



SDG 14: Life Below Water: an example of overfishing and Baltic Cod (*Gadus morhua*)

Foreword

The Baltic Sea is a unique, isolated, and shallow sea basin, situated on the continental shelf and surrounded by the terrestrial areas of Central, Eastern, and Northern Europe. The limited access to the world's oceans (only through the narrow Danish Straits), the freshwater runoff from rivers and their catchment areas, and the infrequent infusions of dense, oxygenated and salt-rich marine waters from the North Sea mainly during unique meteorological conditions – sustained winds that blow first from the east then from the west – result in its variable salinity both vertically and horizontally (it is higher in the western region and in the depths, lower in its eastern part and in surface waters that are separated from deeper waters by the halocline) (Lehmann et al. 2022; Valentinsson et al. 2019). This sea has a general brackish character, with an average surface salinity level of about 7 PSU ('Practical Salinity Unit'; 7 grams per kg of water, in older data corresponding to 7‰), while common marine (ocean) waters contain about 35 PSU of salt (e.g. Itämeri.fi 2025a). Such living conditions give rise to the unique Baltic Sea fauna, which must survive in (and adapt to) the neither marine nor freshwater environment that in reality contains both freshwater and marine organisms (e.g. Itämeri.fi 2025b; NaturalnieBałtyckie.pl 2025). The picture of the Baltic Sea environment is completed by Orío, Heimbrand & Limburg (2022), who summarised that the limited exchange of the waters, eutrophication, and climate change (with a mean annual surface water temperature increase of about 1°C per decade during 1990–2008) lead to oxygen depletion, especially in its depths, what is an essential habitat in the life history of organisms, including fish such as cod. Finally, the Baltic Sea catchment area is home to about 85 million people (about 15 million live within 10 km of the seaside), making it a traditional and important food source and leading to close interactions between human needs and the local wildlife.

Background

The Atlantic cod, *Gadus morhua*, is a marine predatory fish (Phylum: Chordata; Class: Actinopterygii; Order: Gadiformes) native to the North Atlantic region (Davie 2005). According to summaries by HELCOM (2013) and Wilmot (2005), these fish can reach 1.5–2



m in length and have an average mass of 40 kg (in the Atlantic). They can live up to 20 (30) years; reproduction is possible after sexual maturity at 2–7 years (mean, depending on sex and population). The diet depends on the size of the fish – starting from plankton in newly hatched larvae, through benthic invertebrates and other fish as the cod grows and becomes more coastal. Juveniles live closer to the coasts, and adults hunt for other fish (including their own species) in open waters; the cod has an essential ecological role as a top predator.

The cod is listed as ‘Vulnerable’ both on the HELCOM Red List for the Baltic Sea and Kattegat, and the IUCN Red List of Threatened Species (HELCOM 2013; Sobel 1996). The Baltic populations of cod (sometimes distinguished as the *G. morhua callarias* subspecies) occur throughout the Baltic Sea, including the Kattegat. There are two, genetically distinct populations (stocks) of cod in the Baltic: the western population and the eastern population (Birgersson, Söderström & Belhaj 2022; Han et al. 2025; Hinrichsen et al. 2016; Schade et al. 2022; Valentinsson et al. 2019). The Baltic subspecies grows smaller than the Atlantic cod. Baltic cod are adapted to brackish waters. Still, their reproduction requires oxygenated habitats with salinities higher than the Baltic surface average (thus, reproduction is restricted to the western areas of the Sea and to the deeper waters; HELCOM 2013; ICES 2024). Baltic cod attempts to spawn during the spring-summer months (depending on population and region), producing planktonic eggs that hatch after about a dozen days (FAO 2025; Hüsey, Hinrichsen & Huwer 2012; ICES 2019; ICES 2024; Karasiova, Voss & Eero 2008; Tomkiewicz & Köster 1999). Cod needs saline, oxygenated waters to ensure egg floating, survival, and development – eggs and larvae die when they sink to the bottom. For example, eggs of the western population of Baltic cod float in at least 19 PSU and survive in temperatures of 5–8°C with the oxygen level estimated to be at least 2 mg/l (discussed by Hüsey, Hinrichsen & Huwer 2012). Eastern Baltic cod eggs are adapted to float in about 12–14 PSU (Hinrichsen et al. 2016; ICES 2019). However, early life stages were also discovered to be advectively transported with the water, thus transportation toward less saline waters may cause sinking and death (Hinrichsen, Hüsey & Huwer 2012). The typical depth of occurrence of adult (eastern) Baltic cod is about 40–70 m – they chose more saline bottoms (the halocline appears there, separating surface waters with low salinity from saline deeper waters; Schade et al. 2022; Vallin & Nissling 2000). Still, during reproduction, fish migrate even deeper – to cold, saline waters like Bornholm Deep, Gdańsk Deep, or Gotland Basin (where they select a water layer that is sufficiently saline, but not anoxic - which is a common condition in Baltic depths) (Karasiova, Voss & Eero 2008; Tomkiewicz & Köster 1999; Vallin & Nissling 2000). Hinrichsen et al. (2016), ICES (2024) and Schmidt, Garate-Olaizola & Laurila (2024) explained that the highest relative survival rate of eastern



