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Enhancing invasive fish management with electrofishing: A case study from Longluan Lake, Taiwan

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ABSTRACT: The spread of invasive alien species poses serious threats to freshwater ecosystems worldwide. Longluan Lake, a critical wetland in Kenting National Park, Taiwan, has been increasingly impacted by non-native fish species, including Channa striata, Oxyeleotris marmorata, and Oreochromis spp., which disrupt the native biodiversity and ecological balance. To enhance management efficiency, electrofishing was introduced in 2020 as a supplementary removal method alongside traditional techniques, including lure fishing, longline fishing, and fyke netting. Between 2020 and 2024, a total of 20 removal events were conducted, resulting in the capture of 18,677 individuals, of which 13,654 were non-native species. Electrofishing substantially increased capture rates of small-bodied and juvenile invasive fishes, with annual averages of *C. striata* and *O. marmorata* rising more than fourfold compared to pre-2020 levels. Notably, the mortality rates associated with electrofishing (9.2%) were also lower than those of fyke nets (32.8%), indicating reduced ecological disturbance to native species. Abundance Biomass Comparison (ABC) curve analyses revealed declining W values for key invasive species and partial recovery of native assemblages after the introduction of electrofishing. Our findings demonstrate that electrofishing, when integrated with conventional fishing methods, provides an effective and ecologically sustainable approach for managing invasive fish in wetland ecosystems.

KEY WORDS: electrofishing, invasive fish control, invasive species, Longluan Lake, Taiwan, wetland management.

INTRODUCTION

The rapid expansion of global trade and transportation has facilitated the spread of invasive alien species (IAS) at an alarming rate, posing severe threats to ecosystems worldwide. Invasive species have become a major ecological challenge, disrupting native biodiversity and altering habitat dynamics. According to the *Catalogue of Life in Taiwan* (Taicol), Taiwan hosts 392 exotic animal species, including approximately 26 non-native freshwater fish species (Liang *et al*., 2020).

Longluan Lake, situated within Kenting National Park on the Hengchun Peninsula, serves not only as a critical water resource for flood prevention and irrigation but also as an essential wintering ground for migratory birds. From September to April, the lake provides food, shelter, and vital ecological resources for avian populations (Huang *et al*., 2018, 2019). However, the proliferation of invasive fish species—most notably the striped snakehead (*Channa striata*), marble goby (*Oxyeleotris marmorata*), tilapia (*Oreochromis* spp.), three-spot gourami (*Trichopodus trichopterus*), and predatory carp (*Chanodichthys erythropterus*)—has increasingly threatened native aquatic species and disrupted the lake's ecological balance since 2017 (Huang *et al*., 2018, 2019).

Between 2017 and 2019, Kenting National Park implemented 12 fish-removal operations using longline fishing, lure fishing, and fyke netting. These efforts successfully removed 1,640 exotic fish while sparing 644 native individuals. However, despite these measures, juvenile *C. striata* and *O. marmorata* residing in marshy areas remained largely unaffected by conventional fishing techniques. Given the limitations of traditional removal methods, an alternative approach was necessary to enhance the efficiency of invasive fish control.

Kenting National Park introduced electrofishing in 2020 as a supplementary removal technique to address this gap. Electrofishing has been widely recognized for its efficiency in managing invasive species (Rytwinski *et al*., 2019; Snyder, 2003). Previous studies have demonstrated that electrofishing can significantly improve removal success, particularly for juvenile fish less susceptible to conventional methods (Weaver, 1993; Cucherousset and Olden, 2011). However, its potential ecological impacts and effectiveness in large-scale removal efforts require further evaluation. Therefore, this study aims to assess the role of electrofishing in enhancing invasive fish management in Longluan Lake, examining its effectiveness, ecological implications, and potential for integration into long-term conservation strategies.

