Behavioural Processes 210 (2023) 104908

Contents lists available at ScienceDirect

Behavioural Processes

journal homepage: www.elsevier.com/locate/behavproc

Acute noise is harmful on the anti-predator behaviour of commercially important juvenile coral reef fishes

Nathan William Price [a,b], Yijung Liu [b], Kao-Sung Chen [c], Cheng-Hao Tang [d], Chi-Fang Chen [e], Ming-Chung Cheng [f], Colin Kuo-Chang Wen [b,g,*]

[a] Biodiversity Program, Taiwan International Graduate Program, Academia Sinica and Tunghai University, Taipei 11529, Taiwan
[b] Department of Life Science, Tunghai University, Xitun District, Taichung 40704, Taiwan
[c] Planning and Information Division, Fisheries Research Institute, Council of Agriculture, Keelung 202008, Taiwan
[d] Department of Oceanography, National Sun Yat-Sen University, Kaohsiung 80424, Taiwan
[e] Department of Engineering Science and Ocean Engineering, National Taiwan University, Taipei 10617, Taiwan
[f] Eastern Marine Biology Research Center, Fisheries Research Institute, Council of Agriculture, Taitung, Taiwan
[g] Center for Ecology and Environment, Tunghai University, Xitun District, Taichung 40704, Taiwan

ARTICLE INFO

Keywords:
Aquaculture noise
Boat noise
Epinephelus coioides
Fish behaviour
Response latency

ABSTRACT

Fish stock enhancement has been utilised in Taiwan for more than 30 years, yet the impacts of anthropogenic noise on the enhancement programs remain unknown. Anthropogenic noise can induce physiological and behavioural changes in many marine fishes. Therefore, we investigated the effects of acute boat noise (from stock enhancement release sites) and chronic noise (from aquaculture processes) on the anti-predator behaviour in three juvenile reef fishes: *Epinephelus coioides, Amphiprion ocellaris* and *Neoglyphidodon melas.* We exposed fish to aquaculture noise, boat noise and a combination of both, followed by a predator scare and documented kinematic variables (response latency, response distance, response speed and response duration). For the grouper *E. coioides*, their response latency decreased in the presence of acute noise, while their response duration increased in the presence of both chronic and acute noise. Among the anemonefish *A. ocellaris*, all variables remained unaffected by chronic noise, whereas acute noise increased the response distance and response speed. In the case of the black damselfish *N. melas*, chronic noise decreased the response speed, while acute noise decreased the response latency and response duration. Our results indicate that acute noise had a stronger influence on anti-predator behaviour than chronic noise. This study suggests that acute noise levels at restocking release sites can impact anti-predator behaviour in fishes, potentially altering fitness and likelihood of survival. Such negative effects and interspecific differences must be considered when restocking fish populations.

1. Introduction

Noise produced by anthropogenic activities is increasing in many marine ecosystems (Slabbekoorn et al., 2010). Initially, most concerns for anthropogenic noise in the marine environment focused on the most intense sound sources (e.g. military and construction activities) and as research has emerged, greater attention has now been given to boat noise. Boat noise is a major source of underwater noise, as boats are often present in large numbers and travel close to marine life (Williams et al., 2015). The impact of motorboat noise spans a range of potential disturbances, from infrequent acute events to continuous chronic occurrences in areas such as boat channels, harbours and tourism hotspots. Boat noise can negatively affect the behaviour, reproduction, orientation and survival of coral reef fishes (Holles et al., 2013; Simpson et al., 2016a; b; Fakan and McCormick, 2019; de Jong et al., 2020; Mills et al., 2020). Some of the most disruptive boat noise effects are regarding risk assessment and anti-predator behaviour in fishes (Picciulin et al., 2010; McCormick et al., 2018). Noise-induced stress can reduce the likelihood of prey detecting an approaching predator, resulting in failing to react with the appropriately rapid startle and escape response, and thus increasing the chance of mortality (Simpson et al., 2016b). Further applications using these kinematic variables to project the demography of reef fishes in the anthropocene has also been well documented (Simpson et al., 2016a; McCormick et al., 2019).

* Correspondence to: No. 1727, Sec. 4, Taiwan Boulevard, Xitun District, Taichung City 407224, Taiwan.
E-mail addresses: nathanwprice92@gmail.com (N.W. Price), kechn12383@gmail.com (Y. Liu), kschen@mail.tfrin.gov.tw (K.-S. Chen), chifang@ntu.edu.tw (C.-F. Chen), ckcwen@thu.edu.tw (C.K.-C. Wen).

https://doi.org/10.1016/j.beproc.2023.104908
Received 20 September 2022; Received in revised form 18 June 2023; Accepted 22 June 2023
Available online 25 June 2023
0376-6357/

Noise is often overlooked in aquaculture facilities, aquariums and restocking programs. Restocking (also termed stock enhancement or the biomanipulation of fish populations) has been used to combat the effects of overharvesting (Bell et al., 2006). Restocking methods utilised on marine ecosystems have mainly aimed to recover commercially important fish populations (Lorenzen et al., 2013). There have also been recent attempts to restock certain species of coral reef fishes (e.g parrotfish; Bowling, 2014), with evidence suggesting herbivorous fish restocking coupled with added protection, can facilitate reef recovery (Obolski et al., 2016). This approach is based on the re-introduction of cultured fish (i.e., reproduced and reared using aquaculture methods) into the reef (Abelson et al., 2016). The choice of release location often considers specific factors (i.e., water temperature, salinity, distance from aquaculture facility and accessibility), while failing to investigate other factors (i.e., noise levels). In aquariums, laboratories and aquaculture facilities, noise is often generated by various sources including pumps, airstones and water filters (Davidson et al., 2007; Hasan et al., 2018). In these closed environments, fishes are unable to escape areas of loud noise and are consequently subjected to chronic noise exposure. Although some freshwater fishes (e.g. goldfish, *Carassius auratus* and rainbow trout, *Oncorhynchus mykiss*) have shown some negative effects to aquaculture noise (Wysocki et al., 2007; Gutscher et al., 2011), the effects on coral reef fishes remain largely unknown. Although research on the effects of aquaculture noise on reef fish is lacking, noise has been shown to cause physiological responses during embryogenesis (Fakan and McCormick, 2019).

