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Occurrence of *Myxobolus arcticus* and *M. neurobius* (Myxozoa: Myxosporea) in Masu Salmon *Oncorhynchus masou* from Northern Japan

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Abstract. — Adult masu salmon (*Oncorhynchus masou*) from seven rivers in Hokkaido and northern Honshu were examined for the geographical distribution of *Myxobolus arcticus* and *M. neurobius* in northern Japan. Maturing masu salmon from Japanese coastal waters of the Okhotsk Sea, Japan Sea, and western North Pacific Ocean were also studied for the prevalence of these myxosporeans. *Myxobolus arcticus* occurred mainly on the Japan Sea coast of Honshu, whereas *M. neurobius* was found in Hokkaido along the coasts of the Okhotsk Sea and Japan Sea. Sea-caught masu salmon showed various degrees of infections with *M. arcticus* and *M. neurobius*. This indicates that masu salmon migrating in Japanese coastal waters are a complex of mixed stocks that originate in various rivers. Prevalence data support the recently proposed autumn migration route of maturing masu salmon from the Okhotsk Sea to Japan Sea.

Introduction

Masu salmon (*Oncorhynchus masou*) differ from other species of Pacific salmon (*Oncorhynchus* spp.) in that this species is geographically restricted to the Japan Sea, Okhotsk Sea, and western North Pacific Ocean off Far East Asia (Machidori and Kato, 1984). In northern Japan, masu salmon go to the sea after they spend 1 or 2 years in fresh water and return to their native rivers for spawning after they spend one winter in the ocean (Kato, 1991). In Hokkaido and northern Honshu, masu salmon are of considerable importance to the inshore fishery at sea and to the game fishing in rivers.

Myxobolus arcticus and *M. neurobius* are myxosporean parasites of the brain and spinal cord of masu salmon from Japan (Awakura et al., 1982; Nagasawa et al., 1987; Awakura, 1989). These species are freshwater parasites: aquatic oligochaetes serve as alternate hosts and transmission to salmonids occurs in fresh water (Kent et al., 1993; Urawa, 1994; Urawa and Awakura, 1994). Salmon become infected as juveniles and carry the infection almost throughout their life (Urawa, 1994). The parasites show distinct geographical distribution and are thus used as useful natural markers for stock identification of Pacific salmon, such as masu salmon (Awakura, 1989; Urawa, 1989), chinook salmon (*O. tshawytscha*)(Urawa and Nagasawa, 1991, 1995), and sockeye salmon (*O. nerka*) (Margolis, 1982; Moles et al., 1990).

The present study was undertaken to determine the distribution of *M. arcticus* and *M. neurobius* in northern Japan and the occurrence of these parasites in masu salmon caught in Japanese coastal waters to elucidate the migration and stock composition of these salmon.

Materials and Methods

Four hundred twenty-six masu salmon were sampled in seven rivers in Hokkaido and northern Honshu from June to October in 1981-1989 to determine the distribution of *M. arcticus* and *M. neurobius* (Fig. 1). These salmon were all mature adults that had returned to the natal streams for spawning. A total of 2,677 maturing masu salmon were also caught at 14 sites in Japanese coastal waters of the Okhotsk Sea, Japan Sea, and western North Pacific Ocean from October to June in 1981-1990 (Fig. 2). The fish were frozen immediately after capture and stored at -20℃ until

