

**Effects of dam removal on resident fish movement in
Cijiawan River, Taiwan**

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Abstract

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Freshwater fish change their movement patterns in response to natural or anthropogenic changes in habitat. Dam removal, a major restoration practice to restore river longitudinal connectivity, can affect river habitat with changes in flow regimes and morphological changes due to the sudden release of dam-trapped sediments. In Taiwan, a mid-size dam, Cijiawan #1 dam, was removed in 2011 to provide access to upstream habitat for the endangered target species, Taiwan salmon (*Oncorhynchus masou formosanus*). A three-phase radio telemetry tracking experiment was conducted to identify the movement patterns before, during and after dam removal. Some tagged fish were also displaced downstream to observe homing behavior. The movements of non-displaced fish showed reduced movement over time and persistence of location which indicates that the influence of disturbance due to capture and tagging was temporary. Displaced fish showed significant long distance movement toward their original home range immediately after release, but became as sedentary as non-displaced fish over time. The displaced fish homing behavior was limited by the barrier effect before dam removal, but daily movements and total absolute stream distance covered both increased after dam removal as fish began accessing upstream habitat. During the dam removal phase, fish below the dam moved very little when the heavy machinery was in the stream and then made long distance movements when

upstream habitat was accessible after deconstruction. The rapid response of Taiwan salmon in this study confirmed that the new habitat opened by the dam removal project could be utilized almost immediately, but the sensitivity to habitat degradation indicates that extra attention to short-term habitat impacts should be considered for future stream restoration practices.

Keywords: Dam removal; Radio telemetry; Fish movement; Taiwan salmon (*Oncorhynchus masou formosanus*); Cijiawan River

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Introduction

Well-functioning stream ecosystems provide important support for natural and human sustainability (Postel & Richter, 2003). However, freshwater systems have been jeopardized by human alteration (Beechie, Beamer, & Wasserman, 1994; Bisson, Quinn, Reeves, & Gregory, 1992) and there is a rising awareness of the consequences of habitat degradation (Holmes, 1998; Kondolf et al., 2007; Ormerod, 2003). Millions of dollars are now spent for river and stream restoration projects every year (Bernhardt et al., 2005; Dudgeon et al., 2006; Malakoff, 2004; Palmer, Hart, Allan, & the National River Restoration Science Synthesis Working Group, 2003). Natural watershed processes that create and maintain stream habitats have recently become a more common objective for stream restoration practices, although most restoration actions still aim to create specific habitats (Roni et al., 2002).

One of the most important aspects of natural stream ecosystems is connectivity. Connectivity from a landscape perspective can be defined as the flow of energy, matter and organisms between landscape components (Ward, Tockner, Arscott, & Claret, 2002). In stream ecology, connectivity can be categorized into four dimensions: longitudinal connectivity between upstream and downstream, lateral connectivity from the stream channel to riparian area and valley walls, vertical connectivity between different water depths and the interaction between surface water and the hyporheic zone, and the temporal variation of all three spatial aspects (Ward, 1989). Many species depend on different parts of streams for functional needs at different life stages. For movement and migration between growth, reproduction and refuge habitats, longitudinal connectivity is critical. However, dams and flow regulation reduce both longitudinal and lateral connectivity of the stream (Ward & Stanford, 1995).

In-stream barriers alter stream velocity, water depth and create impassable flow drops at the outflows, which change the hydrology and thermal regimes of aquatic systems (Bergkamp, Dugan, & McNeely, 2000) and obstruct the longitudinal movement of aquatic species (Warren & Pardew, 1998; Wheeler, Angermeier, & Rosenberger, 2005),

especially upstream movements. In-stream barrier improvements, such as culvert replacement, fish passage construction, and dam removal, are becoming major stream restoration practices and an effective way to increase the availability of habitat for a nominal cost (Hart et al., 2002; Roni, et al., 2002). Although not as common currently as other project types, dam removal projects will only increase as aging dams become more costly to relicense or maintain, and the scientific and public communities become more aware of the negative effects of dams (Doyle, Harbor, & Stanley, 2003).

Freshwater fish movement patterns, like other animals', are a choice between staying within a small local area or ranging over longer distances. The choice has consequences in terms of energetic costs, growth rates, susceptibility to predation, and mortality. However, fish also change their movement pattern in response to natural or anthropogenic changes in habitat. Fish movements are affected by many factors including methods used to capture and study these movements.

The objective of this study is to identify the effects of Cijiawan #1 dam removal on Taiwan salmon movement patterns. Using radio telemetry tracking devices, daily locations of tagged Taiwan salmon were recorded and the extent of daily movement and habitat range determined. In addition to comparing pre and post dam removal movement patterns, the deconstruction impact on downstream Taiwan salmon population movement was also evaluated during dam removal.

Literature Review

Salmonids and freshwater movement

Pacific Salmon are known for their anadromous life history, spawning in freshwater, migrating to the sea to mature, and returning to freshwater to spawn (Quinn, 2005). There are also some nonanadromous salmonids that spend their entire life in freshwater. They have evolved to be highly sedentary and stay in the stream where they were born throughout their lives (Miller, 1954; M. K. Young, 1998). Other freshwater salmonids exhibit downstream migration to a larger river or lake to grow and return to their natal upstream tributaries for spawning (Varley & E., 1988). These movements in freshwater can range from a few to hundreds of kilometers depending on the species and the watershed.

Some freshwater fish, including several salmonids, have restricted movement patterns and spend most of their life in a short reach of stream without regular long distance movements. For these sedentary fish, the relatively small area of habitat they inhabit has to provide sufficient resources or ecological function to meet their life-history needs (Gerking, 1959; Hughes, 2000). Bachman (1984) and Miller (1957) suggested that some adult fluvial salmonids demonstrate highly sedentary characteristics and spend their whole life in a habitat range of no more than 20 m. However, individuals who are sedentary most of the time still might move fairly long distances over short time periods before settling once more into a stationary pattern (Brown & Mackay, 1995). Reasons for longer movements includes passive and active dispersal of fry, life stage shifts in habitat use or diet, diel movements between feeding and resting areas, and seasonal and spawning movements.

Migration

Even freshwater fish that usually stay in localized areas exhibit daily or seasonal movement patterns associated with variable resource utilization for particular habitat

needs during specific life stages, or in response to environmental change (Lucas & Baras, 2001). Northcote (1978, 1984) defined migration as the movements that result in alternating between two or more separate habitats, occur with a regular periodicity within an individual's life time, involve a large proportion of the population and involved directed movement at some stage of the lifecycle. Based on the movements between different functional habitats, Northcote also categorized migration drivers as reproductive, feeding, or refuge related.

Reproductive migration, movements from feeding or refuge habitat to spawning habitat, occurs in freshwater salmonids too. Because of the different environmental characteristics and spatial separation between feeding habitats and suitable spawning sites (Northcote, 1997), even for some generally sedentary species like cutthroat trout (*Oncorhynchus clarki*), distinguishable movement can be observed for their spawning needs (Hilderbrand & Kershner, 2000; Schrank & Rahel, 2004). Brown trout (*Salmo trutta*) have also been found to make long distance movements to spawning habitats with appropriate substrate (James, Erickson, & Barton, 2007; Meyers, Thuemler, & Kornely, 1992), and return to the pre-spawning location within a few days post-spawning (Burrell, Isely, Bunnell, Van Lear, & Dolloff, 2000).

Freshwater resident salmonids sometimes also make long distance movement to different habitats for their survival due to environmental fluctuations, natural or anthropogenic, seasonal or accidental. Most cutthroat trout exhibit site fidelity, but long distance movements are still sometimes made for environmental reasons such as seasonal water level changes (Bernard & Israelsen, 1982), or temperature changes (Brown & Mackay, 1995). Depending on the difference between the tolerance range of temperature and natural temperature regimes, freshwater fish adjust their movement pattern to meet their favorable thermal status. Brook trout (*Salvelinus fontinalis*) exhibit temperature driven movements from high temperature near-shore shallows to deeper water habitat near steep shorelines (Mucha & Mackereth, 2008). Temperature driven movements between different water depths can also be found on a daily basis, in response to day-night temperature differences. Some foraging freshwater fish change their daily temporal feeding movement pattern from dusk and dawn to middle of the

day when temperature drops out of their thermal optimum (Baras & Lagardère, 1995). Juvenile sockeye salmon (*Oncorhynchus nerka*) in lake environments showed vertical movement from low-temperature deep water to surface twice a day for feeding and the higher metabolic rate of digestion in warmer water (Brett, 1971; Narver, 1970).

Hydrologic events and changing discharge are important factors that stimulate freshwater movement. Some freshwater salmonids initiate their spawning migration during or following periods of high flows (Jonsson, 1991; Northcote, 1984). In many mountain streams or high latitude regions, the rising temperature in spring brings snow melt and increasing stream flow, which provide accessibility to upstream habitat and trigger longitudinal migration to spawning areas (Northcote, 1984). However, when the discharge increases beyond the fish's swimming ability migration behavior is restrained (Jonsson, 1991; Northcote, 1984).

Fish movement patterns are also related to their size and the habitat status. Freshwater brown trout (*Salmo trutta*) movement patterns are positively related to average daily flow and negatively related to average daily water temperature (R. G. Young, Hayes, Wilkinson, & Hay, 2010). Cutthroat trout spawning, migration and homing movements are negatively related to body size (Schrank & Rahel, 2006). Cutthroat trout often move out of habitats occupied by brook trout to avoid competition and predation (McGrath & Lewis, 2007).

Effects of dam removal

One of the most important habitat impacts of dam removal is the morphological change due to the sudden release of dam-trapped sediments and change of flow regimes. Previous studies observed several morphological changes in downstream reaches including fine sediments introduced into channel substrates (Cheng & Granata, 2007; Stanley, Luebke, Doyle, & Marshall, 2002), pool filling (Wohl & Cenderelli, 2000), channel scouring (Burroughs, Hayes, Klomp, Hansen, & Mistak, 2009; Doyle, Stanley, & Harbor, 2003), and decreased heterogeneity of channel forms (Bushaw-Newton et al.,

2002; Kanehl, Lyons, & Nelson, 1997; Stanley, et al., 2002). These geomorphic alterations imply direct effects on aquatic biological communities (Kibler, Tullos, & Kondolf, 2011).