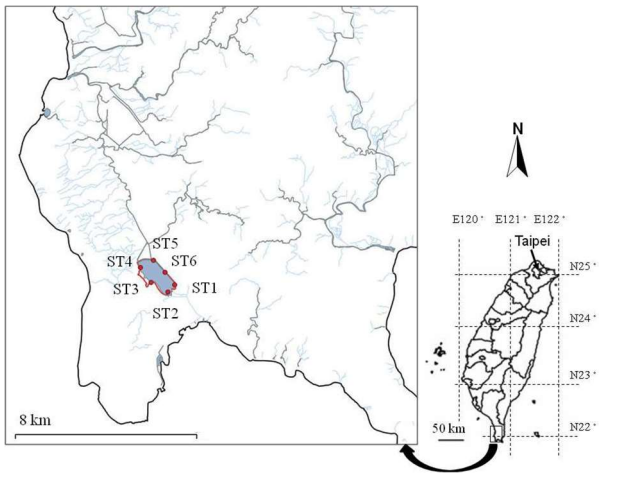

Fig. 1. Locations of study plots in Longluan Lake. ST1 to ST6 indicated study plots 1 to 6.

MATERIALS AND METHODS

Location

Longluan Lake is an approximately rectangular water body, measuring 1,600 meters in length and 700 meters in width, with an average depth of 3.5 meters and a total area of approximately 1,750,000 m^2 (Figure 1). This study builds upon previous alien species removal efforts conducted by Liang *et al*. (2022), extending the work at six sampling sites within Longluan Lake from 2020 to 2024. Between April 2020 and September 2024, 20 fish-removal events were conducted, prior to the arrival of overwintering birds. In addition to longline fishing, lure fishing, and fyke netting, electrofishing was introduced in 2020 to enhance the removal of non-native fish species, particularly juveniles residing in marshy areas. For each removal event, the captured fish were identified to the species level based on FishBase (2024). Each individual was measured for body length and weight; native fish were immediately released in situ, whereas exotic fish were retained for removal. During a protocol adjustment phase in 2021, the mortality rates associated with different fishing techniques—including lure fishing, fyke netting, and electrofishing—were assessed to understand their ecological implications better.

Fishing Methods

***Longline Fishing*:** Longlining, a fishing technique specifically adapted for *C. striata*, employs a submerged longline rig to target this species. While not used between 2020 and 2021, longlining was implemented in exotic fish removal operations from 2022 to 2024. During each event, two longlines (10 meters in length each) were deployed per sampling site for two consecutive days. Floating markers and sinking anchors were positioned accordingly to mark the beginning and end of each line. Additional 0.5-meter fishing lines were attached perpendicularly to the main line at 1-meter intervals, each fitted with baited hooks (1.5 cm soft bait). A total of 10 hooks were used, positioned at water depths ranging from 0.5 to 1 meter.

***Lure Fishing*:** Lure fishing was conducted using a spinning rod and various artificial lures (vibrating minnow, jig bait, and vibration, lure weight: 9 – 11 g; hook size: 2 – 4). Fishing was performed during peak fish feeding periods (05:00 – 09:00 and 15:00 – 19:00). In each sampling plot, one or two fishers were assigned; specifically, two fishers were placed at sites ST1, ST2, and ST3, whereas one fisher was assigned at the remaining sites. Two fishing sessions were conducted daily, one in the morning and one in the afternoon. The total number of fish captured over the two-day period was recorded.

***Fyke Netting*:** Fyke nets (also known as chilopod nets or great-wall nets) used in this study consisted of long, square-shaped cages measuring 5 meters long with a mesh size of 1.0 cm. At each sampling plot, one or two fyke nets were deployed (two nets were installed at sites ST1, ST5, and ST6, whereas one net was used at the remaining sites). Each net was baited with a 20 g mixture of rice, tilapia feed, and eel powder. Fyke nets were deployed at 15:00 each day and retrieved at 07:00 the following morning. Anchors were attached to both ends of the net, with a float marker placed on one end for identification. The total number of fish captured via fyke netting was recorded over two nights.

***Electrofishing*:** Electrofishing was performed using a *Meidi* 380 kW adjustable direct current (DC) backpack electrofisher. Electrofishing was conducted daily during two time periods, from 06:00 – 08:00 and 14:00 – 18:00. This method was primarily applied in densely vegetated areas and shallow waters. The electrofisher temporarily immobilized fish, allowing for manual capture with hand nets. To assess the impact of electrofishing compared to other fishing techniques, mortality rates of captured fish were systematically recorded throughout the study period.

