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# Spatial and Temporal Changes of Formosan Landlocked Salmon (*Oncorhynchus masou formosanus*) in Chichiawan Stream, Taiwan[1]

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**Yeong-Tyi Day, Hsien-Shao Tsao, Kun-Hsiung Chang and Yao-Sung Lin (1993)** Spatial and temporal changes of formosan landlocked salmon (*Oncorhynchus masou formosanus*) in Chichiawan stream, Taiwan. *Bull. Inst. Zool., Academia Sinica* **32**(2): 87-99. The population abundance of Formosan landlocked salmon (*Oncorhynchus masou formosanus*) in Chichiawan Stream was estimated visually by snorkeling over a time period from September, 1987 to January, 1991. The salmon population decreased during this time. Yearly fluctuation in abundance was larger in young than in adult salmon; young salmon were more abundant in summer than in winter. Salmon abundance decreased downstream, while the temporal variability of abundance increased. In the area just above a sand-retention dam, salmon abundance was lowest and temporal variability was highest. During the study period, salmon abundance in sections with high salmon density showed a greater tendency to decrease; at the same time, the stream became wider, shallower, and slower. The decrease of stream depth was the major factor affecting adult salmon density, although it was not significant for young salmon. Typhoon Lynn, which occurred during the salmon breeding season, destroyed the cohort born in 1987. Salmon population size was also decreased by habitat degradation caused by natural disturbances (i.e. typhoons, floods, etc.) and man-made factors (i.e. the construction of sand-retention dams, agricultural activities, etc.).

**Key words:** *Oncorhynchus masou formosanus*, Sand-retention dam, Typhoon, Endangered species, Local extinction, Population trend.

The masu salmon (*Oncorhynchus masou*) is mainly distributed throughout the Sea of Japan and adjoining areas (Ade 1989). Its anadromous form is limited to the Sea of Japan, Pacific spawning streams and adjacent inshore waters. Non-migratory forms occur in some other areas, and a relic population exists in the mountain streams of Taiwan (Ade 1989). A local population of masu

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salmon in Taiwan was first discovered in 1916. This population, the Formosan landlocked salmon (*O. m. formosanus*), probably originated from the masu salmon of the Sea of Japan and passed through the Tsushima channel 100,000 to 800,000 years ago (Numachi *et al.* 1990).

The Formosan landlocked salmon is considered an endangered species in Taiwan (Lin and Chang 1989). Distribution of this isolated population has been reduced to the Chichiawan Stream, and since 1985 its size has been reported as being less than 2,000 individuals (Lin and Chang 1989, Lin *et al.* 1990). Biotic, isolation, and habitat alteration factors are all contributing to species extinction (MacArthur and Wilson 1967, Frankel and Soulè 1981). Isolated populations in small headwater streams, such as brook trout (*Salvelinus fontinalis*), are especially vulnerable to the influence of stochastic events and may suffer localized extinction (Phillips *et al.* 1987).

In order to preserve the Formosan landlocked salmon, a series of studies have been conducted at Chichiawan Stream and adjacent areas since 1985. Morphological studies have revealed that this isolated population in Taiwan is a subspecies of *O. masou* (Juang 1988, Jan *et al.* 1990, Hosoya 1992). This salmon is highly selective of breeding site substrate size (Juang 1988, Lin *et al.* 1988b, 1989). It has also been found that aquatic insects (Yang *et al.* 1986, Huang 1987, Lin *et al.* 1988b) the major food item of this salmon and plankton (Rei *et al.*, 1988) are abundant in the Chichiawan Stream. However, the phosphate concentrations in the stream water increase suddenly in May and July, when fertilizers are sprayed in the area (Tsao 1988). Toxic materials in the stream water were also monitored by Lee *et al.* (1987); he found that 28 kinds of pesticides (mainly heterocyclic nitrogen compounds) are used on the farmland along the west bank of the stream. Lin *et al.* (1988a; 1988b) and Tsao (1988) studied the physical habitat of the Chichiawan Stream; they reported that average water temperature was 12.4 °C and average turbidity were between 0.5 and 0.95 ppm. After culturing and propagation (Yu *et al.* 1986 1987), 250 tagged salmon were restored to the stream in 1988.

As an extension of a previous study (Lin *et al.* 1990), this paper reports on temporal and spatial changes in the abundance of young and adult salmon. The impacts of natural disturbances and man-made factors on the salmon population are also described.

