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Prevalence of *Myxobolus arcticus* (Myxozoa: Myxosporea) in Five Species of Pacific Salmon in the North Pacific Ocean and Bering Sea

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Abstract. — Five species of Pacific salmon (genus *Oncorhynchus*) captured on the high seas of the North Pacific Ocean and Bering Sea were examined for the freshwater brain myxosporean *Myxobolus arcticus*. In the western North Pacific Ocean, the prevalence of parasite infection was relatively high in chinook (*O. tshawytscha*, 57.5%), sockeye (*O. nerka*, 30.4%), and coho (*O. kisutch*, 18.8%) salmon, but low in chum (*O. keta*, 6.7%) and pink (*O. gorbuscha*, 0%) salmon, being reflected by a mode of freshwater life of host fish before their seaward migration. Distinct regional differences in prevalence were observed in chinook salmon: infected fish were frequently found in the western North Pacific Ocean (especially west of 170°E), but rarely in the eastern North Pacific Ocean and Bering Sea, suggesting the restricted geographical distribution of *M. arcticus* in chinook salmon. The parasite may be useful as a biological indicator to separate the continental origin of high-seas chinook salmon.

Introduction

Myxobolus arcticus Pugachev & Khokhlov, 1979 is a freshwater protozoan parasite of salmonids occurring in Asian Far East and North America facing the North Pacific Ocean and adjacent seas. Although its spores are found in the nervous tissues, the parasite is harmless to host fish. The parasite survives almost throughout the complete life cycle of host fish including their ocean migration. The freshwater oligochaetes *Stylodrilus heringianus* and *Lumbriculus variegatus*, both belonging to the family Lumbriculidae, are known as alternate hosts of *M. arcticus* (Kent et al., 1993; Urawa and Awakura, 1994). Spores are ingested by these oligochaetes following death of adult salmon after spawning in the natal freshwater area. In the gut wall of the oligochaetes the parasite develops to triactinomyxon spores. They are released into water and then infect juvenile salmon hatched in the next spring (Urawa and Awakura, 1994). The parasite has a restricted geographical distribution, which specifies the parasite as an effective biological tag for stock identification of sockeye salmon *Oncorhynchus nerka* (Konovalov, 1975; Margolis, 1982; Quinn et al., 1987; Wood et al., 1987; Moles et al., 1990) and masu salmon *O. masou* (Awakura et al., 1982, 1995; Urawa, 1989). However, this type of utilization was limited to local areas, and little information is available on the occurrence of *M. arcticus* in high-seas Pacific salmon (*Oncorhynchus* spp.)

The present study was conducted to show the prevalence of *M. arcticus* in five species of Pacific salmon collected in the North Pacific Ocean and Bering Sea, and to evaluate the parasite's usefulness as a biological tag for stock identification of high-seas salmon.

Contribution A No. 347 from the Hokkaido Salmon Hatchery.

Materials and Methods

A total of 342 fishes, comprising 83 chinook salmon (*O. tshawytscha*), 156 sockeye salmon, 16 coho salmon (*O. kisutch*), 47 chum salmon (*O. keta*), and 40 pink salmon (*O. gorbuscha*), was caught on the high seas of the North Pacific Ocean and Bering Sea (41-55°N, 157°E-141°W) between May and August in 1982, 1983, 1986 and 1987 by seven Japanese research vessels (*Kaiun maru*, *Hokusei maru*, *Hokushin maru*, *Hoyo maru*, *Iwaki maru*, *Oshoro maru*, and *Wakatake maru*)(see Appendix). Heads or whole bodies of the fishes were frozen after capture, shipped to Japan, and stored under the frozen condition

Table 1. Measurements (μm) of the spores of *Myxobolus arcticus* from the brain of four species of Pacific salmon caught in the western North Pacific Ocean.

Host fish	Number of spores measured	Spore			Polar capsule	
		length	width	thickness	length	width
Chinook salmon	19	13.8±0.5*	8.4±0.5	–	7.6±0.4	2.6±0.4
		(12.9-14.8)	(7.7-9.8)	–	(6.7-8.3)	(2.1-3.2)
Sockeye salmon	25	14.6±0.8	9.0±0.6	7.2±0.3	8.1±0.5	3.1±0.2
		(13.4-16.8)	(7.9-9.9)	(7.0-8.0)	(7.1-9.1)	(3.0-4.0)
Coho salmon	25	14.8±0.6	8.9±0.5	6.9±0.3	8.0±0.4	3.0±0.1
		(13.8-16.0)	(8.0-9.8)	(6.1-7.3)	(7.0-8.7)	(2.9-3.3)
Chum salmon	25	14.7±0.7	9.3±0.4	6.8±0.3	8.4±0.6	3.2±0.2
		(13.0-15.8)	(8.9-9.9)	(6.1-7.4)	(7.1-9.1)	(3.0-4.0)

*Mean±SD (range).

