Role of fish species introduction in reservoir fisheries in China: Case study on icefish

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1 Introduction

Reservoirs are important water resources in China both for economic reasons and for providing livelihoods for displaced people. There are about 86000 reservoirs in China. Most of reservoirs are used for fisheries production even though they are not built for this purpose.

Fish species introduction is a very important method to increase fisheries production and economic output in China. A good example is the introduction of the icefish *Neosalanx taihuensis* into reservoirs and lakes in most areas of China. *N. taihuensis* is a freshwater icefish, belonging to the family Salangidae (Order: Cluperiformes). *N. taihuensis* mainly inhabits the middle and lower reaches of the Yangtze River, including its tributaries and affiliated lakes (Fang 1934a,b; Chen 1956; Xie and Xie 1997), and is the most dominant fish in some lakes, e.g. Taihu Lake and Caohu Lake (Chen 1956; Ni and Zhu 2005; Guo *et al.* 2007).

Figure 1 . Icefish *Neosalanx taihusensis*

N. taihuensis is a small-sized, transparent, high-valued fish of an adult total length of 58-79 mm. It is characterized by early onset of maturity, short life span, high reproductive potential, strong adaptive ability, delicious meat taste and a high international market price (Figure 1). It feeds mainly on zooplankton and its life span is only one year. There are two spawning strains for the fish, one in spring and the other in autumn. Normally the spring spawning strain is used for transplantation. The spawning time peaks in April when water temperature is about 15° in the Yangtze River Reaches. In some large reservoirs, the introduced fish becomes the dominant economic species. However, in some other reservoirs, the production is not stable.

The present study was aimed to provide basic information of production, management strategies and biological characteristics in target reservoirs and lakes in China and guide introduction and management practices of the fish. The results may also provide technical references for other countries in Asia for the introduction of icefish.

2 Methodology

Data of icefish introduction, yield, water bodies and environmental parameters were collected from published papers, fisheries administration bureaus, and field investigation in 20 provinces, autonomous regions and municipal cities from South to North China.

For life history and reproduction strategy study, fish were sampled using combination methods of seine net (350 m length and 12 m width, 2 mm mesh size) and light luring in the Tian-e-zhou Oxbow (29°30′ N, 112°13′ E; Figure 2), Xiangxi Bay of the Three Gorges Reservoir (TGR) (30°57′-31°34′ N, 110°25-111°06′ E), and Danjiangkou Reservoir, the second largest reservoir in China after the Three Gorges Reservoir, Hubei province. When sampling, the seine net was drawn parallel to the shore in the area with a water depth of about 1.5 m for about 200 m distance. Sampling was conducted primarily once a month in 2007 and 2008. Specimens were kept in ice and brought to the laboratory for further analysis. Water temperature was measured twice a day, between 0700 and 0800 hrs and between 1700 and 1800 hrs, respectively, and the mean value of two measurements was considered as the daily mean water temperature.