## STUDY AREA

Chichiawan Stream (Fig. 1) is about 6 km long and has a width of 7.1 – 12.3 m on average. The stream is an upper tributary of the Tachia River. The east bank of the stream is generally steep, and its vegetation is dominated by both Taiwan red pine (*Pinus taiwanensis*) and Formosan alder (*Alnus formosana*). The west bank is less steep, and farms along it produces cabbages, peaches, pears and apples. Blocking the stream are three major sand-retention dams which were built in the 1970's. These dams are four to ten m high and seven to 26 m wide (Chiueh *et al.* 1987, Chan and Chang 1989). A detailed description of the study area was given by Lin *et al.* (1990).

Typhoon Lynn passed over the upper Tachia River watershed in late October, 1987, and Typhoon Sarah struck central and southern Taiwan in mid-September, 1989. Both typhoons brought floods and subsequent landslides along the riverbanks of Chichiawan Stream.

## METHODS

We have defined the upper reach of Chichiawan Stream as the stretch between

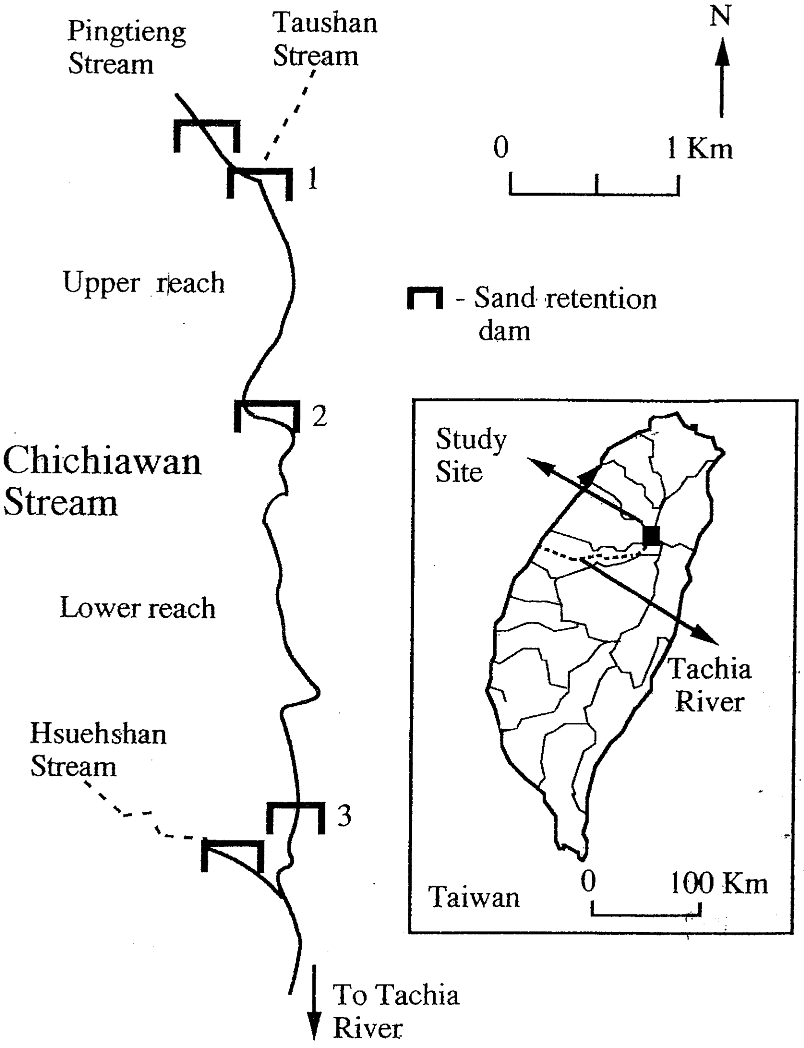


Fig. 1. Map showing location of study area. Dashes represent tributaries without occurrences of Formosan landlocked salmon. 1, 2, and 3 indicate sand-retention dams in the Chichiawan Stream.

dams 1 and 2 (1.5 km long), and the lower reach as the section between dams 2 and 3 (2.7 km long). The stream between dams 1 and 3 was further divided into fourteen 300-m long sections. In each section, salmon counts were made visually by divers (Hankin and Reeves 1988, Kinzie 1988, Heggenes *et al.* 1990, Lin *et al.* 1990). Visual counts were taken once during each summer and winter from 1987 to 1991; a survey was conducted upstream in a zigzag pattern.

Numbers and sizes of salmon in each section were recorded. Salmon visually estimated as less than 20 cm in total length (TL) were categorized as young; this group includes age 0+ and 1+ (Lin *et al.* 1990). Those with estimated TL greater than 20 cm were categorized as adult (age 2+ and older). Fry (TL $<$ 5 cm), which occur in January, were not included in our count.

