



HAL
open science

Chronic Boat Noise Impacts on the Early Life Stages of Cichlids (*Maylandia zebra*): Preliminary Findings

Wenjing Wang, Théophile Turco, Paulo J Fonseca, Raquel O Vasconcelos, Gérard Coureaud, Maria Clara P. Amorim, Marilyn Beauchaud

► **To cite this version:**

Wenjing Wang, Théophile Turco, Paulo J Fonseca, Raquel O Vasconcelos, Gérard Coureaud, et al.. Chronic Boat Noise Impacts on the Early Life Stages of Cichlids (*Maylandia zebra*): Preliminary Findings. 6th International Conference on the Effects of Noise on Aquatic Life, Jul 2022, Berlin, Germany. pp.1-11, 10.1007/978-3-031-10417-6_179-1 . hal-04214489

HAL Id: hal-04214489

<https://cnrs.hal.science/hal-04214489v1>

Submitted on 16 Nov 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 **Preliminary findings of chronic boat noise impacts on the early**
2 **life stage of cichlids (*Maylandia zebra*)**

3 **Wenjing Wang, Théophile Turco, Paulo. J. Fonseca, Raquel O. Vasconcelos, Gérard**
4 **Coureaud, Maria Clara P. Amorim and Marilyn Beauchaud**

5 Wenjing Wang (*)

6 Equipe de Neuro-Ethologie Sensorielle, ENES/CRNL, CNRS UMR 5292, INSERM UMR-S
7 1028, UCBL1, Faculté des Sciences et Techniques, Université Jean-Monnet (UJM), Saint-
8 Étienne, France

9 e-mail: wenjing.wang@univ-st-etienne.fr

10 Théophile Turco

11 Equipe de Neuro-Ethologie Sensorielle, ENES/CRNL, CNRS UMR 5292, INSERM UMR-S
12 1028, UCBL1, Faculté des Sciences et Techniques, Université Jean-Monnet (UJM), Saint-
13 Étienne, France

14 e-mail: theophile.turco@univ-st-etienne.fr

15 Paulo. J. Fonseca

16 Departamento de Biologia Animal and cE3c - Center for Ecology, Evolution and
17 Environmental Changes & CHANGE - Global Change and Sustainability Institute, Faculdade
18 de Ciências, Universidade de Lisboa, Portugal.

19 e-mail: pjfonseca@fc.ul.pt

20 Raquel O. Vasconcelos

21 Institute of Science and Environment, University of Saint Joseph, Macao S.A.R., China

22 e-mail: raquel.vasconcelos@usj.edu.mo

23 Gérard Coureaud

24 Equipe de Neuro-Ethologie Sensorielle, ENES/CRNL, CNRS UMR 5292, INSERM UMR-S
25 1028, UCBL1, Faculté des Sciences et Techniques, Université Jean-Monnet (UJM), Saint-
26 Étienne, France

27 e-mail: gerard.coureaud@cnrs.fr

28 Maria Clara P. Amorim

29 Departamento de Biologia Animal, Faculdade de Ciências, Universidade de Lisboa, Portugal;
30 MARE – Marine and Environmental Sciences Centre / ARNET - Aquatic Research Network,
31 Faculdade de Ciências, Universidade de Lisboa, Portugal.

32 e-mail: mcamorim@fc.ul.pt

33 Marilyn Beauchaud

34 Equipe de Neuro-Ethologie Sensorielle, ENES/CRNL, CNRS UMR 5292, INSERM UMR-S
35 1028, UCBL1, Faculté des Sciences et Techniques, Université Jean-Monnet (UJM), Saint-
36 Étienne, France

37 e-mail: beauchaud@univ-st-etienne.fr

38 **1. Abstract**

39 Anthropogenic noise is globally recognized as a stressor for animals. However, despite
40 evidence of detrimental effects of noise exposure on fish, knowledge about chronic effects on
41 critical early life stages is still scarce. Using a split-brood design to exclude the genetic effect,
42 we exposed African cichlids (*Maylandia zebra*) from the same brood to boat noises (~120dB)
43 and to control condition (~100dB) for 12 weeks, starting when mouthbrooding females

44 released their young. Treatment fish were exposed to motorboat noises from 9 am to 6 pm to
45 mimic a typical daily boating activity. Larvae total length and foraging activity was measured
46 on week 1 and week 12. We did not find a significant effect of chronic boat noise exposure
47 on these variables. However, whether noise has any impact within the study period or after
48 week 12 is not clear. Future work will focus on analyzing the data weekly over the 12 weeks
49 exposure period to further substantiate the current results. Addressing the effect of
50 anthropogenic noise on early life stages have implications for our understanding of the effect
51 of this pervasive stressor on aquatic organisms.

52 **2. Keywords**

53 Anthropogenic noise, Long-term noise, Cichlidae, Early-life stage, Growth, Foraging

54 **3. Introduction**

55 *3.1 Anthropogenic sound effect*

56 Anthropogenic underwater noise from commercial shipping, oil and gas exploration, naval
57 operations, fishing, and construction work, has been shown to have increased low-frequency
58 ambient noise at an average rate of 2.5–3dB per decade since the 1960s (McDonald et al.,
59 2006; Miksis-Olds and Nichols, 2016). The higher concentration of human activities in some
60 areas increases the noise above the ambient level not only locally but also away from the
61 source. As many anthropogenic activities generate low-frequency sound, it propagates long-
62 range making it a particularly pervasive pollutant (Miksis-Olds and Nichols, 2016).

