Temperature effects on the distribution of two invasive tilapia species (Tilapia zillii and Oreochromis niloticus) in the rivers of South China

Dang En Gua, Fan Dong Yua,b, Meng Xua, Hui Wei, Xi Dong Mu, Du Luo, Ye Xin Yang, Zhi Pan and Yin Chang Hu

ABSTRACT
Competitive interactions not only exist between invasive and native fish species but also between different invasive species, especially between those that have broad niche overlap. Nile tilapia (Oreochromis niloticus) and Redbelly tilapia (Tilapia zillii) are the most common invasive tilapia species in the rivers of South China. There may be specific factors that influence their competitive interactions and disturbance patterns, and temperature has been considered the most important factor. To study how temperature affects the distribution patterns and competitive interactions of these two invasive tilapia species, field surveys and laboratory experiments were conducted. Field surveys showed that latitude affected the ratio but not the biomass of all tilapia species. Nile tilapia was more abundant in the southern (warmer) sites, and Redbelly tilapia was more abundant in the northern (colder) sites. The distribution patterns of the two tilapia species were also related to latitude and minimum winter temperature. The results of the laboratory-based temperature experiments further confirmed that Redbelly tilapia can tolerate lower temperatures than Nile tilapia. However, the Nile tilapia were larger in field surveys, and laboratory experiments also showed that Nile tilapia are stronger competitors in warmer water because of their larger body size. Therefore, we suggest that the distribution patterns of these two invasive tilapia species were related to temperature conditions.

ARTICLE HISTORY
Received 5 March 2018
Accepted 24 August 2018

KEYWORDS
Competitive interactions; distribution pattern; latitude; Nile tilapia (Oreochromis niloticus); redbelly tilapia (Tilapia zillii); temperature

1. Introduction

Introduction of alien species is a leading cause of species extinctions and biodiversity loss (Davies et al. 2010; Houde et al. 2015). Biotic interactions caused by invasive species, such
as competitive interactions, predation, parasitism, and hybridization, negatively impact native species (Blanchet et al. 2007; Carey and Wahl 2010; Houde et al. 2015). Among these interactions, competition between native and non-native species is a common phenomenon that occurs in most animal communities (Blanchet et al. 2007; Alcaraz et al. 2008; Linde et al. 2008). In fish communities, successful invaders may outcompete native species for food and habitat, which affects the native species’ habitat selection, food choices, and apparent survival (Blanchet et al. 2007; Martin et al. 2010; Gu et al. 2015; Raymond et al. 2015). Although many studies have highlighted the competitive interactions between alien and native fish species in freshwater communities, there is a general lack of understanding of the interactions between different alien species (Taniguchi et al. 1998; Blanchet et al. 2007; Martin et al. 2010; Kornis et al. 2013; Raymond et al. 2015; Gu et al. 2016). In many cases, invasions by alien species involve multiple closely related fish, such as different Asian carp or tilapia species; however, less attention has been given to the competitive interactions between different alien species (Irons et al. 2007; Wu and Yang 2012; Zengeya et al. 2015; Gu et al. 2016).

Tilapia comprise a group of freshwater fish that are among the most common invaders worldwide and have become the dominant species in many rivers in South China (Gu et al., 2014, Hu 2015). Tilapia is the common name for the African cichlids that include Oreochromis, the mouthbrooding Sarotherodon, and substrate-spawning tilapia (Bhassu et al. 2004; Dunz and Schliewen, 2013). Tilapia (Oreochromis mossambicus) were first introduced to South China in 1957; since then, more than seven tilapia species have been introduced to China (Zhu et al. 2008). To date, five tilapia species (O. aureus, O. niloticus, Tilapia zillii, S. galilaeus, and a hybrid of O. mossambicus and O. niloticus) have been identified in the rivers of South China (Gu et al. 2016). Among these species, O. niloticus and T. zillii are most common, and they were both introduced to mainland China in 1978 and widely distributed in the study area (Gu et al. 2016, 2018). The earliest tilapia species introduced to China, O. mossambicus, has become increasingly rare now that O. niloticus populations have increased because these two species have similar ecological niches (Gu et al., 2016). A similar situation has also occurred for O. aureus (Hu 2015). Oreochromis mossambicus, O. aureus, and O. niloticus share numerous characteristics, such as spawning type (aerna-spawning maternal mouthbrooders), flexible habitat requirements, fast growth, and omnivorous feeding habits (De Silva et al. 2004; Zhu et al. 2008).