Data Collection and Analysis

Data on fish species, body length, and capture location for each removal event were meticulously documented for native and exotic fish. To examine the differences in body length among capture methods, the mean body lengths of *C. striata* and *O. marmorata* caught by electrofishing and traditional fishing methods (lure/longline fishing for *C. striata* and fyke nets for *O. marmorata*) were compared using an unpaired t-test with unequal variances. Normality of length data was examined prior to analysis, and results are presented as mean ± SD. When the assumption of normality was not met, the non-parametric Mann–Whitney U test was applied. To evaluate the differences in mortality rates among fishing methods (lure fishing, fyke netting, and electrofishing), a chi-squared test of goodness-of-fit was applied to compare observed mortality frequencies among methods. All statistical analyses were conducted

Table 1. Numbers (individuals) of fishes caught from 2017 to 2023

Scientific Name / Year	2017	2018	2019	**2020**	**2021**	**2022**	**2023**	**2024**	**Total**
	Non electrofishing*			Add electrofishing					
Channa striata	40	220	136	624	501	567	509	810	3,408
Oxyeleotris marmorata	18	54	31	244	119	76	139	81	762
Chanodichthys erythropterus	198	155	48	266	112	166	121	311	1,377
Oreochromis spp.	47	122	127	736	451	486	1,096	845	3,911
Trichogaster trichopterus	253	62	125	1,188	611	538	1,876	962	5,615
Ambassis sp.	1	0	1	6	15	4	29	91	147
Other exotic fishes	0	0	3	40	10	0	10	14	78
Cyprinus carpio carpio	7	7	6	10	11	7	12	11	71
Hemiculter leucisculus	98	85	301	1,478	412	422	1,002	487	4,285
Carassius auratus auratus	1	1	3	6	0	2	122	7	142
Paratanakia himantegus	2	8	57	160	111	31	40	26	435
Rhodeus ocellatus ocellatus	2	0	4	14	22	13	5	5	65
Rhinogobius sp.	0	0	1	214	74	13	143	112	557
Other native fishes	0	0	6	16	2	0	24	8	56
Total (individuals)	667	714	849	5,002	2,451	2,325	5,128	3,771	20,908

Other exotic fish included: *Gambusia affinis* (26 individuals), *Poecilia reticulata* (13 individuals), *Pterygoplichthys pardalis* (13 individuals), *Clarias batrachus* (16 individuals), *Parachromis managuensis*(1 individuals). Other native fishes included: *Anguilla marmorata* (21 individuals), *Planiliza subviridis* (5 individuals), *Monopterus albus* (22 individuals), *Eleotris acanthopoma* (2 individuals), *Mugil cephalus* (5 individuals) *Data from 2017 to 2019 based on Huang *et al*., 2021.

Table 2. Yearly differences in fish captures based on electrofishing

Scientific Name / Year	2017–2019	**2020–2024**
	Non electrofishing	**Add electrofishing**
Channa striata	132±90.1	602.2±126.3
Oxyeleotris marmorata	34.3±18.2	131.8±68
Chanodichthys erythropterus	133.7±77.2	195.2±89
Oreochromis spp.	98.7±44.8	722.8±266.6
Trichogaster trichopterus	146.7±97.3	1035±539.2
Ambassis sp.	0.7±0.6	29±36
Other exotic fishes	1.0±1.7	14.8±15
Cyprinus carpio carpio	6.7±0.6	10.2±1.9
Hemiculter leucisculus	161.3±121.1	760.2±470.1
Carassius auratus auratus	1.7±1.2	27.4±53
Paratanakia himantegus	22.3±30.2	73.6±59.3
Rhodeus ocellatus ocellatus	2±2	11.8±7.1
Rhinogobius sp.	0.3±0.6	111.2±75.2
Other native fishes	2±3.5	10±10
Total (individuals)	743.3±94.5	3735.4±1340.1

using standard statistical software, and differences were considered statistically significant at $p < 0.05$. To assess potential ecological stress resulting from different removal methods, this study employed **Abundance Biomass Comparison (ABC) curves** to evaluate population stress levels in three target species: *Hemiculter leucisculus*, *C. striata*, and *O. marmorata*. The ABC curves were used to compare population dynamics before (2017–2019; Liang *et al*., 2022) and after (2020–2024) the introduction of electrofishing. ABC analysis involves comparing the abundance and biomass trajectories of a given species or assemblage, with the computed **W value** serving as an index of stress exposure.

