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Oncorhynchus masou and *O. rhodurus*

With Particular Reference to Their Potential

For Introduction into Ontario Waters

RESEARCH BRANCH

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DEPARTMENT OF LANDS AND FORESTS

RENE BRUNELLE, MINISTER

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Part A - Introduction

The decline of various premium fish stocks in the Great Lakes has created a lively interest in exotic fishes among various fishery agencies. The deteriorative environmental changes associated with advancing eutrophication (Beeton, 1965) and the invasion or introductions of many new and often undesirable species, appear to be essentially irreversible changes from the fishery management point of view. Attempting to maintain or restore natural faunal balance is, therefore, no longer an important consideration. It now seems realistic to seek new species with characteristics making them better suited to the new environmental circumstances than the historical species (Christie, 1968). This search led the Ontario Department of Lands & Forests in 1966 to mount surveys of the fishes of eastern Europe (Martin, 1967), and Japan.

The author visited Japan during September and early October of 1966. The itinerary included visits to laboratories and points of ecological interest in south-eastern Hokkaido (Fig. 1) and in Honshu. The present report presents observations made during the tour along with information obtained from a review of the literature.

The main objective of the Japanese tour was to obtain first-hand information concerning the two native salmons *Oncorhynchus masou* and *O. rhodurus*. Of the seven species of Pacific salmon, only these two, and the sockeye (*O. nerka*) are known to

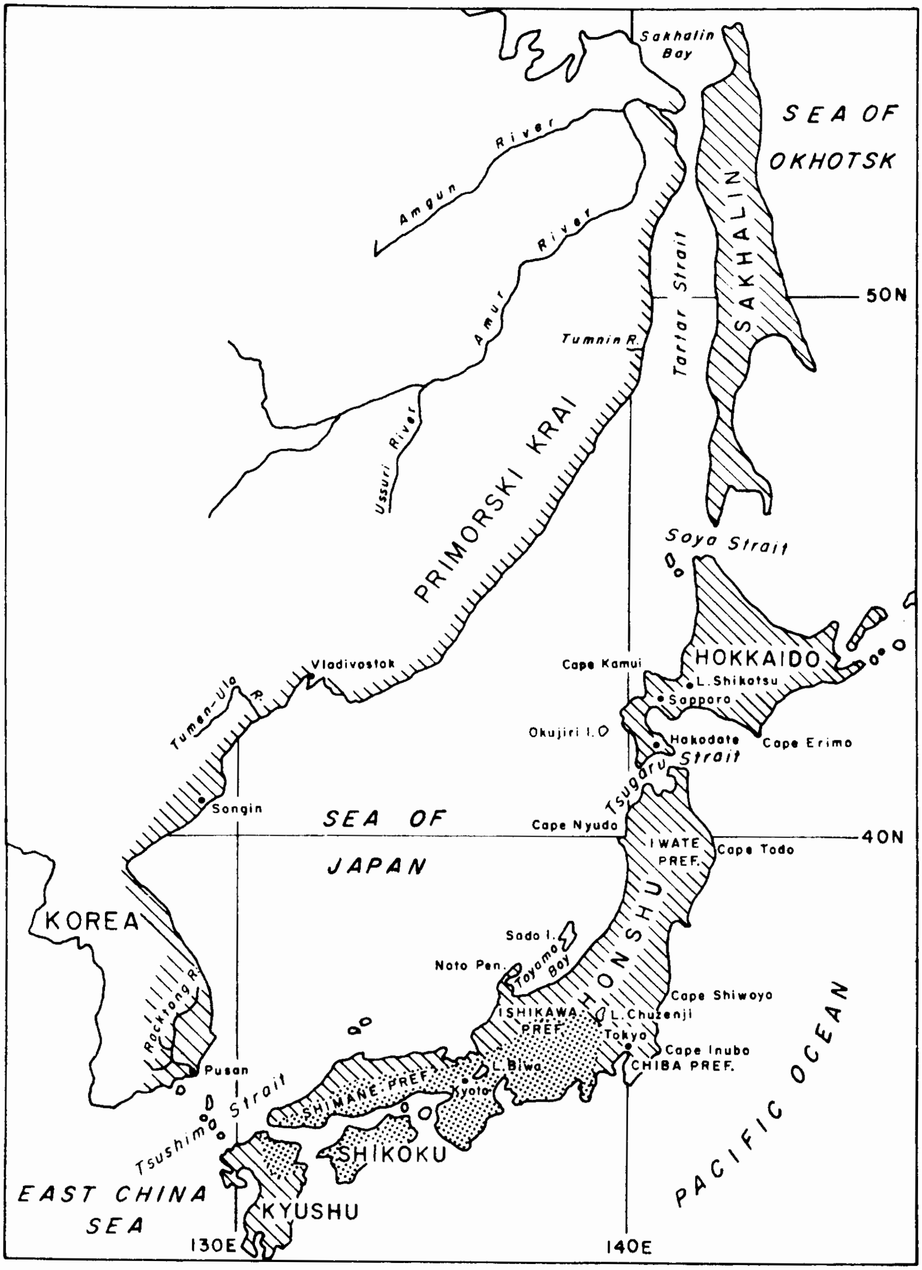

Fig. 1 Map of Japan and adjacent areas showing the distribution of Oncorhynchus masou and O. rhodurus

form natural land-locked populations. These species, moreover, are piscivorous in their feeding habits, and this appeared a special asset. The Great Lakes have enormous stocks of smelt (Osmerus mordax) and alewife (Alosa pseudoharengus) which are of relatively low value. In the surveys, particular attention was given to salmonid species which might utilize this abundant forage.

The literature concerning the North American Pacific salmons is voluminous but oddly enough very little information on Far Eastern forms has found its way into English language fishery journals. This paper attempts to summarize what if known about the ecology of the land-locked forms of the two species, but it will be obvious that there are many gaps in the information. Some of these arose out of communication difficulties, but in many cases, the facts were simply not known. For reasons which will be given later, there is a possibility that these gaps will never be filled. However, the salmons are of great interest biologically, and in the author's opinion, they are both excellent candidates for North American introduction. It is hoped, therefore, that this paper will stimulate intensive study of the species.

Another species which had aroused interest was the Ayu (Plecoglossus altivelis Temminck & Schlegel). It is a smelt-like salmonoid and is the only representative of the family Plecoglossidae. The algae-feeding habit of the species recommended it for possible introduction in the lower Great Lakes where excessive growth of sessile shoreline algae is a serious problem (Neil & Owen, 1964). The investigation revealed however, that on several counts, the species holds little promise. It was found for example, that the fish is not likely to be able to withstand the low winter temperatures in the Great Lakes, and that it only feeds on algae while living in streams. Further details on the life history and management of this interesting species, along with a general review of the Japanese Salmonidae, are available in a manuscript report (GFS-5-68) which is on file at the Glenora Fisheries Station.

