***	51 225	67 024
2013	Follow management plan		65 900	68 700***	31 355	42 977
2014	Follow management plan		70 301	73 400***	28 909	45 289
2015	20% reduction in catches	29 085		55 800***	38 079	50 008
2016	Precautionary approach^	≤ 29 220		46 900***	29 313	37 438
2017	Precautionary approach^	≤ 26 994		36 957***	25 496	30 965
2018	Precautionary approach^	≤ 26 071		34 288***	15 907	21 605
2019	Precautionary approach^	≤ 16 685		29 912***	8 383	11 938
2020	Precautionary approach^	0		7 500***	2 319	2 899
2021	Precautionary approach^	0		3 595***		
2022	Precautionary approach^	0				

** Reported landings in 1992–1995 and 2000–2009 are likely to be minimum estimates due to incomplete reporting.
*** TAC is for SDs 25–32 and is calculated as EU + Russian autonomous quotas.
^ ICES stock-based advice (for the eastern Baltic cod stock).

Table 14. History of the advice, catch and manangement. From ICES 2021d.

Cod in subdivisions 22–24, western Baltic stock. ICES advice and official landings. All weights are in tonnes.

Year	ICES advice	Total catch from the stock corresp. to the advice	Commercial catch corresp. to advice*	Agreed TAC**	ICES estimated total commercial landings subdivisions 22–24 (eastern and western Baltic cod stocks)
2007	Keep SSB at Bpa		< 20 500	26 700	23 736
2008	Rebuild SSB to Bpa		< 13 500	19 200	20 082
2009	Rebuild SSB to Bpa		< 13 700	16300	15 549
2010	Management plan		< 17 700	17 700	14 120
2011	See scenarios		-	18 800	16 332
2012	Management plan		21 300	21 300	17 072
2013	Management plan		20 800	20 000	12 968
2014	Management plan		17 037	17 000	13 538
2015	MSY approach		8 793	15 900	13 418
2016	MSY approach (F = 0.23)	≤ 7 797		12 720	10 629
2017	MSY approach (F = 0.15)	≤ 3 475	≤ 917	5 597	5 865^
2018	MAP F ranges: Flower to FMSY adjusted by SSB2018/MSY Btrigger (F = 0.11–0.188)	3 130–5 295	1 376–3 541	5 597	5 850^
2019	MAP range: FMSY Flower to Fupper (F = 0.15–0.45)	9 094–23 992	5 867–22 238	9 515	7 701^
2020	MAP range: FMSY Flower to Fupper (F = 0.18–0.43)	5 205–11 006	3 065–8 866	3 806	3 329^
2021	Management plan	5 950 (range 4 275–9 039)	4 635 (range 2 960–7 724)	4 000	
2022	MSY approach	≤ 698			

* Values since 2016 are for the western Baltic cod stock only, whereas in earlier years they are for the area of subdivisions 22–24 and include a fraction of the eastern Baltic cod stock.
** Included in TAC for total Baltic, until and including 2003.
*** Two options based on implementation of the adopted mesh regulation.
^ Including BMS.

For example, in 2018 the ICES advice using a precautionary approach (PA) was equal to 26,071 tonnes, while the agreed TAC was 34,288 tonnes in subdivision 24-32 as shown in Table 15. Hence the difference is 8,217 tonnes. For many years this deviation prevailed and thus created a non-sustainable fishing policy. Furthermore, the catch is often not equal to fish landings, where the difference is due to discards, a practice that has been banned in the Baltic Sea through the Landing Obligation (LO) fully implemented in 2019.

Table 15. ICES advice, catches and TAC 1988-2018 (ICES, 2019c).

Year	ICES advice	Catches corresp. to advice	Landings corresp. to advice	Agreed TAC	ICES landings subdiv. 25-32	ICES Baltic stock catches subdiv. 24 & 25-32
1988	TAC	n.a.	150 000		194 000	210 527
1998	40% reduction in fishing mortality from 1996 level	n.a.	60 000	140 000	67 428	74 940
2008	No fishing	n.a.	0	42 300	42 235	55 578
2018	Precautionary approach	≤ 26 071		34 288	15 907	21 065

According to ICES, landings of Eastern Baltic cod in subdivisions 24 and 25-32 in 1984 reached the largest catch historically in these subdivisions. In 2018 the landings in the same subdivisions were estimated at 21,605 tonnes. This is equivalent to almost 5% of the 1984 total landings. As shown in Table 16, total catch, total landings and discards in 2018 are equal to 19,010 tonnes, 15,907 tonnes and 3,103 tonnes respectively for the Eastern cod stock in SD 25-32. However, demersal discards showed a nominal overall decrease in 2015 because of the obligation to land all commercial catches of cod, salmon, herring, and sprat in the Baltic Sea (ICES, 2019c).

Table 16. Cod in subdivisions 24–32, eastern Baltic stock. History of ICES estimates of landings, discards, and catch by area. Weights are in tonnes (ICES, 2019c).

	Eastern BC stock in SD 25-32			Eastern BC stock in SD 24			Eastern BC stock in SD 24 & 25-32
Year	**Discards**	**Total landings**	**Catch**	**Discards**	**Total landings**	**Catch**	**Total catch**
1988	7 253	194 787	202 040		8 487	8 487	210 527
1998	2 299	67 428	69 727	631	4 582	5 213	74 940
2008	3746	42 234	45 980	787	8 811	9 598	55 578
2018	3 103	15 907	19 010	300	2 295	2 595	21 605

According to ICES, in 2018 the total bycatch of cod was estimated between 360-1,306 tonnes in SD 25-32 with a range of 66-417 tonnes in SD 24 (ICES, 2020f).

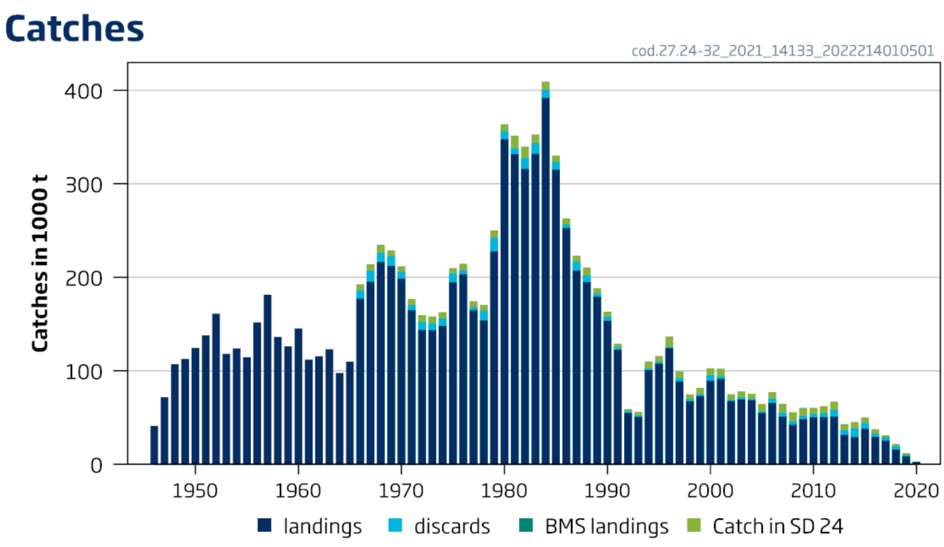
IUU sincerely threaten the sustainability of fish stocks. In general, unreported landings are the greatest source of IUU catches. Unreported landings of cod during the period 2000-2007 represent about 35% of unreported landings of all species in the Baltic Sea (Aps et al., 2012). The WBC stock size has fluctuated over the years, with high fishing pressure and poor recruitment, but where the discard rate has been considered relatively low according to observer programmes on Denmark, Sweden, Poland and Germany, with an average discard rate of 8 % over the years 1994-2017 (ICES, 2019a). Table 17 shows that while total catches in the Western Baltic decreased by around 75% between 1988 and 2018, the share of recreational catches relative to total catches increased from around 7% in 1988 to 20% in 2018.