63 *3.2 Anthropogenic sound effect on adult aquatic animals*

64 Underwater sounds carry important information such as cues from the surrounding
65 environment or from other animals. Aquatic animals use these acoustic information for
66 communication, navigation, mating, foraging, agonistic displays, territorial defence, and

67 reproduction (Kasumyan, 2009). However, the hearing frequency range of most marine
68 animals overlaps with anthropogenic noise, such as boat noise (Erbe et al., 2014; Merchant et
69 al., 2020; Nikolopoulos et al., 2016). Underwater anthropogenic noise negatively affects
70 aquatic animals, for example by masking important acoustic information (Clark, 2009; Clark
71 et al., 2009; Codarin et al., 2009; McCauley et al., 2003) impairing hearing by causing
72 permanent and/or temporary hearing threshold shifts (Kastak et al., 2008; McCauley et al.,
73 2003) and inner ear hair cell loss (Lara et al., 2022). Among other consequences, one may
74 quote changing in hormone levels and other stress responses (Kusku, 2020; Kusku et al.,
75 2020; Wysocki et al., 2006), inducing avoidance response (Fewtrell and McCauley, 2012;
76 Pearson et al., 1992), increasing predation risk (Voellmy, Purser, Simpson, et al., 2014) and
77 metabolism (Lagardère, 1982), decreasing growth performance (Kusku et al., 2020) and
78 foraging performance (Purser and Radford, 2011).

79 ***3.3 Importance of early life stages***

80 There are few studies focused on the effect of chronic noise on developmental period of fish
81 (Faria et al. 2022). Early life experiences has been shown to have impacts on adult behaviour
82 and the effects could be complex and long-lasting (Carlson, 2017). However, as increasing
83 noise made by humans alters the underwater soundscape, it is expected that it will affect the
84 early life stages of aquatic organisms, which are generally regarded as the most sensitive
85 period in the whole life span. Fish during early life stages suffer high mortality even under
86 normal environmental fluctuations and challenges (Catalán et al., 2020) and increased
87 mortality could have profound consequences on populations (Slabbekoorn, 2019).

88 ***3.4 Anthropogenic sound effects on early life stages***

89 The limited studies on the impact of anthropogenic noise during the developmental period in
90 aquatic animals point to species-specific effects. For example, noise was shown to decrease
91 growth rate and increase overall stress responses in Lusitanian toadfish embryos (Faria et al.,

92 2022), increase the heart rate of damselfish embryos (Fakan and McCormick 2019; Jain-
93 Schlaepfer et al. 2018), increase heart rate, yolk sac use and cortisol levels of the zebrafish
94 larvae (Lara and Vasconcelos, 2021), reduce feeding success in winter flounder larvae
95 (*Pseudopleuronectes americanus*) (Gendron et al., 2020), and reduce the settlement of coral
96 reed fish larvae to reefs (Simpson et al., 2016).

97 ***3.5 Effect of chronic Anthropogenic sound***

98 Noise effects are also dependent on exposure duration. It is notable that most of the studies
99 about the anthropogenic noise effects are focused on the acute or relatively short-term
100 exposure, likely due to long-term experiments being harder to carry out. There is evidence
101 that long-term anthropogenic noise negatively affects animals (Barber et al., 2010; Crino et
102 al., 2013; Kusku, 2020) but knowledge about the chronic effects of noise on critical early life
103 stages (larvae and/or juvenile period) is still scarce.

104 ***3.6 Animals for the present study***

105 *Maylandia zebra* is an African cichlid living on the sediment-free rocky coast in Lake
106 Malawi. This species is able to produce sounds during social interactions, such as territory
107 defense (Bertucci et al., 2010; Chabrolles et al., 2017) or mating (Simões et al., 2008). This is
108 an aggressive species with well-established dominance hierarchies. Maternal mouth-brooding
109 is also an important feature of the species, lasting for three weeks before the female releases
110 the larvae. Due to increased human activities and development of fishing and tourism
111 industries (Allison and Mvula, 2002; Makochekanwa, 2013) in lake Malawi man-made noise
112 has become a pollutant of concern. As *M. zebra* is an established study model in behaviour
113 and bioacoustics (Amorim et al., 2019; Bertucci et al., 2010; Chabrolles et al., 2017; Mellor
114 et al., 2011), it provides an excellent opportunity to assess the effects of long-term
115 anthropogenic noise on growth and behaviour during the early life stages.

116 Here, we investigate the impacts of chronic anthropogenic noise on growth and foraging
117 during a critical developmental period. We hypothesized that long exposure to boat noise acts
118 as a stressor on the early life stages having the potential to affect growth and foraging.

119 **4. Materials & Methods**

120 ***4.1 Females and juveniles rearing conditions***

121 We purchased *Maylandia zebra* from Oxyfish (Verlinghem, France) and raised fish in stock
122 tanks (l x w x h: 120 x 60 x 50 cm) at ENES laboratory (Saint-Etienne, France). Each holding
123 tank were fed daily with commercial cichlid food (JBL NovoRift sticks and Tetra flakes). All
124 tanks were equipped with an external filter (Tetra EX filter, Tetra GmbH, Melle, Germany),
125 aeration and PVC tubes as shelters. The water temperature was maintained at $25 \pm 1^\circ\text{C}$ with a
126 pH of 8.0 and a 12:12h light: dark cycle.