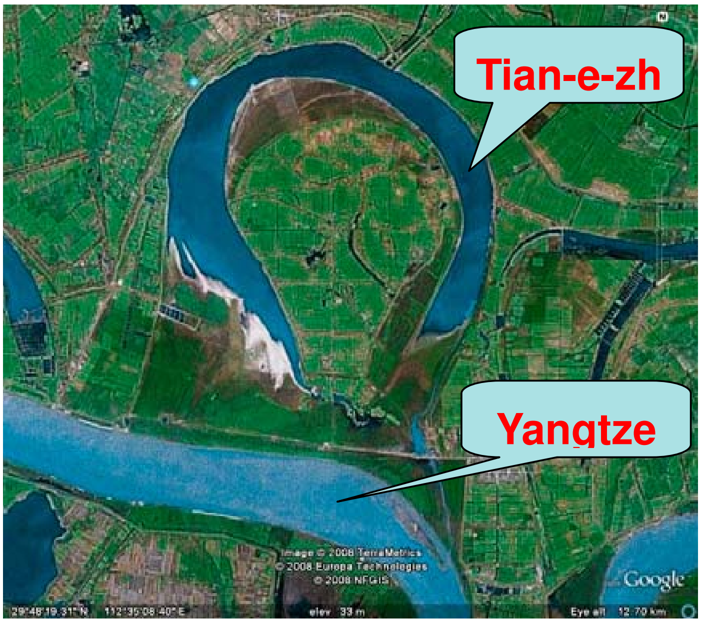


Figure 2. Tian-e-zhou Oxfow

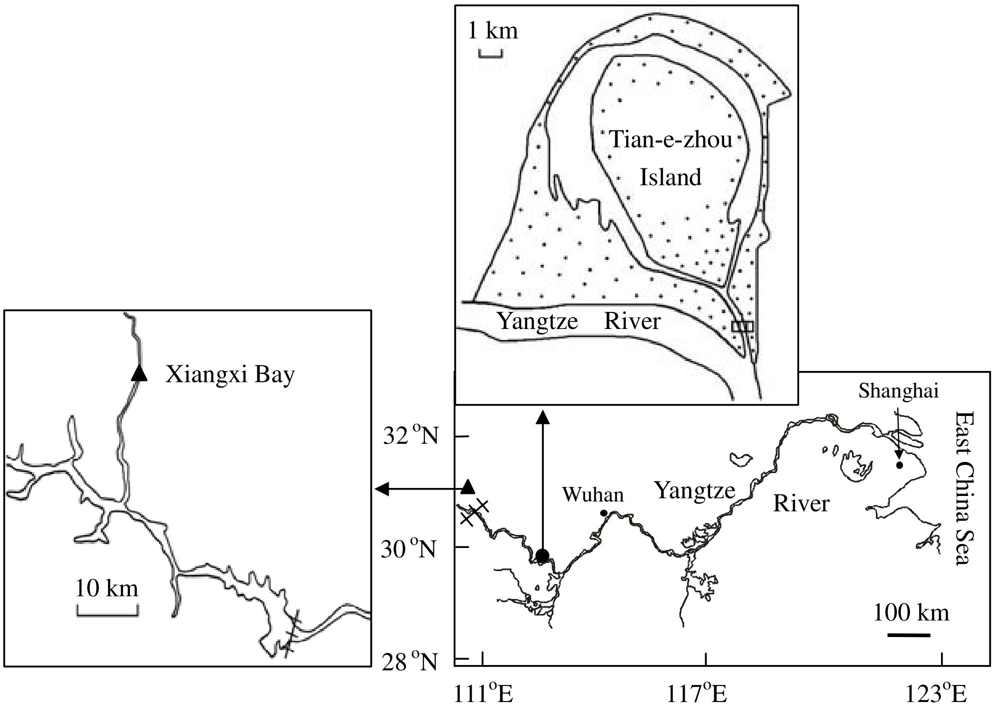


Figure 3. Sampling locations for *Neosalanx taihuensis* in the Three-Gorge Reservior (TGR) at the Xiangxi Bay (▲) and the Tian-e-zhou Oxbow (TEZO) (●),a flood-regulating weir and Three-Gorges Dam in the middle and lower reaches of the Yangtze River.

In the laboratory, the standard length and the body weight determined to the nearest 0.1 mm and 0.01g, respectively. When the sample size was less than 200, all the individuals were measured and weighed; when the number was more a minimum of 200 fish were sampled. Females were identified from secondary sexual characteristics (mainly for mature females with gonad at stage IV or V) and/or gonad examination with the naked eye after dissection (mainly for immature individuals) (Xu and Lu 1965). Sex could only be identified for individuals with gonad developed to stage II or further (see results).

