IMPACT OF INTRODUCTION OF ALIEN SPECIES ON THE FISHERIES AND BIODIVERSITY OF INDIGENOUS SPECIES IN THE ZHANGHE RESERVOIR OF CHINA AND TRI AN RESRVOIR OF VIETNAM

Mitigating Negative Environmental Impacts/ Study/ 07MNE03UM

ZHANGE RESERVOIR, CHINA REPORT

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ABSTRACT

China has a long history of introducing alien species (e.g., tilapia, rainbow trout) to develop aquaculture. These alien species have brought numerous benefits for economic development, but there has been little study of the ecological and economic impacts of these species. The objective of this research was to estimate the environmental impacts of the 1992 introduction of Taihu icefish (*Neosalanx taihuensis*) in Zhanghe Reservoir. Historical data on fish catches and fish species composition were collected from relevant reservoir management agencies and the Zhanghe Reservoir Fisheries Management Company. The primary data on fish catches were collected through seining surveys of fish at thirteen locations in the reservoir, surveying the species structure at fish landing points, and analyzing questionnaires completed by fishermen. Dissolved oxygen, water temperature, pH, and Secchi disc visibility were measured weekly. Total alkalinity, nitrate-nitrogen, nitrite-nitrogen, total ammonia- nitrogen, phosphate and chlorophyll-*a* concentrations were also measured monthly. Before 2005, the mean icefish yield was approximately 150 t yr^{-1}. The yield of icefish in Zhanghe Reservoir unexpectedly decreased significantly in 2006, and the fish were nearly extirpated in 2007. Icefish and bighead carp *(Aristichthys nobilis)* have similar feeding habits. Because of the reduction in competition for food, the yield of bighead carp increased gradually from 2003 through 2008. The decreasing yield of icefish was attributed to the rapid increase in yield of culters (*Culter alburnus* and *Culter mongolicus*). Culters eat icefish as their main food, and the culter yield was steady at ~50 t per year before 2004, but increased to 120 t in 2008. The reason for this increase was the intentional removal of the top predator yellowcheek (*Elopichthys bambusa*) from this reservoir. Before 2008, people recognized yellowcheek as the inhibitor to increased icefish yield and have tried to eliminate this species from Zhanghe Reservoir since 2004. The disappearance of the top predator yellowcheek indirectly led to the extirpation of icefish and increased yield of bighead carp in Zhanghe Reservoir. This provides us with strong evidence that not only can alien species influence indigenous species, but also vice versa.

INTRODUCTION

Zhanghe Reservoir (104 km^2 surface area) is a temperate oligotrophic lake located in the center of Hubei. It consists of two parts, the upstream and downstream lake (Figure 1). These two parts are connected by a narrow channel. The maximum depth of this reservoir is 70 m, and total volume is 20.35 x 10^9 m^3. The main fish species originated from the Zhanghe and Yangtze rivers, thus the fish community is mainly comprised of the major Chinese carps (Yao, 2002), yellow catfish (*Pelteobagrus fulvidraco)* and yellowcheek (*Elopichthys bambusa*). Yellowcheek are a large, carnivorous, and pelagic species confined to the Chinese mainland (Xiao et al., 2001), Russia (Bogutskaya and Naseka, 1996; Reshetnikov et al., 1997; Pietsch et al., 2000) and Vietnam (Rainboth, 1991; Kottelat, 2001). In the basin of Yangtze River, it is the largest top predator and plays a very important role in the maintenance of the reservoir ecosystem. Due to the fact that there is no industry around the upstream lake, there is a relatively good water quality and negligible pollution or eutrophication. The low extent of human interference makes the upstream lake a very good model to investigate the effect of alien species.

The Taihu icefish (*Neosalanx taihuensis*) belongs to the Salangidae family, and is a very important commercial fish in China. Icefish were commonly distributed in eastern China lakes during the early 1950s. To meet consumptive demand, the harvest of wild icefish increased significantly from the 1950s through the 1970s. By the end of the 1970s, the populations of Taihu icefish had declined to dangerously low levels. Since then, Taihu icefish have been introduced to many inland lakes and reservoirs to recover the populations of this threatened species. In 1992, 200,000 fertilized Taihu icefish eggs were introduced into the Zhanghe Reservoir, resulting in a 5.7 t icefish catch three years later (Yao, 2002). From 1996 to 2006, Zhanghe Reservoir continuously produced Taihu icefish, and the species developed into a mainstay for commercial harvest by the Zhanghe Reservoir Fisheries Management Company.

In this study, we collected historic and contemporary data on the yields of different fish species in Zhanghe Reservoir to investigate the interactions between alien and indigenous species.

METHODS

Field Study

Field sites were located in the upper and lower Zhanghe Reservoirs in Jingmen, Hubei, China. Lab work was conducted in Huazhong Agricultural University, China. Historical data on fish catches and species composition were collected from relevant reservoir management agencies, the Zhanghe Reservoir Fisheries Management Company.

During the one-year study period in 2008, fish catches and species composition were collected through: (1) seining fish at four upstream, five midstream and four downstream locations of the two reservoirs once during each season (winter, spring, summer and autumn); (2) collecting data at fish landing points; (3) collecting data during the annual harvest by the fisheries management companies; and (4) providing data sheets to all fishermen in the reservoir for recording the fish species caught and offering a 20 RMB (~3 USD) reward for each sheet returned.

Physical data were collected from September 2007 to August 2008. In the laboratory, total phosphorus (TP) concentration was measured by colorimetry after digestion of the entire sample with $K_2S_2O_8$ + NaOH to orthophosphate (Ebina, 1983). Total nitrogen (TN) was digested simultaneously with TP. After digestion, TN was measured as nitrate and absorbance was measured at 220 nm. Nitrate-N (NO_3^--N) was analyzed using the automated Korolev/cadmium reduction method (APHA, 1992).

The values of temperature, pH, conductivity, and water transparency were obtained in situ. Temperature was measured by a WMY-01 digital thermometer (Shanghai Huayan

Instruments Co., Ltd.). Conductivity and pH were determined with DDB-303A and PHB-4 pH meters, respectively (Shanghai Precision & Scientific Instrument Co., Ltd). Dissolved oxygen (DO) was measured by a JPB-607 DO meter (Shanghai Precision & Scientific Instrument Co., Ltd). Transparency was measured with a Secchi disk.

Biological data were also collected from September 2007 to August 2008. Chlorophyll *a* was determined with a spectrophotometer (Lorenzen, 1967) after filtration through Whatman GF-C glass filters and a 24 h extraction in 90 % acetone. Phytoplankton determinations were carried out on samples preserved in acetic Lugol's solution and formaldehyde (Saraceni, 1974), then sedimented for 48 h. The supernatant was removed and the residue was collected. After complete mixing, 0.1 ml concentrated samples were counted directly through a 0.1 ml counting chamber using a Nikon microscope at a magnification of 400 x. Phytoplankton species were identified according to Hu et al. (1980). The count (including colonial forms) was conducted by enumerating single cells. Algal biomass (expressed as mg fresh weight l^{-1}) was estimated from the closest geometric volume of each taxon, assuming a mean density of 1 g mm^{-3}. If the species within taxa showed a large size difference, the individuals of that species were divided into several cell size classes in order to determine the volume accurately.

Crustacean zooplankton were sampled using a 5 l modified Patalas bottle sampler. Samples were obtained by straining 50–80 l reservoir water collected from different depths through a 64 mm mesh plankton net and were preserved according to Haney (1973). Crustacean plankton were identified according to Chiang (1979) and Sheng (1979) and counted under a magnification of 6.3 x 10.

At the end of the study, stomach content analysis was performed on fish collected at each experimental site to determine the electivity index and dietary overlap of each species using Ivlev's electivity index (1961) and Schoener's overlap index (1970). Twenty fish from each species were collected randomly from each field site one day before the end of experiment for stomach content analysis.

Workshops

After completion of the analyses, two one-day workshops were organized in China to present findings from this project as part of a continuing consultation process. Farmers, reservoir management entities, and government officials attended and gave input toward general recommendations on policies for the introduction of alien species. Detailed information including the agenda and a list of participants is presented in Appendix 1.

RESULTS

Field Study

Annual means and ranges of the main physical chemical and biological parameters in Zhanghe Reservoir are listed in Table 1. Pronounced stratification was observed from April to November and a complete homogenization took place from January to March. Water temperature was the highest in July (24.4 $^{\circ}$C) and the lowest in February (14.3 $^{\circ}$C). The lowest Secchi depths (Sd) occurred in March, July and November. In general, Sd was higher in the north basin than in the south basin. The maximum pH was in April. The maximum conductivity was in August. Mean DO concentration had a maximum in October and minimum in September. The minimum concentrations (about 10 μg/l) of nitrate-N were recorded in November and March (Figure 2).

The cladoceran *Bosmina longirostris* and the calanoid *Phyllodiaptomus tunguidus* dominated the crustacean plankton community during the study period (Figure 3). The highest density peak of total planktonic crustaceans was present in April (25.4 individuals/l) when *Bosmina* *sp.* dominated total cladocerans. The density of *Cyclopoida* was below 0.3 individuals/l throughout the entire study period.