Table 17. Discards, recreational and total catch of western Baltic stock 1988-2018 (ICES, 2020f).

	Management area SDs 22-24		
Year	**Discards**	**Recreational catch**	**Total catch**
1988		2 082	31 241
1998	6 206	3 410	43 833
2008	1123	3 039	24 274
2018	469	1 600	7 907

In addition to discards, fishing business leads to the occurrence of bycatch and to Illegal, Unreported and Unregulated (IUU) fishing including recreational catch as shown in Figure 8.

Figure 8. Historical landings of the EBC. Source: ICES, 2021a



3.3. EU environmental laws and directives

In Europe, Member States have the sole competence to decide on management measures in the 12-mile zone (coastal zone). There are therefore major differences in the level of environmental protection of Member States. Outside of the 12-mile zone the European laws apply.

3.3.1. Habitat Directive and Natura 2000

The Habitat Directive (EU, 1992) is the main law within Europe for the spatial protection of vulnerable species and ecosystems. It enables the protection of sensitive areas and associated species in Europe, both on land and in the marine environment. The Habitats Directive was established in 1992 it is closely linked to the Bird Directive from 1979 (EU, 2009) which together allow for the establishing a network of protected areas in Europe, the Natura 2000 network in which characteristic species and specific areas or habitats can be protected.

The Natura 2000 network was set up for both terrestrial and marine protection. Member States could decide to add areas based on their importance for marine biodiversity and protection of vulnerable and threatened species. Although many areas have been designated, currently it has over 3,000 named marine sites covering over 318,133 km^2, implementation measures are lacking in most of them. Especially those outside of the 12 mile zone (Perry et al., 2020).

3.3.2. Marine Strategy Framework Directive

The Marine Strategy Framework Directive (MSFD) was established in 2008 to regulate sustainable use of Europe's marine ecosystems (EU, 2008). This goal is to be achieved by applying the ecosystem approach to regulating human activities that affect the marine ecosystem. The main objective of the MSFD was to achieve Good Environmental Status (GES) for the marine environment by 2020. In broad terms, GES refers to ecologically diverse and dynamic oceans, and clean, healthy and productive seas within intrinsic fishing conditions. The use of the marine ecosystem must be at a sustainable level so as to secure its potential use for current and future generations.

GES is defined at the marine region or sub-region level using 11 qualitative descriptors. Each EU Member State has developed a strategic plan for its own waters that sets out how it was to achieve GES by 2020. For cod, four of the 11 descriptors are important: (3) commercial fish and seafood; (4) food webs; (5) eutrophication and (9) hazardous substances in fish.

Article 6 of the MSFD outlines the need for measures leading towards GES benefit from international/regional cooperation in the implementation. Regional Sea Convention are introduced as a forum where to implement marine strategies in a coherent way at the regional level.

3.3.3. Regional Sea Conventions (RSCs) – HELCOM and the BSAP

The Regional Sea Conventions (RSCs) provide a platform in which countries can engage with neighbouring countries for the conservation of their common marine environment. RSCs work on all maritime activities and environmental pressures resulting from them, as well as biodiversity and ecosystem protection. Through the RSCs coordinated monitoring programmes are implemented in their basins, and joint programs environment improvement are implemented. Fisheries management is not part of their remit.

The RSC that focuses on the Baltic sea basin is the Baltic Marine Environment Protection Commission (the Helsinki Convention – HELCOM established in 1974) to which the nine Baltic Sea Countries (including Russia) as well as the EU are signatories. In 2007 the Ministerial Meeting of Helcom adopted the Baltic Sea Action Plan, a strategic programme of measures for achieving Good Environmental Status in the Baltic by 2021. By 2017 it became clear that this target would not be achieved by far and the choice was made to update the Action Plan.

The updated HELCOM Baltic Sea Action Plan Focus on fish (HELCOM, 2021) contains 199 specific actions divided over four focus areas:

- Biodiversity, with its goal of a "Baltic Sea ecosystem is healthy and resilient",
- Eutrophication, with its goal of a "Baltic Sea unaffected by eutrophication"
- Hazardous substances and litter, with its goal of a "Baltic Sea unaffected by hazardous substances and litter", and
- Sea-based activities, with its goal of "Environmentally sustainable sea-based activities".

The actions should be implemented na later than 2030 (earlier when possible) and the overall aim of plan is for "a healthy Baltic Sea environment with diverse biological components functioning in balance, resulting in a good ecological status and supporting a wide range of sustainable economic and social activities

3.3.4. The European Green Deal and the Biodiversity Strategy 2030

To deal with the global challenge of climate change as well as the biodiversity crisis the European Commission announced a Green Deal for Europe in 2020 (EU, 2019a). The Green Deal provides an umbrella for a framework of strategies, action plans, legislation and regulations all aimed at reaching overarching targets for restoration and recovery. One of the strategies introduced shortly after the Green Deal was announced is the updated Biodiversity Strategy 2030 (EU, 2021).

The Biodiversity Strategy was adopted by the EU member states in 2021, it lists specific commitments and actions to be delivered no later than 2030:

Actions and comittments in the Biodiversity Strategy:

*"**Establishing a larger EU-wide network of protected areas on land and at sea***

The EU will enlarge existing Natura 2000 areas, with strict protection for areas of very high biodiversity and climate value.

Launching an EU nature restoration plan

Through concrete commitments and actions, the EU aims to restore degraded ecosystems by 2030 and manage them sustainably, addressing the key drivers of biodiversity loss.

As part of this plan, the Commission will propose binding nature restoration targets by the end of 2021.*

Introducing measures to enable the necessary transformative change

The strategy highlights unlocking funding for biodiversity, and setting in motion a new, strengthened governance framework to

- *ensure better implementation and track progress*
- *improve knowledge, financing and investments*
- *better respecting nature in public and business decision-making*

Introducing measures to tackle the global biodiversity challenge

These measures will demonstrate that the EU is ready to lead by example to address the global biodiversity crisis. In particular, working towards the successful adoption of an ambitious global biodiversity framework under the Convention on Biological Diversity."

European commission (n.d.c.)

