Citation for the published paper:
Sven-Gunnar Lunneryd, Maria Kristina Boström. Paul Eric Aspholm. (2015) Sealworm (Pseudoterranova decipiens) infection in grey seals (Halichoerus grypus), cod (Gadus morhua) and shorthorn sculpin (Myoxocephalus scorpius) in the Baltic Sea. Parasitology research. Volume: 114, Number: 1, pp 257-264.
http://dx.doi.org/10.1007/s00436-014-4187-z.

Sealworm (*Pseudoterranova decipiens*) infection in grey seals (*Halichoerus grypus*), cod (*Gadus morhua*) and shorthorn sculpin (*Myoxocephalus scorpius*) in the Baltic Sea

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Abstract

The anisakid nematode *Pseudoterranova decipiens*, known as the sealworm or cod worm, can infect the flesh of several fish species. The parasite causes cosmetic problems for the fish industry and can cause abdominal discomfort if consumed by humans. There are only scattered studies on the abundance or distribution of the sealworm in fish and seals in the Baltic Sea. To remedy this situation, the extent of sealworm infection was investigated in cod (*Gadus morhua*) and shorthorn sculpin (*Myoxocephalus scorpius*) collected along the Swedish coast. A relative presence of the sealworm was also investigated in samples from grey seal (*Halichoerus grypus*) stomachs. Up to 100% of the fish were infected in some of the areas. Sculpin were generally worse infected than cod, both in abundance and prevalence of parasites. General linear models showed a significant correlation between the number of seals in an area and the prevalence of sealworms in cod. There was a sharp decrease of infected fish in areas with salinity lower than 7 ‰. Even though the northern Baltic proper and the southern Bothnian Sea have a high number of grey seals, only one sealworm was found in a sculpin in that region, and none in cod. In grey seal stomachs the sealworm was only found in samples from the central Baltic proper; further north all anisakid nematodes identified in seals were *Contracaecum osculatum*. The results indicate that seal presence drives the distribution in the southern parts of the Baltic and that low salinity, or some other variable which correlates with salinity, limits the distribution in the northern part.

Keywords: Baltic Sea, cod, grey seal, *Pseudoterranova*, sealworm, sculpin.

Introduction

Infection by the larval stages of the parasitic sealworm, *Pseudoterranova sp.*, in commercial fish species has been of great concern in the North Atlantic fisheries (McClelland 2002). So far it has not been raised as an urgent issue in the Baltic Sea area except in the southern parts (Myjak et al., 1994, Szostakowska et al., 2005, Buchmann and Kania, 2012, Nadolna and Podolska, 2014). However, with an increasing population of seals, the parasite's final hosts, there are concerns of an increasing problem. Data on the population of grey seals in the Baltic suggest an annual rate of increase of 7.5% since 1990; (Harding et al. 2007) and in 2013 the counted population on shore was 28,000 (www.rktl.fi). The highest density of grey seals in the Baltic is found between latitudes 58° and 61°, which correspond with ICES subdivision 27 in the north to subdivision 31 in the south (Figure 1). There are also scattered colonies along the Swedish coast in the southern Baltic (Harding et al. 2007). In addition, there is a population of a few thousand harbour seals in subdivisions 24 and 25 (Härkönen & Isakson 2010; Olsen et al. 2010). With a fishing industry in the Baltic depending on cod (*Gadus morhua*), which is a common intermediate host for the parasite, the increasing seal population is a problem.

Pseudoterranova sp. are intestinal roundworms or nematodes belonging to the family *Anisakidae* and can be considered a cosmopolitan genus, with a confusing taxonomy (Paggi et al. 2000). Genetic studies by Buchman and Kania (2012) determined that the nematodes found in cod flesh from the southern Baltic are *Pseudoterranova decipiens*. The sealworm has a complex life cycle, with a free-living stage and three obligate hosts required for the parasite to complete its life-cycle. The eggs are excreted in the faeces of a seal and sink to the sea floor where they hatch into free-living larvae. A benthic invertebrate ingests the larvae. After the infected invertebrate is eaten by a fish, the larvae migrate from the stomach of the fish into the muscle tissue. It is at this stage that the 2-3cm long larvae become clearly visible in the fillets of the fish and create a problem for the fishing industry if the host is a commercially important species. When the fish is ingested by a seal, their definitive host, the parasites continues to moult into an adult stage whose eggs are then released with the seal faeces, and thus the life cycle is completed (McClelland 2001).

