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POPULATION AND DISTRIBUTION OF THE FORMOSAN LANDLOCKED SALMON (*ONCORHYNCHUS MASOU FORMOSANUS*) IN CHICHIAWAN STREAM

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Yao-Sung Lin, Sien-Shao Tsao and Kun-Hsiung Chang (1990) Population and distribution of the Formosan landlocked slamon (*Oncorhynchus masou formosanus*) in Chichiawan Stream. *Bull. Inst. Zool., Academia Sinica* 29 (3, Supplement): 73-85. Four underwater population censuses were conducted to investigate the number and distribution of the Formosan landlocked slamon in a 4.2 km section which was further divided into 14 subsections of the Chichiawan Stream between September 1987 and January 1989. In addition, weekly censuses were conducted during May 1987 till April 1988 at four selected stations to monitor seasonal variation of the salmon population.

Significant seasonal variation in the number of fish in the Chichiawan Stream was observed. The fish population was rather stable between July through October, but declined greatly in the winter. They tend to hide in caves more often when water temperature fell below 12°C during the winter.

Estimated abundance of the salmon has been declining during the study period. The decrease in the population of this fish was caused mainly by the continuous diminution in the number of younger fish. Whereas number of elder fish remained quite constant. The distribution pattern for both younger and elder fish was quite similar in the Chichiawan Stream. Temporal fluctuation for total number of elder and younger fish during the study periods for each section in the Chichiawan Stream were related to the location of sand-retention dams. Effects of flooding and dams on population and distribution of the Formosan landlocked salmon were also discussed.

Key words: Formosan landlocked salmon, *Oncorhynchus masou formosanus*, Population ecology

The Formosan landlocked salmon (*Oncorhynchus masou formosanus*) has always been considered a rare species in Taiwan. Since it was first described by Aoki (1917), various studies have been conducted on the systematics, zoogeography and ecology of this fish (Behnke *et* *al.*, 1962; Jordan and Oshima, 1919; Kano, 1940; Koshigi and Nakamura, 1938; Lin *et al.*, 1988 and Lin *et al.*, 1989; Watanabe and Lin, 1985; Yang *et al.*, 1986). Half a century ago, the salmon was widely distributed in six upper tributaries of the Tachia River (Kano, 1940). Due to overfishing and ecological disturbance, however, the salmon is seen only in Chichiawan Stream in recent years (Lin *et al.*, 1989). Therefore, protection of the remaing population and its habitat is urgently needed to save this glacial relict in the world. Since 1984, this fish is protected under the Culture Assests Preservation Act and funds for long-term research projects have been proprovided since 1986.

In this paper, we report our observations on the relative abundance, seasonal change and distribution pattern of the Formosan landlocked salmon between September 1987 and January 1989 in Chichiawan Stream. The effects of flood and sand-retentsion dams on the salmon is also discussed.

STUDY AREA

Chichiawan Stream, an upper tributary of the Tachia River, is located at east Taichung Hsien in Taiwan (Fig. 1). The Tachia watershed is mountainuous with elevations above 1400 m and the lithology is of Tertiary in age and is composed of argillite, slate and quartzite (Ho, 1975 a and b). Since fragil slate is the major component of the local bedrock, landslides occur frequently, particularly during periods of heavy rain or typhoon season. Consequently, the stream beds contain an abundance of large rocks, primarily deposited by weathering of sandstone and slate. Kano (1940) indicated that the upper Tachia River is unique for its high altitude combined with gentle inclination of the river bed, a large production of aquatic insects known to be important as fish food and a stable sand and pebble substrate which is suitable spawning ground for the salmon. Most of the areas to the west bank of Chichiawan Stream have been converted into orchards and vegetable land in the 1970's. Fertilizers are used intensively in croplands during the growing season from March to October. Therefore, filamentous algae occur in certain parts of the Chichiawan Stream.

The watershed receives an annual precipitation of 1000 to 1500 mm. In general, the rainy season starts in May and extends through September with fairly predictable typhoon and flood occurring in the summer or fall. These floods combined with mass soil movement typically scour the channel system and removed streamside vegetation.

