Bull. Inst. Zool. Academia Sinica 29(3, Supplement): 95-104 (1990)

MASU SALMON PROPAGATION IN HOKKAIDO, JAPAN

HIROSHI MAYAMA

Hokkaido Salmon Hatchery, Fisheries Agency of Japan
2-2 Nakanoshima, Toyohira-ku, Sapporo, 062 Japan

(Accepted April 10, 1990)

Hiroshi Mayama (1990) Masu salmon propagation in Hokkaido, Japan. *Bull. Inst. Zool., Academia Sinica* 29(3, Supplement): 95-104. Masu salmon, *Oncorhynchus masou*, is one of the important salmon in northern Japan in addition to chum salmon, *O. keta*, because of its high marketability and commercial value. Recent environmental changes in rivers have been resulted in serious decreases in masu salmon resources. In the propagation program on masu salmon, conservation of juveniles in rivers by fishing regulation and release at the fry-stage have been carried out. In order to rehabilitate the decreased resources of this species, release of hatchery-reared smolts is considered to be the most efficient method of augmentation. In addition, release of fingerlings late autumn before their overwintering is also expected to be one of the efficient techniques. Masu salmon reenhancement should be achieved by combination with these means or techniques. Then, conservation and management of the native stocks is the most important factor in the efficient proceeding of restoration programs.

Key words: Masu salmon, Propagation, Transplantation

In 1987 we celebrated the 100th anniversary of salmon propagation in Hokkaido, and the resource of chum salmon, *Oncorhynchus keta*, has increased extremely since the early 1970's as a result of efficient hatchery technology combined with intensive scientific research (Kaeriyama, 1989; Kobayashi, 1980). On the other hand, it is very difficult to get accurate statistics information about the coastal catches of masu salmon, *O. masou*, because the catches have been included in the catch records of pink salmon, *O. gorbuscha*. In recent years, the annual catch in coastal waters around Japan is estimated to be about 1,000 to 2,000 tons, which is only about 1 to 2% of the total commercial salmon catch in Japan. However, because of its high marketability and commercial value, this species is regarded important in addition to chum salmon. And, it is especially important salmon resource of the Japan Sea coast where the landings of chum salmon are less than the coasts of Pacific and Okhotsk Sea.

The changes in number of adults caught in rivers of Hokkaido for their artificial propagation are compared between masu and chum salmon (Fig. 1). With the limited information about captured adults in rivers, it is obvious that masu salmon has decreased and been stagnant at low level in contrast to chum salmon. Recent environmental changes in rivers such as artificial obstructions to

