Zoological Studies **48**(4): 460-467 (2009)

Zoological Studies

Site Fidelity of and Habitat Use by the Formosan Landlocked Salmon (*Oncorhynchus masou formosanus*) during Typhoon Season in Chichiawan Stream, Taiwan as Assessed by Nano-tag Radio Telemetry

Yuya Makiguchi[1,*], Lin-Yan Liao[2], Yoshifumi Konno[1], Hisaya Nii[3], Katsuya Nakao[3], Jin-Chywan Gwo[4], Hiroshi Onozato[5], Yii-Shing Huang[4], and Hiroshi Ueda[1,6]

[1]*Division of Biosphere Science, Graduate School of Environmental Science, Hokkaido University, North 9 West 9, Kita-ku, Sapporo, Hokkaido 060-0809, Japan*

[2]*Shei-Pa National Park Headquarters, Construction and Planning Agency, 4 Wuling Rd., Pingdeng Village, Heping Township, Taichung County 424, Taiwan*

[3]*Hokkaido Farming Fisheries Promotion Corporation, North 3 West 7, Chuo-ku, Sapporo, Hokkaido 060-0003, Japan*

[4]*Department of Aquaculture Taiwan National Ocean University, 2 Pei-Lin Road, Keelung 202, Taiwan*

[5]*Matsumoto Institute of Microorganisms, 2904 Niimura, Matsumoto 390-1241, Japan*

[6]*Laboratory of Aquatic Bioresources and Ecosystems, Field Science Center for Northern Biosphere, Hokkaido University, North 9 West 9, Kita-ku, Sapporo, Hokkaido 060-0809, Japan*

(Accepted December 25, 2008)

Yuya Makiguchi, Lin-Yan Liao, Yoshifumi Konno, Hisaya Nii, Katsuya Nakao, Jin-Chywan Gwo, Hiroshi Onozato, Yii-Shing Huang, and Hiroshi Ueda (2009) Site fidelity of and habitat use by the Formosan landlocked salmon (*Oncorhynchus masou formosanus*) during typhoon season in Chichiawan Stream, Taiwan as assessed by nano-tag radio telemetry. *Zoological Studies* **48**(4): 460-467. Movements of (time-series horizontal position) and habitat use by adult Formosan landlocked salmon (*Oncorhynchus masou formosanus*) were examined in a Taiwanese stream, (Chichiawan Stream) using nano-tag telemetry in summer (typhoon season) 2007. A great flood caused by a typhoon occurred during the tracking period in this study, but the flood did not change the positions or habitat use by the adult salmon. Ten tagged fish predominately used microhabitats near boulders and made frequent short movements of < 200 m between habitats. Our results suggest that adult salmon are basically sedentary in summer, but undertake small-scale movements to secure food. In conclusion, this study provides useful information for the conservation of the Formosan landlocked salmon by showing that boulders in streams may serve as refuges from floods brought by typhoons.
http://zoolstud.sinica.edu.tw/Journals/48.4/460.pdf

Key words: *Oncorhynchus masou formosanus*, Nano-tag telemetry, Movement, Typhoon flood.

The Formosan landlocked salmon (*Oncorhynchus masou formosanus*) is known as the most southerly distributed salmonid in the world, and it is only found in the Chichiawan Stream basin and Hsuehshan Creek (Tachia River system) located in Shei-Pa National Park, central Taiwan (Oshima 1955, Lin et al. 1990, Fig. 1). This is a subspecies of the masu salmon complex (*O. masou*) and spends its entire life in freshwater streams. The fish was formerly abundant in 6 tributaries of the upper Tachia River basin including Chichiawan, Kaoshan, Yousheng, Nanhu, Sakaran, and Hohuan Streams (Lin et al. 1990, Tsao et al. 1998, Fig. 1). However, the number of salmon in the basin has drastically declined in recent years to approximately 200 individuals due to habitat

