CORYNOSOMA ACANTHOCEPHALANS IN THEIR PARATENIC FISH HOSTS IN THE NORTHERN BALTIC SEA

SINISALO T.* & VALTONEN E.T.*

Summary:

Cystacanth stages of three *Corynosoma* (Acanthocephala) species, *C. strumosum* and *C. semerme*, and a new species in the Bothnian Bay, *C. magdalenii*, were studied in the fourhorn sculpin (*Myoxocephalus quadricornis*) in 1996-1997. The length of the trunk and proboscis differentiated the three species in the fish. The stability of the *Corynosoma* infection was studied by comparing the present results with those collected from the same areas (central and coastal) in 1977-1982 (Valtonen, 1983a). As *C. magdalenii* and *C. strumosum* were not separated at that time, the joint infections of these two species (called "*C. strumosum*") were compared. The stability of infection with *C. semerme* in the central Bothnian Bay was noticeable (prevalences were 82.9 in earlier period and 81.9 % in later period), while the prevalences of "*C. strumosum*" in the same areas had decreased (21 and 13.5 %, respectively). This is suggested to be due to the disappearance of the marine bull-rout, *Myoxocephalus scorpius*, from the Bothnian Bay during the 1990s due to an overall decline in salinity throughout the Baltic Sea. In the coastal area *Corynosoma* infection was clearly lower than in central area in both periods.

KEY WORDS : paratenic hosts, seals, *Corynosoma*, stability, *Myoxocephalus quadricornis*, Baltic Sea.

Résumé : LES ACANTHOCÉPHALES DU GENRE *CORYNOSOMA* CHEZ LEUR HÔTE PARATÉNIQUE DU NORD DE LA MER BALTIQUE

En 1996-1997, nous avons étudié les stages cystacanthes de trois espèces de *Corynosoma* (Acanthocephala), *C. strumosum* et *C. semerme*, ainsi qu'une nouvelle espèce *C. magdalenii* parasite du chabot à quatre cornes (*Myoxocephalus quadricornis*) dans le golfe de Bothnie. Les longueurs du tronc et du proboscis permettent de différencier les trois espèces de parasites. La stabilité temporelle de l'infection par *Corynosoma* est étudiée en comparant nos résultats à ceux obtenus dans la même zone géographique (centrale et côtière) en 1977-1982 (Valtonen, 1983a). Comme *C. magdalenii* et *C. strumosum* n'étaient pas différenciées à cette époque, elles ont été groupées sous l'appellation "*C. strumosum*" pour les comparaisons. La stabilité de l'infestation par *C. semerme* dans la partie centrale du golfe de Bothnie est remarquable (les prévalences étaient de 82,9 % lors de la première étude et 81,9 % pour notre étude), alors que les prévalences de "*C. strumosum*" dans la même zone géographique ont diminué de 21 % à 13,5 %. Il est suggéré que cela puisse être lié à la disparition du chabot à épines courtes, *Myoxocephalus scorpius*, du golfe de Bothnie durant les années 1990 à la suite d'une baisse générale de la salinité dans la Mer Baltique. Dans la zone côtière, et pour les deux périodes d'étude, l'infestation par *Corynosoma* était nettement inférieure à celle trouvée dans la zone centrale.

MOTS CLÉS : hôte paraténique, phoque, *Corynosoma*, stabilité, *Myoxocephalus quadricornis*, Mer Baltique.

INTRODUCTION

Three *Corynosoma* species occur simultaneously and mature in two seal species, the ringed seal (*Phoca hispida botnica*) and the grey seal (*Halichoerus grypus*), in the Bothnian Bay, the most northern part of the Baltic Sea (Nickol *et al.*, 2002; Valtonen, unpubl.). *Monoporeia affinis*, the amphipod intermediate host, ingests *Corynosoma* acanthors released from the intestines of the seals. In the amphipods the acanthors develop into cystacanth larvae and are then transferred by fish paratenic hosts to the seals.