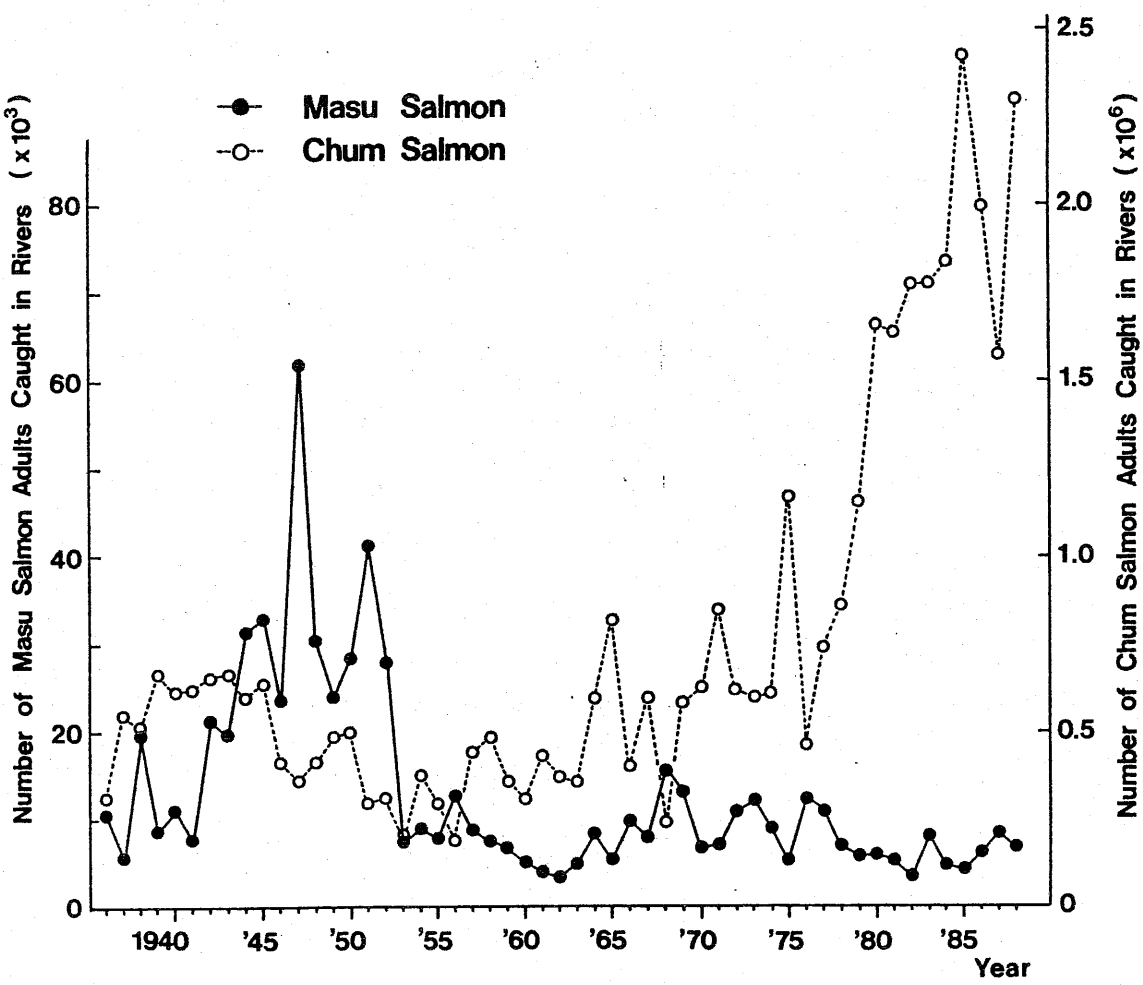

Fig. 1. Annual change in number of masu and chum salmon adults caught in rivers of Hokkaido.

fish-migration and decreases in water flow resulting from intensive water utilization projects, and increase of game fishermen angling juvenile masu salmon have seriously affected the masu salmon resources of Japan (Kobayashi, 1980; Sano, 1964; Takahashi, 1988).

Masu salmon usually spend one, sometimes two years, in freshwater before migrating to sea in the spring as smolts (Kubo, 1980). In Hokkado, all females migrate to sea, while a part of male spend their whole life in freshwater (Fig. 2). Since previous Japanese salmon propagation porgrams, masu salmon fry have been released from April to June, either as unfed or after 1-3 months feeding, following the technique applied in the propagation of chum and pink salmon. Fry of these two species migrate to sea in ealry spring soon after their release. The present practice of salmon ranching in north America and Europe, is to rear the young salmon to a size and time that they normally migrate to the sea (Larsson, 1980; Wahle and Smith, 1979). The release of masu salmon at the fry-stage has not been considered a successful method in streams where the environ-