Upstream effects after dam removal include rapid change of hydraulic parameters, such as steeper slopes and faster flow velocities, that can induce rapid geomorphic changes like channel incision and bank failure (Hart, et al., 2002). Depending on the amount of sediments released and the stream's sediment transport capacity, the duration of geomorphic habitat adjustments to dam removal can vary from several years to more than a decade to reestablish an equilibrium channel (Pizzuto, 2002; Stanley, et al., 2002).

In addition to changing habitat morphology, dam removal may also influence downstream water quality (Knittel, 2010; Thomson, Hart, Charles, Nightengale, & Winter, 2005). Because of their large ratio of surface area to volume, finer sediments tend to trap relatively more contaminants than coarse sediments. The sudden release of the impounded fine sediment behind a dam may constitute a major contamination hazard to the river (Stone & Droppo, 1994; Wood & Armitage, 1997). Along with sediment release and bank failure, turbidity is another important water quality issue. Although increased turbidity should be mostly temporary (Kanehl, et al., 1997; B. D. Winter, 1990), turbidity and suspended sediments can still affect fish physiology and behavior which can reduce survival rates (Bash et al., 2001). Rapid changes in channel slope and increasing velocities could also dissolve more air into water than usual. The super-saturation might increase chances for gas-bubble disease in fish (Weitkamp & Katz, 1980; Wik, 1995).

The ecological response to dam removal can vary over a wide range of time scales. The newly passable channel could be usable within days after removal. Other ecological responses, such as riparian reforestation and aquatic food web reestablishment could take years, even decades, depending on watershed processes (Hart, et al., 2002). To monitor the recovery processes, the effects on fish assemblage structure and spatial distributions (Catalano, Bozek, & Pellett, 2007) or to evaluate the ecological benefit (Brenkman, Mumford, House, & Patterson, 2008; Chung et al., 2008), a long-term monitoring program with appropriate indicators is needed (Pess, McHenry, Beechie, &

Davies, 2008; Woodward et al., 2008).

Biotelemetry tracking on fish movement

Historical methods for studying fish movements include mark and recapture, population surveys, fishery logs, and stream side or underwater observations (Furevik, Bjordal, Huse, & Fernö, 1993; Nielsen, Johnson, & American Fisheries, 1983; Sutterlin, Jokola, & Holte, 1979). These conventional methods provide basic answers regarding behavioral questions, but fish were monitored as a group with little individual information. Newer technology such as biotelemetry has been shown to be an effective method to study individual fish behavior in natural environments (Cooke et al., 2004), and provides continuous physiological and behavioral monitoring. Because of the complexity of the aquatic environment, technical limitations of the instruments, and scales of research, there are many different methodologies for fisheries telemetry studies. Generally radio or acoustic transmitters are attached to or implanted in study individuals and signals are received by antenna or hydrophone with manual tracking or fixed data logging setup (J. D. Winter, 1996). Radio telemetry tagging is especially useful for directly studying fish movement and behavior at the individual level. Several studies have used the method to track resident salmonid seasonal movements and movements between feeding, refuge, and reproductive sites (Meka, Knudsen, Douglas, & Benter, 2003; Muhlfeld & Marotz, 2005; Schmetterling, 2001), but the temporal scale of observation and frequency of observations must be sufficient to determine the movements of interest (Hilderbrand & Kershner, 2000).

Successful telemetry studies rely on the ability to attach the transmitter to the experimental fish without negatively affecting the physiology, behavior, or mortality of the fish. Transmitter implantation and surgical procedures can influence the physiology, swimming ability, and behavior of the fish (Bridger & Booth, 2003; Cooke, Woodley, Brad Eppard, Brown, & Nielsen, 2011). It is best to anesthetize the fish before attaching the transmitter. Appropriate anesthetics must allow for rapid induction and recovery times (Marking & Meyer, 1985) to avoid permanent chemical or physiological damage affecting

fish mortality and behavior.

External transmitter attachment is suitable for short-term research in environments that lack high velocities or physical obstructions such as vegetation that can elevate the risk of entanglement. The relatively simple and faster procedure of external attachment has the benefit of less fish handling and less physiological damage. For some cases, such as physiological limitations associated with stomach and peritoneal cavity size of the experimental fish (Bridger & Booth, 2003) or special life stage (e.g., post spawning) with minimal physiological strength (J. D. Winter, 1996), external attachment might be the only choice. For smaller fish, the external attachment can significantly lower its swimming ability (McCleave & Stred, 1975), but for larger fish, the effect is minimal (Arnold & Holford, 1978) or even absent (Thorstad et al., 2009).

Transmitters can be implanted intragastrically by pushing the transmitter into the fish's stomach. Intragastric insertion is generally considered a gentle, quick, and easy procedure that can be accomplished using a minimal level of anesthesia. The general concern of intragastric insertion is possible short tag retention times due to regurgitation. Mellas and Haynes(1985) reported 80% of experimental rainbow trout regurgitated the transmitter at least once in a 2-week period. Another concern of intragastric insertion is a decrease in fish feeding behavior, possibly due to the decreased stomach volume or food intake being blocking by the transmitter. Slower growth rates, caused by decreased feeding, were found in some gastrically implanted fish (Adams, Rondorf, Evans, Kelly, & Perry, 1998; Jepsen, Davis, Schreck, & Siddens, 2001).

Surgical implantation in the peritoneal cavity has the advantages of placing the transmitter near the center of gravity of the fish. Compared with external attached transmitters, it not only protects the tag from environmental entanglement, it also reduces any influences on fish swimming ability by lowering the drag forces. On the other hand, surgical implant procedures require longer handling times, deeper anesthesia, and may result in the greatest possibility of wound infection (Bridger & Booth, 2003). However, some procedural and surgical techniques, such as incision closure with absorbable sutures, speeds up wound healing and recovery (Jepsen,

Mikkelsen, & Koed, 2008). Surgical implantation appears to have a minimal effect on mortality, growth, and behavior of salmonids (Adams, et al., 1998). Compared with gastric implantation, surgical procedures are recommended based on fewer effects on feeding behavior and fish growth (Jepsen, et al., 2008).

Early recommendations stated that the transmitter should be less than 2% of the fish body weight (J. D. Winter, 1983). Further research on transmitter implantation in mid-sized freshwater fish suggests a broader range of tag weight ratios up to 8% and antenna length up to 94mm are tolerable without apparent effects on fish mortality, swimming ability, and behavior pattern (Brown et al., 2010; Chittenden et al., 2009), but the exit wound of the extending antenna might cause some inflammation (Adams, et al., 1998).

Intraperitoneal implantation of radio telemetry transmitters might also negatively influence fish behavior. The hydraulic drag on the antenna likely results in decreased swimming performance of small tagged fish (Adams, et al., 1998; Murchie, Cooke, & Schreer, 2004). Predator avoidance of tagged fish might be diminished by impaired swimming ability (Bams, 1967) or predators may be attracted either to the signals emitted from the tags, or the exposed antenna. Adams et al.(1998) found that fish with gastric or surgical implants were eaten by predators in significantly greater numbers than controls. However, with new technology and surgery procedures, tagged fish now are given ample time to compensate for the excess tag mass, and the tags are smaller with flexible antennas or even no external antennas at all. Several recent studies found no difference between control fish and surgical implanted fish in swimming performance (Anglea, Geist, Brown, Deters, & McDonald, 2004; Cooke & Bunt, 2001), predation avoidance (Anglea, et al., 2004), nor in social behavior (Connors, Scruton, Brown, & McKinley, 2002), if the proper tag size is chosen.

As for the potential injuries caused by capturing methods, gill-net and rod-fishing showed no effects on fish growth and movement patterns (Mäkinen, Niemelä, Moen, & Lindström, 2000). Electrofishing can cause critical spinal injuries on fish's survival and long-term growth, especially with pulsed shocks (Dalbey, McMahan, & Fredenberg,

1996). However, McMichael (1998) indicated that the percentage of electrofishing injuries decreased with larger fish and larger reach and stream scales.

To the best of author's knowledge, there is only one other study using radio telemetry before and after dam removal to assess changes in fish movements (Ellsworth, Banks, & VanderKooi, 2011; Ellsworth & VanderKooi, 2011). That study of larval Lost River suckers and shortnose suckers demonstrated that radio telemetry tracking data can provide detailed information about individual fish movement and the utilization of newly opened passage from dam removal. By offering direct evidence of fish using new areas that become accessible after stream longitudinal connectivity restoration, radio telemetry is proving to be an effective method for monitoring and effectiveness evaluation for dam removal projects.

Dam Removal in Taiwan for Taiwan salmon

In Taiwan, a mid-size dam, Cijiawan #1 dam, was removed last year solely for stream longitudinal connectivity restoration to improve upstream movement of the target species, Taiwan salmon (*Oncorhynchus masou formosanus*), which were monitored throughout the project. Found only in the Cijiawan River basin (within the Tachia River basin) located in Shei-Pa National Park, central Taiwan, Taiwan salmon are known as the most southerly distributed salmonid in the world (Y. S. Lin, Tsao, & Chang, 1990; Oshima, 1955). They are now endangered due to habitat degradation, regional agricultural development and channel-altering in-stream hydraulic facilities. Just like the fluvial form of masu salmon (*Oncorhynchus masou*) that live in a mountain stream in Kyushu, Japan (Sakata, Kondou, Takeshita, Nakazono, & Kimura, 2005), Taiwan salmon attain maturity, spawn and live their whole life in freshwater and maintain parr marks on their flanks into adulthood. Due to habitat degradation and over fishing, the population of Taiwan salmon decreased sharply in the 1980s. Only about 200 fish were counted during the snorkeling survey in 1989 (Y. S. Lin & Chang). In 1996, Taiwan salmon were listed as endangered in the Red Book of the International Union for Conservation of Nature (IUCN).

