# Metazoan endoparasites as biological indicators of Baltic cod biology

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Chapter

# Metazoan Endoparasites as Biological Indicators of Baltic Cod Biology

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## Abstract

The Baltic cod is a substock of the Atlantic cod *Gadus morhua*, and it is divided into two subpopulations (the western and the eastern stock) living in the semi-enclosed Baltic Sea. This brackish water area is receiving high salinity water from the North Sea through the Danish straits (the Great Belt, Øresund, and Little Belt) and freshwater from precipitation and the drainage areas in surrounding countries whereby marked differences with regard to salinity conditions occur in various parts of the area. The biological and hydrographical conditions determine the parasite fauna found in the Baltic cod, and therefore several of the Baltic parasites are biological indicators. Recommended indicator parasites comprise trematodes (*Cryptocotyle lingua*, *Diplostomum spathaceum*, *Lepidapedon elongatum*, *Hemiurus lühei, Brachyphallus crenatus),* nematodes *(Hysterothylacium aduncum, Contracaecum osculatum, Anisakis simplex, Pseudoterranova decipiens, Capillaria gracilis*), and acanthocephalans (*Echinorhynchus gadi*, *Corynosoma* spp., *Pomphorhynchus laevis).*

**Keywords:** Baltic cod, parasites, life cycle, ecological indicators

## 1. Introduction

The Baltic Sea is a dynamic ecosystem composed of zoological and botanical communities continuously exposed to marked changes of salinity, temperature, and oxygen conditions [1]. It is receiving high salinity water from the North Sea through the Danish straits (Great Belt, Øresund, and Little Belt) whereas freshwater is received from precipitation and drainage areas in surrounding countries including Denmark, Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland, and Germany whereby highly varying salinity occur in different parts of the basin. One of the main marine fish stocks in the Baltic Sea is a subpopulation of the Atlantic cod (*Gadus morhua*) termed the Baltic cod. It is composed of a western substock (spawning in the western Baltic) and an eastern substock (with a main spawning zone in the Bornholm Basin), and these two fish groups have a mixing zone around the island of Bornholm [2]. The Atlantic cod, when considering its entire area of distribution, is able to carry a long range of parasites (more than 120 species) belonging to many different systematic groups [3]. Many of the metazoan endoparasites have relatively complicated life cycles some of which include invertebrates, fish, birds, or mammals (**Figure 1**). The distribution in the Baltic of these major animal groups is dependent on biological and hydrographical conditions in various salinity zones, and their distribution will to some extent determine the parasite fauna found in the Baltic cod whereby these can