From 1973 to 1978, sand-retention dams were built along Chichiawan Stream and its upper tributaries where the Formosan landlocked salmon concentrated. All these dams were over 4 m in height which form barrier for upstream migration of the salmon. There are three sand-retention dams within our study area (Fig. 1). Mean width and depth of the study section is about 9 m and 50 cm, respectively. Dam located at the upperstream end is denoeted as Dam 1 (0 m) and that at the downstream Dam 3 (4.2 km). Dam 2 is located mid-way at 1.5 km downstream from Dam 1. *Oncorhynchus masou formosanus* is the dominant fish in the study area, and the kooye minnow (*Varicorhinus barbatulus*),

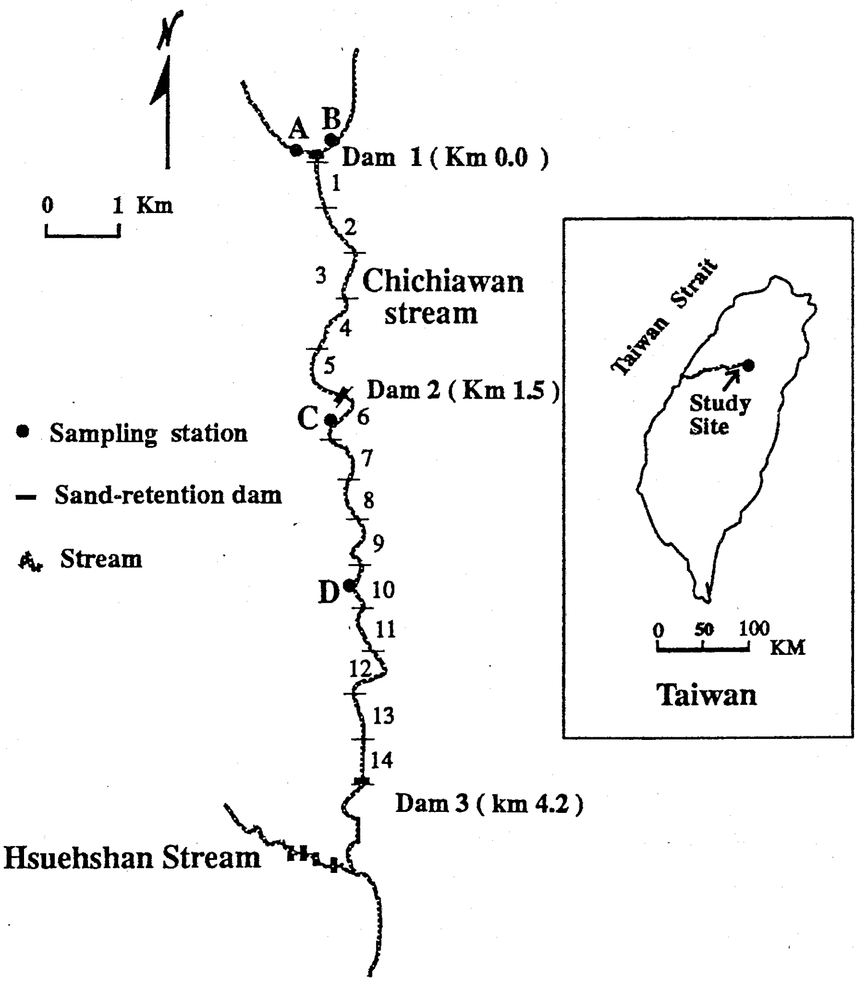

Fig. 1. Locations of the dams and sampling sections (1-14) and stations (A,B,C and D) in Chichiawan Stream.

coexists.

Water temperature ranged between 8°C in December and 17°C in the summer, with an average of 14°C. Oxygen content of the water is usually greater than 5 mg/l, pH values varied with season in the range of 7.4 to 8.5, and hardness ranged between 119 to 163 mg/l in terms of $CaCo_3$ concentration.

FIELD SURVEY METHODS

Because the salmon is vulnerable and its population endangered, no fishing technique was allowed to use in this study. Underwater population censuses were employed to investigate the number and distribution of the salmon between Dam 1 and 3. The study portion of Chichiawan Stream was equally divided into 14 contiguous sections (Fig. 1). A team of two divers entered the water slowly from a chosen section so as not to disturb the fish, and then snorkeling slowly toward the upstream sections. Number of fish seen in each section were recorded seperated as elder fish (longer than 20 cm) and younger fish (5-20 cm). Frys less than 5 cm long usually were difficult to spot. Counts of two trained divers agreed quite well. A total of 4 such censuses were made during the period September 1987 till January 1989. Each time it took about 20 working hours to complete the whole 4.2 km census sections.