W > 0 indicates a stable, non-stressed population.

W ≈ 0 particularly when the abundance and biomass curves intersect, suggests mild or negligible population stress.

W < 0 reflects significant ecological stress, indicating population decline or disruption.

This analytical approach provides a refined assessment of ecological stressors affecting freshwater fish populations, offering critical insights into species resilience and ecosystem stability (Yemane *et al*., 2005). The ABC curve calculations and statistical analyses were conducted using **PRIMER 6.0 software** (Clarke and Gorley, 2006).

RESULTS

Since the introduction of electrofishing in 2020, a total of 20 fish removal operations were conducted at Longluan Lake through 2024, resulting in the capture of 18,676 individuals. Among them, 13,654 were non-native species, while 5,022 were native species. The dominant invasive species were the three-spot gourami (*T. trichopterus*, 5,175 individuals), tilapia species (*Oreochromis* spp., 3,614 individuals), and striped snakehead (*C. striata*, 3,011 individuals). After the implementation of electrofishing in 2020, the overall removal efficiency of invasive fish species increased significantly (Table 1). In particular, the average annual catch of *C. striata* and marble goby (*O. marmorata*) rose to 602.2 ± 126.3 and 131.8 ± 68 individuals, respectively, compared to 132 ± 90.1 and 34.3 ± 18.2 individuals before 2020 (Table 2).

Electrofishing also showed distinctive capture performance across fish sizes. It was especially effective in shallow and vegetated areas, enabling the removal of small-bodied invasive species that were previously difficult to catch, such as *Gambusia affinis* and *Ambassis*

Table 3. Proportions of mortality by lure fishing, fyke net, and electrofishing.

Scientific Name	lure	fyke net	electrofishing
Channa striata	0.0	0.0	7.9
Oxyeleotris marmorata	0.0	0.0	6.3
Chanodichthys erythropterus	0.0	26.3	8.6
Oreochromis spp.	0.0	30.0	23.8
Trichogaster trichopterus	-	31.5	7.8
Gambusia affinis	-	-	33.3
Pterygoplichthys pardalis	0.0	0.0	-
Ambassis sp.	-	100.0	0.0
Clarias batrachus	-	-	0.0
Cyprinus carpio carpio	0.0	0.0	0.0
Hemiculter leucisculus	-	41.8	7.1
Paratanakia himantegus	-	58.1	18.8
Rhodeus ocellatus ocellatus	-	57.1	20.0
Anguilla marmorata	-	-	0.0
Monopterus albus	-	-	0.0
Rhinogobius sp.	-	-	13.5
Average Mortality	0.0	32.8	9.2

"-": Indicates that the species was not caught by this fishing method

Table 4. Changes in W values of ABC curves before and after electrofishing events.

Scientific Name \ W Values	Before	After	note
Channa striata	0.011	-0.057	Decrease
Oxyeleotris marmorata	0.101	-0.001	Decrease
Chanodichthys erythropterus	-0.096	0.011	Increase
Oreochromis spp.	-0.034	-0.031	Unchanged
Trichogaster trichopterus	0.104	-0.02	Decrease
Hemiculter leucisculus	-0.094	0.005	Increase
Paratanakia himantegus	-0.002	0.021	Increase
Rhodeus ocellatus ocellatus	-0.016	0.026	Increase

sp. In contrast, traditional methods such as lure fishing and fyke nets were more effective in capturing larger individuals, such as hybrid tilapia. Regarding mortality rates of captured fishes, electrofishing averaged 9.2%, significantly lower than the 32.8% observed in fyke net, indicating less disturbance to native fish populations. A chi-squared goodness-of-fit test rejected the null hypothesis of equal mortality among fishing methods, confirming significant differences among lure fishing, fyke netting, and electrofishing (χ^2 =40.89, df=2, $p < 0.05$; Table 3).