Both Chlorophyll-*a* concentration (Figure 4) and total algal biomass (Figure 5) peaked in March, and reached a minimum value in August. These metrics showed quite similar seasonal dynamics. Dense populations of centric diatoms contributed greatly to the maxima of chlorophyll α and algal biomass. During the complete thermal homogenization of the water column (December 2007 to January 2008), *Mougeotia sp.* and *Fragilaria crotonensis* were dominant, and *Mougeotia sp.* reached a maximum biomass of 0.58 mg/l in December. When water temperature reached minimum in February, the filamentous green alga *Ulothrix subtilissima* peaked (Fig. 6). In the early spring (March), the unicellular centric diatom *Cyclotella rhomboideo-elliptia* contributed greatly to the phytoplankton assemblages. With the appearance of thermal stratification at the end of March, the dominance of diatoms was quickly replaced by *Mougeotia sp*.

The most common fish caught in Zhanghe Reservoir were silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), topmouth culter (*Culter alburnus*), Mongolian culter (*Culter mongolicus*), culter dabryi (*Erythroculter dabryi*), and yellow catfish. The historical yields of the species mentioned above (except yellow catfish, as the yields of this species were not calculated annually) are shown in Figures 7 and 8. Unfortunately, Taihu icefish were not recorded being caught after 2006 (Figure 9). After three sampling efforts, only 54.8 grams of Taihu icefish were caught. Interestingly, the inventory of top predator yellowcheek was negatively related to the yield of culters (Figure 10).

The stomach contents of a total of 259 specimens of topmouth culter (total length 24-53 cm) are shown in Table 2. Among the specimens examined, 178 (68.7%) had food in their stomachs. The diet of topmouth culters consisted of at least 17 different species. Taihu icefish was the most important prey by mass (34.4%) and number of individuals (39.5%), bighead carp and silver carp also made crucial contribution to the diet, followed by *Gobius sp*. The stomach content analysis showed that the Taihu icefish were greatly preyed by culters .

A comparison of stomach content between Taihu icefish and bighead carp showed that they shared some common species for diets. The main taxa in the Taihu icefish diet were *Calanoida*, *Cyclopidae,* and *Rotifera*. Those three taxa also were common in the diet of bighead carp, although the latter mainly consumed *Glenodium* as well (Table 3).

Workshops

Two one-day workshops were organized in China. One was held on 12 March 2009 at Zhanghe Reservoir and was organized jointly by Jingmen Aquatic Products Bureau (JMAPB) and the College of Fisheries of Huazhong Agricultural University (HZAU). The workshop was attended by 108 participants, of which 43 were women, representing provincial and district government agencies, reservoir management entities, farmers and community members. The workshop was opened with a welcome address by Mr. Yan Liqing from the Management Center of Zhanghe Reservoir (MCZHR), followed by a self-introduction of all participants. Mr. Wang Yangzhong from JMAPB explained the objectives of the workshop to the participants, and then Professor Wang Weimin gave a presentation to introduce the history, activities, and achievements of ACRSP during the past years. Two additional presentations entitled, "The status and perspective of fisheries in Zhanghe Reservior" and "The impact of an introduction of an alien species on the fisheries and biodiversity of indigenous species in Zhanghe Reservoir of China," were addressed by Mr. Zhang Hongfeng from MCZHR and Mr. Li Yang from HZAU, respectively. An open discussion followed the presentations. In the afternoon, all the participants visited Zhanghe Reservoir and Huiting Reservoir in Jingmen, Hubei, China.

Another one-day workshop was held on 30 May 2009 at Hubei Aquatic Products Bureau (HBAPB) which was organized jointly by HBAPB and HZAU. This workshop was attended by 93 participants, of which 38 were women, representing provincial and district government agencies, reservoir management entities, farmers and community members. The workshop was opened with a welcome address by Mr. Shi Fengxiang from HBAPB, followed by self-introduction of all participants. Professor Wang Weimin briefed the participants on objectives of the workshop, followed by a presentation that introduced the history, activities and achievements of ACRSP during the past years. Mr. Shi Fengxiang gave a presentation titled "The development of the aquaculture industry in Hubei province," followed by the presentations "The status and perspective of fisheries in Zhanghe Reservoir" (Mr. Zhang Hongfeng), "Impact of introduction of alien species on the fisheries and biodiversity of indigenous species in Zhanghe Reservoir of China" (Mr. Li Yang), "Structure, design and establishment of a database application system for alien aquaculture species in Hubei province, China" (Dr. Wei Kaijian), and "Managing alien species for sustainable development of aquaculture and fisheries" (Dr. Ma Xufa). An open discussion followed the presentations. Themes of discussion included: impacts (environmental, ecological, social and economic) arising from the introduction of non-native aquatic species; aquaculture and aquaculture-related operations involving non-native species; constraints in establishing good practices in the introduction of aquatic species; and recommendations on potential mitigation- remediation procedures and contingency plans.

DISCUSSION

Taihu icefish, which was considered a threatening alien species before this study, is now facing the threat of extirpation itself in Zhanghe Reservoir. The unexpected results of these investigations indicate that not only can alien species influence indigenous species, but also vice versa. The stomach content analysis showed that Taihu icefish were greatly preyed upon by culters. The significant decline in the yield of icefish can be attributed to the increasing of population of culters (*Culter alburnus* & *Culter mongolicus*) after 2005.

Yellowcheek are commonly recognized as a barrier to increased yield of fish at lower trophic levels (Yao, 2002). Zhanghe Reservoir received occasional introductions of yellowcheek when the river flooded, but since there is no suitable environment for breeding and over-fishing exists as well, the population decreased very rapidly from the 1970s to the 1980s. To increase the yield of Taihu icefish, the Zhanghe Reservoir Fisheries Management Company has been working to eliminate this predator since 1998. The intentional overfishing led to a near extirpation of yellowcheek in 2004 and finally its extirpation in 2006.

The disappearance of the top predator resulted in a significant increase in smaller predators which it consumed. In Zhanghe Reservoir, these predators are the culters. As the Taihu icefish is a more palatable food for the culters, the efficiency at which culters prey upon this fish is much higher than predation from yellowcheek on icefish. Contrary to the topmouth culter populations in the Yangtze River and Donghu Lake (Chu, 1976), icefish were the main food source (followed by bighead carp and *Gobius sp*.) for the topmouth culter in Zhanghe Reservoir. So, the reason for decline in the icefish yields is clear. As the top predator yellowcheek were eliminated there was an increase in culter populations, which exerted predation pressure upon icefish and decimated their population and harvest.

Due to similarities in feeding habits, the bighead carp (*Aristichthys nobilis*) compete for the food with Taihu icefish in Zhanghe Reservoir. The decrease of Taihu icefish in 2006 reduced this competition, thus causing the yield of bighead carp to increase gradually from 2006 to 2008.

This study has shed light upon the trophic interactions that affect Taihu icefish populations in Zhanghe Reservoir. Since this alien species was introduced in 1992, it became well integrated into the local ecosystem. As populations stabilized, the annual yield of icefish was maintained at a level of approximately 150 t for nearly a decade. The top predator yellowcheek had been wrongly considered to have a negative impact in the fisheries development of Taihu icefish, and was intentionally eliminated from the reservoir. The removal of yellowcheek allowed the predatory culter populations to expand, causing the collapse of the Taihu icefish. Even with the immediate correction of this error, it will take several years for the Taihu icefish fishery to recover. Future studies need to build a detailed model to estimate the roles of different species involved in the foodweb, which may be helpful for predicting the ecosystem effects of future management decisions and aid in the manipulation of fish harvest.

ANTICIPATED BENEFITS

The protection of native species is an important issue facing several countries in Asia, where the introduction of alien species is viewed with skepticism. Results of this research showed that indigenous species can significantly influence alien species, as well as vice versa. The threat of alien species to native ecosystems should neither be ignored nor be overrated. This investigation has helped the Zhanghe Reservoir Management Company identify the true cause for the decline of the Taihu icefish fishery in Zhanghe Reservoir. More generally, the findings of this study will caution other fisheries management agencies before they consider attempting to manipulate entire ecosystems, creating a more reliable open water fishery.

