

Taiwan salmon or salmon in Taiwan? Celebrating the 100th anniversary of the discovery of Formosa landlocked salmon

Francis Juanes¹  · Peter S. Rand² · Christopher P. Burridge³

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Formosa landlocked salmon (FLS), *Oncorhynchus formosanus*, is a Critically Endangered species (IUCN Red List, Kotlatal 1996) native to Taiwan and only remaining in a small mountain stream, Chichiawan Stream in Shei-Pa National Park (Yan 2000). The species is at a critical crossroads; it is facing a variety of threats including small population numbers, fragmented habitat due to damming, invasive species, and climate change. It is thought that FLS originally migrated south from the Sea of Japan when ocean waters were cooler than they are today (Numachi et al. 1990; Gwo et al. 2008; Gwo 2019a). They inhabited one river system, the Tachia River, and became landlocked when sea level rose. It is now relegated to small populations between flood and erosion control dams. Conservation strategies will depend on how the authorities answer the question posed in the title of this paper; do they want to conserve FLS as a distinct taxonomic entity with the likelihood that it will go extinct given its limited genetic variability, or should they perform genetic rescue, thereby bringing in new genetic material from a different species/subspecies to increase genetic variability but risking the unique status of FLS?

Professor Jin-Chywan Gwo, from the National Taiwan Ocean University (NTOU, Taiwan) convened an international symposium, 11–12 November 2017 at the National Taiwan Museum (NTM) in Taipei, to celebrate the 100th anniversary of the discovery of the FLS in 1917 by a Japanese scientist (Takeo Aoki; Japan had colonized Taiwan during that time). The objectives of the symposium were to provide an update on the status and biology of the species, review what is known about the masu complex from which

FLS originated, and formulate potential conservation strategies for recovery.

FLS is part of the masu complex centered in Japan, *Oncorhynchus masou* sensu lato, which includes 3 other species/subspecies (masu, Biwa, and amago salmon). Morphological and meristic data suggest species-level differences for FLS (Chang and Gwo 2009; Gwo 2019b; Ho and Gwo 2019), as do most genetic studies (Numachi et al. 1990; Gwo et al. 2008; Chang et al. 2009; Hsu and Gwo 2010; Hsu et al. 2010). Agreement on species or subspecies level designation appears a stumbling block for the conservation of FLS. A similar situation exists for Biwa salmon, a small population restricted to Lake Biwa in central Japan (one of the oldest in the world). Despite strong differences between Biwa and the other subspecies, there is still debate about its species designation (some of it occurring before the symposium), and, as a consequence, it has not yet been formally named.

Before the opening of the symposium, an international workshop was held to discuss the ‘Successes and Challenges in the Conservation of Pacific Salmon in the 21st Century’ on the campus of NTOU in Keelung, on the coast north of Taipei. Professor Gwo opened the symposium with a review of lessons from the conservation of FLS which highlighted potential reasons for the recent decline in its abundance in Taiwan. Next, Peter Rand (Prince William Sound Science Center and Chair of the IUCN Salmonid Specialist Group) reviewed the status of salmon appearing on the IUCN Red List, including FLS. The following talk by Sergei Zolotukhin (Pacific Fisheries Center, TINRO, Khabarovsk, Russia) reviewed the biology and distribution of masu salmon on the northern part of its range, a region that has been poorly studied to date. Next, Kentaro Morita (Hokkaido National Fisheries Institute, Japan) broadly reviewed ontogenetic changes in thermal habitat of Pacific salmon, suggesting strong potential effects of rising temperatures. Francis Juanes (University of Victoria, Canada) next summarized the status and conservation of Pacific salmon in Canada. Finally, Kazumi Hosoya (Kindai University, Japan)

✉ Francis Juanes
juanes@uvic.ca

¹ Department of Biology, University of Victoria, Victoria, BC, Canada

² Prince William Sound Science Center, Cordova, AK, USA

³ School of Natural Sciences, University of Tasmania, Hobart, TAS, Australia

ended the workshop with a presentation highlighting a new approach for the conservation of FLS that incorporates both “ex-situ preservation” and “in-situ conservation”.

