Technical contribution

Weight-length relationships of 14 species of icefishes (Salangidae) endemic to East Asia

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Summary

Length-weight relationships (LWRs) of 14 species from 17 populations of salangids, which cover most species in the family Salangidae, were analyzed from 12 regions in China and Japan. A total of 952 specimens were used to estimate the relationship parameters. The allometric factor b values varied from 2.56 in *Salanx cuvieri* to 3.53 in *Neosalanx oligodontis*. Additionally, the condition factor a value was calculated setting b = 3 in the remaining six species. Nine maximum-size records and 17 LWRs of salangids are established for the first time, which will fill in some of the empty spaces on rare neotenic species in the Fishbase.

Introduction

The Salangidae family compose six genera and approximately 17 species. They are endemic to Eastern Asia and mostly found in the coastal waters off Sakhalin, Vladivostok, Japan, the Korean Peninsula, mainland China, and northern Vietnam, as well as inland lakes and out-flowing rivers in China (Cheng and Zheng, 1987; Kim and Park, 2002; Nelson, 2006). Many species in this family were commercially exploited throughout much of their habitats before 1990s, and formed important parts of inland catches in the Yangtze and Pearl River basins in China.

The salangids are neotenic or paedomorphic fish, having cylindrical and elongated bodies and cartilaginous endoskeletons. Aside from a miniaturized body size, they also have innate biological characteristics, referred to as extreme 'r-selected' species, such as early maturation, relatively high fecundity, and a life span of less than one year (Roberts, 1984; Nelson, 2006).

Species identification is extremely scarce for paedomorphic fishes (Hanken and Wake, 1993). The taxonomy of salangids has remained a matter of considerable dispute because of their neotenic or paedomorphic features (Fang, 1934; Zhang, 1987) as well as high complexity and heterogeneity in habitats (Zhang et al., 2007; Zhang, 2008). From 2003 to 2011, we conducted a series of taxonomic and population genetic research on salangids to uncover some of the most important relationships within the family Salangidae (Zhang et al., 2007; Zhao et al., 2008, 2010). Taxonomic revision was also carried out based on phylogenetic relationships and genetic distance, taking into account some key morphological characters. Previous studies not only ensured accurate species identification for the family Salangidae but also provided samples for the present study.

Currently, icefish resources have seriously declined around the world. Therefore, we attempted to present strategies for strengthening basic studies on their biology and ecology. Weight-Length (W-L) relationship was estimated by fitting an exponential curve, $W = aL^b$ (Ricker, 1973). This measurement is the most essential information on fish biology and fishery stock assessment. The present study aimed to provide basic information on the W-L relationship of a group of rare neotenic species in the family Salangidae in order to protect the fish and to fill in the empty spaces in the relationships presented in FishBase (http://fishbase.sinica.edu.tw/Summary/FamilySummary.php?ID = 82).

Materials and Methods

Samples were collected with a salangid trawl of 1 mm to 2 mm mesh in 12 regions in China and Japan (Fig. 1; 21°00′–41°00′N, 100°00′–142°00′E) between November 2003 and January 2011. The samples were deposited in the fish collection of the Museum of the Zoological Institute, Chinese Academy of Science (ASIZB). The specimens were preserved in 10% solution of buffered formalin for the consequent sorting, identification and measurement. Prior species identification followed by Wakiya and Takahasi (1937) and Zhang (1987) were followed, using a correction proposed by Zhang et al. (2007). In order to ensure accurate species identification for the neotenic family, morphology-based species identification was further confirmed by DNA barcodes.

Two salangids, *Hemisalanx prognathus* and *Neosalanx jordani*, were too rare to collect during the study period; thus, we used previous deposit samples from the ASIZB. All specimens were measured to the nearest 0.01 cm for total length with a digital micrometer and to the nearest 0.01 g for total weight using a digital electronic balance. No significant difference could be found in the external morphology between the two sexes of these fish, except a line of anal scales in mature males. Thus a combined-sex data was used in the analysis. Based on the study of Froese (2006), the values of log W were plotted to that of log L in each species to identify and remove the outliners before determining the length-weight relationships (LWRs).