Changes in salmon abundance was calculated as rates, with positive values indicating an increase and negative values indicating a decrease. Abundance rates from summer to winter were calculated as:

$$\frac{(\text{number in summer} - \text{number in winter})}{\text{number in summer}},$$

while those rates from winter to summer were calculated as:

$$\frac{(\text{number in winter} - \text{number in summer})}{\text{number in winter}}.$$

Salmon abundance over time along the stream was assessed according to a Friedman test (Conover 1980). Each section was categorized based on average abundance (mean) of salmon over time. A high-density section was defined as having an average abundance greater than the total salmon abundance average of all sections over time; a low-density section was defined conversely. Coefficients of variance (CV = standard deviation / mean) were calculated to provide an index of temporal variability in abundance for each section (Lin *et al*. 1990). Changes in salmon average abundance (mean) and temporal variability (CV) in the lower reach were checked with a trend test (D) for small sample size (Lehmann 1975; n = 9), with

$$D = (T_1-1)^2 + (T_2-2)^2 + \ldots\ldots + (T_N-N)^2,$$

where $T_i$, $i = 1..N$ is the ranks of a series. We also used the same test to determine the degree of decrease in salmon abundance for each section (n = 8). If the D equaled zero, the salmon abundance in a particular section followed a perfect upward trend. A larger D indicated that salmon abundance tends to decrease over time.

Measurements of the depth (cm), width (m) and current velocity (m/min) of Chichiawan Stream were taken in January of both 1988 and 1991. Perpendicular transect lines were established at every 10 or 20 m between dams 1 and 3. Measurements were taken as follows: Stream width was measured with a ruler tape at each transect; depth was measured from one side of the stream with ruler sticks at 1/3, 1/2, and 2/3 of the width of each transect; and velocity was measured at 1/3 of water depth from the surface at depth measuring points with a Hydro-Bios digital flowmeter (model 438 110). Average width, depth, and velocity of each 300 m stream section were then calculated. The discharge of a stream section was calculated as:

$$\text{Discharge (m}^3\text{/min)} = \text{Width (m)} \times \text{Depth (m)} \times \text{Velocity (m/min)}$$

Differences in stream width, depth, and velocity between 1988 and 1991 were compared using a paired *t*-test. A separate *t*-test was used to compare differences in the above three variables between high-density and low-density sections. Analyses were performed using SYSTAT (Wilkinson 1987).

## RESULTS

The total abundance of Formosan landlocked salmon in Chichiawan Stream decreased between September, 1987 and January, 1991, mainly due to a decrease of young salmon (Fig. 2). In general, total abundances in summer (sampling in July or September) were greater than those in winter (sampling in January or February). The abundance of young in summer was 1,307 in 1987 and 646 in 1990. The abundance of young in winter was 745 in February, 1988 and 275 in January, 1991. Abundances of summer adult decreased gradually from 1987 to 1990, but winter abundance did not exhibit this phenomenon.