Part B - Japanese Geography in Relation to the Fish Fauna

The following is a brief outline of some zoogeographical aspects which will provide background for the ecological and transplantation considerations in the later sections.

The Japanese archipelago consists of four main islands lying between 24°N and 46°N latitude. The largest island, Honshu is about the size of Great Britain (87,000 sq. mi.). The southerly islands, Kyushu (16,000 sq. mi.) and Shikoku (7,000 sq. mi.) complete what is known as Japan proper. The northern island, Hokkaido (30,000 sq. mi.) has traditionally been regarded as discrete by the Japanese people and it also has some distinctive climatic and ecological features.

The climate of the archipelago is influences by the adjacent Asian mainland, by the cold Oyashio current which bathes the coasts of the Sea of Japan on the north-west and the warm Kuroshio current washing the Pacific Ocean shores along the south-east flank. The mountainous terrain modifies these primary factors. In general, Hokkaido has a cool temperate climate (microthermal, humid continental with cool summers, in the classification of Finch and Trewartha, 1949), like that of Ontario south of North Bay. Forests range from mixed deciduous and coniferous in the south to coniferous in the north. The northern third of Honshu and the central highlands correspond climatically to the central tier of states in the U.S.A.: - Ohio, Illinois, Nebraska etc. (microthermal, humid continental with warm summers, in the Finch and Trewartha classification). The rest of Japan is warmer, mesothermal, humid, subtropical, with warm summers) corresponding in general to the American south, and varying widely according to altitude and geographical position.

Japan has relatively few lakes. The country has a narrow, high profile and volcanic activity was the most important agent in lake formation. There are only 20 lakes larger than 2,500 acres (10 km^2) and the total natural freshwater lake area amounts to only 700 square miles (1,780 km^2). Lakes represent 0.5% of the total land area which is in contrast with Ontario where 10% of the land is taken up by lakes (17% if the provincial waters of the Great Lakes are included).

The lakes, while few in number, are interesting and highly varied with respect to type. Lake Biwa (Fig. 1) is not only the largest in Japan at 260 square miles (674.4 km), but it is considered the third oldest lake in the world (Horie, 1962). Many Japanese lakes are recent and some have not lost the acidity associated with the volcanic origin. These are generally not suitable for fish. Also, because of the volcanic origin, 37% of the 626 lakes and ponds listed by Horie (1962), lack outlet rivers. There are many other interesting limnological features, but no generalized conditions of water chemistry or trophic status distinguish these waters from lakes elsewhere. Water temperatures and seasonal thermal stratification likewise are normal for the circumstances of geography and climate.

By contrast with the sparse lakes, there are many rivers and they tend to be short and steep. Monsoon rains flush and scour the streams at intervals and it was the author's impression that before irrigation and hydro-electric dams provided flood control, these rigorous conditions must have demanded unusual tenacity of the native stream-dwelling fishes.

The fish fauna of Japan shows the influence of the above factors and of the insular situation of the country. The number of exclusively freshwater fish species is rather small, reflecting the long separation of the archipelago from the mainland (Okada, 1960). Included in this group are about forty well-diversified cyprinoids and 3 catfishes (family lctaluridae). In total, there are 126 species and sub-species representing 32 families.

The cool climate towards the north and the extensive river systems favour the production of salmons and trout. The highest commercial yield is obtained from the chum salmon (O. keta) which goes to sea soon after emergence from the gravels of the spawning beds. The pink salmon (O. gorbuscha) also enters the sea at the fry stage, and is also successful in Japan. This may suggest that the ideal adaptation for salmon involves marking maximum use of the extensive stream gravels during the winters when climatic conditions are fairly stable. Since the fish require relatively little food before descending to the sea, this pattern also has the advantage of freeing the fish from the productivity limitations imposed on other species by the rivers. By contrast, the sockeye salmon is not a major component of the domestic salmon catch and it seems very likely that this relates to the fact that there are not many lakes with river outlets to the sea, to serve as nurseries for the pre-smolts. Kokanee (O. nerka adonis) on the other hand, occur naturally in a number of lakes, and have been successfully established in many more (Tokui, 1964). Neither the coho (O. kisutch) or the chinook (O. tschawyscha) salmons have large populations in Japan. The reasons for this are less clear, but that the ecological role of these species in other waters appears to be played by O. masou and O. rhodurus in Japan is a fact of considerable importance, and will be dealt with at greater length in a later section.

Ecological observations in Japan today are seriously hampered by changes in the fish stocks and in the environment. Transplantations of the more important salmonids have been so extensive that the original ranges and racial types are often obscure.

The onrush of industrial progress has had serious effects on the fishes. The short steep rivers which have been so productive of migratory salmons in the past are also ideal for the production of hydro-electric power and dams now obstruct most of the major salmon rivers. Gravel is mined wholesale from the rivers for construction purposes and this wreaks havoc with the spawning and juvenile habitats of many fishes. The quick flushing rates of the rivers have minimized inland (but not seashore) pollution until recently but it is becoming more worrisome, particularly in cases where lakes receive the river flows. The official approach is to attempt to replace natural reproduction with fish culture on an enormous scale. Whether this policy will succeed remains to be seen, but the matter has considerable pertinence to the questions to be discussed here. It is my opinion that the endemic salmons are in danger and if introduction of these species to Ontario is to be attempted it will be necessary to begin soon, while eggs may still be obtained.

Part C - Description of *O. masou* and *O. rhodurus*

The available information on the ecology of these two salmons suggests that any differences are hardly sufficiently great to justify two separate presentations. This view was also taken by Tanaka (1965), who cited the opinion of Imanishi (1951) that there is no ecological distinction. It was often the case moreover, that facts were available for one species and not the other, in some aspect of life history. It is hoped that this will not lead to underestimation of the importance of any real differences which exist. On the other hand, a composite picture of a single fish with the generalized features as described will be useful for ecological orientation, and for contrast with other species.

1. Taxonomic Status and Morphological Description

In the freshwaters of Japan the sub-order Salmonoidei (after Berg) is represented by the families Salmonidae, Plecoglossidae, Osmeridae, and Salangidae. There is only one species in the family Plecoglossidae. The following is the species list generally in use by Japanese workers for the salmonid fishes.