In addition, biweekly censuses were conducted during March 1987 till April 1988 at 4 selected stations (A, B, C and D, Fig. 1) to monitor seasonal variation of the salmon population in the study area. These stations were chosen on account of the ease of accessibility as well as the representability of major types of habitat. Two of the stations (A & B) were above Dam 1, one (C) close to the hatchery and the other (D) near orchard section III of Wuling Farm. A distance of 85 m, which was further divided into 18 transects of 5 m intervals, was surveyed at each station. Relative abundance of the salmon near these stations were judged by the above mentioned underwater census method along zig-zagged connection of the transects. Scuba diving was used at station A to overcome deep pool habitat. Crevices and spaces in the substrate were also examined as salmon may hide in there during the winter.

RESULTS

Estimated abundance of the Formosan landlocked salmon in the study sections of Chichiwan Stream has been declining during the study period (Table 1). It was around 646 in the summer of 1986 (Lin et al., 1988), reached a high of 1798 in

Table 1. Total population estimate and average number per km (in parthesesis) of eolder and younger fish of *Oncorhynchus masou formosanus* in Chichiawan Stream at sections upstream and downstream of Dam 2 during the period from September 1987 through January 1989.

Age of fish	Census location	Population estimate			
		Sept. 1987	Feb. 1988	July. 1988	Jan. 1988
Elder fish	Upstream	221(147)	123(82)	157(105)	138(92)
	Downstream	270(100)	295(109)	341(126)	312(116)
	Total	491(117)	418(100)	498(119)	450(107)
Younger fish	Upstream	548(365)	185(123)	245(163)	90(107)
	Downstream	759(281)	560(207)	314(116)	108(40)
	Total	1307(311)	745(177)	559(133)	198(47)
Total	Upstram	769(513)	308(205)	402(268)	228(152)
	Downstream	1029(381)	855(317)	655(243)	420(156)
	Total	1798(428)	1163(277)	1057(252)	648(154)

September 1987, and has been decreasing till the end of the study. A 35-40% drop in the population occurred between 1987 and 1988. The remaining population further decreased for another 40% and the estimated population was only 648 in January 1989. The first drop between 1987 and 1988 was caused by the flood duing October 23-25, 1987 when Typhoon Lynn intruded the upper Tachia River watershed.

The decline in total population was mainly contributed by the continuous decrease of the younger fish (Table 1). A total of 85% decrease in the younger fish population occurred between September 1987 and January 1989, whrereas the number of elder fish remained fairly constant and dropped only 8.4% during the same period. At the beginning, younger fish constituted about 70% of total population in the study area. The proportion declined continuously as time progressed, and at the end of our census only 30% of the population were under 20 cm in length. This indicated that recruitment of the 1987 cohort was low.

Number of elder fish in the 14 contiguous sections of Chichiawan Stream in January 1989 showed a significant correlation with the number of younger fish in the preceeding July ($r= 0.55$, $p < 0.05$) and February ($r= 0.68$, $p < 0.01$). It also had a strong positive correlation with the number of elder fish in the previous July ($r= 0.83$, $p < 0.01$) and February ($r= 0.55$, $p < 0.05$). This may imply that rates of decline in fish population among most sections in the Chichiawan Stream were constant.

Many factors may affect the distribution pattern of the Formosan landlocked salmon in Chichiawan Stream. Among them, sand-rentention dams may be an important factor. As evidenced by the fact that in most of the occasions, the number of fish in sections right below a dam was higher than that of sections just above the dam (Fig. 2, cf sections: 1 vs 5, 5 vs 6 and 6 vs 14). Flooding may also affect the distribution pattern, as some fish would be washed down from the upper reach to the lower reach during the flood, and could not swim back to the upper reach because of the dam. Comparison of the population size of the landlocked salmon between upper stream (Dam 1 to 2) and lower stream (Dam 2 to 3) at four different periods revealed that the percentage of population in the upper reach to total population declined drastically from 42.8% to 26.5% between September 1987 and February 1988. However, it remained rather constant at 38% and 35% between July 1988 and January 1989. The major difference being that, a serious flood occurred in October 1987 between the former two censuses dates, whereas no flood occurred between the latter two censuses.