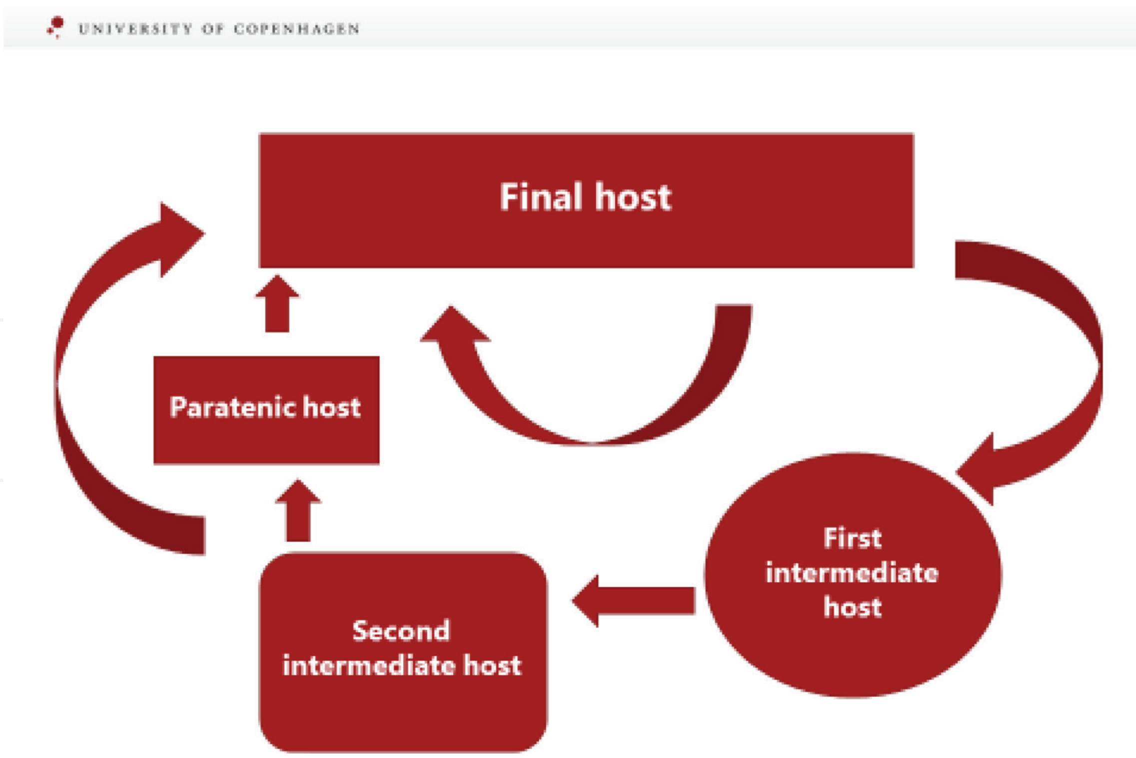


**Figure 1.**
*Diagrammatic presentation of the life cycle of different parasites with inclusion of no, one, or two intermediate hosts and transport hosts (paratenic hosts).*

be applied as biological indicators. The use of parasites in fish as indicators has been suggested and documented by numerous authors [4–13]. Although many parasite species display a high degree of host specificity, some parasite species infect a broad variety of fish. The occurrence of fish species other than the cod will therefore add to the overall infection pressure and thereby affect the exposure of Baltic cod to various parasite species with low specificity. Sharing of parasites occurs with important local fish species such as the Baltic salmon (*Salmo salar*), sea trout (*Salmo trutta*), European eel (*Anguilla anguilla*), herring (*Clupea harengus*), sprat (*Sprattus sprattus*), eelpout (*Zoarces viviparus*), flounder (*Platichthys flesus*), plaice (*Pleuronectes platessa*), and turbot (*Scophthalmus maximus*). In addition freshwater species including smelt (*Osmerus eperlanus*), perch (*Perca fluviatilis*), pike (*Esox lucius*), three-spined stickleback (*Gasterosteus aculeatus*), ruffe (*Acerina cernua*), roach (*Rutilus rutilus*), and pikeperch (*Stizostedion lucioperca*) occur with increasing frequency towards the northern parts of the Baltic characterized by low salinity [14]. The invertebrate fauna in the Baltic is highly variable and shifts from a dominance of marine animal species in the western Baltic to freshwater species in the eastern and northern parts of the sea. Of special importance is the presence of potential intermediate hosts such as the marine snail, the common periwinkle *Littorina littorea* which is frequently found in the western Baltic but absent in the eastern Baltic. In contrast, the freshwater snail, *Lymnaea (Radix) peregra*, is absent in the most saline parts of the western Baltic but extremely common in the eastern Baltic [15]. Important invertebrates, besides molluscs, when discussing parasites of fish, are also the copepods, amphipods, and polychaetes because they act as intermediate hosts in several life cycles of parasites found in Baltic fishes. Marine mammals occur in the Baltic, and especially the grey seal (*Halichoerus grypus*) population increase has recently been associated with marked changes in the parasite fauna of cod in the Baltic [13, 16–21]. However, other pinniped species such as ringed seal and harbour seal contribute to some extent in various parts of this brackish water system. A series of fish-eating birds, especially sea gulls, occurring in the Baltic play an important role as final hosts for digeneans and nematodes [14, 15, 22] (**Table 1**).