A widely used relationship equation between length and weight is the power function: $W = aL^b$, where W is the total weight in grams and L the total length in centimeters (Rick-
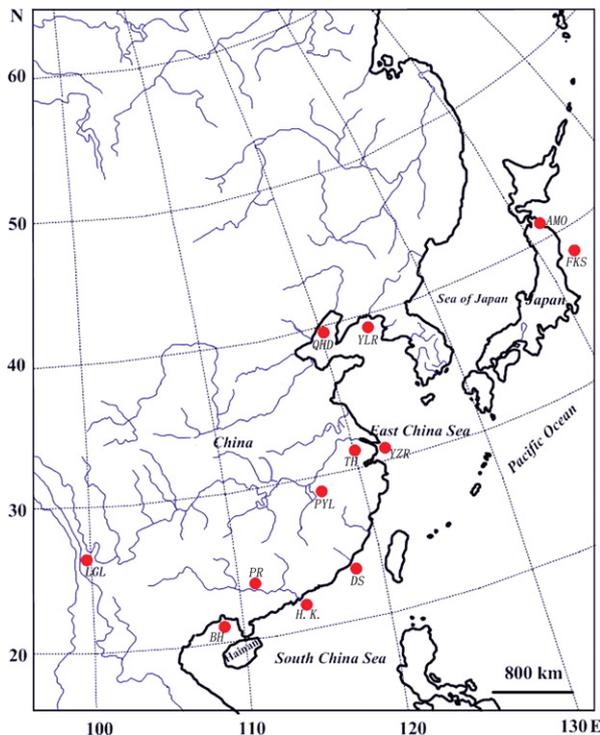
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Fig. 1. Sampling location of Salangidae species analyzed in the present study. AMO, Aomori, Japan; FKS, Fukujima, Japan; LGL, Lugu Lake, China; TH, Taihu Lake, China; H.K., Hongkong, China; QHD, Qinhuangdao, China; DS, Dongshan, China; PR, Pearl River, China; YLR, Yalu River, China; BH, Beihai, China; PYL, Poyang Lake, China; YZR, Yangtze River, China

er, 1973; Mendes et al., 2004). The function can be converted into the logarithmic equivalent $\log W = \log a + b \log L$, where a is the regression intercept and b the regression slope. The coefficient of determination R^2 was used as an indicator of the quality of the linear regression. In this study, the degree of association between W and L (or log W and log L) was evaluated by R^2. Statistical analysis was considered significant at P < 0.05.

Additionally, most deviations from b = 3 stem from narrow length ranges or narrow sample sizes (Carlander, 1977; Froese, 2006). The coefficient a was directly determined from $a = W/L^3$ by setting $b = 3$ and calculating geometric mean a when necessary.

Results and Discussion

In this study, 952 individuals from 17 populations belonging to 6 genera and 14 species were measured. *Neosalanx tangkahkeii* and *Protosalanx chinensis*, based on their strong ecological adaptability, comprised the marine and freshwater populations, whereas *P. chinensis* included an introduced population (Table 1; and Fig. 1).

According to Zhang et al. (2007), *N. tangkahkeii*, *N. taihuensis* and *N. pseudotaihuensis* are synonyms. Furthermore, *Neosalanx* sp. endemic to South China is regarded as a new species (Zhang et al., 2007). Detailed information including collection locality, sample size, length and weight ranges, LWRs parameters, as well as the 95% confidence interval (CL) of a and b and the determination coefficient (R^2) are summarized in Table 1.

Sampling sizes ranged from 16 for *Hemisalanx brachyrostralis* to 197 for *Neosalanx anderssoni*, indicating that most of the species had adequate sample sizes (more than 30 individuals) for analysis. The a values ranged from 0.00015 for *Salangichthys microdon* to 0.01538 for *S. ishikawae*. The b values ranged from 2.24 for *S. ishikawae* to 4.49 for *Neosalanx* sp. from GuangXi. The R^2 values ranged from 0.892 for *S. ariakensis* to 0.978 for *N. anderssoni* (Table 1).

Bagenal and Tesch (1978) indicated that the range of b values usually encountered in fish is between two and four. Froese (2006) further confirmed that the exponent b should normally fall between 2.5 and 3.5. The present study results were consistent with those observations (Table 1). The b values of nine species (64.3%) were within the normal range of 2.5–3.5, however, three species (21.4%) had b values >3.99 in which *Neosalanx* sp. from Guangxi showed the highest b value at 4.49. Two species (14.3%) had b values <2.5, with *S. ishikawae* having the lowest at 2.24. We further set $b = 3$ and calculated geometric mean a in the five species mentioned above (Table 1).