*To whom correspondence and reprint requests should be addressed. Tel: 81-11-7062583. Fax: 81-11-7062598.
E-mail:yuya-m@fsc.hokudai.ac.jp

alterations such as construction of erosion-control dams and agricultural land development (Lin and Chang 1989). Because of the decline in the number of individuals, the salmon was listed as an endangered species by the Republic of China (ROC) on Taiwan in 1984. Further, the World Conservation Union, IUCN (Kottelat 1996) listed this species as a critically endangered species in its *Red Data Book* in 1996. The Taiwanese government is concerned about the species and has undertaken projects to restore its habitats. The Shei-Pa National Park Administration launched a program for its restoration, including maintenance of salmon refuges and spawning sites, provision of fish passage through erosion-control dams, and so on. Moreover, artificial propagation of the salmon has been ongoing since 1985. Nevertheless, the number of fish was still decreasing in the late 1980's and 1990's (Lin et al. 2004). At present, several small populations are maintained only in short reaches of the Chichiawan Stream basin and Hsuehshan Creek of Shei-Pa National Park (Fig. 1).

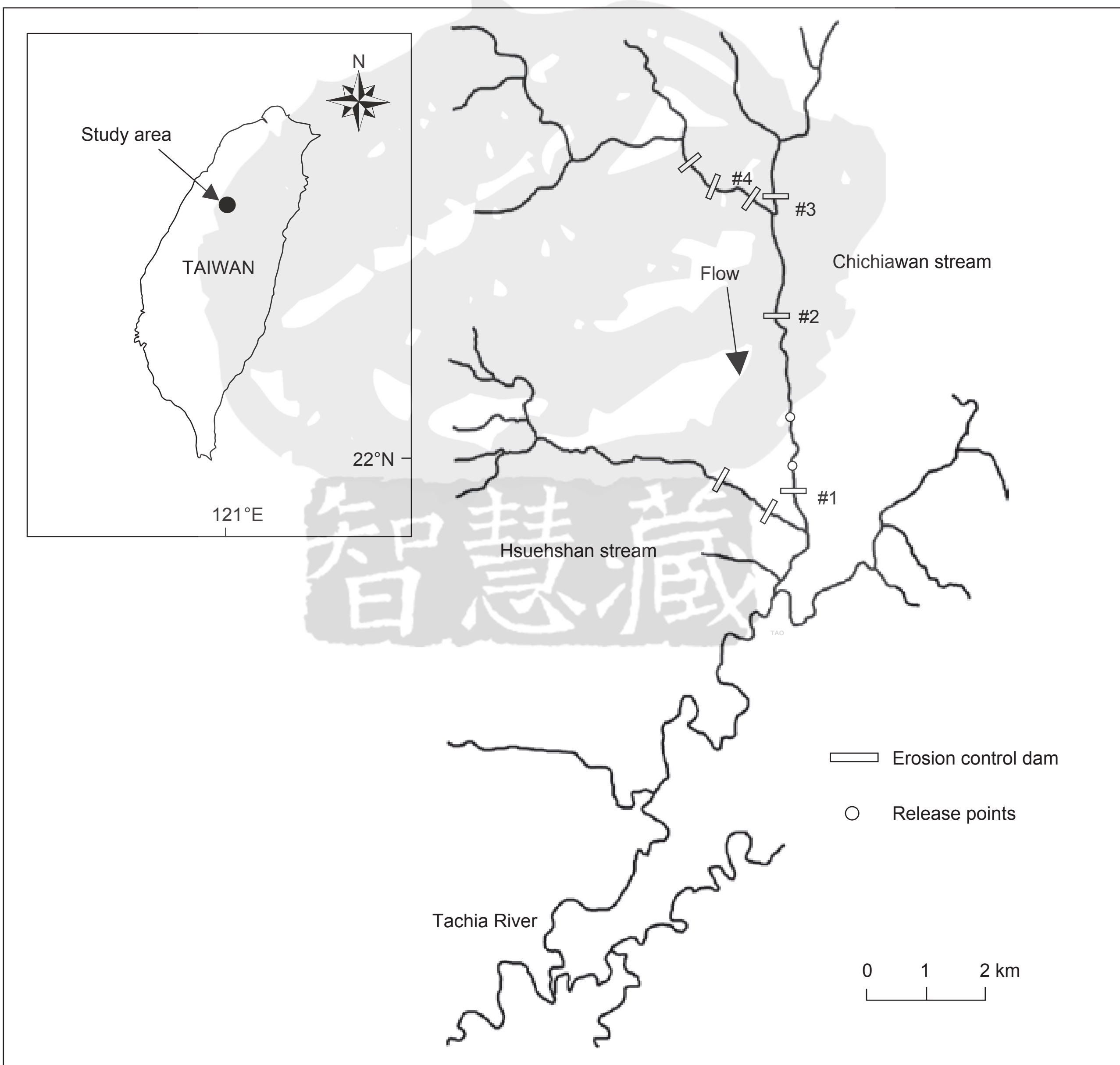

Fig. 1. Study sites along the Chichiawan Stream basin, Taiwan and the erosion-control dams installed in the basin (#1 - #4).