ACKNOWLEDGMENTS

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FIGURES AND TABLES

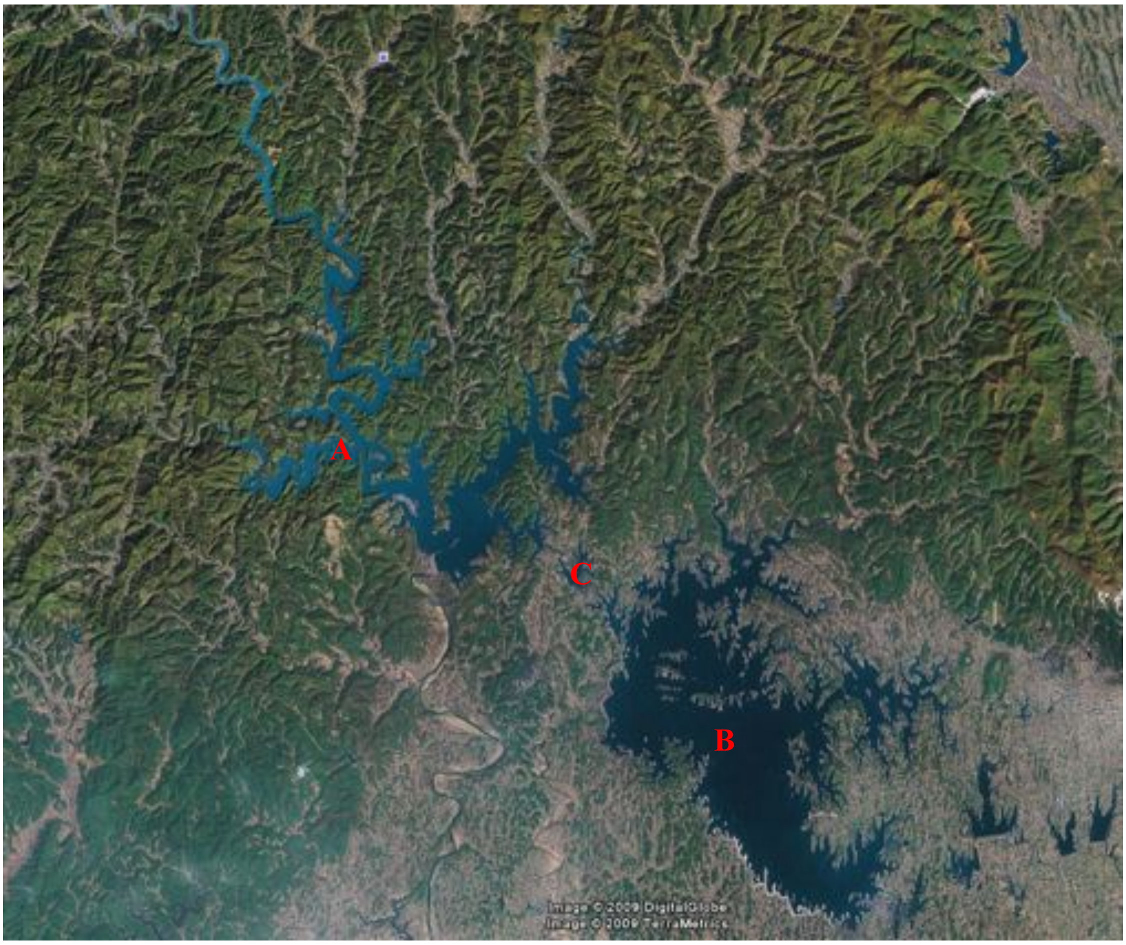

Figure 1. Satellite image of Zhanghe Reservoir (Google Earth, 2009). The upstream lake of Zhanghe Reservoir (A) flows into the downstream lake (B) via a connecting channel (C).

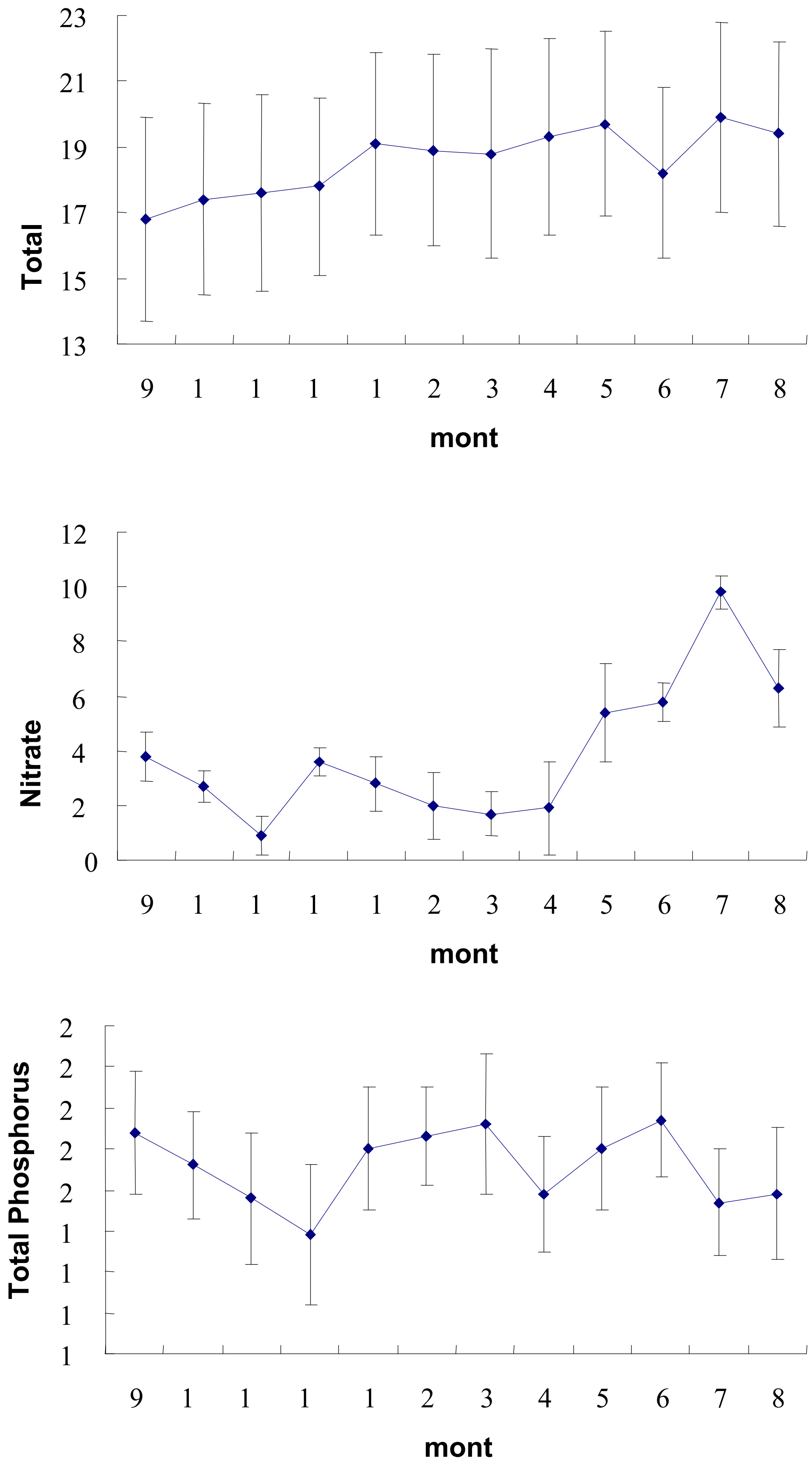

Figure 2. Temporal variation of TN, nitrate-N, and TP (mg/L) in Zhanghe Reservoir, China.

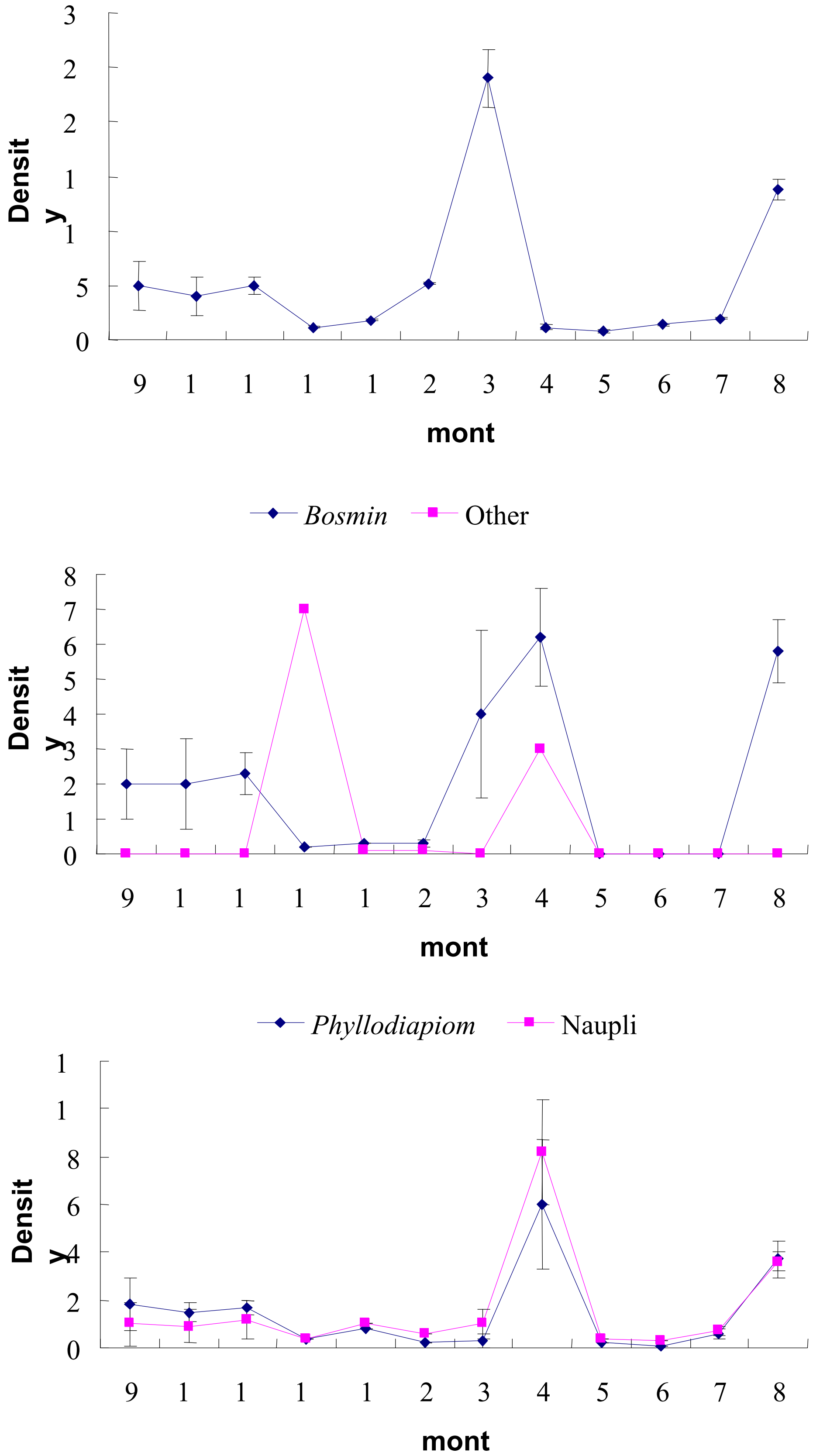

Figure 3. Temporal variations in the density (individuals/l) of crustacean plankton in Zhanghe Reservoir, China, 2007-2008.