The younger fish were more liable to flood than the elder fish. For example, although almost half of (44%) the elder fish in upstream water was lost after the flood (Table 1, cf. Sept. 1987 and Feb. 1988), the elder fish in downstream water increased slightly (9%). On the other hand, both the upstream and downstream younger fish population decreased significantly after the flood, and the loss upstream was about 2.5 times that of the downstream population.

The distribution pattern for both younger and elder fish were quite similar in the Chichiawan Stream. Distribution of the former in the 14 sections was posi-

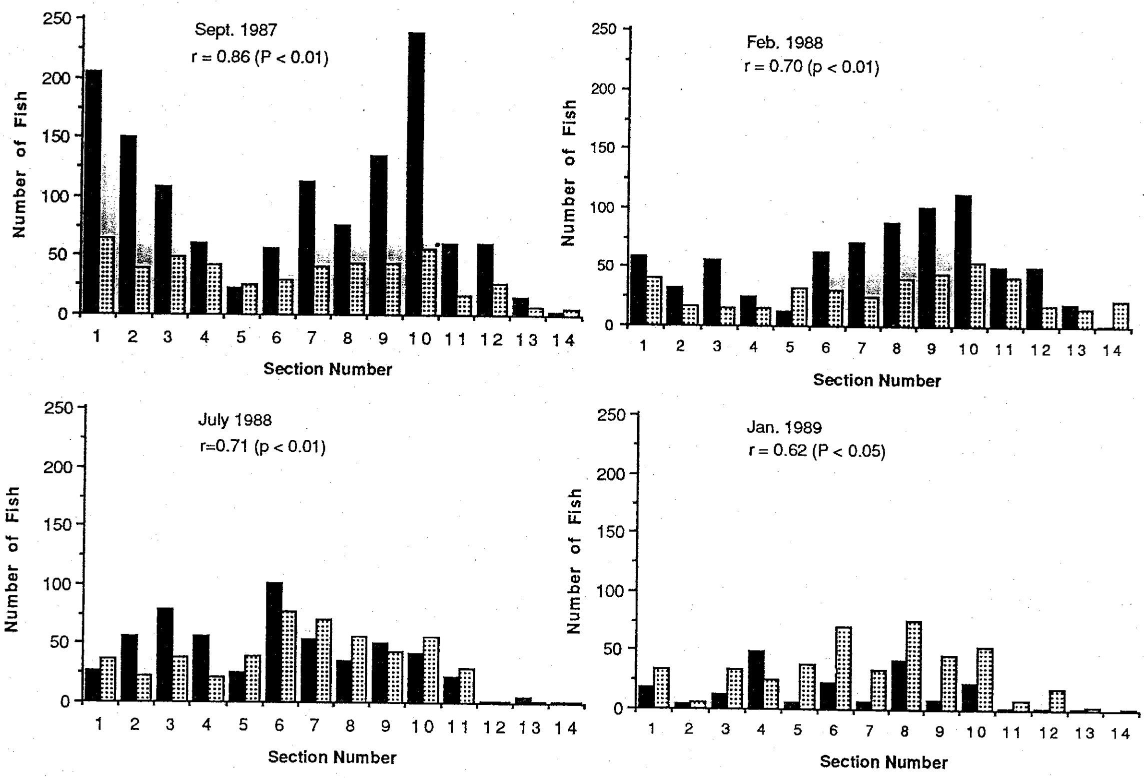

Fig. 2. The total number of elder fish (□) and younger fish (■) of the Formosan landlocked salmon along the 14 sections in Chichiawan Stream at four sampling periods.

tively correlated with that of the latter in all the sampling dates (Fig. 2; Sept. 1987. r= 0.86, $p < 0.01$; Feb. 1988, r= 0.70, $p < 0.01$; July 1988, r= 0.71, $p < 0.01$; Jan. 1989, r= 0.62, $p < 0.05$). Distribution pattern of the Formosan landlocked salmon in the stream was stable in certain periods, and varied greatly in other period. For example, number of fish in the 14 sections in September 1987 was positively correlated with that in February 1988 (Fig. 3, r='0.69, $p < 0.01$). Similar result was also found between July 1988 and Jnanuary 1989 (Fig. 3, r= 0.67, $p < 0.01$). However, the distribution pattern in February 1988 showed no correlation to that of July 1988 (r= 0.49, $p > 0.05$).

