



Natural resources and bioeconomy studies 111/2024

Report on scientific cod fishing and monitoring in 2023 in Åland, Finland

Jari Raitaniemi and Ari Leskelä



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Referencing instructions:

Raitaniemi, J. & Leskelä, A. 2024. Report on scientific cod fishing and monitoring in 2023 in Åland, Finland. Natural Resources and Bioeconomy Studies 111/2024. Natural Resources Institute Finland. Helsinki. 20 p.

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ISBN 978-952-419-006-0 (Online)

ISSN 2342-7639 (Online)

URN <http://urn.fi/URN:ISBN:978-952-419-006-0>

Copyright: Natural Resources Institute Finland (Luke)

Authors: Jari Raitaniemi and Ari Leskelä

Publisher: Natural Resources Institute Finland (Luke), Helsinki 2025

Year of publication: 2025

Cover picture: Jari Raitaniemi 2024

Abstract

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At present, Eastern Baltic cod (*Gadus morhua*) in the southern Baltic Sea grows slowly, shows low condition factor and is heavily infected by the larvae of liver worm (*Contracaecum osculatum*). It has been hypothesized that either the heavy infection by liver worms, lack of suitable food due to lack of oxygen in the deep bottoms of the Baltic Sea or both together cause severe problems for the cod. The final host of the liver worm is grey seal (*Halichoerus grypus*), and the worm is carried to cod via prey, smaller fish. There is a small-scale cod fishery in the Finnish waters in the Sea of Åland, where cod are large sized and in good condition. Grey seals are abundant in these waters.

In this study, the occurrence of *Contracaecum* larvae in the livers of cod especially in the Sea of Åland and the prey of the cod in the year 2023 were examined and presented together with the results from the years 2020, 2021, and 2022. The size of measured cod in 2023 varied from 30 to 118 cm (total length). Similarly, as in 2020–2022, the number of *Contracaecum osculatum* larvae on liver surface correlated with cod length. The Fulton's condition factor of the cod in all years was high (1.01–1.13 in Åland). More importantly and similarly as in the previous years, the condition of the cod was not found to be in a statistically significant relation to the number of *Contracaecum* larvae on the liver surface nor the number of larvae per liver weight. The most common food items were *Saduria* and clupeid fish. The samples from all three years support the conclusion that when there is enough food for the cod, the effects of *Contracaecum osculatum* infection on the condition and growth of cod are small or even insignificant.

Keywords: *Gadus morhua*, Cod, *Contracaecum osculatum*, the Sea of Åland, Hangö, liver worm, the Baltic Sea

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1. Introduction

Major declines of the eastern Baltic cod (*Gadus morhua*) (hereafter referred to as Baltic cod) stock have been reported (Vallin et al. 1999, Cardinale & Arrhenius 2000, Hjerne & Hansson 2001, Köster et al. 2001), and EU commission allowed no direct fisheries on the stock in 2020–2024. However, in recent years and after a long break, it has been possible to catch cod in the waters especially south and west of Åland and southwestern coast of Finland (Figures 1 and 2). The cod in these waters have been reported to be in good physical condition in contrast to the cod in the southern Baltic Sea.

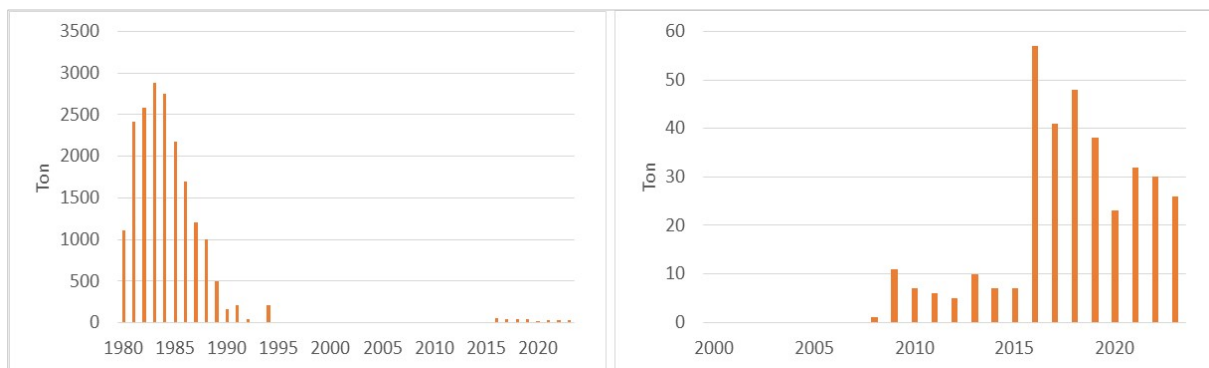


Figure 1. The landings of cod by Finland in ICES subdivision 29 (SD 29) in 1980–2023 (left) and in different scale in 2000–2023 (right) (Finnish fisheries statistics).