Family - Salmonidae (salmons, trout, whitefish, graylings)

Sub-family - Salmoninae

Genus - *Oncorhynchus*
- *O. tschawytscha* (Walbaum) - chinook salmon, masunosuke
- *O. gorbuscha* (Walbaum) - pink salmon, karafutomasu
- *O. keta* (Walbaum) - chum salmon, sake
- *O. kisutch* (Walbaum) - coho salmon, ginmasu
- *O. nerka* (Walbaum) - sockeye, kokanee, himemasu
- *O. masou* (Brevoort) - cherry salmon, sakuramasu, yamabe
- *O. rhodurus* (Jordan et McGregor) - biwa-masu

Genus - *Salmo* (Parasalmo of Vladykov 1963)
- *S. gairdneri* (Richardson) - rainbow trout (introduced), nigimasu

Genus - Salvelinus - Chars
S. malma (Walbaum) - dolly varden, oshorokoma
S. pluvius (Hilgendorf) - iwana
S. leucomaenis (Pallas) - amemasu
S. imbricus (Jordan et McGregor) - gogi
S. fontinalis (Mitchill) - American brook trout (introduced), kawamasu

Genus - Hucho
H. perryi (Brevoort) - ito uwo

The number of species of far eastern salmons is by no means unanimously agreed upon. Most present-day Japanese workers accept the two as described herein, and Vladykov (1963) concurs with them. Hikita (1962) recognizes one more, O. kawamurae, a species close to the sockeye, and now apparently extinct. Jordan and McGregor (1925) recorded another, O. ishikawae which was subsequently recognized as land-locked O. masou and given sub-specific rank as O. m. ishikawae by some authors (Tsuyuki and Roberts, 1966). Still another species (O. iwame Kimura and Nakamura) of localized distribution was added to the list as recently as 1961. At the opposite extreme Behnke, Koh and Needham (1962) suggest that there is only one species, which has three sub-species O. m. masou, O. m. rhodurus and an unnamed Formosan sub-species. Because of the effects of transplantation and stock decline, this debate may never be fully resolved, but since it does not affect discussion of the ecology of the fish, the list of seven species will be used.

O. masou has a pleasant common name in English translation - "cherry salmon", but this is not so for O. rhodurus.

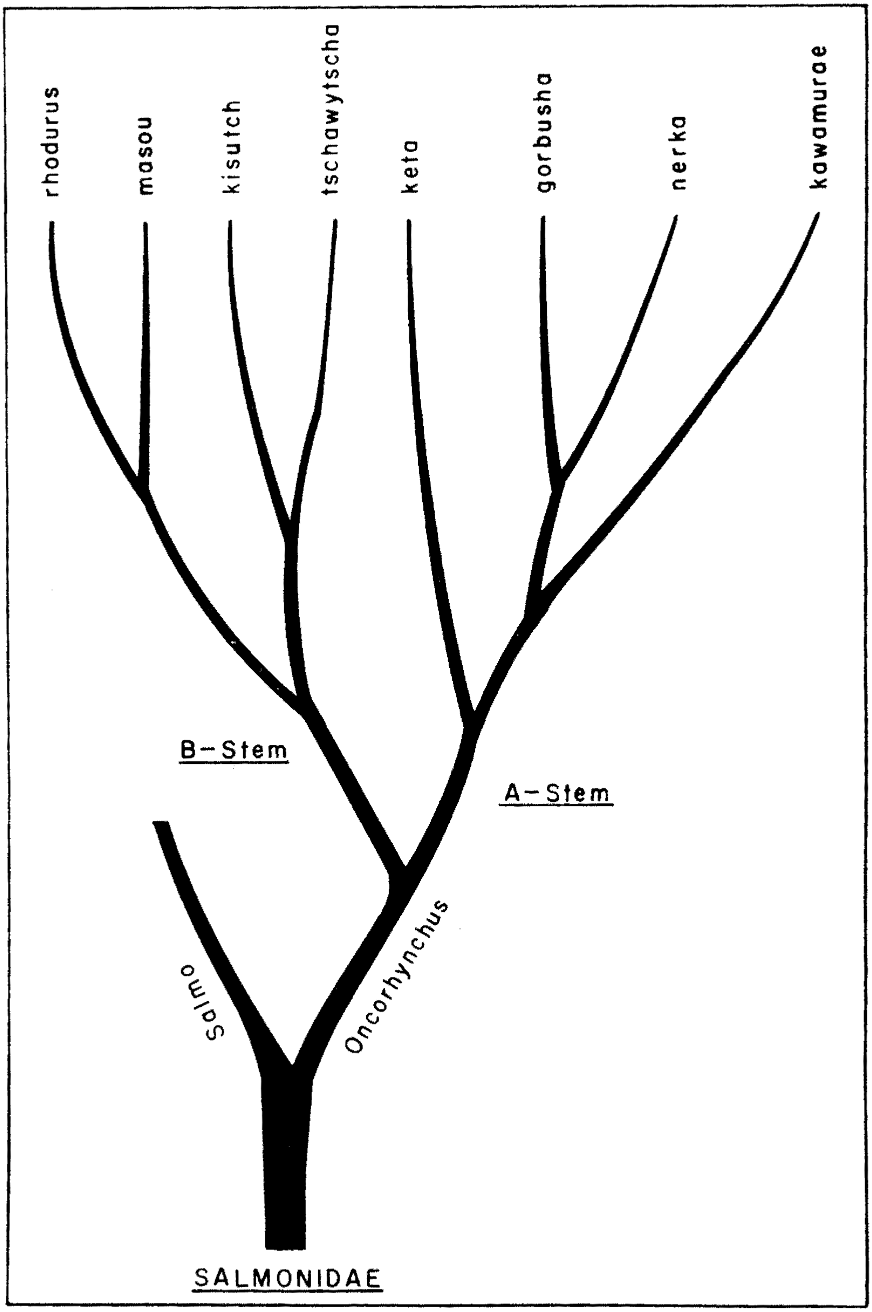

Fig. 2 Phylogenetic relationships within the genus Oncorhynchus from Hikita (1962)

Recently, Ricker and Loftus (1968) have used the name redspot salmon for O. rhodurus and this seems adequately descriptive. Throughout the remainder of this paper therefore the two Japanese species will be referred to as the cherry and redspot salmons.