Table 2. Prevalence (%) of *Myxobolus arcticus* in five species of Pacific salmon caught in the North Pacific Ocean and Bering Sea.

Fish	North Pacific Ocean			Bering Sea
	West of 180°	East of 180°	Total	
Chinook salmon	57.5 (19/33)*1	0 (0/5)	50.0 (19/38)	0 (0/45)
Sockeye salmon	30.4 (42/138)	5.6 (1/18)	27.6 (43/156)	ND*2
Coho salmon	18.8 (3/16)	ND	18.8 (3/16)	ND
Chum salmon	6.7 (3/45)	50.0 (1/2)	8.5 (4/47)	ND
Pink salmon	0 (0/37)	0 (0/3)	0 (0/40)	ND

*1Percent prevalence (number of fish infected/number of fish examined).
*2No data.

until dissected for parasite studies. The myxosporean *Myxobolus arcticus* was the most detectable as spores in the medulla oblongata of salmon (Urawa, unpublished data). Then, a slide smear was made from the medulla oblongata removed from each fish and immediately examined at x 200 magnification until the spores were identified or for approximately 5 min if no parasites were found. Throughout the test, the western and eastern North Pacific Ocean is defined as the waters west and east of 180° longitude, respectively. The ecological terms in parasitology used here are in accordance with those of Margolis et al. (1982).

Fresh spores detected from each host species were measured with a calibrated ocular micrometer, according to the guideline proposed by Lom and Arthur (1989).

Results

Description of parasite

The spore of *M. arcticus* is pyriform in front view with sharp tip of valves, and has two polar capsules at the anterior end. Spore dimensions are 12.9-16.8 μm in length, 7.7-9.9 μm in width, and 6.1-8.0 μm in thickness. The polar capsules are cucumiform, being 6.7-9.1 μm long and 2.1-4.0 μm wide (Table 1).

Host range

Myxobolus arcticus was found in chinook, sockeye, coho, and chum salmon, but not in pink salmon (Table 2). Of the infected fish collected from the western North Pacific Ocean, the prevalence was highest (57.5%) in chinook salmon, and lowest (6.7%) in chum salmon.

Geographical distribution

Myxobolus arcticus was found in chinook salmon captured in the western North Pacific Ocean between 157° 30'E and 177° 30'E, but not in the southern Bering Sea and eastern North Pacific Ocean (Table 2, Fig. 1). The prevalence was especially high (83%) in fish from the waters west of 170° E (between 43° 58'N and 49° 54'N). In sockeye salmon, the prevalence was also much higher in the western North Pacific Ocean (30.4%) than in the eastern waters (5.6%)(Table 2), but there was no apparent difference in prevalence within the western waters (Fig. 1).