* Department of Biological and Environmental Science, University of Jyväskylä, P.O. Box 35 (YAC341), 40351 Jyväskylä, Finland.
Correspondence: Tuula Sinisalo.
Tel.: +358-40-755 2055 – Fax: +358-14-260 2321.
E-mail: tsinisal@byti.jyu.fi

Corynosoma strumosum (Rudolphi, 1802) Lühe, 1904 and *C. semerme* (Forsell, 1904) Lühe, 1905 are the most widely distributed acanthocephalan species among oceanic seal populations (Dailey, 1975; Popov *et al.*, 1980; Shults, 1982; Strauss *et al.*, 1991; Measures & Gosselin, 1994). However, *C. magdalenii* (Montreuil, 1958) has rarely been reported. It was described from a few grey seals captured in the Gulf of St. Lawrence in Canada (Montreuil, 1958) and from three ringed seals from the Gulf of Finland (Delyamure *et al.*, 1980). Later *C. magdalenii* was found in grey seals of the southwestern archipelago of Finland around the Åland Islands (Nickol *et al.*, 2002). The cystacanth stage of *C. magdalenii* has so far been reported only from the anadromous brook charr (*Salvelinus fontinalis*) in eastern Canada (Frimeth, 1987 a, 1987b).

Only *C. strumosum* and *C. semerme* were recorded in earlier studies of fish and seals from the Bothnian Bay (Helle & Valtonen, 1980, 1981; Valtonen 1983a, 1983b).

However Nickol *et al.* (2002) recently redescribed the adult stages of *C. magdalenii* and *C. strumosum*. We suggest that the previously unclear description of *C. strumosum* in relation to *C. magdalenii* caused confusion and that *C. magdalenii* was consequently not detected.

The occurrence and abundance of definitive, paratenic and intermediate hosts of *Corynosoma* in the Baltic Sea have all varied during recent decades. Ringed seal numbers collapsed to about 2,500 individuals in the 1980s (Helle, 1986; Härkönen & Lunneryd, 1992). Both the ringed and the grey seals suffered from hunting and reproduction abnormalities caused by pollution, which has led to a lowered reproductive capacity (Helle, 1980, 1986; Harding & Härkönen, 1999). After hunting was prohibited in 1988 the stocks of both seal species recovered. In 1996, the population sizes of both seal species were about 5,500 individuals each, and increasing grey seal colonies in particular have been recorded in central and northern parts of the Baltic Sea (Harding & Härkönen, 1999). Ringed seal is a resident species in the Bothnian Bay (Helle & Valtonen, 1981) but grey seals only visit the area in the spring (Helle, pers. comm.).

The intermediate host of *Corynosoma*, *Monoporeia affinis*, is the most common benthic crustacean among the macrozoobenthos of the Bothnian Bay and its abundance has been reported to vary in the coastal area of the Bothnian Bay but to be more stable in the deeper central areas of the sea (Andersin *et al.*, 1978; Valtonen, 1983a; Lindström, 1991; Wikner, 1996).

In the study area of the Bothnian Bay the brackish water has a salinity of 3 ‰ (Haapala & Alenius, 1994). The fish fauna includes about 30 reproducing species, most of which are of freshwater origin, but several marine fish species also reproduce in the area (Andreasson & Petersson, 1982). Among the changes in fish fauna in the area from 1980s to present is the disappearance of the bull-rout from the Bothnian Bay (Timola, pers. comm., Bothnian Bay Research Station, University of Oulu). In the earlier study of Valtonen (1983a) on the paratenic hosts of *Corynosoma* species in the Bothnian Bay, the bull-rout was the most intensively parasitized fish.

The aim of this study is three fold:

- To examine population differences between *C. magdalenii* and *C. strumosum* at their cystacanth stages.
- To study the stability of *Corynosoma* infections in the Bothnian Bay by comparing the results of the present findings with those collected in 1977-1982 from the same area and using the same sampling procedure and methods as in the study of Valtonen (1983a).
- To study the local distribution of *Corynosoma* species in fish in the Bothnian Bay by comparing central and coastal areas.

