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Optimal time of year and fishing methods for controlling exotic fishes in Longluan Lake, Taiwan

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Abstract

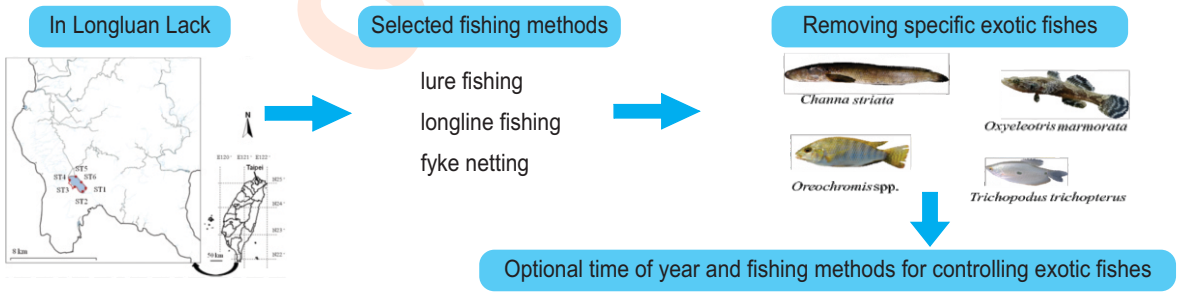
Aim: This study aimed to identify the optimal time and fishing methods for removing exotic fishes, including striped snakehead (*Channa striata*), marble goby (*Oxyeleotris marmorata*), tilapia (*Oreochromis* spp.), three-spot gourami (*Trichopodus trichopterus*), and predatory carp (*Chanodichthys erythropterus*), from Longluan Lake, which is located in Kenting National Park in Taiwan.

Methodology: The selected fishing methods included lure fishing, longline fishing, and fyke netting. A total of 2,284 individuals were collected over 12 removal events in Longluan Lake from 2017 to 2019. Among the collected fish, 1,640 fish represented exotic species, and 644 fish represented native species.

Results: Among the collected fish, 1,640 fish represented exotic species, and 644 fish represented native species. Based on the results of this study, we suggest that the optimal time for managing exotic fishes is from April to June, when is the period representing lower water levels in Longluan Lake. For removing specific exotic fish in Longluan Lake, employing lure fishing in natural habitat is effective for *C. striata* and *Oreochromis* spp., utilizing fyke netting in natural habitat is workable for *T. trichopterus* and *C. erythropterus*, and operating fyke netting in artificial habitat is useful for *O. marmorata.*

Interpretation: The habitat preferences and sampling efficiency of gears vary among exotic fishes, however, a combination of applying lure fishing and fyke netting in both habitat types will achieve the greatest advantage for controlling exotic fishes in the Longluan Lake.

Key words: Exotic fishes, Fyke netting, Invasive species, Longluan Lake, Sampling efficiency



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Introduction

The invasion of exotic fishes, which threaten biodiversity and impose considerable economic costs, can cause adverse effects on aquatic ecosystems (Donaldson and Cook 2016). Exotic fishes have long been a serious threat to aquatic biodiversity in the lentic habitats of Taiwan; for example, the effects of Indian glass fish (*Parambassis ranga*) in SunMoon Lake (Chen and Kuo 2009; Liang *et al.,* 2006). Atleast 26 exotic freshwater fishes have been successfully established in Taiwan before 2014, no further research has been conducted to evaluate techniques for management of alien fishes in aquatic ecosystems on the island (Liang *et al.,* 2020). Longluan Lake is located in Kenting National Park in Taiwan. In addition to providing flood prevention and irrigation water, Longluan Lake is an important habitat for winter birds, as it supplies food, shelter, and various ecological resources from September to April (Fang *et al.,* 2016). The invasion of exotic fishes in Longluan Lake has become a serious concern (Huang *et al.,* 2018; Huang *et al.,* 2019). Long-term monitoring data have revealed high frequencies of exotic fishes, with tilapia (*Oreochromis* spp.) constituting the highest proportion. Other exotic fishes, including three-spot gourami (*Trichopodus trichopterus*), marble goby (*Oxyeleotris marmorata*), striped snakehead (*Channa striata*), and predatory carp (*Chanodichthys erythropterus*) have also been reported (Huang *et al.,* 2018; Huang *et al.,* 2019).

