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Report on scientific cod fishing and monitoring in 2022 in Åland, Finland

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Abstract

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At present, Eastern Baltic cod 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 cod. The final host of the liver worm is grey seal (*Halichoerus grypus*), and the worm is carried to cod via prey, smaller pelagic 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 2022 were examined and presented together with the results from the years 2020 and 2021. The size of measured cod in 2022 varied from 30 to 141 cm. Similarly as in 2020 and 2021, the number of *Contracaecum osculatum* larvae on liver surface correlated with cod length, but the number of larvae per liver weight did not. The Fulton's condition factor of the cod in all years was very high (1.11–1.14 in Åland). More importantly and similarly as in the previous years, the condition of the cod was not found to be in 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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Contents

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 2020–2022. However, in recent years and after a long break, it has been possible to catch cod in the waters 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.

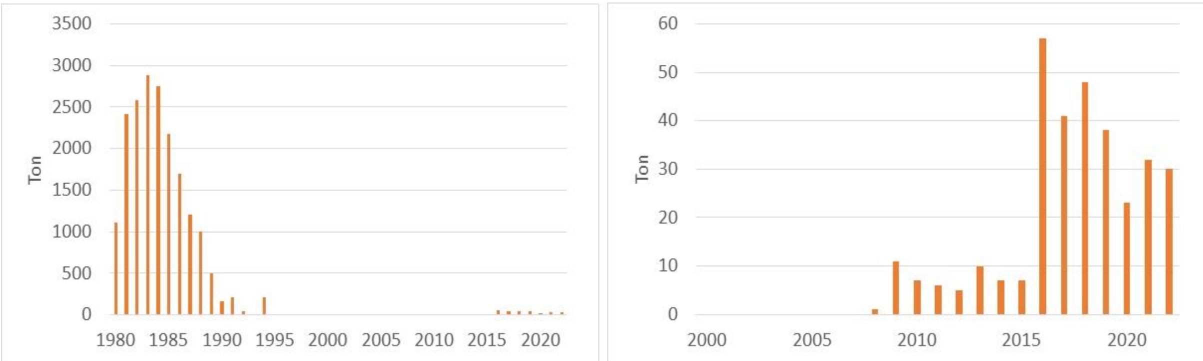

Figure 1. The landings of cod by Finland in ICES subdivision 29 (SD 29) in 1980–2022 (left) and in different scale in 2000–2022 (right) (Finnish fisheries statistics).

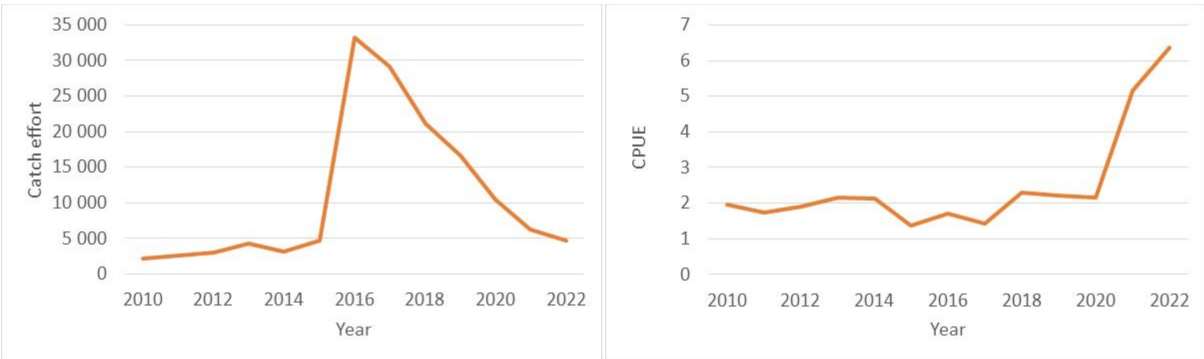

Figure 2. Catch effort (Fishing days x the number of gillnets with mesh size ≥ 120 mm (60 mm bar length), left) and catch per unit effort (CPUE, right) of cod fishery in statistical rectangles 49 and 58 (49G9 and 48G9, SD 29) in 2010–2022 (Finnish fisheries statistics, daily records).