Marine restoration efforts began in Taiwan with the building and casting of artificial reefs in 1973, followed by the establishment of a stock enhancement system in 1987 (Liao, 1997). Between 2002 and 2018, official fishery organisations (i.e., Taiwan Fisheries Sustainable Development Association) performed stock enhancement of 21 species (20 finfish and 1 crab) releasing more than 133,593,000 individuals at various locations around Taiwan (Chang et al., 2011; Hsu et al., 2020). Since then, coastal and offshore fishery stocks have been assessed (Ju et al., 2020), however very few evaluation cases of the restocking programs exist, meaning the effectiveness is highly controversial. Most restocking programs release juvenile fishes at fishing harbours, which are very common along the coast, with one found every 8.84 km (Wen et al., 2010). These harbours have high fishing and recreational boat activity producing underwater noise. In addition, some restocking processes take place while using boats to release juvenile fishes. The boat noise commonly found in fishing harbours or close to reef communities impacts how juvenile reef fish assess risk (McCormick et al., 2018); it can decrease the speed at which the fish responds to a startle (Holmes et al., 2017; McCormick et al., 2019) and cause latent long-term effects on learning (Ferrari et al., 2008), all potentially reducing their fitness and survival.

Despite 30 years of the highly controversial stock enhancement programs, the noise pollution in the culturing process and predator-induced mortality following noise exposure at release sites has been largely overlooked in Taiwan, consequently, to date there are no studies on the subjects. We address this by investigating whether chronic noise in the aquaculture processes and acute boat noise from fish stock enhancement release sites can affect the anti-predator behaviour in a juvenile grouper and two juvenile damselfish species. We habituated two fish groups (one quiet group and one group exposed to aquaculture noise) and subjected each group to either ocean sound or boat noise followed by a visual scare. To our knowledge, this is the first study investigating the effects of anthropogenic noise on a juvenile predatory reef fish.

2. Materials and methods

2.1. Study sites and noise recordings

Kenting National Park (KNP) is located on the Hengchun Peninsula on the southernmost tip of Taiwan (Fig. S1a). Prior to the COVID-19 pandemic, the park attracted millions of visitors annually and was one of the most popular water activity-based attractions in Taiwan (Kung et al., 2018; Fig. S1b). Since the COVID-19 pandemic, the park still attracts a huge amount of national tourists annually. The boat noise and ocean treatments used in this study were recorded during the day at three sites (Houbihu, Shanghai and Hongchaikeng) in KNP Fig. S1a) from 27/09/2016–29/09/2016 using a digital microphone (Ruizu T&F-80, calibrated by the Underwater Acoustics Laboratory, National Taiwan University) in an underwater housing. The calibration was conducted following the below formula.

$$SEN_2 = SEN_1 - 20\text{loglog}\quad\frac{V_{1P-P}}{2\sqrt{2}} + 20\text{loglog}\quad\frac{V_{2P-P}}{2\sqrt{2}}$$

V_{1P-P} is the peak-to-peak Voltage value of standard microphone (B&K-8103); SEN_1 is the sensitivity of microphone B&K-8103; V_{2P-P} is the peak-to-peak Voltage value of the objected sound recorder in our experiment; SEN_2 is the sensitivity of the objected sound recorder. The calibrated report was uploaded to depositar. The boat noise was mainly produced by the engines of fishing boats, sportfishing yachts and glass-bottom boats, although sometimes other anthropogenic sounds such as jetskis were recorded alongside the primary boat noise (Fig. S1b). The ocean sound (without boat noise) was recorded at a greater distance from anthropogenic activities at Houbihu and Hongchaikeng. Initial sound analysis revealed the boat noise frequency was 100–750 Hz and the ocean sound was 300 Hz-45 kHz, and loudest (closest) noise levels were 80 ± 10 dB and 60 ± 10 dB. Aquaculture noise level was measured in the laboratory and consisted of noise produced by filters, air pumps and water pumps and was 70 ± 10 dB. The noise level of quiet treatment was measured in the laboratory without any filter equipment and was 10 ± 5 dB. The sound level of both aquaculture noise and quiet treatments were measured with a waterproof recorder in the tank then read through software Audacity.

2.2. Study species

The orange-spotted grouper, *Epinephelus coioides* (Hamilton, 1822) is found on coral reefs and brackish water over mud and rubble from the Western Indian Ocean to Western Pacific. This species is extremely sought after in local and international markets, where they are generally the most expensive live fish in markets (Ranjan et al., 2014). The high market value of species belonging to the genus *Epinephelus* is leading to the expansion of grouper aquaculture, with grouper aquaculture being most advanced in Taiwan (Pierre et al., 2007).