Previous studies showed that fishes usually undergo several distinct stages of growth in their early development, manifesting a rather abrupt change in structural and/or physiological occurrences. Corresponding b values vary by a large amplitude during this period (Safran, 1992; Hang and Chang, 1999). As mentioned previously, salangids possess neotenic features, which seldom occur in fish. Their miniature bodies lack some features in structure and morphology typically observed in adult fishes, and their annual life cycles result in very fast maturation and a simple population structure. The variability of b values observed in the Salangidae might be caused by their innate biological characters, such as neoteny, however, further detailed studies are necessary.

Three species in the family Salangidae, namely, *Hemisalanx brachyrostralis*, *Salanx ariakensis* and *Neosalanx anderssoni* are on the Chinese and Japanese Red Lists, respectively (Zhang, 2008). However, the basic information on the family Salangidae is very limited. All salangids are catalogued as 'Not Evaluated' or 'Data Deficient' in the International Union for Conservation of Nature (IUCN) Red List Status, and they have no LWR records in FishBase. Our study provides LWRs for 14 species from 17 populations of the family Salangidae, widely distributed in Asia. Compared with Fish-Base, this study produced new records of maximum total lengths for eight species: *Neosalanx anderssoni* (11. 49 cm), *N. tangkahkeii* (7.46 cm for a marine population and 7.93 cm for a freshwater population), *N. argentea* (4.75 cm), *N. oligodontis* (6.76 cm), *Neosalanx* sp. (3.19 cm), *Salanx prognathus* (13.87 cm), *Hemisalanx brachyrostralis* (13.62 cm), and *Salanx ariakensis* (14.75 cm), The measurements for *N. argentea*, *N. oligodontis*, *Neosalanx* sp. and *H. brachyrostralis* are the first data ever reported for these Salangidae species.

On the other hand, *Protosalanx chinensis* and *Neosalanx tangkahkeii* have been widely introduced into lakes or reservoirs in China since the beginning of the 1980s to counteract the declining natural resource of salangids and form new populations in the transplanted area. Table 2 summarizes the estimated parameters of LWRs for the populations typically introduced in China. As shown in Table 2, the investigations covered geographic, seasonal, and inter-annual variations. Therefore, it is appropriate to discuss isometric versus allometric growth of the species (Froese, 2006). The b values are all within the normal range and R^2 values >0.99 in these

Table 1
Descriptive statistics and estimated parameters of the length-weight relationships for the 14 *Salangidae* species