127 Stock tanks were checked daily to find the females at the beginning of the mouth-brooding
128 period, which were then isolated individually. The mouth-brooding period lasted for 3 weeks
129 after which we used round-head tweezers to open the mouth of the female and help them
130 release all larvae. These were transferred immediately into experimental aquaria (L x l x h: 30
131 x 20 x 20 cm). The aquaria were equipped with PVC tubes as shelters, sand as substrate
132 (Aquasand Nature, Zolux déco), and aeration. Each aquarium was equipped with an
133 underwater loudspeaker developed by Fonseca & Maia Alves (2012) and placed in the
134 middle of the aquarium (see below). Fish were fed daily with commercial food (JBL
135 NovoMalawi sticks for Malawi cichlids, JBL NovoRift, and cichlid flakes, Tetra).

136 ***4.2 Noise playback***

137 We used motorboat sounds that were originally recorded by V. Médoc in the Grangent lake
138 ($45^\circ 45' 07.54''$ N, $4^\circ 25' 56.47''$ E, Loire, France) at 1-m depth (hydrophone Aquarian
139 Audio Products H2a-XLR, AFAB Enterprises, Anacortes, WA, USA; sensitivity: -180 dB re.

140 1 V μPa^{-1} , frequency response within ± 4 dB in the range 20 Hz–4.5 kHz, connected to a
141 ZOOM H4 Handy recorder). Twenty-five original boat sounds were excerpted and linearly
142 faded at both ends using Audacity 3.1.3 (<http://audacity.sourceforge.net>) to make them
143 emerge from silence, then they were used in the playbacks.

144 The aquaria background noise was around 100 dB re. $1\mu\text{Pa}$ and was used as the control
145 condition in our experiment. To keep it around 100 dB re. $1\mu\text{Pa}$, we changed one-third of the
146 water every 2 days instead of installing underwater filters in the experimental or control
147 aquaria.

148 Boat noise was played back through a DENON PMA-100M amplifier connected to a
149 TASCAM US-366 preamplifier and controlled by a laptop running Audacity, and was
150 delivered through the above mentioned underwater loudspeaker. The loudspeaker was placed
151 in the middle of each experimental aquarium, including control aquaria but without
152 connecting to the laptop. The excerpts of boat noise playbacks were adjusted to 120 dB re.
153 $1\mu\text{Pa}$ before broadcasting to the fish. All modified boat noise was played back and then
154 recorded by a pre-calibrated chain composed of a H2A-HLR hydrophone placed 3 cm away
155 from the speaker and connected to a ZOOM H4 recorder. Sound pressure levels of playbacks
156 were calculated by integrating the average power spectra of the recorded sound files.

157 Boat noise after adjusting the sound level was used to generate the audio tracks for the
158 experiment. Different boat sounds were randomly positioned along nine 1-hour audio to
159 mimic the variability in the daily activity of small leisure boats, and in the remaining time
160 they were replaced by silent tracks. The number of boats varied from 6 to 15 boats per track.
161 The boat noise was broadcast to the fish from 9 a.m. to 6 p.m. Boat noise was broadcast to
162 the boat noise fish treatment every day during 12 weeks.

163 ***4.3 Experimental design***

164 Five different pregnant females were used for the experiment and each female gave one
165 clutch (n = 12 to 21 larvae). Following a split-brood design, larvae from each clutch was
166 divided randomly into two groups, and transferred directly into the aquarium assigned to
167 either the boat noise or the control treatment, where they stayed for 12 weeks.

168 During the experimental period, we took a 10 min video of foraging activity in the daytime
169 once a week using a video camera (HD 1080p C920; Logitech International SA, Lausanne,
170 Switzerland) positioned in front of the aquarium. The frame rate of the camera was set at 120
171 fps (frames per second). Fish were fed with commercial food pellets every day. During
172 filming of the foraging activity, fish were fed to satiation. All the videos were analysed with
173 Behavioural Observation Research Interactive Software (BORIS; Friard and Gamba 2016) to
174 extract the foraging behaviour events. Each time one fish opened its mouth to catch the food
175 pellet was counted as a proxy for eating. The total number of foraging events was divided by
176 the number of fish in the aquarium to get the average foraging activity per fish. Behaviours
177 were counted at the group level (the sum of the numbers of the behaviours of all fish in one
178 aquarium) with the software because the larvae were too small to be labelled or identified.

179 We measured the total length (TL) of each individual every week. A transparent box with 0.5
180 cm grid paper on the bottom was prepared for measuring the total length. To disturb the fish
181 as little as possible, all fish in one aquarium were taken out simultaneously with a net that
182 spanned the width of the aquarium, and fish were then placed together in the measuring box.

183 The water in the box was changed between measurements from different aquaria. We took a
184 photo from the top of the box to later measure the fish length. This was possible as the depth
185 of the water was no more than the body depth of the fish inside. After taking the photo we
186 immediately placed them back in the aquarium. With the software ImageJ (Rueden et al.,
187 2017), we used the grid paper as the scale and measured the total length of each fish. From

188 the total length of each fish, we calculated the average TL of each group under the two
189 different conditions at week 1 and at week 12, representing the start and the end of the
190 experiment, respectively.

191 ***4.4 Statistical Analyses***

192 Statistical analyses were conducted using R (version 4.2.1). According to the Shapiro–Wilk
193 test, only the foraging per fish at week 12 was non-normal. Therefore we used a Wilcoxon
194 signed-rank test to test treatment effect on foraging at week 12, and we used t-test on total
195 length (week 1 and 12) and foraging at week 1.