The common clownfish, *Amphiprion ocellaris* (Cuvier, 1830) is commonly found on or close to shallow reefs, living in symbiosis with three anemone species (Fautin and Allen, 1994) in the Western Indo-Pacific. They are one of the most commercially exploited ornamental species in the aquarium trade, and most ornamental fishes are harvested from the wild, as only 1–10% of species in the trade are estimated to be captive-bred (Wabnitz et al., 2003). Continued increasing demand means supplies are dependent on wild catches (Abol-Munafi et al., 2011). Few countries have successfully reared *A. ocellaris* in captivity and developed successful broodstocks, which are progressively more important to alleviate pressure from the wild populations (Mazzoni et al., 2019).

The black damselfish, *Neoglyphidodon melas* (Cuvier, 1830) inhabits a variety of coral reef habitats and are generally associated with the soft coral upon which they feed (Allen et al., 2003) in the Indo-Asian Pacific, from the Red Sea and East Africa through Southeast Japan and Northern Australia. Although they do not support an important fishery, they are often reported as bycatch and are a popular food source in countries such as Indonesia (Iskander, 2011).

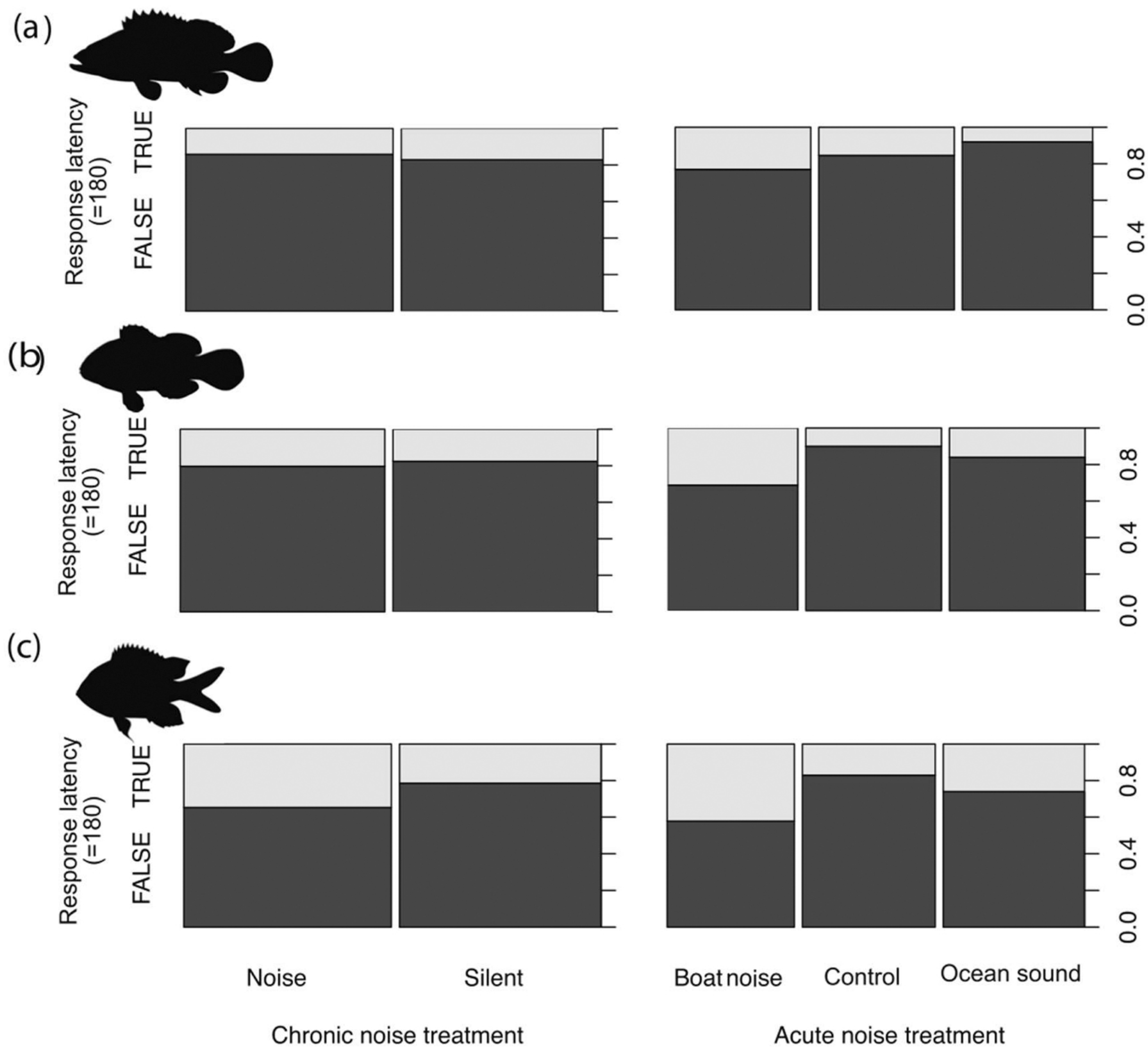

Fig. 1. The ratio of zero and non-zero data for anti-predator behaviour in (a) *Epinephelus coioides,* (b) *Amphiprion ocellaris* and (c) *Neoglyphidodon melas* under chronic aquaculture noise and acute boat noise treatments. Response latency was chosen to represent zero data as other variables (distance, speed and duration) exhibited the same results.