Between May 1987 and April 1988, significant seasonal variation in the number of fish was observed in three out of the four sampling stations (Fig. 4). It is obvious that the population was highest at station A, then followed in sequence by stations D, C and B. The increase in fish population during the first few months was probably related to the recruitment of fry to detectable size in scuba diving. The population were rather stable between July through October, 1987. A flood occurred when Typhoon Lynn struck Taiwan in late October, thus a drop in fish population was observed at station A. However, an increase in population occurred at the downstream stations C and D. The continuous decline of the fish population between November and February were probably related to high mortality of the fish after breeding

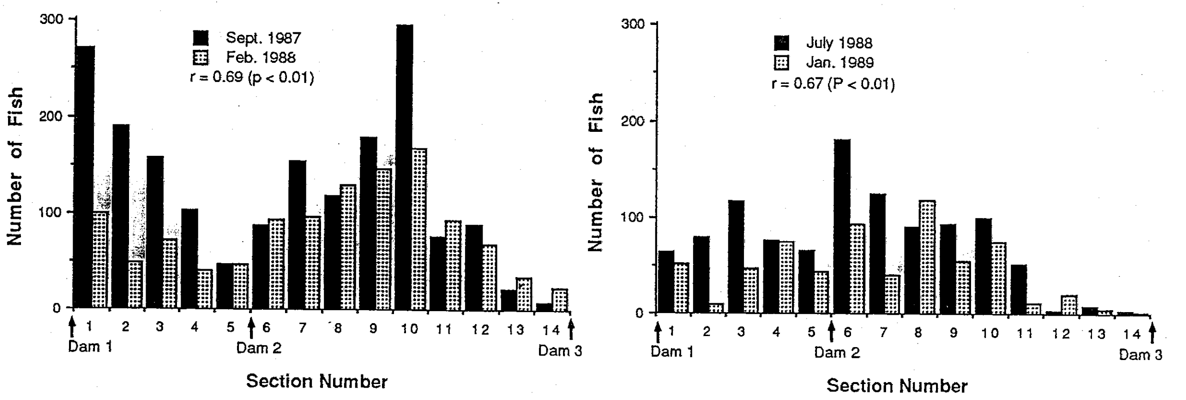

Fig. 3. Total number of fish observed in the 14 sections of Chichiawan Stream at four sampling periods.

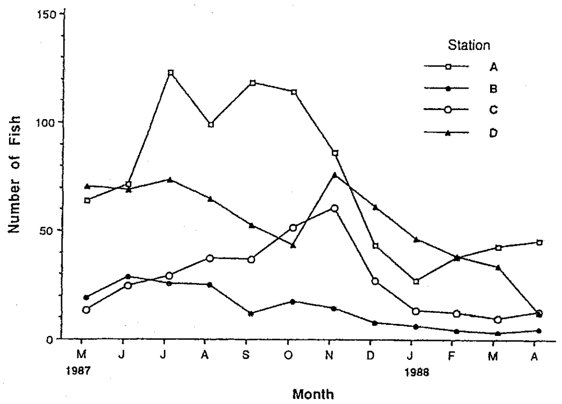

Fig. 4. Seasonal variation in abundance of fish at the four stations from May 1987 through April 1988. A 85-m distance of stream was surveyed for fish at each station.

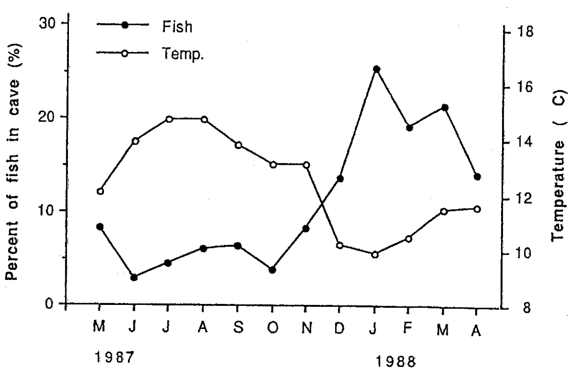

Fig. 5. The relationship between water temperature and the proportion of fish in the cave to total number of fish observed.

season. The Formosan landlocked salmon exhibit territories, chasing and nest building behavior during the breeding seasons. These behavior might injure the salmon and increase their mortality, particularly during the winter. In addition, the fish tends to hide in caves more often when water temperature fell below 12°C during the winter (Fig. 5).