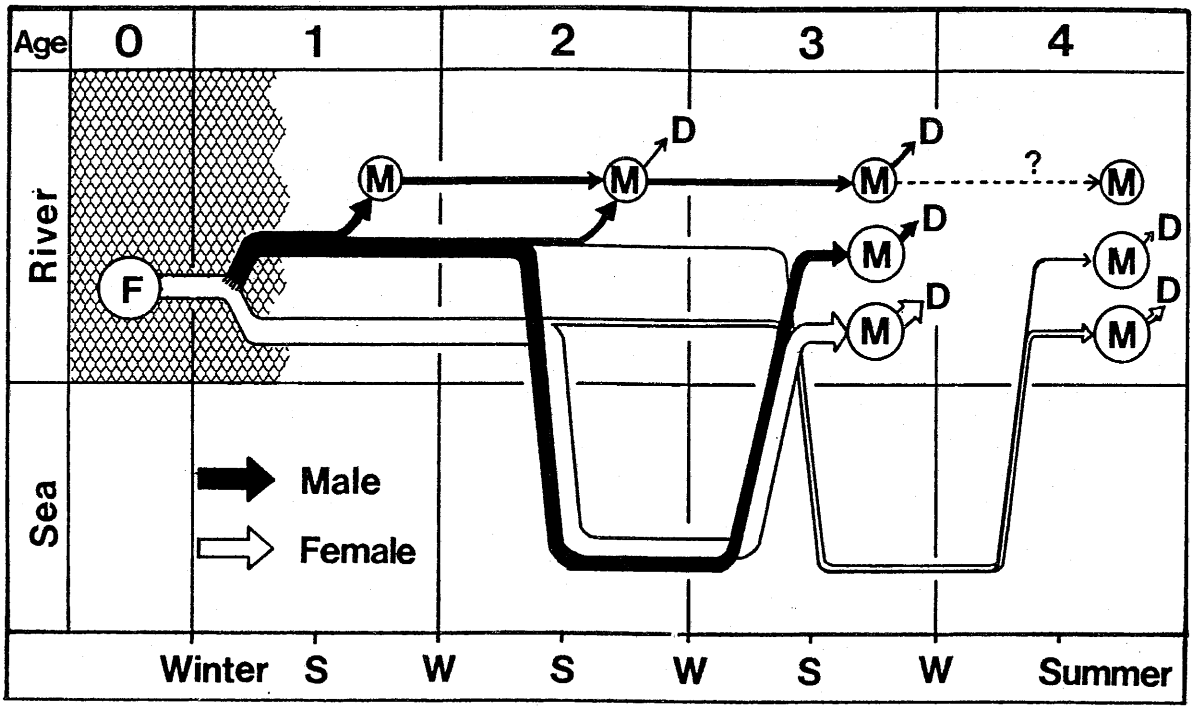

Fig. 2. Life cycle of masu salmon in Hokkaido. F, fertilization; M, maturation; D, death.

ment has been devastated, and then, artificial release of smolts is considered to be a more efficient method of augmentation.

In this report, the propagation methods of anadromous-type masu salmon in order to achieve high smoltification and the results of release experiments for the technological development in Japan, mainly in Hokkaido, are summarized.

CONSERVATION OF JUVENILE MASU SALMON BY FISHING REGULATION

Masu salmon occurs widely in Japan, but the habitat of anadromous, or ocean, form "Sakuramasu" is only in coasts of the Japan Sea, the Okhotsk Sea and the northern Pacific Ocean of Japan (Machidori and Kato, 1984). The fluvial, or river resident, form is called "Yamame" or "Yamabe". Angling juvenile masu salmon has been popular game fishing in northern Japan. And also, cultured river-resident-type masu salmon which spend throughout their life in freshwater, are released into mountain streams for the fishing.

"Hokkaido Prefectural Inland Waters Fisheries Regulation" forbids all Pacific salmon, including adult masu salmon, fishing but the juvenile masu salmon, "Yamabe". As for juvenile masu salmon, this regulation prohibits the fishing for a two-month-period during their seaward migration as smolts. And furthermore, 32 river-systems in Hokkaido are designated as reserves for wild masu salmon, where catching every kind of aquatic animals is prohibited throughout the year, by "the Fisheries Resource Conservation Act of 1951". And also, in 12 prefectural "yamabe" protective rivers or areas, fishing for juvenile masu salmon is forbidden for almost all the season except winter by a local governmental regulation. Even so, we can fish them in the open area of many rivers.

FRY RELEASE

As described above, from the beginning of masu salmon artificial propagation in Hokkaido, masu salmon fry has been released into streams from hatcheries, generally located in the middle reaches of rivers, at their size of 4 to 5 cm in fork length and 0.5 to 1.5 g in body weight. This makes difficult for fry to disperse upstream (Tanaka et al., 1971) because of their poor swimming ability, and therefore, food productivity in the area upstream the release sites can not be utilized effectively. So, it is efficiency to release adequate number of fry to the uppermost portions of the streams depending on their capacity by streams.

On the other hand, it is known that rearing at higher density with large amount of fry causes deficiency of swimming capability. From the rearing experiments of chum fry, it was made clearly that training in the current and to adjust rearing densities with their growth are effective to produce strong fry (Kobayashi, unpublished). This is also important problem to develop a technique producing healthy fry correlated with increasing survival rate after the release.

SMOLT RELEASE

Technological development studies for releasing masu salmon smolts, have been carried out since 1981 in Hokkaido. In the first experiment smolts were released during late April and early May in 1981 (Mayama et al., 1985). Much information and knowledge on their life after the release was obtained. The results are summarized here.