Condition (K) of females was calculated by

$$K = BW / SL^3 \times 10^5$$

Females were dissected, and the gonads removed, and weighed (GW, 0.001g), ovaries fixed in Bouin's solution for 24 h (except during spawning seasons, only left ovary was fixed), and preserved in 70% alcohol for histological examination. At the same time, the right ovary (stage IV and V) was weighed (Ws, 0.001g), and preserved in 5% formalin for fecundity determination. Number of oocyte (N) in the right ovary was then counted under a dissecting microscope. The absolute fecundity (AF) was then calculated by:

$$AF = N \times GW / Ws$$

For all females gonadosomatic index (GSI) was calculated by:

$$GSI = GW / BW \times 10^2$$

For ovarian histological examination, the center part of the fixed left ovaries from each female was removed, dehydrated in a series of alcohols and embedded in paraffin wax, and sectioned at 7 µm using a microtome (Leica RM 2235, Germany), and stained with Harris's hematoxylin and eosin Y. A six-stage maturity scale (Schreck and Moyle 1990) was used to classify the maturity of gonads based histologically and externally (see results). The diameter of 200 randomly selected oocytes in sectioned ovaries at each stage (stage II, III, IV and V), in which the nucleus was visible, were recorded to the nearest 10 µm. The mean diameter of oocytes at each stage was calculated using this data.

3 Results

3.1 Review of practices of icefish introductions

Two upsurges occurred in the introduction of icefish in China. The first one was during the period 1979-1985, when it was introduced into Yunnan Province, and large-scaled production of the fish occurred in nine lakes including Dianzhi Lake. The second phase was in 1995-2000, when icefish was introduced into thousands of reservoirs and lakes in most of provinces and municipal cities. During this period, a total of 1 million ha of water area was transplanted with 3 billion icefish eggs.

Icefish was introduced into Lake Dianchi, a plateau lake with a surface area of 3.06×10^4 ha in Yunnan province from Lake Taihu, Jiangsu province in April 1979, when 13000 fertilized eggs were transported to Yunnan by train. Of these eggs 6825 fry were hatched and stocked into Lake Dianchi. In 1981, 6.5 t of the fish was harvested. The harvest peaked at 3200 t in 1987 and then decreased to less than 100 t in recent years (Figure 4).

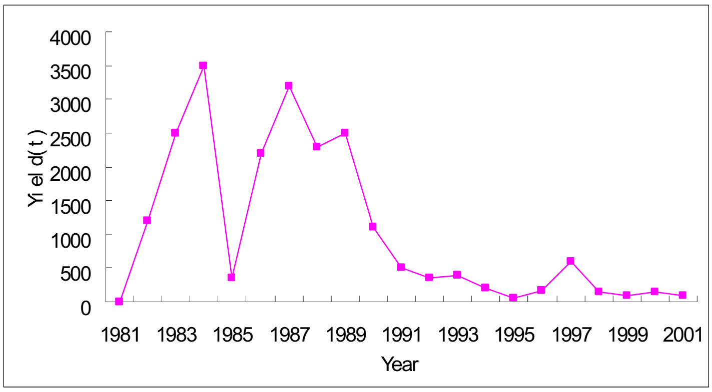


Figure 4 Icefish yield in Lake Dianchi from 1981 to 2001

In 1982 and 1984, 210000 icefish eggs were introduced into Lake Xingyun (0.35×10^4 ha) in Yunnan province. The yield reached 78t, 200t, 400t and 400t from

1985 to 1988, respectively. The yield of Lake Fuxian, a downstream lake (2.12×10^4 ha) connected to Lake Xingyun, also reached 70 t, 191t, 334t and 1232t from 1987 to 1990, respectively, even though no eggs were introduced into the lake. With the success of icefish introductions into Lakes Dianchi and Xingyun, icefish was introduced into almost all lakes in Yunnan province. Typical lakes with higher production of icefish include Lake Erhai (2.43×10^4 ha), Lake Qilu (0.33×10^4 ha), Lake Yilong (0.33×10^4 ha), Lake Yangchenghai (0.31×10^4 ha), Lake Qingshuihai (500 ha) and 3 reservoirs in Chuxiong. Untill 1991, lakes and reservoirs with a total surface area of 9.8×10^4 ha were transplanted with icefish, amounting to 90% of the water area of the province, and consequently icefish became the most important commercial fish of Yunnan province.

Other provinces of successful transplantation of icefish include Fujian, Jilin, Hubei, Henan and Shandong.