196 ***4.5 Ethics notes***

197 The research carried out comply with relevant guidelines and regulations including French
198 national guidelines, permits, and regulations regarding animal care and experimental use
199 (approval no. D42-218-0901, ENES lab agreement, Direction Départementale de la
200 Protection des Populations, Préfecture du Rhône).

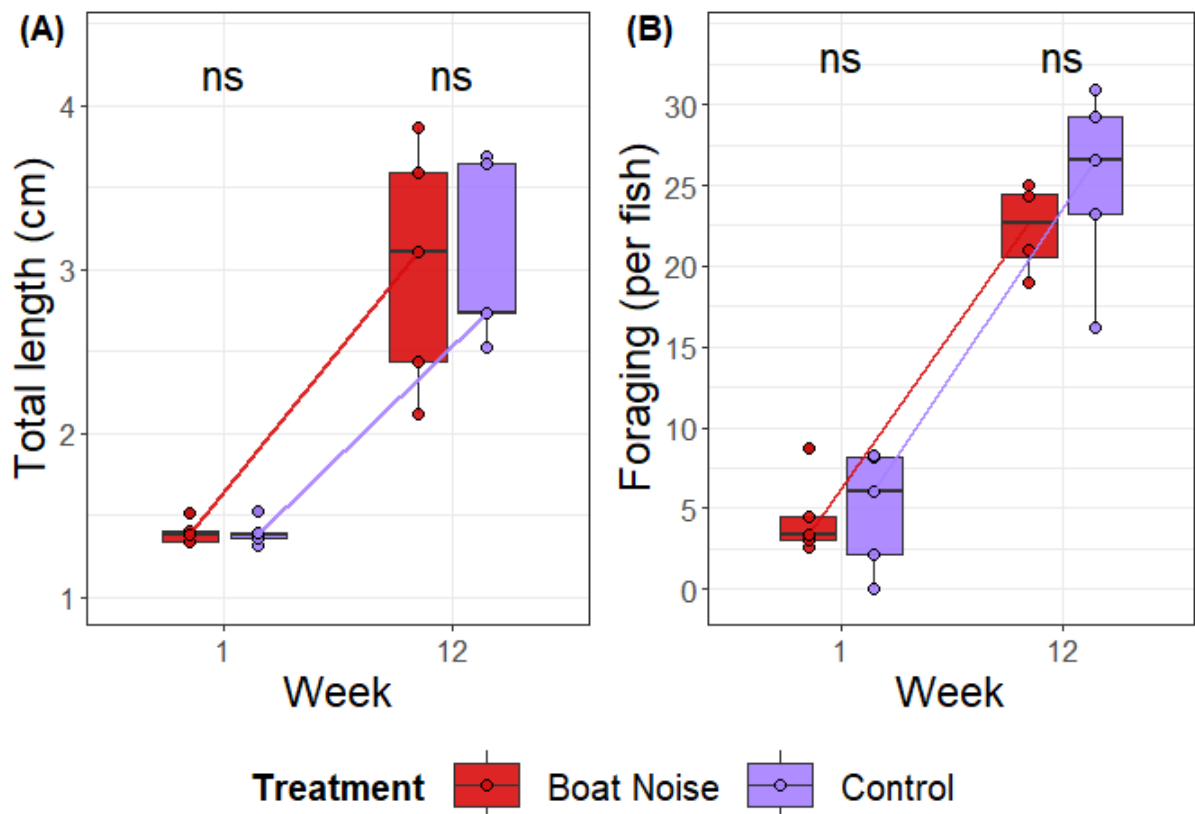
201 **5. Results**

202 ***5.1 Total length***

203 At the beginning of the experiment, the average total length (TL) of the larvae from the boat
204 noise condition was 1.39 (\pm SD, range: \pm 0.07, 1.33-1.50 cm), and the average TL of the larvae
205 for the control condition was 1.39 (\pm 0.07, 1.32-1.52 cm). There was no difference in the TL
206 at the beginning of the experiment (p-value = 0.97) (Fig. 1A). After 12 weeks of exposure to
207 the boat noise, the average total length (TL) of the fish under boat noise condition was 3.02
208 (\pm 0.74, 2.11-3.86cm), and the average TL of the control fish was 3.06 (\pm 0.56, 2.52-3.69cm).
209 Total length of fish after 12 weeks of exposure to boat noise did not differ from the fish under
210 control condition (p-value = 0.92, Fig. 1A).

211 **5.2 Foraging**

212 The result of foraging activity was shown by times of eating per fish during 10 minutes of
213 filming. In the first week, the foraging activity per fish under the boat noise condition was
214 4.94 (± 3.72 , 0-8.33), and the foraging per fish under the control condition was 4.44 (± 2.47 ,
215 2.63-8.7). There was no difference in the foraging per fish at the beginning of the experiment
216 (p-value = 0.81, Fig. 1B). After 12 weeks of exposure to the boat noise, the foraging per fish
217 under boat noise condition was 25.21 (± 5.84 , 16.17-30.86), and the foraging per fish under
218 the control condition was 28.83 (± 14.74 , 19-54.83). The results showed no difference
219 between the fish under 12 weeks of boat noise exposure and under control condition (p-value
220 = 0.84) (Fig.1B).



221

222 Fig 1. Effects of boat noise on Total Length (A) and Foraging (per fish) (B) at week 1 and
223 at week 12 of the experiment. Red represents fish exposed to boat noise condition, and blue

224 represents fish exposed to control condition. Dots represent 5 different groups, and the boxes
225 represent the 25th to 75th percentiles.