When niche overlap leads to immediate and intense competition, Nile tilapia tends to quickly gain the competitive advantage because of its large size and fast growth (Hu 2015; Gu et al. 2016). In China, Nile tilapia and its hybrids account for more than 90% of aquaculture production (Gu et al. 2016). Consequently, Nile tilapia and its hybrids are the most widely distributed tilapia species in South China (Zhu et al. 2008; Gu et al. 2014, 2016). Redbelly tilapia (Tilapia zillii) is not as common as Nile tilapia in Chinese aquaculture because it is smaller and grows more slowly (He et al. 2013). However, this species can tolerate colder waters and has higher breeding and survival rates; thus, natural populations have developed in many rivers in South China (He et al. 2013). Redbelly tilapia has less niche overlap with Nile tilapia than other tilapia species, which indicates that there may be certain conditions that mediate their competitive interactions (Gu et al., 2016).

Fish species distribution patterns often result from competitive interactions that are mediated by abiotic conditions (Taniguchi et al. 1998). Many classic studies demonstrated examples of biotic interactions that depend on environmental conditions, a phenomenon called ‘condition-specific competition’ (Dunson and Travis 1991; Alcaraz et al. 2008). For example, Alcaraz et al (2008) showed that the competitive interactions between invasive mosquitofish and endangered cyprinodont fish depended on the salinity of
freshwater bodies. Helland et al. (2011) found that changes in ice phenology may alter species interactions in northern aquatic systems, and the observed outcome of competition in natural populations of two species strongly depended on the duration of ice cover. Taniguchi et al. (1998) showed that the competitive ability of three fish species varied across a range of temperatures and longitudes. The influence of abiotic conditions on competitive interactions is likely to be most important in regions with varied abiotic environmental conditions, especially for invasive fish in new habitats (Keller and Taylor 2008; Leisnham et al. 2009). In aquatic ecosystems, rivers exhibit gradients in abiotic factors, such as temperature, current speed, water velocity, and substrate composition, as they flow downstream (Taniguchi et al. 1998). For alien tilapia species, temperature is considered a major factor that limits their population distribution (Shipton et al. 2008; Hu 2015).

In previous studies, Redbelly tilapia was shown to tolerate colder temperatures than Nile tilapia (Martin et al. 2010). Nile tilapia are able to survive well at 15°C (Lowe et al. 2008), but only 30% survive when temperatures drop to 10°C (Charo-Karisa et al. 2005). However, Redbelly tilapia can survive at temperatures as low as 6.5°C (Hauser 1977). Thus, the current study focused on how temperature affects the distribution patterns and competitive interactions of these two invasive tilapia species. In a previous survey, we found that Redbelly tilapia was abundant in two northern sites and Nile tilapia was abundant in several southern sites (Gu et al. 2016). Thus, based on our previous results, we postulated that the competitive interactions between these two invasive tilapia species were likely to be determined by winter temperatures.

This study evaluated how temperature might mediate the distribution of these two invasive tilapia species in the rivers of south China. The abundance of fish communities and the relative degrees of invasiveness of the two tilapia species (i.e. weight and numerical ratios) were investigated in the rivers of South China, where natural tilapia populations have been established. Furthermore, laboratory investigations were conducted to verify mortality and competitiveness in response to various temperature conditions. Based on our findings, temperature influence on the distribution of these two tilapia species was then discussed.

2. Methods

2.1. Distribution patterns of Nile and Redbelly tilapia

Surveys were carried out at 22 sites where natural tilapia populations have been established in Guangdong Province, Guangxi Province, and Hainan Province, South China (Figure 1). The 22 sites were located along the main streams of large rivers of South China: the Xijiang River, Beijiang River, Dongjiang River, Jianjiang River, Moyangjiang River, Hanjiang River, Zengjiang River, Liuxi River, and Nandujiang River.

The study area has a subtropical climate with mean temperatures between 19°C and 25°C, and mean annual rainfall of 1,400–2,400 mm (Guangdong Province Meteorological Service Network; Hainan Province Meteorological Information Service Network). The survey sites were located along six latitudes, and the minimum winter temperatures at the sites ranged from 10°C to 18°C (Huang, 2012). According to meteorological record and the temperature record in January 2017, when latitude increased, the minimum winter temperatures significantly decreased ($P < 0.001$, $R^2=0.898$) (Huang, 2012; Guangdong Province Meteorological Service Network; Hainan Province Meteorological Information Service Network).