Recent studies have begun to identify the physical parameters and habitat use of Taiwan salmon (Chung, Lin, Yo, Tzeng, & Yang, 2007; Chung, et al., 2008; Day, Tsao, Chang, & Lin, 1993; J. Y. Lin, Tsao, Lee, & Yu, 2004; Y. S. Lin, et al., 1990; Tsao, Lin, Behnke, & Bergersen, 1998). Low stream temperatures are critical to Taiwan salmon survival and egg hatching. Due to downstream channel widening and solar energy accumulation, upstream temperatures are colder than downstream. Former agricultural activities, now mostly restricted or abandoned, and tourist activities along the stream also make upstream habitat more suitable in terms of possible water quality contamination for Taiwan salmon.

Unlike most of the anadromous or fluvial life forms of salmonid, Taiwan salmon spend their whole life in mountain streams. Previous radio telemetry tracking research documented their sedentary nature, occupying a small habitat range without long distance migration. Adult Taiwan salmon are basically sedentary in summer, but undertake small-scale movements to secure food with an effective foraging strategy for the supply of drifting food in high-elevation streams. During flood events, Taiwan salmon were observed using big boulders and deep pools in main channels as temporary refuge (Makiguchi et al., 2009). However, the migration barriers in the stream still limited Taiwan salmon from moving upstream to cooler temperature habitats for spawning or returning to their home range after accidental displacement by flood events.

The removal of Cijiawan #1 dam opened a new passage intended to increase the Taiwan salmon's longitudinal movement and make upstream quality habitats, in terms of lower average water temperature, accessible for downstream populations but it was unknown if they would migrate longer distances to reach better habitat.

Methods and Materials

Study area

The Cijiawan River is located on the Wuling Farms, in the upper Tachia River basin in central Taiwan (Figure 1). The stream length is approximately 13 km with an average width of 9.7m. Cijiawan basin area is 76 km² (Y. S. Lin, et al., 1990) with a 100 m elevation range (1,700 to 1,800 m). Secondary forest from reforestation in the 1950s to 1960s covers the hill slopes west of the river, while grasslands formerly used for agriculture cover much of the eastern slopes. A famous tourism and leisure farm, with 35 hectares of orchards that include temperate fruit trees and tea, lies within the watershed. The stream is steep with an average channel slope of 11.8%. The dissolved oxygen is consistently greater than 7 mg/l, and pH values range from 7.0-8.3 (Y. S. Lin & Chang, 1989; Tech Reservoir Management Committee, 1983). The local air temperature ranges from -8~29°C, and the streambed is characterized as predominantly cobble-boulder substrates (Wang, 1989).



Figure 1 Location of Cijiawan #1 dam, Ta-Chia River, central Taiwan

Experimental design

The study consists of three phases: pre-dam removal, dam removal and post-dam removal. Fish were captured and tagged for each phase and released in various locations (Table 1).

Table 1 Experimental design and sample collection during the 3 project phases

Phase	Pre-dam-removal	Dam removal	Post-dam-removal
Fish capture site	100-350m above dam	1. 0-100m below dam 2. Tributary junction 700m below dam	1. 1,200m above dam 2. 2,300m above dam
Fish number	10	10 (5 from each site)	20 (10 from each site)
Capture method	Gill-netting Electro-shocking	Angling	Angling Gill-netting
Tagged fish release sites	Displaced at pools 500m below dam	Released at own capture site	1. 10 (5 from each site) Released at own capture site 2. 10 (5 from each site) Displaced at pools 500m below dam
Number of tracking days	37	43	30*
Study dates	16 March 2011 to 22 April 2011	19 May 2011 to 30 June 2011	15 August 2011 to 13 September 2011

*Due to the typhoon Nanmadol, no tracking records are available from August 27 to 29.

Fish capture and release locations

For the pre-dam removal phase, fish were collected upstream of the dam and deliberately displaced in pools about 500m downstream of the dam. Homing behavior and the barrier effects of the dam were observed by noting their daily locations. These fish were tracked from 16 March 2011 to 22 April 2011. The fish for the dam removal phase were caught downstream of the dam, tagged and released in areas near their

catch location. These fish were tracked from 19 May 2011 to 30 June 2011. Fish for the post-dam removal phase were collected at 2 different areas upstream from the dam. For each group, half of the fish were displaced in pools about 500m downstream of the dam for the contrast to pre-dam-removal phase, and the other half were released at capture site for reference. These fish were tracked from 15 August 2011 to 13 September 2011.

Sample size constraints

Protected by the Endangered Species Protection Acts, the sample size of any experiment involving wild Taiwan salmon is determined by the Council of Agriculture and Environmental Protection Administration. The sample size of this experiment was limited to 40 fish for the three phases. The Taiwan salmon tagged for monitoring in this study were collected from specific areas of Cijiawan River based on the experiment design (Table 1). To minimize possible wounds from the catching processes, angling was most frequently used, followed by gill-netting and electro shocking. Fish in this study were assumed to be adults as previous studies suggest that fish over 20 cm in fork length are adults (Day, et al., 1993). The majority of them showed no characteristics of sexual maturity, so their genders could not be identified by their appearance. The potential differences between genders are not discussed in this study.

Tagging

Individual fish were anaesthetized (FA100 eugenol; Tanabe Seiyaku, Osaka, Japan) and their total length and body weight recorded. A 1 cm incision was made on the ventral surface in a cephalic-caudal direction posterior to the origin of the pelvic fins. The transmitter (NTQ-2, Lotek Engineering, Newmarket, Ontario, Canada: 0.3 g in air, 10.0 mm long, 5.0 mm wide, and 3.0 mm high extended with a 18 cm antenna), previously sterilized in ethanol, was inserted into the body cavity above the pelvic girdle. The antenna was pushed through the abdominal cavity. The incision was closed using two independent permanent-silk sutures. The fish were marked externally with a red tag attached to the front of the dorsal fin for visual recognition in the field. The process was

kept under 5 minutes, fish were kept moist and 300 ml of water was injected into the branchia at minute 4 to help resuscitate the fish. After the implantation, fish were kept in storage barrels with an aerator for at least 24 hours to observe recovery of their swimming ability.

To extend the battery life, the signal burst interval was set at 10 seconds, which met the tag factory configuration limit and provided the longest possible interval for efficient field tracking. Because Taiwan salmon have been shown to have minimal nocturnal movement (Makiguchi, et al., 2009), an automatic 12-hour on/off switch mode was also set to extend the battery life.

Daily tracking

The tagged fish were released at designated locations, depending on the study phase and experiment design (Table 1). Locations of each fish were identified 1-2 times every day during each phase. There is some deviation in total tracking records among phases and individual fish depending on field conditions and the tag's battery life. Signals from the radio telemetry tag were received through a hand-held directional antenna. The locations of the samples were determined by manual bank-side tracking with two radio receivers (model SRX_400 and SRX_600; Lotek Engineering Inc.). The two trackers, walking along the stream bank, recorded the location and identification (ID) number of the radio transmitter where the strongest signal was received. The distances between different locations were calculated by GPS coordinates with a margin of error about 10m, depending on the satellite reception, or by previously tape-measured marks at certain areas. The accuracy of the manual bank side tracking was about 5m for the trackers to confirm the signal strength differences between locations. Movement was defined as the distance between different recorded locations.

At the end of each phase, all fish with live tags were attempted to be caught from the stream to surgically remove the implanted tags. A total of 9 fish were successfully retrieved and released back to stream after their tags were removed (4 fish of

pre-dam-removal; 3 fish of deconstruction; 2 of post-dam-removal). Among the retrieved fish, 2 of them were caught on the site unintentionally with non-functioning tags, and their final locations were then recorded for reference.

Data Pooling

To increase the sample size, radio telemetry tracking data from 2007 were pooled for the analysis of the general movement patterns for displaced and non-displaced fish. In August 2007, 10 Taiwan salmon, captured from Cijiawan River near the observation deck, were surgically implanted with radio telemetry tags. The implanted tags were bigger (NTC-3-2, Lotek Engineering, 1.1 g in air, 15.5 mm long, 6.3 mm wide, and 4.5 mm high) than tags used in 2011, but the weight was still less than 2% of the fish. After recovering from the surgery, half of the tagged fish were released at the location where they were captured, and the rest of them were released 770m downstream. During the 40-day tracking period, each fish had 120-145 tracking records, and a total of 541 significant movements (longer than 10m) were documented across 1,300m of barrier-free stream. Most of the non-displaced fish showed site fidelity right after their release; the 5 displaced fish showed some long range movement early after the release and became sedentary later.

Data analysis

Because each phase, including 2007 and 2011 data, had a slightly different numbers of tracking days, a 30 day period, divided into three 10-day periods, was chosen for analysis. The fish movement patterns are separated into three different metrics: average daily distance moved, total absolute stream distance covered, and for displaced fish, oriented return movement to capture site. To find the possible temporal change of fish movement pattern due to the acclimatization from tagging process, the differences between 3 periods of average daily distance moved and absolute stream distance

covered were tested. To eliminate the effect of some lost signals in the daily tracking record, mostly due to limited stream bank access in bad field condition such as hard rain and rising discharge, fish movement data in 10-day periods were averaged for tests of differences.

A different period length was chosen for the dam removal phase based on the deconstruction time table. Before the heavy machinery entered the stream channel on day six after the study period started, the tagged fish were predicted to have the same movement pattern as other non-displaced fish. However, the shockwave from the machinery, the sudden increase of sediment and suspended load in the flow, and the rapid morphological change could force fish below the deconstruction site responding to avoid any lethal impact and search for more appropriate habitat. Therefore, according to the dam removal project working time table, the tagged fish movement tracking records were divided into three periods: day 01-06, the no disturbance period; day 07-15, the active machinery period; day 16-43, the habitat recovery period. The fish average daily distance moved and total absolute stream distance covered for each period of the dam removal phase were compared to fish movement patterns of other non-displaced fish (pooled by 2011 phase 3 and 2007 data).