That the Pacific salmons had their origins in the freshwaters of the Far East (Neave, 1958) is rather generally accepted, as is the apparent cline between the more trout-like cherry salmon and the more highly specialized pink and sockeye types. Hikita (1962) segregates a B stem in the phyletic tree (Fig. 2) consisting of the coho, chinook, redspot, and cherry from a more recently evolved A stem containing the chums, pinks and sockeye. The B stem fish are the closest to the Salmo types and all have short deep bodies as fingerlings. The A stem fish all have elongate bodies as fingerlings, and are the more elaborately modified fish in breeding condition. Table I summarizes some of Hikita's meristic determinations to illustrate the morphological cline. Similar counts for the rainbow trout are included in the table for comparison. The B stem fish have low gillraker counts, and with the exception of the chinook salmon, low pyloric caeca counts. The affinities and evolutionary sequence suggested by Fig. 2 are similar to the outline given by Hoar (1958) for behavioural patterns in juvenile salmon in relation to the down-stream migration, and by Tsuyuki and Roberts (1966) for the proteins of the muscle tissue.

The degree of dependence on freshwater habitat also shows

Table I

Some Meristic Determinations
Within the Genus Oncorhynchus from Hikita (1962)

(Numbers in Parentheses are average)

	Species	A.	B.	P.C.	V.	G.	Lat. L.
	rhodurus	13-17(16)	11-13(13)	45-70	65-66	17-20(20)	119-137
B	masou	13-18(16)	11-14(13)	35-68(50)	63-69	16-22	12-140(123)
STEM	kitsutch	15-18(18)	12-14(13)	40-80(63)	67-68(67)	19-23	137-146
	tschawytscha	17-20(19)	16-19(17)	127-170(153)	71-72	20-23(24)	129-152(147)
	keta	14-18(17)	11-15(13)	125-215	62-69	21-25(23)	132-146
A	gorbuscha	16-19(18)	11-14(12)	91-188(126)	67-70(68)	26-33(31)	127-204(178)
STEM	nerka	15-19(18)	11-15	80-117(91)	66-69(67)	33-39	120-140(133)
	Salmo gairdneri*	12		42	58	20	120

A. - Anal Fin Rays
B. - Branchiostegals
P.C. - Pyloric caecae
V. - Vertebrae
G. - Gillrakers
Lat. L. - Lateral Line Scales

* from Jordan and Evermann (1896)

the phyletic cline. The redspot and cherry salmons spend at least one year in freshwater and land-lock readily. Chinook and coho salmons also spend some time in freshwater but are not known to occur naturally in land-locked situations. Pink and chum salmons spawn in freshwater but the fry go to sea soon after emergence, as indicated earlier. The sockeye is a highly specialized fish, and its long freshwater life history is considered (Hoar, 1958) a secondary adaptation. Rounsefell (1962) considered the sockeye and coho salmons to be "adaptively anadromous" while the chums, pinks and chinooks were "obligatory anadromous". His analysis was carried out without reference to the Far Eastern salmons and it is felt that because one of the two examples of land-locked coho given has later proven to be the cherry salmon (the _O. ishikawae_ of Jordan and McGregor), it would be more appropriate to consider _O. masou_, _O. rhodurus_ and _O. nerka_ "adaptively anadromous", with coho added to the list of "obligatory anadromous" salmons.

The morphological similarity between _O. masou_ and _O. rhodurus_ can be seen in Table 1. There are minor differences in form and Hikita (1962) indicates that in his specimens the ventral fin ray counts for the cherry salmon are rather fixed at 10, while the redspot is more variable around a mean of 11. Oshima (1957) demonstrated in hybridization experiments that the red spots of _O. rhodurus_ are genotypic, and recessive to the _O. masou_ coloration.

The taxonomy of these salmons has been no doubt complicated by the fact that each occurs as a river resident, lake resident and sea-run type and within these types there is considerable variability in form and markings. Juveniles of both species in all three types, have deep bodies, large distinct parr marks and small black spots dorsally. Smolts become relatively more elongate and silvery with a black-tipped dorsal fin. Sea-run adult cherry salmon are terete with blue back and silver underbody. At spawning, anadromous cherry salmon have a red-to-pink under-belly with a series of vertical bars of the same colour on an olivaceous-to-black background. Males are more vividly coloured than females and the head is often pure black. The male head is elongated in spawning condition but the hook is not as pronounced as with some of the other members of the genus.

A considerable fraction of the juvenile cherry salmon remain in the rivers and are called "Yamabe". In fry rearing experiments reported in the literature (Fujita, 1933; Saguir, 1936) from 40 to 60% of fry from anadromous cherry salmon runs became Yamabe,--that is, they failed to smolt. Males predominate among the Yamabe (to 75%) while smolts and ocean-caught cherry salmon are mainly females.

There are sea-run populations of redspot salmon (Shiraishi, Suzuki and Tamada, 1957) but the species appears to be more commonly found as river and lake resident stocks. The river resident form of redspot is known as "Amago". Yamabe and Amago retain parr marks and black spots through life, with the red spots of O. rhodurus also persisting in Amago. The background colouring deepens in both Amago and Yamabe and the deep body is retained. Spawning livery adds rusty and brownish hues to the overall pattern.

Lake-dwelling cherry and redspot salmon show considerable variation in appearance from lake to lake. All apparently smolt and lose the parr marks, and the O. rhodurus their red spots. At spawning they are not considered to be as brightly coloured (Okada, 1960) as the anadromous forms.

2. Distribution

The range of the cherry salmon lies between 24°N Lat. and 55°N Lat. The 24° southern extreme is the high mountain (over 2,000 m.) relict in northern Taiwan (Behnke, Koh and Needham, 1962) which was referred to earlier. The main area of concentration is the Sea of Japan as illustrated in Fig. 1. Stocks are known on the east side of Korea, and northward to Vladivostok. Tanaka (1965) suggests the distribution is continuous along the coast of Primorskii Krai to the Amur River but no references to localities other than the Amur River itself were found. Runs have been reported on the west side of the Kamchatka Peninsula but no references to runs on the north shores of the Sea of Okhotsk could be found. In Japan spawning runs are found northwards from Cape Inubo on the Pacific Ocean side of Honshu and north from Shimane Prefecture on the Sea of Japan side. The salmon are most abundant in

Hokkaido, and to the south in Honshu they are progressively more confined to rivers and lakes at higher altitudes. They are absent from Shikoku, the Kuril Islands (north-east from Hokkaido) and the Rhyuku chain of islands which extend south-westward from Kyushu.

The distribution of the redspot is Shikoku and the Pacific side of Honshu from the Tokyo Bay area south-westward to and including the northern tip of Kyushu (Oshima, 1957). This is also illustrated in Fig. 1. Biologists in Japan gave the general impression that the climate throughout the redspot range is somewhat warmer than throughout most of the cherry salmon range. This may reflect a better ability of the redspot to tolerate warm water. There is, however, no known difference in type of habitat preferred. Interestingly, Oshima (1957) indicates that where the distributions overlap, the two species may be found in the same stream system, but they are never captured together. Cherry salmon introduced into Lake Biwa are said to be distinct from the native redspot salmon (T. Miura, personal communication).