Baltic cod was noted in Bornholm Basin. At the same time, the observed decrease in survival toward Gdańsk Deep and the Gotland Basin was likely caused by oxygen depletion. Therefore, cod reproduction also relies on inflow events of oxygen-rich saline marine water from the North Sea, which refreshes the deep waters of those depths, and ensure the proper habitat conditions for egg and juvenile development (Orio, Heimbrand & Limburg 2022; Schmidt, Garate-Olaizola & Laurila 2024). Additionally, the eggs from older females (older than 5 years, thus larger) survived better than those from younger females (Vallin & Nissling 2000). This leads to a different survival context: cod is a vital cultural and commercially exploited resource in the Baltic Sea region, with catches in the second part of the 20th century remaining at least above 100,000 tonnes annually (with a peak of 400,000 tonnes in the 80s, when favourable reproduction conditions appeared), then, in the 21st century, a sudden decline was noted, with catches totalling only up to about 20,000 tonnes (Eero et al. 2023; ICES 2024; Möllmann 2025b; Möllmann et al. 2021). The fishing industry is an important ecological and evolutionary factor, e.g., by selecting for older/larger individuals caught in nets. In 2017–2018, the biomass of mature, spawning (and commercial size) cod and recruitment of juveniles were the lowest observed (ICES 2020). Finally, Han et al. (2025) have recently demonstrated that eastern Baltic cod underwent evolutionary ‘shrinkage’ due to size-selective overfishing over just the past 25 years (1996–2019), with a decrease in the mean size of mature (reproducing) individuals from about 40 cm to 20 cm.

Implementation

‘Undoubtedly, most of the Baltic fish stocks are critically endangered in a low productivity state and a fast recovery even under a fishing ban is unlikely’ (Möllmann 2025b).

A successful program would establish a self-sustaining population in which the fish will reproduce naturally in the wild: produce eggs that float in water with sufficient salt and oxygen, hatch juveniles, and grow into adults. During this process, they will feed on organisms available in the environment and, after reaching maturity, reproduce in healthy habitats. To stop and reverse the observed critical decline in cod populations in the Baltic Sea, different actions may be proposed:

- legal regulations (limits) for the fishing industry – to reduce top-down pressure from humans (fishing industry) so that the existing population can reproduce and grow in numbers, because mature individuals will not be caught by fishing nets,



- artificial hatching and release methods – to supply existing natural populations with individuals hatched in breeding facilities, which may ensure higher survival levels of early stages,
- improving the quality of the natural spawning habitats and of the Baltic ecosystem – habitat restoration to improve the oxygenation of the deep waters of Bornholm and Gdańsk Deeps, and Gotland Basin used by cod for reproduction, so eggs and juveniles may survive better in nature. Reconstruct a healthy ecosystem, for example, to ensure the food for every life stage of cod to improve their survival and health.

Legal regulations: because of the observed decrease in length (size) and biomass of the harvested cod (eastern population), and regarding the Baltic Sea multiannual management plan (MAP) for cod by the European Parliament and the Council of the European Union, (2016), the International Council for the Exploration of the Sea (ICES) recommended in 2017 that ‘catches in 2018 for the eastern Baltic cod stock should be no more than 26,071 tonnes’ (ICES 2017). However, as early as in 2019, ICES advised a zero catch limit for direct eastern cod fishing, followed by a ban for the western population (BalticWaters 2025; ICES 2019). Because population recovery is poor, the advice remains in place for 2026 (BSAC 2025; European Commission 2025; ICES 2025). Small bycatch (non-intentional catch of other species while fishing) was allowed, as it occurs while fishing for flatfish (FishSec 2025; ICES 2025; Möllmann 2025b). Nevertheless, because the fishing industry is both traditional and a commercial sector of Baltic countries, the European Commission supports the application of selective fishing methods, including trawl selective fishery (to avoid catching cod) (ICES 2020; ICES 2023; ICES 2025). Finally, Möllmann (2025a; 2025b) summarises that the objectives of restoring the cod population above the minimum biomass, ensuring reproduction to replenish the stock assumed by MAP, were largely not obtained. Overfishing in previous years led to critically low biomass, which today results in low reproductive capacity and makes recovery difficult and unlikely in the short term, even with no fishing (ICES 2025; Möllmann 2025b). The ICES also advises that eastern Baltic cod conservation activities cannot be considered without the broader context of the ecosystems affected (degraded) by human activity and related climate change (ICES 2025).