Analysis of *C. striata* body length captured between 2020 and 2024 showed that individuals caught by lure fishing and longline methods had a significantly greater average length (41.1 ± 7.5 cm), with most individuals ranging between 30 and 50 cm, whereas those captured by electrofishing were much smaller (15.4 ± 14.7 cm), with the majority under 10 cm in length (unpaired t-test, $p < 0.05$; Figure 2). Therefore, combining electrofishing with lure and longline methods enables effective removal across different life stages of *C. striata*, enhancing control of population growth.

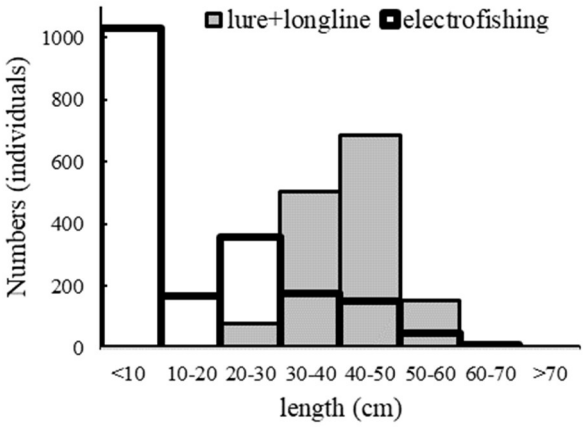

Fig. 2. A comparison of captured individuals and body length of ***Channa striata*** between the lure+longline nets and electrofishing.

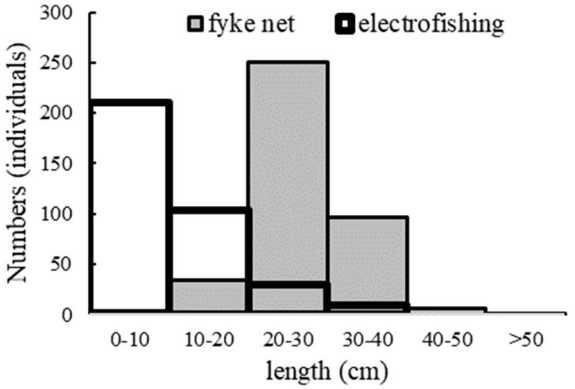

Fig. 3. A comparison of captured individuals and body length of ***Oxyeleotris marmorata*** between the fyke net and electrofishing.

Similarly, for *O. marmorata*, individuals captured by fyke nets had a significantly larger average length (26.7 ± 6.0 cm) than those caught by electrofishing (10.2 ± 6.9 cm; unpaired t-test, $p<0.05$; Figure 3). Therefore, integrating electrofishing with fyke netting can enhance removal efficiency by targeting different size classes of *O. marmorata*.

According to ABC curve analysis (Table 4), the W values of *C. striata* and *O. marmorata* declined from 0.011 to -0.057 and from 0.101 to -0.001, respectively, after the introduction of electrofishing, indicating that these populations experienced significant pressure and a downward trend in abundance. Conversely, native species such as crucian carp (*Carassius auratus auratus*) and *H. leucisculus* showed recovery trends, suggesting ecological stress alleviation after invasive species suppression.

DISCUSSION

The implementation of electrofishing since 2020 has significantly enhanced the effectiveness of invasive fish species removal in Longluan Lake, particularly in

shallow and vegetated areas that are otherwise difficult to manage using traditional fishing techniques. The substantial increase in catch numbers of *C. striata* and *O. marmorata* after the adoption of electrofishing underscores the method's capacity to suppress dominant invasive species. This aligns with prior studies emphasizing the effectiveness of electrofishing under variable hydrological conditions and habitat structures (Reynolds, 1996; Penczak and Głowacki, 2008).