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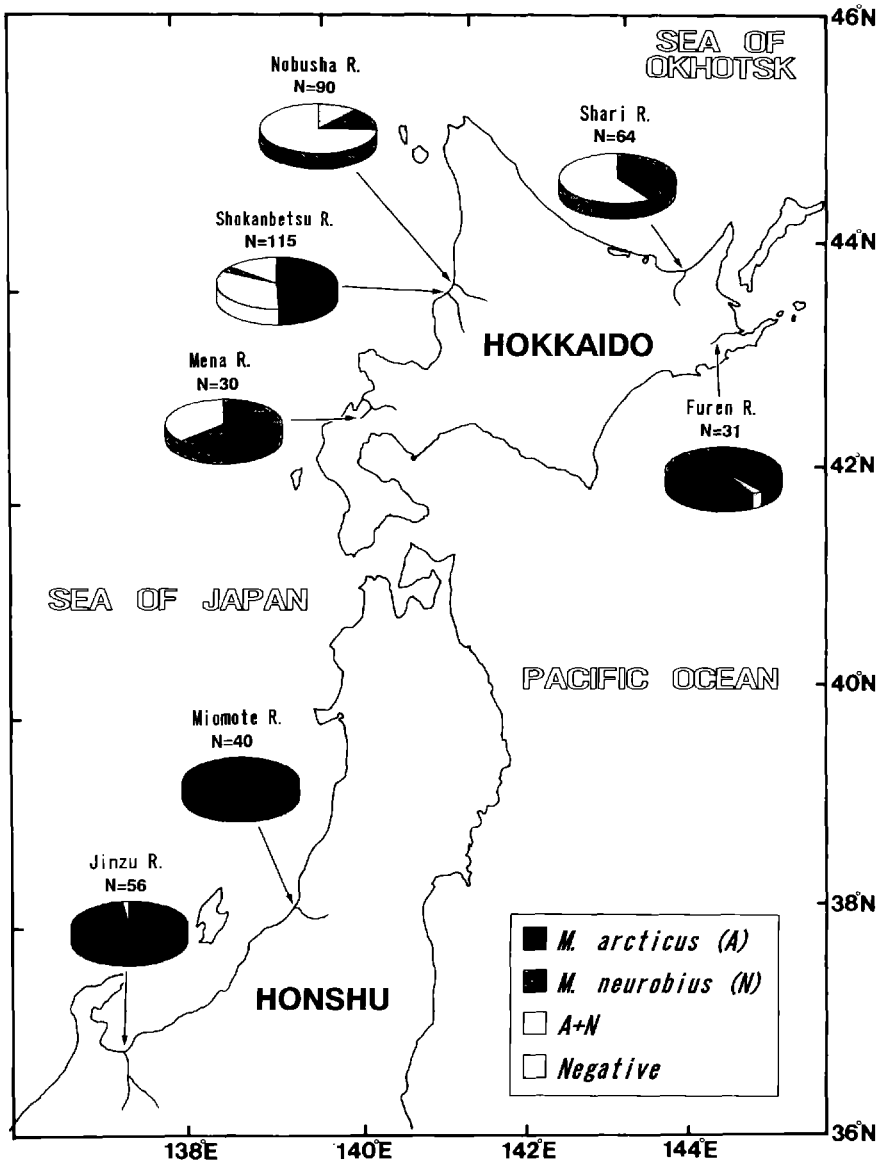

Fig. 1. Geographical distribution of *Myxobolus arcticus* and *M. neurobius* in mature masu salmon from seven rivers in northern Japan. Pie diagrams display prevalences of single and concurrent infections with the two myxosporean species.

they were examined. Spinal cords and medulla oblongata were removed from the fish, smeared on a slide glass individually, fixed in methyl alcohol, stained with Giemsa, and examined for the presence of spores of *M. arcticus* and *M. neurobius*. Prevalence is the percentage of fish infected in a sample (Margolis et al., 1982).

Results

Distribution of myxosporeans in northern Japan

There was a distinct regional difference in distribution of *M. arcticus* and *M. neurobius* in northern Japan (Fig. 1). In Hokkaido, *M. neurobius* occurred in rivers flowing into the Okhotsk Sea and Japan Sea, except for the Shokanbetsu River: 26-63% of fish