3. Movements and Homing

There are few tagging data, but in general Japanese workers feel that the oceanic movements of cherry salmon are the most restricted of all their Pacific salmons because catches are made fairly close to the coasts. Tanaka (1965) shows that the seasonal southward pattern of catches of cherry salmon in the Sea of Japan corresponds with the southward movement of the Polar Front.

The southward extension of this pattern almost takes the fish out of the Sea of Japan altogether. This movement was shown to coincide with the 10°C surface isotherm. The return northward in the spring similarly follows the warming of the ocean progressively further northward. The northward movement of the 10° isotherm seems also to be the factor determining the timing of the arrival of the various cherry salmon runs at their home streams.

In Hokkaido streams cherry salmon are found in water temperatures reaching 20°C in late summer, but the role of temperature in the upstream movement is not known. The mature cherry salmon apparently proceed upstream before the chum salmon enters the rivers in September.

In Lake Biwa juveniles and older redspot salmon inhabit the hypolimnion in summer and are found at all depths at other times (Miura, 1966). The adults do not leave the lake until the spawning migration is in progress. Osanai (1964) similarly relates depth distribution to seasonal temperature change in the land-locked cherry salmon of Uryu Reservoir. Some salmon remain in spawning streams as residuals in both species (Tokui, personal communication), but most of the fish descend to the lake as fry, rather than remaining until of smolting size. Osanai (1964) for example, reported that Okada and Inoue (1958) found: "....Since conditions on the streams connecting to the lake are poor as environment for fry, larvae move into the lake shortly after hatching." The higher productivity of the salmons in comparison with rainbow trout was considered by the Japanese biologists to be related to this lower dependence on the stream. No suggestions were offered by the Japanese biologists to explain why the food limitation should cause fry descent in the salmon but not in the rainbow trout.

In both sea-run and lake stocks, the fish have been observed in numerous small spawning aggregations far up in tributaries. The Japanese feel that because of such behaviour, the lake cherry salmon are less readily overfished than kokanee which tend to concentrate in fewer spawning locations. It is assumed that homing plays an important role in maintaining these small cherry salmon stock units, but Shiraishi (personal communication) suggests that cherry salmon exhibit more straying than kokanee, and will divert to favourable spawning habitat if stocked in a less favourable situation.

4. Catch and Abundance.

The annual catch of cherry salmon is in the range of 2000 to 5000 metric tons. This represents only 5% of the total annual catch of salmon in Japan. The only other known harvest which is of consequence is that of the U.S.S.R. which amounts to about 1000 metric tons each year. The Japanese fishing is primarily conducted by traps and line fishing near the shore along both the Pacific and Japanese Sea coasts with lighter catches being taken by gillnets in the open sea. The fishing generally takes place between January and June. The peak of the fishing season is in March in the southern areas, and in April or May, to the north.

In the fresh-waters the adults, Yamabe, Amago and the lake-locked fish are all taken by angling. All are highly prized food fish and apparently provide excellent sport. No data on the inland catches were forthcoming but they may reach substantial totals.

There are strong and weak production years but no information was obtained on cyclic tendencies. This is mainly because the catch statistics for pink and cherry salmon are often combined.

There is some evidence that cherry salmon production has declined from earlier times (Tanaka, 1965). The extent of the decline is not known, but it can be noted that chum salmon catches dropped by two-thirds between the turn of the century and the nineteen-fifties (Sano, 1966). Cherry salmon would be more profoundly affected by dam construction, and their abundance likely declined at least this much.

For salmonid introductions in general, the Japanese look on Kokanee as the most productive, cherry salmon second and rainbow trout third. The only example for which statistics were available was that of Lake Towada where annual catches approximate 1,000,000 kokanee, 100,000 cherry salmon and 200 rainbow trout.

5. Spawning and Early Life History.

Sakura-masou means "cherry trout" in Japanese and this refers to the coincidence of the return of the adults with the appearance of the cherry blossoms in May. They spend the summer in the river and move to the headwaters for spawning in September or October. The fish feed actively in the river and most of the gonad development takes place there. Tanaka (1965) describes a June sample of cherry salmon from the Shinsha River on the west coast of Hokkaido in which the gonads averaged 1.7% of body weight in females and 0.5% for males. At the time of spawning the ovaries make up 20% of the body weight and the testes 5% more.

Fecundity varies with the geographical location as well as with fish size. In general, however, the Hokkaido anadromous cherry salmon average about 2,500 eggs for 2.5 kg. (5.5 lb.) females. Yamabe which are much smaller, spawn from 200-400 eggs. The eggs are moderately large, averaging about 5 mm for both sea-run adults and Yamabe.

The spawning of cherry salmon takes place further upstream than kokanee. In a redspot stock studied by Shiraishi, Suzuki and Tamada (1957) current velocities ranged between 0 and 30 cm/sec. and averaged 13.9 cm/sec. (0.5 ft/sec.). Spawning behaviour is like that of other members of the genus. In the stock described by Shiraishi _et al_. (1957) redds averaged 1,400 cm^2 (220 sq. in.) and were more elongate in areas where the flow was greater. The males guarded and the females dug the nests to depths between 10 and 30 cm, averaging 22 cm (8.7 in.). It was also shown in this study that the eggs were buried under about 8 cm (3 in.) of gravel when 50% of the stones measured less than 4 mm. in diameter. Where the substrate consisted of predominately fine materials, there was little excavation and the nest tended to be more mounded. The constitution of the gravel in the chief spawning area examined by these authors is shown in Table II.

No reports of shoal-spawning among the lake-dwelling forms of either species, were located.

Yamabe and sea-run cherry salmon have been observed spawning together. All fish which return from the sea die after spawning, but Yamabe males are known to spawn several times. In ponds both sexes can ripen repeatedly. This is considered a further indication of the primitive phyletic position of these fish within their genus.

The range of temperature at which spawning takes place appears highly variable. In the Shiribetsu River, peak cherry salmon spawning activities occur at 15°C, but elsewhere temperatures required for spawning were generally thought to be between 5 and 12°C.

The incubation period for the cherry salmon is similar to that of the kokanee, with 430-480 centigrade degree-days (above 0°C) required for the hatch. The Japanese generally reckon on 55 to 60 days to hatch cherry salmon at 8°C.