Along the Swedish west coast the sealworm is common in both harbour seals (Lunneryd 1991) and in fish (Lunneryd et al. 2001) but in the Baltic Sea there have only been a few reports of sealworms so far. The first major study of the occurrence of anisakid nematodes in Baltic cod, conducted in 1976, showed no records of the sealworm. However, at that time there were very few seals in the southern Baltic, so it was not surprising that there were no sealworms (Grabda 1976). Later studies (Myjak et al. 1994; Szostakowska et al. 2005; Buchmann and Kania 2012) revealed that the sealworm was present in cod caught in ICES subdivision 25 and 26 southern Baltic. In addition, sealworms were also found in low numbers in cod stomachs collected in 2002 and 2003 in the southern Baltic proper and in subdivision 27 (Perdiguero-Alonso 2008). Thulin (1989) did a study of parasites and fish diseases in Swedish waters and found sealworms only in cod caught off the Swedish west coast and not at all in the Baltic Sea, despite extensive sampling. (Buchmann and Kania, 2012) compared the sealworm infection levels in cod collected in 1982-83 from the Bornholm Basin with that in cod collected in 2011, and noted that no nematodes were found during 1982-83 while at least 2% of the samples surveyed in 2011 were infected with 1 to 4 sealworms. The presence of the nematodes in Baltic cod in recent times has been well known among fishermen (several personal communications) but has not been public knowledge in e.g. Sweden until very recently. It is therefore important to collect knowledge about the biology and distribution of this parasite. Factors discussed as determinants of the distribution of sealworms are seal distribution, intermediate host distribution and environmental factors such as temperature and salinity (Measures 1996; Marcogliese 2001a; Hauksson 2011).

The spatial distribution in the Baltic Sea is of special interest because of its uniqueness in being a brackish sea. Salinity has been shown to limit the survival of the sealworm larvae (Measures, 1996). As regards the survival and hatching rates of sealworm eggs in different salinity environments, studies have shown no difference between sea water (35 ‰ salinity), brackish water (17 ‰ salinity) and fresh water, but the larvae were much more sensitive: those hatched in water with higher salinity survived about 10 times as long as those hatched in freshwater (Measures 1996). In the Swedish coastal areas of the Baltic Sea there is a gradient of salinity from around 9‰ in the southern Baltic proper to about 5‰ in the southern Bothnian Sea. In this lower range of salinity in the Baltic Sea, it is not known how well the sealworms survive.

The aim of this study was to examine the relative presence and distribution of sealworms in the middle Baltic Sea. The presence of the sealworm was investigated in cod, a commercially important species, and in shorthorn sculpin (*Myoxocephalus scorpius*), a relatively sedentary species chosen in order to reflect the accumulation of the sealworm population in local waters (Aspholm et al.1995; Midtgaard et al. 2003). Sealworm presence was also examined in seal stomachs collected along the Swedish coast. Variables such as fish length, salinity and seal population density were examined in order to understand how they might influence the distribution of the sealworm.

Materials and Methods

Fish and parasite sampling

Fish were collected along the east coast of Sweden, using different types of gear, such as gill nets, long lines, pots and trawls. Fish lengths were measured to the nearest centimetre. The cod were gutted by the fishermen and either examined fresh or stored on ice before being frozen for later examination. Shorthorn sculpin were all deep frozen for later investigation. No attention was paid to nematodes observed on or in the intestines or livers.

Fish were filleted and skinned with their pectoral and pelvic fins removed. The backbones, the flesh around the fins and the skin were carefully inspected visually for nematodes, using a light table. The fillets of sculpin were sliced thinly for examination on the light table because their musculature is not as transparent as cod musculature. It is important to note that this method does not reveal all nematodes in the flesh (McClelland & Martell 2001; Llarena-Reino 2012), but if applied consistently it can give an accurate relative estimate of their abundance and prevalence. In order to support this consistency, the same light table was used throughout the study and samples were always examined by the same two researchers. There is a probability of of identification error by counting *Anisakis simplex* larvae in the flesh instead of *Pseudoterranova* *decipiens*. However, these larvae are commonly found in the intestines of cod in the southern Baltic (Szostakowska et al. 2005; Nadolna and Podolska 2014). Because *Anisakis simplex* mostly occur in the visceral cavity (ICES 2012 b) and *Pseudoterranova decipiens* in the flesh the chance of mistake is minimized. In cases of uncertainty, nematodes were mounted on slides and, with glycerol as a clearing agent, examined under the microscope.

Abundance is defined as the mean number of sealworms found per fish examined (i.e. uninfected fish are included) and prevalence as the proportion of fish infected (Margolis et al. 1982).

Seals and parasite sampling

Nematode samples consisting of 2,195 specimens were collected from seal stomachs during dietary investigations of by-caught and culled seals (Lundström et al. 2010). The stomachs were deep frozen before the investigation. Samples of up to 50 randomly picked nematodes were taken from each stomach and stored in a mixture of 70 % ethanol and 10-20 % glycerol. The nematodes were mounted on slides for microscopic examination and glycerol was used as a clearing agent to make the nematode cuticle more transparent. The nematode species and life stage were identified by internal characteristics (ICES 1984, 2012a, b).