Recent advances in biotelemetry technology enable the tracking of animal behavior or movements at the individual level (Cooke et al. 2004), which is a powerful tool to study the behavior of fish in their natural environments. Biotelemetry studies have shown that stream-dwelling salmonids commonly migrate between feeding, refuge, and reproductive sites (Schmetterling 2001, Meka et al. 2003, Muhlfeld and Marotz 2005). Thus, maintaining connectivity among habitats may lead to successful conservation and management of fluvial populations of salmonids including the Formosan landlocked salmon (Rieman and Mcintyre 1995). A better understanding of seasonal movement patterns of the salmon can potentially help in the conservation of this species. Several studies examined the relationship between habitat use of Formosan landlocked salmon and physical parameters in streams using underwater observations (Lin et al. 1990, Day et al. 1993, Tsao et al. 1998, Lin et al. 2004, Chung et al. 2007 2008). However, little is known about seasonal movement patterns of the Formosan landlocked salmon. Furthermore, every year, typhoons hit Taiwan and sometimes cause great floods in Chichiawan Stream. Previous studies indicated that floods often have severe deleterious effects on fluvial salmonid fish and their habitat corridors (Elwood and Waters 1969, Dolloff et al. 1994, Carline and McCullough 2003, Sato 2006). However, there is no information about the effects of typhoon floods on the movements of and habitat use by Formosan landlocked salmon using biotelemetry techniques because no biotelemetry instruments were available for such a small-size species until recently.

The objectives in this study were (i) to describe the movement patterns of and habitat use by adult Formosan landlocked salmon in Chichiawan Stream in summer, and (ii) to evaluate the effects of floods caused by typhoons on their movements and habitat use using a recently developed nano-tag radio telemetry technique.

MATERIALS AND METHODS

Study site

Chichiawan Stream (24º21'-24'N, 121º17'-19'E) is located at Wuling Farms, on the upper reach of the Tachia River, in central Taiwan (Fig. 1) and drains 3 mountains over 3000 m (Tao, Chihyu, and Pingtien Mountains). The stream is approximately 3.0 km in length and 7.1-12.3 m in width with a mean gradient of 118 m/km and a total stream basin area of 76 km^2 (Lin et al. 1990). The elevation is approximately 1700-1800 m, and water temperatures of the stream are usually < 17°C. The study reach was characterized as predominantly rubble-boulder substrates. There are some erosion-control dams in Chichiawan Stream, which are approximately 10 m high and prevent the salmon from migrating up- and downstream. After the #2 erosion-control dam was broken by typhoons in the 1990s, Formosan landlocked salmon could then move between the #1 and #3 erosion-control dams.