2.3. Experimental design

This study was divided into three parts: fish habituation, sound exposure, and visual scare. All fish used in this study were captive-bred in low or no air-stone noise tanks. They were obtained at approximately 2.5 cm (total length, TL) and fed with brine shrimp (Artemia) twice per day. The fish were separated into two groups: a quiet group without an air stone (10 ± 5 dB) and a chronic noise group (70 ± 10 dB) with an air stone. They were kept in tanks (90 ×60×40 cm, 30 cm water depth), with 26 individuals in each treatment group. After 7 days of treatment, the fish were individually transferred to smaller plastic tanks (40 ×20×30 cm, 20 cm water depth) with a measuring tape and grid placed under the tank. They were then exposed to the second treatment, which consisted of no-sound control, acute ocean sound, or acute boat noise, for 15 min each. Two different types of 15-minute noise treatments were selected from the loudest segments of our recordings, and each individual fish was played back the same 15-minute noise sequence. The two types of noise were played back using Sansui 2-way speakers (60 dB/W, 6 ohms, 50 Hz to 4 kHz) connected to a laptop, which contained the recorded sounds in WAV format. The control group did not undergo the aforementioned noise playback process. Immediately after exposure to the acute noise or ocean sound (80 ± 10 dB), each individual was subjected to a predator scare using a 3D printed predatory grouper fish model (15 cm TL). A single observer (YL) manually released the suspended predator model, which was then propelled by gravity towards the holding tank, stopping 5 cm before reaching the tank (Fig. S2). Each individual fish was confirmed to have noticed the predator model before it was released in order to validate the visual scare.

2.4. Kinematic variables

Video recordings (Canon D90 with 60 fps setting) were used during the noise exposure and predator stimulus to avoid additional reaction changes from the presence of an observer. Each fish was tested individually and limited to three tests to avoid habituation and loss of reaction from repeated stimulation. Video analysis also allowed the startle response to be documented. The videos were analysed with PowerDirector® software, and a single observer (YL) recorded whether the fish startled to the predator scare (Fig. S3). Video footage was analysed frame by frame to measure minute changes in behaviour. The anti-predator behaviour was determined following McCormick et al. (2019). The kinematic variables measured were:

1. Response latency (seconds) was the time between onset of the predator stimulus and onset of C-start response.

Table 1
Results from the (a) hurdle analysis zero model and (b) non-zero model, two-way ANOVA (analysis of variance) showing the effects of chronic aquaculture noise and acute boat and ocean sound on the anti-predator behavioural metrics for three coral reef fish species. Values in bold are statistically significant ($p < 0.05$).

(a)				
Zero model (0 vs 1)		*p* value	*p* value	
Species	Factors	Chronic noise	Acute noise	
Epinephelus coioides	All	0.387	**0.04**	
Amphiprion ocellaris	All	0.671	**0.02**	
Neoglyphidodon melas	All	0.074	**0.03**	
(b) Non-zero model (two-way ANOVA)				
Species	Factors	Chronic noise	Acute noise	Interaction
Epinephelus coioides	Response latency	0.505	**0.001**	0.527
	Response distance	**0.032**	0.771	0.323
	Response speed	0.553	0.087	0.722
	Response duration	**0.009**	**0.001**	0.461
Amphiprion ocellaris	Response latency	0.510	0.362	0.326
	Response distance	0.557	**0.001**	0.427
	Response speed	0.590	**0.046**	0.250
	Response duration	0.474	0.091	**0.013**
Neoglyphidodon melas	Response latency	0.262	**0.026**	0.398
	Response distance	0.083	0.781	0.597
	Response speed	**0.039**	0.112	0.588
	Response duration	0.806	**0.006**	0.254

2. Response distance (cm) was the total distance travelled during the first two flips of the tail (Domenici and Blake, 1997).
3. Response speed (cm/second) was the distance covered divided by the duration of the response.
4. Response duration (seconds) was the total response time from the start of the stimulus to the end of response.

2.5. Data analysis

The frequency range of the noise recordings were analysed using Audacity(R) version 2.4.2 recording and editing software. As some fish did not respond to the predator stimulus, we used a two-step model to analyse the zero-data (count of no reaction) and non-zero data (anti-predator behaviour) to evaluate the effects of noise. The zero-data for each of the three species among treatments were examined using chi-squared tests (Zeileis et al., 2008). Non-zero data were Box-Cox transformed to meet the assumption of a normality test (Hammer et al., 2001). Transformed data were then analysed using a two-way analysis of variance (ANOVA) to compare the behavioural metrics of the three species between the two factors (chronic and acute noise exposure). When significant differences were detected in the ANOVA, Tukey's post-hoc HSD (honestly-significant-difference) test was used to determine the factors (Yandell, 1997). Power analysis was also performed with a 2×3 experimental design, alpha = 0.5, 0.5 and the effect size (medium) was chosen based on related literature. The power analysis for our sample size ($n = 26$ for each group) was 0.99 (Cohen, 2013). The Box-Cox transformation was conducted in PAST 4.1 (Hammer et al., 2001) and the hurdle model, chi-squared, ANOVA, HSD and power analysis were performed and results were plotted in R language using the *pwr2* package (v. 3.5.2; R Core Team, 2018).

Table 2
Tukey's pairwise HSD (honestly significant difference) results for zero model groups that showed significant differences for acute noise from two-way ANOVA tests. Values in bold are statistically significant ($p < 0.05$). The abbreviations in the table, diff: average difference; lwr & upr: lower and upper bounds of the 95% confidence interval; p adj: adjusted *p* value of the difference.