Models for spatial distribution and infection presence of *Pseudoterranova sp.* in fish

To understand the influence of different variables on the spatial distribution and infection patterns of the sealworm in cod and shorthorn sculpin, we used a generalized additive model (GAM), with a backward stepwise approach. This method was chosen as it compensates for the unbalanced sampling design between different seasons and collection areas (Hastie & Tibshirani 1990). The explanatory variables used were year, length of the fish, gear type (net, hook, pot), salinity and a seal density index. The seal density was derived from a function of the number of hauled out seals in nearby colonies and the distance between sampling areas and haul-outs. The distance was scaled between 1 (0 km) and 0 (100 km) using a cosine function:

seal density index= relative haul out size×cosine (distance×π/(max distance/2)).

Only haul outs closer than a max distance of 100 km to the sampling areas were used as this distance was assumed to cover the absolute majority of grey seal movements from a haul out (Sjöberg & Ball 2000). The seal density index was also calculated with the assumption that a single grey seal is twice as important a vector for the transmission of the nematodes as a harbour seal where the two species occur in the same area (Brattey 1990). The estimate of haul out size was an average of the maximum number of counted seals during the moult period for the years 2006 to 2010. The index was log-transformed before used it in the analyses.

First we used a quasi-Poisson distribution with the log transformed abundance, i.e. sealworms per individual fish, used as the nominal response variable. A quasi-Poisson model is more suitable than the classical Poisson distribution when dealing with over-dispersed data (Wood, 2006). Secondly we used a zero-inflated negative binomial distribution (ZINB) with the abundance of sealworms per individual fish used as the nominal response variable; this differs from the quasi-Poisson model in that all zero values are removed. The models were fitted with the function 'gam' in the ‘mgvc’ package in R-project (R-project 2011).

The full models for cod and shorthorn sculpin were formulated thus:

Response variable = Year + s(Length) + (Geartype) + s(Salinity) + s(Seal Density Index)

where s is an isotropic smoothing function (thin plate regression spline). In order to simplify the interpretation of the results, the maximum degrees of freedom (measured as number of knots, k) allowed to the smoothing functions were limited for the variables length, salinity, seal density index (k=4). Gear code was treated as a factor. Gear type was excluded from the ZINB model for shorthorn sculpin as the majority of the shorthorn sculpin were caught in nets and there was not enough replication for the other gear types.

Results

Parasites in fish and seals

In total 1,043 cod and 665 shorthorn sculpin were examined for the larval stage of sealworm (Table 1). Two of the cod samples, X1 and X2 (in table 1 and figure 1), were collected offshore and ended up as outliers and were therefore excluded from further analyses. 966 cod were thus included in the analyses. All samples were collected along the Swedish coastline, from the southern Baltic up to the southern part of the Bothnian Sea, between 2004 and 2011. A total of 2,029 nematodes were found in the musculature and all nematodes examined were sealworms. A total of 2,169 anisakid nematodes were identified in subsamples from 82 grey seal stomachs, however only six samples contained sealworms. Of the 20 sealworms found, two were in life stage L3, two in L4 and 16 in the adult stage. The sealworms were found in seals collected in ICES subdivision 25 and 27 (Table 2).

Spatial distribution and infection patterns

The final models for sealworm abundance in shorthorn sculpin and cod are presented in Tables 3 and 4. All the effects attained in the final models are highly significant. For the quasi-Poisson models for both shorthorn sculpin and cod, the variables year, length, salinity and seal density index all had a significant effect on the predicted abundance. For shorthorn sculpin the final model explained 76.9 % and for cod 35.5 % of the abundance. In the zero inflated negative binomial models, the variables length, salinity and seal density index had a significant effect on the predicted abundance for both species. For shorthorn sculpin the final model explained 71.4 % and for cod 27.1 % of the abundance. Because shorthorn sculpin is a more sedentary species than cod, it is more relevant to show the effects of the significant univariate predictors included in the final version of the quasi Poisson model, where zero values were included (Figure 2). For cod we present the predictors for the zero inflated negative binomial distribution, excluding the zero values (Figure 3). For both species there is a trend of more nematodes with longer fish length, with higher salinity and (for the southern part of the Baltic only) with higher seal density index. An obvious trend further north with decreasing salinity is lower infection rate despite high seal density index. In the south the pattern is more complex but the infection rates increase with higher seal density. Analysis of the residuals did not reveal any major departure from the main model assumptions of normality and homogeneity of variance.

Discussion

This investigation of anisakid nematodes in grey seals in the Baltic Sea confirms that the species is a final host for sealworms in the area. This picture is confirmed by a Polish study of 9 seals stranded and by-caught in Poland. The most common species was *C. osculateum*, 59.3% of all specimens, sealworm contributed with 31% while the number of *A. simplex* was less than 1% (Skrzypczak et al., 2014). In grey seals from Finnish waters where all identified nematodes were *Contracaecum osculatum* (Valtonen et al. 1988). *C. osculatum* was the dominant species in this study as well and constituted 97 % of all identified nematodes. *Anisakis simplex* was found in one seal from the southern Baltic. Sealworms were not found at all in grey seals from the northern parts of the study area but in subdivision 27 they were found in 14% of the samples (in 37 seals).