Transmitter attachment

Tracking surveys were conducted in Aug. and Sept. 2007 (summer; typhoon season). Salmon used for the tracking surveys were captured using a cast net between the #1 and #3 erosion-control dam just before tagging. Ten individuals (with fork lengths of 20.3-28.9 cm and body weights of 97.5-238.5 g) were used in the study. Fish in this survey could not be sexed by appearance because the majority of fish showed no characteristics of sexual maturity. Fish were tagged with nano-tag radio transmitters (NTC-3-2, Lotek Engineering, Newmarket, Ontario, Canada: 1.1 g in air, 15.5 mm long, 6.3 mm wide, and 4.5 mm high with a 28 cm long antenna) and were assumed to be adults as previous studies suggested that fish over 20 cm in fork length are adults (Day et al. 1993). Each fish was transferred to a tank with water containing FA100 (eugenol; Tanabe Seiyaku, Osaka, Japan) at a dose of 0.5 ml/L. The fish were placed on a surgical table, ventral side down. During the surgical procedure, the gills were continuously perfused with water containing FA100 at a dose of 0.1 ml/L. A 10 mm incision was made on the ventral surface in a cephalic-caudal direction posterior to the origin of the pelvic fins. The transmitter, previously sterilized in ethanol, was inserted into the body cavity above the pelvic girdle. The antenna was pushed through the body wall using a hollow needle. The incision was closed using 3 independent permanent silk sutures (3/0 Akiyama, Tokyo, Japan). The operation took approximately 5 min per fish. In addition, an aminoglycoside antibiotic (kanamycin ointment, Meiji Seika Kaisha, Tokyo, Japan) was applied to the incision. After surgery, the fish were allowed to recover from the anesthesia for at least 1 d in a water tank before being released. The nano-tag accounted for 0.72% ± 0.18% (range, 0.46%-1.13%) of a fish's body weight. Winter (1983) recommended that the weight of the transmitter should be < 2% of a fish's body weight. Previous studies suggested that surgically implanted radio and acoustic transmitters do not affect the feeding, growth, or physiological states or swimming performance of juvenile Atlantic salmon (*Salmo salar* L.; Moore et al. 1990), chinook salmon (*O. tshawytscha*; Adams et al. 1998, Martinelli et al. 1998, Jepsen et al. 2001), or rainbow trout (*O. mykiss*; Lucas 1989, Martin et al. 1995). Thus, it is unlikely that there were adverse effects from the surgical implantation of tags on the movement and behavior of the tagged fish in this study.

Radio telemetry tracking

The tagged fish were released at 2 points between the #1 and #2 dams (see Fig. 1), and tracked from 7 Aug. to 1 Sept. 2007. The locations of tagged fish were intermittently determined by manual bank-side tracking with 3 radio receivers (model SRX600; Lotek Engineering). Signals from the transmitters were received through a hand-held directional Yagi antenna, which had 8 elements. In preliminary tests, hidden transmitters were easily found within 1 m^2 ranges using the receivers and Yagi antennas. Positions of tagged fish more than 3 m apart were considered distinct. The identification (ID) number of the radio transmitter was displayed and recorded when signals from the radio transmitters were received. Fish movements in the river were plotted on a map of the stream during tracking. When tracking, observers tried to see each fish before approaching its position to record habitat characteristics such as whether or not there were boulders, deep pools, or large woody debris. Tagged fish were usually checked twice during the daytime by walking within 30 m of the stream bank until a signal was detected. Observers did not disturb the fish or enter the stream during monitoring. To quantify movements of the tagged fish, observers marked the bank at a point perpendicular to the thalweg and measured the distance to the nearest mark using a combination of maps after identifying a fish's position. Daily movement consisted of the different locations through the tracking period. The total movement was defined as the sum of all movements recorded during tracking.

Daily average water temperatures during the tracking periods were 14.5-16.9°C in Aug. and Sept. 2007. A water-level gauge was installed 1.3 km upstream from #1 erosion-control dam to measure water levels during the tracking periods. Water levels were recorded once every morning during the tracking periods. All statistical analyses were performed using R statistical software (http://www.r-project.org).

RESULTS

Ten tagged fish were released on 7 and 9 Aug. 2007 and were intermittently tracked for 23-25 d. Five tagged fish moved upstream in the first few days after release (ranging 330-1570 m; Fig 2a) and were generally sedentary after that upstream movement. One tagged fish (ID 28) moved upstream after release and then downstream in the initial few days following tagging (Fig 2a) and then was also sedentary. On the other hand, 4 fish did not move from the area of the release sites during the survey (Fig. 2b).

Typhoon Sepat passed through the middle of Taiwan during the study, and the typhoon's heavy rains caused a flood in Chichiawan Stream on 18 Aug. 2007. The water level in Chichiawan Stream on 18 Aug. rose approximately 3 m compared to the normal water level on 7 Aug. (Fig. 3). The water level remained high for several days after 18 Aug. Water level data could not be collected after 23 Aug. because the water-level gauge was washed away by the flood. Contrary to our expectations, the positions of the tagged fish did not change during the heavy floods (Fig. 2).