	Treatments	diff	lwr	upr	*p* adj
Epinephelus coioides	Control-boat	-0.105	-0.275	0.065	0.309
	Ocean-boat	-0.179	-0.351	-0.008	**0.039**
	Ocean-control	-0.074	-0.247	0.099	0.573
Amphiprion ocellaris	Control-boat	-0.213	-0.398	-0.027	**0.021**
	Ocean-boat	-0.153	-0.338	0.033	0.130
	Ocean-control	0.060	-0.124	0.244	0.720
Neoglyphidodon melas	Control-boat	-0.240	-0.459	-0.022	**0.027**
	Ocean-boat	-0.155	-0.370	0.061	0.207
	Ocean-control	0.086	-0.127	0.298	0.608

3. Results

E. coioides ($n = 156$), *A. ocellaris* ($n = 156$) and *N. melas* ($n = 156$) were exposed to various sound treatments followed by a visual predator stimulus to document how anthropogenic noise affects escape responses. The hurdle analysis revealed chronic noise did not influence the zero-count data for any factors and species (Fig. 1; Table 1a), whereas acute noise influenced the zero count data for *E. coioides* ($p = 0.04$), *A. ocellaris* ($p = 0.02$) and *N. melas* ($p = 0.03$). Tukey's post-hoc test revealed significant differences between ocean-boat noise for *E. coioides* and control-boat noise for both *A. ocellaris* and *N. melas* (Table 2). These results suggest fishes exposed to acute noise displayed a higher chance of exhibiting no response to the predator stimulus.

E. coioides response latency was not significantly affected by chronic noise, but by acute noise ($p = 0.001$; Fig. 2; Table 1). Tukey's post-hoc test revealed that acute noise decreased the response latency in *E. coioides* (Table S1). Chronic noise significantly decreased the response distance following the predator scare ($p = 0.032$). Both chronic and acute noise significantly increased the response duration ($p = 0.009$ and $p = 0.001$, respectively). Overall, acute noise decreased the response latency and increased the response duration (Fig. 2).

The response latency of *A. ocellaris* appeared to be unaffected by both chronic and acute noise, whereas acute noise significantly increased the response distance ($p < 0.001$) and response speed ($p < 0.046$; Fig. 3; Table 1). *A. ocellaris* response duration was not affected by any treatments and the post-hoc test did not show any significant differences between treatments (Table S1).

Acute noise significantly altered the response latency and response duration in *N. melas* ($p = 0.026$ and $p = 0.006$, respectively). Tukey's post-hoc test revealed that acute noise decreased the response latency and response duration compared to control or ocean sound (Fig. 4; Table S1). None of the treatments appeared to affect the response distance of *N. melas* (Table 1). The exposure to chronic noise led to a decrease in response speed ($p = 0.039$), whereas acute noise had no effect (Fig. 4). It appeared both chronic noise and acute noise can affect the anti-predator behaviour in *N. melas* (Fig. 4).

4. Discussion

The zero and non-zero models examining the anti-predator behaviour of three juvenile fishes yielded similar results, acute noise is the major factor driving the changes of the behavioural metrics. The zero-model revealed that acute noise increased the number of no-response individuals in all study species, whereas chronic noise did not have this effect. Juvenile fishes might have the ability to adapt relatively quickly to chronic noise levels (i.e. aquaculture noise exposure from our study), as damselfish can resume normal pre-noise behaviour 20 min

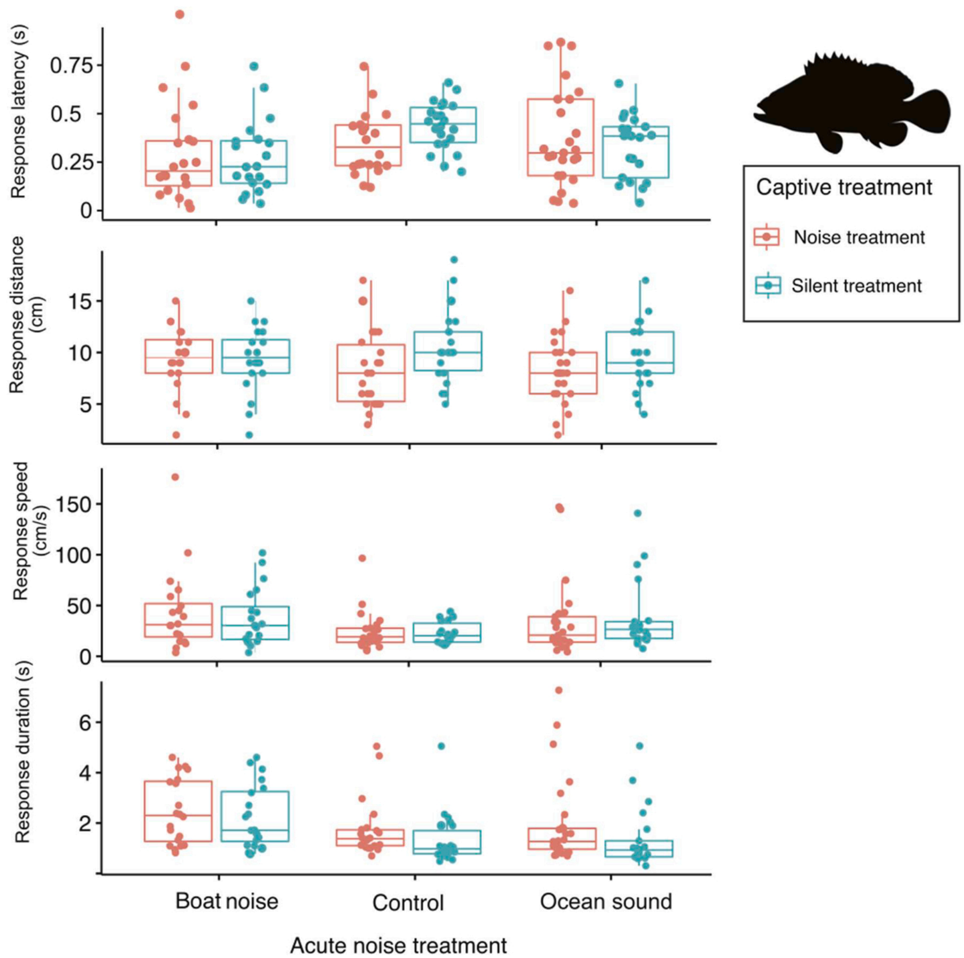

Fig. 2. Anti-predator behaviour in *Epinephelus coioides* exposed to chronic aquaculture noise or no noise in captivity, followed by acute boat noise or ocean noise treatments. Anti-predator behaviour include response latency (seconds), distance (cm), speed (cm/s) and duration (seconds).

after noise exposure (Holmes et al., 2017).