For the two fish species investigated, the most important factors for the abundance of the nematodes were salinity, seal density and fish length. The models for sculpin explained more of the variation of abundance of nematodes than the models for cod. A reason for this may be that sculpins are more sedentary (sculpins lack a swimbladder), whereas cod can and do migrate long distances (Otterlind 1985). In any given sampling area the cod caught may be from genetically different stocks with different migration patterns (Ovegård et al. 2012). This means that different individuals found in one area may have been subjected to different infection rates. Some individuals may have spent most of their lives in areas with little or no infection risk. Fish that are more sedentary near a coastline with a higher seal density have a higher likelihood of infection (Haukson 2002; 2011). An example of this is the two samples, X1 and X2, which were caught with a trawl far from the mainland (30 km and 70 km respectively) and which showed a low infection rate (Table 1).

The most obvious parameter driving the distribution of the sealworms was salinity. At around 7‰, in areas north of Öland, there is an apparent decrease in the abundance of nematodes. There are many variables both biotic and physiological variables that correlate with the salinity gradient in the Baltic Sea; hence salinity itself may not be the main reason for the limit in distribution. It seems reasonable to look for a biological factor, such as the distribution of the parasites' intermediate hosts, whose distribution in turn is linked to salinity. The number of invertebrate species declines in the Baltic with declining salinity (Bonnsdorf 2006) and it could be lack of suitable hosts with lower salinity which is important. The sealworm uses both benthic meiofauna hosts and epibenthic copepods in the first larval stage. Later it uses macro-invertebrate hosts, such as amphipods, mysids etc. for the second larval stage (McClelland

2002). Different macro invertebrates have different importance in transmitting the sealworm to fish, e.g. mysids have been shown to be more important than amphipods (Margoglise 2001). No sealworms were found in cod north of latitude 59°, but one was found in a sculpin from the Bothnian Sea, in subdivision 30. This means that the parasite occurs in the area but it is rare. This observation was verified by local fishermen who on rare occasions have noticed the sealworm in cod fillets. The higher latitudes showed the lowest abundance of sealworm despite the highest seal density index (Table 2).

In the Baltic there is an increasing conflict between seals and the inshore fishery using nets, long lines and traps. Damage to catch and gear caused by seals in Sweden was estimated to cost the industry more than five million euro in 2004 and the majority of this was caused in the Baltic (Westerberg et al. 2006). The economic impact from the sealworm problem was not included in this figure. Contacts within the fishing industry are unable to say what amount of landed cod is destroyed because of sealworm contamination or sold for a lower price due to extra labour costs during filleting. We do know that the problem affects mainly the inshore fishery, a sector of the fishing industry that already has a problem with seals, as they catch the highest amount of infected fish (Westerberg et al. 2006).

Studies of seal diets in the Baltic Sea show that there has been a change from pelagic fish species, especially herring and sprat, to a more benthic diet, with cod becoming an important prey in recent years (Lundström et al. 2010). This change could influence the prevalence of the sealworm as it increases the probability of an infected cod being predated. It is anticipated that parasite prevalence will be given more attention in the future and that further studies are needed. The seal population will probably continue to increase and as a consequence cause higher sealworm infection rates in commercially valuable fish.

Acknowledgements

We thank Olle Karlsson (Swedish Museum of Natural History) for providing seal haul-out data, Karl Lundström for collecting nematodes from the seal stomachs and Massimiliano Cardinale for analytical support. Also, thanks to the people who assisted in collecting fish over the years, both university students and commercial fishermen. This study was financed by the Swedish Agency for Marine and Water Management, the Seals and Fisheries Program and Nybelins Fund. All work was carried out with approved applications submitted to the Ethical Board on Animal Experiments.

References

Andersen K (2001) A note on the variation in sealworm (*Pseudoterranova decipiens*) infection in shorthorn sculpin (*Myoxocephalus scorpius*) with host age and size at two locations in Norwegian inshore waters. NAMMCO Sci Publ 3: 39-46

Aspholm PE, Ugland KI, Jødestøl KA, Berland B (1995) Sealworm (*Pseudoterranova decipiens*) infection in harbour seals (*Phoca vitulina*) and potential intermediate fish hosts from the outer Oslofjord. Int J Parasit 25: 367-373

Bonsdorff E (2006) Zoobenthic diversity-gradients in the Baltic Sea: continuous post-glacial succession in a stressed ecosystem. J Exp Mar Biol and Ecol 333: 383–391

Brattey J, Bishop, CA Myers, RA (1990) Geographic distribution and abundance of *Pseudoterranova decipiens* (Nematoda: Ascaridoidea) in the musculature of Atlantic cod *Gadus morhua* from Newfoundland and Labrador. Can Bull Fish Aquat Sci 222: 67-82