In general, activity range of the Formosan landlocked salmon were restricted. Direct visual observations of the salmon also revealed they show little or no macro-movement in the Chichiawan Stream. In March 1988, 250 hatchery-produced sub-adults (1.5-2.5 yr) were tagged and introduced into Chichiawan Stream (N= 200) and Hseuhshan Stream (N= 50). Of these, 45 fish were still sighted during the next ten months and none of them were observed beyond 800 m of their original release area except after flooding.

Coefficient of variation (CV= standard deviation/mean) were calculated to provide indices of temporal variation for total number of elder and younger fish during the study periods for each section in the Chichiawan Stream (Fig. 6). Temporal fluctuation (CV) for younger fish in sections 1 through 12 were higher than that of the elder fish, however, the reverse was true in sections 13 and 14. This may suggest that environment exerted more effect on younger fish than that of elder fish.

The highest CV value (126%) for elder fish was observed at section 14 just above Dam 3. It declined progressively from section 14 upstream and dropped dramatically to 2 and 3% in sections 9 and 10. respectively. The total number of fish in these two sections were very stable with a range from 99 to 102 fish during the study periods, regardless of the occurrence of heavy flooding and great fluctuation of the number of the fish in other sections. From section 9 upstream, the CV values increased continuously to 49% in section 6 below Dam 2. These evidences indicated that mid-stream section between dam 2 and 3 have a very stable fish population, but the population fluctuation increased progressively toward the upstream and downstream dam, respectively. The CV values varied from 18 to 66% between sections 1 and 5. For younger