MATERIALS AND METHODS

Fish samples were collected between August 1996 and June 1997. A total of 340 fourhorn sculpins (*Myoxocephalus quadricornis*) were caught by gill nets from the coastal area A (see Fig. 1) (the mean depth approx. 11 m) and central area B (see Fig. 1) (the mean depth approx. 40-45 m) of the Bothnian Bay in the northern part of the Gulf of Bothnia. Two samples were collected from the coastal area in June (n = 29) and October (n = 52) 1997, and three samples from the deeper central area in August 1996 (n = 107) and June (n = 38) and October (n = 114) 1997. Sampling methods and areas were the same as in the studies of Valtonen (1983a). In addition, we examined 42 bull-rout (*Myoxocephalus scorpius*) between March and April 1999 from the southern part of the Gulf of Bothnia, area C (see Fig. 1), where the salinity is double that in the Bothnian Bay (7 ‰). Internal organs and the mesenteries of the sculpins were examined for parasites. After relaxation in water for at least two hours, the parasites were conserved in 70 % ethanol, stained with Mayer's carmalum, dehydrated in ethanol, cleared in xylene, and mounted in Canada balsam. *Corynosoma* specimens (60 specimens of *C. semerme*, 33 specimens of *C. magdalenii* and seven specimens of *C. strumosum*) were identified by measuring the length of their trunk and proboscis and recording the extent of the trunk spines (Nickol *et al.*, 2002). Canonical discriminant functions were used to differentiate the species at the cystacanth stage.

Mean abundance, mean intensity and prevalence were calculated according to Bush *et al.* (1997). The occurrence of *Corynosoma* assemblages in the coastal and in the central areas was compared by Pearson χ^2 -test. The relationship between the habitats (coastal *vs* central) and the time periods (1977-1982 *vs.* 1996-1997) for the *Corynosoma* infections was examined using logistic regression analysis. The automated forward stepwise variable selection procedure was applied to select the model that best fitted the data (Forward LR). Variable selection was repeated using the automated backward stepwise elimination procedure (Backward LR). By comparing hierarchical sets of regression models, the significance of each interaction and main effect was calculated using likelihood ratio statistics if forward and backward methods did not result in the same model. All statistical analyses were performed using SPSS Professional Statistics 10.0 (Norusis/SPSS Inc. 1997).

In this study, we use the term "*C. strumosum*" to refer to both *C. magdalenii* and *C. strumosum* when comparing the two study periods and when studying the stability of the infection.

Fig. 1. – Map of the Bothnian Bay and its location within the Baltic Sea. Research areas: A, B and C are given as also 20 and 40 metre isobaths.

RESULTS

The mean trunk and proboscis length of *C. semerme*, *C. strumosum* and *C. magdaleni* cystacanths diverged in the paratenic hosts (Table D). *C. strumosum* has, on average, the longest trunk, whereas *C. semerme* is clearly the shortest, differentiating *C. semerme* from *C. strumosum*. The range of the trunk length of *C. strumosum* partly overlaps that of *C. magdaleni*. The mean length of the proboscis was shortest in *C. magdaleni* (420 μm) and longest in *C. strumosum* (590 μm). The three *Corynosoma* species were differentiated by the length of the trunk and proboscis (Fisher's linear discriminant analysis, Wilk's Lambda = 0.241, $\chi^2 = 279.451$, $p < 0.001$, function 1; eigenvalue = 2.245, function 2; eigenvalue = 0.278). The percentages of correct classifications were: 97.5 % for *C. semerme*, 100 % for *C. strumosum* and 81.8 % for *C. magdaleni* (Table I, Fig. 2).