Moreover, body length analysis indicated that electrofishing is particularly effective at removing smaller or juvenile individuals, which are often underrepresented in captures by lure fishing and fyke nets. This size-selective advantage suppresses population recruitment by significantly reducing the regenerative potential of invasive fish populations. These findings are consistent with previous studies that suggest electrofishing can exert selective pressure on different size classes of fish (Dalbey *et al*., 1996; Reynolds, 1996). Further, our study demonstrates that integrating electrofishing with lure and longline fishing techniques effectively captures individuals across various growth stages, from juveniles to adults, thereby enhancing removal efficiency. This observation aligns with experimental results by Mycko *et al*. (2018), who reported that combining electrofishing and angling provided a more comprehensive capture of smallmouth bass populations. Similarly, field surveys by Ruetz *et al*. (2007) in freshwater wetlands of Lake Michigan found that the joint application of electrofishing and fine-meshed fyke nets effectively compensated for size and species-specific biases of individual methods. Likewise, combining electrofishing with fyke nets to remove *O. marmorata* showed enhanced effectiveness, as fyke nets tended to capture larger individuals, while electrofishing effectively removed smaller ones (Ruetz *et al*., 2007). Integrating these methods thus minimizes the risk of population gaps or missed size classes and offers high potential for population-level control. Taken together, the literature and our findings suggest that combining electrofishing with traditional removal methods increases capture efficiency across different body sizes and more effectively limits recruitment opportunities, resulting in more comprehensive suppression of invasive fish populations.

Integrating multiple capture techniques - electrofishing, lure fishing, and longline fishing - provides a complementary approach that targets different size classes of invasive fish. For instance, the combination of electrofishing and fyke nets for *Oxyeleotris marmorata* effectively covered both juveniles and adults, enhancing the comprehensiveness of population removal. However, mortality rates of captured individuals varied considerably among fishing capture methods. Electrofishing exhibited a relatively low mortality rate (9.2%) compared to fyke nets (32.8%), suggesting it is less harmful to non-target species and can be optimized to minimize ecological disturbance. Field observations revealed that the high mortality associated with fyke nets was primarily due to prolonged confinement, physical injury, and interspecific aggression within the traps, particularly among small-bodied fish such as *H. leucisculus*. This aligns with previous reports that passive gear, such as fyke nets, can induce substantial stress and hypoxia in captured fish, particularly when deployed in low-oxygen or densely vegetated environments (O'Neal, 2007; Fischer and Quist, 2014). Studies have shown that small fish trapped for extended periods can suffer mechanical abrasion, starvation, or predation from other captured species (Chopin and Arimoto, 1995; Snyder, 2003; Rytwinski *et al*., 2019). Reducing soak time, increasing mesh size, and incorporating aeration measures—such as float valves or escape gaps—have been recommended as mitigation strategies (Yemane *et al*., 2005). As noted in prior literature, adjustments in electrical parameters and post-capture handling can reduce the likelihood of physical injury or delayed mortality in non-target species (Dalbey *et al*., 1996), making electrofishing a more ecologically sustainable option when combined with improved passive gear designs.

ABC curve analysis further confirmed the population-level impacts of electrofishing, with marked reductions in W values for key invasive species, signifying community-level shifts. This observation is consistent with the principle that reduced propagule pressure, the number and frequency of introduced individuals, is critical in preventing long-term establishment and spread of invasive taxa (Britton and Gozlan, 2013). At the same time, native species such as *Paratanakia himantegus*, *C. auratus* and *H. leucisculus* exhibited signs of recovery, reflecting improved ecological balance in the wetland system. Despite its effectiveness, electrofishing still poses a risk of hypoxia-related mortality, particularly among stunned individuals. Enhancing dissolved oxygen availability immediately following capture may mitigate this effect and support the recovery of non-target species, particularly native taxa.

CONCLUSION

This study demonstrates that electrofishing is a highly effective and ecologically valuable method for managing invasive fish species in freshwater wetland systems. When integrated with other fishing techniques, electrofishing facilitates the comprehensive removal of fish across life stages, thereby suppressing recruitment and supporting long-term population control. The observed decline in invasive fish dominance and partial recovery of native species indicate that sustained removal efforts, guided by adaptive and targeted strategies, can contribute to the ecological restoration of wetland

habitats. Future removal operations should continue to refine electrofishing protocols, particularly with reaching a balance between sampling efficiency and the conservation of native biodiversity.

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