Journal of Helminthology (2006) **80,** 193–197 DOI: 10.1079/JOH2006352

Influence of climatic changes on the parasites of Atlantic cod *Gadus morhua* off coastal Labrador, Canada

R.A. Khan* and C.V. Chandra

Department of Biology and Ocean Sciences Centre, Memorial University of Newfoundland, St John's, Newfoundland, Canada, A1B 3X9

Abstract

A study was conducted in 2000 and 2003, following the collapse of the commercial fishery in 1990, to compare metazoan parasites of Atlantic cod *Gadus morhua*, captured off coastal Labrador, with samples taken in 1980 and 1986. Fish were captured by otter trawl offshore in the North Atlantic Fish Organisation subarea 2J. Parasites were removed from the digestive tract, stained, identified and compared between the different groups. Both the prevalence and mean abundance of trematodes, larval nematodes and *E. gadi* were significantly lower in fish taken in 2000 and 2003 than in 1980. While mean values of trematodes and nematodes declined in 1986, those of *Echinorhynchus gadi* remained unchanged in 1986 and 1990. Four-year-old cod sampled in 1990 harboured significantly fewer *E. gadi* than older age groups. The most commonly occurring trematodes included *Podocotyle reflexa*, *Lepidapedon elongatum*, *Derogenes varicus* and *Hemiurus levinseni* while the larval nematode, *Anisakis* sp. was predominant. Comparison of offshore samples taken in 2000 and 2003 with others taken in previous years suggests an overall decline of parasites coincident with a change in climatic conditions, the absence of a major food source, namely capelin *Mallotus villosus*, of cod and ultimately the decline of the Labrador population.

Introduction

Several distinct stocks or populations of Atlantic cod *Gadus morhua* have been reported off the coast of Newfoundland and Labrador based on tagging and recapture, variation in growth rate, time to attain maturity, meristics, time of spawning, biochemical and genetical approaches and parasites as biological tags (Templeman, 1974; Cross & Payne, 1978; Appy & Burt, 1982; Khan & Tuck, 1995). During the late 1980s, catch rates of cod declined progressively in total biomass over the entire continental shelf to its lowest level ever recorded (Rose & O'Driscoll, 2002). Overexploitation, predation by seals (*Phoca* spp.), climatic change or a combination of all these factors were suggested as causes for the decline, especially off the coast of Labrador where the stock has become virtually extinct. Decline of the stocks culminated ultimately in a moratorium on fishing during the early 1990s and since this time, recovery remains uncertain. However, an offshore monitoring programme has continued, involving surveys by otter trawls and other methods. As the prevalence and mean abundance of metazoan parasites infecting the digestive tract were substantial, especially in samples originating off the coast of Labrador, it appeared feasible to ascertain whether or not parasite levels remained constant after the decline of the cod biomass. Consequently, the present study was conducted to compare the metazoan parasites of cod captured in the North Atlantic Fisheries Organisation (NAFO) subarea 2J in 2000 and 2003. In addition, a comparison was made with parasite data that had been collected in 1980, 1986 and 1990 from cod taken in the same general area with samples taken in 2000 and 2003 to ascertain whether there were any differences or trends.

Materials and methods

Atlantic cod, 5–7 years of age, were captured by otter trawl about 190 m deep during the month of November, 2000 ($n = 24$) and in January, 2003 ($n = 23$) off the coast of

Fax: 709 737 3220
E-mail: rakhan@mun.ca

Labrador in the NAFO subarea 2J (fig. 1). Fish were frozen at −30°C and necropsied about 3 months later. At necropsy, a record was made of organisms present in the stomach and also the degree of fullness. Parasites were removed subsequently from the digestive tract following conventional parasitological methods and preserved in 70% ethanol with 10% of glycerol. Trematodes were stained with either carmine and/or Mallory's triple stain before mounting in Canada balsam for subsequent identification. Nematodes and an acanthocephalan were cleared in either Rubin's fluid or glycerol and mounted also in Canada balsam prior to identification.