Buchmann K, and Kania P (2012) Emerging *Pseudoterranova decipiens* (Krabbe, 1878) problems in Baltic cod, *Gadus morhua* L., associated with grey seal colonization of spawning grounds. J Fish Dis 35: 861-866

Grabda J (1976) The occurrence of anisakid nematode larvae in Baltic cod (*Gadus morhua callaris* L) and the dynamics of their invasion. Acta Ichtyol et Piscat VI: 3-20

Hastie T, Tibshirani R (1990) Generalized Additive Models. Chapman and Hall London

Hauksson E (2002) Decreases in sealworm (*Pseudoterranova sp* (p) abundance in short-spined sea scorpion (*Myoxocephalus scorpius scorpius*) following declines in numbers of seals at western Iceland. Pol Biol 25: 531–537

Hauksson E (2011) The prevalence, abundance, and density of *Pseudoterranova sp* (p) larvae in the flesh of cod (*Gadus morhua*) relative to proximity of grey seal (*Halichoerus grypus*) colonies on the coast off Drangar, northwest Iceland. J Mar Biol Article ID 235832 8pp

Hårding KC, Härkönen T, Helander B, Karlsson O (2007) Status of Baltic grey seals: Population assessment and extinction risk. NAMMCO Sci Publ 6: 33-56

Härkonen, T and Isakson, E (2010) Status of harbour seals *(Phoca vitulina)* in the Baltic proper. NAMMCO Sci Publ 8: 71-76

ICES (1984) *Phocascaris/Contracaecum* larvae (Nematoda) in fish. Smith J. W. and Wootten R. ICES Identification Leaflets for Diseases and Parasites of Fish and Shellfish. Leaflet No 9: 4 pp

ICES (2012) a *Pseudoterranova* larvae ("codworm"; Nematoda) in fish. Revised and updated by Matt Longshaw ICES Identification Leaflets for Diseases and Parasites of Fish and Shellfish. Leaflet No 7: 4 pp

ICES (2012) b *Anisakis* larvae ("herringworm"; Nematoda) in fish. Revised and updated by Matt Longshaw ICES Identification Leaflets for Diseases and Parasites of Fish and Shellfish. Leaflet No 8: 4 pp

Llarena-Reino, M., Gonzalez, A. F., Vello, C., Outeirino, L., and Pascual, S (2012) The accuracy of visual inspection for preventing risk of *Anisakis spp*. infection in unprocessed fish. Food Control 23: 54-58

Lundström K, Hjerne O, Lunneryd SG, Karlsson O (2010) Understanding the diet composition of marine mammals: grey seals (*Halichoerus grypus*) in the Baltic Sea. ICES J Mar Sci 67 (6): 1230-1239

Lunneryd SG (1991) Anisakid nematodes in the harbour seal *Phoca vitulina* from the Kattegat-Skagerrak and the Baltic. Ophelia 34: 105-115

Lunneryd SG, Ugland KI, Aspholm PE (2001) Sealworm (*Pseudoterranova decipiens*) infection in the benthic cottid (*Taurulus bubalis)* in relation to population increase of harbour seal *(Phoca vitulina*) in Skagerrak, Sweden. NAMMCO Sci Publ 3: 47-55

Marcogliese DJ (2001a) Distribution and abundance of sealworm (*Pseudoterranova decipiens*) and other anisakid nematodes in fish and seals in the Gulf of St Lawrence: potential importance of climatic conditions. NAMMCO Sci Publ 3: 113-128

Marcogliese DJ (2001b) Review of experimental and natural invertebrate hosts of sealworm (*Pseudoterranova decipiens*) and its distribution and abundance in macro invertebrates in eastern Canada. NAMMCO Sci Publ 3: 27-37

Margolis L, Esch GW, Holmes JC, Kuris AM, Shad GA (1982) The use of ecological terms in parasitology. J Parasit 68:131-133

McClelland G (2002) The trouble with sealworms (*Pseudoterranova decipiens*) species complex (Nematoda): a review. Parasitology 124 Suppl: S 183-203

Measures LN (1996) Effect of temperature and salinity on development and survival of eggs and free-living larvae of sealworm (*Pseudoterranova decipiens*). Can J Fish Aquat Sci 1996, 53(12): 2804-2807, doi: 101139/f96-241

Midtgaard T, Andersen K, Halvorsen O (2003) Population dynamics of sealworm, *Pseudoterranova decipiens* sensu lato, in sculpins, *Myoxocephalus scorpius* from two areas in Norway between 1990 and 1996. Parasit Res 89(5): 387-392

Myjak P, Szostakowska B, Wojciechowski J, Pietkiewicz H, Rokicki J (1994) Anisakid larvae in cod from the southern Baltic. Sea Archive of Fishery and Marine Research 42: 149-161

Nadolna K, Podolska, M. (2014) Anisakid larvae in the liver of cod (*Gadus morhua*) L. from the southern Baltic Sea. J Helmint. 88: 237-246