About 70,000 hatchery produced smolts averaged 28 g body weight and 13.8 cm fork length, were released into the Shiribetsu River of the Japan Sea coast. These fish were marked by adipose-fin-clipping. The fish originated from eggs taken at the same river. Approximately 60,000 fish except resident parr were estimated to have migrated to sea.

A total of 481 individuals were recovered at the coast around mouth of the home river from mid-February to late June in the following spring. The number of marked masu salmon adults recovered at 10 day intervals, increased in mid-April in accordance with the overall rise in coastal commercial catches. Upstream migration from the sea into the spawning river, was apparently over by late May or early June, when records of marked fish rapidly disappeared in the coastal fisheries. The individual weights of marked fish recovered were initially rather small, less than 2 kg until mid April. In late April the average body weight exceeded 2 kg, and reached 2.7 kg in late May (Fig. 3). It is evident that masu salmon fed actively and grew continuously until their upstream migration into the river. The sizes of all marked fish recovered throughout the season in coastal waters, varied between 29 and 70 cm FL and between 0.2 and 6.1 kg BW. The accepted hypothesis that all masu salmon spend one winter in the ocean had been doubted because of the wide variation in body size of adult masu salmon (Machidori and Kato, 1984). In our observations that marked masu salmon of the same brood stock, and year class had a wide range in adult body size,

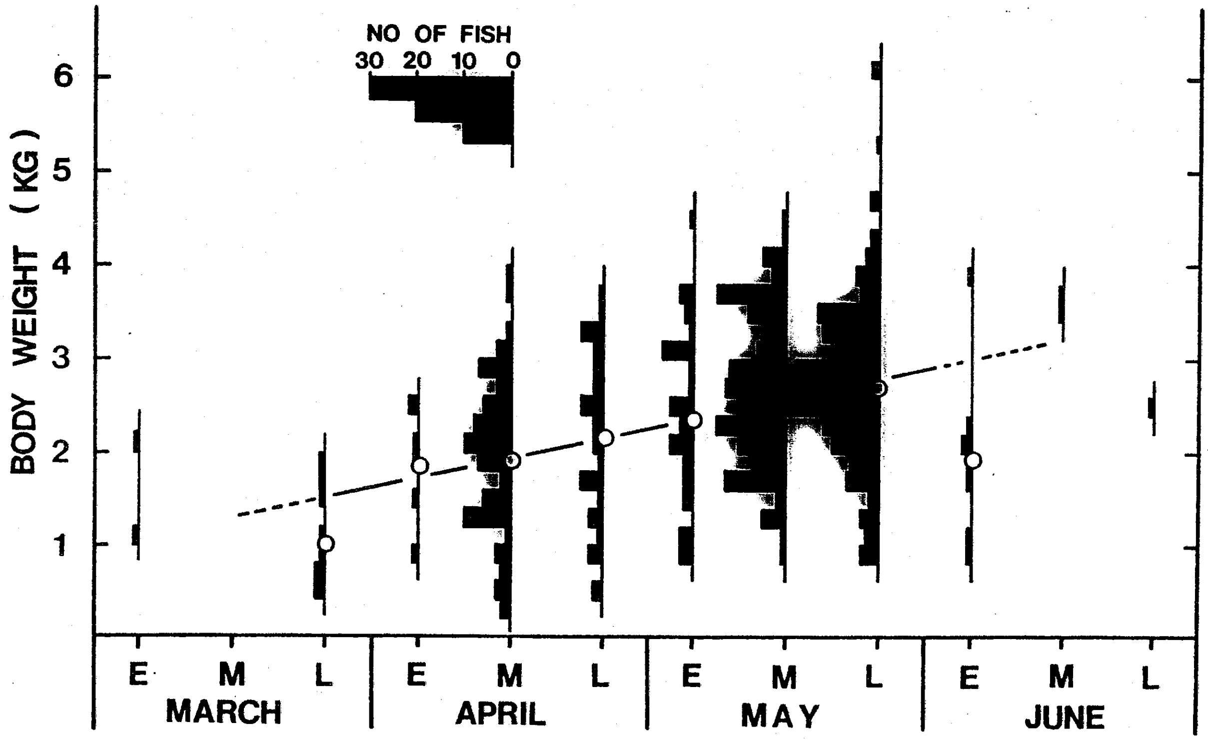

Fig. 3. Seasonal change in body weight distribution of marked masu salmon recovered in coastal waters adjacent to mouth of the natal river, 1982. E, M, L in frame of month indicate early, middle and late month, respectively (from Mayama et al., 1985).

and that only one marked individual returned to the river as 4-year-old fish after spending two winters in freshwater and one winter in the ocean, it was clearly demonstrated that all masu salmon studied in this experiment spent only one year, including one winter, in the ocean before returning to the natal river for spawning.