3.3.5. EU restoration law

One of the new legal instruments announced in the 2030 Biodiversity Strategy is a 'restoration law' which shall have nature restoration targets to restore biodiversity and degraded ecosystems with the aim to increase biodiversity, mitigate and adapt to climate change, and prevent and reduce the impact of natural disasters (EU, 2020a). Originally announced for 2021 the European Commission has indicated that it expects to publish the legal proposal in early 2022. The Council of EU ministers and the European Parliament will then debate and amend the proposal in a co-decision process that is set to conclude later in the year or early in 2023.

3.3.6. Action plan to conserve fisheries resources and protect marine ecosystems

As part of the New 2030 Biodiversity Strategy an Action Plan to conserve fisheries resources and protect marine ecosystems is to be developed, the public consultation on this plan concluded in December 2021 (EU, 2021a) and the plan is expected to be released in March 2022. The plan is closely linked to the technical measures regulation and will focus on the reducing by-catch of undersized and sensitive species and reduction of impacts on sensitive habitats.

3.4. Ecosystem-based management – a cornerstone of official EU fisheries and environmental policies

Ecosystem-based management (EBM) is a management approach and tool that is formally part of the EU legislation of fisheries through the CFP and also the Baltic multiannual management plan, there termed 'ecosystem approach' or 'an ecosystem-based approach to fisheries management' (EU, 2013) it is also referenced in the MSFD (EU, 2008), in this way providing a linking pin between fisheries and environmental policy.

The basic assumptions of ecosystem-based management have been practised by indigenous people for centuries (Long et al., 2015), and as a (fairly) modern concept it can be traced back to environmental ethics in the 1960s (Garcia, 2003, Szaro et al., 1998). There is no fixed definition of EBM, and there are plenty of similar terms (Wang, 2004). There is also a difference between the term 'ecosystem approach', which designates a vision of sustainable use of natural resources, and 'ecosystem management', which is more often described as a place-based management tool (Maltby, 2000).

However, despite the lack of an unanimous definition there are some basic criteria that are connected with EBM, and the following key principles have been summarised by Long et al. (2015) through a literature review of published papers, where the most frequently used criteria are the three at the top (highlighted in bold by the authors):

Key principles of EBM:

(i) ***Consider Ecosystem Connections***
(ii) ***Appropriate Spatial & Temporal Scales***
(iii) ***Adaptive Management***
(iv) *Use of Scientific Knowledge*
(v) *Stakeholder Involvement*
(vi) *Integrated Management*
(vii) *Sustainability, Account for Dynamic Nature of Ecosystems*
(viii) *Ecological Integrity & Biodiversity*
(ix) *Recognize Coupled Social-Ecological systems*
(x) *Decisions reflect Societal Choice*
(xi) *Distinct Boundaries*
(xii) *Interdisciplinarity*
(xiii) *Appropriate Monitoring*
(xiiv) *Acknowledge Uncertainty*

Source: Long et al., 2015

The ecosystem approach gained momentum through the Earth Summit in Rio in 1992, where the concept was introduced as a management tool to attain the objectives of the Convention on Biological Diversity, CBD (Maltby, 2000). Since then, the term has developed further and is often used in combination with a specific type of management area (Söderström, 2017). Of importance for European fisheries management is the term ecosystem-based fisheries management (EBFM). The term has increased in popularity since the early 2000s (Lidström & Johnson, 2020). The basis of EBFM is the shift from single-species management to multispecies management, where several aspects of the ecosystem and the interaction between them are taken into consideration in management, i.e. a more holistic approach (Pikitch et al., 2004, Trochta et al., 2018, Lidström & Johnson, 2020). A very well cited paper from Pikitch et al. (2004), published in Science, describes the following objectives within EBFM:

Key objectives of EBFM:

(i) "avoid degradation of ecosystems, as measured by indicators of environmental quality and system status;

(ii) minimize the risk of irreversible change to natural assemblages of species and ecosystem processes;

(iii) obtain and maintain long-term socioeconomic benefits without compromising the ecosystem;

(iv) generate knowledge of ecosystem processes sufficient to understand the likely consequences of human actions. Where knowledge is insufficient, robust and precautionary fishery management measures that favor the ecosystem should be adopted."

Source: Pikitch et al., 2004, page 346

The authors emphasise the need to move away from single-species management, and stress that the whole ecosystem and its processes are taken into consideration. As an example the fishing pressure for only one species might be considered sustainable, but taking other ecosystem functions into account the effects on other parts become too high, especially when a top predator is the target species (such as cod). The precautionary principle is highlighted, where greater uncertainty should result in more precautionary fisheries. A reverse burden of proof is suggested, where fisheries only should take place if proven not to harm the rest of the ecosystem. Furthermore, it is essential that the outtake of biomass does not exceed the productivity of the ecosystem and that the resilience and integrity of ecosystem processes are kept intact (Pikitch et al., 2004). As pointed out by Trochta et al. (2018), the inclusion of EBFM in a management plan does not necessarily result in effective implementation. Since there is no universal definition of EBFM, the management, and management plans, must be adapted to the local context to be relevant (Trochta et al., 2018).

3.4.1. EBM within CFP

In the CFP, the term 'ecosystem-based approach to fisheries management' is used and is described as follows:

Introduction

> *(13) An ecosystem-based approach to fisheries management needs to be implemented, environmental impacts of fishing activities should be limited and unwanted catches should be avoided and reduced as far as possible. (CFP 2013, p 2).*

PART 1, **GENERAL PROVISIONS**, Article 2 Objectives

> *(3) The CFP shall implement the ecosystem-based approach to fisheries management so as to ensure that negative impacts of fishing activities on the marine ecosystem are minimised, and shall endeavour to ensure that aquaculture and fisheries activities avoid the degradation of the marine environment. (CFP, 2013, p 8).*

PART 1, **GENERAL PROVISIONS**, Article 4 Definitions

> *(9) 'ecosystem-based approach to fisheries management' means an integrated approach to managing fisheries within ecologically meaningful boundaries which seeks to manage the use of natural resources, taking account of fishing and other human activities, while preserving both the biological wealth and the biological processes necessary to safeguard the composition, structure and functioning of the habitats of the ecosystem affected, by taking into account the knowledge and uncertainties regarding biotic, abiotic and human components of ecosystems; (CFP, 2013, p 9).*

PART III, **MEASURES FOR THE CONSERVATION AND SUSTAINABLE EXPLOITATION OF MARINE BIOLOGICAL RESOURCES**, TITLE II Specific measures, Article 9 Principles and objectives of multiannual plans

> *(5) Multiannual plans may contain specific conservation objectives and measures based on the ecosystem approach in order to address the specific problems of mixed fisheries in relation to the achievement of the objectives set out in Article 2(2) for the mixture of stocks covered by the plan in cases where scientific advice indicates that increases in selectivity cannot be achieved. Where necessary, the multiannual plan shall include specific alternative conservation measures, based on the ecosystem approach, for some of the stocks that it covers. (CFP, 2013, p 13).*