Olsen MT, Andersen SM, Teilmann J, Dietz R, Edren SMC, Linnet A, Härkonen T (2010) Status of the harbour seal *(Phoca vitulina)* in Southern Scandinavia. NAMMCO Sci Publ 8: 77-94

Otterlind G (1985) Cod migration and transplantation experiments in the Baltic. J Appl Ichthyology 6

Ovegård M, Berndt K, Lunneryd SG (2012) Condition indices of Atlantic cod (*Gadus morhua*) biased by capturing method. ICES J Mar Sci, doi101093/icesjms/FSS145

Paggi L, Mattiucci S, Gibson D I, Berland B, Nascetti G, Cianchi R, Bullini L (2000) *Pseudoterranova decipiens* species A and B (Nematoda, Ascaridoidea): nomenclatural designation, morphological diagnostic characters and genetic markers. Syst Parasitol 45(3): 185–197

Perdiguero-Alonso D, Montero F E, Raga J A, Kostadinova A (2008) Composition and structure of the parasite faunas of cod, *Gadus morhua* L (Teleostei: Gadidae), in the North East Atlantic. Parasites Vectors 1-23 doi:101186/1756-3305-1-23

R-project D C T (2011) A language and environment for statistical computing R. Foundation for statistical computing Vienna Austria

Sjöberg M, Ball J P (2000) Grey seal, *Halichoerus grypus*, habitat selection around haul-out sites in the Baltic Sea: bathymetry or central-place foraging? Can J Zool 78: 1661-1667

Skrzypczak M, Rokicki J, Pawliczka I, Najda K, Dzido J (2014) Anisakids of seals found on the southern coast of Baltic Sea. Acta Parasitologica, 59: 165-172

Szostakowska B, Myjak P, Wyszyn´ski M, Pietkiewicz H, Rokicki J (2005) Prevalence of anisakin nematodes in fish from Southern Baltic Sea. Polish J of Microbiology 54:41–45

Thulin J, Höglund J, Lindesjö E (1989) Fisksjukdomar i kustvatten (Fish diseases in coastal waters of Sweden, in Swedish with English summary). Naturvårdsverket informerar 99-0459652-2: 1-126

Valtonen ET, Fagerholm HP, Helle E (1988) *Contracaecum osculatum* (Nematoda: Anisakidae) in fish and seals in Bothnian Bay (northeastern Baltic Sea). Int J Parasitol 18: 365-370

Westerberg H, Lunneryd SG, Wahlberg M, Fjälling A (2006) Reconciling Fisheries Activities with the Conservation of Seals through the Development of New Fishing Gear: A Case Study from the Baltic Fishery—Grey Seal Conflict. Am Fish Soc Symp 49: 1281–1291

Wood SN (2006) Generalized Additive Models: An introduction with R Chapman and Hall Boca Raton Florid

Legends to Figures

Fig. 1. Map with positions where cod and shorthorn sculpin were collected. Large bold figures indicate ICES area. The details for each position are found in table 2.

Fig. 2. Each plot represents the effects of the predictors on the abundance of sealworm in shorthorn sculpin estimated in the final Quasi Poisson model, where zero values were included (see table 3). The ranges of the variables are represented on the x-axis and the probability (logic scale) of the abundance of sealworm is represented on the y-axis. The dotted lines represent the 95 % confidence intervals around the response curve.

Fig. 3. Each plot represents the effects of the predictors on the abundance of Sealworm in cod estimated in the final Zero Inflated Negative Binominal distribution model, excluding the zero values. (see Table 4). The ranges of the variables are represented on the x-axis and the probability (logic scale) of the abundance of sealworm is represented on the y-axis. The dotted lines represent the 95 % confidence intervals around the response curve.

Tables with their legends

Table 1. Sampling areas with positions and collection details. No. fish is the number of fish examined. Prevalence is the proportion of infected fish, abundance is the mean number of sealworms found in all fish in a sample. Salinity in the sampling area is based on data from HELCOM. Seal density index is derived from a cosine function of the number of hauled out seals in nearby colonies and the distance to the colony.

Fish species	No	Subdivision	No. fish	Prevalence	Abundance	SD	Salinity	Seal density index
Shorthorn sculpin	1	30	18	0.06	0.06	0.24	5.2	6.8
	2	29	10	0	0	0	6.4	6.8
	3	29	56	0	0	0	5.7	7.1
	4	27	52	0.02	0.02	0.14	6.4	7.8
	5	27	59	0.25	0.34	0.66	6.7	7.7
	6	28	95	0	0	0	7.7	5.8
	7	27	50	0.38	0.72	1.2	7.1	5.6
	8	27	50	0.36	0.62	1.05	7.4	5.3
	9	27	129	0.22	0.43	0.52	7.3	5.5
	10	27	34	0.12	0.18	6.65	7.5	5.6
	11	25	48	0.79	6.4	6.47	7.5	6.4
	12	25	12	0.83	4.25	9.53	7.9	6
	13	24	52	1	14.17	1.36	8.6	6
Cod	3	29	106	0	0	0	6.3	7.1
	4	27	71	0.03	0.03	0.17	6.4	7.8
	7	27	50	0.34	0.5	0.76	7	5.6
	14	28	56	0.05	0.07	0.32	7.4	4.9
	9	27	52	0.08	0.08	0.27	7.2	5.5