Trapping of spawners for hatchery work was carried out from late August to mid October with a peak around mid September. A total of 361 marked masu salmon were recaptured in the river.

By checking on the ratio of their mixture among the landing masu salmon throughout the fishing season, it was estimated that a total of 3,967 marked fish would return in coastal areas, including in river, within 50 km from the natal river mouth, and that the return rates, smolt-to-adult, were 6.5%.

The migration range of masu salmon in the ocean is extremely limited compared to that of other salmon species. And, masu salmon inhabit coastal waters during their marine life more extensively than do other species (Machidori and Kato, 1984). In fact, masu salmon may spend 8-9 months in coastal waters of Japan; only in the summer do they live in the Okhotsk Sea. Because of this, fishing mortality prior to the return to spawning rivers is probably very high.

FINGERLING RELEASE IN LATE FALL

Although smolt production and its

release is considered to be the most effective technique for a rapid rehabilitation of reduced masu salmon population, it is difficult to enlarge smolt production quantitatively under the present facilities and annual budget. There are, however, many salmon hatcheries in Japan where the operation for chum salmon only involves parts of the year (Fig. 4). In order to produce smolts in natural streams, the rearing of large numbers of masu fingerlings in periods when hatcheries for chum salmon were idle has been tested (Mayama et al., 1988). The fingerlings were released into rivers in late fall just before their overwintering seasons. The experimental release of masu salmon fingerlings having been reared for about 8 months, was carried out in early November before the beginning of the chum salmon operation period. These fish released into the main stream dispersed widely downstream or upward in a short period. After overwintering in the suitable space, released fish migrated to the sea as smolts in the next spring. Return rates to the natal rivers were considerable. The period when water temperature was between 5 and 10°C prior to declining of masu salmon's swimming capability was the most effective for fingerling release in late fall. Achieving a size of 9 cm fork length before overwintering was a prerequisite for a high rate of smoltification in the next spring. During overwintering season, quantity of food is abundant in streams of