Fish were collected between June and October 2013–2016, during which the average temperatures did not differ greatly. In this area, rainfall is mostly concentrated from June
to October, when there are minor differences in hydrological conditions (Radhakrishnan et al., 2011). Field survey was conducted according to the ‘Monitoring manual of fish resources in the Yangtze River’ (Chen 2013) and the ‘Standards and specifications on the monitoring of alien fish species’ (Ministry of Agriculture and Rural Affairs, China). All sites have been traditional fishing grounds for several generations, and all samples were collected from commercial fishing boats. Fishing in rivers by boats in this district requires a fishing license provided by the Oceanic and Fishery Administration. Regulation of certain fishing activities helps prevent illegal fishing activities, such as electro-fishing and overfishing. Moreover, the number of fishing boats and fishermen over the study period remained steady. Thus, the fisheries data used should accurately reflect the fish resources at each site. Each sampling period lasted 2 days, and all fishing boats at each site were involved. At the 22 sites, 258 boats were investigated, and the number of boats investigated at each site ranged from 4 to 38 (average, 12). In this study, fish were primarily caught with gillnets and shrimp pots. Catches were weighed by us with the help of the fishermen, and all fish were identified to the species level and counted following the methods described by Pan (1991).

Figure 1. Geographic distribution of the sampling locations in South China.

The following data were collected at every site: (1) $W_F$, total weight of fish caught (kg); (2) $N_F$, total number of fish caught; (3) $W_T$, total weight of all tilapia species caught (kg); (4) $N_T$, total number of all tilapia species collected; (5) $W_I$, total weight of Nile tilapia ($W_{IN}$) (kg) and Redbelly tilapia ($W_{IR}$) (kg); (6) $N_I$, numbers of Nile tilapia ($N_{IN}$) and Redbelly tilapia ($N_{IR}$); and (7) site latitude.

We calculated the weight ratio of tilapia relative to all fish collected as $R_{WT} = W_T/W_F$, and the numerical ratio of tilapia relative to all fish caught as $R_{NT} = N_T/N_F$. We calculated the weight ratio of Redbelly tilapia to the two target tilapia species as $R_{WIR} = W_{IR}/W_I$, and
the numerical ratio of Redbelly tilapia to the two target tilapia species as $R_{NIR} = N_{IR}/N_I$. The distribution patterns of the two tilapia species were plotted by $R_{WIR}$, $R_{WIN}$, $R_{NIR}$, and $R_{NIN}$.

Latitude is closely related to the minimum temperature in our surveys areas (Huang, 2012; Guangdong Province Meteorological Service Network; Hainan Province Meteorological Information Service Network); therefore, latitude was used as an indicator of temperature in this study. $R_{WIR}$, $R_{NIR}$, $R_{WIT}$, and $R_{NIT}$ data were transformed by arcsine square root transformation. Linear regressions were used to determine the relationship between latitude and abundance of all five tilapia species ($R_{WT}$, $R_{NT}$). The relationships between latitude and Redbelly tilapia weight ratio ($R_{WIR}$) and numerical ratio ($R_{NIR}$) were also analyzed by linear regressions. The minimum recorded winter temperatures were also used to discuss the relationship between temperature and $R_{WIR}$, $R_{NIR}$, $R_{WT}$, and $R_{NT}$. However, temperature data was scheduled according to the county-level administrative regions where the sites were located. In this study, several sites were located in the same region and shared the same data, but the latitude and actual temperature of these sites differed. Thus, we used latitude as a primary indicator in this study, and temperature was used as a supplementary indicator. Statistical analyses were performed with SPSS 16.0 (SPSS Inc., Chicago, IL, USA), and the results were considered significant at $P \leq 0.05$.

### 2.2. Influence of low temperature on mortality

To study the relationship between temperature and mortality of the two target tilapia species, experiments were carried out from 5 to 25 September 2016 in the laboratory at the Pearl River Fisheries Research Institute, Chinese Academy of Fishery Sciences, Guangzhou City, Guangdong Province, China. Samples of the two tilapia species were obtained from the Liuxihe River (Renhe site), Guangzhou City, 2 weeks prior to the start of the experiment, and 100 individuals per species were caught. Prior to the experiments, the tilapia individuals were kept in large glass tanks with water from one lake of the Pearl River Fisheries Research Institute.