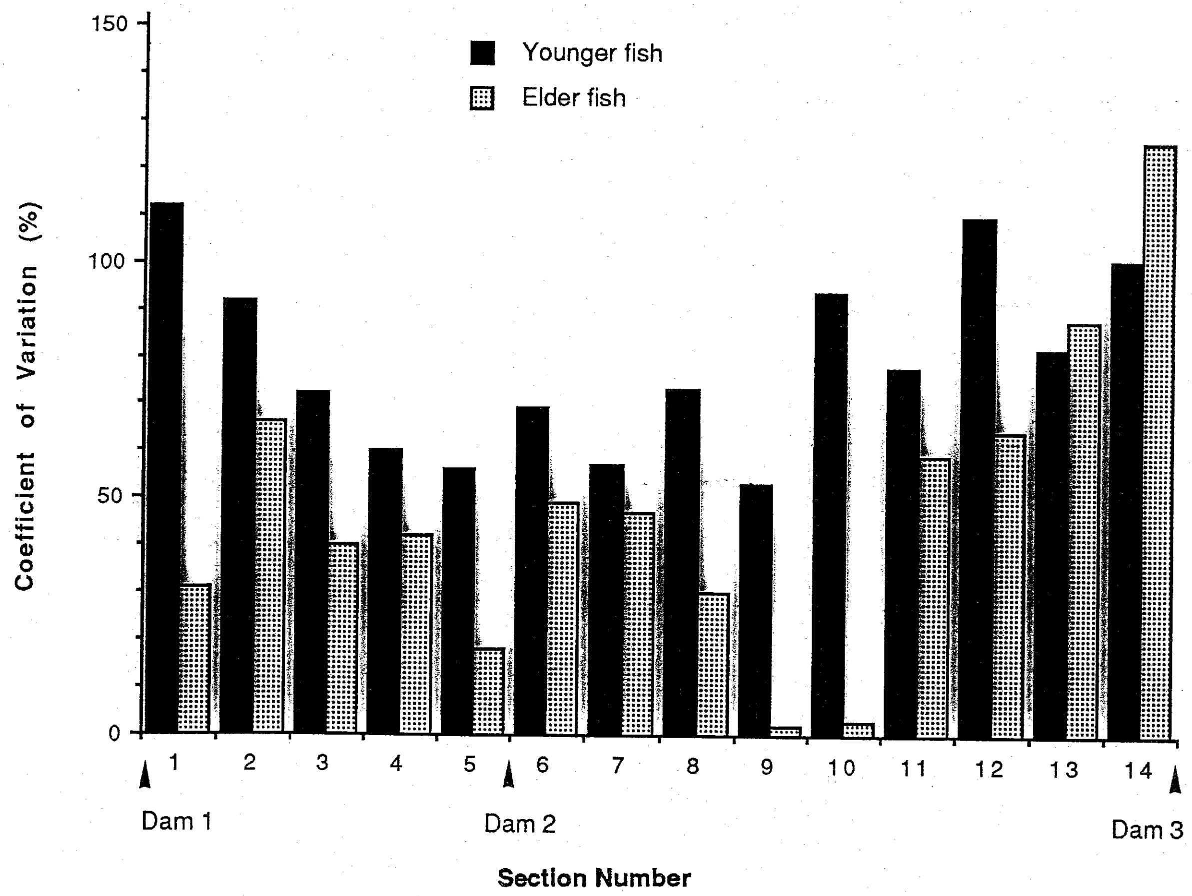

Fig. 6. Coefficient of variation of the population estimated for total number of elder and younger fish during the periods from September 1987 through January 1989.

fish, the highest CV values (112%) occurred in section 1 just below Dam 1, followed by 110% in section 12 and 101% in section 14 near Dam 3. The CV values for younger fish declined progressively downstream from section 1 right below the Dam 1 to section 5 just above the Dam 2.

DISCUSSION

About half a century ago, the Formosan landlocked salmon was distributed in at least six headwater streams of the upper Tachia River System, including Chichiawan, Hsuehshan, Yousheng, Nanhu, Hohuan and Sukairan Streams (Kano, 1940). Anglers were attracted to these streams and the population had already reached a state close to endangered at that time (Koshigi and Nakamura, 1938). Today, its distribution is probably limited to a 5-km reach of Chichiawan Stream and the lowest of 100-m reach of Hsuehshan Stream. Diminution in distribution range of this fish is probably due to a combination of factors such as overexploitation, population fragmentation by dams, nature catastrophy and agricultural impacts.

After the opening of the East-West Cross-island Highway in 1960, many forests along the upper Tachia River, including the riparian zone of Chichiawan Stream, were converted into agriculture land for temperate fruits and vegetables. Water from the stream is diverted for irrigation in the agriculture land throughout the year. Intensive agricultural practices have contributed to the deterioration of the riparian areas by stream bank sloughing, channel instability, erosion, and sedimentation. These contributed to the decline of the Formosan landlocked salmon for the last twenty years (Lin et al., 1989). Peters (1967) found that sediment pollution caused by agricultural practices in the stream could eliminate trout population in the lower reaches of a stream. Wang (1989) found that turbidity level in the agriculturally-influenced Yousheng Stream was 7-fold greater than that of the natural Hsuehshan Stream. Cordone and Kelley (1961) also pointed out that there is abundant evidence that sediment is deterimental to aquatic life in salmon and trout streams. Sediment concentrations exert direct influence on survival of trout and salmon eggs by diminishing the apparent velocity and oxygen concentrations within a redd (Coble, 1961; Wickett, 1954). This presents an obvious example of the magnitude of sediment loading and turbidity associated with agricultural and other erosive land-use practices in the Tachia River areas. Therefore stream sedimentation is one of the greatest nonpoint sources of pollution porblems, primarily because of agriculture, silviculture and road construction in the upper Tachia River watershed. These types of intensive land use can cause degration of riffle habitats critical for salmonid fish reproduction and the production of invertebrate food organisms essential for juvenile fish (Cedarholm and Lestelle, 1974; Iwamoto et al., 1978).

Typhoons intrude Taiwan frequently and the subsequently serious floods always caused landslides in the streams and habitat degratation of the fish. Typhoon Lynn struck the upper Tachia River areas in October 23-25, 1987 which was in the middle of the early October till late November spawning season of the Formosan landlocked salmon. Flood destroyed the spawning ground and the eggs already present in the stream bottom. It nearly eliminated the 1987 year class. Adults were less severely affected by flooding than juveniles. Elwood and Waters (1969) observed that flooding seemed to have relatively little effect on native brook trout of one year old or older. However, they found that flood nearly eliminated two year classes of trout by destroying eggs and/or fry. Seegrist and Gard (1972) also observed that flooding in Sagehen creek reduced year class strength of both brook trout and rainbow trout when the floods occurred after the species had spawned. Young-of-the-year were more severely affected by flooding than adults. Hoopers (1975) found that that severe flooding reduced the population of marked young-of-the-year trout by 96%, while other classes decreased less dramatically. Allen (1949) estimated that 80 to 90% of the ova produced by brown trout were destroyed by a series of floods that destroyed redds. Onodera and Ueno (1961) estimated the mortality of stocked brook trout fingerlings at 67.9 to 83.7% after a series of severe floods.