Temporal change of fish movement patterns were tested using analysis of variance (ANOVA). For each phase of the study, the temporal change of movement patterns among different 10-day periods was tested. If the earliest period differed significantly in daily distance moved and total absolute stream distance covered compared to any later period, the earlier periods were considered abnormal activity due to acclimatization from implantation surgery and sudden change of habitat. Because the same tagged fish were tracked multiple times during each period, the tracking records of the periods could not be considered independent. Therefore, ANOVA with repeated measures was used for the tests.

All non-displaced fish movement records, including the 2007 data, were analyzed to identify normal Taiwan salmon movement patterns. Independent t-tests were used to identify the homing behavior of displaced fish. In addition to average daily distance

moved and total absolute stream distance covered, the orientation of homing behavior of displaced fish is analyzed using binomial test for distinguishing between oriented and random directional movement.

Using only 2011 data, the effect of dam removal on Taiwan salmon movement patterns were examined by comparing fish movements from displacement downstream in Phase 1 with movements during dam deconstruction. Independent t-tests were used to compare differences of movement patterns between different phases of dam removal. To address the random effect of each individual fish, a generalized linear mixed-effect model (GLMM) was developed to find the likelihood factors that affect individual fish movement. GLMM with additional random-effect terms are often appropriate for representing clustered, and therefore dependent, factors such as data gathered over time on the same individuals. This model assumes normality of the random effects with mean 0 and a specified variance structure. The proposed mixed effects model is:

$$Y_{i,j} = \beta_0 + \beta_1 * 1_{\{\text{Phase 3}\}} + \beta_2 * 1_{\{\text{period 1}\}} + b_i + \epsilon_{i,j}$$

Where

- $i = 1, 2, \dots$, indicates each individual fish;
- j represents the days that have observations;
- $Y_{i,j}$ is the distance moved each day;
- β_0 is intercept, β_1 and β_2 are coefficients that the model will estimate;
- b_i is the random effects from fish movement
- b_i is normally distributed $b_i \sim N(0, \sigma_b^2)$ and independent
- $1_{\{\text{Phase 3}\}}$ and $1_{\{\text{period 1}\}}$ are indicator variables to indicate whether the data were in phase 3 (after dam removal), or in period 1 (day 01-10 after released) of phase 1 or 3;
- $\epsilon_{i,j}$ is the error term, $\epsilon_{i,j} \sim N(0, \sigma_\epsilon^2)$;
- there might be series correlation: $Cov(\epsilon_{i,j}, \epsilon_{i,j+1}) = \rho$, $Cov(\epsilon_{i,j}, \epsilon_{i,j+2}) = \rho^2$, ...

The indicator variables were introduced to GLMM to represent the dam removal project effect (changes before and after dam removal, β_1) and the acclimatization effect of releasing fish to different habitats (β_2). Significant estimates of the factors could indicate possible effects on fish movement patterns, and the positive/negative value would specify the relationship of the factor to fish movement.

Results

Tracking data

For the first phase of the study (pre-dam removal), 10 displaced fish (from upstream to below dam) were tracked daily for 38 days. Eight of the ten fish were tracked throughout the entire period. The signal from one fish (ID #46) was lost right after release and was never located by radio telemetry. However, at the end of phase one during retrieval of tagged fish, that fish was caught right below the dam. The final location of fish #46 was documented, but no movement data are available. Fish #47 was tracked for 13 days and then its signal was lost. It stayed at the release location for the first 5 days, and then moved 240m upstream to another pool. It remained at the same location till the signal was lost. However, it was caught at that pool later during the sample collecting for the phase two studies (dam removal) on May 12. For fish #47, only tracking data on the first 13 days were included in the analysis (Figure 2).

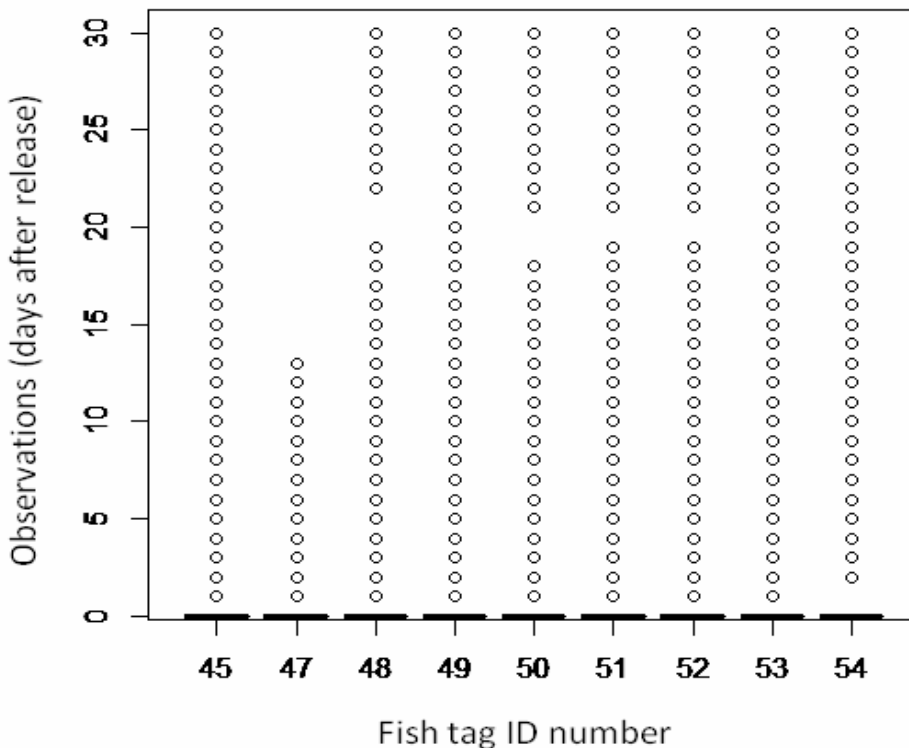


Figure 2 The observation days of tagged fish in phase 1

For phase 2 (dam removal), 10 fish were tagged and released back to their original location below the dam. Dam deconstruction started on May 23, 2011 with sediment placement on the right bank below the dam. This sediment was designed to protect the road above the bank with part of remaining dam structure. It also provided a temporary ramp for the heavy machinery to access the destruction site. The turbidity and suspended sediment load in the stream increased immediately with this sediment movement. Dam deconstruction was started on May 25 with a jack hammer removing the concrete block of the dam until the bed rock exposed. On May 31, the left half of the dam was completely removed, and the excavator went along the downstream channel for 100m to move any big concrete remains on the side to keep the flow fast for maximum sediment transportation. Although the rising turbidity during the deconstruction eliminated any in-stream visual contact, all ten fish were tracked with steady signals and in fixed locations without any downstream drifting pattern, which meant all tagged fish successfully avoided and survived the instant impact of deconstruction, including the rising turbidity, the sharp suspended concrete chunks, and the shock wave from machinery working in the channel. Most of the tagged fish were tracked 25 to 40 days, but fish #55 was lost on June 2 (Figure 3). After deconstruction, only 3 (#58, #59, #60) of the remaining 9 tagged fish stayed at their original locations. The other 6 fish showed upstream movements. Except for fish #56, which stopped at the new scour pool at the dam removal site, the other 5 fish (#57, #61, #62, #63, #64) showed very long distance movements (2,600m to 4,500m) to upstream habitat (Figure 4).