That evening the anniversary was celebrated at a cultural event at the NTM in Taipei. The events were hosted by Dr. Gwo and Dr. Shieh (NTM). The evening started off with a short play performed by students from the National Changhua Senior High School, recreating the events of the discovery of FLS, its description by Dr. Masamitsu Oshima, and the aftermath. Next, Taeko Oshima, a renowned concert pianist based in Switzerland and granddaughter of Masamitsu Oshima, performed 4 solo piano pieces including Schubert’s ‘The Trout’. The evening ended with a performance of Taiwanese folk songs by William Lin and friends.

The next morning delegates were welcomed by the NTM’s Director, followed by an address from Dr. Masanobu Oshima, a noted Japanese cancer researcher and grandson of Masamitsu Oshima, recounting his grandfather’s scientific legacy. It also included a remote-recorded welcome from Tomoo Oshima (Dr. Oshima’s father and Masamitsu Oshima’s son), an emeritus professor at the Yokohama City University School of Medicine.

The scientific part of the symposium began with Professor Gwo’s keynote talk summarizing the natural history and conservation of the FLS in Taiwan and opening the session on ‘Recent progress on conservation of FLS’. The talk included results of recent work on phenotypic anomalies found in FLS in Chichiawan Stream. Next, Ho (National Museum of Marine Biology, Taiwan) spoke about the history and nomenclature of the FLS and suggested that the species name *O. formosanus* is the only valid name for FLS. The next three talks focused on the long-term ecological history of FLS and possible theories for their origin in Taiwan. Lee (Institute of GeoSciences, NTOU) suggested that FLS likely migrated from Japan during one of the glacial periods in which the Kuroshio Current changed directions, colonising Taiwan through one its many rivers. However, the rapid uplifting of the Island over the last million years (1–3 cm/year) led to their habitat becoming landlocked. Shieh (NTM) provided potential mechanisms for the current distribution of FLS restricted to the upper reaches of the Tachia River, as these were the only systems where temperatures remained cool enough for FLS survival and anadromy ceased once the glaciers subsided. Yang (Providence University, Taiwan) followed with a talk proposing that the present distribution of FLS can be explained as a function of the existence of a dammed lake upstream of the Tachia River. FLS were migratory and used the upper reaches to spawn, which explains why some fish have retained the hook nose morphology and cherry spawning color. Lin (National Taiwan Normal University) followed with a talk describing the resilience of Taiwanese ecosystems to the frequent typhoon disturbances including stream systems and their fish fauna. Chen

(Tunghai University, Taiwan) spoke about the feminization of freshwater fish, including FLS, due to endocrine disrupting compounds which are ubiquitous chemicals found in many aquatic systems. The final talk of the opening session delivered by Cheng (National University of Tainan, Taiwan) focused on five basic principles for the conservation of FLS based on environmental ethics.

The second session, focused on ‘The status of *O. masou*: an update’, opened with a keynote talk by Rand who spoke about the need for a range-wide status assessment of masu salmon using IUCN criteria, and some the challenges posed in conducting a red-list assessment for the species. Zolotukhin followed with an overview of the biology and distribution of masu salmon in its spawning range in the Amur River basin in the Russia Far East. The current status of the population is low relative to historic levels. Commercial fisheries for the species are banned, but subsistence and sport fishing continues at low levels where it is still a valuable trophy species. In the second session, talks focused on the biology and status of Japanese masu salmon populations. Yamamoto (National Research Institute of Fisheries Science, Japan) examined the genetic population structure of masu salmon subspecies across its range using microsatellite and mitochondrial DNA markers, finding limited variability except for Biwa salmon, with only a single-base difference between FLS and either masu or Amago. Iwatsuki (University of Miyazaki, Japan) found evidence for all four subspecies when examining the genetic structure of the *O. masou* complex in the southernmost Japanese population from Kyushu Island. Morita reviewed the life history diversity of masu salmon with an emphasis on iteroparity in resident forms. The migrant forms of masu salmon are semelparous, but the stream resident forms are iteroparous for both sexes in contrast to what is known about other Pacific salmon species. Kitanishi (Oita University, Japan) found that genetic diversity was positively correlated with the effective number of breeders, but negatively with elevation in masu salmon populations in the Aotsuta River, Hokkaido. No correlations were found for river length, gradient or any other environmental factor. The last talk of this session and the first day was by Hosoya who introduced the idea of a metapopulation as an ‘ichthyological conservation unit’ for freshwater fishes and highlighted the differences between ‘in situ’ and ‘ex situ’ protection as a framework for preservation vs. conservation management decisions.