The proportion of *C. semerme*, *C. strumosum* and *C. magdaleni* individuals in the fourhorn sculpins in 1996-1997 were 98.3 %, 0.3 % and 1.4 %, respectively (total no of worms being 2,516) (Table II). The prevalences of *C. semerme*, *C. magdaleni* and *C. strumosum* infections were 81.9 %, 8.9 % and 3.1 % in the central area and

9.9 %, 2.5 % and 0 % in the coastal area, respectively. Majority (70 %) of the sculpins in the central area were infected with only *C. semerme* (Table III). The most common double infection was the *C. semerme*-*C. magdaleni* assemblage. Except one fish, fourhorn sculpins infected with either *C. strumosum* or *C. magdaleni* were also infected with *C. semerme* (Table III). The occurrence of *C. semerme* (Pearson $\chi^2_1 = 94.926$, $p < 0.001$) and *C. semerme*-*C. magdaleni* assemblages (Pearson $\chi^2_1 = 5.156$, $p = 0.023$) were both significantly greater in the central area than in the coastal waters. *C. strumosum* occurred only in the central area (Table III).

When studying the relationship between the habitats and the time periods, the logistic regression model for *C. semerme* in the Bothnian Bay included the terms "habitat" (change in log likelihood if term removed = 10.317, df = 1, $p = 0.001$), "time period" (change in log likelihood if term removed = 7.680, df = 1, $p = 0.006$) and "interaction of habitat and time period" (change in log likelihood if term removed = 4.883, df = 1, $p = 0.027$). The prevalence of the *C. semerme* infection in the central area was nearly the same in the two time periods but in the coastal area the level of the infection had decreased significantly from 23 % to 9.9 % (Table IV). In the case of "*C. strumosum*" the main effects ("habitat" and

Trunk length (mm)	Cystacant stage			Adult stage	
	n	x	range	x	range
<i>C. semerme</i>	60	1.9	1.5-2.3	4.0**	3.0-5.0**
<i>C. strumosum</i>	7	3.1	2.5-3.5	6.5*	5.0-7.0*
<i>C. magdalenii</i>	33	2.7	1.7-3.6	4.7*	3.6-5.3*

Proboscis length (µm)	Cystacanth stage			Adult stage	
	n	x	range	x	range
<i>C. semerme</i>	60	510	340-580	□	500-600**
<i>C. strumosum</i>	7	590	510-680	653*	624-700*
<i>C. magdalenii</i>	33	420	300-500	476*	440-500*

Table I. – The length of the trunk and proboscis (mm) of the cystacanths of three *Corynosoma* species in the Bothnian Bay in 1996-1997. * from Nickol *et al.*, 2002, ** from Petrochenko, 1958, □ = unavailable.

Fig. 2. – The length of the proboscis and trunk (mm) of the three *Corynosoma* species in fourhorn sculpins (*M. quadricornis*) in the Bothnian Bay in 1996-1997. Each symbol represents a single parasite specimen, x = *C. semerme*, ▼ = *C. strumosum* and □ = *C. magdalenii*.

Parasite	No of worms	%	Range	Mean abundance
<i>C. semerme</i>	2,472	98.3	1-60	7.27
<i>C. strumosum</i>	8	0.3	1	0.02
<i>C. magdalenii</i>	36	1.4	1-3	0.11

Table II. – The proportion of *Corynosoma* species in fourhorn sculpins in the Bothnian Bay in 1996-1997 (number of fish = 340).

“time period”) were significant. The logistic regression model included the term “habitat” (change in log likelihood if term removed = 29.132, df = 1, $p < 0.001$) and the term “time period” (change in log likelihood if term removed = 10.142, df = 1, $p = 0.001$). The prevalence of “*C. strumosum*” decreased in both areas (Table IV).

The bull-routs ($n = 42$) from the southern part of the Gulf of Bothnia harboured only two species: *C. semerme* (prevalence 54.7 %, mean intensity 4.5) and *C. strumosum* (prevalence 9.5 %, mean intensity 1.5).

DISCUSSION

The three *Corynosoma* species that occurred in grey seals from the Archipelago Sea in the southern part of the Gulf of Bothnia (Nickol *et al.*,

	Coastal (n = 81)		Central (n = 259)		p
	%	n	%	n	
<i>C. semerme</i>	8.6	7	70.3	182	< 0.001
<i>C. magdalenii</i>	1.2	1	0	0	NS
<i>C. semerme</i> + <i>C. magdalenii</i>	1.2	1	8.5	22	0.023
<i>C. semerme</i> + <i>C. strumosum</i>	0	0	2.7	7	NS
<i>C. semerme</i> + <i>C. magdalenii</i> + <i>C. strumosum</i>	0	0	0.4	1	NS

Table III. – The occurrence of *Corynosoma* species and their assemblages in fourhorn sculpins (*M. quadricornis*) from the coastal and the central areas of the Bothnian Bay in 1996-1997. The frequencies of the *Corynosoma* assemblages were tested by Pearson χ^2 -test and its significance level (p) are given.