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, 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) that is a consequence of large anoxic bottom areas (Limburg et al. 2018), and possibly due to other reasons as well. 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. 2012).

In the catch samples of cod in 2020 and 2021 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). 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). 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 third 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 Hangö area at the southernmost coast of Finland have been examined similarly.

2. Material and methods

Samples were collected from scientific fishery, which was executed by commercial fishermen from March to December in 2020–2022 and regulated by fisheries authorities in Åland and the Finnish ministry of Agriculture and Forestry (Figure 3).

Figure 3. The fishing areas in the Åland Sea (within Finnish statistical squares 58 and 49 i.e. ICES rectangles 48G9 and 49G9) marked with the larger yellow arrow and Hangö area marked with the smaller 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). 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 osculatum 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). 130 specimens were examined from the year 2022, earlier 170 and 125 specimens had been examined similarly from the years 2020 and 2021, respectively.

In addition, 18 specimens, which had been caught in April 2022 from Hangö at the southernmost coast of Finland, were examined similarly. 12 and 37 specimens had been examined earlier in 2020 and 2021, respectively.

3. Results and discussion

In the measured cod specimens in 2020, 2021, and 2022 by an official of the government of Åland, most abundant individuals in all three years were 60–70 cm of length (average 64.5 cm in 2020, 64.6 cm in 2021, and 66.9 cm in 2022). Some shift towards larger sizes during 2020–2022 can be detected in the length groups 50, 60, and 70 cm (Figure 4). Fulton's condition factor of these specimens (gutted weight) was on average 0.93 in 2020, 0.92 in 2021, and 0.90 in 2022 (Figure 5). The average condition factor with total weight of the specimens that were sampled for further examinations was 1.12 in 2020, 1.14 in 2021, and 1.11 in 2022 (Figure 5). The condition remained on average above 1 in all length and weight groups (Figure 6).

The number of *Contracaecum* larvae on liver surface (Figure 7) correlated with cod length (average 64.3 cm in 2020, 65.4 cm in 2021, and 65.2 cm in 2022), which was also found by Sagebakken et al. (2019). A correlation between the number of larvae (on liver surface) per liver weight and cod length was found in 2020, but not in 2021 or 2022 (Figure 8).

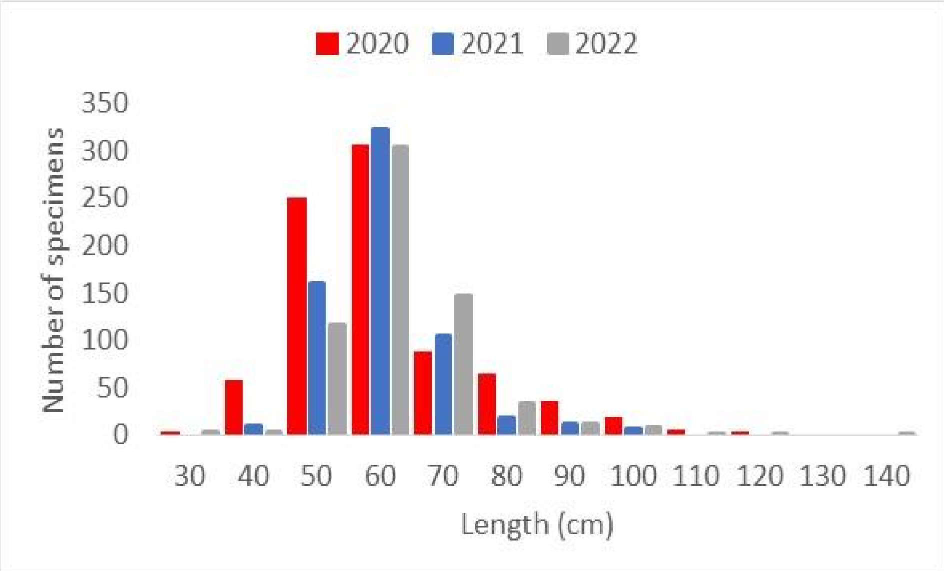

Figure 4. Length distribution of cod measured by an official from government of Åland in 2020 (n = 813), 2021 (n = 632), and 2022 (n = 630). Lengths rounded down to the closest ten.