The effects of chronic aquaculture noise yielded varied results in this experiment. The control silent groups demonstrated that chronic noise may not necessarily have a significant impact on the anti-predator behaviour in some subject species. Specifically, *A. ocellaris* was not affected by chronic noise, while the response distance of *E. coioides* was significantly smaller compared to the control group. Interestingly, certain behaviour remained unchanged even when exposed to chronic noise followed by acute noise exposure. We suspect that these discrepancies in our findings are most likely due to the different auditory sensitivities of each species. Pomacentrids, which include *A. ocellaris*, exhibit similar hearing abilities, which differ from serranids (Wright et al., 2009). Furthermore, it is worth noting that two species, the grouper *E. coioides* and black damselfish *N. melas*, were bred in an environment with air stones producing low noise levels, suggesting a potential habituation to aquaculture noise even at lower levels. Conversely, anemonefishes were bred in tanks without air-stoning and also displayed less sensitivity to chronic noise. To gain a deeper understanding of the long-term effects of chronic noise on the anti-predator behaviour of reef fishes, further studies are necessary. These investigations should focus on the extended impacts of chronic noise on anti-predator behaviour.

We conducted this experiment to investigate the combined effects of aquaculture noise and boat noise playback on informing better decisions regarding release sites for restocking programs in Taiwan. Recent evaluations of 16 commercial fish species in Taiwan's coastal and offshore waters revealed alarming statistics: 10 stocks have collapsed, 2 are severely overfished, 2 are overfished, 1 is slightly overfished, and only 1 remains in a healthy state (Ju et al., 2020). While these evaluations primarily focus on offshore fish stocks and species distinct from those in our study, there is also a notable lack of research assessing the status of coral reef fish populations in Taiwan. Our results indicate that chronic aquaculture noise may alter the anti-predator behaviour of commercially important fishes, such as *E. coioides*, while acute boat noise can lead to significant changes. Moreover, despite decades of restocking efforts, our findings potentially offer an explanation for the persistently low abundance of certain reef fish species in Taiwanese water, particularly *E. coioides* (Wen, unpubl. data). Given the crucial importance of optimal release sites and improving survivability during and post aquaculture, it is imperative to focus on research that enhances the effectiveness of restocking programs. Our findings, being the first to inform policymakers about better aquaculture practices and release sites, hopefully pave the way for further research aimed at improving the survivability of fishes in these much-needed restocking programs.

Our results add to the growing body of literature highlighting the dangers of boat noise and how boat noise leads to behavioural changes to a predatory threat (Voellmy et al. (2014); Holmes et al. (2017); Ferrari et al. (2018); McCormick et al. (2018); McCloskey et al. (2020). Velasquez Jimenez et al. (2020) examined the effects of noise from 4-stroke motorboats and bulk carrier ships on the routine swimming behaviour and escape response in whitetail damsels, *Pomacentrus chrysurus*. Fish exposed to the ship noise moved shorter distances and had a higher response latency, but both noise exposures affected the escape response of individuals to a simulated predation threat. These results are similar to our findings, as *N. melas* exhibited significantly higher response latency and response duration. However, the results are