Typhoon Lynn, which occurred in Oc-

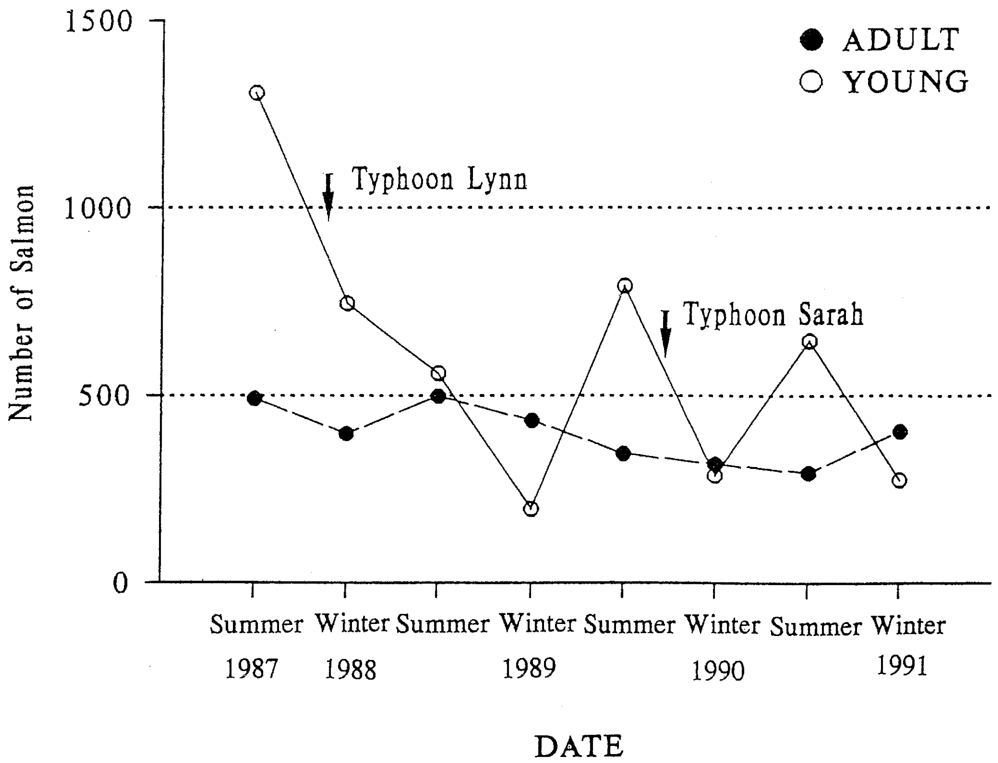


Fig. 2. Temporal variation of young and adult Formosan landlocked salmon from September, 1987 to January, 1991.

tober, 1987, impacted fish born in autumn, 1987. Although the decrease rate for the period between summer and winter with the typhoon was not different from those for similar periods without a typhoon (Table 1), the impact of the typhoon was revealed by the recruitment patterns observed between the following winters and summers. The abundance of young decreased 25.0% between the winter and summer of 1988, but increased 299.5% and 124.3% in 1989 and 1990 respectively. Between February and July 1988, adult abundance increased 25.1%, but decreased by 20.3% and 7.2% in 1989 and in 1990, respectively (Table 1). The generation born in 1987 was destroyed by Typhoon Lynn, which lead to a serious decrease in the abundance of young the following spring, and ultimately lead to the observed decrease in adults (to 295) in summer, 1989.

Salmon abundance differed significantly among sections over time ($p < 0.001$, Friedman two-way analysis of variance). No significant upward trends (i.e. $D < 32$; $p < 0.05$) were detected in any section (Table 2), i.e., salmon abundance showed no significant increase over time in all sections. In three section (1, 8, and 9), the abundance of young revealed a significantly downward trend, while sections 13 and 14 revealed slight increase ($32 < D < 84$). Adult abundances in sections 7 and 9 experienced significantly downward trends, while those in sections 6, 12, and 14 increased slightly.

The negative effects of the sand-retention dams were revealed by observed salmon distribution based on type division for each

Table 1. Increase (positive value) or decrease (negative value) in rates of Formosan landlocked salmon in Chichiawan Stream. Summer indicates samplings in July or September. Winter indicates samplings in January or February.

| | Typhoon | Adult | Young |
|---|---|---|---|
| Summer Winter | | | |
| Sep. 1987 to Feb. 1988 | Lynn | −18.9 | −43.0 |
| July 1988 to Jan. 1989 | | −13.1 | −64.6 |
| July 1989 to Jan. 1990 | Sarah | −7.8 | −63.6 |
| July 1990 to Jan. 1991 | | 37.0 | −57.4 |
| Winter Summer | | | |
| | Lynn | | |
| Feb. 1988 to July 1988 | | 25.1 | −25.0 |
| Jan. 1989 to July 1989 | | −20.3 | 299.5 |
| | Sarah | | |
| Jan. 1990 to July 1990 | | −7.2 | 124.3 |

section. The average adult abundance for all sections was 28.4, and for young salmon 42.9. The number of low-density sections for adult fish was greater than that for young fish in the upper reach (4 vs. 2; Table 2). Four adjacent low-density sections were found for both young and adult salmon above Dam 3 in the lower reach; section 8 was high-density for adult fish but low-density for young fish (Table 2). In this section, the mean abundance of young salmon was 41.0, which was close to the total average abundance of young salmon (Table 2). This indicated that the arrangement of section type was similar in the lower reach for both adult and young fish, that is, high- and low-density sections were not randomly distributed along the stream, but the arrangement of section type was affected by the sand-retention dams.

Young and adult abundances decreased further downstream in the lower reach (Table 2); the CV value exhibited an upward trend in the lower reach (Table 2), indicating that the temporal variability of salmon abundance increased in the habitat close to Dam 3. The CV values of young salmon were significantly greater than those of adults (Komogorov-Smirnov two-sample test, $p < 0.05$, $n = 14$), revealing that the variation of young abundance was larger over time than the variation of adult abundance in a section.