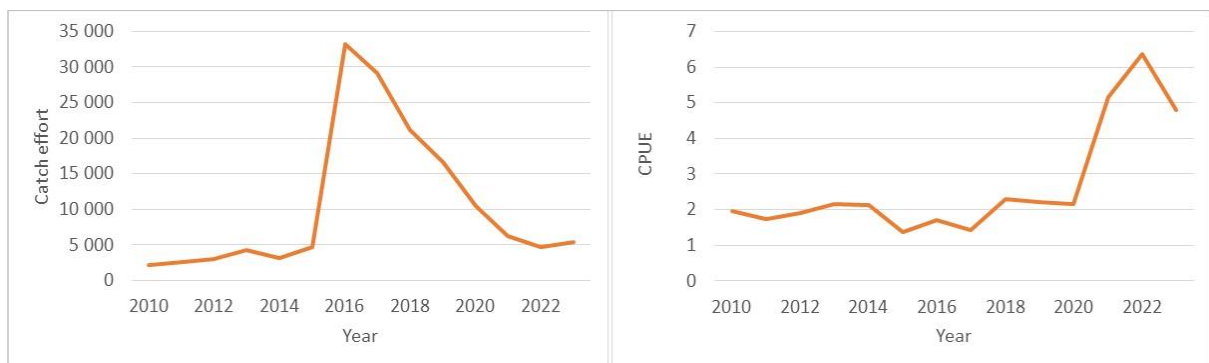


Figure 2. Catch effort (Fishing days x the number of gillnets with mesh size ≥ 120 mm (60 mm bar length), left) and catch per unit effort (CPUE, right) of cod fishery in statistical rectangles 49 and 58 (49G9 and 48G9, SD 29) in 2010–2023 (Finnish fisheries statistics, daily records).

Eastern Baltic cod in the southern Baltic Sea, i.e. in its most important distribution area, is heavily infected by the larvae of liver worms (*Contracaecum osculatum*; Zuo et al. 2016, Zuo et al. 2017, Sokolova et al. 2018, Mohamed et al. 2020, Ryberg et al. 2020). The condition factor and growth of the eastern Baltic cod is at present very low (e.g. Sokolova et al. 2018), probably due to both liver worms and lack of suitable food (Neuenfeldt et al. 2020), which are a consequence of large anoxic bottom areas (Limburg et al. 2018), and possibly due to other reasons as well. The increase of cod otolith hypoxia proxies (Mn:Mg) has also been detected (Heimbrand et al. 2024).

According to Heimbrand et al. (2023), the cod caught from the Swedish half of Åland Sea in 2021 and 2022 had grown clearly faster and to larger sizes than those in the southern Baltic Sea. However, their growth was on average not as fast as that of the cod in the North Sea in the 1960s (Daan 1974).

The final host of the liver worm is grey seal (*Halichoerus grypus*), and this parasite is carried to the cod via its prey, probably mostly smaller fish. The abundance of the parasite infections in the Baltic Sea has increased together with the number of grey seals. However, in the 1970's, when the Baltic grey seal population was significantly smaller than at present (e.g. Galatius et al. 2020), *Contracaecum osculatum* was found in the livers of several fish species in the Finnish Archipelago Sea: most commonly in cod, but also in salmon (*Salmo salar*), fourhorn sculpin (*Myoxocephalus quadricornis*), herring (*Clupea harengus*), and burbot (*Lota lota*). In the Bothnian Bay, *C. osculatum* was also found in smelt (*Osmerus eperlanus*) and shorthorn sculpin (*Myoxocephalus scorpius*) (Valtonen et al. 1988, Valtonen et al. 2012).

In the catch samples of cod in 2020–2022 in Åland, *Contracaecum* larvae were commonly found on the surfaces of the livers, especially those of large specimens, sometimes in very large numbers (Raitaniemi & Leskelä 2021, 2022, 2023). This was, however, not seen to affect the condition factor of the cod, which was on average higher than what has been recently found in the southern Baltic Sea (Sokolova et al. 2018). Based on Baltic seal counts, grey seals are abundant and increasing in the adjacent waters (Kunnasranta 2022, HELCOM 2023). Baltic International Trawl Surveys (BITS) do not cover this area, and thus there is a lack of knowledge about the stock size of cod in the Sea of Åland. The annual Baltic International Acoustic Survey (BIAS) passes these waters, and occasional cod of various sizes from fingerlings to larger specimens have been caught in the trawl.

This is the report of the fourth year in the sampling and monitoring program to collect data and gather information of the cod in Åland waters. Scientific cod fishing and monitoring has been implemented as a co-operation by local fishermen, the Government of Åland and Natural Resources Institute Finland (Luke). The main aim of the program is to collect data on cod length, weight, and condition in the catch, determine abundance and prevalence of liver worm infection, and examine the food of cod. These data are compared with earlier results and published results from elsewhere in and near the Baltic Sea. In addition, cod samples from one fisher in Hanko (Hangö) area at the southernmost coast of Finland have been examined similarly. As the scientific cod fishing in the Sea of Åland has been continued since 2020, a study on changes in the catch per unit effort was included to detect possible trends in the abundance of cod in the area.

2. Material and methods

Samples were collected from scientific fishery, which was executed by commercial fishermen from March to December in 2020–2023 and regulated by fisheries authorities in Åland and the Finnish ministry of Agriculture and Forestry (Figure 3). In Åland, the samples of 2023 were collected from the same depression area to the south/southwest of the main island as in earlier years (deepest points 240 m or more) and in addition, from Sottunga, which is to the southeast of the main island and where there is a small depression with depths mostly at 50–70 m (deepest point 87 m).