Tagged fish predominantly used "a boulder habitat" (microhabitat near boulders) throughout the tracking survey (Table 1). The proportions of habitat types used by tagged salmon were similar before and after the typhoon event (Chi-squared test, $p = 0.62$; also see Table 1).

To understand daily movements of the tagged fish, the percent of fish moving different distances among habitats was examined (Fig. 4). The proportions of fish moving upstream and downstream were nearly equal (52.7% moving upstream vs. 47.3% moving downstream; Chi-squared test, $p = 0.43$; Fig. 4), and the proportion of "short movements" (movement distance between habitats of < 200 m) was 95.0%.

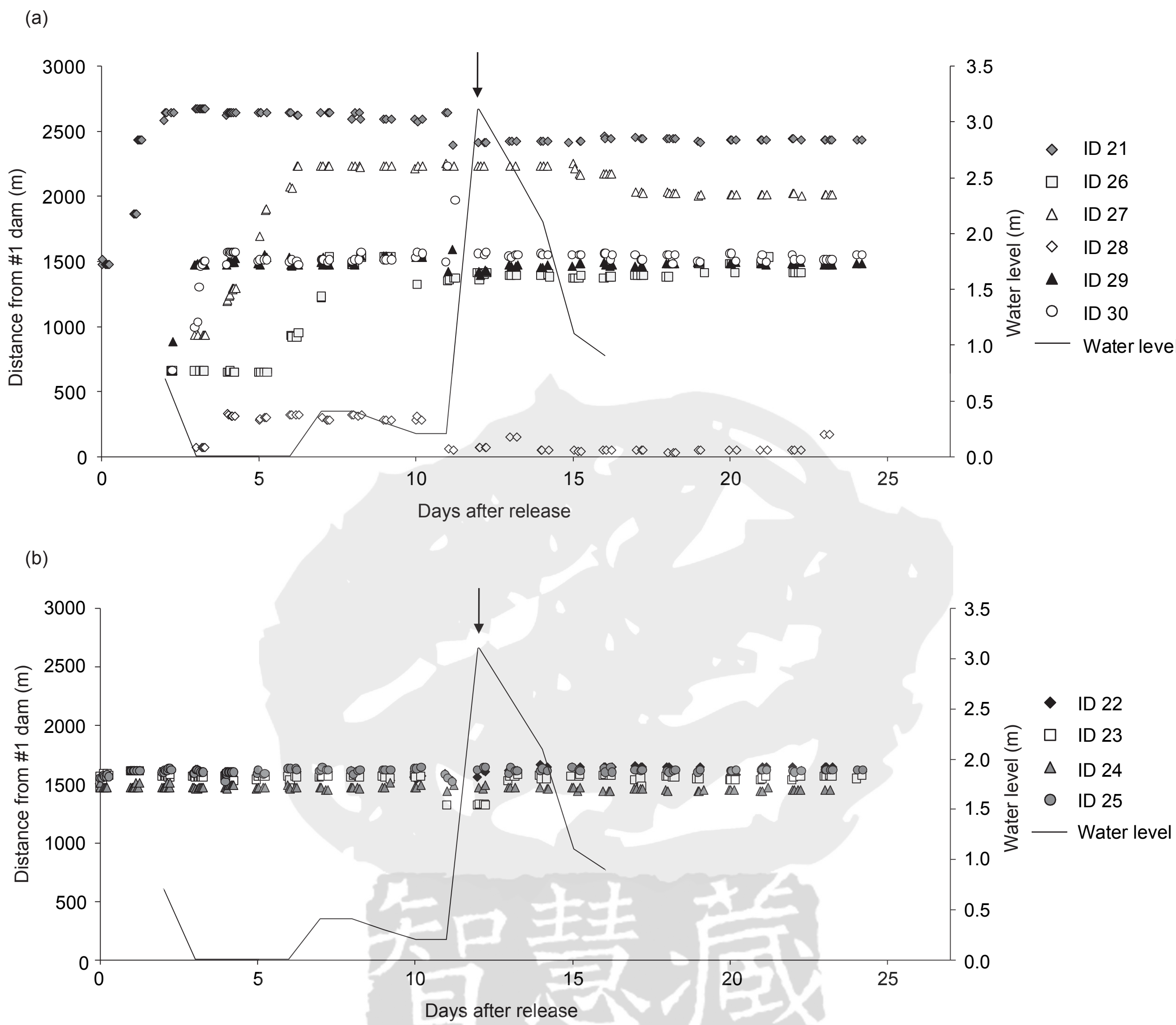

Fig. 2. Movement distances of 6 (a) and 4 tagged fish (b) during the tracking periods. Symbol shapes denote each individual. Y-axes show the distance toward upstream. The gray line shows water levels measured in the tracking section. The vertical arrow shows the flood caused by typhoon Sepat on 18 Aug. 2007.