#### 2.2.1. Mortality

Individuals of the two tilapia species were transferred into two glass tanks that each contained 25 L of water. Each tank contained five individuals, and 5 Nile tilapia and 5 Redbelly tilapia were used in this experiment. The two tanks were placed in a climate-controlled chamber in which the temperature was adjusted from high to low to simulate the natural temperature changes that occur during winter months. During the 2-week acclimation period, ambient temperatures surrounding the tanks were lowered from 26°C to 18°C each day. During the experiment, the ambient temperatures around the tanks were lowered from 20°C to 12°C at dusk; the temperature rose and fell at a constant speed, which is consistent with temperature records of the northern sites in the winter. All treatments were replicated three times.

The mortality (number of deceased individuals/total number of fish) of the two tilapia species was calculated and averaged for each species; mortality rates are presented as percentages. The mortality of the two species was compared using one-way analysis of variance (ANOVA). A pairwise comparison was also conducted. All statistical analyses were performed using SPSS 16.0 (SPSS Inc., Chicago, IL, USA), and the results were considered significant at $P \leq 0.05$. 
2.2.2. Lethal time prediction

The two tilapia species were transferred into one big glass tank which contained 60 L of water. The square big tank was divided to two parts by a glass pane, and each part contained 20 tilapia (10 Nile tilapia and 10 Redbelly tilapia). The big tank was placed in a climate-controlled chamber in which the temperature was maintained at 14 °C. The time of death of each individual was recorded. All treatments were replicated three times.

Lethal times of the two tilapia species were predicted by Probit Analysis using SPSS 16.0 (SPSS Inc., Chicago, IL, USA).

2.3. Competitive interactions

To assess competitive interaction over food between the two tilapia species, control experiments were carried out in artificial glass tanks from 30 January to 14 February 2018 in the laboratory at the Pearl River Fisheries Research Institute, Chinese Academy of Fishery Sciences, Guangzhou City, Guangdong Province, China. Nine big glass tanks were used (0.4-m long × 0.4-m wide × 0.4-m deep), and they were each divided into two small tanks using glass panes, where fish was separated from connected water.

All experiments were conducted at a water temperature of 22 °C under a natural photoperiod. Sixty individuals of each species were used (Nile tilapia, 18.95 ± 9.17 g; Redbelly tilapia, 9.88 ± 6.02 g), and the size ratio was similar to that recorded in our field surveys. The fish used in the experiments were caught from Huadi River, Guangzhou City, and healthy individuals were used. Fish were kept in glass tanks for 2 weeks prior to the start of the experiment. There were 20 individuals (10 Nile tilapia and 10 Redbelly tilapia) in one big glass tank, 10 Nile tilapia in one small tank, and 10 Redbelly tilapia in one small tank. All treatments were replicated three times. In the experiment, each tank contained 50 L of water; 1/3 of the water was replaced daily with freshwater, and the fish were fed mixed feed; the feed was calculated by the 3% of the total weight of fish in each tank (Zhu et al. 2008).

The relative growth (((final g − initial g)/initial g) × 100%) of the two tilapia species when cultured were calculated and compared with Redbelly tilapia growth with an ANOVA. The relative growth of the two tilapia species when cultured together compared with their growth when cultured alone was also analyzed by ANOVA. All statistical analyses were conducted using SPSS 16.0 (SPSS Inc., Chicago, IL, USA), and differences were considered significant at P ≤ 0.05.

The use of the fish in this study was approved by the Aquatic Animal Research Committee at Pearl River Fisheries Research Institute. All experiments were performed according to the Chinese Association for Laboratory Animal Sciences guidelines for the care and use of laboratory animals.

3. Results

3.1. Distribution patterns

The total catch from the 22 sites was 3,186.54 kg, and 23,257 samples were collected. The total catch for each site ranged from 18.23 to 573.05 kg (average, 144.84 kg), and the number of fish caught per site ranged from 205 to 3,648 (average, 1,057). The average weight of each Nile tilapia individual (137.86 ± 86.74 g) was significantly larger than that of Redbelly tilapia (58.86 ± 30.88 g) (P < 0.001). Nile tilapia was found at 22 sites; total caught of it in each site ranged from 0.11 to 80.56 kg, and the number of individuals...
caught ranged from 3 to 653. Redbelly tilapia was found at 20 sites; individual weights ranged from 0.29 to 11.23 kg, and the number of individuals caught ranged from 4 to 392. The weight and numerical ratios of Redbelly and Nile tilapia are shown in Figures 2 and 3, respectively. At the sites located north of the 12 °C winter isotherm, Redbelly tilapia was more abundant than Nile tilapia by both weight and individual numbers. South of the 14 °C winter isotherm, Nile tilapia was more abundant. Between the two latitudes, the two species were almost equally abundant.