Figure 3. The fishing areas in Åland waters (within Finnish statistical squares 58, 49, and 50 i.e. ICES rectangles 48G9, 49G9, and 49H0) marked with the large and middle-sized yellow arrow and Hangö area marked with the smallest arrow (contains data from the National Land Survey of Finland, Background map series 02/2021).

- 1) From each fishing trip, the fishermen delivered the usual log-book data together with the number of caught cod.
- 2) Monthly, an official from the Government of Åland measured individual length and weight of 25 randomly selected cod from at least one fishing trip. When needed, cod from two or more trips per fisherman were measured.
- 3) In addition, an official from the Government of Åland took liver and stomach samples and otoliths from 5 of the 25 randomly selected cod (point 2 above). Occasionally additional small specimens were sampled, as well. The liver and stomach of each specimen were frozen for later examination.

In laboratory, the specimens of *Contracaecum*-larvae were counted from the surface of each liver. The numbers were classified in five categories used earlier in Denmark and Sweden (Table 1).

Table 1. Liver worm *Contracaecum osculatatum* abundance classification (Rygerg et al. 2021).

| Category | Number of worms |
|----------|-----------------|
| 0 | 0 |
| I | 1–10 |
| II | 11–20 |
| III | 21–30 |
| IV | > 30 |

The contents of each stomach were weighed and examined to recognize the species of prey and to estimate the degree of digestion (scale of 3 categories). 204 specimens were examined from the year 2023; earlier 170, 125, and 130 specimens had been examined similarly from the years 2020, 2021, and 2022, respectively.

In addition, 9 specimens, which had been caught in April 2023 from Hangö at the southernmost coast of Finland, were examined similarly. 32, 12, and 18 specimens had been examined earlier in 2020, 2021, and 2022, respectively.

Trends in the catches per unit effort (CPUE) were analyzed based on fishermen's obligatory catch reports collected by Finnish authorities. During the period of scientific fishing, only a small number of vessels has been contributing to the fishery. Among those few vessels, we selected those which had some cod fishing history before the beginning of the scientific cod fishing, and which had participated in the scientific cod fishery every year. We assumed that the vessels involved in cod fishery already before the start of the scientific fishing did not change their fishing behavior remarkably during the scientific fishing (i.e. there was no learning factor). With those conditions, the period of available data was 2016–2023, four years of scientific cod fishing and four years before that. As can be seen in the Fig. 2, before 2016 both the effort and the CPUE in cod fishery in Åland was low for several years.

3. Results and discussion

In the measured cod specimens in 2020, 2021, 2022, and 2023 by an official of the government of Åland, most abundant individuals in the main fishing area in all four years were 60–70 cm of length. The mean length has had an increasing trend in the catches. In Sottunga, however, the cod were smaller with mean length of 55 cm. Some shift towards larger sizes can be seen in the length distributions (Figures 4 and 5). Among the largest measured specimens with total length above 70 cm, Fulton's condition factor has slightly decreased from 2021 on (Figure 6). In the two Åland areas in 2023, the condition factors were fairly similar among 50–59 cm (1.15 and 1.17) and 60–69 cm (1.09 and 1.13) size groups in the Åland Sea depression area and Sottunga, respectively. In Hangö, only the length group 50–59 cm could be examined (8–22 specimens / year). There a slight decrease in condition may have taken place, too, in the sampled specimens from 1.01 in 2020 and 2021 to 0,96 in 2023. No relationship could be identified between the length or weight with the condition of the fish (Figure 7).

Similarly, as in 2020–2022 (Raitaniemi & Leskelä 2021, 2022, 2023), in 2023 there tended to be more *Contracaecum* on liver surfaces of cod specimens longer than 60 cm than in smaller cod. The number of larvae (on liver surface) per liver weight did not correlate with cod length, which was also seen in the samples from 2021 and 2022.

In Sottunga, the number of *Contracaecum* larvae on cod liver surfaces was smaller than in the Åland Sea depression area in both length groups 50–59 cm and 60–69 cm, which included enough of specimens to compare the numbers (Table 2). This suggests that the effect of the *Contracaecum* larvae on cod condition is small or negligible, as the above-mentioned condition factors in the same length groups were so similar in these two areas. On the other hand, other local factors may affect the condition, as well.