226 **6. Discussion**

227 **6.1 Growth**

228 In this study, we did not find significant effects of 12 weeks of boat noise exposure on the
229 total length and foraging behaviour of *M. zebra*. The lack of effects on growth is consistent
230 with the findings for another cichlid (*Neolamprologus pulcher*) (Bruitjes and Radford, 2014)
231 in which 4 weeks of noise exposure did not affect hatching success or post-hatching larvae
232 growth and survival. A study on rainbow trout (*Oncorhynchus mykiss*) juveniles reared under
233 the noise made by the intensive aquaculture systems for 5 months (Davidson et al., 2009) also
234 suggested no impact in the growth and survival of the noise-exposed fish when compared to
235 control. However, some other studies have shown that long-term noise exposure has
236 detrimental effects on growth. For example, the total length of Lusitanian toadfish larvae
237 (*Halobatrachus didactylus*) after 2 weeks of boat noise exposure was smaller than in the
238 control condition (Faria et al., 2022). The larvae of freshwater sheepshead minnow
239 (*Cyprinodon variegatus*) and killifish (*Fundulus similis*) exposed to high noise for 12 days
240 were also smaller than those under quiet conditions (Banner and Hyatt, 1973). Studies on
241 larvae of Atlantic cod (*Gadus morhua*) showed that even larvae 2 days after hatching were
242 smaller under noise than under control conditions, although there was growth compensation
243 at later stages (Nedelec et al., 2015). Different effects on the total length under noise
244 exposure might be species-specific, namely due to interspecific differences on fish hearing
245 and the presence of a swim bladder or other resonant structures, which can cause different
246 vulnerability to anthropogenic noise (R. Fay and Popper, 2012; R. R. Fay et al., 2008).
247 Differences in experimental procedures, including whether they are field- or lab-based

248 (Popper and Hawkins, 2019), the sound type (Bruitjes and Radford, 2014; Kusku et al.,
249 2020), boat type (Jain-Schlaepfer et al., 2018; McCormick et al., 2019), amplitude levels
250 (Lara and Vasconcelos, 2021) and exposure duration (Popper and Hawkins, 2019) could also
251 have an impact on the fish's response to the noise.

252 **6.2 Foraging**

253 We also did not find evidence that foraging activity was affected by chronic noise exposure
254 during early life stages, when comparing that behavior on weeks 1 vs 12. Although other
255 studies have shown that foraging can be affected by additional man-made noise (Bracciali et
256 al., 2012; Purser and Radford, 2011; Voellmy et al., 2014), habituation, sensitization, and
257 tolerance can occur in most animals after repeated and/or chronic noise exposure (Bejder et
258 al., 2009). This suggests that young *M. zebra* fish may have habituated or gained tolerance to
259 the added noise. However, as habituation should be the result of a longitudinal process, the
260 comparison at one-time point (week 12) cannot provide strong evidence for distinguishing
261 between habituation and tolerance (Bejder et al., 2009). Magnhagen et al. (2017) examined
262 the effect of noise on foraging behavior in both roach and the Eurasian perch in the field.
263 These authors found that perch can habituate to noise exposure as their feeding attempts first
264 decreased and then increased gradually over the five days of the experiment (Magnhagen et
265 al., 2017). However the roach, which has higher hearing sensitivity, presented fewer feeding
266 attempts than the perch and did not habituate to the noise during the experimental period
267 (Magnhagen et al., 2017). This study on perch and roach suggests that fish are able to
268 habituate to anthropogenic noise or that the time needed for habituation has interspecific-
269 differences.

270 As hearing sensitivity in larvae and juveniles has not been studied in our study species, it is
271 possible that the 120 dB boat noise level fell below hearing thresholds, thus not causing an
272 effect. Noise is known to affect foraging behaviour by directly reducing appetite

273 (Charmandari et al., 2005), or indirectly through a reduction in activity and locomotion
274 (Mendl, 1999). It is also possible that it alters cognitive processes involved in food detection,
275 or distracts the attention of the fish (Chan and Blumstein, 2011; Mendl, 1999).

276 The current study considered only two time points, the start and the end of the experiment,
277 preventing from acknowledging possible effects of noise over the full 12 weeks period.
278 Future analyses should focus on more time points within the long-term noise exposure. This
279 will give a better insight regarding the effects of noise along the development of fish, and on
280 whether these effects are reversible or not.

281 **7. References**

282 Allison, E. H., Mvula, P. M. (2002). *Fishing Livelihoods and Fisheries Management in*
283 *Malawi*.

284 Amorim, M. C. P., Fonseca, P. J., Mathevon, N., Beauchaud, M. (2019). Assessment of
285 fighting ability in the vocal cichlid *Metriacroma zebra* in face of incongruent
286 audiovisual information. *Biology Open*, 8(12), bio043356.
287 <https://doi.org/10.1242/bio.043356>

288 Banner, A., Hyatt, M. (1973). Effects of Noise on Eggs and Larvae of Two Estuarine Fishes.
289 *Transactions of the American Fisheries Society*, 102(1), 134–136.
290 [https://doi.org/10.1577/1548-8659\(1973\)102<134:EONOEAE>2.0.CO;2](https://doi.org/10.1577/1548-8659(1973)102<134:EONOEAE>2.0.CO;2)