Serious flooding in non-spawning season also have great effect on the fish population. In September 13-14, 1989 the upper Tachia watershed further received a precipitation of more than 1500 mm during the strike of Typhoon Sarah. The water level in Chichiawan Stream was elevated for more than 3 m in certain sections of the Chichiawan Stream (Chang Ming-Sang, personal comm.). Physically, the effects of this typhoon and flood was severe in the extreme: large trees were uprooted, a small dam was destroyed, bottom materials were scoured and shifted, many aquatic invertebrates were eliminated, and large deposit of sands and gravels were left above the dams. Pool areas were also filled with sand that decreased available space for the fish. The fish population probably further declined from the January 1989 estimate as a result of the flooding.

Some localities within the Tachia River watershed are subject to landslides because of steep topography and readily fractured slate bedrock. To reduce sedimentation in the downstream Techi Reservoir, many sand-rentention dams 4-10 m in height were built in the 1970's. Four dams were built in the lower reach of Hsuehshan Stream, five in the upper reach of Chichiawan Stream and one in the lower reach of Yousheng Stream.

Construction of the sand-retention dams also severely affected the fish popultation and its distribution. The three dams in our study section of Chichiawan Stream were built in 1973. Prior to the construction of the dams, environmental conditions of the stream downstream and upstream of these dams were similar, if not identical. And the fish populations were contiguous. The presence of sand-rentention dams impeded natural hydraulic processes. It hastened transport of sediment downstream above the dam. Thus the upper reaches of the dams previously suitable for the salmon gradually became a monotonous, slate- and sandstone-bottomed shallow run devoid of fish life. This situation was observed in the upper 800 m above Dam 3 and 50 m above Dam 1 in 1990. That may be the reason why more fish were observed in the reaches below the dams than above the dams. Lack of adequate spawning and rearing grounds in reaches both above and below the dams has contributed to the decline of the Formosan landlocked salmon in the past This situation became even worse when flood occurred.

The impact of the dams on the stream habitat for the fish is less serious in the middle sections between two dams. The CV values for adult fish in sections 6-8 below Dam 2 and sections 11-14 above Dam 3 ranged from 30 o 120%, but it was only 2-3% in the middle sections 9-10.

With decreasing water temperatures, more Formosan landlocked salmon tend to hide in caves. Similar results was also observed in yearling steelhead trout (*Salmo gairdneri*) and juvenile coho salmon (*Oncorhynchus kisutch*) (Bustard and Narver, 1975). They indicated that the hiding response is probably a means of avoiding predation during a period of low, clear water and reduced swimming ability. This is probably also true for the Formosan landlocked salmon in the Chichiawan Stream that have a low flow and clear water in the winter.

Protection of high-quality habitat is essential for the continued existence of the Formosan landlocked salmon population in the upper Tachia River. In order to maintain and enhance wild landlocked salmon populations, managematic strategies have focused on protection of the existing habitat and continued monitoring of the landlocked salmon populations. In the future, restoration of degraded habitat will remain a top priority.

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七家灣溪櫻鮭（櫻花鉤吻鮭）之族羣與分布

林曜松　曹先紹　張崑雄

自 1987 年 9 月至 1989 年 1 月間，共 4 次於七家灣溪潛水調查一全長 4.2 公里再劃分爲 14 小段之河段內櫻花鉤吻鮭的族羣與分布。此外，於 1987 年 5 年至 1988 年 4 月，隔週一次，在四個採樣站同法調查其族羣之季節變化。

七家灣溪內此魚的族羣量有明顯的季節變化。7 至 10 月間，族羣量相當穩定，冬季有減少的趨勢。當水溫低於 12°C 時，躲藏在洞穴中魚的比率增加。

研究期間此魚的族羣量持續地減少。魚羣的減少，主要發生在幼魚數量的持續減少，而年長魚的族羣則較穩定。年長魚與幼魚的分布型態相近，在各河段內二者族羣數的時間變化與攔砂壩的位置有關。洪水及攔砂壩對鮭魚族羣及分布之影響亦一併討論之。