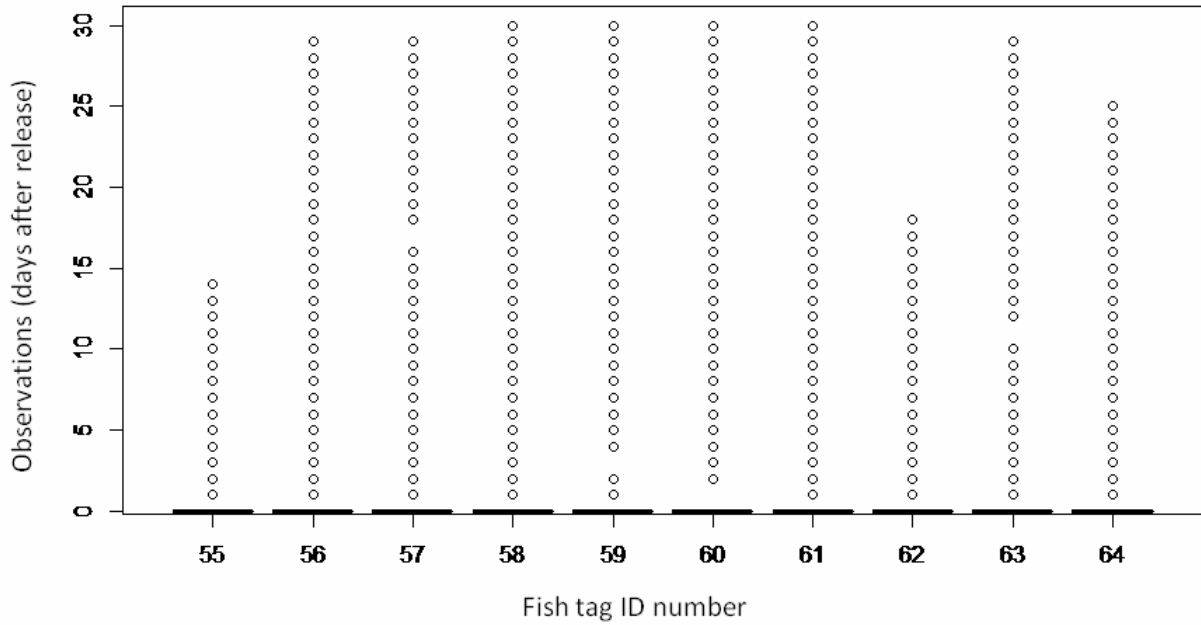


Figure 3 The observation days of tagged fish in phase 2

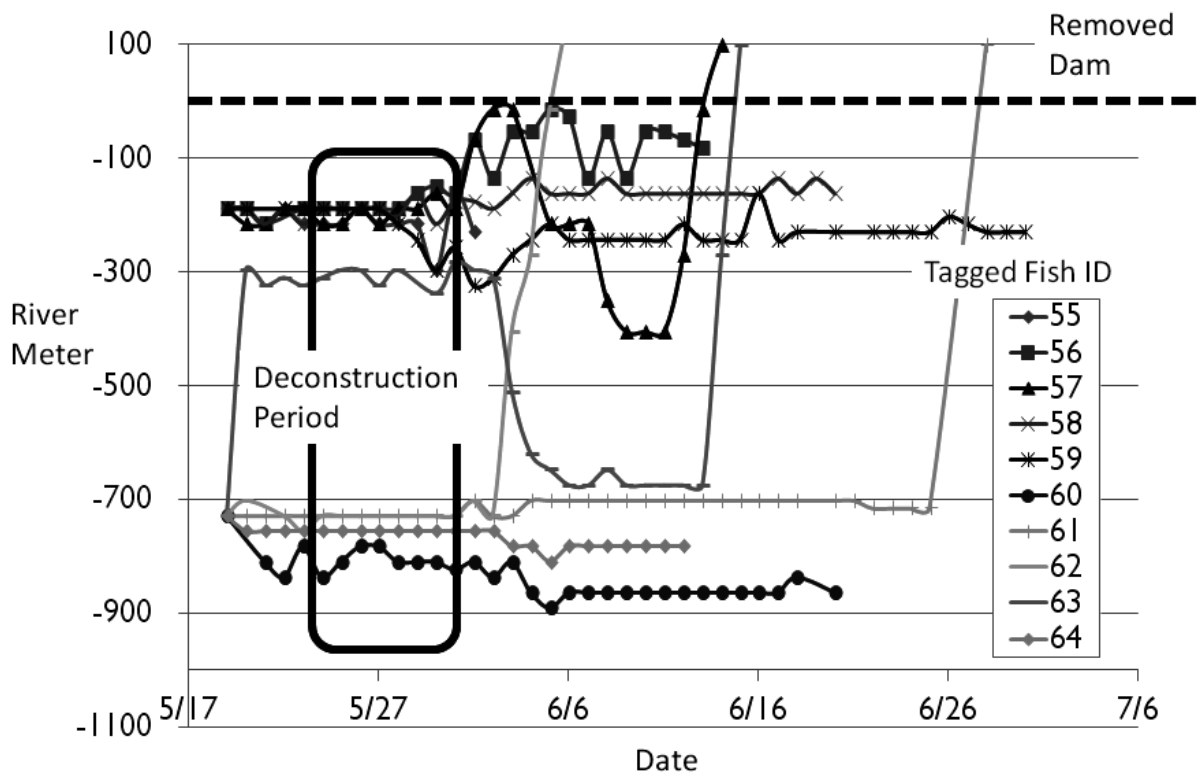


Figure 4 The daily location of tagged Taiwan salmon during deconstruction

For the last phase of the study (post-dam removal), 10 tagged fish were released at their capture site and another 10 below the removed dam. All tagged fish were tracked for 30 days. Some fish were not located during the first 5 days due to the long distances now available for movement that could not be covered by foot. Fish # 80 stayed at the displaced location for 5 days, then showed steady downstream movement and then lost its signal. The downstream drift may indicate fish mortality from the surgery process, and the tracking data from fish #80 were withdrawn from further analysis. Fish #71 also lost its signal after being located 4 times in the first 10 days. Although the few records showed some upstream movement of fish #71, due to possible tag malfunction, these data were not analyzed. On August 27 to August 30, typhoon Nanmadol hit southern Taiwan. The Wuling area only got a little over 100mm precipitation, but the rising flow in Cijiawan River made stream bank trails inaccessible during the typhoon period. Most of the fish (17 out of 18) remained at their location after the flood, which indicated that Taiwan salmon swimming ability could handle this amount of flow increase without being washed away (Figure 5).

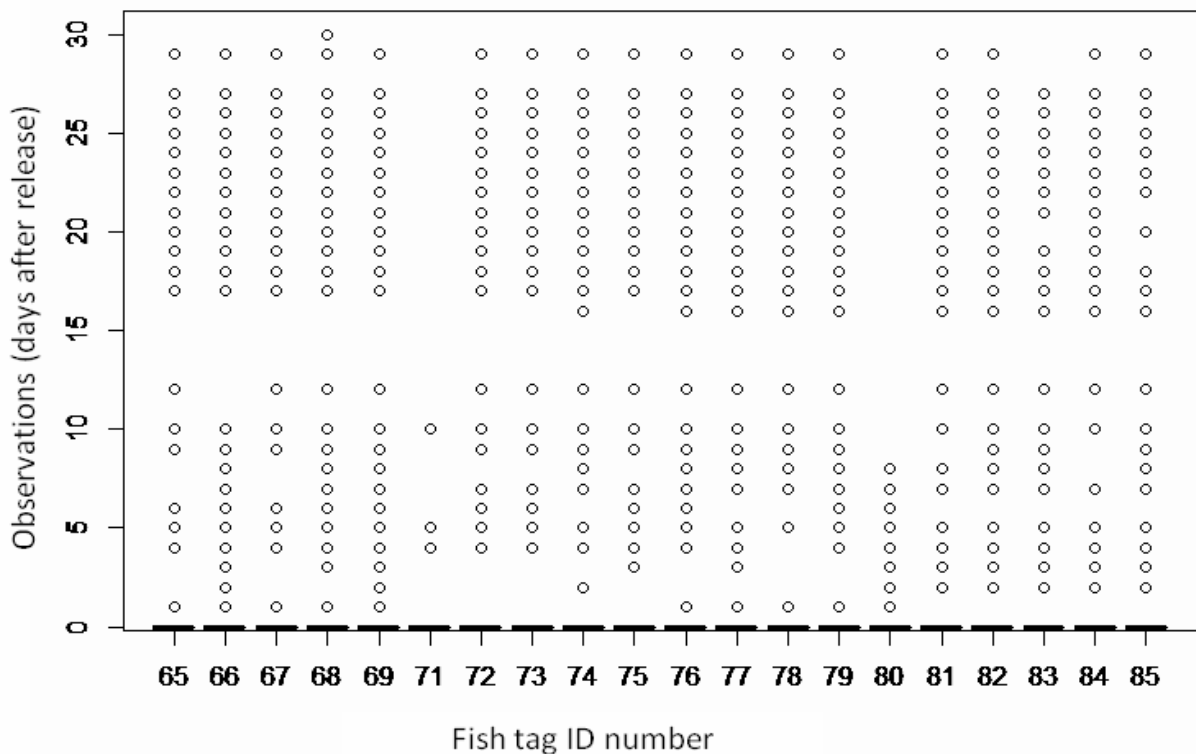


Figure 5 The observation days of tagged fish in phase 3

Movement of non-displaced fish

To analyze the movement pattern of Taiwan salmon, the non-displaced fish tracking records from both 2007 and 2011 were pooled. However, the data from the dam removal phase were eliminated because that movement might have been influenced by the sudden habitat disruption.

Among all non-displaced fish (N=14), the average distance moved each day declined from $76.58\text{m}\pm 70.36\text{m}$ in the first ten days, to $40.46\text{m}\pm 49.58\text{m}$ in days 20-30, and finally down to $10.73\text{m}\pm 9.03\text{m}$ in the last period (day 21-30; Figure 6). The repeated measures ANOVA test also confirmed that the average daily distance moved of non-displaced fish differed significantly between the 10-day periods ($p=0.003$). Individual differences between each time period were tested by paired t-test. Results showed that movement in the last period was significantly different from all other periods ($p=0.004$ to day 01-10, $p=0.039$ to day 11-20). Although decreasing by nearly 50%, the average daily distance moved during the second period, day 11-20, was not significantly different from the first period, day 01-10. In terms of average daily distance moved after released at the original capture site, the non-displaced fish did still temporally change their movement pattern. The average daily distance moved started to decrease 20 days after release. Due to the battery life of the radio telemetry tags used in this experiment, it was not clear whether the movement pattern after day 21 had already recovered to the previously observed routine sedentary pattern. However, the tracking results and the decreasing average daily distance moved still showed that non-displaced fish had a certain level of restricted movement and the daily distance moved of tagged fish could be influenced by the acclimatization from tagging procedures for early periods after release (Figure 6).

The total absolute stream distances covered by non-displaced fish between each 10-day period were analyzed too. The total absolute stream distance covered was defined as the widest range of stream habitat in river-meters over which the fish had ever appeared in a given period of time. Differing from the non-directional daily moving distance record reflecting fish daily activities, the total absolute stream distance covered could represent more about possible migration range or home territory. For all

non-displaced fish (N=14), the 10-day total absolute stream distance covered declined from 316.05m±381.91m during the first ten days, to 103.24m±130.57m in day 20-30, and finally down to 27.19m±19.59m in the last period day 21-30 (Figure 7). The total absolute stream distance covered was significantly different between the 10-day periods (repeated measures ANOVA with no sphericity, p=0.02). The paired t-test showed only the first period, day 01-10, was different from the last period, day 21-30, and the second period, day 11-20, differed significantly from the other periods (p=0.163 to first period; p=0.130 to last period). The results indicate that non-displaced tagged fish changed their movement pattern after being released to original habitat, regarding their gradually narrowing the total absolute stream distance covered among time. The decreasing trend and the relatively small range of total absolute stream distance covered for non-displaced fish showed the temporary influence from tagging and releasing procedures, and the restricted home range usage of Taiwan salmon (Figure 7).