291 Barber, J. R., Crooks, K. R., Fristrup, K. M. (2010). The costs of chronic noise exposure for
292 terrestrial organisms. *Trends in Ecology Evolution*, 25(3), 180–189.
293 <https://doi.org/10.1016/j.tree.2009.08.002>

294 Bertucci, F., Beauchaud, M., Attia, J., Mathevon, N. (2010). Sounds Modulate Males'
295 Aggressiveness in a Cichlid Fish. *Ethology*, 116(12), 1179–1188.
296 <https://doi.org/10.1111/j.1439-0310.2010.01841.x>

297 Bracciali, C., Campobello, D., Giacoma, C., Sarà, G. (2012). Effects of Nautical Traffic and
298 Noise on Foraging Patterns of Mediterranean Damselfish (*Chromis chromis*). *PLOS*
299 *ONE*, 7(7), e40582. <https://doi.org/10.1371/journal.pone.0040582>

300 Bruintjes, R., Radford, A. N. (2014). Chronic playback of boat noise does not impact
301 hatching success or post-hatching larval growth and survival in a cichlid fish. *PeerJ*,
302 2, e594. <https://doi.org/10.7717/peerj.594>

303 Carlson, B. A. (2017). Early life experiences have complex and long-lasting effects on
304 behavior. *Proceedings of the National Academy of Sciences*, 114(44), 11571–11573.
305 <https://doi.org/10.1073/pnas.1716037114>

306 Catalán, I., Reglero, P., Itziar, A. (2020). Research on early life stages of fish: A lively field.
307 *Marine Ecology Progress Series*, 650, 1–5. <https://doi.org/10.3354/meps13491>

308 Chabrolles, L., Ammar, I. B., Fernandez, M. S. A., Boyer, N., Attia, J., Fonseca, P. J.,
309 Amorim, M. C. P., Beauchaud, M. (2017). Appraisal of unimodal cues during
310 agonistic interactions in *Maylandia zebra*. *PeerJ*, 5, e3643.
311 <https://doi.org/10.7717/peerj.3643>

312 Chan, A. A. Y.-H., Blumstein, D. T. (2011). Attention, noise, and implications for wildlife
313 conservation and management. *Applied Animal Behaviour Science*, 131(1), 1–7.
314 <https://doi.org/10.1016/j.applanim.2011.01.007>

315 Charmandari, E., Tsigos, C., Chrousos, G. (2005). ENDOCRINOLOGY OF THE STRESS
316 RESPONSE. *Annual Review of Physiology*, 67(1), 259–284.
317 <https://doi.org/10.1146/annurev.physiol.67.040403.120816>

318 Clark, C. (2009). Acoustic masking in marine ecosystems as a function of anthropogenic
319 sound sources. *IWC/SC/61/E*, 395.
320 [https://www.academia.edu/30786331/Acoustic_masking_in_marine_ecosystems_as_a](https://www.academia.edu/30786331/Acoustic_masking_in_marine_ecosystems_as_a_function_of_anthropogenic_sound_sources)
321 [_function_of_anthropogenic_sound_sources](https://www.academia.edu/30786331/Acoustic_masking_in_marine_ecosystems_as_a_function_of_anthropogenic_sound_sources)

322 Clark, C., Ellison, W., Southall, B., Hatch, L., Van Parijs, S., Frankel, A., Ponirakis, D.
323 (2009). Acoustic masking in marine ecosystems: Intuitions, analysis, and implication.
324 *Marine Ecology Progress Series*, 395, 201–222. <https://doi.org/10.3354/meps08402>

325 Codarin, A., Wysocki, L. E., Ladich, F., Picciulin, M. (2009). Effects of ambient and boat
326 noise on hearing and communication in three fish species living in a marine protected
327 area (Miramare, Italy). *Marine Pollution Bulletin*, 58(12), 1880–1887.
328 <https://doi.org/10.1016/j.marpolbul.2009.07.011>

329 Crino, O. L., Johnson, E. E., Blickley, J. L., Patricelli, G. L., Breuner, C. W. (2013). Effects
330 of experimentally elevated traffic noise on nestling white-crowned sparrow stress
331 physiology, immune function and life history. *Journal of Experimental Biology*,
332 216(11), 2055–2062. <https://doi.org/10.1242/jeb.081109>

333 Davidson, J., Bebak, J., Mazik, P. (2009). The effects of aquaculture production noise on the
334 growth, condition factor, feed conversion, and survival of rainbow trout,
335 *Oncorhynchus mykiss*. *Aquaculture*, 288(3), 337–343.
336 <https://doi.org/10.1016/j.aquaculture.2008.11.037>

337 Erbe, C., Williams, R., Sandilands, D., Ashe, E. (2014). Identifying Modeled Ship Noise
338 Hotspots for Marine Mammals of Canada’s Pacific Region. *PLOS ONE*, 9(3), e89820.
339 <https://doi.org/10.1371/journal.pone.0089820>

340 Faria, A., Fonseca, P. J., Vieira, M., Alves, L. M. F., Lemos, M. F. L., Novais, S. C., Matos,
341 A. B., Vieira, D., Amorim, M. C. P. (2022). Boat noise impacts early life stages in the
342 Lusitanian toadfish: A field experiment. *Science of The Total Environment*, 811,
343 151367. <https://doi.org/10.1016/j.scitotenv.2021.151367>

344 Fay, R., Popper, A. (2012). Fish Hearing: New Perspectives from Two “Senior”
345 Bioacousticians. *Brain, Behavior and Evolution*, 79, 215–217.
346 <https://doi.org/10.1159/000338719>