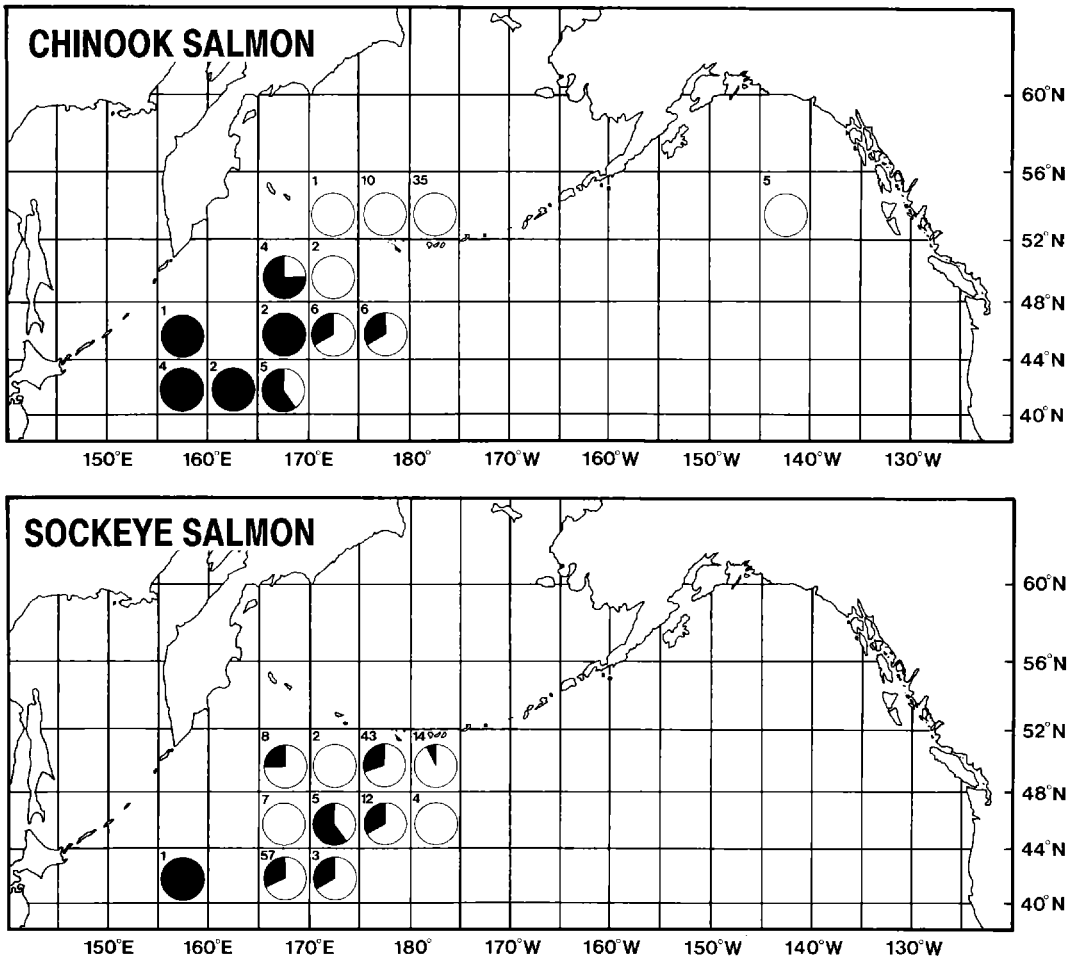

Fig. 1. Prevalence of *Myxobolus arcticus* in chinook salmon (top) and sockeye salmon (bottom) caught on the high seas of the North Pacific Ocean and Bering Sea by 4°× 5° area between May and August in 1982, 1983, 1986, and 1987. Closed portion of each pie shows the parasite prevalence in each area. Numeral within each area indicates number of fish examined.

Discussion

Four species of the genus *Myxobolus* have been recorded from the brain or spinal cord of salmonids (Schuberg and Schröder, 1905; Yasutake and Wood, 1957; Pugachev and Khokhlov, 1979; Gonzalez-Lanza and Alvarez-Pellitero, 1984). Pugachev and Khokhlov (1979) described two species of *Myxobolus* from the nervous system of salmonids from the Kamchatka Peninsula: *M. arcticus* (pyriform spores) and *M. neurobius* (oval spores). The latter species was first recorded from brown trout (*Salmo trutta*) in Europe by Schuberg and Schröder (1905), but their obscure descriptions caused subsequent taxonomic confusion. A detailed taxonomic study is now being carried out for the brain myxosporeans of North American salmonids by S. Urawa and L. Margolis (Pacific Biological Station). According to their unpublished data, the species of pyriform spores, which has been identified as *M. neurobius* in North America (Arthur et al., 1976; Margolis, 1982, 1984; Bailey and Margolis, 1987; Quinn et al., 1987; Wood et al., 1987; Moles et al., 1990), should be treated as *M. arcticus*. Apparently, the pyriform myxosporean found in high-seas salmonids is also identifiable to *M. arcticus*.

There were apparent differences in the prevalence of *M. arcticus* among five species of Pacific salmon

caught in the North Pacific Ocean. The parasite infections frequently occurred in chinook, sockeye and coho salmon, but rarely in chum salmon. No pink salmon were infected. The first three species usually spend the first 1 or 2 years of their life in fresh water before migrating to the ocean, whereas chum and pink salmon migrate seaward soon after emerging from the gravel beds. Then, the observed low prevalence of infection in chum and pink salmon is probably attributable to a lack of opportunity to gain the parasite due to the short period of their freshwater residence.