3.4.2. Tracing EBM through WFD, MSFD, MSPD and HELCOM BSAP

EBM is, as described previously, part of official EU legislation. Something close to a definition, or at least a description, can be found in the Marine Strategy Framework Directive (MSFD), where 'an ecosystem-based approach' is presented as a basis for environmental management. This description has since functioned as a definition to which subsequent legislation refers back (Söderström and Kern, 2017). The description is as follows:

> *"By applying an ecosystem-based approach to the management of human activities while enabling a sustainable use of marine goods and services, priority should be given to achieving or maintaining good environmental status in the Community's marine environment, to continuing its protection and preservation, and to preventing subsequent deterioration."*

(MSFD 2008) 20, §8

For example, the Marine Spatial Planning Directive (MSPD), from 2013 refers back to the MSFD regarding EBM, giving no definition of its own. Furthermore, the Directive displays several of the core characteristics of EBM. Söderström and Kern (2017) has traced these characteristics of EBM within European marine environmental legislation, where the following core criteria were identified from the scientific literature (well aligned with the key principles of EBM identified by Long et al., 2015): (i) a holistic approach with human inclusion, (ii) scale dependency and integration, (iii) sound science, (iv) participation and (v) adaptive management and ecosystem services. The MSPD includes all of these key elements to a great extent, but also the old Water Framework Directive (WFD) from 2000, although no mention is made of EBM per se. In summary, the development of directives including key principles from EBM has progressed from moderate in the WFD to large in the MSPD, where the MSFD provides the description of EBM used in future legislation (Söderström and Kern, 2017). Additionally, the HELCOM Baltic Sea Action Plan (BSAP), from 2007, highlights the importance of the ecosystem approach in its preamble:

> *"ACKNOWLEDGING that the ecosystem approach is based on an integrated management of all human activities impacting on the marine environment and, based on best available scientific knowledge about the ecosystem and its dynamics, identifies and leads to actions improving the health of the marine ecosystem thus supporting sustainable use of ecosystem goods and services;"*

(BSAP, 2007, preamble, p 3)

In the newly updated HELCOM BSAP (2021) it is highlighted further, where the BSAP in itself is described as a tool for the practical implementation of ecosystem-based management in the Baltic Sea area.

Striving for good environmental status (GES) is also the core objective in the MSFD. The importance of ecosystem functions and food webs is stressed, aligning environmental targets with healthy fish stocks. The qualitative descriptors for determining good environmental status (GES), (3) and (4) in ANNEX I, read: *"(3) Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock"* and "(4) *All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity"*. The connections between environmental targets and fishing opportunities, as well as elements of EBM, is evident. These connections are further highlighted in policy through the Baltic Sea multiannual plan.

3.4.3. Adding precaution to the agenda

The precautionary principle, or precautionary approach, is an old notion in environmental science and can be traced back to German environmental policy in the 1980s dealing with polluted marine environments and the *Vorsorgeprinzip* addressing foresight and planning, although the exact origin is somewhat unclear (Peel, 2005). The principle truly gained momentum after the UN Conference on Environment and Development (UNCED) in Rio 1992. The original text in the *Rio Declaration on Environment and Development*[8] is formulated as follows: *"Principle 15. In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."* (United Nations, 1992). In the same year, 1992, the precautionary principle was established as the basis for European environmental law in the Treaty on European Union (Foster et al., 2000). In the subsequent Treaty Establishing the European Community, the Precautionary Principle is discussed in the context of environmental protection, in TITLE XIX, ENVIRONMENT, Article 174:2: *"Community policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Community. It shall be based on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay".* (EU, 2012, page 255).

The precautionary approach has evolved rapidly in environmental management since the 1990s and is now widely recognised in environmental regulation at the national, regional and global scale, as explored further by Peel (2005). Both within the European Union and internationally the precautionary approach has increased rapidly, not only in environmental science but in other fields as well.

The core values and application of the precautionary approach have been debated in academia and management, with both strong advocates and strong opponents. Although the role of scientific uncertainty is the main subject of debate, there are also other topics that are discussed such as whether the label of 'a principle' or 'an approach' is most suitable (content-wise, not only in terms of semantics) (Peel, 2005).

The precautionary principle is enshrined in many international treaties and so on, but the interpretation of the principle varies and numerous interpretations can be found, and the legal community remains divided on the application of the principle (Foster et al., 2000).

For managers, the topic of precaution is evident in environmental regulation, where both international regulations and domestic laws urge decision makers to *"take account of the precautionary principle or to apply a 'precautionary approach'"* (Peel, 2005 p. 4).

8 Annex I to the Report of the united nations conference on environment and development. A/CONF.151/26 (Vol. I)

Decision-makers must address several topics, such as *"(i) How uncertainties in the scientific knowledge underlying decision-making are to be identified, (ii) what reliance to place upon uncertain scientific information in making determinations about possible threats of damage, (iii) what other sources of knowledge to consider in the absence of definitive scientific opinion about health and environmental threats, (iv) how to 'balance' various factors in decision-making where uncertainties exist, and (v) whether the potential for scientific uncertainty necessitates changes to conventional modes of decision-making in the health and environmental field, particularly those which purport to be 'science-based'"* (Peel, 2005 page 4-5).

The precautionary principle is nowadays institutionalised in environmental management, but in several different ways. The main point of integrating scientific uncertainty in decision-making processes is context dependent, and the nature of the uncertainty varies on a case by case basis, leaving room for interpretations and omitting a one-size-fits-all solution. This leaves room for interpretation, and thus a scientific as well as policy discourse over the nature of the precautionary principle per se (Peel, 2005).

ICES uses its own interpretation of the precautionary approach in the scientific advice for fishing opportunities. It is based on the UN Fish Stock Agreement (1995), where Annex 2 provides guidelines for applying a precautionary approach within a MSY framework (ICES, 2013). However, ICES considered the guidelines unclear and thus interpreted the precautionary approach in the following way: *"(...) it is most useful to recognize that MSY and a precautionary approach are complementary, and this is the spirit in which ICES applies these concepts."* (ICES, 2013, p. 3). It is further stated that: *"In a sense, a precautionary approach is a risk-averse concept intended to avoid unproductive situations while an MSY approach is intended to make the best use of the ecosystem productivity. A precautionary approach (PA) is a necessary, but not sufficient condition for MSY."* (ICES, 2013, p. 3).

Depending on the level of data on a certain stock, it is classified as a Category 1-6 stock, where Category 1 (stocks with quantitative assessments) is the highest with full analytical assessments, and Category 5 is stocks with only landings or short data series available and Category 6 is negligible landings and bycatches (ICES, 2019d). For stocks from categories 3, 4, 5 and 6, the ICES PA approach is always applied, while stocks from Category 1 and 2 can be set for either the MSY approach or PA approach depending on the stock, see Figure 9.

With this said, the ICES PA approach is not the same, but rather a specific practical adaptation of, the precautionary approach as a concept used in environmental management etc, i.e. the more general term. The two terms, *ICES PA Approach* and the *Precautionary Principle/Approach*, should not be confused since the former is part of the specific setting of ICES advice and stock assessment, while the latter is used in a more general and broad context of precaution per se.