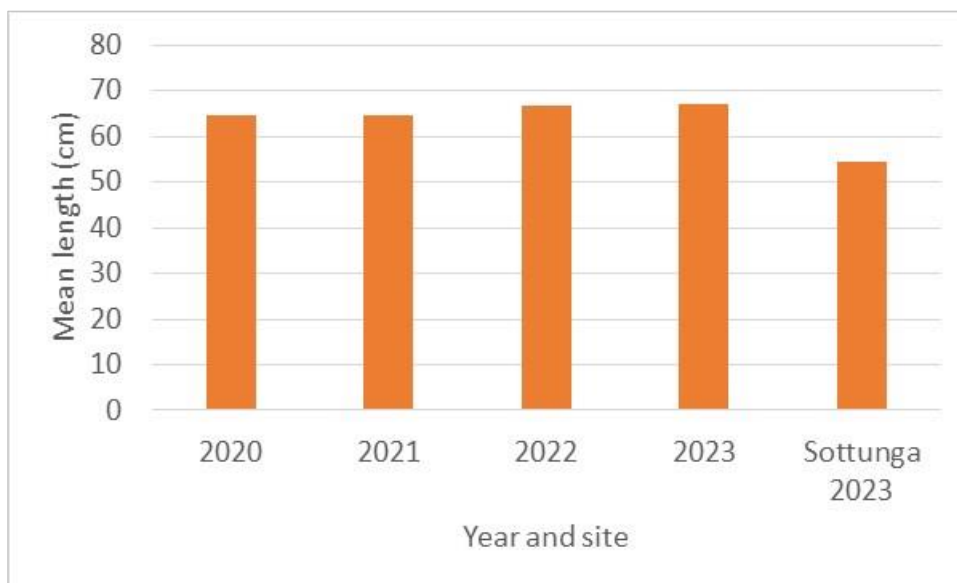


Figure 4. The mean length of cod caught from the depression area south/southwest of Åland main island and those from Sottunga in 2023.

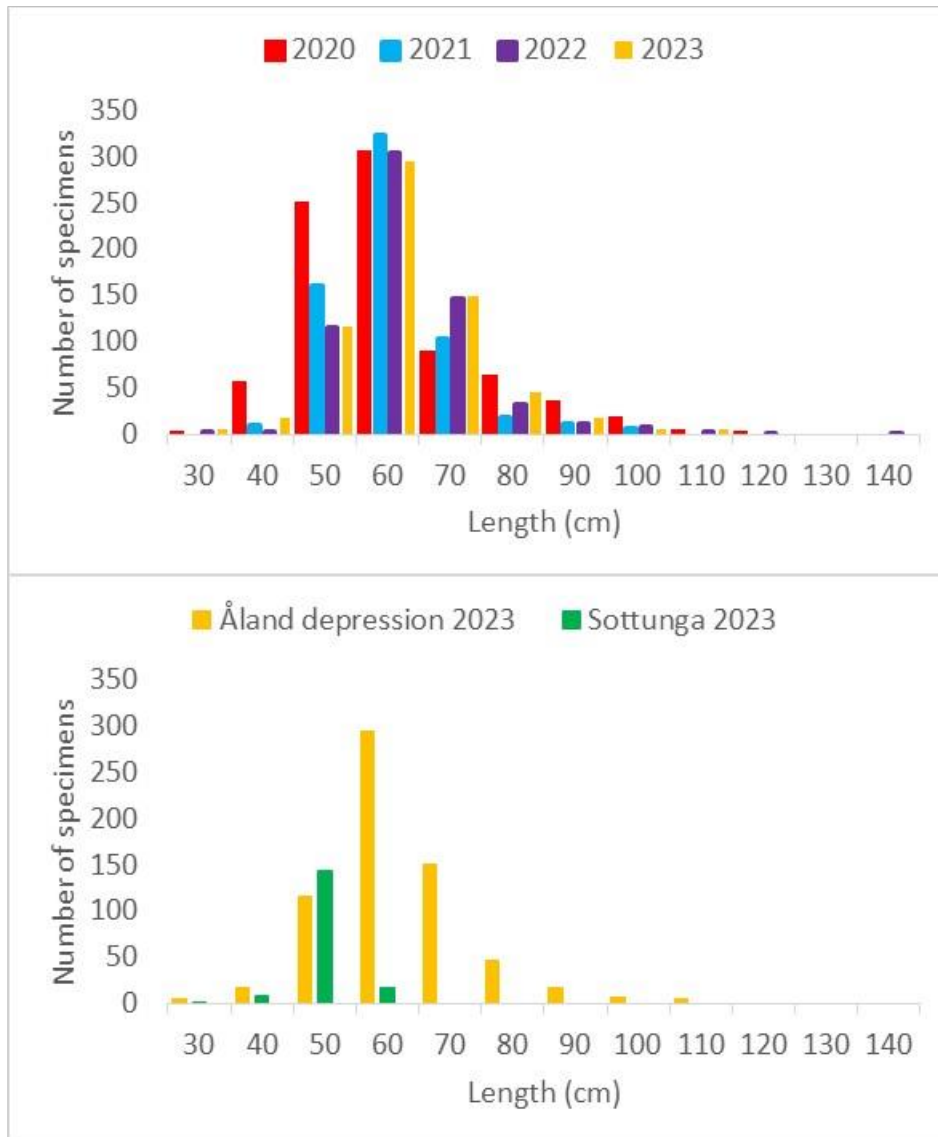


Figure 5. Length distribution of cod measured by an official from government of Åland in 2020 (n = 813), 2021 (n = 632), 2022 (n = 630), and 2023 (n = 657 at the depression to the south/southwest of Åland island, above) and the comparison of the length distributions in 2023 in the above-mentioned area and in Sottunga (n = 170). Lengths rounded down to the closest ten.