In 1986, 150,000 icefish eggs from Lake Taihu were introduced into Chitan Reservoir, a deep valley-type reservoir (3600 ha) in the upper Minjiang River, Fujian province. And then in 1987 and 1990, 160,000 and 300,000 eggs were introduced again into the reservoir. In 1990, 18 t icefish was harvested. This is the first case of successful introduction of icefish into this type of reservoir in China.

3.2 Successful cases of icefish introduction in other provinces

Typical provinces for large-scaled introduction of icefish and with good economic gains include Shandong, Henan, Inner Mongolia, Hubei, Tianjing, Yunnan, Anhui and Shanxi. The transplanted surface area and transplanted egg numbers in these provinces amounted to more than 80% of the total in China.

Typical water bodies for successful introduction of icefish include Lake Dianchi, Lake Fuxianhu, Lake Erhai Lake and Songhuaba Reservoir in Yunnan province, Beitang Reservoir, Huanggang Reservoir, Yingcheng Reservoir in Tianjing City, Luhun Reservoir, Baiguishan Reservoir, Guxian Reservoir and Yahekou Reservoir in Henan Province, Lake Daihai, Molimiao Reservoir in Inner Mongolia, Xiashan Reservoir, Sanlizhuang Reservoir, Xujiayan Reservoir, Yeyuan Reservoir and Qingfengling Reservoir in Shandong province, Zhanghe Reservoir, Xujiahe Reservoir and Fushui Reservoir in Hubei province, Xinanjiang Reservoir in Zhejiang province and Hongjianzhuo Reservoir and Fengjiashan Reservoir in Shanxi province.

Table 1. Specific instances of successful transplantations of ice fish in selected reservoirs

Reservoir (ha)	**Province**	**No. transplanted (years)**	**Yield in t (years)**
Chitan (3,600)	Fujian	610,000 (1986, 1987 and 1990)	18 (1990)
Baiguishan (5,660)	Henan	210,000 (1987)	110 (1919), 150 (1992),

			120 (1993); current annual 100t
Fushui (5,500)	Hubei	500, 000	5 (1994); 5 (1996); 15 (1997
Zhanghe (1.04×10^4)	Hubei	200,000	5.7 (1996); 80- 120 t (1997-2004); 270 t (2000)

3.3 Effect assessment of icefish introduction

It is commonly believed that the introduced icefish may affect water environment and biodiversity. It may also affect the relationship of phytoplankton and zooplankton, and compete for food especially zooplankton with other zooplanktivores and most in the early life stage which feed on zooplankton.

Results indicated that after the large scale production of icefish in Lake Erhai in 1991, the density and biomass of zooplankton in 1997 dropped to 1.712×10^6 individuals/L and 0.5412mg/L, respectively, compared to that of 8.905×10^6 individuals/L and 1.598 mg/L in 1992 , respectively. It is also believed that the icefish may be also the reason resulting in production decrease or disappearance of some indigenous fish (Qin et al., 1999).

Since icerfish are small sized, and of a short life span fish with high relative fecundity, they are typical "R" strategy survivors. As soon as they are successfully transplanted in a water body, large populations can be established in a short time (Huang and Chang, 2001; Li, 2003). Icefish feed on zooplankton, mainly crustaceans and copeopods, but not eggs or larvae of other fish species Liu et al., 1994; Guo & Xie, 2005; Liu et al., 2007. It is generally believed that icefish may affect other fish's resources through competiton for food (Liu et al., 2006). However, the procedure and mechanics of effect remain unclear. Growth and development of early life stage fishes are the key factors determining survival and annual population intensity (Ludsin & Devries, 1997; Xie et al., 2005; Srinivasan & Jones, 2006; Xie & Watanabe, 2007). In the middle and lower reaches of the Yangtze River, the icefish reproduce mainly in March and April (Zhang et al.,1982; Gong et al., 1999), but other fish reproduce mainly from April to June (Hubei Institute of Hydrobiology, 1976). The larvae and fry of most fishes including piscivorous fishes feed on zooplankton (Hubei Institute of Hydrobiology, 1976 ;Cao et al, 2007). Since the reproductive season of the icefish is earlier than for others, and its population is big, they may result in food scarcity for other fish species in their early life stages, and affecting the growth and survival of the later. Based on this hypothesis, we proposed a new project on the study on the effect of icefish transplantation on other fish resources. This project was just approved by the National Science Foundation of China (NSFC). It will start from

Januray 2010 to December 2012.