In the river the juvenile cherry salmon behave like young

Table II

The Composition of Spawning Gravels
used by _O_. _rhodurus_

(from Shiraishi, Suzuki and Tamada, 1957)

Pebble Diameter Class (mm)	Percentage Composition
30	3
30-20	7
20-10	23
10-8	8
8-6	9
6-4	4
4-2	13
2	33
	100

coho salmon. They are aggressive and territorial. They are active at reduced light levels but not truly photo-negative. Sea-run cherry salmon usually smolt after one year in the river. The smoltification process has been shown by Kubo (1959) to be size-specific, and induced by both rising water temperature and low light exposure.

6. Food and Feeding

In general cherry and redspot salmon fry eat microcrustaceans, and convert their diets progressively to aquatic insects and other invertebrates, and then to small fish as they grow. Smolts do not feed. In the sea it is thought that juveniles first eat the larger planktonic crustaceans and later fish, but there are few data concerning this part of the life history. After the return to the streams the diet usually consists entirely of fish. Of lakes stocked with cherry salmon those which originally had stocks of pond smelt (*Hypomesus olidus*) or into which these fish were introduced, were most frequently successful. Osanai (1964) found scarcely anything else but the smelt in stomachs of cherry salmon in Uryu Reservoir. In Lake Biwa, the young redspot subsist on planktonic crustaceans and gammarids but the larger fish live on the goby Isaza (*Chaenogobius isaza* Tanaka) and Ayu (Miura, 1966). Cherry salmon are known to eat kokanee fry also and since kokanee are considered more productive, the two fish are not planted together in the same lake.

7. Age and Growth

Among the anadromous cherry salmon of Hokkaido, 90% spawn as three-year olds (one freshwater winter, one ocean winter). The remainder spend two winters in freshwater before smolting and entering the sea for one whole year.

The Yamabe usually mature one year younger than the sea-run fish, but lake fish are often older before maturing. Although data are scanty Miura (1966) indicated that the Lake Biwa redspot males spawn as age 3 or 4 fish, and the females as age 4 or age 5. These ages, in the usual convention employed by salmon biologists, refer to the number of years from the deposition of the eggs.

Cherry salmon belonging to the ocean migrant stocks grow rapidly. The smolts are 11 or 12 cm (4.4 or 4.8 in.) long when descending the Hokkaido rivers as eighteen month old fish. When captured as adults in the rivers, during the summer following the marine sojourn, cherry salmon have been found to be 36-71 cm (14.4-28.4 in.) in length, as illustrated in Table III. In the lakes cherry salmon never attain the large size of anadromous fish, but their size is respectable nonetheless. Hikita (1962) lists the range of total length for land-locked redspot as 16.2-56.8 cm (6.5-22.7 in.). Amago fall in the lower end of this range and he lists the size of Lake Biwa spawning adults as 44.9-48.2 cm (18.0-19.3 in.) total length. Miura (1966) estimated, by back-calculation from the scales, that the fish of this stock attain 24.0 cm (9.6 in.) by the start of the second year, 36.5 cm (14.6 in.) by the third year and 42.0 cm (16.8 in.) by the fourth.

8. Parasites and Diseases

Virtually no information on these subjects was available.

9. Hatchery Culture

There has been a cherry salmon propagation program in effect in Japan for many years. As with other parts of the hatchery operation, it has the objective of countering the effects of the dams by taking eggs from as many of the upstream migrants as possible. The eggs are hatched in the usual way, but the sac fry are held in outside gravel-bottomed raceways. The fry bury themselves in the gravel until the springtime when they emerge and exit into the river.

The Maena River cherry salmon hatchery has a spring water supply which results in an unusually fast incubation. Spawning occurs in mid-September and the eggs are "eyed" by mid-October and hatch by mid-November. Yolk absorption is completed in the fry channels and the fry emerge in January and are released into the nearby river.

In Lake Biwa, the redspot eggs are collected from commercially netted fish, rather than from spawn-collecting stations and the fry are released directly into the lake. It is interesting to note that the propagation costs in this case amount to 20% of the annual value of the redspot yield. It appears that neither the

Table III*

Total length[1] and body weight of adult masu salmon
in the streams of Hokkaido

Stream	Sex	Total length Range cm	Total length Mean cm	Body Weight Range kg	Body Weight Mean kg	Source
Shiribetsu River	Female	39.6-64.4	55.4	1.913-3.553	2.550	Handa (1932)
	Male	36.3-57.8	48.8	1.538-3.131	2.325	Handa (1932)
Nishibetsu River		46.2-74.3	57.1	1.200-4.163	2.138	Handa (1932)
Chitose River		50.0-71.0	62.7	1.5 -5.1	3.4	Akiba (1936)

1 In the data given by Handa, length is designated as body length. However it is assumed that this means total length. In the case of masu salmon, there is not much difference between fork length and total length.

* Table 3 of Tanaka (1966)

cherry nor redspot salmon programs is successful however, because in both cases the yields are continuing to fall. With the cherry salmon the extensive mining of river gravels is blamed for poor survival of the planted fry. Currently a rearing program is underway in Hokkaido to test the survival of smolts released into the rivers one year after hatching. This has reduced the overall dependence on the river habitat, but the success of the program would seem now to depend on the presently unknown importance of the role played by the Yamabe. River habitat around Lake Biwa has also been seriously depreciated both by pollution and gravel removal, and it is possible in this case that planting fry into the lake imposes low survival.

Part D - Discussion

The foregoing sections describe a number of features of cherry and redspot salmon which might make them useful additions to the North American fish fauna. Attempts to acclimatize the North American Pacific salmons to various parts of the world, have a very long history (Davidson and Hutchinson, 1938), and the reasons for this are readily understood. The various species are all fish of large size, high productivity, premium food quality, and often they are fine sporting fish as well. The Japanese salmons also have these qualities. Moreover, they occupy an unique position as the only naturally land-locked piscivorous Pacific salmons, and this is an attractive combination of characteristics. It is a further advantage that they have more southerly distributions than the other Pacific salmons and appear to be well within their climatic range in Southern Ontario.

The observations on the ecology of the two salmons suggest several possible adaptive advantages which serve them under the Japanese conditions. One can speculate first of all, that an early ascent of the rivers might permit the cherry salmon to take possession of the spawning beds to the exclusion of competing salmon species, and the ability to tolerate the warm water temperature could be the mechanism which makes this possible. It is also possible that the flexibility in the life history pattern of the Japanese fish would act in their favour. In the Japanese situation where many lakes have no doubt been closed and opened by volcanic activity in the long course of time, it can be argued that the cherry and redspot salmons were selected for their ability to persist in both fresh and salt water.