Logarithmic transformation of parasite data was performed to remove any variability. One-way ANOVA was used to compare abundance and then followed by a post-hoc test (Scheffe's F-test, $P \leq 0.05$) if the initial analysis was significant. Additionally, a comparison was made of data taken in 2000 and 2003 with that of cod captured in the same general area in the years 1980 ($n = 52$) and 1986 ($n = 66$) (Khan & Tuck, 1995; Lee & Khan, 2000). Chi-square and Fisher's exact probability tests were used to compare prevalence between fish groups. Prevalence (%) and mean abundance ($\bar{x}$) are used in accordance with the terminology suggested by Bush *et al.* (1997).

Results

There were variations in the quantity and type of prey ingested and also in parasite levels in Atlantic cod sampled off coastal Labrador in 2000 and 2003. Sixty seven percent of the cod caught offshore in 2000 lacked food in the stomach while 40% contained remnants of crustaceans, beaks of unidentified squid and fragments of unidentified fish. An additional study conducted in the same area in 2003 revealed all fish had been feeding on crustaceans, primarily gammarid amphipods and shrimp (*Pandalus borealis*) but their stomachs were not distended. The prevalence and abundance of parasites from the digestive tract of Atlantic cod displayed some variation at the offshore Labrador location between 2000 and 2003 but also indicated significant differences between two of the groups (table 1). Both the prevalence and abundance of trematodes and an acanthocephalan, *Echinorhynchus gadi* increased between years 2000 and 2003 while the nematodes, mainly larval forms, were similar between years. The latter comprised primarily of *Anisakis* sp. which occurred in all fish harbouring the larvae (72%) while *Hysterothylacium aduncum* was observed less often (28%). Four species of trematodes, namely *Podocotyle reflexa*, *Hemiurus levinseni*, *Derogenes varicus* and *Lepidapedon elongatum* were detected in cod but none was dominant either as a percentage of fish examined or as a percentage of the total number of digeneans collected.

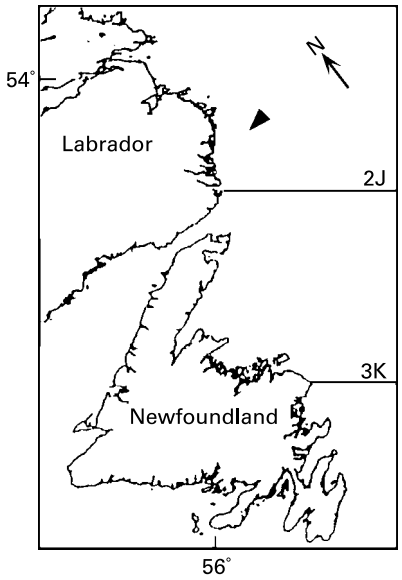

Fig. 1. Location of the North Atlantic Fisheries Organisation (NAFO) subarea 2J (arrowhead) where samples of Atlantic cod were taken in 1980, 1986, 2000 and 2003. The 3K refers to another NAFO fishing subarea.

Comparison of data from the present study with two others that were conducted in 1980 and 1986 on cod sampled in the same general area of NAFO subarea 2J offshore showed a dramatic decline in parasite loads in 2000 and 2003. All major taxa of parasites decreased significantly in mean abundance and prevalence from 1980 to 2000 and 2003 (table 1). Moreover, the decline in the abundance of trematodes and nematodes occurred initially in 1986 and showed either no or only a slight change in 2000 and 2003. However, the abundance of the acanthocephalan, *E. gadi,* declined from 1980 and 1986 (fig. 2). Additionally, the prevalence of all taxa, initially recorded as 100%, declined eventually to lower levels in the years 2000 and 2003 (table 1). These results suggest that Atlantic cod in the area from 1986 onwards either changed their feeding strategy or some of their prey that were intermediate hosts were unavailable.