There was no significant relationship between the weight of all tilapia caught and latitude \((P = 0.068)\). There was also no significant relationship between latitude and the numerical ratio of tilapia to all fish caught \((P = 0.285)\) (Figure 4).

The weight ratio of Redbelly tilapia at each site was significantly and positively related to latitude (linear regression: \(R^2 = 0.719; P < 0.001\)) (Figure 5). The numerical ratio of Redbelly tilapia at each site was also significantly and positively related to latitude (linear regression: \(R^2 = 0.790; P < 0.001\)) (Figure 5). The weight ratio of Redbelly tilapia at each site was significantly and positively related to temperature (linear regression: \(R^2 = 0.645; P < 0.001\)). The numerical ratio of Redbelly tilapia at each site was also significantly and positively related to temperature (linear regression: \(R^2 = 0.698; P < 0.001\)).

### 3.2. Mortality

The temperature experiment results further confirmed that Redbelly tilapia can tolerate lower temperatures than Nile tilapia \((P < 0.01)\). When the temperature was quickly lowered to 12 °C all Nile tilapia died, but only one Redbelly tilapia died among all

---

**Figure 2.** Weight ratios of the two target tilapia species at 22 sites in South China.
three experiments. When the temperature was maintained at 14°C, Nile and Redbelly tilapia all died during the 10-day experiments, but the lethal time of Nile tilapia was significantly shorter ($T = -3.240$, $P = 0.014$). The estimated lethal times are shown in Figure 7. The median lethal times of Nile and Redbelly tilapia were 3.3 and 4.5 days, respectively.

### 3.3. Competitive interaction

In the competition experiments, growth did not differ between the two tilapia species ($F = 3.187$, $P = 0.149$). However, there was significantly less growth of Redbelly tilapia...
when cultured with Nile tilapia compared with those cultured alone ($F = 24.880$, $P = 0.008$). Moreover, there was significantly more growth of Nile tilapia when cultured with Redbelly tilapia compared with those cultured alone ($F = 8.153$, $P = 0.046$) (Figure 8).

4. Discussion

Introduction of tilapia and other invasive fish species has harmed native fish populations and reduced biodiversity (Canonico et al. 2005; Arthur et al. 2010). Research in regions where tilapia species have been introduced revealed that tilapia pose a high risk of invasion in most areas and have even caused the extinction of native fish species because of competitive displacement (Canonico et al. 2005; Martin et al. 2010; Vicente and Fonseca-Alves 2013). However, very little published work exists on the competitive interactions between different tilapia species, even though many areas have been invaded by more than one tilapia species (Wu and Yang 2012; Hu 2015; Gu et al. 2016). Although there are more than five tilapia species in the rivers of South China, *O. niloticus* and *T. zillii* are most common. However, the distributions of these two tilapia species do not
completely overlap. In a previous survey, we found that Redbelly tilapia was more abundant in colder sites and Nile tilapia was more abundant in warmer sites (Gu et al., 2016). Moreover, previous research has indicated that Redbelly tilapia can tolerate colder temperatures than Nile tilapia (Martin et al. 2010). Therefore, temperature may mediate the competitive interactions of two invasive tilapia species in the rivers of South China. In our study, we used field surveys across large spatial scales and a series of control experiments in the laboratory on small spatial scales to elucidate whether temperature likely influences the distributions of these two invasive tilapia species.

In our survey, 23,257 individual fish weighing a total of 3,186.54 kg were caught at the 22 sites. The average weight and number of fish caught at each site were 144.84 kg and 1,057, respectively. Therefore, these data are useful for explaining the abundance of different fish species. Although temperature has been considered a major factor that limits the distribution of tilapia populations, our study found that there was no significant relationship between latitude and weight or numerical ratios of all five tilapia species that were caught (Figure 4). Therefore, our findings revealed that temperature did not affect the
overall biomass of tilapia populations; rather, it affected the relative abundance of different tilapia species.