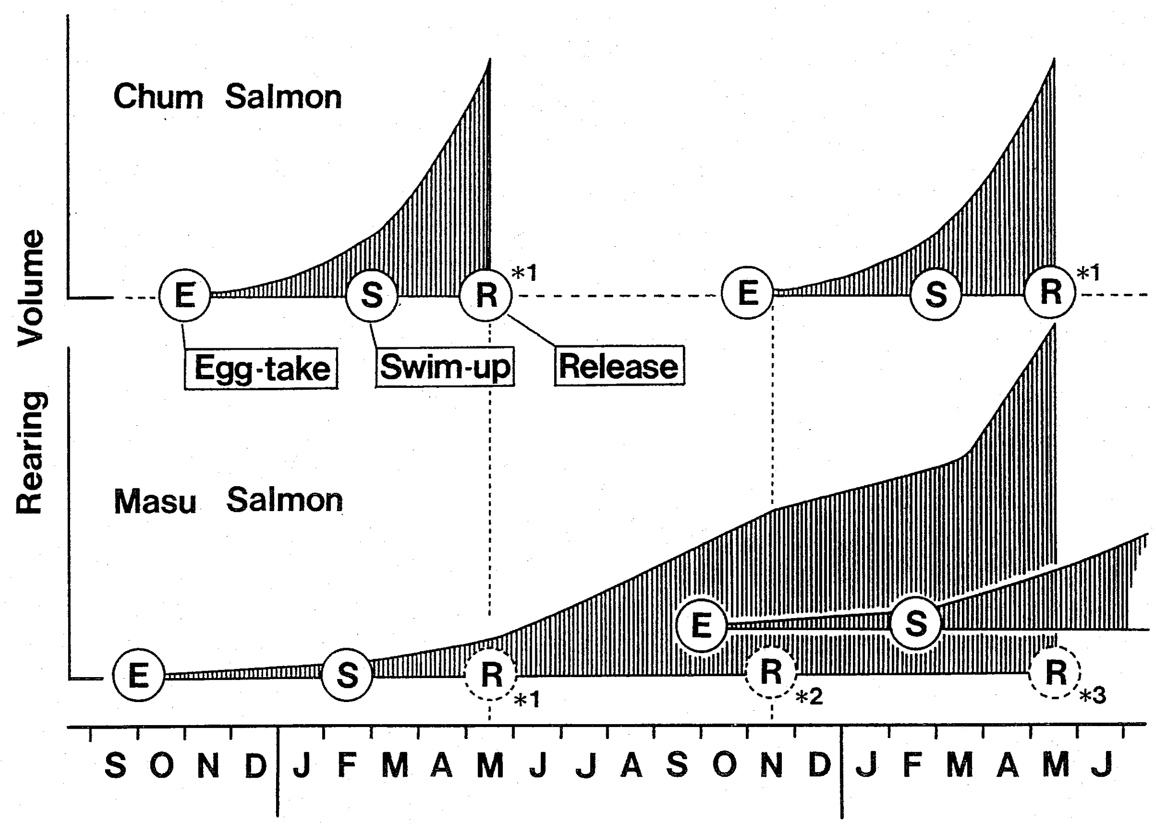

Fig. 4. Diagram of seasonal hatchery operation for producing chum and masu salmon. *1, fry-release; *2, fingerling-release in late fall; *3, smolt-release

Hokkaido (Atoda and Imada, 1972a, 1972b; Mayama and Ohkuma, 1983), while masu salmon's feeding becomes inactive (Inoue and Ishigaki, 1968; Mayama and Ohkuma, 1983). Therefore, relative sufficient food may be provided to the additional overwintering fish which are released. And in the subsequent spring season when they smoltificate and migrate to sea, active feeding and rapid growth occur (Kubo, 1980). However, there is sufficient capacity to be able to assure the growth of native resident and released fish because of high level of food supply accompanied with high discharge and rising temperature (Mayama and Ohkuma, 1983).

The "fall-release" method is expected to be a highly efficient technique in masu salmon propagation in Japan in the future. Numerous streams which offer better conditions for fingerlings in autumn than for fry in spring may thus be utilized.

EFFECT OF TRANSPLANTATION ON THE ADULT RETURN

It has been confirmed that the release of masu salmon smolts is an efficient method to re-establish native stocks in a short time. However, due to extreme difficulties in obtaining large numbers of eggs from wild spawners, transfers of offspring from other rivers have been practiced in order to produce sufficient amounts of smolts. Salmon eggs have been transplanted frequently to various area since early times (Davidson and Hutchinson, 1938). In particular, almost the chum salmon resource in Japan has been supported by artificial propagation, resulting in a great number of eggs being transplanted among many rivers. But, in genetic study of the chum salmon population structure by Okazaki (1982), he suggested that it was nearly impossible to expect good results from a transplantation between latitudinally distant river. He also reported high genetic divergence between populations and significant differences in allele frequencies have been observed even among proximal river populations of masu salmon (Okazaki, 1986).

Experimental transplantations of stocks have been carried out between two contrasting rivers, the Shrari River on the Okhotsk Sea coast and the Shiribetsu River on the Japan Sea coast (Mayama, 1989), to clarify the differences in migration behavior and survival. Two groups of smolts, one from the native stocks and another from the introduced stocks, were released at the same time into each river (Mayama et al., 1989). The release experiments were repeated twice using adjoining brood-year fish. The recapture rates of the introduced groups were significantly lower than the native groups in both rivers (Fig. 5). One of the factors causing the lower return rate of the transplanted stocks was suggested to be the difference in the timing of seaward migration. Furthermore, influences of genetic adaptation to the receiving environment during the life history have to be considered. But, I cannot fully explain why the survival of introduced stock is extremely low. The effects of masu salmon transplantation from nearby rivers have previously been evaluated (Mayama et al., 1988). The results indicate that preservation of the native stocks is the most important factor in their rehabilitation programs, and if transplantations of stocks are carried out the choice of donor river has to be carefully examined in order to

