Stock Identification of Chinook Salmon (*Oncorhynchus tshawytscha*) in the North Pacific Ocean and Bering Sea by Parasite Tags

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The continental origins of chinook salmon (*Oncorhynchus tshawytscha*) in the North Pacific Ocean and Bering Sea were estimated by using two freshwater parasites (*Myxobolus arcticus* and *M. kisutchi*) as biological tags. The parasite survey of adult chinook salmon from major spawning rivers in North America and Kamchatka indicated that *M. arcticus* was commonly found in Asian chinook stocks (prevalence=57-94%), while rarely among most North American stocks except for those from Vancouver Island, B. C. The unweighted overall sample prevalence of *M. arcticus* was 67.7% and 2.3% in Asian and North American stocks, respectively. *Myxobolus kisutchi* was found only in chinook salmon from the Columbia River (prevalence=8-11% and 43-65% in fall and spring adult stocks, respectively) and its vicinities. The prevalence of *M. arcticus* in high-seas samples of chinook salmon showed a distinct longitudinal cline in the North Pacific Ocean: the overall prevalence was 92% west of 160°E, 81% between 160°E and 170°E, 58% between 170°E and 180°, and 38% between 150°W and 160°W, whereas it was only 0-3% in the central Bering Sea. These results suggest that Asian chinook salmon are widely distributed in the North Pacific Ocean, occurring possibly as far east as 150°W, and are probably predominant in the waters west of 180°. The extreme low prevalence of *M. arcticus* in central Bering Sea chinook salmon suggests that up to 98% of chinook salmon caught in this area are of North American origin. One chinook salmon infected with *M. kisutchi* was found in the Gulf of Alaska, suggesting the presence of Columbia River chinook salmon in this area.

INTRODUCTION

Chinook salmon (*Oncorhynchus tshawytscha*) are widely distributed along the Pacific coast of North America and Asia, although they are the least abundant of five major species of high-seas Pacific salmon. In North America, chinook salmon spawn in rivers from California to western Alaska. Asian spawning grounds range from the Anadyr River to the Amur River in Russia, but most Asian chinook salmon spawn in rivers of the Kamchatka Peninsula (Major et al. 1978). Chinook salmon spawn in many streams, but their spawning is concentrated in larger river systems. Chinook salmon have two life history patterns designated "stream type" and "ocean type"

† This paper was completed after the sudden passing of our dear friend Leo Margolis. We shall miss his warm personality and his outstanding scientific contributions.

(Healey 1983). Stream type (spring) chinook salmon are typical in Asian and northern North American populations and spend one or more years in fresh water before migrating to the sea. Ocean-type (fall) chinook salmon are typical of populations on the North American coast south of 56°N, and migrate to the sea after a few days to a few months of freshwater residence.

Chinook salmon occur broadly in the North Pacific Ocean, Bering Sea and the adjacent waters, but oceanic distribution patterns of individual stocks are not well known yet. Four methods may be applied for the stock identification of high-seas chinook salmon: tagging, scale pattern analysis, genetic analysis, and use of parasites as biological tags. However, low abundance of chinook salmon makes it difficult to determine the status of individual stocks by tagging (Harris 1988). While about 3,000 chinook salmon were tagged and released on the high seas over the last three decades, only 14 have been recovered in coastal areas (Myers et al. 1993). Several scale pattern studies were conducted to determine the origin of high-seas chinook salmon (Ito et al. 1985, 1986; Myers et al. 1987, 1993), but were not conclusive due to discrepancies in the results (see Healey 1991). Recently developed genetic techniques may be useful to determine stock origins of high-seas chinook salmon, but the coast-wide genetic baseline covering the Pacific rims, especially Asian area, has not been completed.