Discussion

There is sufficient evidence to indicate that environmental conditions in the late 1980s and onwards changed off the Labrador coast affecting some species of invertebrates, marine fish and seabirds. Drinkwater (2004) reported that during the decade of the 1990s the ice cover was extensive and colder than normal water temperatures prevailed in the Labrador Sea. These extreme oceanographic conditions were associated with a decline in zooplankton abundance which in turn might have affected the food availability of capelin *Mallotus villosus* that have virtually disappeared from coastal Labrador (Carscadden *et al.*, 2002a). When a comparison is made of the range of prey chosen during the 1980s, fewer groups were consumed or available as a food source (see Lilly, 1984; Lilly *et al.*, 1984; Lee & Khan, 2000). Atlantic cod and seabirds such as the black-legged kittiwake *Rissa tridactyla* which feed primarily on capelin, experienced reproductive failure coincident with the decline of the capelin stock off the Labrador coast

https://doi.org/10.1079/JOH2006352 Published online by Cambridge University Press

Table 1. Prevalence (%) and mean abundance ($\bar{x}$) of metazoan parasites from the digestive tract of Atlantic cod sampled off the coast of Labrador, North Atlantic Fisheries Organisation (NAFO) division 2J, in 1980, 1986, 2000 and 2003.

		Year			
Infection data	Parasite taxa	1980	1986	2000	2003
Prevalence (%)	Trematoda	100	3	17	48
	Nematoda	100	55	75	35
	Acanthocephala	100	90	33	60
Abundance ($\bar{x} \pm$ s.e.)	Trematoda	29.3 ± 3.3*	0.2	0.9 ± 0.1	1.4 ± 0.3
	Nematoda	16.1 ± 1.8*	1.6 ± 0.3	3.6 ± 0.5^{+}	0.6 ± 0.1
	Acanthocephala	12.6 ± 1.4*	10.3 ± 3.3*	0.9 ± 0.1^{+}	3.1 ± 0.6

*Significantly different ($P \leq 0.05$) from all other groups but not from each other.
$^{+}$Significantly different ($P \leq 0.05$) from 2003.

(Carscadden *et al.*, 2002b; Rose & O'Driscoll, 2002). It was reported that capelin distribution shifted southwards as a result of changing environmental conditions most likely related to food and temperature (Carscadden *et al.*, 2002b). Consequently, the diet of cod has shifted to a variety of less nutritive and opportunistic prey since the 1990s (only 7 of 3383 stomachs had capelin) and stomach indices declined from a fully extended state during the 1970s and 1980s to 0.2 to 0.4 (Rose & O'Driscoll, 2002). Capelin, which is rich in lipid, represents an energy source and is essential for growth and reproduction. Its absence in the diet of cod off coastal Labrador probably affected cod health, sexual maturity and survival. Additionally, the mean weight of Arctic char *Salvelinus alpinus*, an anadromous species that also feeds on capelin, declined during this period off Labrador (Dempson *et al.*, 2002). Moreover, stocks of the northern shrimp *P. borealis* and spider crab *Chionoecetes opilio* which were once major food sources of cod during the winter prior to this time, have increased to levels for increased commercial exploitation (Lilly *et al.*, 2000; D. Taylor, unpublished data). Consequently, changing oceanographic conditions have most likely affected a great part of the food chain off the coast of Labrador including the metazoan parasites in the digestive tract of cod.

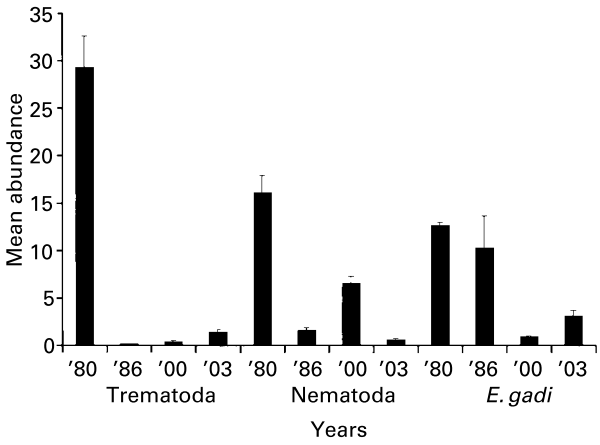

Fig. 2. Mean abundance ($\bar{x} \pm$ s.e.) of Trematoda, Nematoda and *Echinorhynchus gadi* (Acanthocephala) from the digestive tract of Atlantic cod sampled in the North Atlantic Fisheries Organisation (NAFO) subarea 2J at intervals from 1980 to 2003.