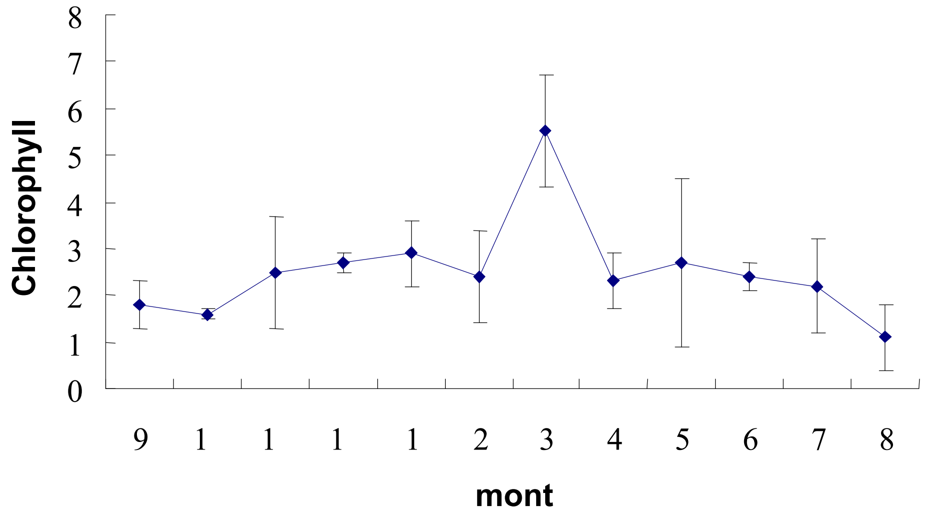

Figure 4. Temporal variations of total algal biomass (μg/l) in Zhanghe Reservoir, China during 2007-2008.

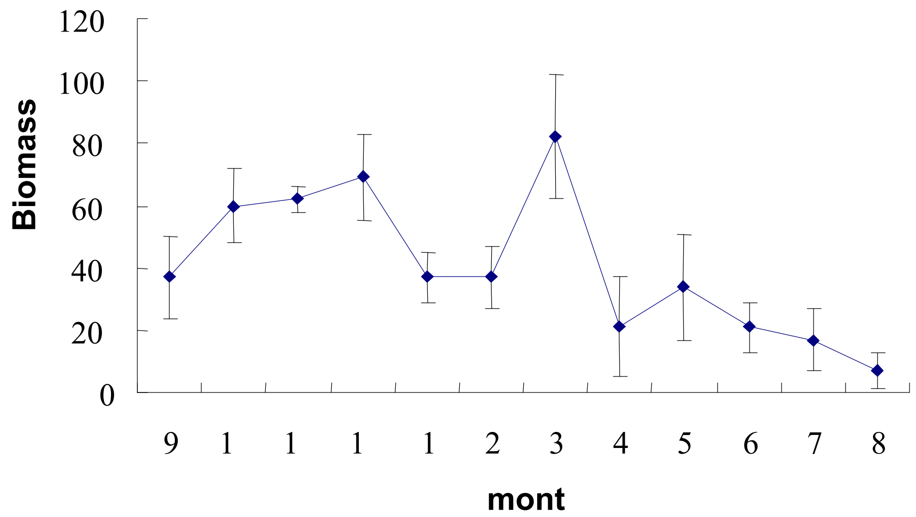

Figure 5. Temporal variations of chlorophyll *a* (μg/l) in Zhanghe Reservoir, China, during 2007-2008.

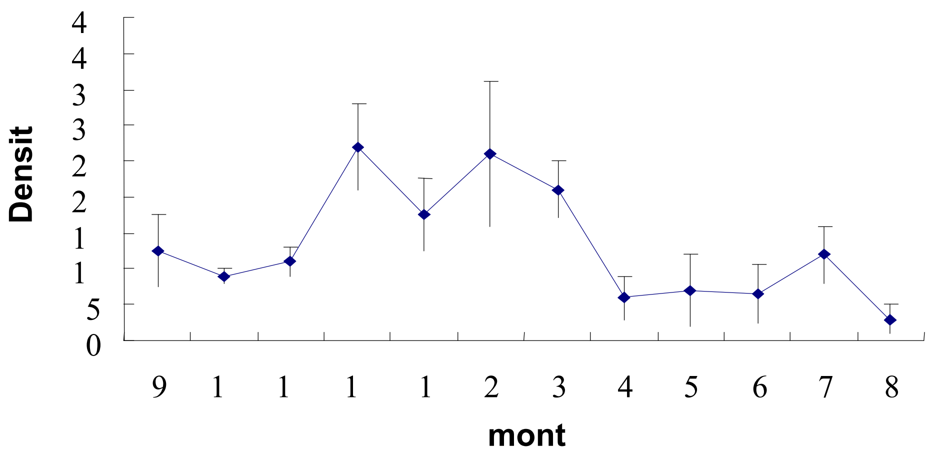

Figure 6.Temporal variations in filamentous green alga *Ulothrix subtilissima* density (×10^4 ind./l) for periodic samples in Zhanghe Reservoir, China, 2007-2008.

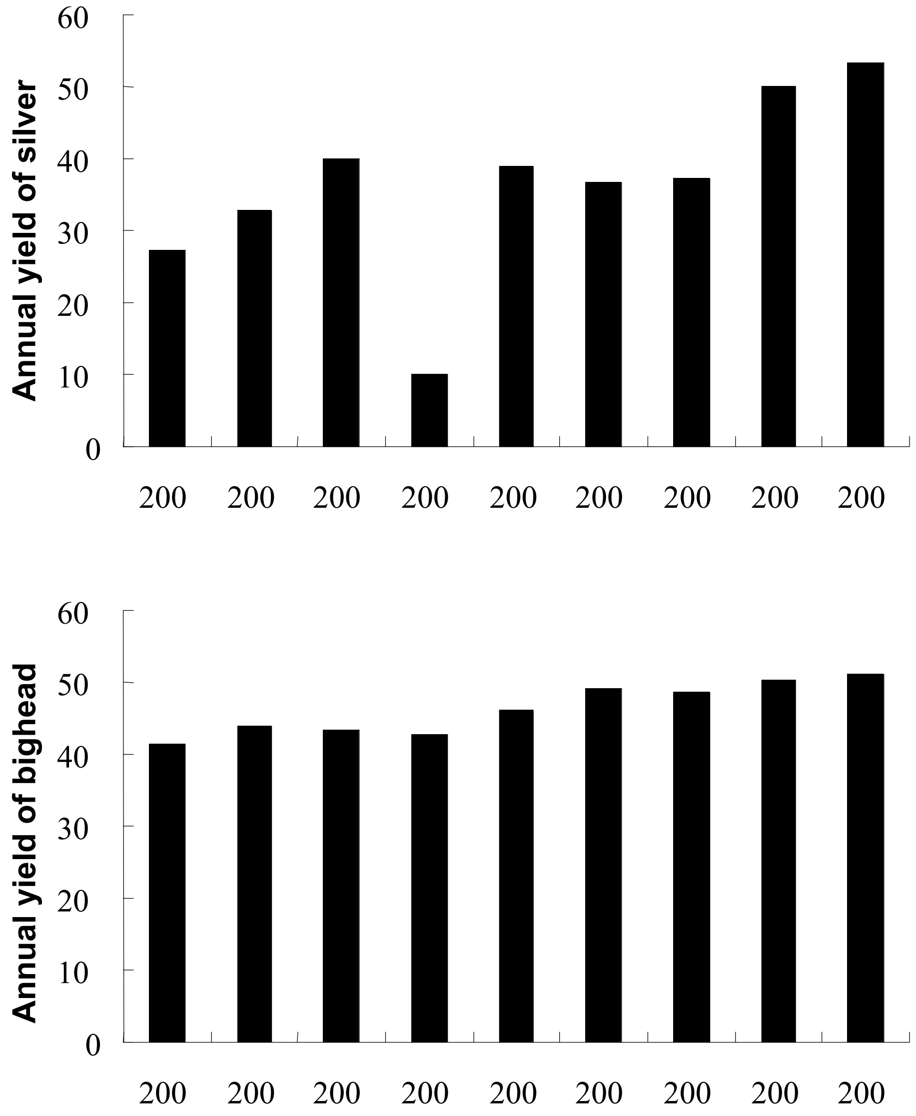

Figure 7. Annual yield (t) of silver carp and bighead carp in Zhanghe Reservoir, China 2000-2008.