Table 1. The frequency (the number of times) of habitat type use by adult Formosan landlocked salmon in Chichiawan stream in summer (before and after floods). Figures in parenthesis show the percentage of habitat type used

	Summer		
Habitat type	Before floods	After floods	Total
Boulder	188(73.2)	155(71.1)	343(72.2)
Deep pool	68(26.5)	63(28.9)	131(27.6)
Large woody debris	1(0.39)	-	1(0.21)
Plunge pool	-	-	-
Total	257	218	475

DISCUSSION

This study is the first attempt to examine the effects of a flood caused by a typhoon in Chichiawan Stream on movements of and habitat use by adult Formosan landlocked salmon at the level of the individual using nano-tag radio telemetry. The flood caused by typhoon Sepat on 18 Aug. 2007 did not change the positions of tagged fish. The tagged fish predominantly used boulder habitats and deep pools during the flood, and the proportion of habitat type used by the salmon did not vary between before and after the flood (see Table 1). These results indicate that boulders and deep pools may provide adult Formosan landlocked salmon with feeding and resting habitats or refuges during high-water-level events as well as at times of normal water levels. Boulders in the stream reduce energy expenditure by the fish (Harwood et al. 2002) and increase the survival rate of salmon during the early life stages (Nykanen and Huusko 2003). In addition, boulders can provide refuges to Formosan landlocked salmon from flood events (Chung et al. 2008; this study). We therefore suggest that boulders in Chichiawan Stream are an essential habitat component for Formosan landlocked salmon.

Non-anadromous salmonids exhibit a wide variety of migration patterns with spatial, seasonal, and ontogenetic shifts (Northcote 1997). Sakata et al. (2005) investigated the movement of fluvial masu salmon in a mountain stream in Kyusyu, Japan using mark-recapture methods and found that they exhibited strong sedentary tendencies in summer. Adult Formosan landlocked salmon displayed similar patterns, but short movements from 1 habitat to another (< 200 m) were frequently observed in the summer (typhoon season). In general, productivity in high-elevation streams is usually low (Ward 1986). Wilzbach et al. (1986) reported that cutthroat trout (*O. clarki pleuriticus*) fed less efficiently in high- than in low-elevation streams. Young (1996) examined summer movements of cutthroat trout in a small montane stream using radio telemetry and revealed that cutthroat trout continually cruised, suggesting that the supply of drifting food might not be sufficient for salmonids to establish limited feeding territories in such an environment. Those previous studies led

Fig. 3. View of the #1 erosion-control dam at approximately 10 m in height in Chichiawan Stream with (a) normal flow on 7 Aug. 2007 and (b) during a flood caused by typhoon Sepat on 18 Aug. 2007.

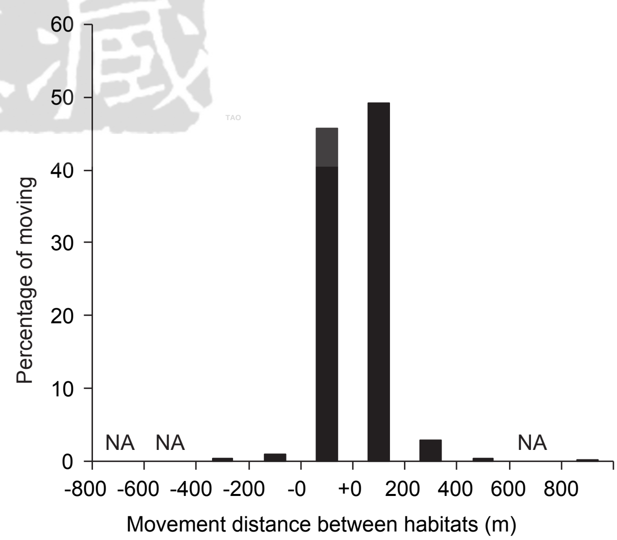

Fig. 4. Moving percentages of tagged fish between habitats summer in 2007 (solid bars, n = 478). "+" and "-" respectively indicate upstream and downstream movements.

to the idea that frequent short-distance movements may be more effective as a foraging strategy in high-elevation or low-productivity streams. Therefore, adult Formosan landlocked salmon might undertake repeated small-scale movements.