<i>C. semerme</i>	1977-1982 Central	1996-1997 Central	1977-1982 Coastal	1996-1997 Coastal
No fish	515	259	296	81
Prevalence (%)	82.9	81.9	23.0	9.9
Mean Abundance	10.1	9.4	1.2	0.3
Number of parasites	5,227	2,445	359	27
Max / fish	77	60	44	16
<i>"C. strumosum"</i>	1977-1982 Central	1996-1997 Central	1977-1982 Coastal	1996-1997 Coastal
Number of the fish	515	259	296	81
Prevalence (%)	21.0	13.5	9.1	2.5
Mean Abundance	0.3	0.2	0.1	0
Number of parasites	159	49	37	2
Max/ fish	6	3	3	1

Table IV. – Comparison of *C. semerme* and "*C. strumosum*" infections between the periods of 1996-1997 and 1977-1982 in fourhorn sculpins from the Bothnian Bay. "*C. strumosum*" included both *C. magdalenii* and *C. strumosum*.

2002) and in ringed seals from the Bothnian Bay in the northern part of the Gulf of Bothnia (Valtonen & Helle, unpubl.) were also all found in the paratenic fish host, the fourhorn sculpin in the Bothnian Bay. *Corynosoma semerme* was the dominant *Corynosoma* species in ringed seals throughout the 1970s to 1990s (Helle & Valtonen, 1980, 1981; Valtonen, 1983b; Valtonen & Helle, 1988; Valtonen, unpubl.). The proportion of *C. semerme* from all acanthocephalan cystacanths in the fourhorn sculpin was similar in 1996-1997 to that in 1977-1982 (98.3 % and 97.0 %, respectively (see Valtonen, 1983a). The respective figures for "*C. strumosum*" were 1.7 % in 1996-1997 compared to 3.0 % in 1977-1982.

The trunk length of *C. semerme* cystacanths differed distinctly from the other two *Corynosoma* species, whereas the cystacanths of *C. magdalenii* and *C. strumosum* were not easily separated. Many anatomical features of *C. strumosum* were similar to but larger than those of *C. magdalenii*. However, the most conspicuous differences between *C. strumosum* and *C. magdalenii* at the cystacanth stage, the shorter proboscis, the more slender trunk and the greater extent of ventral trunk spines in *C. magdalenii* were sufficient to differentiate the two species in the paratenic host (see also Nickol *et al.*, 2002). The occurrence of the parasites in the paratenic host is dependent on intermediate and definitive host abundance (Brattey *et al.*, 1990; Lunneryd, 1991). In the Bothnian Bay, ringed seals (*Phoca hispida baltica*) are encountered abundantly in the central area but they visit coastal waters during a few weeks in October-November (Helle & Valtonen, 1981). The other definitive host, the grey seal (*Halichoerus grypus*) (Nickol *et al.*, 2002), visits the Bothnian Bay regularly in the spring. However during the latter part of the 1990s, summer colonies of grey seals increased in the study

area and especially in the area of our coastal site (Helle, pers. comm.). The population of the intermediate host, the amphipod *Monoporeia affinis*, has been more stable in the deeper central area than in the shallower coastal area throughout the studies (Andersin *et al.*, 1978; Lindström, 1991; Wikner, 1996). The lower prevalence and abundance of *Corynosoma* infections in the coastal area compared to the central area arises from the greater variability and more patchy occurrence of both the definitive seal hosts and the intermediate amphipod host in the coastal area.