15	27	60	0.12	0.15	0.48	7.2	5.6
16	25	123	0.46	1.23	2.03	7.5	6
17	25	57	0.14	0.81	4.4	7.6	6.1
11	25	157	0.5	1.44	2.5	7.5	6.4
18	25	85	0.31	0.65	1.45	7.7	5.3
19	25	50	0.18	0.2	0.45	7.8	3.7
13	24	50	0.74	3.08	3.52	8.6	6
20	24	49	0.57	1.49	2.36	8.3	5.4
X1	24	47	0.17	0.21	2.04	10.2	5.7
X2	24	30	0.2	0.43	0.46	9.6	2.8

Table 2. The number of grey seal stomachs examined in each ICES subdivision. Number of seals with the sealworm present and the number of nematodes for each species identified.

ICES	**No seals**	**No seals with**	**Number nematodes**			
		Sealworm	Sealworm	*C. osculatum*	*A. simplex*	Unidentified
23	1	0	0	0	51	0
24	1	0	0	8	0	0
25	1	1	8	6	0	0
27	37	5	12	1 078	0	15
28	2	0	0	38	0	0
29	8	0	0	132	0	1

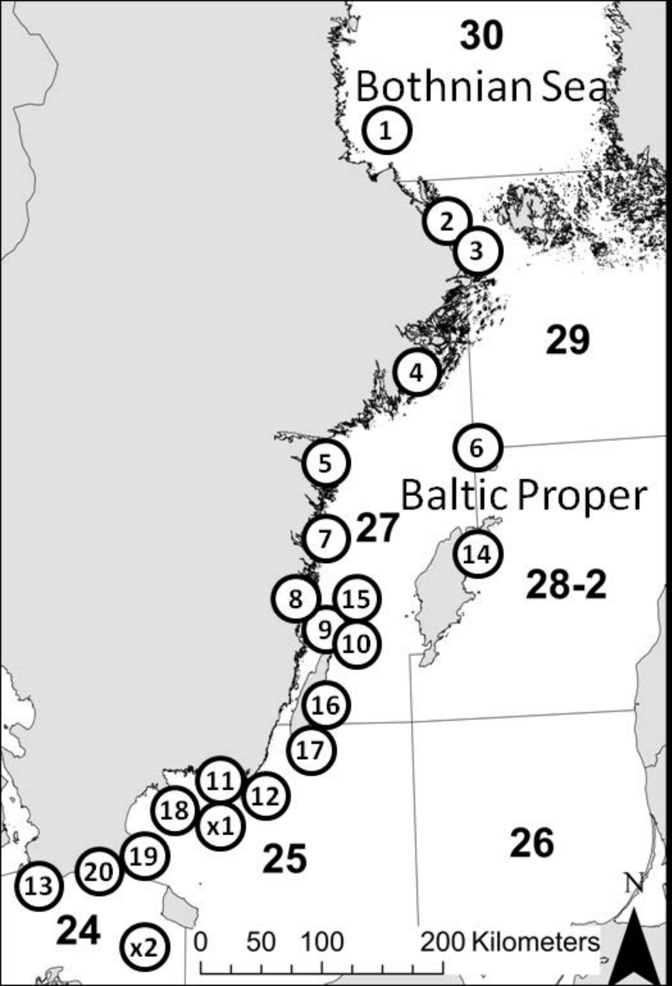
30	28	0		0	844	0	10
Total	**82**	**6**		**20**	**2 098**	**51**	**26**