Connected to that, in 2000 the European Commission adopted a Communication on the use of the precautionary principle, with the aim of informing all stakeholders how the Commission intends to apply the principle (European Commission, 2000). It is stated that the Precautionary Principle should not be confused with scientific data assessment: *"The precautionary principle, which is essentially used by decision-makers in the management of risk, should not be confused with the element of caution that scientists apply in their assessment of scientific data." (European Commission, 2000, page 3).*

ICES classification categories used for advice on fishing possibilities:

"Category 1 – Stocks with quantitative assessments. Includes stocks with full analytical assessments, and forecasts that are either age-/length-structured or production models."

"Category 2 – Stocks with analytical assessments and forecasts that are only treated qualitatively. Includes stocks with quantitative assessments and forecasts which, for a variety of reasons, are considered indicative of trends in fishing mortality, recruitment, and biomass."

"Category 3 – Stocks for which survey-based assessments or exploratory assessments indicate trends. Includes stocks for which survey, trends-based assessments, or other indices are available that provide reliable indications of trends in stock metrics, such as total mortality, recruitment, and biomass."

"Category 4 – Nephrops stocks where information on possible abundance can be inferred and stocks for which a reliable time-series of catch can be used to approximate MSY. This is where there are reasonable scientific grounds to use life-history information and density information from neighbouring areas to provide advice."

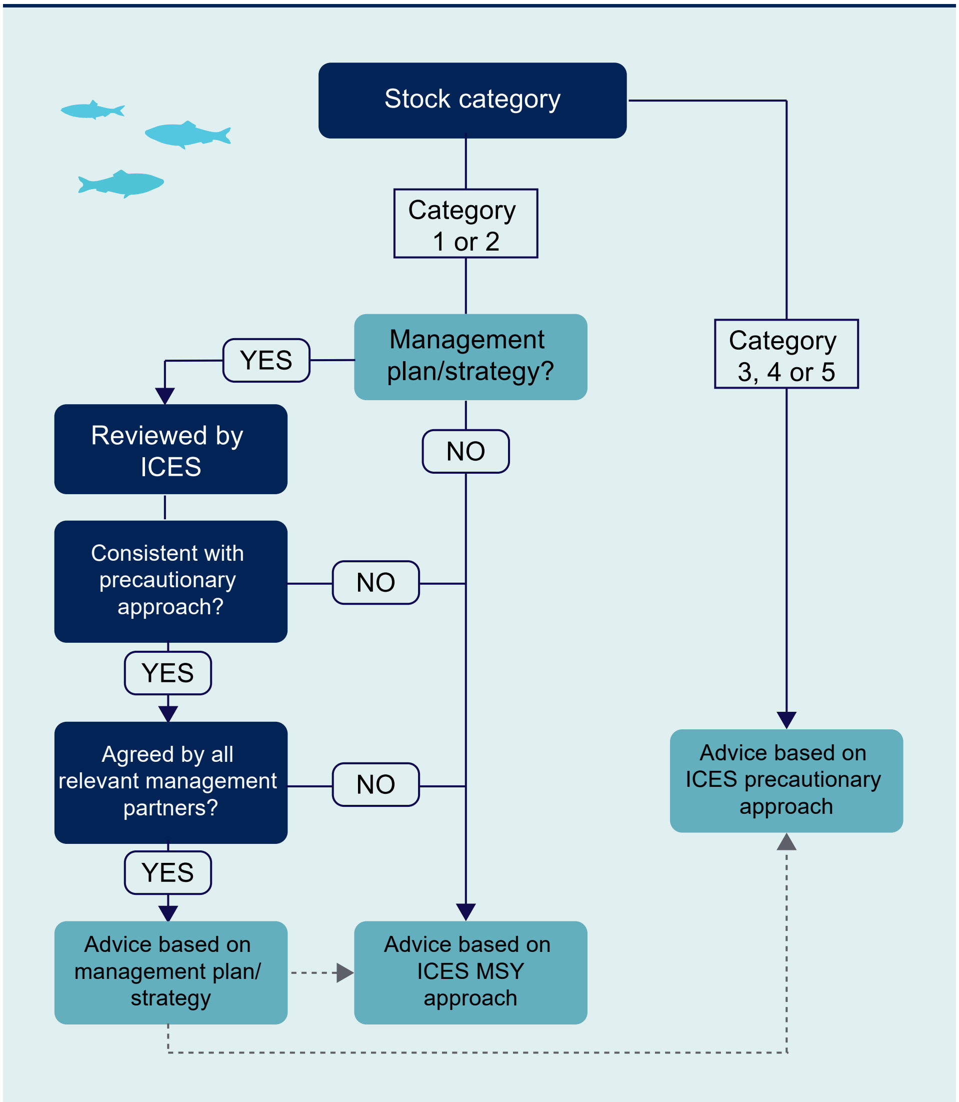
"Category 5 – Stocks for which only landings or a short series of catches are available."

"Category 6 – Negligible landings stocks and stocks caught in minor amounts as bycatch. Includes stocks where landings are negligible in comparison to discards, as well as stocks that are primarily caught as bycatch species in other targeted fisheries."

Source: ICES (2019d)

In essence, the Commission emphasised that the precautionary principle forms a structured way to address risk and risk management and that it is applicable where scientific evidence is insufficient, inconclusive or uncertain. The precautionary principle is described as a politically accepted risk management strategy in several fields when there are concerns for human, animal or plant health. It is stated that: *"The Communication makes it clear that the precautionary principle is neither a politicisation of science or the acceptance of zero-risk but that it provides a basis for action when science is unable to give a clear answer." (European Commission, 2000, page 2).*

Figure 9. ICES flow diagram showing the basis of ICES advice. Adapted from: ICES (2019d). General context of ICES advice

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Chapter 4
Conclusions and recommendations

It is clear that both environmental factors as well as fishing pressure are contributing simultaneously to the bad condition of the cod in the Baltic Sea - a process that has progressed for a long time. To pave the road to recovery of the Baltic cod several measures need to be addressed on different scales and levels. However, the actions require time and cooperation, where some issues are hard to address from the Baltic Sea region only, such as combating climate change.

Overall, the conclusions and recommendations of this report are all aligned with the principles of EBM and fall into the categories: i) environmental factors, ii) improved management, and iii) fishing regulations.

4.1. Recommendations

1 Management must align with the principles of ecosystem-based management

It is imperative - and a legal requirement - that the management decisions taken adhere to the holistic view of EBM. EBM is a key principle of the CFP and the Baltic MAP, as well as other EU environmental legislation. All our recommendations in this chapter address the implementation of EBM in one way or another. In the Baltic Sea Region it is clear that EBM exists more on paper than in practice.

The following measures for the implementation of EBM are stressed within research, and all are highly important in the context of the dire state of the Baltic Sea.

In order to implement EBM, research emphasises the following measures :

- Strengthened multi-species management, see also point 4 below.
- Actively taking other aspects of the ecosystem and its functions into consideration. This is also highlighted in the CFP.
- Apply the precautionary approach, i.e. where there is high uncertainty, fisheries management should be more precautionary.
- Apply a reversed burden of proof, i.e. a suggested action should only take place if proven not to harm the ecosystem.
- Avoid a too large outtake of biomass that threatens the productivity, resilience and integrity of the ecosystem.
- Flexibility in the management plans to adapt to the local context, i.e. what is necessary in one place is not necessarily as relevant in another.