Artificial hatching: Schmidt, Garate-Olaizola & Laurila (2024) summarised that decades of overfishing, eutrophication, and unfavourable environmental conditions in spawning areas (low oxygen levels, low salinity) led to poor recruitment of this fish. Thus, following the previous attempts (e.g. Støttrup, Overton & Sørensen 2008), they propose the hatch-release



method, with juveniles acclimated to Baltic Sea salinity, to support the natural population. Forty parental eastern Baltic cod (2/5 of which were females), collected from nature in February 2021, were settled in the artificial tank at the research station in Gotland, Sweden. After spawning, the released eggs were collected and placed in small batches to observe their development. The attempt aimed to acclimate larvae to low salinity of 7 PSU (from the 17 PSU in the fertilisation water) to enhance the survival of released juveniles in nature and minimise the mortality from low-oxygen conditions. Thus, eggs or hatched larvae were exposed to 10 acclimation time-schedules. Their study showed that reducing the salinity before hatching the larvae resulted in high larval mortality, whereas reducing the salinity a few days after hatching had little effect on larval neutral buoyancy and supported their future survival. The latter procedure was proposed for consideration in future attempts to hatch and release Baltic cod larvae.

Quality of spawning habitats and of the ecosystem: The environmental degradation in the Baltic (e.g. eutrophication, despite the attempts to reduce this), expanding anoxic underwater deserts, climate change, and other changes in the environment (including changes in fauna) are affecting the biological lifecycle of cod. The Baltic Sea is infamous for the development of anoxic environments in deep waters – the deoxygenation, correlated with eutrophication, impacts the survival of cod eggs and larvae, and may have an impact on the metabolism of adult fish as well as on the availability of prey at different life stages of this predator (Hansson & Gustafsson 2011; ICES 2025; Orio, Heimbrand & Limburg 2022). The herring and sprat – regarded as important members of cod’s food base – were identified to be recently more abundant in the northern parts of the Sea, thus they are less overlapping with the range of cod (Funk et al. 2021; ICES 2025), which is leading to a change in diet and may affect the condition of the cod. Environmental changes may lead to a temporal overlap between cod planktonic larvae and potential predators. Finally, growth in the grey seal population (a conservation success) unexpectedly led to an increase in parasitic infestations of cod, harming their health. This seal is the end host of the liver worm *Contracaecum osculatum*, and cod are an intermediate host. It is unknown if Baltic cod’s current poor condition is partially a consequence of infestations, or if the infestations were possible because of the initial poor condition (Behrens et al. 2023; ICES 2025).

Outcomes

The current situation for the eastern Baltic cod population is difficult, despite the fishery being closed since 2019. The fish have high natural mortality and are in poor biological



condition. The stock biomass is assessed as remaining below the lowest level of spawning stock biomass (a value that ensures the population sustains effective reproduction), making recovery difficult and unlikely in the short term (ICES 2025). The anthropogenic pressure, low ecosystem quality (including in spawning habitats), rare inflows of water from the North Sea, shuffled biotic interactions, and climate change cumulatively impact the cod population (e.g. ICES 2025; Möllmann 2025a). However, identifying and understanding the risks is essential and opens the possibility of planning conservation pathways and actions for the future.

Questions

- 1) What are the unique natural conditions of the Baltic Sea that shape the environment for organisms? Consider the limited connection to the world ocean (with possibilities of exchange), depth, vertical stratification of water, salinity, and oxygen.
- 2) Why does the eastern population of cod choose the Bornholm Deep for reproduction? Consider the survival needs of the egg and larva vs. the environmental conditions.
- 3) Cod was an important part of the Baltic Sea fisheries. Why has direct catchment been banned in the European Union since 2019? Briefly reflect on the history of overfishing and the results for the biomass of the current stock.
- 4) How can artificial hatching support natural populations? Consider protecting vulnerable life stages in the hatchery and releasing them after they have acclimated to conditions in the natural environment.
- 5) How do different abiotic, biotic, climatic, and anthropogenic factors influence the cod population? Reflect on the cumulative effect of factors like low salinity, low oxygen, eutrophication, climate change, and switches in biotic interactions that make the recovery of cod difficult, despite the fishing ban.

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