3.4 Life history traits

Gonad development of female *N. taihuensis* was divided into 6 stages based on the ovarian macroscopic appearance and histological characteristics.

Table 2. Gonadal maturity stages of female icefish

Stage	Description; oocyte size	SL (mean±SD) in mm	GSI (mean ±SD)
I	Virgin; Ovary invisible to the naked eye	< 50	-
II	Immature stage; oocytes perinucleolar; diameter ranging 33 to 106um and a mean of 65 ± 1 um	45.1-68.2 (55.9± 0.4)	0.14-2.04; (1.09± 0.04)
III	growth stage; Oocytes visible to the naked eye; 81 – 260 um; 163 ± 3 um	54.5-68.4 (60.7 ± 0. 7)	1.98-5.05 (3.15± 0.16)
IV	mature stage; ovary swollen, full with yellowish to yellow , clearly visible oocytes; yolk globules; 202-422 um; mean 291± 3 um	56.5-68.8 (62.1± 0.6)	4.42- 14.07 (9.33± 0.57)
V	ripe stage; ovary occupied the entire abdominal cavity; transparent yellow and clearly discernible from outside; diameter 281 - 543 um; mean 417 ± 4 um	50.0 -70.1 (62.3± 0.4)	0.56-7.58 (3.25± 0.24)
VI	spent stage; residual oocytes usually present; also atretic oocytes and /or empty follic	54.6-70.6 (65.2± 0.4)	0.56-7.58 (3.25± 0.24)

Condition factor of both mature females and males were significantly different between the two populations (one in the Tian-e-zhou-Oxfow, and the other in the Three Gorges Reservoir), and the condition factor of mature females and males in the Three Gorges Reservoir (TGR) was significantly higher than that of mature females and males in the Tian-e-zhou-Oxfow (TEZO) .

I_G values for mature females were not significantly different between the two populations (Fig.5).

Regressions of W to F_A were F_A = 509.1 + 1225.2 W (r^2 = 0.44, n = 40, P < 0.05) for the mature females in TGR and F_A = 317.8 + 1126.3 W (r^2 = 0.51, n = 33, P < 0.05) for the mature females in TEZO. The F_A was significantly different between the two populations, the F_A of mature females in TGR was significantly higher than that of mature females in TEZO ($P < 0.05$) (Fig. 6).

The oocyte diameter of mature females with gonad at stage V was significantly different between the two populations, and the oocyte diameter of mature females in TGR was significantly larger than that of mature females in TEZO ($P < 0.05$) (Fig. 7).