Chichiawan Stream became wider, shallower, and slower from 1988 to 1991 (Table 3); water discharge decreased significantly (paired $t$-test, $t = -.93$, $p < 0.05$). No correlation between the decreased discharge and degree of decrease in salmon abundance in a section were observed for either young or adult fish. There were no significant differences in stream width, velocity, or depth between high-density and low-density sections for young salmon (separate $t$-test, $p < 0.05$). However, stream depth in six high-density sections of adult fish was greater than stream depth in eight low-density sections (separate $t$-test, $t = -2.52$, df $= 9.4$, $p <$

Table 2. Average abundances (mean) and coefficients of variance (CV) of Formosan landlocked salmon and section types (ST) for 14 sections, observed via snorkeling in Chichiawan Stream (1987-1991).

| | Adult | | | Young | | |
|---|---|---|---|---|---|---|
| Section | Mean | CV | ST | Mean | CV | ST |
| Upper reach | | | | | | |
| Dam 1 | | | | | | |
| 1 | 37.5 | 0.49 | H | 55.3 | 1.15 | H |
| 2 | 12.2 | 1.11 | L | 50.2 | 1.00 | H |
| 3 | 25.6 | 0.60 | L | 47.5 | 0.69 | H |
| 4 | 23.2 | 0.46 | L | 40.0 | 0.42 | L |
| 5 | 27.6 | 0.37 | L | 16.1 | 0.75 | L |
| Lower reach | | | | | | |
| Dam 2 | | | | | | |
| 6 | 61.5 | 0.40 | H | 61.8 | 0.45 | H |
| 7 | 34.2 | 0.50 | H | 59.3 | 0.53 | H |
| 8 | 34.8 | 0.67 | H | 41.0 | 0.68 | L |
| 9 | 31.3 | 0.48 | H | 60.0 | 0.73 | H |
| 10 | 56.7 | 0.42 | H | 80.6 | 0.87 | H |
| 11 | 20.8 | 0.57 | L | 29.3 | 0.88 | L |
| 12 | 21.0 | 0.69 | L | 33.0 | 0.90 | L |
| 13 | 6.6 | 0.68 | L | 21.3 | 0.93 | L |
| 14 | 4.2 | 0.92 | L | 5.2 | 1.57 | L |
| Dam 3 | | | | | | |
| D | 224* | 26* | | 212* | 0* | |
| Total average | 28.4 | | | 42.9 | | |

H = Sections with abundance greater than the total average.
L = Sections with abundance less than the total average.
CV = Coefficients of variance.
D = Trend test for means and CV's of abundance of salmon in the lower reach. If $D < D_{0.05,9}$ (49), the trend was significantly upward. If $D > D_{0.05,9}$ (191), the trend was significantly downward.
* = $p < 0.05$.

0.05; Table 3). In addition, stream width and velocity in high-density sections did not significantly differ from measured width and velocity in low-density sections. Therefore, decrease of stream depth was identified as the major factor affecting adult population size.

Those sections exhibiting significantly declining trends in salmon abundance were also those showing high salmon density (Fig. 3) with the exception of section 8, which was a low-density section for young fish; mean abundance in section 8 (41.0) was close to the total average (42.9) of young salmon. This suggests a greater tendency of high-density sections with good habitat quality losing salmon.

Table 3. Degree of decrease trend of salmon abundance (July, 1987 to January, 1991), and average stream depth, current velocity and width (January, 1988 vs. 1991) of 14 sections along Chichiawan Stream.