None of the Pacific salmon species rely entirely on a single spawning age, so there is some measure of protection against the permanent loss of year classes from the cycle. The effects of the monsoon rains and severe storms on the fast-flushing Japanese rivers appear especially rigorous habitat conditions, however, and it is suggested that the flexibility in the life history patterns of the cherry and redspot salmons may have adaptive significance in these circumstances. Maintaining a residual river population which spawns at a younger age than the anadromous fish, provides better protection against complete year class loss than the normal variation in age at maturity would, and the capacity for some repetitive spawning among the river-dwelling fish would likely be a further asset.

Whether the specialization of the cherry and redspot salmons would limit their success in the Great Lakes can only be answered by test planting. The polymorphism that appears to be an important part of this specialization of course might equally favour adaptation. At present it is predicted than any environmental deficiency would more likely arise in the rivers than in the lakes. In the lakes, temperatures would almost certainly be favourable. The rate of acclimation to decreasing temperatures (both cherry and redspot salmons) is a little slower than that of kokanee. The former two have been successfully held at 1.5°C in the Glenora Fisheries Station for three months or more.

The tolerance of the salmons for warm water temperatures has also been demonstrated experimentally here. The fish are expected to occupy deep water in winter and summer, so the only way this attribute might prove useful in the lake, is by extending the duration of the periods in spring and fall when the salmon would be available to sportsmen in inshore waters.

It is not likely that food would present a problem for cherry and redspot salmons because of the large stocks of forage fish, particularly smelt (Osmerus mordax) in the Great Lakes.

Residual salmon maturing in the streams would be able to withstand the extremes of summer temperatures at least as well as the young rainbow trout do now. There are at least two possible problems, however. In the first place, the rivers feeding the lower Great Lakes tend to be small and sparse, or polluted and obstructed. Whether or not sufficient stream area with adequate gradient could be found to support large populations of the salmon is in question. Secondly, if the salmon failed to retain the habit of descending to the lake as fry for some reason, the potential for high productivity would not be realized.

The question of whether a program of introduction and study of the Japanese salmons should be undertaken must be evaluated in relation to the rather similar, and highly valued rainbow trout stocks on the one hand, and to the present experimental introductions of coho and chinook salmon. The latter is the more important consideration here because the problem of possible danger to the rainbow trout stocks relates to all of the salmon introductions. The salmon question will, therefore, be dealt with first.

The cherry salmon was known to Tody and Tanner (1966) and their choice of the coho for introduction to the Great Lakes was presumably based on the likely larger size of the coho, and on the more readily available egg supplies. These authors recognized, however, that there was a large element of risk involved with both coho and chinook, because neither species had ever been known to form permanent self-sustaining populations in land-locked situations. There was ample evidence that the coho at least could survive and grow well in freshwater (Needham, 1938) and equally strong evidence that there would be no natural reproduction (Foerster and Ricker, 1953). Making the assumption that this inability to reproduce would not interfere with the production of viable spawn from each successive generation, the program was established in Michigan with extensive spawn-collecting and hatchery facilities and it depends on massive annual plantings of smolts of both species. The assumption has known weaknesses. Tody and Tanner (1966) cited the example of Georgetown Lake, Montana, where cohoes of the first domestic generation were hatchery-reared, and produced spawn. Only about 15% of the eggs hatched however. A similar rearing experiment in connection with the California inland coho introduction program (West, 1965) produced eggs from the second freshwater generation, but the eggs were extremely large and fragile. Stockell (1954) reported that chinook salmon introduced into Canterbury Lake, New Zealand, disappeared after three generations, and the decline was associated with progressively declining growth and fertility.

The possibility that coho and chinook salmon will not continue to produce viable domestic spawn is recognized by Tody and Tanner (1966) and by West (1965) but they suggest that intensive selective breeding might quickly produce an adapted line. It is by no means a minor support for that argument, that the pink salmon has become acclimatized in Lake Superior (Schumacher and Eddy, 1960). It has been shown (Hurley and Woodall, 1968) that these fish do not normally survive long in freshwater as juveniles when their seaward migration is prevented and so this is a remarkable example of selection indeed. That such a selection has never occurred naturally among coho and chinook stocks cannot be overlooked as a danger to the program and it is because of this risk that the Japanese salmon represent an excellent potential insurance. It can also be argued that if selection is successful, the resultant fish may very well be sufficiently similar to the cherry or redspot salmons, that the agencies involved might be better advised to use these species immediately any sign of fertility loss or inadequate spawn production develops with the coho or chinook salmons.

Basing a management program on the Japanese fish instead of the coho and chinook salmons could prove more economical. The present Michigan hatchery programs are extremely expensive, because the salmon must be reared to smolting size to prevent any long sojourn in the streams which might affect their productivity. The very least advantage to be expected of the Japanese salmons is that natural reproduction would occur in some areas and would reduce hatchery costs. The maximum advantage would accrue if entirely self-sustaining stocks with high productivity developed. Even with very limited natural production, there is still the possibility that the stocks of Japanese salmon might be sustained with annual fry plantings and this could be very economical management compared with the present salmon programs.

The possibility that introduced salmons might interfere with the already established and successful rainbow trout must be examined seriously. The warming of the water and the greater silt loads in the lower sections of rivers flowing into the Great Lakes resulted in the elimination of the Atlantic salmon (McCrimmon, 1954), and the restriction of brook trout to the cooler headwater sections of the streams. The rainbow trout have proven well suited to the present stream conditions and they may well afford the model against which the success of other exotic species will be judged. There was a strong argument that these fish should not have been placed in jeopardy by any salmon introductions without rather strong evidence in the favour of the new fish. At this point in time, the salmon introduction programs are underway in all of the Great Lakes and the great popularity of the fish makes it essential to carry the programs forward. It is fortunate that stream salmonids can be removed or restocked rather readily so the danger of harming useful rainbow trout stocks is minimal as long as individual genetic lines of rainbow trout are carefully preserved.

Interaction between the Japanese salmons and rainbow trout seems quite likely, but it is difficult to anticipate its nature or effects. Competition for food might be greatest between young stream-resident trout and residual salmon remaining in the river. Conceivably, the trout might also prey on salmon fry during their descent to the lake.

It is suggested that the Japanese fish can be looked upon at least as equivalent to the rainbow trout in growth potential, food and sporting qualities and warm water tolerance. Their overwhelming advantage over the rainbow trout is the potential for high productivity. As pointed out earlier, biologists in Japan and in North America hold that the productivity of rainbow trout is limited by the capacity of the streams in which the trout live for one or two years. The trout production could presumably be increased by smolt planting, but as with the North American salmons, this necessitates expense which might be avoided with the Japanese fish.