A marked regional difference in prevalence of *M. arcticus* infection was observed in chinook salmon. The parasite was frequently encountered in the western North Pacific Ocean (42-53° N, 157-177° E) but not found in the southern Bering Sea (54-55° N, 175° W-178° E) and the Gulf of Alaska (52-55° N, 141-143° W). The scale-pattern analysis has shown that most chinook salmon in the central Bering Sea originate in western Alaska (Major et al., 1978; Myers et al., 1987). The high prevalences of *M. arcticus* in fish from the western North Pacific Ocean as well as no infection in fish from the Bering Sea and Gulf of Alaska suggest that *M. arcticus* frequently occurs in Asian chinook salmon but rarely in North American stocks. This assumption is well corroborated by recent intensive parasitological surveys on chinook adults collected from major spawning rivers of Asia and North America (Urawa, Nagasawa, Margolis and Moles, unpublished data).

Chinook salmon are the least abundant among Pacific salmon, and a high proportion of them is caught in fisheries at sea, often at long distance from their natal rivers, causing regional and international controversy. However, their low abundance makes difficulty in determining the status of individual stocks by tagging experiments (Harris, 1988). In addition, scale pattern studies were not conclusive to determine regional origins of chinook salmon distributed in the North Pacific Ocean due to discrepancies of the results (Major et al., 1978; Myers et al., 1987, 1993; Ito et al., 1985, 1986). Most Asian chinook salmon originate in Kamchatka, where *M. arcticus* is distributed (Pugachev and Khokhlov, 1979; Nagasawa et al., 1994). Thus, *M. arcticus* is expected as a biological indicator to determine the Asian origin of chinook salmon migrating to offshore waters.

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北太平洋およびベーリング海に分布するサケ属魚類5種における粘液胞子虫*Myxobolus arcticus*の寄生率の比較

浦和茂彦・長澤和也

粘液胞子虫*Myxobolus arcticus*は，淡水中でサケ科魚類に感染し，延髄など神経組織で胞子を形成して宿主のほぼ一生を通じて寄生する．ここでは，北太平洋およびベーリング海で漁獲されたサケ属5魚種における*M. arcticus*胞子の寄生率を比較した．北西太平洋における寄生率は，マスノスケ（57.5%），ベニザケ（30.4%）およびギンザケ（18.8%）で比較的高かったが，サケでは低く（6.7%），カラフトマスには寄生がみられなかった．これらの結果は，各魚種の降海するまでの淡水生活様式の違いに原因しており，淡水生活期間の短いサケやカラフトマスでは感染の機会が少ないため寄生率が低いと推定された．マスノスケにおける本虫の寄生率は，海域により明らかな差がみられ，北太平洋の東経170°より西側の海域で高く，北太平洋東部およびベーリング海では著しく低かった．この結果はマスノスケにおける*M. arcticus*の寄生が地理的に限定されていることを示唆し，本虫は海洋に分布するマスノスケの大陸起源を判別する生物標識として使える可能性が高い．

Appendix. Records of *Myxobolus arcticus* in the brain of five species of Pacific salmon caught in the North Pacific Ocean and Bering Sea.

Locality	Date of catch	Number of fish		Prevalence (%)
		examined	infected	
Chinook salmon				
52°N, 141°W	Jul. 18, 1987	2	0	0
55°N, 143°W	Jul. 16, 1987	3*	0	0
55°N, 175°W	Jul. 5, 1986	10	0	0
55°N, 177°W	Jul. 6, 1986	20	0	0
54°N, 179°W	Jun. 14, 1987	5	0	0
54°N, 178°E	Jun. 15, 1987	10	0	0
47°N, 177°E	Jun. 19, 1987	5	2	40.0
46°N, 175°E	Aug. 2, 1987	1	0	0
48°N, 173°E	Aug. 5, 1987	1	0	0
44°N, 173°E	May 7, 1982	4	2	50.0
50°N, 172°E	Jun. 29, 1987	1	0	0
45°N, 171°E	May 9, 1982	2	0	0
53°N, 170°E	Jun. 23, 1987	1	0	0
49°N, 169°E	Aug. 7, 1987	3	2	66.7
49°N, 167°E	Jun. 19, 1987	1	1	100
44°N, 167°E	Jun. 14, 1987	2	2	100
41°N, 167°E	May 10, 1982	4	2	50.0
43°N, 166°E	May 18, 1982	1	1	100
42°N, 163°E	May 24, 1982	2	2	100
43°N, 159°E	Jun. 19, 1987	1	1	100
44°N, 157°E	Jun. 13, 1987	1	1	100
43°N, 157°E	Jun. 14, 1987	2	2	100
43°N, 157°E	Jun. 15, 1987	1	1	100
Sockeye salmon				
51°N, 177°W	May 26, 1983	2	0	0
50°N, 177°W	May 27, 1983	3	0	0
50°N, 177°W	May 28, 1983	6	1	16.7
49°N, 177°W	May 31, 1983	1	0	0
48°N, 177°W	Jun. 1, 1983	2	0	0
44°N, 177°W	Jun. 6, 1983	4	0	0
51°N, 177°E	May 24, 1982	2	0	0
50°N, 177°E	May 25, 1982	6	1	16.7
49°N, 177°E	May 27, 1982	20	7	35.0
49°N, 177°E	May 28, 1982	10	3	30.0
48°N, 177°E	May 29, 1982	5	2	40.0
47°N, 177°E	May 30, 1982	7	3	42.9
44°N, 177°E	Jun. 2, 1982	5	1	20.0
45°N, 173°E	May 8, 1982	2	2	100
51°N, 172°E	May 23, 1983	2	0	0
45°N, 171°E	May 9, 1982	2	1	50.0
44°N, 171°E	May 10, 1982	1	0	0