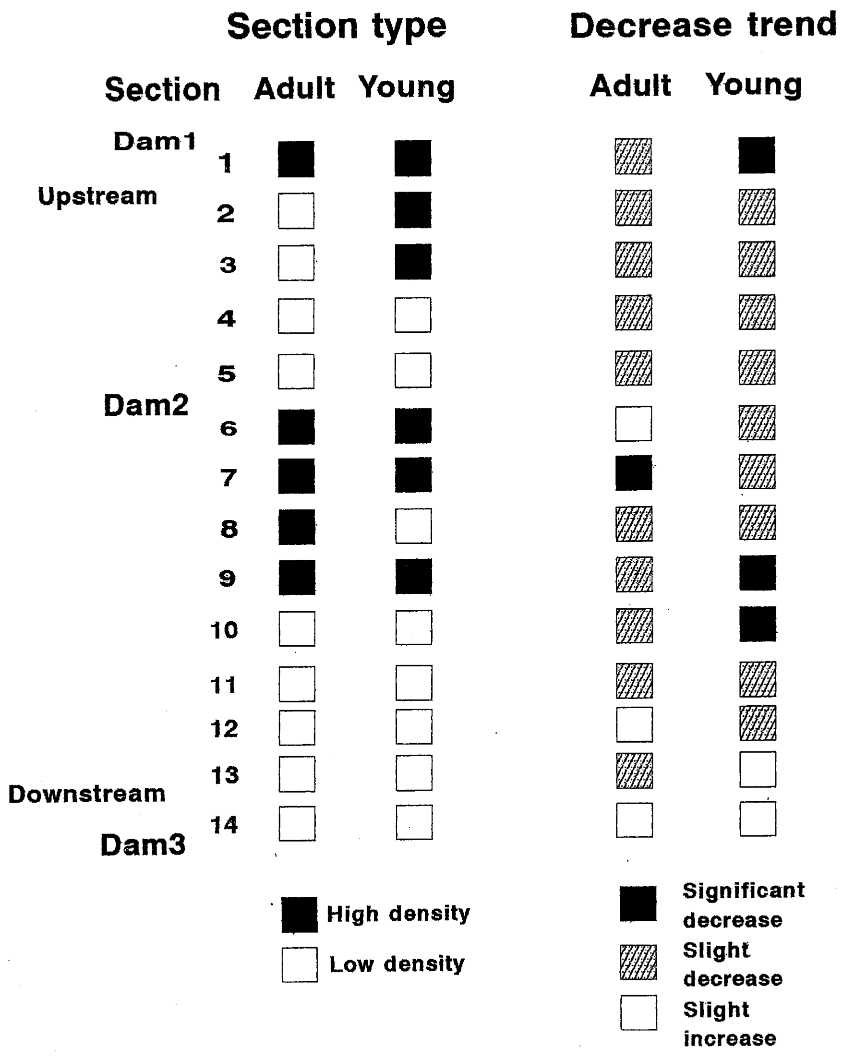
| | Trend D | | Depth (cm) | | Velocity (m/min) | | Width (m) | |
|---|---|---|---|---|---|---|---|---|
| Section | Adult | Young | 1988 | 1991 | 1988 | 1991 | 1988 | 1991 |
| Dam 1 | | | | | | | | |
| 1 | 118 | 138* | 52.6 | 56.0 | 0.92 | 0.39 | 7.1 | 8.5 |
| 2 | 115 | 116 | 48.3 | 27.1 | 0.93 | 0.32 | 8.9 | 8.5 |
| 3 | 136 | 136 | 52.7 | 34.8 | 0.78 | 0.21 | 9.8 | 8.5 |
| 4 | 96 | 126 | 39.1 | 27.6 | 0.66 | 0.09 | 9.6 | 7.1 |
| 5 | 122 | 106 | 45.0 | 25.1 | 0.76 | 0.29 | 8.7 | 9.5 |
| Dam 2 | | | | | | | | |
| 6 | 36 | 102 | 52.3 | 52.6 | 0.48 | 0.42 | 8.7 | 11.3 |
| 7 | 144* | 118 | 33.8 | 33.6 | 0.52 | 0.24 | 8.1 | 10.1 |
| 8 | 132 | 150* | 30.5 | 32.7 | 0.59 | 0.42 | 9.2 | 12.3 |
| 9 | 145* | 138* | 41.1 | 32.4 | 0.54 | 0.50 | 8.2 | 12.1 |
| 10 | 105 | 118 | 45.1 | 46.2 | 0.55 | 0.48 | 8.5 | 9.1 |
| 11 | 120 | 120 | 35.2 | 29.9 | 0.54 | 0.58 | 9.2 | 11.5 |
| 12 | 43 | 88 | 36.9 | 33.3 | 0.63 | 0.43 | 9.6 | 11.1 |
| 13 | 88 | 56 | 28.0 | 38.6 | 0.56 | 0.17 | 10.0 | 12.1 |
| 14 | 80 | 64 | 49.5 | 26.6 | 0.32 | 0.39 | 7.2 | 9.5 |
| Dam 3 | | | | | | | | |
| Mean | 106 | 113 | 42.1 | 35.4 | 0.67 | 0.35 | 8.7 | 10.0 |
| SD | 34 | 28 | 8.4 | 9.6 | 0.17 | 0.14 | 0.8 | 1.6 |
| t | | | −2.37* | | −4.16** | | .81* | |
| p | | | 0.03 | | 0.001 | | 0.02 | |

* : *Downward trend or t*-test, $p < 0.05$.
** : $p < 0.01$
*t* : paired t-test comparing differences of depth, velocity, and width between1988 and 1991.

## DISCUSSION

The abundance of Formosan landlocked salmon in Chichiawan Stream decreased and varied both spatially and temporally between September, 1987 and January, 1991. The abundance of young salmon changed over time, while adult abundance fluctuated less. Natural catastrophes (typhoons, floods, etc.), together with man-made disturbances (i.e. sand-retention dams) affected the observed spatial and temporal variability in salmon abundance.