Table 2. The average number of *Contracaecum* larvae in the livers of cod in length groups 50–59 cm and 60–69 cm in the Åland Sea depression in the years 2020–2023 and in Sottunga in 2023.

| Cod length group (cm) | 50–59 | 60–69 |
|---------------------------|-------|-------|
| Åland Sea depression 2020 | 9.1 | 13.7 |
| Åland Sea depression 2021 | 16.3 | 27.5 |
| Åland Sea depression 2022 | 11.2 | 30.1 |
| Åland Sea depression 2023 | 7.2 | 21.6 |
| Sottunga 2023 | 1.8 | 0.4 |

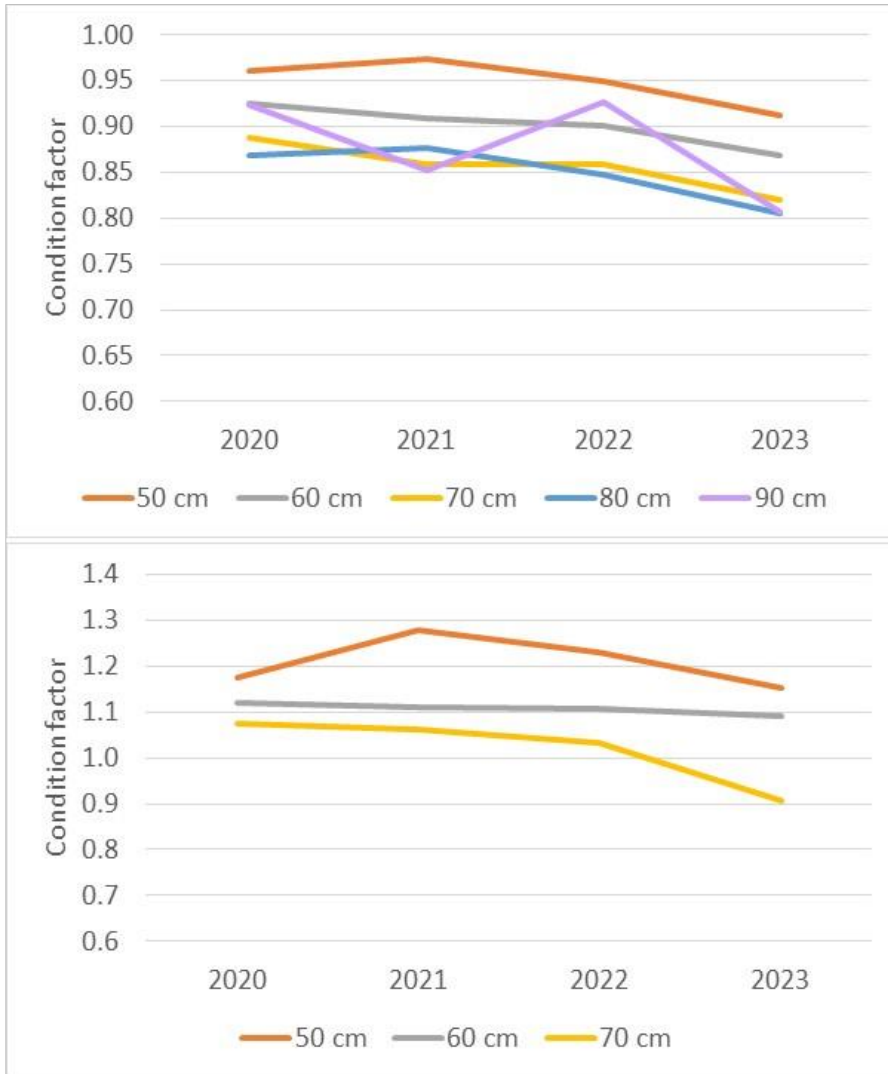


Figure 6. Mean Fulton's condition factor in 10 cm length groups (50–59 cm, 60–69 cm,...) from specimens with gutted weight (above, minimum number in length group 11 specimens) and individually sampled specimens with total weight (below, minimum number in length group 24 specimens) in 2020–2023.

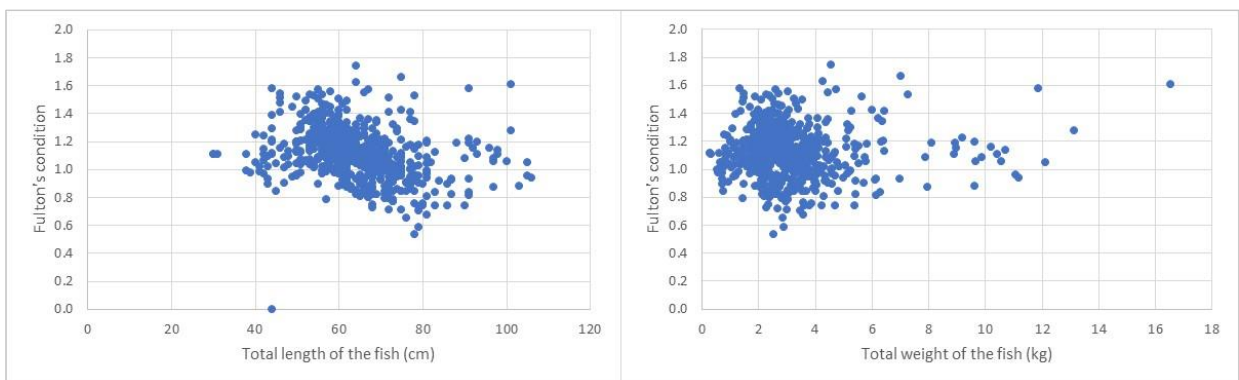


Figure 7. The condition (Fulton's condition factor) in relation to the length (left) and weight (right) of the 624 specimens of cod sampled in 2020–2023 in Åland sea areas.