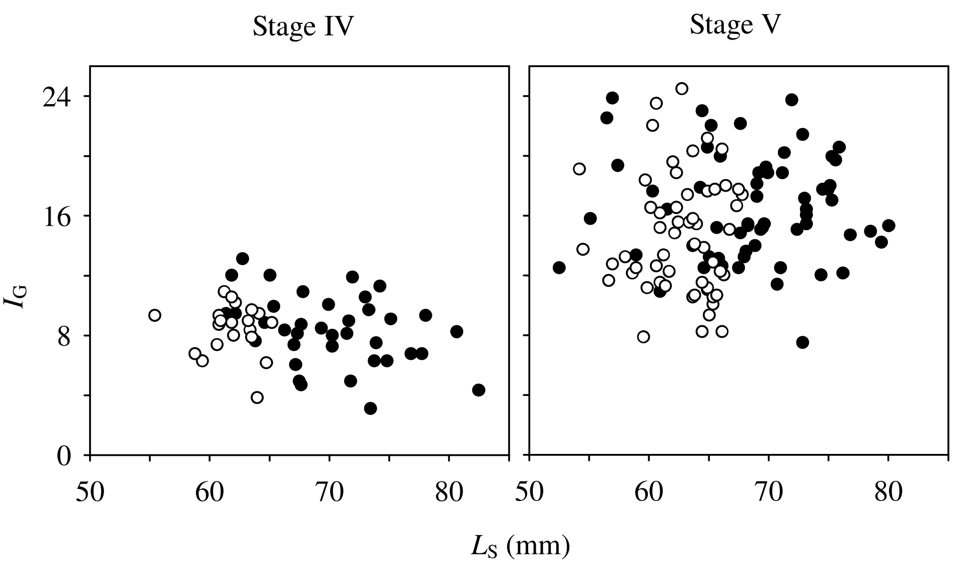


Fig. 5 Variations in gonado-somatic index (I_G) for female *N. taihuensis* in TGR (●) and TEZO (○), 2008.

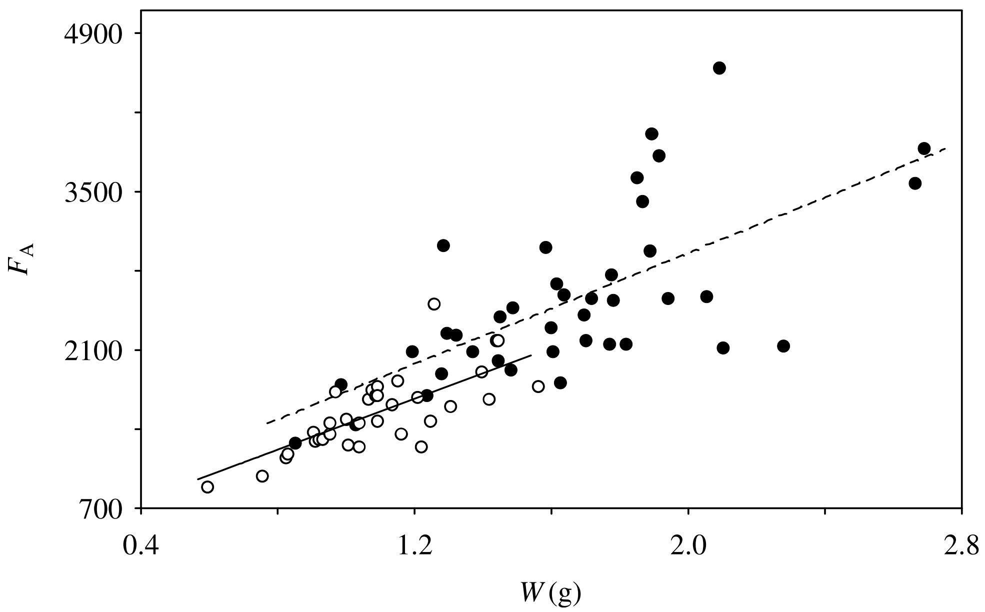


Fig.6. Regression relationship of body weight (W) to absolute fecundity (F_A) for *N. taihuensis* in TGR (●): $F_A = 509.1 + 1225.2\ M_T$ ($r^2 = 0.44$, $n = 40$, $p < 0.05$) and in TEZO

(○): $F_A = 317.8 + 1126.3\ M_T$ ($r^2 = 0.51$, $n = 33$, $p < 0.05$).

From December 2007 to November 2008, icefish were sampled monthly in Danjiangkou Reservoir. Analysis on body length distribution (Fig. 7) and GIS (Fig. 8) indicated that there were two strains of icefish in the reservoir. Most of them were of the spring strain. The reproductive season for the spring strain ranged from February to July, and peaked in March and April. However, the reproductive season for the autumn strain ranged from September to October. There were significant differences in early growth stage, fecundity and egg size between the two strains. The average fecundity of the spring strain was 1960, while that in the autumn strain was only 895. The GIS increased from January and peaked in March. Then it decreased gradually to zero in June. In September, it increased again and decreased to zero in November.