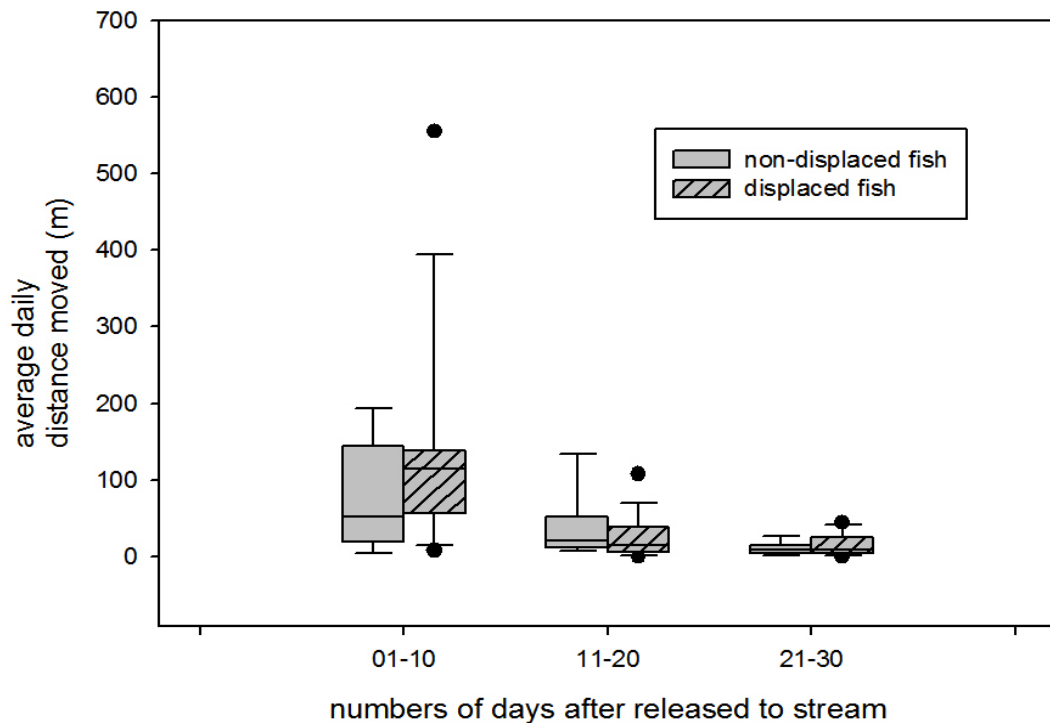


Figure 6 The average daily distance moved by displaced fish and non-displaced fish after release back to stream. Center line, Boxes, horizontal lines, and two outermost points indicate the median, 25% to 75%, 10% to 90%, and 5% to 95% percentiles respectively.

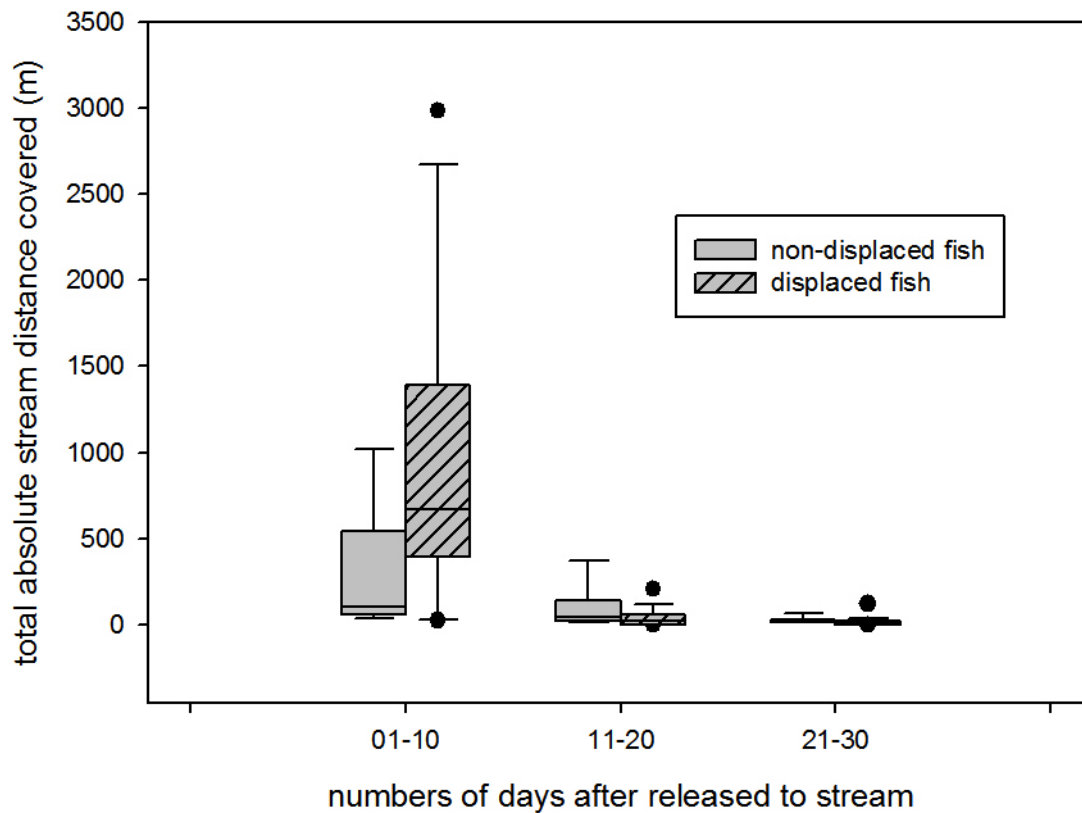


Figure 7 The total absolute stream distance covered of displaced fish and non-displaced fish after released back to stream. Center line, Boxes, horizontal lines, and two outermost points indicate the median, 25% to 75%, 10% to 90%, and 5% to 95% percentiles respectively.

Temporal movement pattern differences of displaced fish

To analyze the homing behavior of displaced Taiwan salmon, all displaced fish tracking records were pooled together, including the 2007 experiment and the 2011 phase 1 (pre-dam removal) and phase 3 (post-dam removal) data. Ten day periods were also used to eliminate the effects of some individual lost data, and the temporal movement pattern differences between periods. Both the acclimatization effect and homing return behavior could possibly alter the routine restricted movement pattern.

Among all displaced fish (N=23), the average daily distance moved declined from $146.54\text{m} \pm 144.46\text{m}$ in the first ten days, to $26.27\text{m} \pm 28.87\text{m}$ in days 20-30, and finally

down to $16.01\text{m}\pm 14.68\text{m}$ in the last period, days 21-30. The repeated measures ANOVA with no sphericity also confirmed that the average daily distance moved by displaced fish differed significantly between three 10-day periods ($p=0.001$). Individual differences between each time period were tested by paired t-test. The results showed that the average daily distance moved of all 10-day periods differed from each other (first period to second period $p=0.001$, and to last period $p=0.000$; second period to last period $p=0.006$) (Figure 6).

The total absolute stream distance covered of all displaced fish ($N=23$) were compared between different 10-day periods, too. The 10-day total absolute stream distance covered of displaced fish declined from $992.63\text{m}\pm 876.88\text{m}$ in the first ten days, to $40.11\text{m}\pm 53.52\text{m}$ in days 20-30, and finally down to $18.70\text{m}\pm 28.53\text{m}$ in the last period, days 21-30. The ANOVA with repeated measures and Greenhouse-Geisser correction of no sphericity showed the total absolute stream distance covered changed with different periods for displaced fish. The paired t-test showed the range of each individual period was different from any others (first period to second period $p=0.000$, and to last period $p=0.000$; second period to last period $p=0.003$) (Figure 7).

The results indicate that for displaced fish, the movement pattern in terms of average daily moving distance and total absolute stream distance covered in three 10-day periods were different from each other. Both the distance moved and habitat range significantly decreased with time. After longer moving distances at the beginning, displaced fish also changed to a more restricted movement pattern at later periods.

Homing return behavior of displaced fish

The displaced fish showed extensive movement especially during early periods after being released. To identify those movements as homing return behavior, the average daily moving distance and total absolute stream distance covered of displaced fish in three 10-day periods were compared with non-displaced fish in the same time periods. For each of three time periods (day 01-10, day 11-20, day 21-30), movement records from all displaced fish and all non-displaced fish were tested for differences using

independent t-tests.

For the first period, day 01-10, 1-tailed t-test showed that displaced fish had significantly larger daily average distance moved ($p=0.05$) and also larger total absolute stream distance covered ($p=0.005$) than non-displaced fish. For the second period, day 11-20, when both displaced and non-displaced fish showed decreased mobility, displaced fish moved less on a daily average in a pattern that did not differ from non-displaced fish ($p=0.277$). However, the displaced fish still had a wider habitat range during day 11-20 ($p=0.046$). For the last phase, the two fish groups showed the same movement pattern in terms of daily average distance moved ($p=0.234$) and total absolute stream distance covered ($p=0.334$).

For the orientation analysis, the final location of each displaced fish was used for identifying the homing behavior's direction. The tracking record showed 19 of a total of 24 displaced fish moved toward their original capture site. Assuming the probability of random direction toward either upstream or downstream is 0.5, the binominal probability result ($p=0.003$) showed that the direction of the homing behavior was not random. The comparison indicated that, after release back to the stream, displaced fish showed significant homing behavior during the first ten days by moving long distances toward their original capture sites.

Movement pattern differences between pre and post dam removal

To minimize systematic errors from annual environmental fluctuation, only 2011 tracking data were selected to compare movement pattern differences between pre and post dam removal. The non-displaced fish of phase 1 (pre-dam removal) and phase 3 (post-dam removal) exhibited limited movement around the original home range upstream from the dam site, so the removal might not have any effect on their movement patterns. Therefore, only displaced fish from phase 1 and phase 3 were compared to identify possible effects on fish movement pattern. The movement pattern was defined as daily distance moved and total absolute stream distance covered. The

daily distance moved records were analyzed with the customized GLMM, and the total absolute stream distance covered were compared between the two phases in 10-day periods.