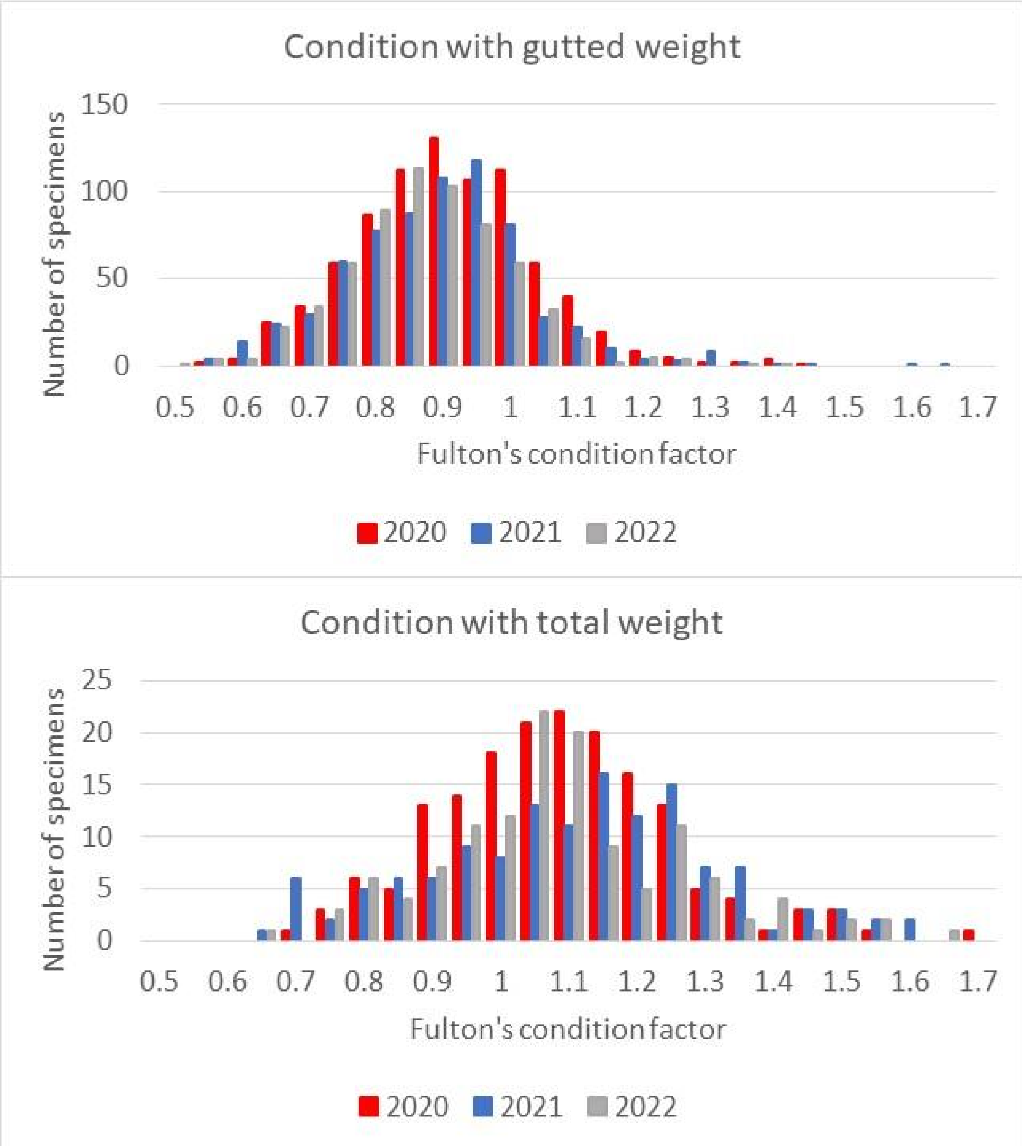

Figure 5. The distribution of Fulton's condition factor in the measured and weighed specimens (above: gutted weight, n = 813 in 2020, n = 632 in 2021, and n = 630 in 2022) and sampled specimens (below: total weight, n = 170 in 2020, n = 125 in 2021, and n = 130 in 2022). Two specimens with condition below 0.3 (in 2020 and 2022 one in each) are not seen in the figures.