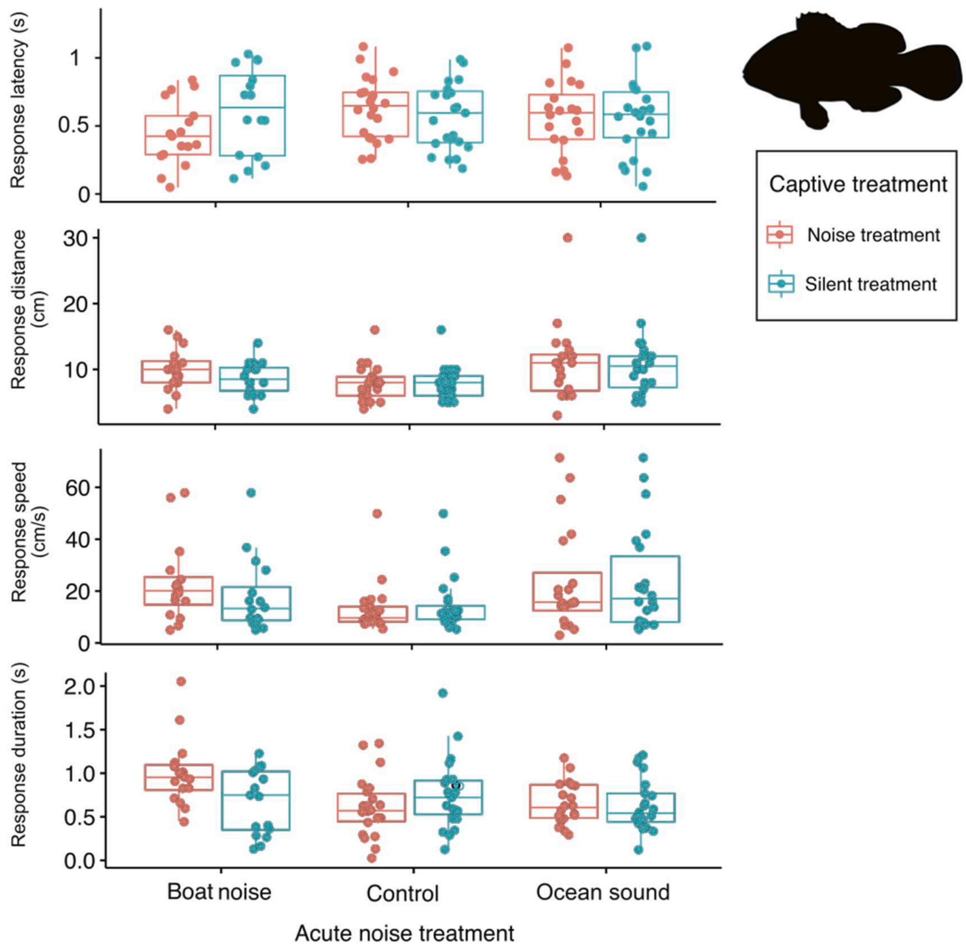

Fig. 3. Anti-predator behaviour in *Amphiprion ocellaris* exposed to chronic aquaculture noise or no noise in captivity followed by acute boat noise or ocean noise treatments. Anti-predator behaviour include response latency (seconds), distance (cm), speed (cm/s) and duration (seconds).

quite the opposite for *A. ocellaris*, as boat noise significantly increased their response distance and response speed. We suspect these differences are species-specific, but behavioural responses could change as a result of habituation and increased tolerance (see Nedalec et al., 2016).

Although anthropogenic noise studies have been conducted in situ and in controlled conditions and have indeed focused on different life stages, sexes, behaviours, noise types and longevity of exposures, most research has focused on pomacentrids and other low-trophic levels species (Holmes et al., 2017; Ferrari et al., 2018; McCormick et al., 2019). To our knowledge, this is the first study documenting the effects of anthropogenic noise on the anti-predator behaviour in juvenile *E. coioides*. Despite the successes of grouper aquaculture in Taiwan, research into how both aquaculture noise and anthropogenic noise in the wild affects groupers is extremely lacking. This is surprising considering the increasing consumer demands, and the fact that groupers represent such a large proportion of stock enhancement species in Taiwan. Further research into how sources of anthropogenic noise affects behaviour and physiology in groupers is incredibly crucial to increase the success of the restocking programs and thus grouper populations.

E. coioides and *A. ocellaris* both exhibited increases in response duration following boat noise playback, and although *N. melas* were significantly affected by boat noise, they exhibited a decrease in response duration. We are uncertain exactly how acute noise affects predator avoidance responses in *N. melas* causing them to exercise a lesser response duration. Staaterman et al. (2020) also found some peculiar results when exposing reef fish to acute boat noise playback. Playback did lead to increased cortisol levels, but there were no observed differences in baseline stress for fish living in noisy vs. quiet areas. The authors predict this may be a result of low overall auditory sensitivity, habituation or acute boat noise simply not posing a threat. This may well be the case in our study, which emphasises the importance of addressing interspecific differences when evaluating impacts of noise on reef fishes.

As the application of our research was to investigate noise levels commonly found at fishery release sites, this meant we could not control the boat engine type or noise levels. It is important to mention research into sound characteristics of boat engines here. McCormick et al. (2018) found the noise from 30 hp 2-stroke outboard motors reduced boldness and activity of fish on habitat patches compared to ocean sound. Whereas noise from a 30 hp 4-stroke outboard motors only influenced space use and did not change ability to respond to chemical alarm cue and not impacting escape response. With the popularity of KNP increasing, for national and international visitors (prior to COVID-19), underwater noise is certainly going to increase. Further research efforts should be directed into different types of boat noise and engine types, to lead to some mitigation of anthropogenic noise in the marine ecosystem. This can offer managers a practical tool, whereby they may reduce the effects of noise pollution on protected communities. We acknowledge that our study manipulated noise via recording and playbacks and used an artificial predatory stimulus. We employed these methods because conducting this experiment in situ, with the presence of real predator threats and real boats would be logistically unfeasible. Simpson et al. (2016a) compared behavioural changes of juvenile reef fish in the presence and absence of boat noise, using real boat noise exposure and laboratory playbacks. They reported impairments under