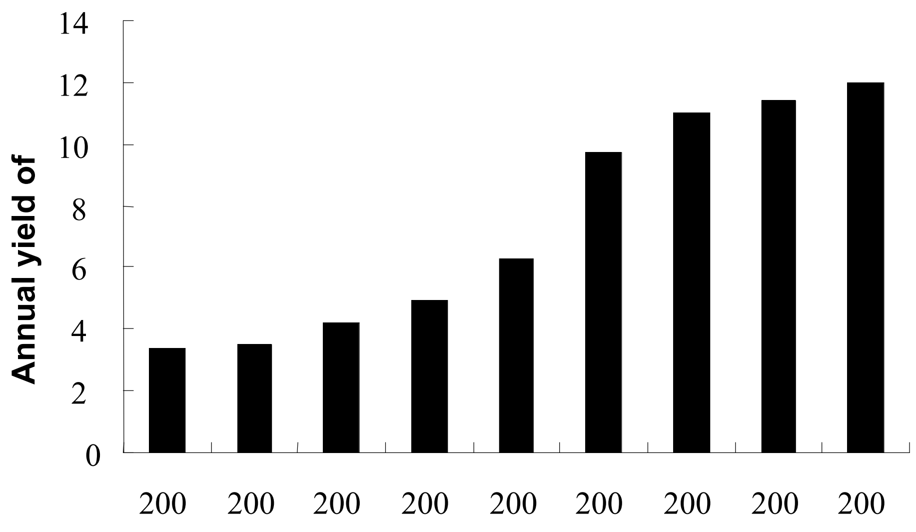

Figure 8. Annual yield (t) of culters (*Culter alburnus*, *Culter mongolicus* and *Erythroculter dabryi*) in Zhanghe Reservoir, China, 2000-2008.

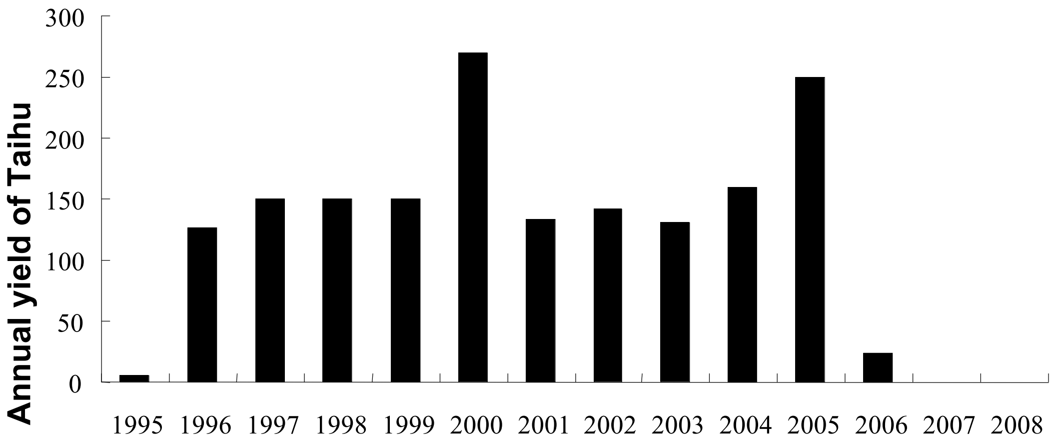

Figure 9. Annual yield (t) of Taihu icefish (*Neosalanx taihuensis*) in Zhanghe Reservoir, China, 1995-2008.

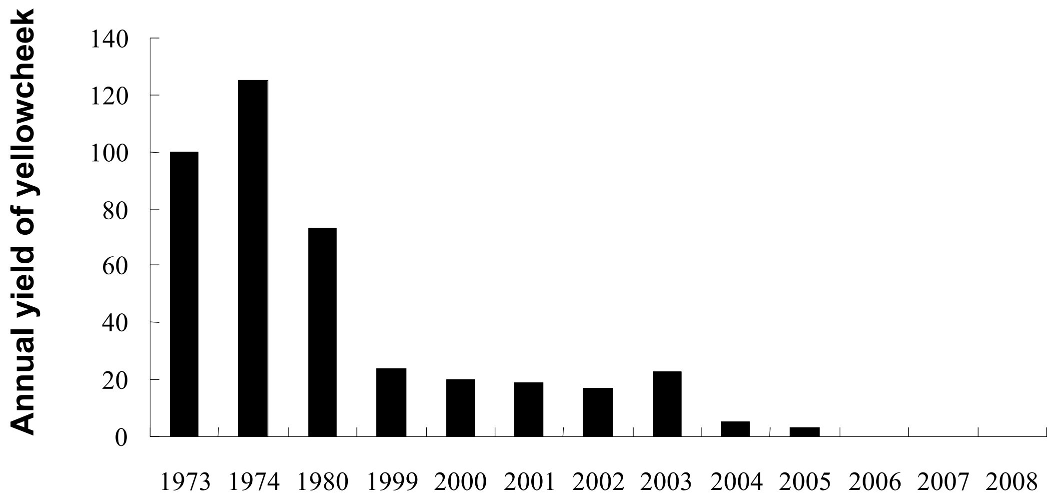

Figure 10. The annual yield (t) of yellowcheek (*Elopichthys bambusa*) in Zhanghe Reservoir, China 1973-2008.

Table 1. Annual means and ranges of physical, chemical, and biological parameters in Zhanghe Reservoir.

	Mean	Range
Secchi disc depth, m	7.01	5.19-7.91
Conductivity, μS/cm	287.0	237.8-345.6
pH	7.4	7.14-7.80
Dissolved oxygen content, mg/l	9.63	7.32-13.83
TP, μg/l	20.7	18.9-21.8
TN, g/l	198.1	168.5-213.0
NO_3-N, μg/l	40.2	10.0-105.0
Chlorophyll a, μg/l	2.32	1.27-5.44
Density, $\times 10^4$ ind./l	13.2	3.4-25.6
Biomass, mg/l	0.407	0.052-0.795

Table 2. Stomach food contents of 259 topmouth culter (*Culter alburnus*), in Zhanghe Reservoir, China.

Species	Food item amount (%) by mass	Food item occurrence (%) by number
Neosalanx taihuensis	34.4	39.5
Aristichthys nobilis	19.7	20.1
Hypophthalmichthys molitrix	10.0	9.8
Gobius sp.	17.0	15.2
Toxabramis swinhonis	3.9	3.5
Erythroculter ilishaeformis	3.8	3.1
Hemibarbus maculatus	2.3	2.1
Erythroculter mongolicus	2.3	1.7
Carassius auratus	1.5	1.0
Pseudorasbora parva	1.5	1.0
Hemiculter sp.	1.2	1.0
Mastacembelus aculeatus	0.8	0.4
Erythroculter dabryi	0.4	0.4
Acanthobrama simoni	0.4	0.4
Megalobrama amblycephala	0.4	0.4
Siniperca chuatsi	0.4	0.4

Table 3. The diet composition (%) of Taihu icefish (*Neosalanx taihuensis*) and bighead carp (*Aristichthys nobilis*) in Zhanghe Reservoir, China, May 2008.

Species of diet	*Neosalanx taihuensis*	*Aristichthys nobilis*
Calanoida	48.38 ± 8.58	14.75 ± 5.90
Cyclopidae	17.89 ± 3.61	8.84 ± 4.02
Nauplius	2.68 ± 1.44	1.48 ± 0.44
Bosmina	6.57 ± 4.92	15.73 ± 7.20
Daphnia	3.59 ± 5.20	4.60 ± 3.79
Moina	0.05 ± 0.11	0.52 ± 1.10
Diaphanosoma	1.69 ± 1.48	2.80 ± 0.70
Simocephalus	0.57 ± 0.93	2.75 ± 1.78
Leptodorkindtii	0.95 ± 0.69	0.46 ± 0.27
Longispina	0.13 ± 0.28	1.22 ± 0.29
Chydorus	0.52 ± 0.28	2.53 ± 0.80
D. magna	0.31 ± 0.56	0.87 ± 0.51
Bosminopsis	0.53 ± 0.34	1.33 ± 0.32
D. cucullata	0.33 ± 0.65	0.15 ± 0.27
D. leuchtenbergianum	0.18 ± 0.28	1.62 ± 0.74
Rotifera	15.63 ± 2.64	17.92 ± 8.29
Glenodinium sp.	0	22.43 ± 8.81

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APPENDIX 1. Workshop agendas.

Agenda 1#

Thursday, 12 March, 2009	
8:30 – 9:00	Breakfast & Registration
9:00 – 9:10	Welcoming remarks Mr. Yan Liqing (Management Center of Zhanghe Reservoir)
9:10 – 9:30	Self-introductions of all participants
9:30 – 9:40	Orientation and introduction of the workshop Mr. Wang Yangzhong (Jingmen Aquatic Products Bureau)
9:40 – 10:10	Presentation “The history, activities and achievements of ACRSP during the past years” Prof. Weimin Wang (Huazhong Agricultural University)
10:10 – 10:50	Presentation “Status and perspective of fisheries in Zhanghe Reserivor” Mr. Zhang Hongfeng (Management Center of Zhanghe Reservoir)
10:50 – 11:20	Presentation “Impact of introduction of alien species on the fisheries and biodiversity of indigenous species in Zhanghe Reservoir of China” Ph.D. student Li Yang (Huazhong Agricultural University)
11:20 – 12:00	Questions and group discussion
12:00 – 13:00	Lunch
13:00 – 15:00	Tour at Zhanghe Reservoir in Jingmen City, Hubei province, China
15:00 – 18:00	Tour at Huiting Reservoir in Jingmen City, Hubei province, China
18:00 – 20:00	Banquet

Agenda 2#

Saturday, 30 May, 2009	
8:15 – 8:45	Breakfast & Registration
8:45 – 9:15	Welcome remarks. Mr. Shi Fengxiang (Hubei Aquatic Products Bureau)
9:15 – 10:00	Self-introduction of all participants
10:15 – 10:30	Break