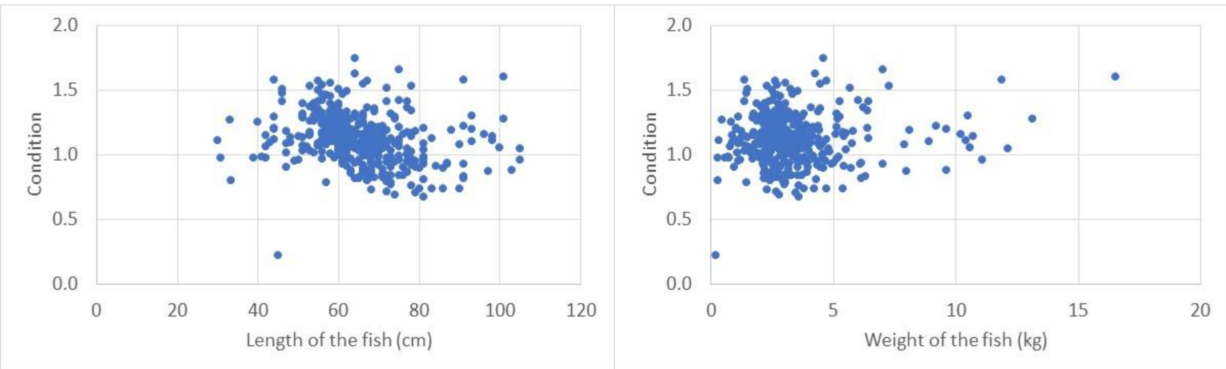

Figure 6. The condition (Fulton's condition factor) in relation to the length (left) and weight (right) of the 424 specimens of cod sampled in 2020–2022 in the Sea of Åland.

Figure 7. 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).

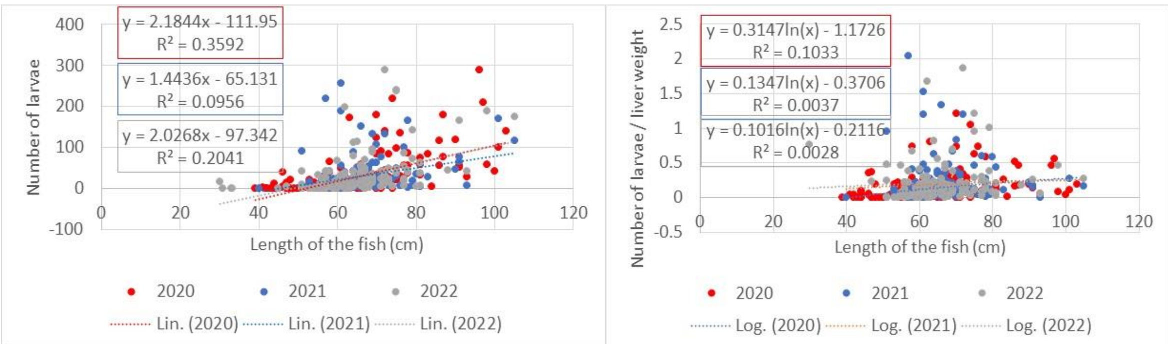

Figure 8. Left: The number of *Contracaecum osculatum* larvae counted on cod liver surfaces and the total lengths of the cod specimens in 2020 (n = 170, correlation: r = 0.359, $p < 0.001$), 2021 (n = 125, r = 0.309, $p < 0.001$), and 2022 (n = 125, r = 0.452, $p < 0.001$). Right: The number of larvae / liver weight and the length of the cod in 2020 (n = 170, r = 0.321, $p < 0.001$), 2021 (n = 125, r = 0.061, $p > 0.10$), and 2022 (n = 125, r = 0.053, $p > 0.10$).