Figure 8. A liver with no findings of *Contracaecum* larvae (above), a few specimens on the liver surface (below left), large number of larvae on the liver surface (below right).

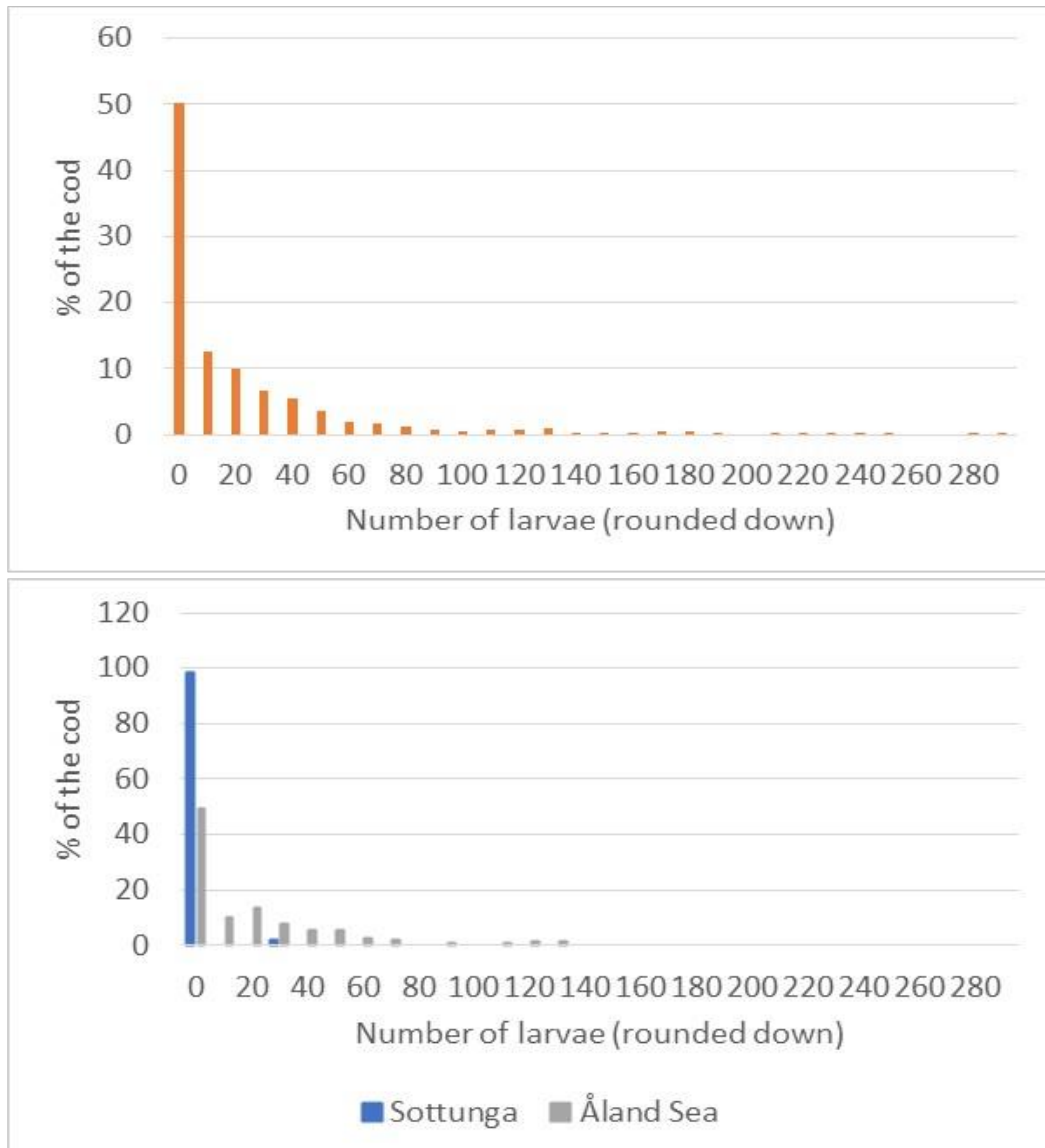


Figure 9. The distribution of the abundance of *Contracaecum* larvae on the liver surfaces of cod in the Åland Sea samples in 2020–2023 (above, N = 638) and in 2023 samples from Sottunga (N = 55) and the Åland Sea (N = 148). The number of larvae is rounded down to nearest 10.