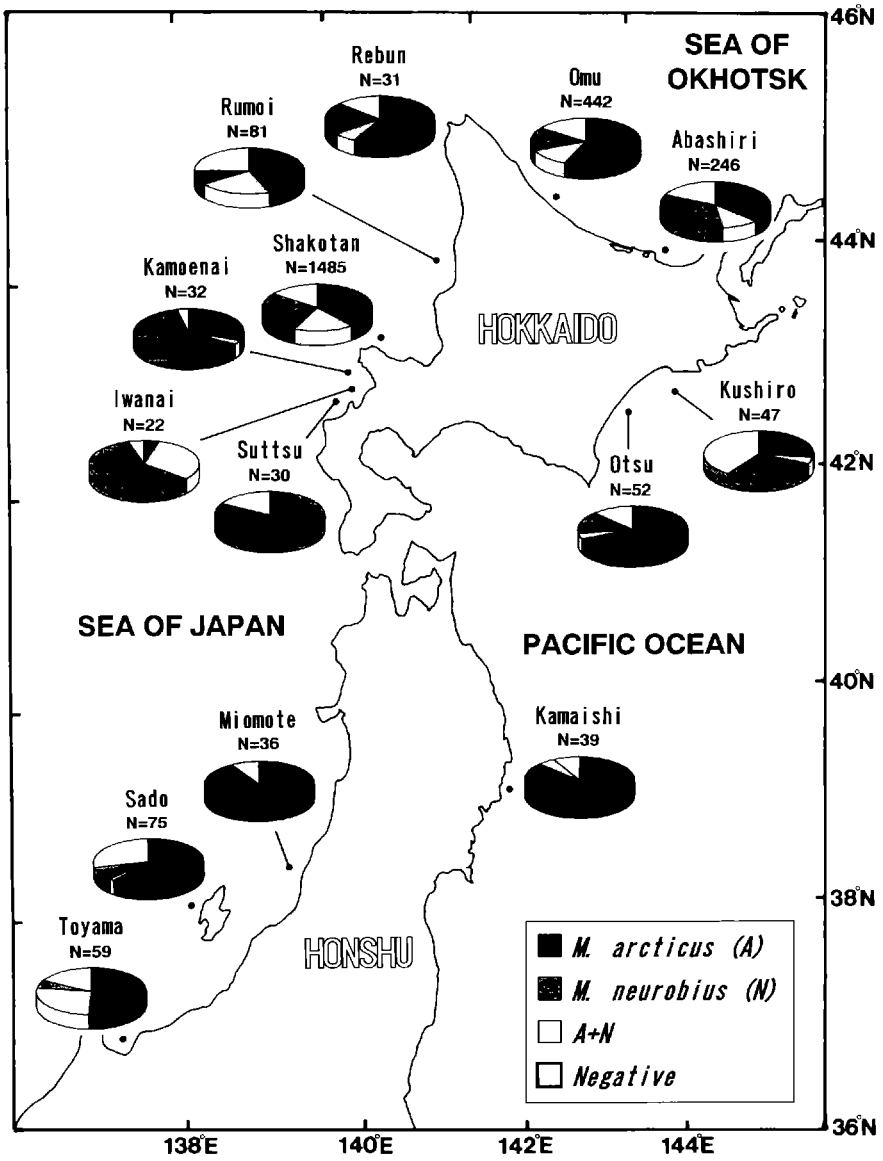

Fig. 2. Geographical distribution of *Myxobolus arcticus* and *M. neurobius* in maturing masu salmon from Japanese coastal waters of the Okhotsk Sea, Japan Sea, and North Pacific Ocean. Pie diagrams display prevalence of single and concurrent infections with the two myxosporean species.

from the Shari River, Nobusha River, and Mena River were infected with *M. neurobius*, but concurrent infections with *M. neurobius* and *M. arcticus* were occasionally observed in the Nobusha River. In the Shokanbetsu River, two myxosporean species were found, although prevalence of single infection with *M. neurobius* was quite low. In the Furen River on the Pacific side, two myxosporean species were present and all fish were infected with *M. arcticus* and/or *M. neurobius*.

In Honshu, *M. arcticus* was present in the Miomote River and Jinzu River flowing into the Japan Sea, with all or nearly all of fish being infected. *Myxobolus neurobius* was not found.

Prevalence of myxosporeans in sea-caught salmon

Over 80% of masu salmon caught in October and November in the Okhotsk Sea off Abashiri and Omu were infected with *M. arcticus* and/or *M. neurobius* (Fig. 2). Similar levels of single and concurrent infections were recorded for masu salmon caught mainly in winter in the Japan Sea off the west coast of Hokkaido such as Rebun, Rumoi, Shakotan, and Kamoenai. However, despite the fact that Iwanai and Suttsu were close to these sites, masu salmon caught in May off Iwanai and Suttsu showed different levels of infection: *M. neurobius* was common, but infection with *M. arcticus* was rare.