The second day of the symposium was focused on anthropogenic threats and genetic conservation. Juanes gave a keynote talk to open the session on ‘Dam removal and its potential impacts’ by giving an overview of the ecosystem effects of dam removal with particular focus on recent large-scale dam removals in the Elwha River, USA. Next, Tsuboi (Japan Fisheries Research and Education Agency) spoke about the strategies for the conservation of isolated salmonid

populations, particularly masu salmon and white-spotted charr (*Salvelinus leucomaenis japonicus*) in the Fuji River, Japan, with implications for FLS in Chichiawan stream. Umatani (Hokkaido University, Japan) followed describing a study where habitat restoration for masu salmon in Japan was accomplished by installing fishways on erosion control dams that allowed salmon to migrate and reproduce upstream. The potential threat of continuously increasing introduced rainbow trout (*Oncorhynchus mykiss*) on native salmonids including masu was explored by Sahashi (University of Tokyo, Japan). Next, Miyamoto (Hokkaido National Fisheries Research Institute, Japan) showed that hybrid (farmed female x wild male) masu salmon had higher survival than farmed salmon in a semi-natural stream likely due to differences in foraging behavior. The final session on ‘Genetic recommendations for the conservation of FLS’ began with Hasegawa (Hokkaido National Fisheries Research Institute, Japan) who summarized results of a study showing that growth of stocked hatchery masu salmon was lower than their wild counterparts due to density-dependent competition leading to depressed food intake rates. The keynote talk in this session was by Burrige (University of Tasmania, Australia) who spoke about changing perspectives on the risks of outbreeding depression when using genetic rescue to conserve and recover genetically depauperate populations. Yada (National Fisheries Research Institute, Japan) followed with a talk describing seawater adaptability of Hon-Masu, a population of masu salmon which was artificially introduced to Lake Chuzenji about 100 years ago. In contrast to other landlocked masu populations, Hon-Masu have retained a parr–smolt transformation and seawater adaptability. Ohkuma (National Fisheries Research Institute, Japan) then presented a proposal for conservation of masu salmon in Japan, concluding that rather than artificial enhancement, better results can be obtained by improving and enlarging reproductive habitat. The final talk by Kuwahara (Lake Biwa Museum, Japan) presented results of a feeding study on Biwa salmon, another masu subspecies. Biwa salmon primarily feed on amphipods, but diets vary seasonally and can include small prey fish.

After the symposium, most of the delegates traveled to Shei-Pa National Park and managed to observe FLS in the Chichiawan Stream. Speakers then formulated a consensus statement that suggested that there is urgent need to reassess the status of FLS on the IUCN Red List and several management actions were strongly recommended. These included continued need for basic ecological information (e.g., growth, feeding and behavior); examination of possible negative interactions of FLS with shovel-jaw carp (*Onychostoma barbatulum*), a colonizing species introduced into FLS habitat due to the destruction of downstream flood and erosion control dams; analysis of the cause of a phenotypically abnormal (large head with pronounced hook jaw) mature

male FLS found in Chichiawan Stream; and investigation of hatchery practices particularly in relation to genetic variation and the co-culture of other potentially invasive species such as rainbow trout.

In conclusion, we express genuine concern over the long duration of inaction and mismanagement, and, along with the speakers and as reflected by the consensus statement, suggest that each of these tasks is an urgent priority. As a first step, work is now underway on an IUCN Red List reassessment of FLS. We hope that the Taiwan Government will listen for the sake of its globally significant Formosa landlocked salmon.

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