In a large part of the livers sampled from the cod, the abundance of *Contracaecum* larvae has been relatively small (Figure 9), and so it was in 2023 (Table 2, figure 9 below). No parasites were found on the surfaces of 15%, 7%, 9%, and 16% of the livers in 2020, 2021, 2022 and 2023, respectively. Considering that Sokolova et al. (2018) were describing the abundances of all *Contracaecum* larvae in the livers of cod in Skagerrak, Kattegat and the most western Baltic Sea areas, the larvae have been abundant in the Åland Sea samples when compared with those areas.

Like in the previous years in the Åland Sea, in 2023 the condition of the cod was not found to be in a statistically significant relation with the number of *Contracaecum* larvae or the number of *Contracaecum* larvae / liver weight, however, the result of correlation test was closer to significance in 2023 (n = 149, r = -0.148, P < 0.1; n = 149, r = -0.162, P < 0.1, respectively). This was possibly in connection with the decreased condition of the larger specimens in 2023

(Figure 6, below). Thus in 2023, the relationship was similar as in the study of Sagebakken & Bergström (2019) from the Åland Sea in 2019. In the southern Baltic Sea, the body condition of infected cod was lower than that of those free of parasites and declined with the intensity of infection (Horbowy et al. 2016, Podolska et al. 2024). The absolute numbers of observed larvae on liver surface gave a similar view on the relationship with condition factor as the use of the five categories of parasite load, presented by Ryberg et al. (2021). Again in 2023, however, the numbers of larvae on liver surfaces in the Åland Sea in 2020–2023 have been larger than the whole number of larvae in the livers of cod counted by Ryberg et al. (2021) even from SD 25, i.e. the area with highest infection rate. When compared with the cod from the ten areas examined by Sokolova et al. (2018), the mean condition of the cod in Åland, 1.04–1.13 in 2020–2023, reminds of those in Skagerrak, The Sound, and Kattegat, where the cod had the highest condition factors (1.04–1.13).

In Hangö at the southern coast of Finland, 48 of the 72 specimens gathered in 2020–2023 were in the length group 50–59 cm. Their mean condition was 0.99, which was somewhat lower than in the Åland Sea in all three studied years (Figure 6, below). Their condition was still higher than in the eastern and western Bornholm Basin, Arkona Basin, and south of Gotland (0.82–0.91, Sokolova et al. (2018)). The mean total length (63 cm) and weight (3.0 kg) of the examined cod in the Sea of Åland in 2023 were higher than in Hangö (54 cm and 1.6 kg), and both were higher than in any of the areas studied by Sokolova et al (2018).

The fact that the number of larvae per liver weight had no or had a very weak relationship with cod condition shows that the situation in the Åland Sea and Hangö is different from the area east of Bornholm in the southern Baltic Sea, where Ryberg et al. (2020) found that condition factor decreased with increasing infection density with *Contracaecum osculatum*.

Although growth data (from the analysis of sampled cod otoliths) were not yet available for this report, the high condition and large body sizes of the cod in the Åland Sea indicate good growth rates. This is also supported by a specimen caught in May 2022 with gutted weight of 29.55 kg (thus full weight was around 35 kg). These results suggest that the poor condition and high mortality of cod in the southern Baltic Sea are due to the combination of starvation and the occurrence of *Contracaecum osculatum* (e.g. Ryberg et al. 2020). In the Åland Sea, the good condition and probably fast growth of cod take place together with fast growth of the liver. Hence, large numbers of worms do not essentially increase the number of larvae per liver weight (Figure 8) and, thus, have little effect on the growth and condition of the cod.

The proportions of different prey groups in cod stomachs were very similar in all years (Figures 10 and 11). In the Åland Sea, *Saduria entomon* was the most common prey along with fish (Table 3). Mysids were also commonly found; in some specimens from 2022 and 2023, more than a hundred mysids could be counted in a stomach (Figure 10, below) In the cod stomachs from Sottunga, no mysids were found. Among fishes, herring was the most common, and the remains of sprat (*Sprattus sprattus*) were also possibly detected among clupeids with smaller backbone. The otoliths of clupeids had often already melted or disappeared. Fourhorn sculpin was the most common of the family Cottidae, but also shorthorn sculpin was identified. These were probably the most common groups among the unidentified species, as well. Eelpout (*Zoarches viviparus*), cod (indicating cannibalism), snakeblenny (*Lumpenus lampretæformis*), and in 2023 three-spined stickleback (*Gasterosteus aculeatus*) and round goby (*Neogobius melanostomus*) were recognized, too.

In Hangö, *Saduria* was similarly the most found prey, but eelpout was the most common fish along with herring. The appearance of several three-spined sticklebacks in 2020 and blue mussels in 2023 in addition to abundant eelpouts, may suggest that the cod in the catches from Hangö had been foraging in shallower water than those caught from the Åland Sea. In BIAS survey catches, three-spined sticklebacks have usually been more abundant in the Åland Sea than in Hangö area, and they have been observed in relatively shallow water, i.e. below 30 (–40) metre’s depth (SUOMU database, Natural Resources Institute Finland).

Saduria were the most common food item in the stomachs of specimens that were sampled in March–August in 2020, 2021, and 2023 (in 10–15 specimens each month). Clupeids were most found in the samples from 2020 and 2021 in November–December and in 2023 May, as well. In 2022, similar differences between seasons could not be seen. Fish generally were an important prey throughout the year.