We found that the distribution of these two invasive tilapia species exhibited different trends across latitudes—Nile tilapia was abundant in the southern sites, whereas Redbelly tilapia was abundant in the northern sites (Figures 2, 3). The weight and numerical ratios of Redbelly tilapia were significantly and positively related to latitude (Figure 5). Redbelly tilapia abundance increased at higher latitudes, whereas Nile tilapia abundance decreased. Because latitude is associated with winter temperatures in our study area (Huang 2012), we propose that the distribution patterns and competition between these two tilapia species were affected by temperature; thus, Redbelly tilapia is likely able to tolerate colder winter temperatures. The results of the laboratory experiments also indicated that Redbelly tilapia can tolerate lower temperatures than Nile tilapia. Nile tilapia had higher mortality rates than Redbelly tilapia at a sustained extreme low temperature (12°C) (Figure 6) and sustained low temperature (14°C) (Figure 7). Therefore, we suggest that low temperatures limit the distribution of Nile tilapia in the northern rivers of South China. Furthermore, the reproduction rates of tilapia species are closely related to temperature. In the northern sites that have lower winter temperatures, the breeding season suitable for tilapia species is shorter; Redbelly tilapia has higher reproductive capacity and is therefore more competitive than Nile tilapia (He et al. 2013).

In southern sites, the average winter temperature is warmer, and the breeding season for tilapia is longer (Huang 2012). Therefore, Nile tilapia, which are larger and grow faster, were easily able to defend against Redbelly tilapia invasion at the southern sites. In a previous study, Nile tilapia significantly reduced native fish growth, and such an impact would be worse when food resources are limited (Gu et al. 2015). In our surveys, the Nile tilapia (average weight, 137.86 g) was larger than the Redbelly tilapia (average weight, 58.86 g). In the control experiments, wild tilapia individuals caught from rivers were used, and the results showed that Nile tilapia were more competitive than Redbelly tilapia in warmer water. The growth rate of Redbelly tilapia significantly decreased when cultured with Nile tilapia, but the growth of Nile tilapia increased when cultured with Redbelly tilapia (Figure 8). Therefore, we suggest that Nile tilapia is more competitive than Redbelly tilapia because of their larger body size, and they can competitively exclude Redbelly tilapia from habitats with limited food resources.

In conclusion, the results of this study revealed that the distributions of Nile and Redbelly tilapia may be mainly determined by winter temperatures. Redbelly tilapia increased with increasing latitude because it can tolerate colder temperatures than Nile tilapia, whereas Nile tilapia increased in the southern rivers because there is minimal temperature limitation and they are stronger competitors. Other ecological characteristics and genetic factors may also influence the respective distributions of these species and should be examined in future studies. Moreover, aquaculture, release, habitat destruction, and water pollution may also affect the competitive ability of different tilapia species, and should also be examined in the future.

Acknowledgments

We thank the fishermen and the Guangdong Oceanic & Fishery Administration of China for their help collecting fish samples. We also thank the reviewers for providing assistance with improving an earlier version of this manuscript. We thank Mallory Eckstut, PhD, from Liwen Bianji, Edanz Editing China (www.liwenbianji.cn/ac), for editing the English text of a draft of this manuscript.
Disclosure Statement

The authors declared that they have no conflicts of interest to this work. We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

Funding

This study was supported by funding from the Central Public-interest Scientific Institution Basal Research Fund, Chinese Academy of Fishery Sciences (CAFS) (2016RC-BR01; 2018SJ-ZH02), National Natural Science Foundation of China (31500465), and Agricultural Biological Resources Protection and Utilization Project, Ministry of Agriculture and Rural Affairs of China (2130108).

Notes on contributors

Dangen En Gu is an assistant researcher of Pearl River Fisheries Research Institute, Chinese Academy of Fishery Sciences with interests in the Monitoring and management of alien fish species.

Fan Dong Yu is a master degree candidate who is studying in Pearl River Fisheries Research Institute, Chinese Academy of Fishery Sciences and Shanghai Ocean University.

Meng Xu is an assistant researcher of Pearl River Fisheries Research Institute, Chinese Academy of Fishery Sciences, where he worked as an ecologist.

Hui Wei is an assistant researcher of Pearl River Fisheries Research Institute, Chinese Academy of Fishery Sciences, where she worked as an ecologist.