It has been well recognized that naturally occurring parasites may be used for stock identification of anadromous salmon (Margolis 1963, 1965, 1982, 1984, 1985; Konovalov 1975; Urawa 1989; Moles et al. 1990; Awakura et al. 1995). In this study, we tried to estimate the marine distribution of Asian and North American chinook salmon on the high seas of the North Pacific Ocean and Bering Sea by using parasites as biological tags.

SELECTION OF PARASITES

The following five conditions must be met to evaluate the usefulness of a parasite as biological tag for stock identification of anadromous salmonids (modified from Margolis 1984):

1. The parasite must be present in one stock or group of stocks and absent or rare in others.
2. The parasite infection should occur within a limited area and time before the stocks become mixed in the ocean. Thus, parasites of freshwater origin are particularly good tags for anadromous salmonids.
3. The parasite must have a long life span, preferably as long as that of its fish host, or at least as long as that period of the host's life over which observations on the stock are being made.
4. The parasite should have no marked effect on survival and behaviour of the fish if the parasite is to be used to estimate proportions of stock in a mixed stock sample.
5. The parasite should be easily detected and identified.

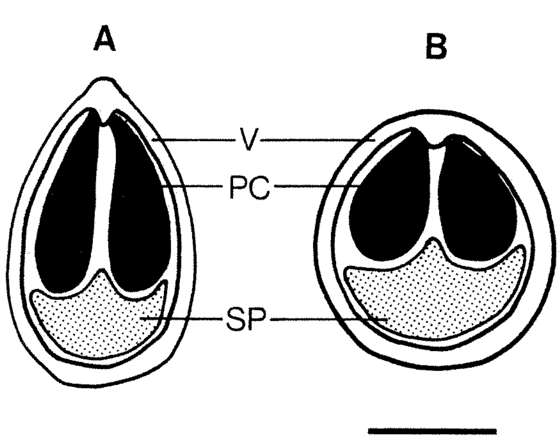
Table 1. Parasites recovered from chinook salmon caught on the high seas of the North Pacific Ocean and Bering Sea.

Parasite species	Site of infection	Origin*
Protozoa (Myxozoa: Myxosporea)		
Myxobolus arcticus	brain and spinal cord	FW
M. kisutchi	brain and spinal cord	FW
Trematoda (Digenea) - adults		
Hemiurus levinseni	stomach and intestine	M
Cestoda - adults		
Eubothrium crassum	pyloric caeca and intestine	M
Cestoda - metacestode stage		
Diphyllobothrium sp. plerocercoid	liver	FW
Nybelinia surmenicola plerocercoid	body cavity	M
Phyllobothrium caudatum plerocercoid	intestine	M
Nematoda		
Anisaskis simplex larvae	somatic musculature	M
?Contracaecum osculatum larvae	intestine	M
Acanthocephala		
Bolbosoma caenoforme juvenile	intestine	M
Copepoda		
Lepeophtheirus salmonis adult	external body surface	M

* FW, acquired in fresh water; M, acquired in the marine environment.

Preliminary samples of chinook salmon caught in the central Bering Sea (55°N, 175-177°W, n=20) and western North Pacific Ocean (41-46°N, 166-177°E, n=13) were examined for parasites (Nagasawa and Urawa 1987). Ten species of parasites were recovered from these chinook salmon (Table 1): 1 Protozoa (Myxozoa: Myxosporea); 1 Trematoda (Digenea); 4 Cestoda; 2 Nematoda; 1 Acanthocephala; and 1 Copepoda. In addition, another myxosporean *Myxobolus kisutchi* was found in a chinook salmon captured in the Gulf of Alaska (Urawa and Nagasawa 1995, as *M. neurobius*).