10:30 – 11:00	The introduction of workshop Prof. Wang Weimin (Huazhong Agricultural University)
11:00 – 11:30	Presentation “The history, activities and achievements of ACRSP during the past years and the achievements of our present project to evaluate the effectiveness of current waste management practices for tilapia intensive culture in Hainan province.” Prof. Wang Weimin (Huazhong Agricultural University)
11:30 – 12:00	Presentation “The development of aquaculture industry in Hubei province” Mr. Shi Fengxiang (Hubei Aquatic Products Bureau)
12:30 – 13:30	Lunch
13:30 – 14:00	Presentation “Status and perspective of fisheries in Zhanghe Reserivor” Mr. Zhang Hongfeng (Management Center of Zhanghe Reservoir)
14:00 – 14:30	Presentation “Impact of introduction of alien species on the fisheries and biodiversity of indigenous species in Zhanghe Reservoir of China” Mr. Li Yang (Huazhong Agricultural University)
14:30 – 15:00	Presentation “Structure design and establishment of database application system for alien aquaculture species in Hubei province, China” Dr. Wei Kaijian (Huazhong Agricultural University)
15:00 – 15:10	Break
15:10 – 15:40	Presentation “Managing alien species for sustainable development of aquaculture and fisheries” Dr. Wang Dan (Institute of Hydrobiology, Chinese Academy of Sciences)
15:40 – 18:00	Questions and group discussion
18:00 – 19:00	Dinner

TRI AN RESERVOIR, VIETNAM REPORT

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ABSTRACT

This study was conducted at Tri An Reservoir of Vietnam from November 2007 to June 2009 to determine the impact of tilapias (*Oreochromis* spp.) on the fisheries and biodiversity of indigenous species in the reservoir. Historical data on fish caught and fish species composition was collected from Dong Nai Fisheries Company and Dong Nai Aquatic Resources Conservation Bureau. To gather current fish species composition data, this study interviewed fishermen about their fishing gears and harvest as well as middlemen at fish landing points. To understand the fluctuations of fishing seasons and locations, gill nets (mesh size 40-60 mm) were used to seine fish at four, five and four locations upstream, midstream and downstream in the reservoir four times per year. Previous surveys in 1983 and 1985 recorded 102 species before the reservoir was established, and since it was built, 109 species have been recorded. However, creel surveys in this study observed only 40 fish species recorded at landing points. The total fish production in 1995, 2000, 2005, and 2008 was 1126, 2301, 2589, and 3823 tons, respectively. However, the total production from four landing points combined was only approximately 1661 tons. This study was unable to use historical catch data from the Dong Nai Fisheries Company and Aquatic Resources Conservation Bureau because the data lacked information on fish species composition and fishing gears used.

There are currently 19 different types of fishing gears in use on the reservoir, of which 14 caught tilapias. Of the five fishing gears with highest total catches, only two caught tilapias. Tilapias represented 4.62% and 5.09% of fishermen's harvest and landing point records, repectively. However, tilapias were sixth most common of the 40 fish species caught from fishermen's data, indicating the rather low productivity of most other fish species in the reservoir. Among the six species with highest biomass, the only economically valuable species recorded were the silver barb (*Barbonymus gonionotus*) and tilapias. The species with low economic value that are abundant in the reservoir accounted for 64% of estimated total fish harvest (3823 tons) in 2008. High production of low value species was also reflected at landing points, with glass fish and river sprat accounting for 355.91 and 243.68 of the total 1661 tons landed in 2008. The abundance of low economic value fishes may affect fisheries and fish biodiversity much more than the impact of alien species.

Fish species composition from fish collected by seine was composed of more species with high economic value. Estimated tilapia catches and landing records show that tilapia species were abundant (84.62 of the total 1661 tons at landing points), second most only to silver barb (147.59 of 1661 total tons). This pattern held, despite the fact that tilapia were not stocked in ten years, while other cultured fish species were stocked regularly. During the peak catches of tilapias in August in 2008, the other top five most commonly caught fishes were not at their peak catches, even though such fish species have similar trophic levels as tilapias. This indicated an important role of tilapias in reservoir's food web.

INTRODUCTION

Tilapias (*Oreochromis* spp.) support an enormous market throughout Asia. Additionally, tilapias have been promoted as a food supply for poor farmers. Tilapias were introduced into Vietnam several times from 1951 to 1997, and have been widely cultured in various systems, including ponds, cages, and rice-fields (Tu, 2003). There were 700 tilapia hatcheries in Ho Chi Minh City in 2003, resulting in a seed production of 400 MT per year (Tu, 2003). According to MOFI (2006), the production of tilapia in Vietnam was 54,000 MT in 2005, with a total cultured area of 2,148 ha in 2004. Such rapid development of tilapia culture resulted in range expansion and invasion into natural environments. In addition, restocking tilapia in reservoirs was also generally aimed at increasing the overall fish catch (FAO-SEAFDEC, 1985). The rapid expansion of tilapia populations in Vietnam's natural waters indicates that the ecosystems are able to support the invasion, and that tilapias are serious concern that deserves research and caution.

Escaped tilapias from aquaculture have established populations in reservoirs (Tu, 2003; 2006). For example, tilapias accounted for about 4% and 20% of the total catch in Tri An and Thac Mo reservoirs, respectively (Tu, 2003; 2006). Some regard tilapias as beneficial to local fisheries, mosquito control, or aquatic plant control; some consider them pests with stunted populations that compete with indigenous fish species; and some consider their effects to be both positive and negative, depending on geographical area (Lowe-McConnell, 2000). It is important to realize that the role of tilapia in a reservoir may differ from other native species found there, since the species complex in a reservoir is not natural for such a system but derived from the rivers that flood it.

The purpose of this study is to investigate the impacts of tilapias on fisheries and biodiversity of indigenous fish species in Tri An Reservoir, Vietnam. Information on the impacts of introduced alien species on fisheries and indigenous fish biodiversity will allow governmental agencies to establish policies, plans, and mechanisms to manage the introduction of alien species.

MATERIALS AND METHODS

This study was conducted at Tri An Reservoir from November 2007 to June 2009. Tri An Reservoir was constructed in 1984 for the main purpose of providing hydroelectric power to southern Vietnam, which it has been doing since 1988. It was formed as a result of a dam constructed on the upper Dongnai River. The Tri An Reservoir is the largest reservoir in Vietnam, with a surface area of 324 km^2 and 15.05 km^3 of water storage capacity. It has an electric capacity of 420 MW, generating an average of 1,700 GWh/year.

Tri An Reservoir is located at 10° through 12°20'N and 107° through 108°30'E. The watershed of Tri An Reservoir is around 15,400 km^2, with a mean reservoir length of 43.5 km, mean width of 7.5 km, maximum depth of 28 m, total volume of 2.76 km^3, and mean area of 323.4 km^2.

The primary data on fish catch and fish species composition was collected during a one-year study period in four ways:

(1) Collecting data during the annual harvest by the fisheries management companies;

(2) Collecting data at fish landing points such as Ap 1, Phu Cuong, and La Nga;

(3) Interviews with fishermen for their fish catch and species composition;

(4) Field sampling to investigate seasonal fish species composition.

Secondary data on historical fish catch and fish species composition in Tri An Reservoir was collected from relevant reservoir management agencies such as the Dong Nai Fisheries Company, Dong Nai Department of Agriculture and Rural Development, Dong Nai Bureau of Fisheries Resources Protection and Management, and Dong Nai Fisheries Extension Center.

Interviews with fishermen for catch and species composition

Interviews with fishermen consisted of two main themes: the type of fishing gear used and the fish catches for each fishing gear. There were 151 fishermen interviewed at locations upstream, midstream and downstream in the reservoir, accounting for around 15% of the total fishermen in the reservoir. At the upstream area, 49 of the interviewed fishermen belonged to La Nga and Thanh Son communes. At the midstream area, 57 of the interviewed fishermen belonged to Phu Cuong and Gia Tan communes. At the downstream area, 45 of the interviewed fishermen belonged to Ma Da and Vinh An communes.

The total number of each type of fishing gear was recorded from Dong Nai Fisheries Company. Detailed information that was not available at Dong Nai Fisheries Company such as catch per unit effort (CPUE), fishing times and durations, and fish species composition was determined directly from fishermen in interviews. CPUE was defined as the daily average catch (kg/day) for each type of fishing gear.

Field sampling to investigate seasonal fish species composition

Fish species composition in Tri An Reservoir was estimated by seining fish at 4, 5, and 4 locations at upstream, midstream and downstream locations in the reservoir four times per year. Field sampling was also carried out using gillnets with a mesh size of 40-60 mm, the net length and depth were 1,000m and 5m, respectively. Gillnets were fixed by floats for a whole day at each location. Seasonal sampling times were November 2007, February 2008, May 2008, and August 2008 representing the dry season (November and February) and rainy season (May and August).

Data analyses

The secondary and primary data from Tri An Reservoir were calculated in the percentage changes of fish catch and fish species composition over time using Microsoft Excel (Redmond, Washington, USA). A linear regression analysis determined the trajectory of CPUE (MT/fisherman) over time and $\alpha = 0.05$ was considered statistically significant.

RESULTS

The state of fish catches over time in Tri An Reservoir

Annual fish stocking rates varied over the years, while overall harvest showed an increasing trend from 1993-2008 (Table 1). A linear relationship between fish catch and effort had an $R^2 = 0.35$ and was not significant. The number of fishermen reached highs in 1998 and 2000 and essentially leveled off since then. If CPUE were defined by dividing the catch by number of fishermen, a linear relationship between CPUE and year shows a statistically significant increase in CPUE across all years (CPUE = (0.144 x year) – 284.88; $P < 0.001$; adjusted $R^2 = 0.65$). These data indicate an increasing harvest and possibly increasing fish production since 1993.