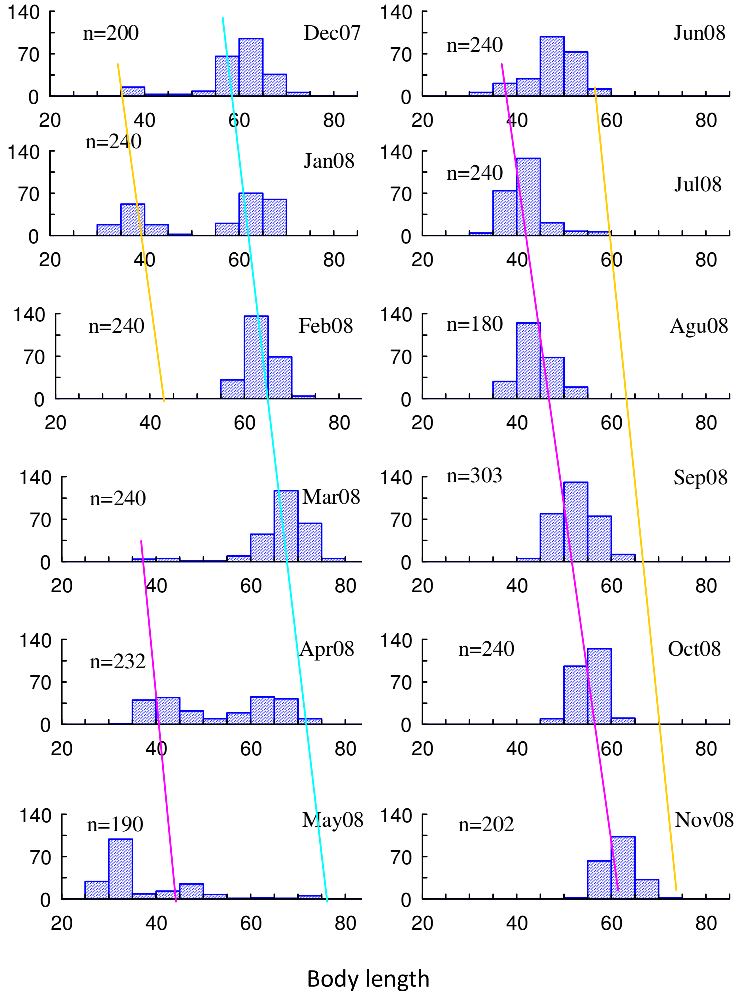
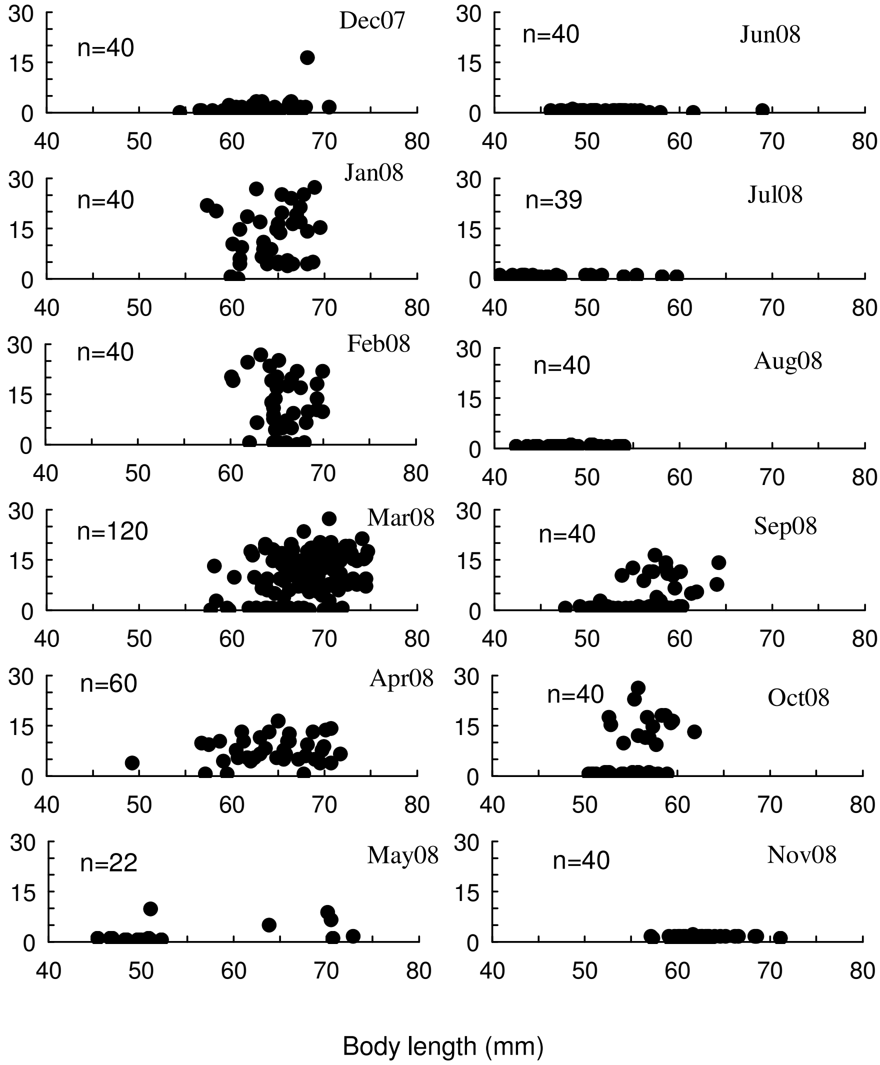