As expectable, mysids were found in the stomachs of the smallest and sculpins in those of the largest cod (Table 3), though in Sottunga smaller cod had eaten small sculpins, too. *Saduria* were also the most common among the smaller size groups of cod, although even the largest cod could also have *Saduria* in their stomachs. In the work of Zuo et al. (2016), *Saduria entomon* were not found to have *Contracaecum* infections, but 11.6% of examined sprat were infected with *C. osculatum*. This explained why cod started to have *Contracaecum* infections at larger sizes than 30 cm length, as small cod prey mostly on invertebrates and larger specimens on invertebrates and fish. In the acoustic surveys (BIAS) in the northern parts of ICES subdivision 29, herring and sprat have been found very abundant in recent years.

Table 3. The number of stomachs, in which different prey were observed in the years 2020–2023 in the Åland Sea.

| Prey | Observations | | | |
|---|--------------|------|------|------|
| | 2020 | 2021 | 2022 | 2023 |
| Number of the specimens of cod | 170 | 125 | 131 | 148 |
| <i>Saduria entomon</i> | 75 | 72 | 79 | 74 |
| Mysidae | 32 | 39 | 37 | 34 |
| Clupeid fish, mostly herring | 34 | 28 | 15 | 12 |
| Cottidae, mostly <i>Myoxocephalus sp.</i> | 11 | 6 | 10 | 3 |
| Other and unrecognized fish | 25 | 25 | 21 | 47 |
| Empty stomachs | 34 | 18 | 20 | 27 |

Table 4. The length of those cod specimens that were found to have eaten different types of prey in 2020–2023 in the Åland Sea.

| Prey | Length of cod |
|---|------------------------------|
| <i>Saduria entomon</i> | mostly in specimens < 90 cm |
| Mysidae | in specimens < 80 cm |
| Clupeid fish | mostly in specimens 50–80 cm |
| Cottidae, mostly <i>Myoxocephalus sp.</i> | in specimens ≥ 60 cm |
| Other and unrecognized fish | in specimens ≥ 50 cm |



Figure 10. Examples of stomach contents: Herring, eelpout and some *Saduria* remains, too (above); mysid and *Saduria* remains (below, photograph Pia Lindberg-Lumme).



Figure 11. Examples of stomach contents: Fish backbones and *Saduria* (above left), mainly *Saduria* (above right), *Saduria* and several fish backbones (middle), clupeid remains (below).

Catch per unit effort (cpue) of those vessels which we selected for the CPUE calculations increased after the beginning of the scientific cod fishing (Figure 12). CPUE peaked in 2022 and decreased slightly in 2023, remaining in relatively high level compared to the whole period we were able to examine. The pattern did not change even if we included all vessels, i.e. those which had participated in the fishery only during some of the years of scientific fishing. However, we assume that the CPUE of the selected vessels gives the most realistic picture of the changes in abundance of cod in the Sea of Åland.

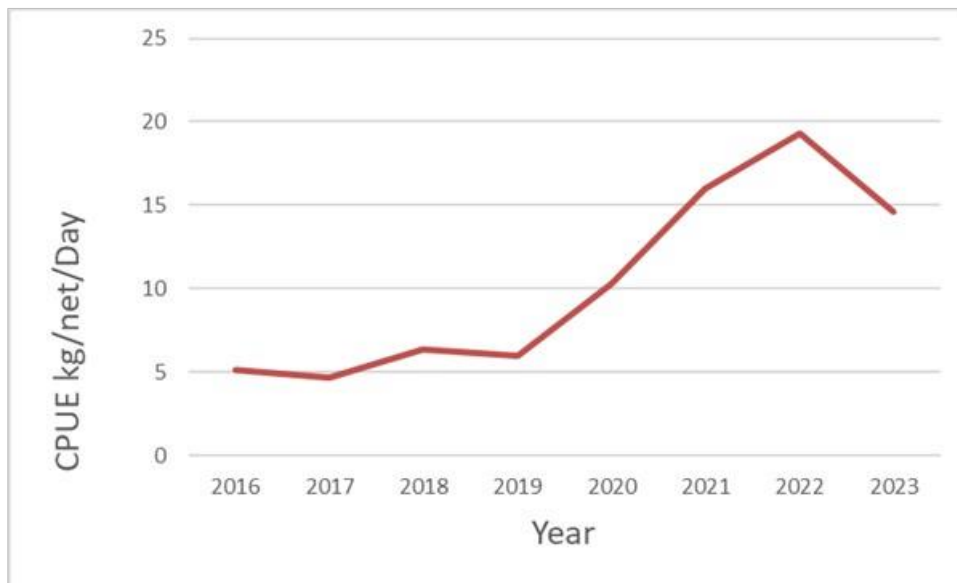


Figure 12. Catch per Unit effort of the vessels which were selected for the CPUE calculations.

Acknowledgements

We thank the Government of Åland for the funding of this study and its officials and the fishers who participated in the sampling process. The Finnish ministry of Agriculture and Forestry funded the examination of the cod samples from Hangö area. The staff of Luke helped with the working facilities at different stages of the work.

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