The present study has revealed that in cod 5 years old and older, none of the four species of trematodes was dominant in 2000 and 2003. In contrast, trematodes that occurred in cod captured offshore in 1980 and 1986 were composed primarily of *H. levinseni* (48%) and *D. varicus* (46%) and less of *P. reflexa* (5%) and *L. elongatum* (1%) (Khan & Tuck, 1995; Lee & Khan 2000). Previous studies on cod have reported that species of *Podocotyle* and *Lepidapedon* were more prevalent in fingerling and yearling stages whereas *H. levinseni* and *D. varicus* were predominant in older fish (Polyansky, 1955; Hemmingsen & MacKenzie, 2001). Moreover, Appy & Burt (1982) observed that in a sample of 739 Atlantic cod examined from eastern Canadian waters, 84 and 90% were infected with *D. varicus* and *H. levinseni*, respectively, while *L. elongatum* occurred in 39% and species of *Podocotyle* were rare. Juvenile cod normally acquire the infections primarily from crustaceans whereas older fish become infected after feeding on prey such as capelin that are infected with the parasites (Polyansky, 1955; Valtonen *et al.*, 1983). Most trematodes occurring in the digestive tract have a limited life span and, consequently, their presence in cod probably occurs after continual ingestion of infected hosts (Hemmingsen & MacKenzie, 2001). Capelin was a major prey of cod living off the eastern coast of Canada including coastal Labrador during most of the year except winter and overlapping autumn and spring (Lilly, 1984; Lilly *et al.*, 1984). During this time, they switched to crustaceans such as gammarids, pink shrimp *P. borealis* and the spider crab *C. opilio*. The absence of capelin in the diet of cod, in 2000 and 2003, coinciding with the decline in abundance and lack of dominance of the four species of trematodes, was probably associated with dependence on crustaceans as prey. A decrease in the levels of larval anisakid nematodes and the acanthocephalan, *E. gadi*, was also connected with a change in feeding habits since crustaceans are the main intermediate hosts from which these parasites are acquired (Polyansky, 1955; Valtonen *et al.*, 1983).

The low abundance of parasites in the digestive tract of cod in the present study suggests that their use as a bioindicator of stocks during climatic change might still be feasible. A previous study had reported that both the prevalence and abundance of parasites were significantly

https://doi.org/10.1079/JOH2006352 Published online by Cambridge University Press

greater off coastal Labrador than those from adjacent geographical populations (Khan & Tuck, 1995). In contrast to a progressive decline in cod parasites off coastal Labrador over two decades, the levels of parasites were significantly different in a small ($n = 15$) sample taken from an isolated inlet in 2000 (R.A. Khan & C.V. Chandra, unpublished data). Gilbert Bay (50°35′N, 56°0′W) is located adjacent to the offshore collection area and ice-covered for six months of the year. Studies conducted recently reported that the population is isolated from stocks in offshore Labrador (Ruzzante *et al.*, 2000; Morris & Green, 2002). Cod, of comparable length, were captured during August 2000 at a depth of 10 m, frozen in dry ice, subsequently thawed and examined for food and parasites in the digestive tract. Capelin occurred in all samples and shrimp *Pandalus borealis* but mysids less often (<20%). The mean abundance of all trematodes and *E. gadi* was 22.8 + 2.5 and 18.9 + 2.1, respectively. Both values were significantly greater than those in cod taken offshore later that year but similar to the mean values recorded in 1980 (see fig. 2 and table 1). However, no difference was observed in the abundance of larval anisakine nematodes between the two sites within the inlet and offshore in 2000, but both were significantly lower than that in 1980. Although four species of trematodes were observed in these fish, as noted previously in offshore samples of cod, their composition differed. The dominant trematode species in Gilbert Bay was *P. reflexa* infecting all cod whereas *L. elongatum* (47%), *H. levinseni* (35%) and *D. varicus* (21%) occurred less often. In spite of the slight difference in the species composition of trematodes, these results, based on major taxa of gastrointestinal metazoan parasites, suggest that cod inhabiting Gilbert Bay were not affected by climatic changes that occurred in samples captured in offshore Labrador.