In particular, *C. erythropterus* has beenen listed as an indigenous invasive species because its original distribution range was observed in mid-Taiwan, and many anglers have purposely introduced it island-wide (Chen *et al.,* 2012). Among these introduced fishes, predatory species, such as *C. striata, C. erythropterus* and *O. marmorata*, impose a great threat on aquatic biodiversity and cause food shortages for wintering birds to endure; additionally, the fish also feed on native fishes, shrimp, crabs, aquatic insects, amphibians, reptiles, and some terrestrial animals (Caughley and Gunn, 1996; Nakagawa and Suzuki, 2008; Simberloff, 1981). These negative impact caused by the exotic fishes have greatly and progressively damaged the biodiversity of both aquatic animals and winter birds in the Longluan Lake. The removal of exotic fishes is essential for protecting wintering birds and for restoring aquatic biodiversity in Longluan Lake. Due to the preference of diverse habitat and feeding strategies of exotic species in Longluan Lake, it is vital to apply various fishing methods to successfully achieve fish removal (Rahman *et al.,* 1999; Saha *et al.,* 2015).

For example, lure fishing is efficient for catching upper-water ambush predators, such as *C. striata* (Lee and Ng 1991; Fazrul *et al.,* 2018); additionally, fyke netting offers high capture efficiency for benthic sit-and-wait predators, such as *O. marmorata* and longline fishing is suitable for fishing complex habitats, such as lakeside swamps (Ross and Winterhalder, 2015). In view of the above, the objective of this study was to determine the optimal time of year and fishing methods, including longline fishing, lure fishing, and fyke netting for controlling exotic fishes in Longluan Lake. In Taiwan and throughout the world, few successful cases studies of methods to control exotic fishes in native lakes have been fully described (Donaldson and Cook 2016; Zavaleta *et al.,* 2001). A study to investigate the optimal time and fishing methods for controlling exotic fishes in Taiwan's lakes would benefit global fish conservation. The objective of this study is to determine the optimal time of year and fishing methods, including longline fishing, lure fishing, and fyke netting, for controlling exotic fishes in Longluan Lake.

Materials and Methods

Longluan Lake is located in Kenting National Park on the Hengchun Peninsula in Taiwan. The Longluan Lake is approximately rectangular, 1,600 m long and 700m wide. The average depth is 3.5m, and the area is approximately 175 ha. For this study, the shoreline of Longluan Lake was divided into six plots for characterizing natural and artificial habitats. Plots ST1, ST2, and ST3 were dominated by soillake shore, stone, sandy sediment, and aquatic vegetation and were defined as natural habitats; plots ST4, ST5, and ST6 were dominated by cement lake shore and sandy sediment and were defined as artificial habitats (Table 1). Each year from March to June, water from Longluan Lake is used to irrigate the surrounding farmland and has a flood prevention function for the subsequent typhoon season. Therefore, during this period, the water level is low. In this study, April to June was defined as low-water period (<2 m depth), and July to September as high-water period (>2 m depth).The composition of exotic fishes was almost similar to that of many lakes in Taiwan and other Asian regions (Lewis 2000). From April 2017 to September 2019, prior to the arrival of overwintering birds, 12 fish-removal events including 7 during low-water periods (April to June) and 5 in high-water periods (July to September) were conducted. Longline fishing, lure fishing, and fyke netting were applied in each event. After species identification with Fish Base (2019), the body weight and total length of each sampled fish was measured. The native fish were released *in-situ* and the exotic species were removed from the lake.