In conclusion, our results emphasize the importance of boulders as a habitat component for Formosan landlocked salmon and provide some ecological information on this subspecies.

Acknowledgments: The authors wish to thank the staff of the Shei-Pa National Park Headquarters, Construction and Planning Agency, Taichung County, Taiwan for their support of this study. We also thank Dr. J.B.K. Leonard (Northern Michigan Univ., Marquette, MI) for critically reading the manuscript, and Dr. A. Moore (CEFAS, Lowestoft, UK), Dr. N.G. Miles, and Dr. T. Tamate (Hokkaido Univ., Sapporo, Hokkaido, Japan) for valuable comments on the manuscript. This study was supported by a Research Fellowship for Young Scientists to Y.M. from the Japanese Society for the Promotion of Science (JSPS, 195295), by a Grant-in-Aid for Scientific Research from the Interchange Association, Japan (IAJ), and in part by a Grant-in-Aid for Scientific Research (A) (18208017) from JSPS to H.U.

REFERENCES

Adams NS, DW Rondorf, SD Evans, JE Kelly. 1998. Effects of surgically and gastrically implanted radio transmitters on growth and feeding behavior of juvenile Chinook salmon. Trans. Am. Fish. Soc. **127:** 128-136.

Carline RE, BJ McCullough. 2003. Effects of floods on brook trout populations in the Monongahela National Forest, West Virginia. Trans. Am. Fish. Soc. **132:** 1014-1020.

Chung LC, HJ Lin, SP Yo, CS Tzeng, CH Yang. 2007. Stage-structured population matrix models for the Formosan landlocked salmon (*Oncorhynchus masou formosanus*) in Taiwan. Raffles Bull. Zool. **Supplement 14:** 151-160.

Chung LC, HJ Lin, SP Yo, CS Tzeng, CH Yeh, CH Yang. 2008. Relationship between the Formosan landlocked salmon *Oncorhynchus masou formosanus* population and the physical substrate of its habitat after partial dam removal from Kaoshan Stream, Taiwan. Zool. Stud. **47:** 25-36.

Cooke SJ, SG Hinch, M Wikelski, RD Andrews, LJ Kuchel, TG Wolcott, PJ Butler. 2004. Biotelemetry: a mechanistic approach to ecology. Trends Ecol. Evol. **19:** 334-343.

Day YT, HS Tsao, KH Chang, YS Lin. 1993. Spatial and temporal changes of Formosan landlocked salmon (*Oncorhynchus masou formosanus*) in Chichiawan Stream, Taiwan. Bull. Inst. Zool. Acad. Sin. **32(Supplement 2):** 87-99.

Dolloff CA, PA Flebbe, MD Owen. 1994. Fish habitat and fish populations in a southern Appalachian watershed before and after hurricane Hugo. Trans. Am. Fish. Soc. **123:** 668-678.

Elwood JW, TF Waters. 1969. Effects of floods on food consumption and production rates of a stream brook trout population. Trans. Am. Fish. Soc. **2:** 253-262.

Harwood AJ, NB Metcalfe, SW Griffiths, JD Armstrong. 2002. Intra- and inter-specific competition for winter concealment habitat in juvenile salmonids. Can. J. Fish. Aquat. Sci. **59:** 1515-1523.

Jepsen N, LE Davis, CB Schreck, B Siddens. 2001. The physiological response of Chinook salmon smolts to two methods of radio-tagging. Trans. Am. Fish. Soc. **130:** 495-500.

Kottelat M. 1996. *Oncorhynchus formosanus*. *In*: 2006 IUCN Red List of Threatened Species. (http://www.iucnredlist.org).

Lin JY, EH Tsao, TC Lee, SL Yu. 2004. Stream physical parameters and habitat requirement: the case of the Formosan salmon. Ecol. Engin. **22:** 305-309.