| Parasite | Final host | First intermediate or transport host | Second intermediate or transport host | Paratenic/ transport host | Distribution |
|---|---|---|---|---|---|
| **Trematodes** | | | | | |
| *Cryptocotyle lingua* | Fish-eating birds | *Littorina littorea* | Fish including cod | NA | Atlantic, western Baltic |
| *Diplostomum* spp. | Fish-eating birds | *Radix balthica* | Fish including cod | NA | Freshwaters and eastern Baltic |
| *Brachyphallus crenatus* | Fish | *Retusa obtusa* | Copepods | Pelagic fish including clupeids | Atlantic, western Baltic, Central Baltic |
| *Hemiurus luehei* | Fish | *Philine denticulata* | Copepods, *Sagitta* sp. | Pelagic fish including clupeids | Atlantic, western Baltic |
| *Podocotyle atomon* | Fish including cod | *Littorina* spp. | Amphipods including *Gammarus* spp. and isopods | NA | Atlantic to southern Baltic |
| *Lepidapedon elongatum* | Fish including cod | *Onoba aculeus* | Polychaetes, molluscs | NA | Atlantic, western Baltic |
| **Nematodes** | | | | | |
| *Anisakis simplex* | Cetaceans (whales) | Euphausiaceans, copepods | Clupeids | Cod and other fish species | Atlantic with immigration of infected herring into western Baltic |
| *Pseudoterranova decipiens* | Pinnipeds (seals) | Crustaceans (copepods, isopods, amphipods) | Cod | Cod | Atlantic, southern Baltic |
| *Contracaecum osculatum* | Pinnipeds (seals) | Copepods, isopods, amphipods | Clupeids and other small fish | Cod | Atlantic to eastern Baltic |
| *Hysterothylacium aduncum* | Fish including cod | Crustaceans including copepods | Small fish | Cod, eelpout | Atlantic to eastern Baltic |
| *Capillaria gracilis* | Fish including cod | Chironomid larvae, oligochaetes | Sand goby, dab | NA | Atlantic to southern Baltic |
| **Acanthocephalans** | | | | | |
| *Echinorhynchus gadi* | Fish including cod | Amphipods | NA | Various fish species | Atlantic to eastern Baltic |
| *Pomphorhynchus laevis* | Fish including cod | Amphipods | NA | ? | Atlantic to eastern Baltic |
| *Corynosoma spp.* | Pinnipeds (seals) | Amphipods | Fish | Various fish species | Atlantic to eastern Baltic |

**Table 1.**
*Parasitic endohelminths with potential as biological indicators.*

## 2. Parasites as indicator species

### 2.1 Digenean trematodes

The skin fluke *Cryptocotyle lingua* may be applied as an indicator for the western Baltic as this digenean *C. lingua* is a marine organism and infects cod in the western Baltic. The high salinity waters in the western Baltic support survival and reproduction of the common periwinkle *Littorina littorea* which is the first intermediate host of the parasite [15, 22]. It is called the skin fluke of cod and flatfishes, and it elicits black spot disease in these hosts. The life cycle comprises the adult hermaphroditic fluke in the intestine of a fish-eating bird, e.g. a seagull. Eggs from the adult fluke enter the aquatic environment with the host faeces. These eggs are ingested by the marine snail *L. littorea*, which acts as the first intermediate host. In the snail the eggs hatch, and the emerging larvae invade the host snail where new stages, sporocysts and rediae, are produced. Cercariae develop in the rediae, and they are shed into the water where the second intermediate host, e.g. the cod, becomes infected by cercariae. These penetrate the host skin and superficial muscle layers where they attain the metacercarial stage [23]. The host reacts to these parasitic stages by mounting both a cellular and a humoral response. Melanophores gather around the parasite which after some time will be located in the centre of a black spot made of host cells. However, the metacercaria is protected against this immune response by a secreted cyst wall. When the final host, the seagull, eats the infected fish, the fish will be digested, but the parasite will be activated and develop into the adult mature stage in the bird's intestine. This parasite will infect cod in the western part of the Baltic where the intermediate snail host is present but not in the eastern part (because *Littorina littorea* is absent there). Therefore, the parasite can be used as a biological tag [15]. If an infected cod is caught in the eastern Baltic, it can be deduced that it must have been migrating from the infection area in the western Baltic.