Longlining is a fishing method that was developed specifically for *C. striata*, where a submerged longline rig was used to capture this specie. During removal of each exotic fish in 2017 and 2018, one longline (used as a main line with a total length of 50 m) was placed in each plot for two days. The number of fish captured by longline fishing was the total number of fish captured during 2 days. Lure fishing mainly uses a spinning fishing rod and lure (vibratingminnow, jigbait, and vibration).This fishing method was performed at key fish feeding times (05:00-09:00 hr and 15:00-19:00 hr). A fisher attempted to capture fish in each plot, and two fishing sessions were conducted on daily basis (one session in the morning and one session in the afternoon). The number of fish captured via lure fishing was determined as the total number of fish captured in 2 days.

Fyke netting was mainly performed by using long square-shaped cages (length: 5 m, mesh size: 1.0 cm) baited with 20 g

mixed rice, tilapia feed, and eel powder. In this study, fyke nets were deployed at 15:00 hr every day until 07:00 hr the next morning. Two anchors were attached to both ends, and a float was placed on one end to mark the position. The number of fish captured via fyke netting was calculated as the total number of fish captured over 2 nights.

Statistical Analysis: In this study, a t-test was used to analyze the differences between the number of fish captured in natural and artificial habitats, as well as the differences between the number of fish captured at low and high water levels. Additionally, One-way ANOVA and Fisher's least significant difference (LSD) analysis were performed to analyze the differences among the capture methods in difference exotic fish (SPSS 2012).

Results and Discussion

From 2017 to 2019, 12 fish-removal events were conducted. A total of 2,230 fish, as well as 54 freshwater shrimp (*Macrobrachium nipponense*), were collected (Table 1). Among the fish collected, 1,640 fish represented exotic species, including *C. striata* (396 individuals) and *O. marmorata* (103 individuals; Table 1). The total biomass of the collected exotic fish was 336.6 kg. The biomass of collected exotic fishes were 21.8, 280.2 and 134.6 kg in 2017, 2018 and 2019, respectively. The ratio of exotic fishes/native fishes decreased from 2017 to 2019, with the number of captured exotic fish decreasing and the number of sampled native fish increasing (Table 1). During 2019, the collected individuals of two native fishes, *Hemiculter leucisculus* and *Tanakia himantegus* showed significant increase as compared to the previous two years.

For five exotic species, more individuals were collected at low water levels than at high water levels (Fig. 1). Moreover, based on the results of t-test, a significantly high number of individuals were collected at lower water levels than at high water levels for four exotic fishes, the exception being *O. marmorata*. Regardless of the water levels, three exotic fishes, namely, *C. striata*, *Oreochromis* spp., and *T. trichopterus*, were sampled at significantly greater numerical abundance in the natural habitat than in the artificial habitat (Fig. 1). More *O. marmorata* individuals were found in artificial habitats than in natural habitats, with a significant difference at low water levels. A contrasting result was observed for *C. erythropterus*, with significantly more individuals collected in the natural habitat atlow water levels than at high water levels, while the reverse situation was recorded at high water levels.

Among the three removal methods assessed, lure fishing captured significantly more individuals of *C. striata* and *Oreochromis* spp. than the other twomethods (Fig. 2). Fyke nets collected significantly greater number of *T. trichopterus, O. marmorata* and *C. erythropterus* than lure and longline fishing methods; however, lure fishing was able to collect some *C. erythropterus*. Although a limited number of collections were made, longline fishing demonstrated fewest captures among the three methods. A significantly greater number of all exotic fish species collected during low water levels indicated that the dry season was appropriate for practicing exotic fish-removal activities in Longluan Lake. In Taiwan, the dry season broadly lasts from October to June (CWB/ROC, 2021).