Total abundances of young salmon in summer seasons were greater than those observed in winter. Lin *et al.* (1990) previously suggested that the smaller number of salmon observed in winter was due to both the hiding-behavior of the fish as well as fish mortality. Many animals regulated by



| | | Section type | | Decrease trend | |
|---|---|---|---|---|---|
| | Section | Adult | Young | Adult | Young |
| Dam1 | 1 | ■ | ■ | ▨ | ■ |
| Upstream | 2 | □ | ■ | ▨ | ▨ |
| | 3 | □ | ■ | ▨ | ▨ |
| | 4 | □ | □ | ▨ | ▨ |
| | 5 | □ | □ | ▨ | ▨ |
| Dam2 | 6 | ■ | ■ | □ | ▨ |
| | 7 | ■ | ■ | ■ | ▨ |
| | 8 | ■ | □ | ▨ | ▨ |
| | 9 | ■ | ■ | ▨ | ■ |
| | 10 | □ | □ | ▨ | ■ |
| | 11 | □ | □ | ▨ | ▨ |
| | 12 | □ | □ | □ | ▨ |
| Downstream | 13 | □ | □ | ▨ | □ |
| Dam3 | 14 | □ | □ | □ | □ |

■ High density
□ Low density

■ Significant decrease
▨ Slight decrease
□ Slight increase

Fig. 3. Diagram showing section type and degree of decrease of salmon abundance in 14 sections of Chichiawan Stream.

mortality and environment follow predictable patterns in annual population fluctuation (Weatherley 1972, Krebs 1978, Flowerdew 1985). In our study, young salmon showed greater relative variability in abundance over time (CV) than adult salmon, i.e., young salmon exhibited larger seasonal variation in abundance than adult salmon.

Typhoon Lynn (October, 1987) and Typhoon Sarah (September, 1989) were two natural catastrophes which occurred during our study period. Flooding which accompanies typhoons causes bank erosion, which dumps sand and small boulders into a stream. It has previously noted that floods are a direct cause of mortality of the eggs and fry (Elwood and Waters 1969), fingerlings (Onodera and Ueno 1961), and young-of-the-year (Hoopes 1975) of brook trout. Tsao (1988) and Lin *et al.* (1990) both found fewer salmon in the upper part of the study area following Typhoon Lynn; they suggested that many salmon were washed over the sand-retention dams. Salmon born in 1987 were, for the most part, killed in the floods accompanying Typhoon Lynn; the recruitment of young was low, thereby affecting adult populations the following two springs. Consequently, the observed number of adults was lowest in summer, 1989. The occasional loss of a year-class due to floods appears to be the major factor in local population extinction (Phillips *et al.* 1987).

The Chichiawan Stream sand-retention dams were constructed in the 1970's. Initially, the newly-created pools below and above the dams provided good habitats for the salmon. However, sand and boulders which were dumped into the stream by floods accumulated above the dams. Subsequntly, the pools changed into slate-bottomed riffles. Our results show that the stream became wider, shallower, and slower between 1988 and 1991. These changes greatly affected both spawning and hatching sites for the salmon (Lin *et al.* 1990). Alexander and Hansen (1986) reported that an experimental introduction of sand sediment into a stream altered that stream's channel to become wider and shallower, and resulting in a reduction of brook trout numbers and an increase in early life stage mortality. Seegrist and Gard (1972) and Elwood and Waters (1969) have both reported that floods contributed to declines in the standing crops of brook and rainbow trout (*Oncorhynchus mykiss*) because of habitat deterioration.

The sand-retention dams have made a great impact on the distribution of Formosan landlocked salmon in Chichiawan Stream. They have divided the stream into two unidirectionally isolated reaches, and have caused the deterioration of habitat quality by decreasing water depth in the sections above the dams. Stream length suitable for salmon survival is now obviously shorter than that of a damless natural stream. A short stream has been noted to a greater probability of local salmon extinction (Phillips *et al.* 1987).

The decrease of stream depth was the main factor correlated with the reduction of section quality for adult salmon. Stream depth has been shown to affect the distribution of other salmonids as well, with younger individuals occurring chiefly in shallower water and older ones existing in deeper water (Egglishaw and Shackley 1982, Kennedy and Strange 1982, Tsao 1988). In Japan, most adult fluvial masu salmon were recaptured in the deep pool in which they were first marked (Nakano *et al.* 1990). Pools with greater depth has been shown to be more suitable for salmonids due to the shelter they provide for the fish (Jones 1975, Egglishaw and Shackley 1982, Marcus *et al.* 1990).