The eye flukes within the genus *Diplostomum* comprise various species, and the form occurring in Baltic fishes was originally termed *D. spathaceum* although recent work suggests a more diverse occurrence of species [8]. The eye fluke in the Baltic cod may be used as an indicator for activity in the eastern part of the Baltic. This digenean is a freshwater organism which is commonly found in the eastern part of the Baltic where water is of low salinity [15]. The life cycle includes birds, fish, and molluscs. The first intermediate host is the pulmonate snail, *Lymnaea (Radix) peregra,* which is a freshwater organism. However, it is able to survive in the brackish water in low salinity areas of the northern, eastern, and southern part of the Baltic), but it is absent in the western parts. The second intermediate hosts are fishes, and the final hosts are fish-eating birds. In the bird intestine, the hermaphroditic digenean produces eggs which are shed with host faeces into the aquatic environment. The egg hatches, and the free-living larva, the miracidium, escapes from the egg and locates a host snail. Following penetration of this intermediate host, further development occurs with new larval stages, sporocysts and daughter sporocysts, being produced. In these stages cercariae are produced and are subsequently shed into the water. The furcocercaria penetrates the host skin or gills of the fish host (second intermediate host), sheds the tail, and migrates through the vascular system to the eye lens where the metacercarial stage develops. Following ingestion by a seagull, the fish will be digested, but the flatworm develops into the adult stage in the host intestine. The pyloric trematode *Lepidapedon elongatum* is a marine species infecting the Baltic cod [24]. It obtains maturity in a very specialized part of the gastrointestinal part, the pyloric caeca. Here the hermaphroditic worm produces eggs which are released with the intestinal content to the sea. A mollusc acts as the first intermediate host. Thus, in the marine snail *Onoba aculeus*, the first larval stages (redia) are developed. These release cercariae infective for the second intermediate host, the polychaete *Nereis diversicolor*. Thus, metacercariae encyst in this free-living and bottom-dwelling worm and become infective for the final host, the cod. When the cod feeds on infected polychaetes, it will acquire the infection because the metacercaria excysts and develops to the adult stage in the pyloric caeca of the fish. Thus, infection with this digenean will mirror the marine life and food of the cod. Infected cod caught in more diluted parts of the Baltic (such as the northern Bothnian Bay), where the first intermediate host is lacking, will indicate migration of cod from more saline parts of the Baltic.

Other digeneans such as *Hemiurus lühei* and *Brachyphallus crenatus* can be found in the stomach or intestine of the Baltic cod. They acquire the infection following ingestion of infected clupeids such as sprat and herring [9, 11]. The first intermediate mollusc hosts (*Retusa obtusa* and *Philine denticulata*, respectively) of these two hemiurid trematodes have a western distribution in the Baltic Sea which restrict infection of the second intermediate host (copepods) to the western and southern Baltic Sea [25, 26]. The copepod communities in different parts of the Baltic Sea were mapped by Ackefors [27] showing suitable copepod hosts throughout the area. Feeding on benthic amphipods can be indicated by finding cod infected by the trematode *Podocotyle atomon*. It will further reflect that the cod has been migrating to certain areas with a minimum salinity. Thus, *P. atomon* occurs in the stomach and intestine of Baltic cod if it has been foraging on amphipods (second intermediate host) in an area where the first intermediate host (*L. saxatilis*) is present [28]. This marine snails are found in the western Baltic with a distribution to the island of Bornholm (southern Baltic) but absent in the most eastern areas due to the low salinity there.

### 2.2 Acanthocephalans

Acanthocephalans comprise a group of endoparasitic worms which are prevalent in the Baltic cod. *Echinorhynchus gadi* is a very common species in the intestine of cod. Heavy infections can be seen in the Baltic cod [29–34], and worm counts of more than 500 worms per fish have been recorded although the mean number per fish often varies from 30 to 60. The intermediate host is amphipods such as various species of *Gammarus*, and the infection level may indicate the extent that the cod feeds on this particular crustacean. Especially flatfishes such as flounder and plaice in the Baltic are found infected with *Pomphorhynchus laevis* [35]. However, other species (cod, trout, eel) can obtain lighter infections with *P. laevis*. The life cycle is rather similar to the one of *E. gadi* applying amphipods as intermediate host. Adult female worms produce eggs which are liberated to the surroundings with host faeces. The oval to fusiform eggs are ingested by an amphipod in which the larva (acanthella stage) is developed. Following ingestion by the fish, the larva reaches the posterior part of the intestine, penetrates the mucosa with its proboscis, attaches in the gut wall, and attains maturity. The intensity in cod is generally very low.