Considering that the wintering bird season lasts from November to March, the optimal time for exotic fish removal was regarded as April to June in Longluan Lake. In addition to avoid the wintering bird season, designating April to June as the removal time would also restrict the spawning and decrease the population size of exotic fishes in Longluan Lake. The

Table 1: Number (individuals) of fishes caught from 2017 to 2019

		Year				
Types	**Scientific name**	**2017**	**2018**	**2019**	**Total**	
Exotic fishes	*Channa striata*[1]	40	220	136	396	1640
	Oxyeleotris marmorata[2]	18	54	31	103	
	Oreochromis spp.	47	122	127	296	
	Trichogaster trichopterus	253	62	125	440	
	Pterygoplichthys pardalis	0	0	2	2	
	Ambassis sp.	1	0	1	2	
	Chanodichthys erythropterus[1]	198	155	48	401	
	Hemiculter leucisculus	98	85	301	484	
	Tanakia himantegus	2	8	57	67	
Native fishes	*Cyprinus carpio carpio*	7	7	6	20	644
	Other native fishes	3	1	15	19	
	Macrobrachium nipponense	3	47	4	54	
	Total (individuals)	670	761	853	2284	
	ratio ofexotic fishes/native fishes	5.1	6.1	2.4	2.8	

[1]Active predator [2]Ambush predator

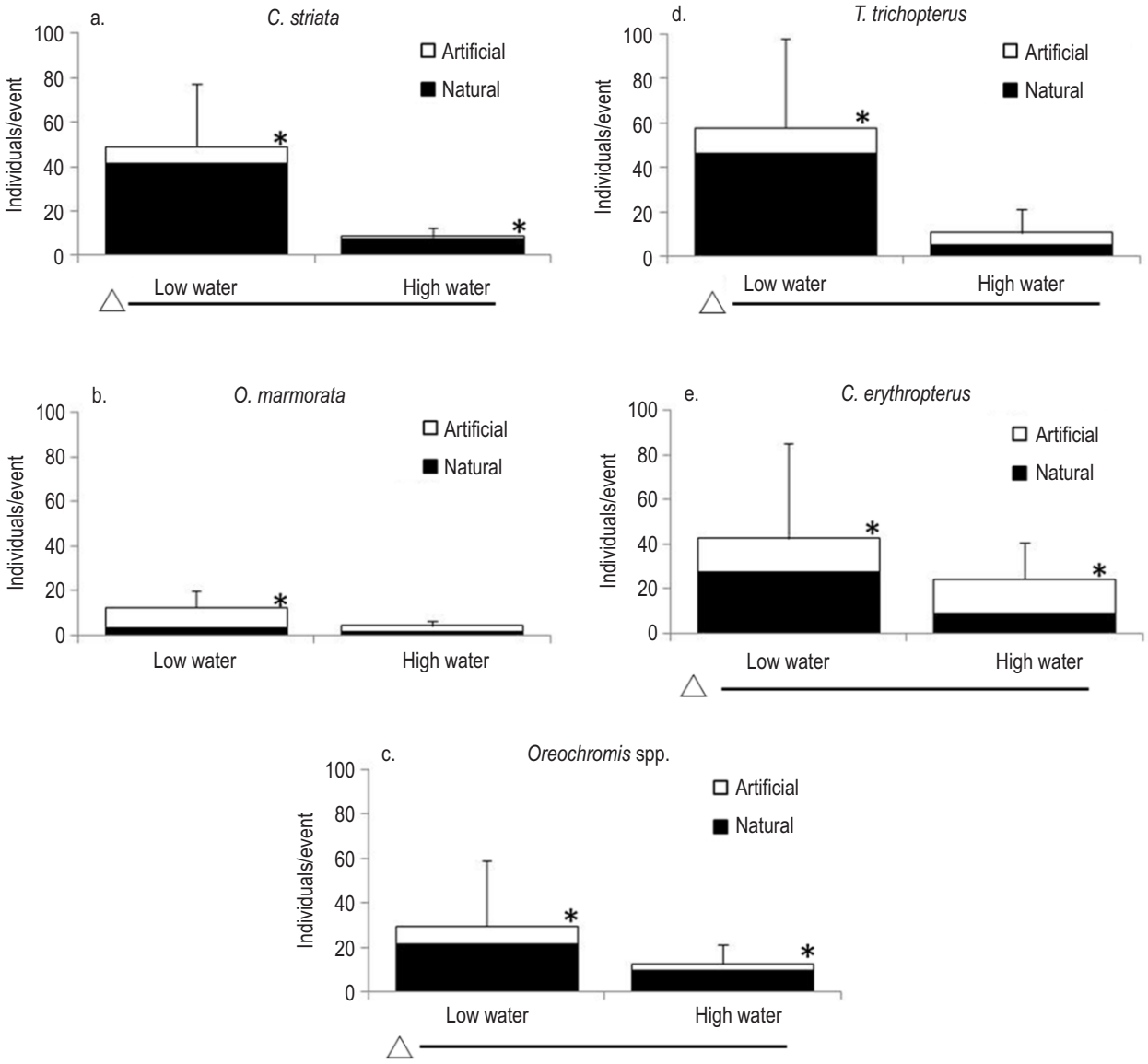

Fig. 1: Number of fishes (individuals/event) caught at different water-level periods and in different habitats. Error bars represent mean±S.D. *denotes a significant difference between artificially habit and natural habit (P<0.05), △ denotes a significant difference between low and high water-level periods (P<0.05).

reproductive seasons of several exotic fishes in Longluan Lake have been to last from early spring to late summer. Li *et al.* (2017) reported that the reproductive period of *C. striata* lasts from April to October and peaks from June to October in Southern Taiwan. Moreover, Herawati *et al.* (2017) documented that *O. marmorata* lays eggs multiple times per year; the breeding season of this specie extends from April to November and peaks from May to July. The breeding season of *C. erythropterus* lasts from May to July (Tso 2010). Thus, the investment of manpower and economic resources for removal of both adult and young fishes from April to June may effectively limit spawning and population growth of exotic fishes in Longluan Lake. The results of this study demonstrated that both lure fishing and fyke netting are effective in capturing exotic fishes in Longluan Lake; however, longline fishing appeared to be an inefficient method. Among these three methods, lure fishing and fyke netting are suggested for controlling exotic fishes in Longluan Lake and similar lentic habitats, although fish species and habitat types affect removal efficiencies for these two methods.

The exotic fishes of *C. striata* and *Oreochromis* spp. were observed via lure fishing, and more individuals of *O. marmorata*,