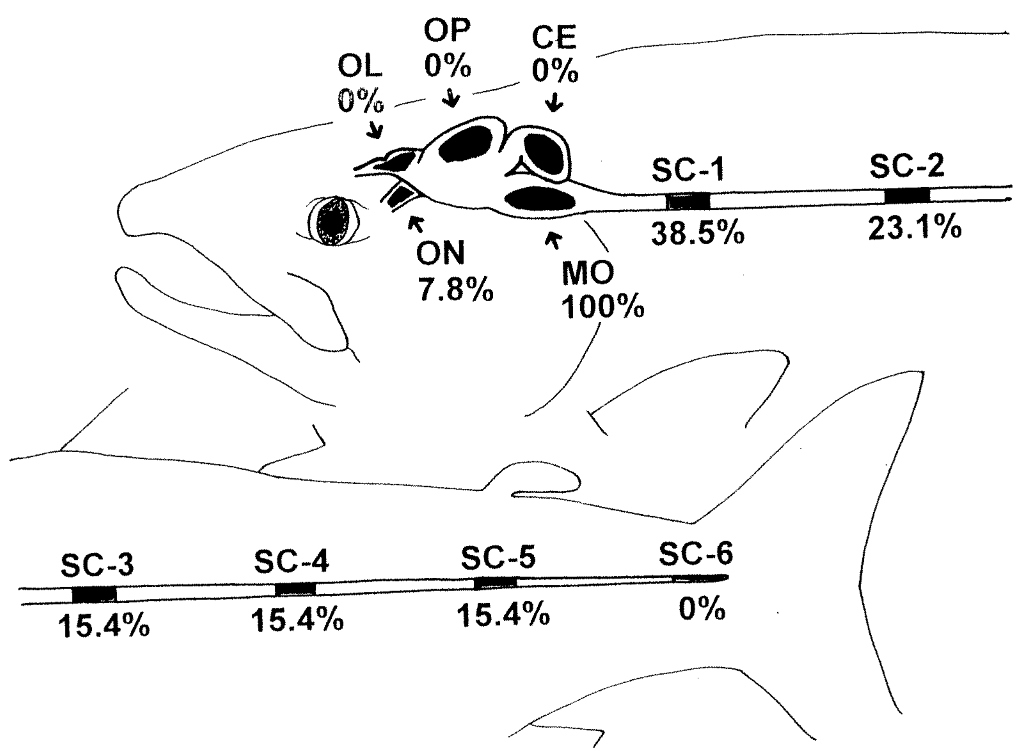
Fig. 1 Spores of *Myxobolus arcticus* (A) and *M. kisutchi* (B) from the brain of chinook salmon. V, valve; PC, polar capsule; SP, sporoplasm. Scale bar indicates 5μm.



Of these, most species (8/11) were acquired at sea, but only three species, *M. arcticus*, *M. kisutchi*, and *Diphyllobothrium* sp. in fresh water. The myxosporean parasites *M. arcticus* and *M. kisutchi* were found in the central nerve tissues, and plerocercoids of the cestode *Diphyllobothrium* sp. in the liver. *Diphyllobothrium* sp. was present across the geographical area, but prevalence of *M. arcticus* and *M. kisutchi* in chinook salmon showed regional differences.

Myxobolus arcticus and *M. kisutchi* are easily differentiated by the spore shapes (Fig. 1). The spore of *M. arcticus* is pyriform in front view (Urawa and Nagasawa 1995), while that of *M. kisutchi* is oval or round (Urawa et al. 1997). The alternate hosts of *M. arcticus* are freshwater oligochaetes (Kent et al. 1993; Urawa and Awakura 1994). The parasites infect juvenile salmon in fresh water before they migrate to the sea, and the myxosporean spores remain in the central nerve tissues throughout the freshwater and marine life of anadromous hosts (Urawa and Awakura 1994). The life cycle of *M. kisutchi* is unknown, but may be similar with that of *M. arcticus*. The parasite spores are easily detected in the medulla oblongata (Fig. 2). There is no record that the parasites cause the host mortality. Thus, two species of freshwater myxosporeans, *M. arcticus* and *M. kisutchi* were candidate for biological tags to identify the origin of high-seas chinook salmon.