Lin YS, KH Chang. 1989. Conservation of the Formosan landlocked salmon *Oncorhynchus masou formosanus* in Taiwan, a historical review. Physiol. Ecol. Jpn. Special **1:** 647-652.

Lin YS, SS Tsao, KH Chang. 1990. Population and distribution of the Formosan landlocked salmon (*Oncorhynchus masou formosanus*) in Chichiawan Stream. Bull. Inst. Zool. Acad. Sin. **29(Supplement 3):** 73-85.

Lucas MC. 1989. Effects of implanted dummy transmitters on mortality, growth and tissue reaction in rainbow trout, *Salmo gairdneri* Richardson. J. Fish Biol. **35:** 577-587.

Martin SW, JA Long, TN Pearsons. 1995. Comparison of survival, gonad development, and growth between rainbow trout with and without surgically implanted dummy radio transmitters. North Am. J. Fish. Manage. **15:** 494-498.

Martinelli TL, HC Hansel, RS Shively. 1998. Growth and physiological responses to surgical and gastric radio transmitter implantation techniques in subyearling Chinook salmon (*Oncorhynchus tshawytscha*). Hydrobiologia **372:** 79-87.

Meka JM, EE Knudsen, DC Douglas, RB Benter. 2003. Variable migratory patterns of different adult rainbow trout life history types in a southwest Alaska watershed. Trans. Am. Fish. Soc. **132:** 717-732.

Moore A, IC Russell, ECE Potter. 1990. The effects of intraperitoneally implanted dummy acoustic transmitters on the behavior and physiology of juvenile Atlantic salmon, *Salmo salar* L. J. Fish Biol. **37:** 713-721.

Muhlfeld CC, B Marotz. 2005. Seasonal movement and habitat use by subadult bull trout in the upper Flathead River system, Montana. North Am. J. Fish. Manage. **25:** 797-810.

Northcote TG. 1997. Potamodromy in Salmonidae: living and moving in the fast lane. North Am. J. Fish. Manage. **17:** 1029-1045.

Nykanen M, A Huusko. 2003. Size-related changes in habitat selection by larval grayling (*Thymallus thymallus* L.). Ecol. Freshw. Fish **12:** 127-133.

Oshima M. 1955. Masu salmon, *Oncorhynchus masou* (Brevoort) and Biwas salmon, *Oncorhynchus rhodurus* (Jordan and McGregor). Tokyo: Nireshobo.

Rieman BE, JD Mcintyre. 1995. Occurrence of bull trout in naturally fragmented habitat patches of varied size. Trans. Am. Fish. Soc. **124:** 285-296.

Sakata K, T Kondou, K Takeshita, A Nakazono, S Kimura.

2005. Movement of the fluvial form of masu salmon, *Oncorhynchus masou masou*, in a mountain stream in Kyushu, Japan. Fish. Sci. **71:** 333-341.

Sato T. 2006. Dramatic decline in population abundance of *Salvelinus leucomaenis* after a severe flood and debris flow in a high gradient stream. J. Fish Biol. **69:** 1849-1854.

Schmetterling DA. 2001. Seasonal movements of fluvial westslope cutthroat trout in the Blackfoot River drainage, Montana. North Am. J. Fish. Manage. **21:** 507-520.

Tsao EHS, YS Lin, RJ Behnke, EP Bergersen. 1998. Microhabitat use by Formosan landlocked salmon, *Oncorhynchus masou formosanus*. Zool. Stud. **37:** 269-281.

Ward JV. 1986. Altitudinal zonation in a rocky mountain stream. Arch. Hydrobiol. **Supplement 74:** 133-199.

Wilzbach MA, KW Cummins, JD Hall. 1986. Influence of habitat manipulations on interactions between cutthroat trout and invertebrate drift. Ecology **67:** 898-911.

Winter JD. 1983. Underwater biotelemetry. *In* LA Nielsen, DL Johnson, eds. Fisheries techniques. Bethesda, MD: American Fisheries Society, pp. 371-395.

Young MK. 1996. Summer movements and habitat use by Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*) in small, montane streams. Can. J. Fish. Aquat. Sci. **53:** 1403-1408.