Xi Dong Mu is a researcher of Pearl River Fisheries Research Institute, Chinese Academy of Fishery Sciences, where he worked as a fisheries scientist.

Du Luo is an assistant researcher of Pearl River Fisheries Research Institute, Chinese Academy of Fishery Sciences, where he worked as an ecologist.

Ye Xin Yang is an assistant researcher of Pearl River Fisheries Research Institute, Chinese Academy of Fishery Sciences, where she worked as a fisheries scientist.

Zhi Pan is a fisheries scientist who worked in Beijing Aquatic Product Technology Promotion Department.

Yin Chang Hu is a professor of Pearl River Fisheries Research Institute, Chinese Academy of Fishery Sciences, where he worked as an ecologist.

References

Alcaraz C, Bisazza A, Garcia-Berthou E. 2008. Salinity mediates the competitive interactions between invasive mosquitofish and an endangered fish. Oecologia. 155:205–213.

Arthur RI, Lorenzen K, Homekingkeo P, Sidavong K, Sanvilaihham B, Garaway CJ. 2010. Assessing impacts of introduced aquaculture species on native fish communities: Nile tilapia and major carps in SE Asian freshwaters. Aquaculture. 299:81–88.

Bhassu S, Yusoff K, Panandam JM, Embong WK, Oyyan S, Tan S G. 2004. The genetic structure of Oreochromis spp (Tilapia) populations in Malaysia as revealed by microsatellite DNA analysis. Biochem Genets. 42:217–229.

Blanchet S, Loot G, Grenouillet G, Brosse S. 2007. Competitive interactions between native and exotic salmonids: a combined field and laboratory demonstration. Ecol Freshw Fish. 16:133–143.

Canonico GC, Arthington A, McCrary JK, Thieme ML. 2005. The effects of introduced tilapias on native biodiversity. Aquat Conserv Mar Freshw Ecosyst. 15:463–483.

Carey MP, Wahl DH. 2010. Native fish diversity alters the effects of an invasive species on food webs. Ecology. 91 (10): 2965–2974.

Charo-Karisa H, Rezk MA, Bovenhuis H, Komen H. 2005. Heritability of cold tolerance in Nile tilapia, Oreochromis niloticus, Juveniles. Aquaculture. 249:115–123.
Chen DQ. 2013. Monitoring manual of fish resources in the Yangtze River. Beijing: Science Press.

Davies KF, Cavender-Bares J, Deacon N. 2010. Native communities determine the identity of exotic invaders even at scales at which communities are unsaturated. Divers Distr. 17:35–42.

De Silva SS, Subasinghe RP, Bartley DM, Lowther A. 2004. Tilapias as Alien Aquatics in Asia and the Pacific: A Review. FAO Fisheries Technical Paper. Rome, No. 453.

Dunson WA, Travis J. 1991. The role of abiotic factors in community organization. Am Nat. 138:1067–1091.

Dunz AR, Schliewen UK. 2013. Molecular phylogeny and revised classification of the haplotilapiini cichlid fishes formerly referred to as “Tilapia”. Mol Phylogenet Evol. 68:64–80

Gu DE, Luo D, Xu M, Ma GM, Mu XD, Luo JR, Hu YC. 2014. Species diversity defends against the invasion of Nile tilapia (Oreochromis niloticus). Knowl Manag Aquat Ecosyst. 414, 07.

Gu DE, Ma GM, Zhu YJ, Xu M, Luo D, Li YY, Wei H, Mu XD, Luo JR, Hu YC. 2015. The impacts of invasive Nile tilapia (Oreochromis niloticus) on the fisheries in the main rivers of Guangdong Province, China. Biochem Syst Ecol. 59:1–7.

Gu DE, Mu XD, Xu M, Luo D, Wei H, Li YY, Zhu YJ, Luo JR, Hu JR. 2016. Identification of wild tilapia species in the main rivers of south China using mitochondrial control region sequence and morphology. Biochem Syst Ecol. 65:100–107.

Gu DE, Hu YC, Xu M, Wei H, Luo D, Yang YX, Yu FD, Mu XD. 2018. Fish invasion in the river systems of Guangdong Province, South China: several possible indicators of their success. Fish Manag Ecol. 25:44–53.