Species	Collection locality	Sample size	Length (cm)		Weight (g)		95%CI of a	a	95%CI of b	b	R^2	a*
			Max	Min	Max	Min						
Salangichthys microdon (Beeker, 1860)	Aomori (AOM), Japan	22	6.09	4.61	0.36	0.11	0.00003~0.00026	0.00015	3.849~4.750	4.30	0.956	0.00132
Salangichthys ishikawae (Wakiya & Takahashi, 1913)	Fukujima (FKS), Japan	21	6.27	5.17	0.92	0.61	0.00604~0.2444	0.01538	1.890~2.583	2.24	0.912	0.00400
Protosalanx chinensis (Basilewsky, 1855)	Lugu Lake (LGL), China (introduced population)	19	10.48	6.84	2.93	0.74	0.00019~0.00473	0.00246	2.631~3.479	3.06	0.923	—
	Taihu lake (TH), China (Freshwater population)	51	14.02	9.36	8.48	2.20	0.00128~0.00247	0.00188	3.031~3.295	3.16	0.968	—
	Hongkong (H.K.), China (marine population)	70	10.00	2.99	2.67	0.08	0.00029~0.00148	0.00088	3.263~3.682	3.47	0.932	—
Neosalanx anderssoni (Rendahl, 1923)	Qinhuangdao (QHD), China	197	11.49	3.70	5.94	0.15	0.00330~0.00448	0.00389	2.748~3.058	2.90	0.978	—
Neosalanx tangkahkeii (Wu, 1931)	Dongshan (DS), China (marine population)	96	7.46	2.32	1.81	0.03	0.00250~0.00374	0.00312	2.709~3.432	3.07	0.940	—
	Taihu lake (TH), China (Freshwater population)	146	7.93	2.37	2.30	0.01	0.00173~0.00300	0.00237	2.969~3.705	3.34	0.950	—
Neosalanx argentea (Lin, 1932)	Pearl River (PR), China	18	4.75	2.73	0.31	0.03	0.00009~0.00102	0.00056	3.413~4.571	3.99	0.940	0.00209
Neosalanx jordani (Wakiya & Takahashi, 1937)	estuary of Yalu River (YLR), China	26	5.25	2.93	0.31	0.03	0.00012~0.00184	0.00098	2.903~4.035	3.47	0.913	—
Neosalanx oligodontis (Chen, 1956)	Taihu lake (TH), China	105	6.76	2.52	0.76	0.03	0.00073~0.00132	0.00102	3.354~3.701	3.53	0.927	—
Neosalanx sp.[a]	coastal water off Guangxi, Beihai (BH), China	27	3.19	1.88	0.13	0.01	0.00030~0.00105	0.00068	3.984~4.995	4.49	0.948	0.00305
Salanx prognathus (Regan, 1908)	estuary of Yalu River (YLR), China	40	13.87	10.79	4.88	2.30	0.00057~0.00293	0.00175	2.732~3.270	3.00	0.922	—
Hemisalanx brachyrostralis (Fang, 1934)	Poyang Lake (PYL), China	16	13.62	10.95	4.69	1.97	0.00003~0.00100	0.00052	3.120~3.856	3.49	0.967	—
Salanx ariakensis (Kishinouye, 1902)	estuary of Yangtze River (YZR), China	30	14.75	9.32	6.34	1.25	(−0.00037)~0.00225	0.00094	2.708~3.776	3.24	0.892	—
Salanx cuvieri (Valenciennes, 1850)	estuary of Pearl River (PR), China	38	11.01	7.28	1.05	0.31	0.00103~0.00367	0.00235	2.301~2.809	2.56	0.913	—
Salanx chinensis (Osbeck, 1765)	Pearl River (PR), China	30	13.73	5.66	4.54	0.44	0.00489~0.01264	0.00877	2.143~2.503	2.32	0.970	0.00212

a*, geometric mean a determined from $a = W/L^b$ by setting $b = 3$.

Table 2
Growth parameters (weight-length) of introduced icefish species

Species	Lakes locality	Weight-length relationships $W = aL^b$			References
		a	b	R^2	
Protosalanx chinensis	Lugu Lake,Yunnan, Southwest China	0.00246	3.06	0.923	This study
	Zaihe Reservoir, Liaoning, North China	0.00254	3.21	0.994	Yuhao Xie et al.(1999)
Neosalanx tangkahkeii	Xingyun Lake, Yunnan, Southwest China	0.00255	3.20	0.998	Peikang Chen et al.(1989)
	Xin'anjiang Reservoir, Zhejiang, Southeast China	0.00392	3.06	0.996	Ruwei Xu and Luo (1996)
	Xujiahe Reservoir, Hubei, Central China	0.00298	3.17	0.998	Weimin Wang et al. (1996)
	Xinfengjiang Reservoir, Guangdong, South China	0.00200	3.28	0.990	Xuezheng Xiao et al.(2003)

populations, indicating that all linear regressions are highly significant statistically. Moreover, the *b* values of these introduced populations showed either isometry or positive allometry (Table 2). Thus, such introductions may have improved the biomass of salangids in the transplant area, but also have the potential to threaten the biological diversity of the Chinese freshwater ecosystem.

The data collected in our study not only augment information in the well-known FishBase but although serve as guidance in the management of natural and introduced stocks of salangids in Eastern Asia.

References

Bagenal, T. B.; Tesch, F. W., 1978: Age and growth (Ch. 5). In: Methods for assessment of fish production in fresh waters, 3rd edn T. Bagenal (Ed.), Blackwell Scientific Publications, Oxford, UK, pp. 101–136.

Carlander, K. D., 1977: Handbook of freshwater fishery biology, **Vol. 1**. The Iowa State University Press, Ames, IA. pp. 431.

Chen, P. K.; Yu, W. R.; He, J. R., 1989: Test on icefish (*Neosalanx taihuensis*) of Nebula Lake in Yunnan province. Freshw. Fish. **1**, 31–32. (In Chinese).