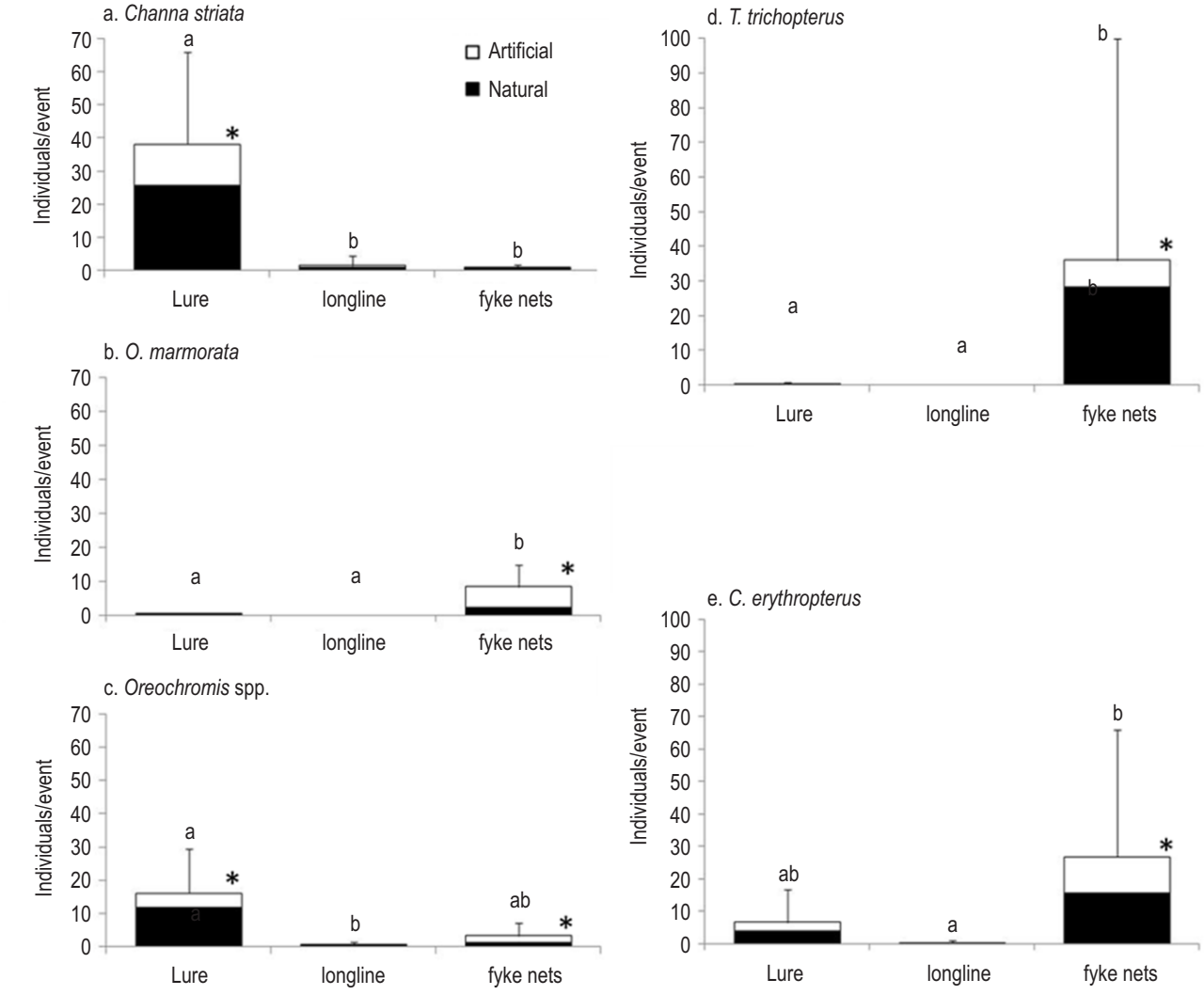

Fig. 2: Numbers of fishes (individuals/event) caught with three fishing methods in different habitats. Error bars represent S.D. from the mean. Different letters above bars indicate significant differences between fishing methods (P<0.05). An asterisk (*) denotes a significant difference between habitats (P<0.05).

T. trichopterus, and *C. erythropterus* were sampled via fyke netting. Feeding behavior and habitat preference may be partially responsible for the differences between exotic fishes and fishing gears. *C. striata* is an active ambusher predator with a broad diet composition, including arthropods, small fishes, amphibians, and reptiles, and is attracted by fish baits (Ferdausi *et al.,* 2015). A similar situation may be encountered by *Oreochromis* spp. as it is an omnivorous predator and can feed on small fishes and animals as they grow (Ganie *et al.,* 2013; Laxmappa *et al.,* 2015; Martin *et al.,* 2010).

For three species that were most abundant in the fyke net, *O. marmorata* is a benthic slow swimmer and sit-and-wait predator that usually conceals itself within interstices in gravel and may prefer to hide or feed on animals trapped within the fyke net (Chen *et al.,* 2010). In Taiwan, *T. trichopterus* is mainly found in swampy areas and ditches with dense vegetation, thus in search of food it gots trapped within fyke nets (Fish Base 2019; ISSG 2019). An active-search predator, like *C. erythropterus* may hunt for prey and fish bait, and gots trapped in fyke nets (Chou and Gao 2017; Tso 2010). However, *C. erythropterus* can also be collected via lure fishing (as shown in the collection record in Fig. 3) due to its food searching behavior. More individuals of *C. striata, Oreochromis* spp., and *T. trichopterus* were captured in natural habitats, and large number of *O. marmorata* were collected in from artificial habitats.