(Pikitch et al., 2004, Trochta et al., 2018)

2 Management measures must be in line with EU environmental legislation and regional commitments

Several environmental factors contribute to the poor status of the Baltic Sea habitats. The degraded environmental condition affects fish as well as other species, and a healthy environment is imperative in order to fully restore fish stocks. However, this is not easy, and it is crucial to take a multi-faceted approach to restore environmental conditions. Implementation of existing legislation and commitments, such as attaining good environmental status (GES) as set out in the Marine Strategy Framework Directive (MSFD), as well as the recently updated HELCOM Baltic Sea Action Plan (BSAP), must be a higher priority.

Regulating fishing activities through the CFP will not be enough to restore cod populations; fish must be considered one biological component among others in an ecosystem and be managed as such. In the Baltic MAP, it is clearly stated that it must contribute to GES in Article 3(3): "*The plan shall implement the ecosystem-based approach to fisheries management in order to ensure that negative impacts of fishing activities on the marine ecosystem are minimised. It shall be coherent with Union environmental legislation, in particular with the objective of achieving good environmental status by 2020 as set out in Article 1(1) of Directive 2008/56/EC.*" In management terms this could be expressed as more precautionary fishing opportunities for certain fish species/populations of high value to environment and ecosystem functions. Furthermore, proper implementation of Article 17 of the CFP[9] would allow for a strengthening between CFP and MSFD, and also for support of low impact, small-scale fisheries.

Recommended actions:

- Strengthen the coherence between the CFP and environmental legislation in management and implementation; targets in the CFP and fisheries management should be considered together with other legal obligations such as GES. This is already a legal requirement in the MAP.
- Apply a precautionary buffer to MSY advice when setting fishing opportunities, i.e. leave room for multi-species interactions and for predator-prey interactions and other ecosystem processes to function.
- Proper implementation of Article 17 of the CFP, which promotes low-impact fishing methods, including ones that also reduce wider environmental impacts such as carbon dioxide emissions.

9 Article 17 Criteria for the allocation of fishing opportunities by Member States . When allocating the fishing opportunities available to them, as referred to in Article 16, Member States shall use transparent and objective criteria including those of an environmental, social and economic nature. The criteria to be used may include, inter alia, the impact of fishing on the environment, the history of compliance, the contribution to the local economy and historic catch levels. Within the fishing opportunities allocated to them, Member States shall endeavour to provide incentives to fishing vessels deploying selective fishing gear or using fishing techniques with reduced environmental impact, such as reduced energy consumption or habitat damage.

3 The need to urgently address hypoxia, eutrophication and climate change

Baltic cod needs clean and well oxygenated sea water, and therefore reduced eutrophication in order to survive. A major difficulty for several species in the Baltic Sea, including cod, is hypoxia: areas close to the bottom with low levels of oxygen or no oxygen at all. Oxygen-depleted areas affect both cod spawning and habitats for juveniles, as well as having a negative effect on benthic fauna that are a part of the cod diet (Carstensen et al., 2014; Casini et al., 2016; Conley et al., 2009). Furthermore, low oxygen is linked to poor growth and condition of cod, especially when combined with low sprat availability (Casini et al., 2016; Limburg & Casini, 2018; Limburg & Casini, 2019; Neuenfeldt et al., 2020). (See also recommendation on cod-sprat-herring management).

Hypoxia is caused by eutrophication, and therefore the reduction of nutrients entering the water is important and must be an ongoing process (Andersen et al., 2017; HELCOM, 2018). Both hypoxia and eutrophication have been a problem in the Baltic Sea Region for decades and institutional arrangements have been developed through the work of HELCOM and also the EU. Efforts must continue over a long period of time and be continuously prioritised. To reduce eutrophication, the recommendations of the current HELCOM BSAP should be implemented; according to recent modelling, a decrease in nutrient load should take place/result if the BSAP is followed (Murray et al., 2019).

Climate change and the subsequent increase in carbon dioxide uptake in water leads to decreases in pH levels, which contributes to acidification. Acidification is harmful to aquatic systems and is believed to harm cod larvae (Stiasny et al., 2016), and higher temperatures in the water is also expected to have a negative impact on cod. The Baltic Sea countries cannot avert climate change alone: this is a global undertaking. However, taking action at the national level as well as engaging in global commitments to reduce climate change, will benefit the Baltic Sea environment, including Baltic cod.

Recommended actions:

- All managers work actively to implement the 2021 HELCOM Baltic Sea Action Plan.
- All MS must continue and strengthen their national and regional efforts to reduce eutrophication and hypoxia.
- Step up the work to combat climate change, at all possible levels.
- Reduce the area of seabed subjected to bottom trawling in order to minimise the leakage of nutrients stirred up from sediments and maximise the binding of CO_2 in the sediments.

4 Proper multispecies management

While implementing an ecosystem-based approach to fisheries management, i.e. to take the interactions between species and the ecosystem functions into account, cod, herring and sprat interactions are particularly important to consider when setting fishing opportunities. This is the rationale behind the Baltic MAP, and those interactions are thoroughly supported in the research literature. As discussed in Section 3, low oxygen levels (hypoxia) are bad for cod. Hypoxia reduces benthic food availability, leading to decreased growth of young fish, especially if the availability of sprat is low (Casini et al., 2016; Neuenfeldt et al., 2020). Lower abundance of food also has a documented effect on reproduction (Mion et al., 2018). Larger cod prey on both herring and sprat, but in recent years the spatial distribution of sprat has shifted towards the north while the cod to a large extent has remained in the more saline south. This has resulted in a reduced spatial overlap and a reduced food availability for larger cod (Casini et al., 2011; Casini et al., 2016). Sprat fisheries in the overlapping areas (mainly SD 25-26) are likely to further reduce food availability for cod (Casini et al., 2016). Reduced fishing of sprat and herring in certain areas has been recommended by scientists as a means to aid cod recovery, particularly in the SD 25-26 areas populated by higher densities of cod and, again, food limitations partially caused by the changed spatial distribution of sprat (Casini et al., 2016; Eero et al., 2012b; ICES, 2020b; Neuenfeldt et al., 2020). However, the reasons for the starving cod with stunted growth are not fully understood, and several factors probably contribute. A recent study supports the idea of low food quality rather than low food abundance (Svedäng et al., 2020). In addition, similar diets between cod and flatfish could affect food availability; another recent study showed increased food competition between cod and flounder during the last decade (Orio et al., 2020). The causes of the low growth rates of cod should be further investigated.

Recommended actions:

- Apply a precautionary approach when setting the fishing opportunities for sprat, particularly in SD 25-26, considering the importance of sprat as prey for cod, the changes in spatial distribution of sprat and unusually high abundance of cod.
- The assignment to ICES should change and broaden to produce proper multi-species stock assessments, instead of the single species assessments carried out today.
- When setting fishing opportunities, apply a precautionary buffer to the MSY advice, i.e. leave room for multi-species interactions, including predator-prey interactions and other ecosystem processes (same as Recommendation 2 above).