Several studies have also reported the use of parasites as tags to distinguish distinct fish stocks assuming that environmental conditions remained stable (Mackenzie, 1983). There are instances of parasites increasing in abundance unrelated to environmental change, such as larval anisakines in cod that were attributed to an increase in seal populations (Chandra & Khan, 1988; Brattey *et al.*, 1990; McClelland *et al.*, 1990). Hemmingsen & MacKenzie (2001) cited two reports of a decline of parasites in cod living in the Baltic Sea, one associated with a decrease in larval nematodes caused by fewer seals than in previous years. The second study cited a decrease in the prevalence and intensity of the acanthocephalan, *E. gadi* attributed either to fewer crustacean intermediate hosts or changes in salinity and pollution levels noted in other studies (Khan & Thulin, 1991). However, it is unlikely that salinity or pollution had any influence on the decline of parasite levels in cod off Labrador since salinity appeared to be stable (3.2%) and contaminants negligible based on the absence of industrial development. It is concluded that climatic change is likely to be responsible for the decline of capelin, the dominant food of cod and ultimately in the decrease in parasite levels in cod sampled off coastal Labrador in the new millennium.

Acknowledgements

This paper was presented at the Black Forest Symposium entitled "Environmental and ecological parasitology: the impact of global change" held in Freudenstadt, Germany, Spring 2005. The authors are grateful to Messrs W. Edison and B. Greene of the Department of Fisheries and Oceans, St John's, Newfoundland for providing cod samples and also appreciate the assistance of Mr R. Finken who kindly prepared the map and graphs and Ms S. Wall for typing the manuscript. This study was supported by funding from the Natural Sciences and Engineering Council of Canada. RAK is grateful to Dr B. Sures for his invitation and support to participate in this Symposium.

References

Appy, R.G. & Burt, M.D.B. (1982) Metazoan parasites of cod, *Gadus morhua* L. in Canadian Atlantic waters. *Canadian Journal of Zoology* **60**, 1573–1579.

Brattey, J., Bishop, C.A. & Myers, R.A. (1990) Geographic distribution and abundance of *Pseudoterranova decipiens* (Nematoda: Ascaroidea) in the musculature of Atlantic cod, *Gadus morhua* from Newfoundland and Labrador. *Canadian Bulletin of Fisheries and Aquatic Sciences* **222**, 67–82.

Bush, A.O., Lafferty, K.D., Lotz, J.M. & Shostak, A.W. (1997) Parasitology meets ecology on its own terms: Margolis *et al.*, revisited. *Journal of Parasitology* **83**, 575–581.

Carscadden, J.E., Frank, K.T. & Leggett, W.C. (2002a) Ecosystem changes and the effects on capelin (*Mallotus villosus*), a major forage species. *Canadian Journal of Fisheries and Aquatic Sciences* **58**, 73–85.

Carscadden, J.E., Montevecchi, W.A., Davoren, G.K. & Nakashima, B.S. (2002b) Trophic relationships among capelin (*Mallotus villosus*) and seabirds in changing ecosystem. *ICES Journal of Science* **59**, 1027–1033.

Chandra, C.V. & Khan, R.A. (1988) Nematode infestation of fillets from Atlantic cod, *Gadus morhua*, off eastern Canada. *Journal of Parasitology* **74**, 1038–1040.

Cross, T.F. & Payne, R.H. (1978) Geographic variation in Atlantic cod, *Gadus morhua*, off eastern North America: a biochemical systematics approach. *Journal of the Fisheries Research Board of Canada* **35**, 117–123.