347 Fay, R. R., Popper, A. N., Webb, J. F. (2008). Introduction to Fish Bioacoustics. In J. F.
348 Webb, R. R. Fay, A. N. Popper (Eds.), *Fish Bioacoustics: With 81 Illustrations* (pp.
349 1–15). Springer. https://doi.org/10.1007/978-0-387-73029-5_1

350 Fewtrell, J. L., McCauley, R. D. (2012). Impact of air gun noise on the behaviour of marine
351 fish and squid. *Marine Pollution Bulletin*, 64(5), 984–993.
352 <https://doi.org/10.1016/j.marpolbul.2012.02.009>

353 Fonseca, P. J., Maia Alves, J. (2012). A new concept in underwater high fidelity low
354 frequency sound generation. *The Review of Scientific Instruments*, 83, 055007.
355 <https://doi.org/10.1063/1.4717680>

356 Friard, O., Gamba, M. (2016). BORIS: A free, versatile open-source event-logging software
357 for video/audio coding and live observations. *Methods in Ecology and Evolution*,
358 7(11), 1325–1330. <https://doi.org/10.1111/2041-210X.12584>

359 Gendron, G., Tremblay, R., Jolivet, A., Olivier, F., Chauvaud, L., Winkler, G., Audet, C.
360 (2020). Anthropogenic boat noise reduces feeding success in winter flounder larvae
361 (*Pseudopleuronectes americanus*). *Environmental Biology of Fishes*, 103(9), 1079–
362 1090. <https://doi.org/10.1007/s10641-020-01005-3>

363 Jain-Schlaepfer, S., Fakan, E., Rummer, J. L., Simpson, S. D., McCormick, M. I. (2018).
364 Impact of motorboats on fish embryos depends on engine type. *Conservation*
365 *Physiology*, 6(1), coy014. <https://doi.org/10.1093/conphys/coy014>

366 Kastak, D., Mulsow, J., Ghoul, A., Reichmuth, C. (2008). Noise-induced permanent
367 threshold shift in a harbor seal. *The Journal of the Acoustical Society of America*,
368 123(5), 2986–2986. <https://doi.org/10.1121/1.2932514>

369 Kasumyan, A. O. (2009). Acoustic signaling in fish. *Journal of Ichthyology*, 49(11), 963–
370 1020. <https://doi.org/10.1134/S0032945209110010>

371 Kusku, H. (2020). Acoustic sound-induced stress response of Nile tilapia (*Oreochromis*
372 niloticus) to long-term underwater sound transmissions of urban and shipping noises.
373 *Environmental Science and Pollution Research*, 27(29), 36857–36864.
374 <https://doi.org/10.1007/s11356-020-09699-9>

375 Kusku, H., Yigit, Ü., Yilmaz, S., Yigit, M., Ergün, S. (2020). Acoustic effects of underwater
376 drilling and piling noise on growth and physiological response of Nile tilapia (
377 *Oreochromis niloticus*). *Aquaculture Research*, 51(8), 3166–3174.
378 <https://doi.org/10.1111/are.14652>

379 Lagardère, J. P. (1982). Effects of noise on growth and reproduction of Crangon crangon in
380 rearing tanks. *Marine Biology*, 71(2), 177–185. <https://doi.org/10.1007/BF00394627>

381 Lara, R. A., Breitzler, L., Lau, I. H., Gordillo-Martinez, F., Chen, F., Fonseca, P. J., Bass, A.
382 H., Vasconcelos, R. O. (2022). Noise-induced hearing loss correlates with inner ear
383 hair cell decrease in larval zebrafish. *Journal of Experimental Biology*, 225(7),
384 jeb243743. <https://doi.org/10.1242/jeb.243743>

385 Lara, R. A., Vasconcelos, R. O. (2021). Impact of noise on development, physiological stress
386 and behavioural patterns in larval zebrafish. *Scientific Reports*, 11(1), Article 1.
387 <https://doi.org/10.1038/s41598-021-85296-1>

388 Magnhagen, C., Johansson, K., Sigray, P. (2017). Effects of motorboat noise on foraging
389 behaviour in Eurasian perch and roach: A field experiment. *Marine Ecology Progress*
390 *Series*, 564, 115–125. <https://doi.org/10.3354/meps11997>

391 Makochekanwa, A. (2013). An analysis of tourism contribution to economic growth in
392 SADC Countries. *Botswana Journal of Economics*, 11(15), Article 15.
393 <https://doi.org/10.4314/boje.v11i15>

394 McCauley, R., Fewtrell, J., Popper, A. (2003). High intensity anthropogenic sound damages
395 fish ears. *The Journal of the Acoustical Society of America*, 113, 638–642.
396 <https://doi.org/10.1121/1.1527962>

397 McCormick, M. I., Fakan, E. P., Nedelec, S. L., Allan, B. J. M. (2019). Effects of boat noise
398 on fish fast-start escape response depend on engine type. *Scientific Reports*, 9(1),
399 Article 1. <https://doi.org/10.1038/s41598-019-43099-5>

400 McDonald, M. A., Hildebrand, J. A., Wiggins, S. M. (2006). Increases in deep ocean ambient
401 noise in the Northeast Pacific west of San Nicolas Island, California. *The Journal of*
402 *the Acoustical Society of America*, 120(2), 711–718.
403 <https://doi.org/10.1121/1.2216565>