Two species within the genus *Corynosoma* (*C. semerme and C. strumosum*) occur in the Baltic. They can both be found in the body cavity and the intestinal wall of Baltic cod but generally at low intensities. The life cycle includes a seal as final host and an amphipod as first intermediate host [36]. The level of infection will reflect the occurrence of finals hosts (pinnipeds) in the area.

### 2.3 Nematodes

The so-called herring worm or whale worm *Anisakis simplex* is a marine species which is commonly found in marine waters. It is also found in various fish species in the Baltic but only in certain areas. The life cycle of *A. simplex* is entirely marine and demands stenohaline crustaceans (euphausiids) as intermediate hosts. Whales, fish, copepods, and/or euphausiids are obligate parts of the cycle ([37, 38]). The mature female worms in the stomach of whales produce eggs which are released with whale faeces to the marine waters. In the egg the larva develops and moults twice into the third larval stage which subsequently is liberated [38]. The crustaceans eat the larvae, become infected with larvae in their haemocoel, and will transmit the worm to fish predators. In the fish the larvae will normally coil and take positions in the body cavity, organs, or flesh. If a predatory fish ingests an infected fish, the larvae will be transferred to the former. Following ingestion by the whale (e.g. a porpoise), the larvae moult twice and attain maturity in the final host [38]. The crustacean hosts (euphausiids) demand high salinity and do not live in the Baltic due to the low salinity there. This means that the life cycle of the worm is not performed in the Baltic. Nonetheless cod, herring, pikeperch, and flounder can occasionally be found infected in certain areas of the western and southern parts of the Baltic. This can, however, be readily explained by the seasonal immigration of infected herring from the North Sea into the Baltic. Thus, it is known that a number of herring stocks occur in the Baltic Sea. They are mostly stationary or perform limited migrations within the Baltic. However, one stock, the spring-spawning Rügen herring, is performing long-range migrations. These fish spawn along the coastline of Germany and Poland in the first months of the year. Following this event they swim out of the Baltic to the North Sea where they feed on euphausiids during the summer season. In this period they become infected with numerous anisakids before they migrate through Øresund towards the Baltic in the autumn. During their stay in the Baltic, they are subjected to predation by cod, salmon, pikeperch, and other predatory fish (even flounder). In this way the infection is spread to other species in this brackish sea [37]. In fact, the parasite is not host specific as a larva and is able to infect many fish species.

The cod worm *Pseudoterranova decipiens*, which generally is associated with cod in Atlantic waters [39, 40], has been considered absent from the Baltic cod population for several decades. However, recent parts of the Baltic cod population were found infected [16]. The increasing population of grey seal, which is the final host of the parasite, in the Baltic Sea can explain the increasing occurrence in the western and Baltic parts. The cod worm *P. decipiens* is a marine nematode species within the family Anisakidae. It is commonly found in cod from the Atlantic, but due to the low abundance of suitable final hosts (pinnipeds such as grey seal), it has been absent from the Baltic [41]. In addition, the low salinity in the eastern part of the Baltic does not support the life cycle of the parasite but cod in the western and southern part of the Baltic (around the island Bornholm) where salinity is sufficiently high to support egg hatching and larval survival of the parasite and the infection of cod has increased [16].