Dempson, J.B., Shears, M. & Bloom, M. (2002) Spatial and temporal variability in the diet of anadromous Arctic charr, *Salvelinus alpinus*, in northern Labrador. *Environmental Biology of Fishes* **64**, 49–62.

Drinkwater, K.F. (2004) Atmospheric and sea-ice conditions in the Northwest Atlantic during the decade 1991–2000. *Journal of the Northwest Atlantic Fisheries Science* **34**, 1–11.

Hemmingsen, W. & MacKenzie, K. (2001) The parasite fauna of the Atlantic cod, *Gadus morhua* L. *Advances in Marine Biology* **40**, 1–80.

Khan, R.A. & Thulin, J. (1991) Influence of pollution on parasites of aquatic animals. *Advances in Parasitology* **30**, 201–238.

Khan, R.A. & Tuck, C. (1995) Parasites as biological indicators of stocks of Atlantic cod (*Gadus morhua*) off Newfoundland, Canada. *Canadian Journal of Fisheries and Aquatic Sciences* **52**, 195–201.

Lee, E.M. & Khan, R.A. (2000) Length–weight–age relationships, food, and parasites of Atlantic cod (*Gadus morhua*) off coastal Labrador within NAFO Division 2H and 2J–3K. *Fisheries Research* **45**, 65–72.

Lilly, G.R. (1984) Annual variability in the diet of Atlantic cod (*Gadus morhua* L.) off southern Labrador and northeast Newfoundland (Div. 2J + 3K) in autumn, 1977–82. North Atlantic Fisheries Organisation Science Council Report. Document 84/VI/79, Serial No. N868, 18 pp.

Lilly, G.R., Almeida, M.A. & Lear, W.H. (1984) Food of Atlantic cod (*Gadus morhua*) from southern Labrador and eastern Newfoundland (div. 2J, 3K, and 3L) in winter. North Atlantic Fisheries Organisation Science Council Report. Document 84/VI/88, Serial No. N878, 9 pp.

Lilly, G.R., Parsons, D.G. & Kulka, D.W. (2000) Was the increase in shrimp biomass on the northeast Newfoundland shelf a consequence of a release in predation pressure from cod? *Journal of the Northwest Atlantic Fisheries Science* **27**, 45–61.

Mackenzie, K. (1983) Parasites as biological tags in fish population studies. *Advances in Applied Biology* **7**, 251–331.

McClelland, G., Misra, R.K. & Mortell, D.J. (1990) Larval anisakine nematodes in various fish species from Sable Island Bank and vicinity. *Canadian Bulletin of Fisheries and Aquatic Sciences* **222**, 83–113.

Morris, C.J. & Green, J.M. (2002) Biological characteristics of a resident population of Atlantic cod (*Gadus morhua* L.) in southern Labrador. *International Commission for Exploration of the Sea Journal of Marine Science* **59**, 666–678.

Polyansky, Y.I. (1955) Data on fish parasitology of the northern seas of the USSR. *Trudy Zoologicheskogo Instituta Akademiya Nauk SSSR*. 158 pp.

Rose, G.A. & O'Driscoll, R.L. (2002) Capelin are good for cod: can the northern stock rebuild without them? *International Commission for Exploration of the Sea Journal of Marine Science* **59**, 1018–1026.

Ruzzante, D.E., Wroblewski, J.S., Taggart, C.T., Smedbol, R.K., Cook, D. & Goddard, S.V. (2000) Bay-scale population structure in coastal Atlantic cod in Labrador and Newfoundland, Canada. *Journal of Fish Biology* **56**, 431–447.

Templeman, W. (1974) Migration and intermingling of Atlantic cod, *Gadus morhua*, stocks of the Newfoundland area. *Journal of the Fisheries Research Board of Canada* **31**, 1073–1092.

Valtonen, E.T., van Maren, M.J. & Timola, O. (1983) A note on the intermediate hosts of *Echinorhynchus gadi* Zoega, in Muller (Acanthocephala) in the Baltic Sea. *Aquilo Series (Zoology)* **22**, 93–97.

(Accepted 21 February 2006)