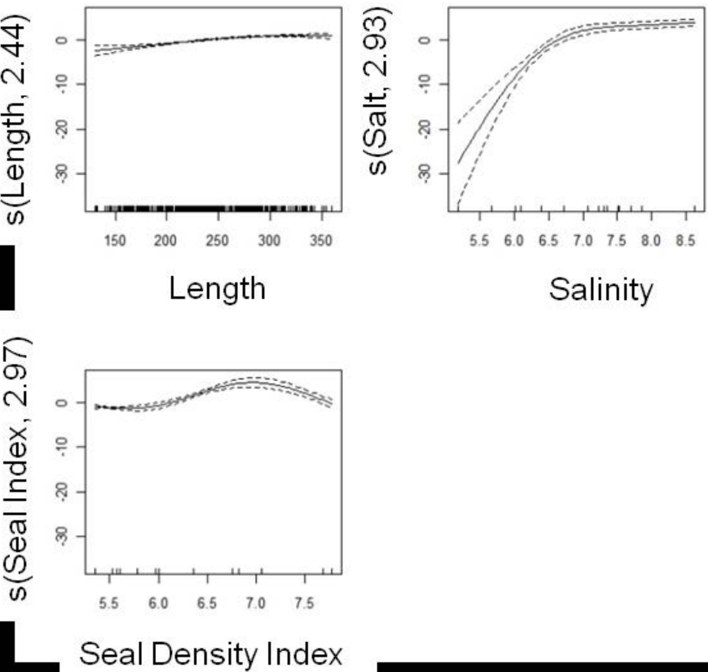
Table 3. Alternative quasi Poisson models fitted for estimating the influence of predictive factors on the abundance of sealworm in shorthorn sculpin and cod. The initial model included year, length of the fish, gear type (net/ hook/ pot), salinity and a seal population density index. DEV is the total deviance explained by the models. GCV is the generalized cross validation value (i.e. lower GCV indicated more parsimonious models).

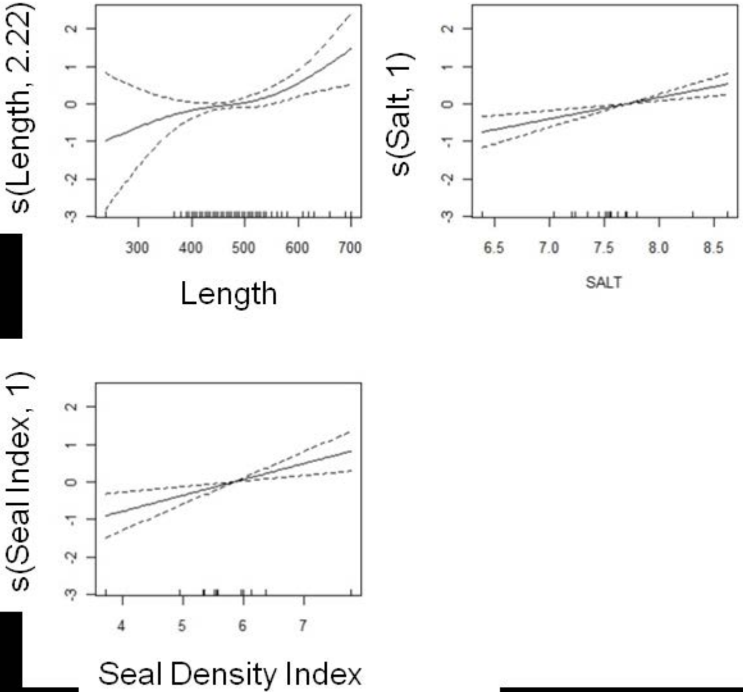
Species	**Model**	**Covariates**	**DEV**	**GCV**
Sculpin	QP1	year, length, gear type, salinity, seal density index	76.9	1.6444
Sculpin	QP2	year, length, salinity, seal density index	76.9	1.6431
Cod	QP1	year, length, gear type, salinity, seal density index	38.9	1.6213
Cod	QP2	year, length, salinity, seal density index	35.5	1.6993

Table 4. Alternative zero inflated negative binomial distribution models fitted for estimating the influence of predictive factors on the abundance of sealworm in shorthorn sculpin and cod. The initial model included year, length of the fish, gear type (net/ hook/ pot (excluded for sculpin)), salinity and a seal density index (the potential fish density pressure of seals, see explanation in text). DEV is the total deviance explained by the models. UBRE is the generalized cross validation value (i.e. lower UBRE indicated more parsimonious models).

Species	**Model**	**Covariates**	**DEV**	**UBRE**
Sculpin	ZINB1	year, length, salinity, seal density index	71.5	-0.62071
Sculpin	ZINB2	length, salinity, seal density index	71.4	-0.63003
Cod	ZINB1	year, length, gear type, salinity, seal density index	29.8	-0.59062
Cod	ZINB2	length, gear type, salinity, seal density index	29.8	-0.59782
Cod	ZINB3	length, salinity, seal density index	27.1	-0.60044


30
Bothnian Sea
1
2
3
29
4
6
5
Baltic Proper
27
7
14
28-2
8
15
9
10
16
17
11
12
18
x1
19
25
26
20
13
24
x2
0
50
100
200 Kilometers
N


s(Length, 2.44)
0
-10
-20
-30
150
200
250
300
350
Length
s(Salt, 2.93)
0
-10
-20
-30
5.5
6.0
6.5
7.0
7.5
8.0
8.5
Salinity
s(Seal Index, 2.97)
0
-10
-20
-30
5.5
6.0
6.5
7.0
7.5
Seal Density Index


s(Length, 2.22)
Length
300
400
500
600
700
s(Salt, 1)
SALT
6.5
7.0
7.5
8.0
8.5
s(Seal Index, 1)
Seal Density Index
4
5
6
7
2
1
0
-1
-2
-3