Natural habitats in Longluan Lake exhibit dense vegetation as a suitable survival space for laterally compressed fishes, such as *Oreochromis* spp. and *T. trichopterus*, and these

habitats supply plenty food for aquatic insects and small fishes for *C. striata*. In contrast, cement dykes and sporadic vegetation, which were observed in artificial habitats, provide inappropriate living space and scarce food items (Huang *et al.,* 2018; Huang *et al.,* 2019). Although a monotonic structure was present in the artificial habitat, *O. marmorata* was discovered in large members than in the natural habitat. *O. marmorata* prefers warm waters with temperature ranging between 15-35°C; additionally, the optimal temperature required for the growth in this species range between 25-30°C (Herawati *et al.,* 2017). *O. marmorata* aggregates in the artificial habitat may result from the water temperature around the cement dykes ranging between 20-34°C during April to September, and many shrimp (*Caridina longirostris* and *M. nipponense*) living around cement dykes provide major prey organisms (Huang *et al.,* 2018; Huang *et al.,* 2019). *C. erythropterus* occurring in both natural and artificial habitats may be attributed to its feeding and movement behavior, because it is an aggressive searcher and pursuer that travels between two habitat types (Chen *et al.,* 2012).

Based on the observations of this study, we suggest that the optimal time for removing exotic fishes in Longluan Lake is from April to June because of low water level and the need to avoid the wintering bird season. If an exotic fish is targeted for removal from Longluan Lake, the utilization of lure fishing in natural habitats is effective for *C. striata* and *Oreochromis* spp.; additionally, the utilization of fyke netting in natural habitat is efficient for *T. trichopterus* and *C. erythropterus*, and the utilization of fyke netting in artificial habitats is useful for *O. marmorata*. Overall, while considering that habitat preference and sampling efficiency of gear can vary among exotic fishes, a combination of lure fishing and fyke netting in both habitat types will result in high productivity for controlling exotic fishes in Longluan Lake. After the exotic fish removal was conducted for 3 years in Longluan Lake, the number of captured exotic fish decreased and the number of sampled native fish increased, this indicated that the population of native fish, especially *Hemiculter leucisculus* and *Tanakia himantegus*, is gradually recovering if a proper and lasting management action is applied to remove exotic fishes from Longluan Lake.

Based on the results of this study, movements to remove exotic fish shall be encouraged to conduct in the similar lentic habitats for biodiversity conservation of native fishes. Recently, Rytwinski *et al.* (2019) reviewed the effectiveness of non-native fish-removal techniques in freshwater ecosystems and indicated that electrofishing has great success for population size control for non-native freshwater fishes if chemical treatments are not included. In Longluan Lake, grassy swamps along the shoreline are the prime habitat for juvenile and young *C. striata*; however,neither lure fishing nor fyke netting function well in highly vegetated areas. Thus, in future, in addition to applying a combination of lure fishing and fyke netting, the adoption of electrofishing in the grassy swamp along the lake perimeter is another option for escalating the removal of exotic fishes from Longluan Lake.

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Add-on Information

Authors' contribution: D.J. Huang and S.H. Liang: Applied for funding, and conceived the project and designed the methodology. **C. D. Tsai, D. J. Huang, Y.W. Chiu, C.W. Tso:** Collected the data; **D.J. Huang, S. H. Liang, and Y.L. Huang:** Organized and analyzed the data; **D.J. Huang, S.H. Liang and Y.L. Huang:** Wrote and revised the article. All authors contributed critically to the draft and give approval for publication.

Research content: The research content is original and has not been published else where.

Ethical approval: Captured native fishes were released back into the sampled water bodies.

Conflict of interest: The authors declare that they have no conflict of interests.

Data from other sources: Not applicable

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