All daily tracking and movement records of displaced fish in both phase 1 and phase 3 were input to the GLMM. Result showed a positive estimate of β_1 (66.61) with a relatively high t value ($t=3.469$). This indicates that whether the fish was in phase 3 or 1 affected the daily distance moved, and that fish tended to move more after dam removal than before dam removal. Although introducing a random factor usually leads to overestimated t values, the high t value of the result ($3.469 > 2.00$) still strongly suggested the estimate β_1 was significant. Also the positive estimate of β_2 (118.70; $t=6.023$) indicated that, after release back to the stream, fish tend to move more in days 01-10 than in other periods, which was consistent with previous results.

For the total absolute stream distance covered, the range of each 10-day period from phase 1 was compared to the same period from phase 3 with independent t-tests. The result showed that only in the first period, day 01-10, did displaced fish move a significantly ($P=0.000$) longer distance after dam removal. For second and third periods, displaced fish traveled through the same range of habitat before and after dam removal (period 2, $p=0.411$; period 3, $p=0.272$). Some of the displaced fish (#76, #77, #78, #79) at phase 3 were captured at further upstream habitats than the displaced fish of phase 1. Even with a smaller sample using only phase 3 fish (#65, #66, #67, #68, #69) captured at locations near to phase 1 displaced fish, the total absolute stream distance covered in the first ten days was still significantly larger after dam removal ($p=0.000$), and the other periods were still the same between different phases (period 2, $p=0.371$; period 3, $p=0.468$). The results indicate that, before dam removal, the homing behavior of displaced fish was limited by the barrier effect, and after dam removal, the displaced fish were then able to move a longer distance for their homing behavior.

Movement patterns in dam removal phase

The average daily distance moved during the no disturbance period in the dam removal phase was already low ($14.83\text{m}\pm 13.59\text{m}$). Compared to all other non-displaced fish, the average daily distance moved during the no disturbance period (day 01-07) in dam removal phase had less acclimatization effect and was significantly different ($p=0.012$) from the first 10-day period of pooled non-displaced fish. The fish moved in a pattern more similar to the steadier patterns of later periods of other non-displaced fish ($p=0.128$ to second period, day 11-20; $p=0.383$ to last period, day 21-30). The average daily moving distance during the period of working machinery (day 07-15) showed a similarly low movement pattern ($14.88\text{m}\pm 8.06\text{m}$), and also only significantly differed from first period of all other non-displaced fish ($p=0.012$ to first period, day 01-10; $p=0.119$ to second period, day 11-20; $p=0.260$ to last period, day 21-30). In the last habitat recovery period (day 16-43), tagged fish were observed to have some long distance movement after the deconstruction work was finished and natural processes took over channel recovery. The daily average distance moved of the habitat recovery phase rose to $117.38\text{m}\pm 143.96\text{m}$ and was significantly different from the last phase for all other non-displaced fish ($p=0.011$).

The total absolute stream distance covered of the no disturbance period in dam removal phase ($78.30\text{m}\pm 127.56\text{m}$) was not significantly different from other non-displaced fish ($p=0.072$ to first period, day 01-10; $p=0.646$ to second period, day 11-20; $p=0.151$ to last period, day 21-30). The fish were still limited to a small range of habitat during the active machinery period in the dam removal phase ($93.15\text{m}\pm 56.01\text{m}$). The pattern was similar to the first two acclimatization affected periods of the other non-displaced fish ($p=0.082$ to first period, day 01-10; $p=0.821$ to second period, day 11-20), but it was significantly different from the last more sedentary period ($p=0.000$). The long distance travel of tagged fish expanded the total absolute stream distance covered to $2185.44\text{m}\pm 2660.55\text{m}$, and was significantly different from any other habitat range using pattern of any periods for all other non-displaced fish ($p=0.016$ to first period, day 01-10; $p=0.007$ to second period, day 11-20; $p=0.006$ to last period, day 21-30).

Compared to other non-displaced fish in different study phases, the results indicated that fish during the early periods of the dam removal phase showed similarly restricted movement pattern, even more sedentary during the active machinery period with less daily movement. Once the deconstruction work was done and the new passage was clear, the fish made unusually long distance movements to leave their seriously degraded location.

Group differences and fish body weight

To detect the possible error from different sample groups, 10-day period fish movement patterns of non-displaced fish were analyzed in different capture groups (Figure 8); group 1 (2007 capture), group 2 (2011 capture near observation deck) and group 3 (2011 capture near old hatchery center). The ANOVA results showed that there were some significant differences among the three sample groups in their sedentary movement pattern. For average daily distance moved, significant differences were found in day 01-10 ($p=0.000$) and day 21-30 ($p=0.025$). For total absolute stream distance covered, significant differences were found in day 01-10 ($p=0.036$). However, the pair-wised t-tests for each two groups of periods with significant results, only group 2 in day 01-10 period was obvious differed from other two groups in average daily distance moved.

The result indicated that there were some possible systematic errors from different sample groups. Fish group 2 (2011 capture near observation deck) tended to move more often in early days after released. The other movement pattern differences between individual groups might be too subtle to detect. However, the small sample size and the possible inconsistent variance of movement records between groups might also affect the power of ANOVA test.

Since there was a significant difference in body weight between sample groups from 2011 ($173.83g \pm 21.45g$ for group 2; $119.38g \pm 13.04g$ for group 3; $p=0.002$), fish movement pattern was analyzed with their weight records. Pearson product-moment

correlation coefficient was used to measure the dependence between fish weight and movement pattern. The result showed for day 01-10, both average daily distance moved ($r=0.84$, $p=0.004$) and total absolute stream distance covered ($r=0.72$, $p=0.027$) were positively related to fish body weight significantly, while after day 11, fish weight did not relate to both movement pattern metrics anymore.

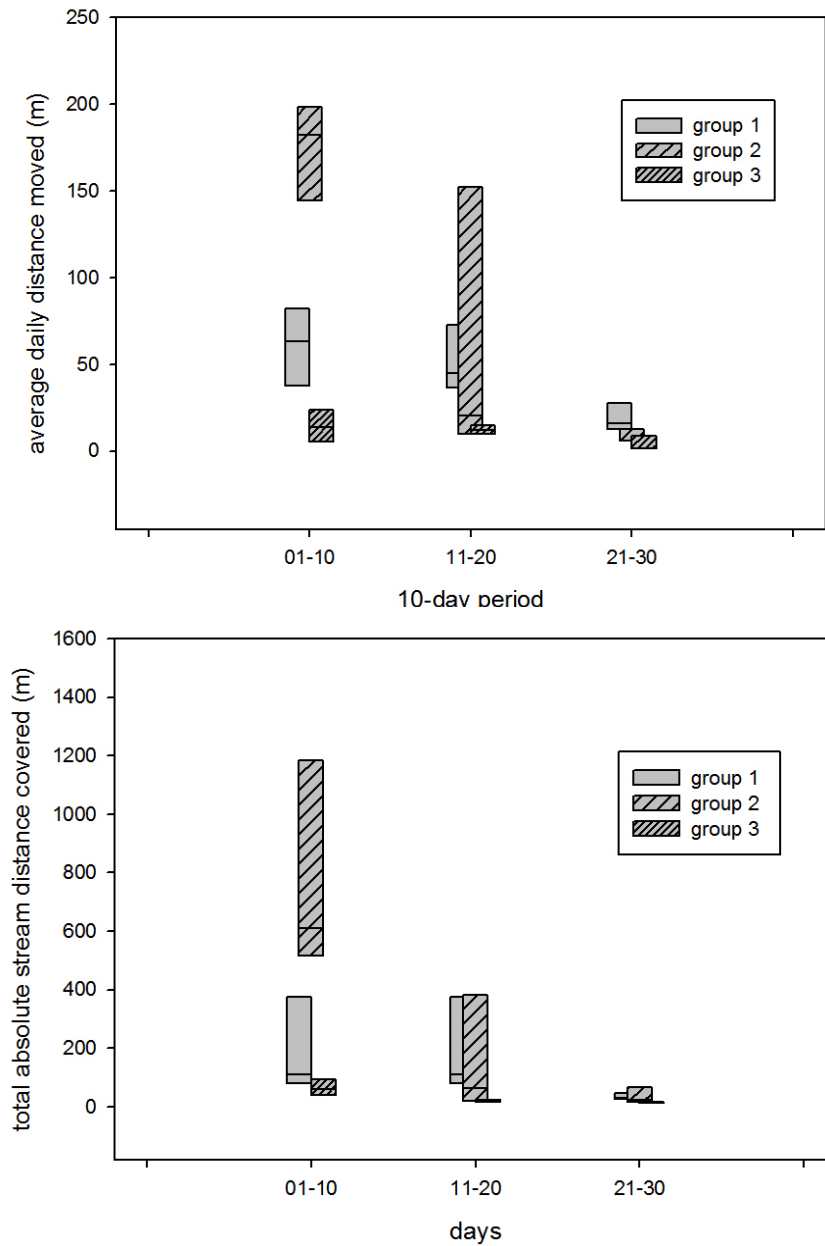


Figure 8 The movement patterns of difference sample groups in 10-day periods. The center line and the box indicate median and the total range.