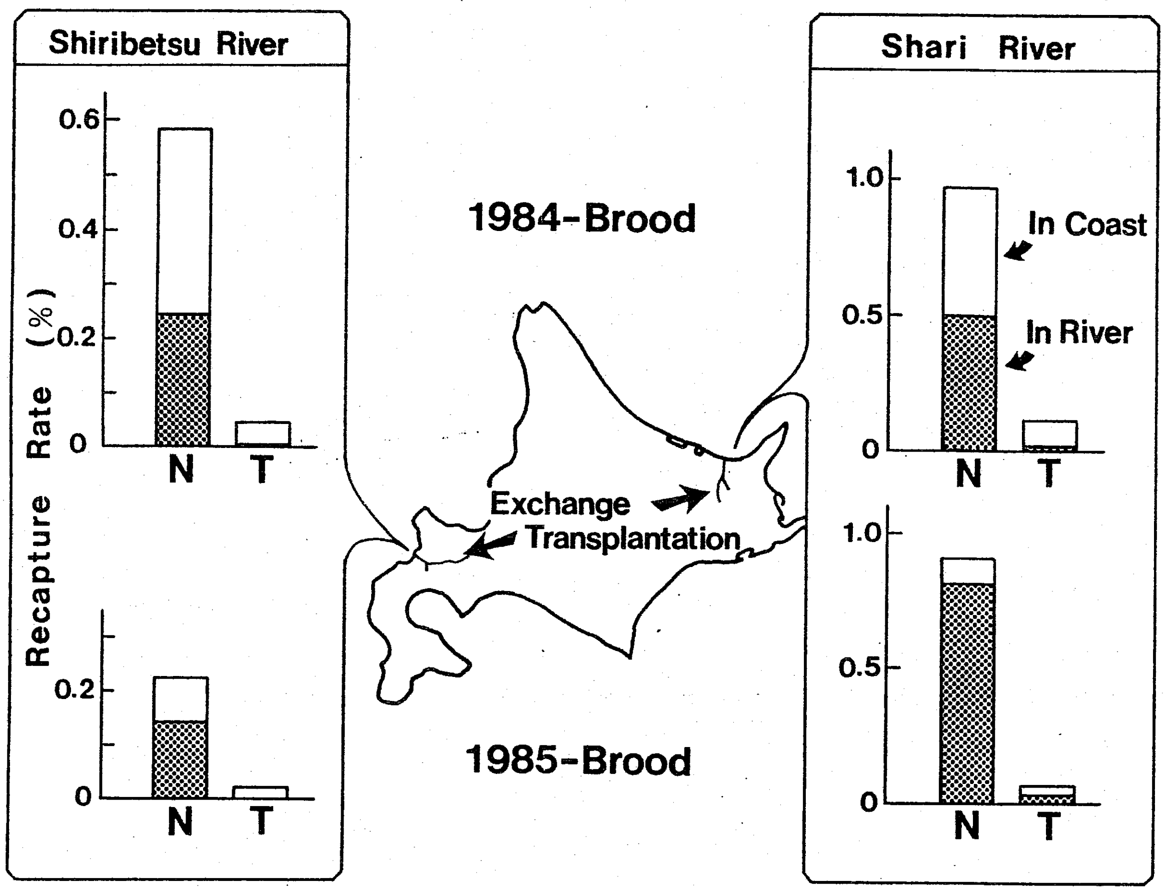

Fig. 5. Comparison of recapture rates, smolts-to-adults, between introduced stocks which were transplanted reciprocally between rivers on the Okhotsk Sea and the Japan Sea side of Hokkaido, and the native stocks. N, native stock; T, transplanted stock (after Mayama et al. 1989).

prevent the disrupting of adaptive gene complexes.

REFERENCES

Atoda, M. and K, Imada (1972a) Studies on the aquatic insect fauna and environmental conditions of the Chihase River, Hokkaido. *Sci. Rep. Hokkaido Fish Hatch.* 27: 59-95.

Atoda, M. and K. Imada (1972b) Studies on the aquatic insect fauna and the environmental conditions of the Shakotan River, the Kenichi River and the Otoshibe River, Hokkaido. *Sci. Rep. Hokkaido Fish Hatch.* 27: 97-149.

Davidson, F. A. and S. J. Hutchinson (1938) The geographic distribution and environmental limitations of the Pacific salmon (genus *Oncorhynchus*). *Bull. U. S. Bur. Fish.* 58: 667-691.

Inoue, S. and K. Ishigaki (1968) Notes on the Biology of juveniel masu salmon (*Oncorhynchus masou*) during winter in the Chihase River, Hokkaido. *Jpn. J. Limnol.* 29(2): 27-36.