404 Mellor, D. T., Tarsiewicz, C. M., Jordan, R. C. (2011). Female Maylandia zebra prefer
405 victorious males. *Journal of Fish Biology*, 78(2), 680–687.
406 <https://doi.org/10.1111/j.1095-8649.2010.02884.x>

407 Mendl, M. (1999). Performing under pressure: Stress and cognitive function. *Applied Animal*
408 *Behaviour Science*, 65(3), 221–244. [https://doi.org/10.1016/S0168-1591\(99\)00088-X](https://doi.org/10.1016/S0168-1591(99)00088-X)

409 Merchant, N. D., Andersson, M. H., Box, T., Le Courtois, F., Cronin, D., Holdsworth, N.,
410 Kinneking, N., Mendes, S., Merck, T., Mouat, J., Norro, A. M. J., Ollivier, B., Pinto,
411 C., Stamp, P., Tougaard, J. (2020). Impulsive noise pollution in the Northeast
412 Atlantic: Reported activity during 2015–2017. *Marine Pollution Bulletin*, 152,
413 110951. <https://doi.org/10.1016/j.marpolbul.2020.110951>

414 Miksis-Olds, J. L., Nichols, S. M. (2016). Is low frequency ocean sound increasing globally?
415 *The Journal of the Acoustical Society of America*, 139(1), 501–511.
416 <https://doi.org/10.1121/1.4938237>

417 Nedelec, S. L., Simpson, S. D., Morley, E. L., Nedelec, B., Radford, A. N. (2015). Impacts of
418 regular and random noise on the behaviour, growth and development of larval

419 Atlantic cod (*Gadus morhua*). *Proceedings of the Royal Society B: Biological*
420 *Sciences*, 282(1817), 20151943. <https://doi.org/10.1098/rspb.2015.1943>

421 Nikolopoulos, A., Sigray, P., Andersson, M., Carlström, J., Lalander, E. (2016). *BIAS*
422 *Implementation Plan: Monitoring and assessment guidance for continuous low*
423 *frequency sound in the Baltic Sea*. BIAS LIFE11 ENV/SE/841.
424 <http://urn.kb.se/resolve?urn=urn:nbn:se:nrm:diva-2262>

425 Pearson, W. H., Skalski, J. R., Malme, C. I. (1992). Effects of Sounds from a Geophysical
426 Survey Device on Behavior of Captive Rockfish (*Sebastes* spp.). *Canadian Journal of*
427 *Fisheries and Aquatic Sciences*, 49(7), 1343–1356. <https://doi.org/10.1139/f92-150>

428 Popper, A. N., Hawkins, A. D. (2019). An overview of fish bioacoustics and the impacts of
429 anthropogenic sounds on fishes. *Journal of Fish Biology*, 94(5), 692–713.
430 <https://doi.org/10.1111/jfb.13948>

431 Purser, J., Radford, A. N. (2011). Acoustic Noise Induces Attention Shifts and Reduces
432 Foraging Performance in Three-Spined Sticklebacks (*Gasterosteus aculeatus*). *PLOS*
433 *ONE*, 6(2), e17478. <https://doi.org/10.1371/journal.pone.0017478>

434 Rueden, C. T., Schindelin, J., Hiner, M. C., DeZonia, B. E., Walter, A. E., Arena, E. T.,
435 Eliceiri, K. W. (2017). ImageJ2: ImageJ for the next generation of scientific image
436 data. *BMC Bioinformatics*, 18(1), 529. <https://doi.org/10.1186/s12859-017-1934-z>

437 Simões, J., Duarte, I., Fonseca, P. J., Turner, G., Amorim, M. C. (2008). Courtship and
438 agonistic sounds by the cichlid fish *Pseudotropheus zebra*. *The Journal of the*
439 *Acoustical Society of America*, 124, 1332–1338. <https://doi.org/10.1121/1.2945712>

440 Simpson, S. D., Radford, A. N., Holles, S., Ferarri, M. C. O., Chivers, D. P., McCormick, M.
441 I., Meekan, M. G. (2016). Small-Boat Noise Impacts Natural Settlement Behavior of
442 Coral Reef Fish Larvae. In A. N. Popper & A. Hawkins (Eds.), *The Effects of Noise*

443 *on Aquatic Life II* (pp. 1041–1048). Springer. <https://doi.org/10.1007/978-1-4939->
444 2981-8_129

445 Slabbekoorn, H. (2019). Noise pollution. *Current Biology*, 29, R957–R960.
446 <https://doi.org/10.1016/j.cub.2019.07.018>

447 Voellmy, I. K., Purser, J., Flynn, D., Kennedy, P., Simpson, S. D., Radford, A. N. (2014).
448 Acoustic noise reduces foraging success in two sympatric fish species via different
449 mechanisms. *Animal Behaviour*, 89, 191–198.
450 <https://doi.org/10.1016/j.anbehav.2013.12.029>

451 Voellmy, I. K., Purser, J., Simpson, S. D., Radford, A. N. (2014). Increased Noise Levels
452 Have Different Impacts on the Anti-Predator Behaviour of Two Sympatric Fish
453 Species. *PLoS ONE*, 9(7), e102946. <https://doi.org/10.1371/journal.pone.0102946>

454 Wysocki, L. E., Dittami, J. P., Ladich, F. (2006). Ship noise and cortisol secretion in
455 European freshwater fishes. *Biological Conservation*, 128(4), 501–508.
456 <https://doi.org/10.1016/j.biocon.2005.10.020>

457