In masu salmon caught in March-June at more southern sites (Sado, Miomote, and Toyama) in the Japan Sea, prevalence of *M. arcticus* was high, but infection of *M. neurobius* was usually low (Fig. 2).

Although masu salmon caught in the western North Pacific Ocean were infected with *M. arcticus* and *M. neurobius*, there was a regional variation in prevalence of these parasites among sampling sites (Fig. 2). Masu salmon caught in May off Kamaishi had a higher prevalence of *M. arcticus* and a lower prevalence of *M. neurobius* than those caught off Kushiro and Otsu.

Monthly changes in prevalence of myxosporeans

In the Shakotan area of the Japan Sea, masu salmon were collected from December to May in 1983-1990, which enabled us to study monthly changes in prevalence of *M. arcticus* and/or *M. neurobius*. *Myxobolus arcticus* occurred most frequently in December and January, but prevalence declined steadily and reached the lowest level in March to May (Fig. 3). Contrary to this, prevalence of *M. neurobius* was low in December but increased thereafter. Prevalence of concurrent infections with *M. arcticus* and *M. neurobius* increased slightly between December and May. These trends were almost stable among the years.

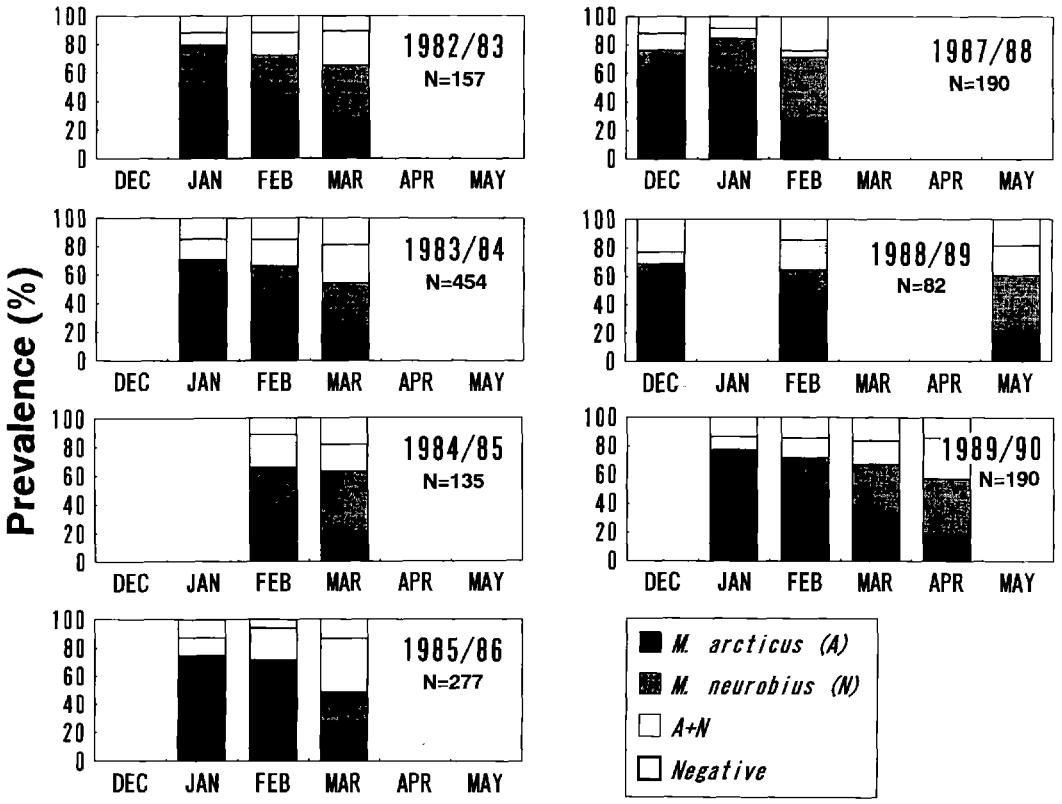

Fig. 3. Monthly changes in percentage prevalence of single and concurrent infections with *Myxobolus arcticus* and *M. neurobius* in maturing masu salmon caught in the Japan Sea off Shakotan in 1983-1990.