5 Do not set TACs higher than scientific advice – apply the precautionary approach

Baltic cod, both the eastern and western stocks, has been systematically overfished for decades, according to historical catch data from ICES (ICES 2021a, ICES 2021d). In the majority of cases, political negotiations have resulted in a TAC exceeding the scientific advice from ICES: in essence, politically sanctioned overfishing, in stark contrast to the goals of the CFP.

Furthermore, the scientific predictions of the SSB have in many cases been proven to be too optimistic, i.e. the expected increase of cod has not occurred (ICES 2021d). In the light of this, it is apparent that there needs to be more precaution in both the scientific advice and in the political TAC negotiations. There is also a clear distinction between the ICES definition of "precautionary approach" in its PA advice, as part of the modelling for stock assessment (ICES, 2019d), and the Precautionary Principle/Approach used in environmental management and other settings. It is a very old principle in environmental policy (Peel, 2005) now widespread in numerous international treaties and similar, including the Treaty on European Union, where the Precautionary Principle is established as the basis for European environmental law (Foster et al., 2000).

It is clear that, although the ICES scientific advice applies a precautionary approach in stock assessment, it is not good enough, since it has resulted in such a rapid decline in the SSB in both cod stocks, further exacerbated by the almost constant overfishing politically sanctioned in the TAC negotiations.

Recommended actions:

- The Commission must change the assignment to ICES to add more precaution in the stock assessment, addressing ecosystem functions and predator-prey interactions.
- Managers and politicians must acknowledge the difference between the ICES precautionary approach and the Precautionary Approach/Principle as is widely used within environmental management.
- It's the responsibility of all MS to adhere to the objectives of the CFP and in environmental legislation and ensure that negotiations do not result in TACs above the scientific advice.

6 Effective fisheries control measures including Remote Electronic Monitoring (REM), restrictions on bottom trawling and restoration of natural demersal habitats

Although the EU amended the Technical Measures Regulation (Regulation (EU) 2019/1241) to include more result-based approaches, for example to reduce unwanted catches and optimise exploitation patterns, there are still not enough efforts to monitor selectivity. The new regulation lacks efficient tools for MS to properly address environmental and sustainable fisheries management objectives such as the protection of sensitive species (European Commission, 2019). Furthermore, the Landing Obligation which was fully implemented in 2019, made it illegal to discard fish but has not put an end to the practice (ICES, 2020a;Valentinsson et al., 2019). In order to avoid bycatch and thus discards, different selective gear has been in use for 25 years, however discard rates have been high despite the use of selective gear (Feekings et al., 2013; Madsen, 2007; Madsen et al., 2021; Valentinsson et al., 2019). As of now, there is insufficient compliance with the regulations already in place. More efficient enforcement is needed (Condie et al., 2014; Valentinsson et al., 2019). EM or REM has been tested worldwide and is shown to be a cost effective solution to monitor catches and address difficulties experienced with observers reports (Bartholomew et al., 2018; Evans & Molony, 2011; Ruiz et al., 2015) as well as safety reasons for the on board observers (Ewell et al., 2020; Michelin et al., 2018).

In the Öresund, there are many large cod individuals and no trend towards small-sized fish (Svedäng & Hornborg, 2017). This is believed to be a result of a trawling ban agreed as long ago as the 1930s to facilitate shipping (Anonymous, 1932). Instead of trawls, gillnets are used (Svedäng & Hornborg, 2017). Bottom trawling is less selective and also contributes to eutrophication (Ferguson et al., 2020), disturbs the carbon cycle (Cavan and Hill, 2020), adds to ocean acidification by releasing more CO_2 (Sala et al., 2021) and destroys cod nursery habitats (Bryhn et al., 2020). In addition, the restoration of stone reefs and natural caves has been proven to facilitate cod recovery (Støttrup et al., 2014). Hence, there are several strong arguments for the restriction of bottom trawling in the Baltic Sea, to aid cod recovery in several different ways.

A shift towards low impact fishing is also supported in Article 17 of the CFP, as has been discussed previously. Legal support for this measure is thus already in place.

Recommended actions:

- Restrict all bottom trawling in the Baltic Sea, since the practice adds to eutrophication, releases carbon dioxide and destroys cod habitats.
- Actively work to restore seabed habitats and natural caves/reefs.
- Promote small-scale, low impact fishing, as stipulated in Article 17 of the CFP.
- Install REM in ALL vessels larger than 12 metres in the whole of the Baltic Sea.

7 Reserve fishing opportunities for fisheries with the lowest bycatch of cod

There is selective gear on trial, and some in use, to increase the selectivity of different fisheries. To reward fishers who use more selective gear, exclusive access to fishing areas or times have been suggested (Condie et al., 2014; Valentinsson et al., 2019). Trust building and cooperation with local fishermen are imperative for the success of the development and implementation of such gear (Bastardie et al., 2021). Furthermore, the inclusion of local knowledge in both research and policy-making is good for compliance (Figus & Carothers, 2017). The introduction of such gear should be carefully planned and gradually introduced for high compliance (Suuronen et al., 2007).

In relation to implementing more selective gear and creating incentives for doing so, it is imperative that fleet capacity is balanced with fishing opportunities. MS are obliged to identify overcapacity under Article 22 of the CFP (Regulation 1380/2013; Berkow, 2018), and to submit a report to the Commission, as well as create and follow an action plan on capacity reduction, if deemed necessary. Furthermore, the allocation of fishing opportunities must prioritise/favour the least harmful fisheries and also take environmental and social aspects into consideration, as is required or encouraged through Article 17 of the CFP.

Recommended actions:

- Encourage stakeholder engagement, as is required by EBM, through cooperation with fishermen and make use of local knowledge.
- For fisheries where cod is a bycatch species, use the most selective gear and make them mandatory in the whole of the Baltic Sea as a matter of urgency.
- Continue to work with fleet reduction, i.e. counteract overcapacity by ensuring that MS report properly to the Commission and promptly follow the required action plan, if a need for fleet reduction is identified (in accordance with Article 22).

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4.2. Concluding remarks

A mix of environmental improvement needs to be achieved, as well as a continuation of fishing restrictions, as are already in place. A holistic approach is necessary which emphasises EBM – an approach which is already mandatory through the CFP. Baltic cod needs improved living conditions. A healthy environment is essential and measures not only related to fishing must be addressed as well, such as eutrophication and other factors impacting the environment. Climate change is a global issue and cannot be solved in the Baltic countries alone, however the EU MS can work to follow the Paris agreement in a global context. Regarding fishing, the Baltic MAP must be followed and TACs should not exceed scientific advice, Article 17 of the CFP needs to be properly implemented, and increased monitoring and other measures to counteract IUU and illegal discarding are required. In addition, since Baltic cod fishery is a cultural heritage as well as an environmental factor, the dialogue with fisheries and environmental groups needs to be enhanced and the 'silo thinking' in several sectors needs to be overcome.