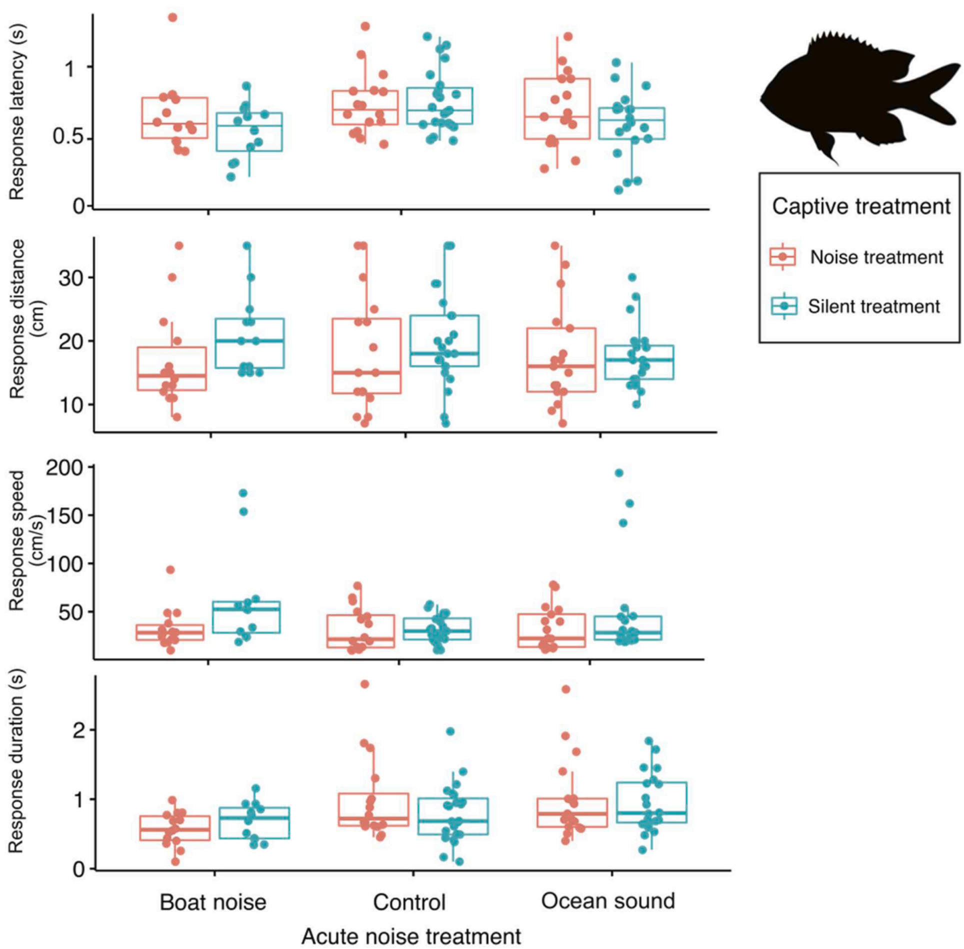

Fig. 4. Anti-predator behaviour in *Neoglyphidodon melas* exposed to chronic aquaculture noise or no noise in captivity followed by acute boat noise or ocean noise treatments. Anti-predator behaviour include response latency (seconds), distance (cm), speed (cm/s) and duration (seconds).

both conditions, meaning laboratory playbacks did not create artificial effects when compared to real boat noise exposure.

There are simple and cheap solutions available to mitigate some of the harmful effects of elevated boat noise and chronic noise pollution in a captive setting. McCloskey et al. (2020) successfully demonstrated the positive effects of an affordable, easily implemented mitigation strategy, consisting of altering motoring practices with speed restrictions and spatial management close to coral reefs. These mitigation strategies could be applied to areas of interest for the restocking programs and tourism hotspots such as KNP. Similarly, Davidson et al. (2007) demonstrated simple and inexpensive structural changes that can be applied to reduce noise levels in aquaculture facilities. Policymakers, managers and users can make noise-conscientious decisions to reduce the harmful impacts of motorboat noise and aquaculture noise on coral reef fishes.

5. Conclusion

Our findings indicate that the escape responses of juvenile reef fishes to predation threats are more negatively affected by acute boat noise exposure compared to chronic aquaculture noise playback. Moreover, we observed notable differences in the response patterns between these two trophic groups. The predatory grouper species, *E. coioides*, known for its sensitivity to acoustic stimuli, exhibited a significantly heightened escape response in the presence of boat noise. This heightened response was evident through reduced response latency, increased response speeds, and prolonged response duration. Conversely, the pomacentrids, belonging to the planktivore and small crustacean feeding trophic group, displayed a relatively less pronounced reaction to the same acoustic stimulus. Our study provides valuable insights that can guide further research focused on environmental factors and anthropogenic impacts at release sites, with the aim of supporting the success of fishery restocking programs in Taiwan. Making informed decisions regarding release sites, combined with modifying boating practices to reduce noise and managing noise in aquaculture processes, will help mitigate the detrimental effects on both hatchery-reared and wild coral reef fishes.

Funding

This research was supported by the Ministry of Science and Technology, Taiwan (110-2311-B-029-002).

CRediT authorship contribution statement

Nathan William Price: Writing – review & editing, Conceptualization. **Liu Yixuan:** Writing – original draft, Investigation, Writing – original draft. **Kao-Sung Chen:** Methodology. **Cheng-Hao Tang:** Methodology. **Chi-Fang Chen:** Formal analysis, Software. **Ming-Chung Cheng**: Methodology. **Colin Kuo-Chang Wen:** Conceptualization, Methodology, Resources, Data curation, Supervision, Funding acquisition, Investigation, Writing – review & editing, Visualization, Project administration, Formal analysis, Software, Visualisation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Nathan William Price, Liu Yi-Jung, Kao-Sung Chen, Cheng-Hao Tang, Chi-Fang Chen, Ming-Chung Cheng, Colin Kuo-Chang Wen. (2022). Data for boat noise on anti-predator escape response of reef fishes (Version 2022–09-15T03:24:36.222863) [Data set]. https://data.depositar.io/en/dataset/data-for-boat-noise-on-antipredator-escape-response-of-reef-fishes.

Acknowledgements

We thank Profs. Jyh-Min Chiang and Yi-Ching Lin for their suggestions on statistical analyses. We also show gratitude to the lab members of Dr. Cheng-Hao Tang and Prof. Chi-Fang Chen for their assistance in the fish breeding process and soundscape analysis. Finally, we dedicate this publication to our dear friend and colleague, Dr. Cheng-Hao Tang, who tragically passed away in 2019.

Ethics statement

All work carried herein followed animal welfare ethics and was approved by Tunghai University (Protocols 110–012).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.beproc.2023.104908.

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