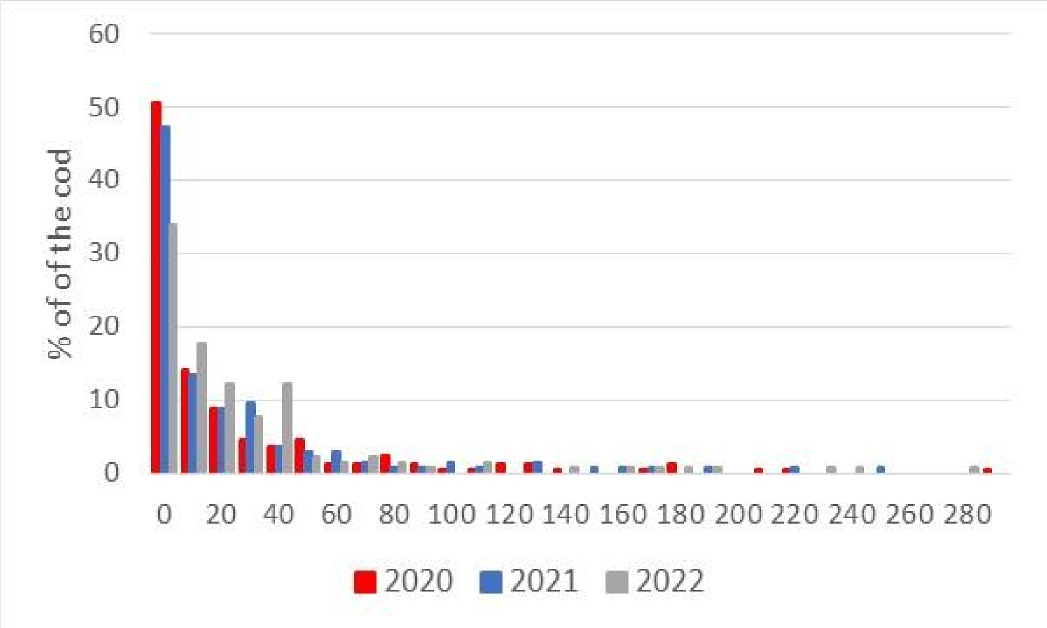

Figure 9. The distribution of the abundance of *Contracaecum* larvae in per cents on the liver surfaces of cod in 2020–2022 (the number of larvae is rounded down to the closest tenth).

In a large part of the livers sampled from the cod, the abundance of *Contracaecum* larvae was relatively small (Figure 9). No parasites were found on the surfaces of 15%, 7%, and 9% in of the livers in 2020, 2021, and 2022, 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 were abundant in the Åland Sea samples when compared with those areas.

The condition of the cod was not found to be in relation to the number of *Contracaecum* larvae (Figure 10), contradictory to what was observed in cod from the southern Baltic Sea by Horbowy et al. (2016) and Sagebakken & Bergström (2019). 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). However, the category with the most infected group (>30 larvae) includes not only individuals with relatively small numbers of larvae, but in addition, some specimens in all years had clearly larger numbers of larvae on the surfaces of their livers, between 200 and 300 (Figure 10), which is more than Ryberg et al. (2021) reported from SD 25 as the highest whole number of larvae in the livers of cod. When compared with the cod from the ten areas examined by Sokolova et al. (2018), the mean condition of the cod in Åland, 1.11–1.14 in 2020–2022, reminded 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, the mean condition of 55 specimens of cod caught in 2020–2022 was 1.00, which despite the small numbers of specimens was somewhat lower than in the Åland Sea in all three studied years. It 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 (65 cm) and weight (3.4 kg) of the examined cod in the Sea of Åland 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 relationship with cod condition (Figure 11) 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*.