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Appendix

Full tables Eastern Baltic cod (EBC) TAC and ICES advice

Appendix Table 1. History of the advice, catch and manangement. From ICES 2021a.

Cod in subdivisions 25–32, eastern Baltic stock. ICES advice and official landings. All weights are in tonnes.

Year	ICES Advice	Catches corresp. to advice	Landings corresp. to advice	Agreed TAC	ICES landings (SDs 25–32)	ICES EBC stock catches (SDs 24 and 25–32)
1987	Reduce towards Fmax		245 000		207 000	223 295
1988	TAC		150 000		194 000	210 527
1989	TAC		179 000	220 000*	179 000	188 361
1990	TAC		129 000	210 000*	153 000	163 276
1991	TAC		122 000	171 000*	123 000	129 020
1992	Lowest possible level		-	100 000*	55 000**	59 110
1993	No fishing		0	40 000*	45 000**	56 154
1994	TAC		25 000	60 000*	100 856**	109 984
1995	30% reduction in fishing effort from 1994 level		-	120 000*	107 718**	115 843
1996	30% reduction in fishing effort from 1994 level		-	165 000*	124 189	136 788
1997	20% reduction in fishing mortality from 1995 level		130 000	180 000*	88 600	99 251
1998	40% reduction in fishing mortality from 1996 level		60 000	136 950*	67 428	74 940
1999	Proposed Fpa (= 0.6)		88 000	126 000*	72 995	81 653
2000	40% reduction in F from 1996–1998 level		60 000	105 000*	89 289**	102 833
2001	Fishing mortality of 0.30		39 000	105 000*	91 328**	102 402
2002	No fishing		0	76 000*	67 740**	74 824
2003	70% reduction in F		See option table	75 000	69 476**	78 093
2004	90% reduction in F		< 13000	45 400	68 578**	75 276
2005	No fishing		0	42 800	55 032**	64 495
2006	Develop management plan		< 14900	49 200	65 532**	77 086

Year	ICES Advice	Catches corresp. to advice	Landings corresp. to advice	TAC Agreed	ICES landings (SDs 25–32)	ICES EBC stock catches (SDs 24 and 25–32)
2007	No fishing		0	44 300	50 843**	64 656
2008	No fishing		0	42 300***	42 235**	55 578
2009	Limit (total) landings to 48 600 tonnes		≤ 48 600	49 380***	48 439**	60 513
2010	Follow management plan		56 800	56 100***	50 277	60 400
2011	See scenarios		-	64 500***	50 368	62 245
2012	Follow management plan		74 200	74 200***	51 225	67 024
2013	Follow management plan		65 900	68 700***	31 355	42 977
2014	Follow management plan		70 301	73 400***	28 909	45 289
2015	20% reduction in catches	29 085		55 800***	38 079	50 008
2016	Precautionary approach^	≤ 29 220		46 900***	29 313	37 438
2017	Precautionary approach^	≤ 26 994		36 957***	25 496	30 965
2018	Precautionary approach^	≤ 26 071		34 288***	15 907	21 605
2019	Precautionary approach^	≤ 16 685		29 912***	8 383	11 938
2020	Precautionary approach^	0		7 500***	2 319	2 899
2021	Precautionary approach^	0		3 595***		
2022	Precautionary approach^	0				

* For the total Baltic Sea until and including 2003.
** Reported landings in 1992–1995 and 2000–2009 are likely to be minimum estimates due to incomplete reporting.
*** TAC is for SDs 25–32 and is calculated as EU + Russian autonomous quotas.
^ ICES stock-based advice (for the eastern Baltic cod stock).

Full tables Western Baltic cod (WBC) TAC and ICES advice

Appendix Table 2. History of the advice, catch and manangement. From ICES 2021d.

Cod in subdivisions 25–32, eastern Baltic stock. ICES advice and official landings. All weights are in tonnes.

Year	ICES advice	Total catch from the stock corresp. to the advice	Commercial catch corresp. to advice*	Agreed TAC**	ICES estimated total commercial landings subdivisions 22–24 (eastern and western Baltic cod stocks)
1987	TAC		9 000		28 566
1988	TAC		16 000		29 159
1989	TAC		14 000	220 000	18 516
1990	TAC		8 000	210 000	17 780
1991	TAC		11 000	171 000	16 693
1992	Substantial reduction in F		-	100 000	17 996
1993	F at lowest possible level		-	40 000	21 228
1994	TAC		22 000	60 000	30 695
1995	30% reduction in fishing effort from 1994 level		-	120 000	33 895
1996	30% reduction in fishing effort from 1994 level		-	165 000	50 845
1997	Fishing effort should not be allowed to increase above the level of recent years		-	180 000	43 624
1998	20% reduction in F from 1996		35 000	136 950	34 216
1999	At or below Fsq with 50% probability		38 000	126 000	42 155
2000	Reduce F by 20%		44 600	105 000	38 347
2001	Reduce F by 20%		48 600	105 000	34 244
2002	Reduce F to below 1.0		36 300	76 000	24 158
2003	Reduce F to below 1.0		***22600 or 28800	75 000	24 624
2004	Reduce F to below 1.0		< 29600	29 600	20 854
2005	Reduce F to below 0.92		< 23400	24 700	22 045
2006	Management plan		< 28400	28 400	22 751

Year	ICES advice	from the stock corresp. to the advice	Commercial catch corresp. to advice*	Agreed TAC**	commercial landings subdivisions 22–24 (eastern and western Baltic cod stocks)
2007	Keep SSB at Bpa		< 20 500	26 700	23 736
2008	Rebuild SSB to Bpa		< 13 500	19 200	20 082
2009	Rebuild SSB to Bpa		< 13 700	16300	15 549
2010	Management plan		< 17 700	17 700	14 120
2011	See scenarios		-	18 800	16 332
2012	Management plan		21 300	21 300	17 072
2013	Management plan		20 800	20 000	12 968
2014	Management plan		17 037	17 000	13 538
2015	MSY approach		8 793	15 900	13 418
2016	MSY approach (F = 0.23)	≤ 7 797		12 720	10 629
2017	MSY approach (F = 0.15)	≤ 3 475	≤ 917	5 597	5 865^
2018	MAP F ranges: Flower to FMSY adjusted by SSB2018/MSY Btrigger (F = 0.11–0.188)	3 130–5 295	1 376–3 541	5 597	5 850^
2019	MAP range: FMSY Flower to Fupper (F = 0.15–0.45)	9 094–23 992	5 867–22 238	9 515	7 701^
2020	MAP range: FMSY Flower to Fupper (F = 0.18–0.43)	5 205–11 006	3 065–8 866	3 806	3 329^
2021	Management plan	5 950 (range 4 275–9 039)	4 635 (range 2 960–7 724)	4 000	
2022	MSY approach	≤ 698			

* Values since 2016 are for the western Baltic cod stock only, whereas in earlier years they are for the area of subdivisions 22–24 and include a fraction of the eastern Baltic cod stock.
** Included in TAC for total Baltic, until and including 2003.
*** Two options based on implementation of the adopted mesh regulation.
^ Including BMS.

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