The nematode larva *Contracaecum osculatum* invading the liver of Baltic cod is using a seal as the final host [13, 14]. The adult worms copulate in the gastrointestinal tract of the seal. Eggs are passed out with host faeces and embryonate in the sea. Two moults occur in the egg before hatching, and the third-stage larva emerges [42]. This is infective to copepods and smaller crustaceans (transport/paratenic hosts) upon ingestion. Fish predating on these animals become infected with the third-stage larva. Sprat and herring will often act as an important paratenic host as they obtain infection by ingesting third-stage larvae contained in copepods, and cod will then acquire infection when predating on these clupeids [43, 44]. Cod will often carry infections in the liver. When fish are ingested by a marine mammal, such as the seal, the worm will moult twice and attain the adult stage in the stomach of the final host [42]. The highly expanding grey seal population in the Baltic Sea during the latest decades [18, 45] is responsible for a marked increase of infections with *C. osculatum* third-stage larvae in cod livers ([13, 17, 20, 21, 46, 47, 48–50]). It has previously, in the 1950s, during an earlier period with a large Baltic grey seal population, been observed that the liver tissue of Baltic cod became emaciated due to the heavy burdens of *C. osculatum* third-stage larvae [51, 52] exactly as was described during the present epidemic [53]. Occurrence of this nematode larva in Baltic cod is clearly an eminent indicator for occurrence and size of the seal population.

*Hysterothyla[cium aduncum* is a marine nematode having its adult stage in the fish, e.g. the eelpout, cod, flounder, or sea trout [14, 22, 35], although cod may act as an intermediate/paratenic host as well [54]. Eggs are delivered to the sea, where they infect smaller crustaceans (copepods, amphipods, mysids, isopods) [55] acting as intermediate hosts. Fish become infected by feeding on these intermediate/transport hosts [54]. Smaller fish can obtain infection with third-stage larvae (if the infecting larvae are small at the time of infection) and will transfer the worms to larger predatory fish upon predation. If the larvae at the time of infection are large, the worms will moult twice and attain maturity directly in the fish digestive tract. This parasite is common in the Baltic cod [34, 56] but appears to be less prevalent when compared to the occurrence in North Sea cod [57, 58] and may affect some hosts if they are heavily infected.

The very thin nematode *Capillaria gracilis* has a very wide geographical distribution. Light infections of this species, using the cod as a final host, have been noted in the intestine, mainly rectum, of Baltic cod. Various invertebrates, such as insect larvae of chironomids, are intermediate host [59], and the presence of the parasite in the cod may reflect the ingestion of these invertebrates.

## 3. Conclusion

The Baltic cod population is vulnerable as it is constantly being exposed to extremely varying hydrographic and biological conditions due to its relatively stationary life cycle in the Baltic Sea. Due to its biological and economical importance of this cod stock, it is monitored and surveyed by the use of classical methodologies within fishery biology. Additional information and higher resolution of parameters, such as local migration within the Baltic and food intake (quantitative and qualitative), will be obtained in a parasitological examination of the fish. It is recommended to include regular parasitological investigation of Baltic cod in future survey programmes. The present work points to use of digenean metacercariae in the cod as indicators of performance in the western Baltic (black spot disease caused by *C. lingua*) and performance in the eastern Baltic (eye fluke disease caused by the genus *Diplostomum*). The presence of intestinal parasites such as the acanthocephalan *E. gadi* reflects the ingestion of amphipods as these crustaceans are obligate intermediate hosts. Occurrence of the anisakid nematode larva *A. simplex* in the flesh, organs, and body cavity of Baltic cod indicates feeding on a specific herring stock. These herrings are migrating seasonally from the North Sea to the Baltic for spawning. The life cycle is not conducted in the Baltic Sea due to the low salinity there, but the import with migrating fish explains the occurrence in stationary Baltic cod. The presence of the cod worm *P. decipiens* and the cod liver worm *C. osculatum* indicates the size of the grey seal population in the Baltic Sea as these nematode species have their adult reproductive stage in the grey seal stomach. The digenean adult hemiurids—comprising *B. crenatus* and *H. luehei*—in the stomach of cod indicate feeding on migrating sprat and herring which have been infected in the western and southern Baltic Sea. The trematode P. atomon occurs in the stomach and intestine of Baltic cod if it has been foraging on amphipods (second intermediate host) in an area where the first intermediate host (*L. saxatilis*) is present. The nematode *Capillaria gracilis* in the rectum of cod indicates that chironomids may be included in the diet of cod. The marine nematode *H. aduncum* (adult in the stomach and intestine) or third-stage larvae in host organs are the least informative species as euryhaline nematode occurs and reproduces in large parts of the Baltic.

## Conflict of interest

The author declares that he has no conflict of interest.


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