Fishing gears and species composition in Tri An Reservoir

There were 19 main types of fishing gears used in Tri An Reservoir, with mean daily catch (CPUE) for each fishing gear ranging from 3.4 to 71.4 kg/day (Table 2). CPUE for each fishing gear changed by season. The most productive gears in terms of CPUE were seine nets, machine scoop nets, lift nets with a light and lift nets without a light. In terms of quantity of fishing gears operating, gill nets, machine scoop nets, lift nets with a light and long lines were the most popular (Table 3). The five fishing gears with highest yearly catches were machine scoop nets (1 light), lift net with a light, gillnets (mesh size 40-60 mm), seine nets and machine scoop nets (18 lights). Fish catch of the top five fishing gears made up 81.7% of the total catch in the reservoir, with a total of 3,124 tons/year.

Proportions of tilapias caught in various fishing gears varied from 0-37% (Table 4). A gill net with mesh sizes varying from 40-140 mm was the main fishing gear used to catch tilapia. Other fishing gears with high tilapia catch rates were the horizontal cylinder basket traps and cast nets. There were 14 fishing gears (73.7%) that caught tilapias, of which 8 fishing gears caught tilapias taken throughout the entire year.

A total of 40 different species were captured by the 19 fishing gears used in the fishery (Table 5). The most abundant species (glass fish *Parambassis siamensis*, river sprat *Corica soborna*, repassan *Cyclocheilichthys repasson* and wrestling halfbeak *Dermogenys pusillus*) accounted for 64% of estimated total fish harvest (3823 tons) in the reservoir in 2008.

Fluctuations of fishing seasons and locations
Twenty fish species were collected in 2008 using seines, with 4 species comprising nearly 80% of the total catch (Table 6). Tilapias (*Oreochromis* spp.) were abundant, ranking second in catch after silver barb (*Barbonymus gonionotus*). Both tilapia and silver barb catches had high fluctuations by season, with peak catches in August and February, respectively. The other fish species with high catch rates were common carp (*Cyprinus carpio*) and repassan (*Cyclocheilichthys repasson*), accounting for 16.9 and 13.6% of the catch, respectively. Timing of the peak catch for tilapias (in August) was different from the other top five fish species with highest catches,

Fish species composition varied considerably with location in the reservoir (Table 7). Most fish species showed fluctuations in catch between upstream, midstream and downstream sites. At the upstream area, tilapias were the most abundant species (26.3% in catch by weight), but they were less abundant at the downstream sites. Silver barb (*Barbonymus gonionotus*) were abundant at the middle and downstream areas of the reservoir.

DISCUSSION

Fingerling stocking has not been consistent in Tri An Reservoir. This is especially true for tilapias, which have not been stocked in the last 10 years. Thus, current tilapia populations in the reservoir exist due to natural reproduction, while other traditional herbivorous fish are stocked more regularly (e.g., silver carp, bighead carp, and common carp). The data showed that 65% of the variation in CPUE was explained by a correlation with year, so CPUE has been steadily improving. However, this survey included reports by fishermen complaining about overfishing (e.g., declines in catch, or average size and age of fish). This contradiction between surveys and CPUE data suggests that the yearly total fish catch data of Dong Nai Fisheries Company may not be an accurate reflection of harvest throughout the reservoir. Improvements in the recording methodology as well as management practices are suggested for local fisheries agencies.

Recording and understanding seasonal variation in CPUE was necessary to estimate the yearly average CPUE for each fishing gear. However, most of the previous historical fish catch data from Tri An Reservoir did not contain this information, so it was difficult to precisely estimate yearly total catch.

The seasonal and total catch data for each fishing gear did not contribute directly to the assessment of tilapia impacts, but provided a general picture of diversity of fishing gear and activities at the reservoir. Among the top fishing gears with highest catches, machine scoop nets, lift nets and seine nets were likely to affect recruitment by catching fish of all size classes. Such gears should be regulated for better fishery management at the reservoir.

Of the top five fishing gears with the highest total catches, lift nets with a light and machine scoop nets (18 lights) were not used to catch tilapia, and machine scoop nets (1 light) tilapias did not focus on tilapia. This may be why tilapia only accounted for 4.62% of fish species composition caught in the reservoir, even though they accounted for 20% by weight of fish taken by seines in 2008. However, 14 of the 19 fishing gears operating in the reservoir caught tilapia. This finding suggests a wide distribution and production of tilapias across the reservoir. Tilapias were caught mainly by gill nets with mesh sizes less than 60 mm, resulting in a decrease in tilapia size and possible overfishing of tilapias in the reservoir.

According to Tung and Trong (2005), there were 109 fish species in Tri An Reservoir. Although our effort was less than that of Tung and Trong (2005), the low number of species caught in 2008 suggests a decline in biodiversity. However, there were no data to prove whether this decrease was caused by the impacts of fishing activity, alien species, or other factors. Sy (2008) implied some negative impacts on biodiversity due to alien carnivorous species in the reservoir, such as peacock bass (*Cichla ocellaris*), but not due to tilapias.

Among the top six species with the highest catches, only two economically valuable species were included: silver barb and tilapias. The fish of low economic value that were abundant in the reservoir included *Parambassis siamensis*, *Corica sorbona*, *Cyclocheilichthys repasson,* and *Dermogenys pusillus*. These fish represented 64% of total catch by biomass. This suggests over-fishing for economically valuable species in the reservoir (Li and Xu, 1995) and fishing down the food web, a situation that probably affected fisheries and fish biodiversity much more than the impact of alien species.

By using nets to seine fish at 4, 5, and 4 locations upstream, midstream and downstream in the reservoir four times per year, we determined that the fish community was composed, to a great extent, by economically valuable species. Tilapias were abundant, ranking second in catch after silver barb, indicating good natural reproduction and a favorable population in the reservoir. In August, when tilapias had their highest total catch, the other top five species caught (silver barb, common carp, repassan, and *Labiobarbus spilopleura*) were not providing large catches. This occurred despite such fish species having similar niches to tilapias, indicating the important role of tilapias in the reservoir's food web.

Most fish species have fluctuations in catch between upstream, midstream and downstream habitats in a reservoir, indicating that habitat and environmental factors play an important role for fish distribution. The upstream area of Tri An Reservoir has more favorable conditions for fish growth and reproduction due to greater nutrient levels and food input from Dong Nai and La Nga rivers. Tilapias were among the dominant economically valuable species successfully occupying this area, with the highest biomass caught in seine surveys, indicating their preference for highly productive areas. There was likely competition for limited plankton food sources at midstream and downstream seining sites. Luong et al. (2002) indicated rather low primary and secondary production at Tri An Reservoir (phytoplankton and zooplankton of 0.36 - 0.82 g dry weight/m^2), possibly resulting in low abundance of tilapias at the downstream area.

To manage the fish species composition at Tri An Reservoir, Luong et al. (2005) suggested stocking indigenous marble goby (*Oxyeleotris marmorata*) to feed on prawns (*Macrobrachium* spp.) and other small fish species of low economic value (glass fish, river sprat, repassan, etc.). In terms of natural food web management, reducing the populations of small, low economic value fish species may allow quick development of economically valuable herbivorous fish such as tilapias, silver carp, and bighead carp. Such an idea could provide greater total economic output from the fishery and deserves further research.

ANTICIPATED BENEFITS

Information on the impacts of the introduced alien species on fisheries and biodiversity of indigenous fish species will allow governmental agencies to establish policies, plans, and mechanisms to manage the introduction of alien species. As reservoirs are widely distributed throughout Asian countries and tilapias have been introduced into many reservoirs either intentionally or unintentionally, these results may support continuous stocking of tilapias without much concern for their negative impacts. The impact of tilapias in food web interactions can be managed by maintaining a suitable fish species composition in the reservoir through stocking and fishing.

FIGURES AND TABLES

Table 1. Stocking and catch over time in Tri An Reservoir.

Year	Fingerling stocking (no. of fish)	Annual fish catch (MT/year)	No. of fishermen
1993	0	800	300
1994	0	833	400
1995	1,300,000	1126	550
1996	1,900,000	1475	748
1997	5,006,000	1825	800
1998	0	1840	1234
1999	1,317,000	2269	1136
2000	1,200,000	2301	1470
2001	1,501,000	2786	1237
2002	1,170,000	3118	892
2003	868,000	3080	978
2004	0	2835	884
2005	0	2589	872
2006	500	2600	721
2007	1,000,000	2837	747
2008*	0	3823	1115

Source: Dong Nai Fisheries Company (1993-2007), * 2008 data were collected by this study.

Table 2. CPUE of fishing gears during dry and rainy seasons.

No.	Fishing gears	CPUE in dry season (kg/day)	CPUE in rainy season (kg/day)
1	Seine net (2 boats)	70.7 ± 4.14	45.3 ± 3.83
2	Machine scoop net (18 lights)	70.42 ± 7.65	59.28 ± 6.46
3	Machine scoop net (1 light)	56.96 ± 5.33	38.64 ± 4.68
4	Lift net (no lights)	53.52 ± 10.9	22.48 ± 3.73
5	Mobile cast net	49.84 ± 4.92	0
6	Seine net (1 boat)	48.8 ± 4.49	40.3 ± 3.0
7	Encircled surrounding net	42 ± 8.0	0
8	Viet trawl net	31.2 ± 6.03	12.64 ± 2.16
9	Mussel trawl net	15.24 ± 1.16	0
10	Gillnet (mesh size 40-60 mm)	14.84 ± 1.2	11.82 ± 0.94
11	Cast net	14 ± 0.98	0
12	Gillnet (mesh size 70-140 mm)	10.1 ± 1.45	8.51 ± 0.73
13	Surface gillnet station	9.68 ± 1.69	7.2 ± 0.44
14	Horizontal cylinder basket trap for marble goby	8.48 ± 1.18	7.04 ± 0.84
15	Horizontal cylinder basket trap for shrimp	6.28 ± 0.58	3.4 ± 0.46
16	Long line	5.76 ± 0.44	4.32 ± 0.5
17	Lift net with light	0	71.44 ± 7.56
18	Horizontal cylinder basket trap for tilapia	0	8.08 ± 1.36
19	Trammel net	0	6.8 ± 1.16

Table 3. Fishing gears and total catches in Tri An Reservoir.