Kaeriyama, M. (1990) Aspects of salmon ranching in Japan. *Physiol. Ecol. Japan*, Spec. Vol. 1:

Kobayashi, T. (1980) Salmon propagation in Japan. *In Salmon ranching* (J. E. Thorpe, ed.). Academic Press, London. 91-107.

Larsson, P.-O. (1980) Smolt rearing and the

Baltic salmon fishery. *In Salmon ranching* (J. E. Thorpe, ed.). Academic Press, London. 157-186.

Machidori, S. and F. Kato (1984) Spawning populations and marine life of masu salmon (*Oncorhynchus masou*). *Internatl. North Paci. Fish. Comm. Bull.* 43; 1-138.

Mayama, H. (1989) Reciprocal transplantation experiment of masu salmon (*Oncorhynchus masou*) population. 1. Comparison of biological characteristics between two masu salmon populations, the Shari River on the Okhotsk Sea coast and the Shiribetsu River on the Japan Sea coast, Hokkaido. *Sci. Rep. Hokkaido Salmon Hatch.* 43: 75-97.

Mayama, H. and K. Ohkuma (1983) Feeding habits of juvenile masu salmon, *Oncorhynchu masou*, in rivers. *Mar. Ranch. Program. Progr. Rep. Masu Salmon Product. Hokkaido Salmon Hatch.* 3: 92-102.

Mayama, H., T. Nomura, and K. Ohkuma (1988) Seaward migration and adult return of the marked masu salmon, *Oncorhynchus masou*, released in late fall before wintering. *Sci. Rep. Hokkaido Salmon Hatch.* 42: 21-36.

Mayama, H., T. Nomura, and K. Ohkuma (1989) Reciprocal transplantation experiment of masu salmon (*Oncorhynchus masou*) population. 2. Comparison of seaward migrations and adult returns of local stock and transplanted stock of masu salmon. *Sci. Rep. Hokkaido Salmon Hatchery* 43: 99-113.

Mayama, H., K. Ohkuma, T. Nomura, and K. Matsumura (1985) Experimental release of masu salmon, *Oncorhynchus masou*, smolts into the Shiribetsu River. Adult returns of marked fish released in the spring of 1981. *Sci. Rep. Hokkaido Salmon Hatchery* 39: 1-16.

Okazaki, T. (1982) Genetic study on population structure in chum salmon (*Oncorhynchus keta*). *Bull. Far Seas Fish. Res. Lab.* 19: 25-116.

Okazaki, T. (1986) Genetic variation and population structure in masu salmon *Oncorhynchus masou* of Japan. *Bull. Jpn. Soc. Sci. Fish.* 52(8): 1365-1376.

Sano, S. (1964) The ecology and protection of reproduction. *Fish and Egg* 104: 1-7.

Takahashi, G. (1988) Sabological study on conservation of stream environment. *Res. Bull. Coll. Exper. Forests, Fac. Agric., Hokkaido Univ.* 45(2): 371-453.

Tanaka, T., T. Ishida, Y. Ishikawa and M. Kunda (1977) Studies on the planting of hatchery-cultured Masu salmon fry into streams. 1. Observations on dispersal and residuary of Juveniles in the Mena River and its tributaries, *Sci. Rep. Hokkaido Salmon Hatchery* 25: 1-17.

Wahle, R.J. and R.Z. Smith (1979) A historical and descriptive account of Pacific coast anadromous salmonid rearing facilities and summary of their release by region, 1960-76. *NOAA Tech. Rep. NMFS SSRF*-736: 1-40.

日本北海道的櫻鮭繁殖

真山 紘

櫻鮭 *Oncorhychus masou* 由於具有很大的市場以及相當高的商業價值，因此在日本北部，是除了大麻哈鮭（*O. keta*）之外，另一種極爲重要的鮭魚。最近，河流環境的改變導致櫻鮭資源的嚴重減少。在櫻鮭的繁殖上，已經進行的有稚魚的禁捕以及仔魚的放流。一般咸認爲放流剛孵化仔魚是促使資源恢復的一個最爲有效的方法。此外，在秋末放流越冬前的稚魚也不失爲一有效方法，促進櫻鮭的產量需藉上述諸法相互配合；然而，對現存資源的保育與經營管理却是成功達到資源復育的一個最爲重要的因子。