Cheng, Q. T.; Zheng, B. S., 1987: Systematic synopsis of chinese fishes. Science Press, Beijing. pp. 67–70. (in Chinese)

Fang, P. W., 1934: Supplementary notes on the fishes referring to Salangidae of China. Sinensia **5**, 505–511.

Froese, R., 2006: Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. J. Appl. Ichthyol. **22**, 241–253.

Hang, Z. L.; Chang, J. B., 1999: Fractal Characteristics of length-weight relationship in fish Acta Hydrobiol. Sinica **23**, 330–336.

Hanken, J.; Wake, D. B., 1993: Miniaturization of body size: organismal consequences and evolutionary significance. Annu. Rev. Ecol. Syst. **24**, 501–519.

Kim, I. S.; Park, J. Y., 2002: Freshwater fishes of Korea. Kyo-Hak Publishing, Seoul. pp. 1–465.

Mendes, B.; Fonseca, P.; Campos, A., 2004: Weight–length relationships for 46 fish species of the Portuguese west coast. J. Appl. Ichthyol. **20**, 355–361.

Nelson, J. S., 2006: Fishes of the World, 4th edn. John Wiley & Sons, Inc., New York, NY.

Ricker, W. E., 1973: Linear regressions in fishery research. J. Fish. Res. Board Can. **30**, 409–434.

Roberts, T. R., 1984: Skeletal anatomy and classification of the neotenic Asian salmoniform superfamily Salangoidea (icefishes or noodlefishes). Proc. Calif. Acad. Sci. **43**, 179–220.

Safran, P., 1992: Theoretical analysis of the weight-length relationships in fish juveniles. Mar. Biol. **112**, 545–551.

Wakiya, Y.; Takahasi, N., 1937: Study on fishes of the family Salangidae. J. Coll. Agr. **14**, 265–296.

Wang, W. M.; Yang, G. R.; Zhang, J. B.; Fan, Q. X.; Liu, X. G.; Chen, X. L.; Cheng, Z. X.; Shang, S. Z.; Xiong, Q. Y., 1996: Growth characteristics of *Neosalanx Pseudotaihuensis* landlocked in Xujiahe Reservoir. J. Fish. China **20**, 18–24 (in Chinese).

Xiao, X. Z.; Lu, M. X.; Wu, Y. Q.; Huang, Z. H., 2003: Research on growth properties of *Neosalanx taihuensis* from Xinfengiiang reservoir. Reserv. Fish. **23**, 28–29; 32. (In Chinese).

Xie, Y. H.; Tang, Z. P.; Fu, L. J.; Li, B.; Sun, J.; Wang, Z. S.; Yang, T. X.; Du, L. J., 1999: The biological aspects of large icefish (*Protosalanx hyalocranius Abbott*) in the Zai He reservoir. pp. 426–432. (in Chinese).

Xu, R. W.; Luo, X. C., 1996: Preliminary studies on growth patterns of *Neosalanx taihuensis* Chen in Xin AnJiang reservoir. J. Z. J. Coll. Fish. **15**, 122–128. (in Chinese).

Zhang, Y. L., 1987: A taxonomic study on the Chinese icefishes of the genus *Neosalanx* (Pisces: Salangidae), with description of a new species from the Lake Taihu. Zool. Res. **8**, 277–286. (in Chinese).

Zhang, J., 2008: Biodiversity of Chinese icefishes (Salangidea) and their diversity conservation. Bull. Biol. **43**, 4–6. (in Chinese).

Zhang, J.; Li, M.; Xu, M.; Takita, T.; Wei, F. W., 2007: Molecular phylogeny of icefish Salangidae based on complete mtDNA cytochrome *b* sequences, with comments on estuarine fish evolution. Biol. J. Linn. Soc. **91**, 325–340.

Zhao, L.; Zhang, J.; Liu, Z. J.; Stephan, M. F.; Wei, F. W., 2008: Complex population genetic and demographic history of the Salangid, *Neosalanx taihuensis*, based on cytochrome *b* sequences. BMC Evol. Biol. **8**, 201.

Zhao, L.; Zhang, J.; Liu, Z. J.; Xu, M. Q.; Li, M., 2010: Population genetic structure and demographic history of *Neosalanx jordani* based on cytochrome *b* sequences. J. Biodivers. Sci. **18**, 251–261.

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