*One of three chinooks captured in the Gulf of Alaska (55°00'N, 143°48'W) was infected with *Myxobolus neurobius*.

Appendix. (continued)

Locality	Date of catch	Number of fish		Prevalence (%)
		examined	infected	
43°N, 171°E	May 11, 1982	3	1	33.3
50°N, 167°E	May 21, 1982	2	0	0
49°N, 167°E	May 21, 1982	2	1	50.0
48°N, 167°E	May 20, 1982	4	1	25.0
46°N, 167°E	May 18, 1982	6	0	0
45°N, 167°E	May 15, 1982	1	0	0
43°N, 167°E	May 12, 1982	57	18	31.6
43°N, 156°E	Jun. 1, 1982	1	1	100
Coho salmon				
42°N, 172°E	May 10, 1983	4	1	25.0
45°N, 171°E	May 9, 1982	3	0	0
42°N, 171°E	May 12, 1982	4	0	0
42°N, 168°E	May 16, 1982	1	0	0
41°N, 167°E	May 10, 1982	4	2	50.0
Chum salmon				
50°N, 177°W	May 27, 1983	1	0	0
47°N, 177°W	Jun. 2, 1983	1	1	100
45°N, 173°E	May 8, 1982	1	0	0
44°N, 173°E	May 7, 1982	2	1	50.0
43°N, 173°E	May 6, 1982	2	0	0
50°N, 172°E	May 22, 1983	1	0	0
48°N, 172°E	May 20, 1983	3	0	0
45°N, 171°E	May 9, 1982	2	0	0
44°N, 171°E	May 10, 1982	1	0	0
42°N, 171°E	May 12, 1982	2	1	50.0
41°N, 171°E	May 13, 1982	3	0	0
41°N, 170°E	May 14, 1982	2	0	0
42°N, 168°E	May 16, 1982	3	0	0
41°N, 168°E	May 15, 1982	4	1	25.0
43°N, 166°E	May 18, 1982	2	0	0
47°N, 167°E	May 19, 1982	2	0	0
44°N, 167°E	May 13, 1982	2	0	0
42°N, 163°E	May 21, 1982	3	0	0
43°N, 161°E	May 26, 1982	1	0	0
42°N, 158°E	May 30, 1982	4	0	0
42°N, 158°E	May 31, 1982	3	0	0
41°N, 158°E	May 29, 1982	3	0	0
Pink salmon				
47°N, 177°W	Jun. 2, 1983	3	0	0
50°N, 177°E	May 25, 1982	1	0	0

Appendix. (continued)

Locality	Date of catch	Number of fish		Prevalence (%)
		examined	infected	
49°N, 177°E	May 27, 1982	1	0	0
48°N, 177°E	May 29, 1982	2	0	0
47°N, 177°E	May 30, 1982	11	0	0
43°N, 172°E	May 11, 1983	2	0	0
42°N, 172°E	May 10, 1983	10	0	0
44°N, 171°E	May 10, 1982	1	0	0
42°N, 168°E	May 16, 1982	2	0	0
46°N, 167°E	May 18, 1982	2	0	0
45°N, 167°E	May 15, 1982	1	0	0
43°N, 166°E	May 18, 1982	1	0	0
43°N, 163°E	May 25, 1982	1	0	0
42°N, 163°E	May 24, 1982	1	0	0
42°N, 158°E	May 31, 1982	1	0	0