The prevalence and mean abundance of *C. semerme* in the deeper study site was nearly the same in the two periods (separated by 14 years, whole time scale of these studies extending over 21 years). It shows that *C. semerme*, the most common marine acanthocephalan species in seals (Dailey, 1975), has adapted to the brackish water ecosystem and survived through the varying history of the Baltic Sea following the latest glacial period (Winterhalter *et al.*, 1981). *Corynosoma strumosum* is also a widespread species in oceanic seals (Shults, 1982; Measures & Gosselin, 1994). However, this study shows that *C. magdalenii* is more prevalent than *C. strumosum* in the Bothnian Bay.

In the definitive host, *Corynosoma* worms mature in two to three weeks (see Valtonen & Helle, 1982). The life cycle of the intermediate host, *M. affinis*, is two years in the Bothnian Bay (Andersin *et al.*, 1984), whereas the paratenic host, fourhorn sculpin, lives up to eight years (Timole & Luotonen, 1986). We suggest that the stability of the *Corynosoma* population in the area is maintained mainly in their paratenic fish hosts. We conclude that paratenic hosts are a reservoir of *Corynosoma* individuals stabilizing the variation in *Corynosoma* populations, which explains the similarity in *C. semerme* infections throughout the 21 years covered by this study. However, the prevalence of "*C. strumosum*" in the fourhorn sculpins decreased between the two periods. The reason for this is most probably the disappearance of the preferred paratenic fish host of "*C. strumosum*", the bull-rout, from the 1990s onwards (Timola, pers. comm.).

The disappearance of *M. scorpius* is a result from the overall decline in salinity throughout the Baltic Sea during the last 25 years; major saline water inflow pulses have not been repeated since 1976 (Wikner, 1996). The bull-rout is a marine species (Valtonen & Crompton, 1990), whereas the fourhorn sculpin is a stenothermal species that favours brackish water rather than a marine environment (Timola *et al.*, 1984) and it is even found in several lakes in Finland as glacial relict (Savolainen, 1975). It is also supported by our findings of *C. strumosum* in *M. scorpius* in the more southern and marine Gulf of Bothnia, even though *C. magdalenii* is also common in the area (Nickol *et al.*, 2002).

Host specificity of *Corynosoma* species at the paratenic host level is low (Nickol, 1985). So far we cannot define the role of the fourhorn sculpin in transferring *C. magdaleni* and *C. strumosum* to seals. However, *Corynosoma* infections were much lower in all other paratenic fish species than in fourhorn sculpin during the study of Valtonen (1983a). In 1996-1997 we found only four *C. magdaleni* cystacanths from four ruffe (*Gymnocephalus cernuus*) (151 examined) and three *C. strumosum* from Baltic herring (*Clupea harengus membras*) (n = 904) (Sinisalo *et al.*, unpubl.). Other fish species were not studied in 1996-1997.

The stability of *C. semerme* over the 21 years period compared to the decrease of "*C. strumosum*" at the same time is interesting. Why did the disappearance of the bull-rout not also affect the *C. semerme* population? During the previous period 82.9 % of all *C. semerme* specimens were found in *M. quadricornis* and only 11.8 % of them in *M. scorpius*. In the case of "*C. strumosum*", 39.0 % of the specimens were found in *M. quadricornis* and 30.1 % in *M. scorpius* (Valtonen 1983a). Thus the disappearance of the bull-rout is having a more powerful effect on the population of "*C. strumosum*" than on that of *C. semerme*. The complex life cycles of the parasites depend largely on the trophic interactions between several different hosts (Minchella & Scott, 1991). Therefore, the constant presence of parasites in a host will provide extensive information on the stability in an ecosystem (Marcogliese & Cone, 1997). Even though we studied the *Corynosoma* infections only during two periods, both periods were covered by extensive data sets collected from exactly the same areas and the same seasonal timing. In a multixenous parasite species, where different stages of parasites occur in three trophic levels of the ecosystem, the temporal variation in the compound communities is stabilized much better than in monoxenous parasites. In the case of *Corynosoma*, the long living cystacanth stages in paratenic hosts act as a stabilizing reservoir of parasites that can infect the definitive hosts.

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