No.	Fishing gears	No. fishing gears		Fish catch (MT)		Total catch (MT)
		Dry season	Rainy season	Dry season	Rainy season	
1	Machine scoop net (1 light)	104	63	889	219	1108
2	Lift net with a light	0	80	0	686	686
3	Gillnet (mesh size 40-60 mm)	228	178	406	189	595
4	Seine net (2 boat)	42	30	356	61	417
5	Machine scoop net (18 light)	25	20	211	107	318
6	Lift net	18	22	101	52	153
7	Mussel trawl net	70	0	128	0	128
8	Seine net (1 boat)	10	20	73	29	102
9	Viet trawl net	22	31	62	35	97
10	Long line	52	108	9	56	65
11	Horizontal cylinder basket trap for marble goby	25	29	25	18	44
12	Horizontal cylinder basket trap for shrimp	39	48	22	20	42
13	Mobile cast net	11	0	33	0	33
14	Surface gillnet station	6	8	5	5	10
15	Gillnet (mesh size 70-140 mm)	2	11	1	6	7
16	Horizontal cylinder basket trap for tilapia	0	12	0	6	6
17	Encircled surrounding net	2	0	5	0	5
18	Trammel net	0	6	0	4	4
19	Cast net	2	0	3	0	3
	Total	**658**	**666**	**2329**	**1493**	**3823**

Table 4. Proportion of tilapias caught in various fishing gears.

No.	Fishing gears	% tilapias in dry season	% tilapias in rainy season
1	Gillnet (mesh size 70-140 mm)	21.34 ± 8.01	26.63 ± 12.16
2	Gillnet (mesh size 40-60 mm)	18.81 ± 5.24	7.82 ± 2.88
3	Horizontal cylinder basket trap for marble goby	7.67 ± 3.27	25.68 ± 5.13
4	Long line	1.99 ± 0.91	15.57 ± 6.45
5	Lift net	8.07 ± 2.19	8.9 ± 3,99
6	Seine net (1 boat)	5.23 ± 1.57	6.88 ± 1.32
7	Seine net (2 boats)	5.96 ± 1.59	3.12 ± 3,22
8	Surface gillnet station	1.62 ± 1.62	3.47 ± 2.95
9	Horizontal cylinder basket trap for tilapia	0	37.46 ± 8.17
10	Trammel net	0	19.0 ± 4.4
11	Cast net	26.07 ± 2.13	0
12	Encircled surrounding net	15.95 ± 2.27	0
13	Mobile cast net	4.01 ± 2.63	0
14	Machine scoop net (1 light)	2.62 ± 1.27	0
15	Viet trawl net	0	0
16	Mussel trawl net	0	0
17	Machine scoop net (18 lights)	0	0
18	Horizontal cylinder basket trap for shrimp	0	0
19	Lift net with light	0	0

Table 5. Fish species composition from 19 fishing gears in Tri An Reservoir.

No.	Fish species	Fish catch (tons)	%
1	*Parambassis siamensis*	727.1	19.02
2	*Corica sorbona*	666.2	17.43
3	*Cyclocheilichthys repasson*	566.1	14.81
4	*Dermogenys pusillus*	448.4	11.73
5	*Barbonymus gonionotus*	278.8	7.29
6	*Oreochromis* spp.	**176.5**	**4.62**
7	*Kryptopterus cryptopterus*	167.7	4.39
8	*Labiobarbus spilopleura*	155.2	4.06
9	*Mystus* spp.	147.3	3.85
10	*Glossogobius giuris*	119.0	3.11
11	*Cyprinus carpio*	92.1	2.41
12	*Oxyeleotris marmoratus*	69.4	1.81
13	*Hemibagrus wyckii*	47.1	1.23
14	*Hypostomus plecostomus*	32.9	0.86
15	*Cichla ocellaris*	20.1	0.52
16	*Wallago attu*	16.9	0.44
17	*Mystus nemurus*	14.8	0.39
18	*Cirrhinus jullieni*	13.1	0.34
19	*Henicorhynchus siamensis*	12.5	0.33
20	*Mystus wyckii*	10.7	0.28
21	*Micronema bleekeri*	6.2	0.16
22	*Osteochilus hasseltii*	5.0	0.13
23	*Clarias batrachus*	4.9	0.13
24	*Macrognathus taeniagaster*	4.9	0.13
25	*Hampala macrolepidota*	4.0	0.11
26	*Labeo chrysophekadion*	3.6	0.09
27	*Ompok bimaculatus*	3.0	0.08
28	*Channa striatus*	1.9	0.05
29	*Hypophthalmichthys molitrix*	1.7	0.05
30	*Notopterus notopterus*	1.7	0.05
31	*Mastacembelus armatus*	1.5	0.04
32	*Ctenopharyngodon idellus*	0.6	0.02
33	*Labeo rohita*	0.4	0.01
34	*Clarias macrocephalus*	0.4	0.01
35	*Anguilla marmorata*	0.2	0.01
36	*Macrognathus siamensis*	0.2	0.01
37	*Macrobrachium rosenbergii*	0.2	0.01
38	*Pangasius hypophthalmus*	0.2	0.01
39	*Hypophthalmichthys nobilis*	0.06	0.002
40	*Paralaubuca barroni*	0.01	0.0002

Table 6. Fish species composition by season in seine surveys.

No.	Species	Proportion of catch by weight (%)				
		Nov. 2007	Feb. 2008	May 2008	Aug. 2008	All year
1.	***Barbonymus gonionotus***	25.5	36.5	33.2	27.2	30.6
2.	***Oreochromis* spp.**	12.3	12.5	17.6	36.6	19.7
3.	***Cyprinus carpio***	16.9	18.9	19.5	12.4	16.9
4.	***Cyclocheilichthys repasson***	22.9	16.7	4.8	9.9	13.6
5.	***Labiobarbus spilopleura***	8.6	8.5	5.8	1.1	6.0
6.	***Mystus* spp.**	1.9	0.8	0.8	6.8	2.6
7.	***Cichla ocellaris***	0	1.5	4.3	2.3	2.0
8.	***Hypostomus plecostomus***	4.1	0.4	1.7	0	1.6
9.	***Mystus nemurus***	0	1.8	3.3	0	1.3
10.	***Anguilla marmorata***	3.4	0	1.6	0	1.3
11.	***Hypophthalmichthys nobilis***	0	0.7	3.5	0	1.0
12.	***Oxyeleotris marmoratus***	2.7	0.3	0	0.7	0.9
13.	***Hampala macrolepidota***	1.4	1.4	0.2	0	0.8
14.	***Kryptopterus cryptopterus***	0	0	0	2.0	0.5
15.	***Ompok bimaculatus***	0.3	0	0.7	0.3	0.3
16.	***Hemibagrus wyckii***	0	0	1.1	0	0.3
17.	***Wallago attu***	0	0	1.1	0	0.3
18.	***Labeo chrysophekadion***	0	0	0.5	0.4	0.2
19.	***Notopterus notopterus***	0	0	0.4	0.1	0.1
20.	***Channa striatus***	0	0	0	0.2	0.1

Table 7. Fish species composition by location in seine surveys.

No.	Species	Percent in weight (%)			
		Upstream	Midstream	Downstream	Reservoir
1.	*Barbonymus gonionotus*	25.2	33.7	32.8	30.6
2.	*Oreochromis* spp.	26.3	19.1	13.9	19.7
3.	*Cyprinus carpio*	14.4	16.5	19.9	16.9
4.	*Cyclocheilichthys repasson*	17.9	10.3	12.5	13.6
5.	*Labiobarbus spilopleura*	5.8	6.0	6.1	6.0
6.	*Mystus* spp.	0	4.4	3.3	2.6
7.	*Cichla ocellaris*	1.7	1.7	2.7	2.0
8.	*Hypostomus plecostomus*	1.7	0.5	2.5	1.6
9.	*Mystus nemurus*	0	1.2	2.7	1.3
10.	*Anguilla marmorata*	1.8	0	2.0	1.3
11.	*Hypophthalmichthys nobilis*	1.4	1.2	0.5	1.0
12.	*Oxyeleotris marmoratus*	1.2	1.5	0	0.9
13.	*Hampala macrolepidota*	0	1.1	1.2	0.8
14.	*Kryptopterus cryptopterus*	0	1.5	0	0.5
15.	*Ompok bimaculatus*	0.8	0.3	0	0.3
16.	*Hemibagrus wyckii*	0.4	0.4	0	0.3
17.	*Wallago attu*	0.8	0	0	0.3
18.	*Labeo chrysophekadion*	0	0.7	0	0.2
19.	*Notopterus notopterus*	0.4	0	0	0.1
20.	*Channa striatus*	0.2	0	0	0.1

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