Fig. 2 Spatial distribution of *Myxobolus arcticus* spores in the nerve tissues of chinook salmon (n=13). Numerals indicate prevalence (%) of the parasite in each nerve tissue. CE, cerebellum; MO, medulla oblongata; OL, olfactory lobe; ON, optic nerves; OP, optic lobe; SC, spinal cord.



BASELINE OF PARASITES

In order to evaluate usefulness of *Myxobolus* as a tag, 5,691 chinook adults returning to major spawning rivers in Kamchatka and North America were examined for parasites (Urawa and Nagasawa 1989, 1991; Urawa et al. 1990). In Asia, more than 75% of Asian chinook salmon spawn in two rivers: the Kamchatka River on the east coast of the Kamchatka Peninsula, and the Bolshaya River on the west coast. Prevalence of *M. arcticus* in adult chinooks was 57% in the Kamchatka River, and 94% in the Bolshaya River. In North America, we examined adult chinooks from 39 spawning rivers and 4 regions from the Sacramento River in California to the Yukon River in western Alaska, which accounted for more than 70% of North American chinook populations (according to spawning estimates by Wahle and Pearson 1987). However, *M. arcticus* rarely occurred among North American stocks except for Vancouver Island, B. C., where it was found in 7 of 9 stocks sampled, with prevalence of 2-56%. The overall prevalence of parasite was 19.5% in Vancouver Island chinook stocks, but only 4.7% in the entire chinook stocks in British Columbia when prevalence was weighted in proportion of number of spawners in each river. The Asian origin chinook salmon are stream-type, whereas the Vancouver Island chinook salmon stocks are almost entirely ocean-type (Healey 1991). Thus, *M. arcticus* infected chinook salmon from Asia can be distinguished from those from Vancouver Island on the basis of freshwater age.

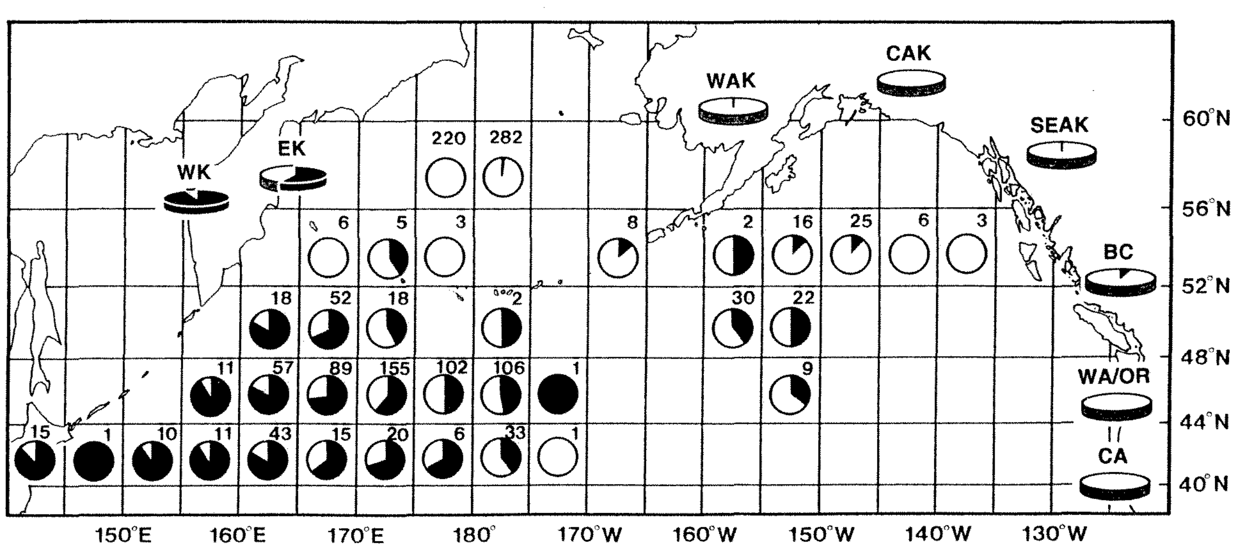
Myxobolus kisutchi has been found only in the Columbia River and its vicinities (the Minter Creek and Shehalus River in Washington)(Yasutake and Wood 1957; Urawa and Nagasawa 1991; Urawa et al. 1997). In the Columbia River, the prevalence was 43-65% in spring chinook salmon, but only 8-11% in fall chinooks (Urawa and Nagasawa 1991). This might be attributable to differences in a period of freshwater residence between spring and fall chinook smolts.