Discussion

The present study shows that sea-migrating, maturing masu salmon included those fish with various degrees of infections with *M. arcticus* and/or *M. neurobius*, whereas the majority of adult masu salmon from spawning rivers were infected with either *M. arcticus* or *M. neurobius*. This indicates that masu salmon migrating in Japanese coastal waters are a complex of mixed individuals that originate in various rivers.

Myxobolus arcticus and *M. neurobius* have their respective distribution patterns in northern Japan (Awakura, 1989; present study). Only *M. arcticus* is distributed in rivers on the Japan Sea coast of Honshu. Thus, the reason why masu salmon caught in spring off Sado, Miomote, and Toyama had a high prevalence of *M. arcticus* infection is probably because these fish mostly originated in nearby rivers (e.g., the Miomote River and Jinzu River). A similar explanation is adopted for masu salmon caught in spring off Iwanai and Suttsu which had a high prevalence of *M. neurobius* infection. It is possible that these fish included individuals that ascend rivers near Iwanai and Suttsu (e.g., the Mena River where only *M. neurobius* occurs). In addition, although we did not examine the distribution of the myxosporeans on the Pacific coast of northern Honshu, there is a possibility that *M. arcticus* only occurs in this region, because this species was prevalent in masu salmon caught in spring off Kamaishi.

Prevalences of *M. arcticus* and/or *M. neurobius* in masu salmon caught off Shakotan in the Japan Sea changed in winter to spring. This is caused by changes in stock composition of masu salmon. Because prevalence of *M. arcticus* was high in December and January, it appears that masu salmon caught in these months included fish originating in rivers on the Japan Sea coast of Honshu. Moreover, it is possible that masu salmon with a high prevalence of *M. neurobius* caught in February to May were from rivers of Hokkaido where this parasite occurs commonly.

Based on information from tagging experiments and biological features, Machidori and Kato (1984) suggested that masu salmon of Japanese origin migrate to the Okhotsk Sea in spring as juveniles and return to the Japan Sea and western North Pacific in autumn as maturing fish for overwintering. Our study demonstrates that there was no marked difference in prevalence of *M. arcticus* and *M. neurobius* in maturing masu salmon caught in the Okhotsk Sea in autumn and in the Japan Sea in winter, indicating that masu salmon move from the Okhotsk Sea through the Soya Strait to the Japan Sea from autumn to winter. These findings support the migration route of maturing masu salmon, proposed by Machidori and Kato (1984), from the Okhotsk Sea to the Japan Sea.

A recent genetic work (Okazaki, 1986) has demonstrated that masu salmon collected in various rivers in northern Japan include a variety of genetically independent stocks. Furthermore, it has been suggested that masu salmon caught in Japanese coastal waters are a mixture of such different stocks (Okazaki, 1989). We examined the distribution of *M. arcticus* and *M. neurobius* in Hokkaido and northern Honshu. However, the number of rivers surveyed was only seven and insufficient to determine the geographical distribution of these myxosporean species in northern Japan. According to Machidori and Kato (1984), there are 70 rivers in Hokkaido and 32 rivers in Honshu which many masu salmon ascend. More work is needed to establish the baseline distribution of *M. arcticus* and *M. neurobius* in order to differentiate stocks of sea-caught masu salmon using these parasites as biological tags.

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北日本のサクラマスにおける粘液胞子虫*Myxobolus arcticus*と*M. neurobius*の出現状況

栗倉輝彦・長澤和也・浦和茂彦

北海道および本州北部の7河川に回帰したサクラマス親魚とオホーツク海，日本海および北太平洋の日本沿岸を回遊するサクラマスにおける粘液胞子虫*Myxobolus arcticus*と*M. neurobius*の寄生率を調べた．*Myxobolus arcticus*は主に本州の日本海沿岸河川に分布したが，*M. neurobius*は北海道のオホーツク海と日本海沿岸河川のサクラマスに多かった．海洋で漁獲されたサクラマスにおける両種の寄生率は多様であり，日本沿岸を回遊するサクラマスは様々な河川を起源とする混合群により構成されると推定された．海洋での粘液胞子虫2種の地理的および季節的出現傾向は，サクラマスが秋期にオホーツク海から日本海へ南下移動するという仮説を裏付けている．