Discussion

Sedentary pattern exhibited in pre and post dam removal phases

Acclimatization to a sudden change in habitat conditions influences fish movement patterns. For the non-displaced fish in this study, both daily average distance moved and total absolute stream distance covered significantly decreased with time after release back to stream following tagging procedures and recovery. After recognizing the placement as familiar original location, the tagged fish moved relatively small distances. The average 10-day total absolute stream distance covered of all non-displaced fish dropped from more than 300m during day 01-10 to less than 30m during day 21-30. The relatively movement range during last period was consistent to other freshwater salmonids daily movement ranges. Brown trout are found with a 15.6 m² home range for routine foraging behavior (Bachman, 1984) and red spotted masou salmon in Japan are found with home range less 20 meters along the stream (Nakano, 1990). However, even with the significant temporal changes of the movement pattern after release, the overall low average daily movement and small total absolute stream distance covered showed that Taiwan salmon do not often make long distance movement. The non-displaced fish still showed obviously restricted movement pattern.

For displaced fish, the movement pattern during the first ten days was influenced by not only the acclimatization effect of being transferred from hatchery tanks back to the stream, but also homing behavior. Compared to non-displaced fish, the displaced fish also significantly decreased both average daily distance moved and total absolute stream distance covered in later periods (day11-20, day21-30), and the patterns were not different from the patterns of non-displaced fish during the same periods. The changing movement pattern indicated that, for displaced fish, although they made significantly long distance movement to return their original home range, they became more sedentary and behaved like non-displaced fish with a month.

Due to the limits of battery life of the tag, it is not known if the final period of

observation represents the end of movement pattern change. With all battery saving features, the tags had a warranty battery life of 50 days out of the factory, but with an average 4.3% loss of battery life per month, the tags prepared at the beginning of the year could lose more than 30% of the battery life when used at the last phase of the experiment. Given the limits of tag battery life, the tracking records only confirmed the decreasing trend of fish average daily distance moved and total absolute stream distance covered. As a result, normal sedentary home range could not be estimated from this study.

Homing behavior and mechanisms

The displaced fish moved longer distances through longer sections of the stream to return their original home range during the first 10 days after release to the stream. The fish later returned to a sedentary pattern, with a significant decrease in daily distance moved and total absolute stream distance covered.

Anadromous salmonids are known for their ability to migrate long distances from their ocean stage back to their natal river for spawning. A precise navigation mechanism is required to successfully return to their specific destination. The olfactory homing mechanism has been regarded as one of the most important cues associated with the natal stream. Juvenile salmon learn odors of specific combination of chemicals associated with their home stream before seaward migration and use these odor memories for navigating through hundreds of kilometers as adults (Dittman, 1994; Hasler, Scholz, & Goy, 1983; Quinn, 2005). However, the homing behavior of displaced Taiwan salmon is within the same river and in a relatively short distance. Without major tributaries, the olfactory difference between upstream home range and downstream release site might be minimal. Unlike the voluntary seaward migration, displacement of Taiwan salmon, either by human for research purposes or due to monsoonal floods, is a random event. Travelling through abundant quality habitat without stopping or hesitation, the going-all-the-way-at-once pattern observed in this study indicates a precise recognition and navigation mechanism for Taiwan salmon to

successfully return to their home range. Further research is needed to identify the navigation ability and mechanism of Taiwan salmon homing behavior.

Habitat exploration pattern in dam destruction phase

While the displaced fish showed more site fidelity and habitat acclimatization in late periods of most study phases, the unusually late long distance movement of non-displaced fish in the dam removal phase was likely influenced by the severe habitat degradation caused by sediment release from the dam removal. The tagged fish showed restricted movement pattern during the active machinery period, possibly staying and hiding from the shockwave impact. When the dam was partly removed and a new passage was formed, the long distance movement in late deconstruction phase was more likely a habitat exploration pattern to a newly accessible habitat. Unlike the oriented homing movement with clear destinations of displaced fish, the new habitat exploring fish move across wide ranges of habitat in relatively short times. Passing some of the most pristine habitat, most of the fish from the destruction phase did not stop moving until they reached the next impassable barrier, Cijiawan #3 dam, almost 5km from their home range. The result showed that, when natal habitat is seriously degraded, Taiwan salmon show unusually intense movement and travel across a wide range of habitat before choosing another new habitat to settle.

Dam removal effectiveness

The GLMM results indicate significant increases in average daily distance moved in homing behavior of displaced fish after the dam removal. Along with significantly wider range of accessible habitat, the displaced fish had better chance to return their natal home range with the dam removal. The restoration of longitudinal connectivity is one of the most important ecological objectives for in-stream barrier removal projects. For the Cijiawan #1 dam removal project, the in-stream migration and the accessibility of upstream habitat to downstream populations were the main goals for restoring

longitudinal connectivity.

Stream restoration effectiveness evaluation usually needs long term monitoring to identify ecological responses that occur over time (Kondolf, 1995). Ecological responses to dam removal also occur over a range of time scales. Establishment of new equilibrium channel morphology can take decades, and the aquatic communities need to re-establish and adjust with the changing physical environment. However, some responses, such as upstream fish movements, previously blocked by the dam, can begin within days after removal (Hart, et al., 2002). The rapid response of Taiwan salmon in this study confirmed that the new passage of dam removal project could be utilized almost immediately.

Field work limitations

The relatively small sample size and tracking time scale limited the statistical power to identify changes in fish movement patterns. Due to the endangered situation of Taiwan salmon, the number of wild Taiwan salmon used in any research is regulated and needs to be approved by the authorities. Invasive procedures involved in this study, such as surgically implantation, made it more difficult to get permission due to potential mortality. The only habitat of existing Taiwan salmon, Cijiawan River, has been protected in Shei-Pa national park for more than 20 years. The strictly restricted access helped the once degraded stream habitat return to a healthier condition. Regrowth of the riparian forest made it difficult for manual foot tracking along the stream bank. With the wide range of possible habitat use for some phases and the low signal burst interval set to prolong the tag battery life, the tracking time scale of this study was limited to covering the entire 5km of the main experiment site once per day.

Due to often observing a fish only once per day, the daily movement record in this experiment might be under-estimated because Taiwan salmon are known to move from resting pools to nearby riffle area for foraging on a daily basis. However, because the feeding movements tend to be small and with a limited area (Makiguchi, et al., 2009),

the long distance movements, which were of major interest in this study to identify changes in movement patterns, could be observed with daily tracking. Although the temporal scale of one to two trackings per day of this experiment might have missed some short term small range movements, the sedentary pattern of Taiwan salmon and the change of movement patterns responding to anthropogenic displacement or dam removal project were confirmed by this study. This study highlighted the importance clearly identifying the ecological attributes of interest and selecting an appropriate temporal scale of field data collecting in advance, especially for radio telemetry tracking, which often has restrict limitation on instruments and field condition.

This study does not address on the movement pattern of Taiwan salmon in their spawning period when the species may exhibit different movement patterns. Also, outside of the spawning season, it is very difficult if not impossible to identify fish gender. Some other salmonids are known to have different movement patterns between genders. Some male salmonids are even observed to have significantly more movement than female within the new habitat after improvement of migration barrier, because of breeding opportunities (Anderson, 2006). Besides, Taiwan salmon is known as a temperature sensitive species preferring low temperature habitat, especially in spawning site selection for better incubation rate and embryonic development (Tzeng, 1999; Yang, 1997). The relationship between Taiwan salmon movement and the spatial and temporal temperature distribution pattern are not discussed in this study. Potential movement pattern differences for spawning behavior and between genders, and the role of temperature variation and longitudinal connectivity is an important aspect for future studies.

Possible error from different sample groups

Some systematic differences of fish movement patterns between different sample groups were observed from the daily tracking data. Systematic errors might come from different sample groups where fish were captured from different locations or at different seasons. However, both 2007 and 2011 tracking experiments were held in seasons that

are not the Taiwan salmon breeding season. The non-displaced data used for group difference analysis were both tracked in summer season. Therefore, the seasonal difference should not be the factor of the movement pattern difference between sample groups in this study.

The movement pattern of the fluvial form of masu salmon was known to be affected by its body size (Sakata, et al., 2005). Fish weight did differ between sample groups, and showed significantly positive correlation to fish movement in early periods after release. Considering the acclimatization effect, the more active movement pattern of stronger heavier fish might result from better recovery from surgical procedures and better swimming ability to explore introduced “new” (actually original capture site) habitat. Therefore sample groups with significantly bigger fish might have different movement patterns in early periods of the experiment.

Future restoration suggestions

This study confirmed the relatively sedentary nature of Taiwan salmon and existence of homing behavior if displaced. Although the actual range of routine movement patterns could not be calculated, the sedentary pattern of Taiwan salmon was observed. The homing behavior also demonstrates the need for stream accessibility of long distance movement, so the longitudinal connectivity restoration and stream migration barrier removal should be also prioritized for future restoration practices.

The unusual habitat exploration pattern showed Taiwan salmon’s rapid response to habitat alternation. For future stream restoration projects, or any other projects in the region that might influence stream habitats, the impact of short-term habitat alteration should be considered to avoid major population shift of Taiwan salmon. However, this study also showed that with appropriate design and precautions, Taiwan salmon can survive the temporary impact of short-term active machinery.

The effectiveness of Cijiawan #1 dam removal project was partially confirmed by the improved homing movements of displaced fish. Without major fish population

mortalities in Cijiawan #1 dam project, dam removal was shown to be a feasible measure for in-stream migration barrier improvement and longitudinal connectivity restoration in the sensitive habitat of Taiwan salmon. With impact assessment and proper precautionary measures, the removal of the rest existing dams on Cijiawan River could now be taken into consideration.

Only few attempts of using radio telemetry have so far been made in dam removal effectiveness evaluation studies. In this research, radio telemetry tracking and individual fish movement record was successfully used for identify the changes in fish movement pattern pre and post Cijiawan #1 dam removal. The importance of specific ecological objectives and corresponding monitoring works has been emphasized (Bernhardt et al., 2007; Palmer et al., 2005). This study demonstrated how a biological experiment designed for monitoring specific ecological objectives provided explicit information to evaluate a stream restoration project. Specific ecological objective setting and matching monitoring design should be part of any future fish conservation or habitat improvement projects, and sufficient sample size and adequate temporal and spatial scales of field experiments are suggested if possible.

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