It has been suggested (Christie, 1968) that one of the reasons for the success of rainbow trout in the Great Lakes streams was their habit of spawning in the springtime. Fall spawners like the Japanese salmons may be subject to much lower survival of eggs and fry because of over-winter floods and ice-scouring. In many situations there may be a need for management support in the way of spawning channels or hatchery operations, in order for the salmon output to exceed the natural output of rainbow trout. The cost-benefit considerations may vary a good deal from place to place, and of course, there is no way the economics can be appraised until actual yield measurements have been made from experimental plantings of the salmon.

The practical questions which evidently dissuaded the Michigan authorities from looking further into the potential of the Japanese fish are as follows:

1) Can the eggs be successfully shipped over such a distance, and

2) Can they be readily obtained in quantity from the Japanese.

The first question can be categorically answered in the affirmative. In the autumn of 1965 a shipment of 50,000 eyed cherry salmon eggs was received in Ontario. Of these, only 25,000 had survived the trip. The high mortality was caused by a packaging arrangement which, while economical for shipments was unsuitable for such a distance. It could be corrected for subsequent transfers. Three small shipments of redspot salmon eggs have been received subsequently with excellent survival. Whitefish and lake trout eggs have been shipped to Japan from Ontario on several occasions in the past several years and were similarly received with little loss. Subsequent culturing presents no special problems.

Since Lake Biwa appears to be the largest land-locked stock of either redspot or cherry salmon, the choice would appear to be between these redspot eggs or anadromous cherry salmon eggs from one of the large Hokkaido runs.

The answer to the second question is less clear. There may in fact be limits on the available numbers of eggs. The intensity of the fish culture program suggests that the Japanese workers would not be able to spare much from the anadromous spawn-take. However, it is possible that the trend towards rearing the cherry salmon in Japan may make more eggs available. The hatcheries were virtually all fry production operations in 1966 and as the change-over proceeds, the spawn supply may exceed the rearing capacity for at least a few years yet. Eggs from anadromous cherry salmon might have to be purchased.

As indicated earlier, the runs of Lake Biwa redspot salmon are in serious decline. It is thought that this has resulted from the depreciation of salmon habitat in the rivers. The Shiga Prefectural Fisheries Experiment Station, which is charged with the management of Lake Biwa, is interested in substituting a shoal spawner for the salmon. The scientists of this station have expressed interest in experimenting with lake whitefish for this purpose and an exchange program might be arranged. The writer has cautioned against the use of whitefish, but even if a whitefish experiment were terminated early, some other species might be tried. With the rapidly decreasing spawn-take they might spare a maximum of 100,000 eggs per year now, but could not be expected to be committed to such a number indefinitely.

Several thousands of lake stock eggs would likely continue to be available each year from Lake Chuzenji in exchange for whitefish and lake trout eggs. With careful rearing these few eggs could provide smolt stocking to establish a limited population in a small lake.

Aside from the practical problem of the longer shipping time necessary if eggs are imported from Hokkaido, where most of the larger anadromous stocks are found, there is the question of the relative merits of using eggs from anadromous cherry or lake-locked redspot salmon. Japanese biologists have no comparative survival data but they view the question in much the same way as we regard the choice between kokanee and anadromous sockeye salmon for introduction to freshwater lakes. The thought is that the historically land-locked fish may have been selected over a long period for survival in lakes, and they should fare better. However, there are many examples of successful transplantation of anadromous cherry salmon into lakes in Japan, and it is known to maintain a much stronger freshwater attachment than does the sockeye in the first place. Given the same egg availability, the lower cost (only shipping charges), shorter shipment period and fresh-water origin argue in favour of the Lake Biwa redspot. Both species should, however, be available in experimental quantities so the detailed comparisons of their characteristics will be possible in Ontario.

Supply difficulties could delay the beginning of a Great Lakes program. If the quantities of eggs were limited it would be necessary to build up brood stocks in small reservoir lakes first. The danger of permitting a new exotic to invade the inland waters before its value has been adequately assessed cannot be minimized (Christie, 1968). All such experiments should be tightly controlled and the species used should be chosen with great care. This kind of management activity is likely to continue in the future with other kinds of fish and the appropriate control mechanisms should be established now. This holds true in a general way for the introduction programs over all the Great Lakes. Uncoordinated efforts involving different species by the various agencies could be mutually damaging, and it would be most desirable to unify the programs on an international and interstate basis.

Part E - Summary

The following summarizes the arguments for and against the introduction of the Far Eastern salmon. It is the author's view that the advantages of the fish far outweigh the possible risk involved in attempting to use them in the program of rehabilitation of the Great Lakes fisheries.

Advantages

1. General ecological suitability - Ontario appears to be well within the climatic range of both species, and in fact, their tolerance to warm water conditions might prove as useful as has

this feature in the rainbow trout. Other features of their ecology seem favourably disposed for the Great Lakes area, and in fact, their plasticity in life history and form might prove especially useful.

2. Land-locked - They may be expected to reproduce in Ontario where suitable stream habitat is found. Perhaps even more important, where natural reproduction is impossible, they will likely continue to produce viable spawn which can be used for hatchery purposes. It has not yet been established that this will be true of the coho and chinook salmon now being introduced into the Great Lakes, so the cherry and redspot salmons represent important alternative species if the other fail.

3. Piscivorous - The oriental salmons normally subsist on fish in lakes and should utilize the abundant stocks of smelt and alewife in the Great Lakes.

4. High quality - They attain attractive sizes, have good food value and are fine game fish.

5. High productivity - Because they normally leave the natal streams as emergent fry rather than as smolts to enter the lakes, their potential productivity is higher than that of the rainbow trout. Moreover, if artificial propagation is required to support their populations, fry stocking is more economical than the smolt plantings now necessary for coho and chinook salmon in the Great Lakes.

Possible Drawbacks

1. Competition with other fish - Similarities in habitat requirements suggest the Far Eastern salmons may compete to some unknown degree with rainbow trout. The productivity of the salmon may make them a much more suitable fish for the Great Lakes but this cannot be assessed without test plantings.

2. Altered behaviour - The factors which trigger the fry descent habit are not understood. If the salmon altered their behaviour patterns in our conditions and persisted in the streams to smolt size, the productivity advantage would be lost.

3. Fall spawners - Natural reproduction is the ideal and it is felt that fish whose eggs over-winter in the streams are at a disadvantage in the lower Great Lakes at least. The productivity differential between these fish and rainbow trout would therefore have to be large to justify a hatchery program for the Far Eastern salmons.

4. Supply - The distances involved in shipment and possibly limited available quantities of salmon eggs may require that brood stocks of the salmon be established in reservoir lakes, before any large-scale program of introduction to the Great Lakes can be attempted. This increases the possibility of uncontrolled spread of the fish before a full assessment of their desirability has been completed.

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