We concluded that *M. arcticus* is useful as an indicator of Asian origin chinook salmon, and *M. kisutchi* is a good indicator of chinook salmon originating from the Columbia River and its vicinities. The baseline prevalence of *M. arcticus* (Fig. 3) was 94% in western Kamchatka, 57% in eastern Kamchatka, and almost 0% in North American stocks except for British Columbia, where it was 4.7%.

OCCURRENCE OF PARASITES IN MARINE CHINOOK SALMON

We examined 1,403 chinook salmon captured in the North Pacific Ocean and central Bering Sea in the summers of 1988, 1989, and 1990 (Urawa and Nagasawa 1991). Ocean-type chinook salmon (freshwater age 0) were not found among these samples. The prevalence of *M. arcticus* was extremely low (less than 2%) in chinook salmon captured in the central Bering Sea, while in the North Pacific Ocean caught in the waters east of 145°W (Fig. 3). The parasite prevalence showed a longitudinal cline in three years, averaging 92% west of 160°E, 81% between 160°E and 170°E, 58% between 170°E and 180°, 38% between 150°W and 160°W, but less than 10% in waters east of 150°W. Another parasite survey for chinook salmon captured in offshore waters

Fig. 3 Prevalence (indicated by black shading in pie chart) of *Myxobolus arcticus* in chinook salmon in the North Pacific Ocean and Bering Sea by 4° x 5° area in the summers of 1988-1990. Numerals within area indicate the number of fish examined. Three-dimensional pie charts indicate the baseline prevalences of the parasite in western Kamchatka (WK), eastern Kamchatka (EK), western Alaska (WAK), central Alaska (CAK), southeastern Alaska (SEAK), British Columbia (BC), Washington and Oregon (WA/OR), and California (CA) chinook stocks.



10% in waters east of 150°W. Another parasite survey for chinook salmon captured in offshore waters along the Alaska Peninsula and Aleutian Islands in August 1996 indicated that prevalence of *M. arcticus* was 9.6% in eastern waters (55-56°N, 156°W, n=52) and 15.4% in central waters (51-52°N, 176°W, n=13).

As for *M. kisutchi*, only one chinook salmon infected with this parasite was found in the Gulf of Alaska in 1987, suggesting the presence of Columbia River chinook salmon in this area (Urawa and Nagasawa 1995).

MARINE DISTRIBUTION OF CHINOOK SALMON

The occurrence of *M. arcticus* suggests that Asian chinook salmon are widely distributed in the North Pacific Ocean west of 150°W, which is beyond the eastern limit of 175°W previously estimated by a tag recovery. Our results suggest that Asian chinook salmon are the predominant stocks in the western waters of the North Pacific Ocean but are rarely found in the Bering Sea. In contrast, North American chinook salmon appear to be the predominant stocks in the Bering Sea but may be largely absent in the western North Pacific Ocean. Tagging and scale pattern studies suggested that western Alaska chinook salmon are predominant in the Bering Sea (Myers et al. 1987, 1993). The other North American chinook stocks may be distributed mainly in the North American coastal waters (Healey 1983). It is an amazing result that Asian chinook salmon are widely distributed in the North Pacific Ocean, despite their relatively low abundance comparing with North American stocks. Further studies are requested to clarify factors determining the ocean distribution of chinook salmon.

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