Fig. 7 Body length distribution of different strains in Danjiangkou reservoir

Spring strain   Autumn Strain   Spring strain



3.5 Technical guidelines for icefish introduction into lakes and reservoirs

Transplantation of icefish with fertilized eggs normally results in the best results. The transplantation density is over 2000 eggs/ha for the new icefish. The fertilized eggs in plastic bags with oxygen were suitable for transportation. The new icefish is suitable to be introduced into water bodies in Southern China, normally, south of the Yellow River. The large icefish is suitable to be introduced into water bodies in Northern China, normally north of the Yangtze River.

3.6 Main problems for transplanting icefish

Failures for transplanted icefish

Though icefish has been transplanted into many waters and recruits have been successfully built, transplantation is not successful in a majority of waters. For example, only 20% of reservoirs transplanted with icefish showed any icefish yield. We need to know what factors affect the survival and reproduction of the introduced icefish. Is it transplantation techniques, natural environment conditions or biological conditions?

Fluctuation of icefish yield

Icefish yield is not stable; even if it is successfully introduced into the new waters. For example, the highest icefish yield reached 300 t a few years after the introduction into Daihai Lake in Inner Mongolia, but the yield was zero after this. In Lake Dianchi, icefish yield lasted for many years, but there has been hardly any since 1997. We need to know what factors affect the stabilization or fluctuation of introduced icefish yields. Is it the food supply, ability to stand up to competitive pressure among fish populations?

Ecological problems caused by the introduction of icefish

These problems include: effects of introduced icefish on water quality and biodiversity; introduced large icefish is known to cause injury on common carp, crussian carp, pray fish and shrimps; relationship between icefish populations and biomass of phytoplankton and zooplankton; competition state for food resources among icefish, silver carp and bighead carp; suitable geographical limits for transplantation of icefish; population dynamics of introduced icefish.

3.7 Research on icefish introduction and fisheries management conducted

Research on techniques of transplantation of icefish were carried out, including reproductive habits (spawning, reproduction, hatching and embryonic development), ecological characteristics (habitat conditions, growth and feeding habits), selection of water bodies for transplantation, capture of broodstock, artificial fertilization, transportation of eggs, artificial hatching, stocking, adult transplantation, assessment of icefish population sizes, determination of recruitment and rational capture.

Results showed that, survival of icefish in the new waters was mainly affected by stocking techniques; reproduction and yield were mainly affected by environmental conditions, food supply and competition state of fish populations. Icefish could successfully build its recruitment population in new waters with rich food supply. However, icefish could were hardly successful when introduced into new waters with high density of silver carp, bighead carp or with rich fish fauna.

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