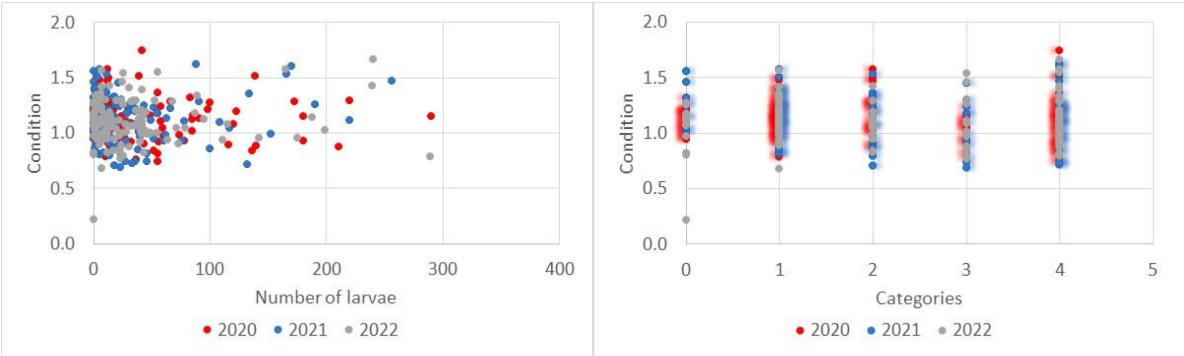

Figure 10. The condition of the cod (Fultons's condition value) in the Åland Sea in relation to the number of *Contracaecum* larvae on liver surface (left) and five categories of larval abundance (right).

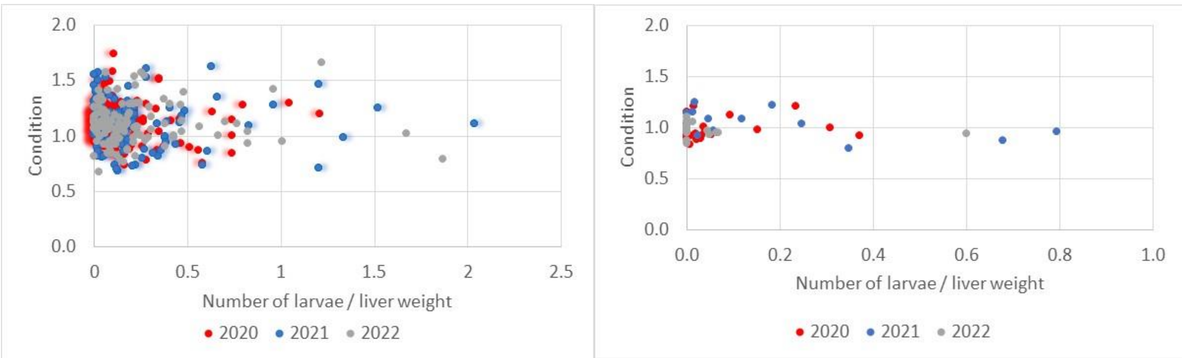

Figure 11. The condition of the cod (Fultons's condition value) in relation to an index of infection density with *Contracaecum* larvae (worms on liver surface/liver weight (g)) in the Åland Sea (left) and Hangö (right).

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 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 12 and 13). In the Åland Sea, *Saduria entomon* was the most common prey along with fish (Table 2). Mysids were also commonly found; in some specimens from 2022, more than a hundred mysids could be counted in a stomach (Figure 12, below). Among fishes, herring was the most common, and the remains of sprat (*Sprattus sprattus*) were also possibly detected among clupeids with smaller backbone. 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), and snakeblenny (*Lumpenus lampretaeformis*) were recognized, too.

In Hangö, Saduria was similarly the most found prey, but eelpout was the most common fish before herring. The appearance of several three-spined sticklebacks (*Gasterosteus aculeatus*) in addition to abundant eelpouts, suggests 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 (SUOMU database, Natural Resources Institute Finland).

Saduria were the most common food item in the stomachs of specimens that were sampled in March–July in 2020 and 2021 (in 10–15 specimens each month). Clupeids were most found in the samples from November–December in the same years (in 4–11 specimens in each month). 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). 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 2. The number of stomachs, in which different prey were observed in the years 2020, 2021, and 2022 in the Åland Sea.

Prey	Observations		
	2020	2021	2022
Number of the specimens of cod	170	125	131
Saduria entomon	75	72	79
Mysidae	32	39	37
Clupeid fish, mostly herring	34	28	15
Cottidae, mostly *Myoxocephalus sp* .	11	6	10
Other and unrecognized fish	25	25	21
Empty stomachs	34	18	20

Table 3. The length of those cod specimens that were found to have eaten different types of prey in 2020–2022 in the Åland Sea.

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

Figure 12. Examples of stomach contents: Herring, eelpout and some *Saduria* remains, too (above); mysid and *Saduria* remains (below, Photograph Pia Lindberg).

Figure 13. Examples of stomach contents: Fish backbones and *Saduria* (above left), mainly *Saduria* (above right), *Saduria* and several fish backbones (middle), clupeid remains (below).

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