Guangdong Province Meteorological Service network, http://www.grmc.gov.cn
Hainan Provincemeteorological information service network, http://www.hainanqx.cn
Hauser W. 1977 Temperature requirements of Tilapia zilli. California Fish Game. 63:228–233.
He YS, Lin XT, Sun J, Zhang PF, 2013. Study of individual fecundity of Tilapia zillii in the Dongjiang River. Ecol Sci. 32:057–062. (in Chinese).
Helland IP, Finstad AG, Forseth T, Hesthagen T, Ugedal O. 2011. Ice-cover effects on competitive interactions between two fish species. J Anim Ecol. 80:539–547.
Houde ALS, Wilson CC, Neff BD. 2015. Competitive interactions among multiple non-native salmonids and two populations of Atlantic salmon. Ecol Freshw Fish. 24:44–45.
Hu YC. 2015. The common alien aquatic species in China. Beijing, China: Science Press.
Huang X F. 2012. Atlas of China Geography. Beijing, China: SinoMaps Press.
Irons K S, Sass GG, McClelland MA, Stafford JD. 2007. Reduced condition factor of two native fish species coincident with invasion of non-native Asian carps in the Illinois River, U.S.A. Is this evidence for competition and reduced fitness? J Fish Biol. 71:258–273.
Keller SR, Taylor DR. 2008. History, chance and adaptation during biological invasion: separating stochastic phenotypic evolution from response to selection. Ecol. Lett. 11:852–866.
Kornis MS, Sharma S, Zander MJV. 2013. Invasion success and impact of an invasive fish, round goby, in great lakes tributaries. Divers Distrib. 19:184–198.
Leisnham PT, Lounibos LP, O’Meara GF, Juliano SA. 2009. Interpopulation divergence in competitive interactions of the mosquito Aedes albopictus . Ecology. 90(9): 2405–2413.
Linde A R, Izquierdo JI, Moreira JC, Garcia-Vazquez E. 2008. Invasive tilapia juveniles are associated with degraded river habitats. Aquat Conserv Mar Freshw Ecosyst. 18:891–895.
Lowe MR, Peterson MS, Brown-Peterson NJ, Schofield PJ, Langston JN, Gregoire DR, Slack WT. 2008. Quantification of Nile tilapia’s ability to survive, grow, and reproduce in estuarine water of coastal Mississippi. Presented at MS-AL Seagrant Bays and Bayous Symposium, October 28–29, 2008 and accessed online October 8, 2010.
Martin CW, Valentine MM, Valentine JF. 2010. Competitive interactions between invasive Nile tilapia and native fish: the potential for altered trophic exchange and modification of food webs.PLoS One. 5(12), e14395.
Pan J.H. (1991) The freshwater fishes of Guangdong Province. Guangzhou: Guangdong Science and Technology Press. (in Chinese)
Radhakrishnan KV, Lan ZJ, Zhao J, Qing N, Huang XL.2011. Invasion of the African sharp-tooth catfish Clarias gariepinus (Burchell, 1822) in South China. Biol Invasions. 13:1723–1727.
Raymond WW, Albins MA, Pusack TJ. 2015. Competitive interactions for shelter between invasive Pacific red lionfish and native Nassau grouper. Environ Biol Fish. 98(1): 57–65.
Shipton T, Tweddle D, Watts M. 2008. ECDC 2008, Introduction of the Nile Tilapia (Oreochromis niloticus) into the Eastern Cape. A report for the Eastern Cape Development Corporation.
Taniguchi Y, Rahel FJ, Novinger DC, Gerow KG. 1998. Temperature mediation of competitive interactions among three fish species that replace each other along longitudinal stream gradients. Can J Fish Aquat Sci. 55:1894–1901.

Vicente IST, Fonseca-Alves CE. 2013. Impact of introduced Nile tilapia (*Oreochromis niloticus*) on non-native aquatic ecosystems. Pak J Biol Sci. 16 (3), 121–126.

Wu L, Yang JZ. 2012. Identifications of captive and wild Tilapia species existing in Hawaii by mitochondrial DNA control region sequence. PLoS One. 7(12): e51731.

Zengeya TA, Booth AJ, Chimimba CT. 2015. Board niche overlap between invasive Nile tilapia *Oreochromis niloticus* and indigenous Congeners in Southern Africa: should we be concerned. Entropy. 17:4959–4973.

Zhu HP, Lu MX, Huang ZH. 2008. New practical techniques to healthful aquaculture of tilapia. Beijing: Ocean Press (in Chinese).