The intensive agricultural practices occurring in the Tachia River watershed have been the main factors contributed to the decline of Formosan landlocked salmon in Taiwan for the past 20 years (Lin *et al.* 1989). The west bank along Chichiawan Stream was cleared for agriculture less than 30 years ago; those agricultural activities eliminated almost all of the vegetation along the streambank. They increased eutrophication, streambank erosion, and levels of sediments washing into the stream (Peters 1967, Tsao 1988, Lin *et al.* 1990, Marcus *et al.* 1990). Natural catastrophes intensified the damage caused by agricultural practices.

The decrease in abundance of salmon in Chichiawan Stream was due to reduction in the stream's carrying capacity. This conclusion is supported by the observed difference in spatial distribution and temporal variability of Formosan landlocked salmon living in Chichiawan Stream. The impacts of sand-retention dams plus typhoon-induced floods on the salmon appear to have been fourfold: (1) the mortality of young salmon may have been increased due to their vulnerability to environmental change; (2) the upstream movement of salmon may have been prevented due to fish being flushed downstream by floods; (3) the spatial distribution and temporal variability of salmon in the stream appear to have been changed because of habitat degradation, with the decrease of stream depth implying a loss of suitable habitat for adult salmon; and (4) the probability of local extinction has increased with the reduction of suitable habitat.

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# 臺灣櫻花鉤吻鮭之空間與時間變異

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自1987年至1991年間，於全長4.2公里之七家灣溪再劃分爲14個溪段中，以浮潛法估算臺灣櫻花鉤吻鮭(*Oncorhynchus masou formosanus*)的族群量。櫻花鉤吻鮭族群量在調查期間逐漸減少。就年間變異而言，各溪段中幼魚的數量波動比成魚劇烈。於攔砂壩上游，愈靠近壩的溪段中之櫻花鉤吻鮭數量愈少，而其年間變異則愈大。由於洪水作用與泥砂堆積，在過去四年期間，七家灣溪變得較寬、較淺以及流速較緩，而深度減少則是降低成魚族群密度的主要原因。鮭魚數量在密度較高的溪段中，較易出現數量減少的趨勢，而琳恩颱風來襲時正值鮭魚的生殖季，使得出生於1987年的同齡群被嚴重地摧毀。自然災害（如颱風與洪水等）與人爲干擾（如攔砂壩與農業活動等）影響了櫻花鉤吻鮭空間與時間上的變異性，並經由棲地惡化使得其數量減少。

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# Reproduction and Development of a Miniature Sand Dollar, *Sinaechinocyamus mai* (Echinodermata: Echinoidea) in Taiwan[1]

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**Bih-Yuh Chen and Chang-Po Chen (1993)** Reproduction and development of a miniature sand dollar, *Sinaechinocyamus mai* (Echinodermata: Echinoidea) in Taiwan. *Bull. Inst. Zool., Academia Sinica* **32**(2): 100-110. The reproduction biology of the miniature sand dollar *Sinaechinocyamus mai* (Wang) was examined from June, 1990 through October, 1991 at Tunghsiao in western Taiwan. Monthly measurements of gonad indexes plus histological examinations of both gonads and capacity for spawning induction reveal that *S. mai* has an annual reproductive cycle which includes spawning in October and November. During gametogenesis, the degree of development of nutritive phagocytes varies inversely with the number of differentiating gametes. The mature eggs of *S. mai* are white in color and 120 $\mu$m in diameter. Red pigment granules were found in the gelatinous coating of the eggs. Early cleavages were found to be equal, radial, and holoblastic. *Sinaechinocyamus mai* produces planktotrophic larvae which metamorphose completely nine days after fertilization when reared in seawater (33‰ S) at 25~28°C.

**Key words:** Sand dollar, Reproductive cycle, Embryogenesis, Larval Development.

*Sinaechinocyamus* is a genus of extremely small clypeasteroids with only two extant species; *S. planus* Liao occurs in Yellow Sea off the China coast (Liao 1979), and *S. mai* (Wang) occurs only off the coast of western Taiwan (Wang 1984). *Sinaechinocyamus mai* commonly occurs in the intertidal and nearshore subtidal waters of western Taiwan (Wang 1984); it never exceeds 11 mm in length.

Since adult *Sinaechinocyamus mai* closely resemble juveniles of the genus *Scaphechinus* in morphology, Mooi (1990) has suggested that *Sinaechinocyamus* is a progenetic miniature form derived from *Scaphechinus. Scaphechinus* occurs in waters surrounding Japan (Nisiyama 1968), and has been found in Pliocene fossil form in Taiwan (Wang 1984).

However, no data are available on the reproductive biology of *Sinaechinocyamus*. Therefore, we have researched *Sinaechinocyamus mai* reproductive biology from Taiwan specimens, including reproductive periodicity, embryogenesis, and larval develop-

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