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4 **TITLE**

5 **Behavior of reef fishes during a submarine magnitude 5 earthquake**

6

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27 **OPEN RESEARCH STATEMENT**

28 Data are archived on Zenodo: <https://doi.org/10.5281/zenodo.7674805>.

29

30 **KEY WORDS**

31 behavior; coral reefs; earthquake; fear; fishes; remote underwater video

32

33 **TEXT**

34 During the early morning of November 10th, 2020, we set up three camera stations on the
35 seafloor of the N’Gouja Marine Protected Area, South-Western part of Mayotte island
36 (Mozambique channel, Western Indian Ocean) to remotely monitor diversity of reef fishes
37 and their grazing behavior. Each camera station was made of a 35 cm-high tripod (weighted
38 by 4kg of dive leads) supporting a watertight enclosure (Bluerobotics, Torrance, CA, USA) in
39 which two action-camera (“GoPro Hero 5 Black”; San Mateo, CA, USA) fueled by external
40 10,000 mAh batteries were enclosed in opposite directions. Camera stations were set up at
41 3m depth on the back part of the fringing reef and were distant from each other by at least
42 15 m. Each camera recorded high-definition video (1920 x 1080 pixels, 25 frames per
43 second) with a field-of-view of ca 90° (“Linear” mode of GoPro) from 06:30. Divers left the
44 surveyed area at 07:13 and no boat or swimmer entered the surveyed area until 11:00 am
45 when two divers set up three additional camera stations (same tripod but GoPro cameras were
46 individually enclosed in the manufacturer’s ‘Super Suit’ underwater housing without external
47 battery) from 45 m to 110m apart from the camera stations set earlier in the morning.

48

49 At 12:19:39 local time, all members of the survey team felt a strong vibration in the sandy
50 ground. This turned out to be a magnitude 5.3 earthquake as estimated by the earthquake and

51 volcano monitoring network of Mayotte. The earthquake was linked to volcanic activity 50
52 km East of Mayotte (REVOSIMA-IPGP, 2021). The 12 underwater cameras recorded the
53 explosion-like sound of the earthquake that lasted *ca* 7 s and 6 cameras (from 3 tripods)
54 recorded shaking motion (Villéger et al., 2023).

55

56 Videos from these cameras enabled us to observe fish behavior before during and after the
57 earthquake (Figure 1). We extracted two minutes of video from each camera starting one
58 minute before the earthquake. For each of these 12 sequences, each fish was tracked across
59 still frames (one each 0.5 s) as long as it was visible on screen and three behaviors were
60 noted: fleeing, hiding in a reef anfractuosity, and feeding. We acknowledge that the same
61 individual could be seen several times on a video while being annotated as two individuals (if
62 it circles around a camera) or on several videos given the short distance between paired-
63 cameras.

64

65 The proportion of fish fleeing significantly peaked during the earthquake (Kruskal-Wallis test
66 and post-hoc Dunn test; $p < 0.05$) (Figure 2). Among the 129 individuals tracked during the
67 earthquake, 61% fled and 6% hid. Only two individuals (<1%) fled in the 40 s before the
68 earthquake and none was then looking for a hiding place in the reef. During the 10 s after the
69 end of the earthquake, 17% of fishes were still fleeing, dropping to less than 5% in the
70 following 20 s. After 30 s no fish were fleeing and none were hiding. Furthermore, the lined
71 bristletooth, *Ctenochaetus striatus*, the most abundant species in the studied ecosystem,
72 significantly decreased its feeding during the earthquake (K-W test; p -value < 0.05) (Figure
73 2). A *C striatus* individual was biting on substrate on average >3 times per 10 s before the
74 earthquake. This per capita feeding rate dropped to < 1 bite/10 s during the earthquake. Then,

75 the feeding rate increased, especially after 20s to >2 bites per fish per 10s. Thus, overall, fish
76 showed a marked but brief response to the earthquake.

77

78 The energy of earthquakes in Mayotte is broadly banded with energy peaks at low
79 frequencies (5-40 Hz) (Retailleau et al., 2022). The earthquake sound recorded by the GoPro
80 had peaks in frequencies from 10 to 600Hz for 1 second then peaks only in low frequencies
81 (<100Hz) for the next 8 seconds (Appendix S1: Figure S1). Hence, as most fishes are able to
82 detect sounds only between 100 and 1000 Hz (Ladich & Fay, 2013) it is likely they detect
83 only the early brief peak of sound above 100 Hz. The sound pressure generated by the
84 earthquake was at least 10 times higher than the ambient sound pressure immediately before
85 the earthquake (Appendix S1). As coral reefs in good condition have an ambient sound
86 pressure > 80 dB rel 1 μ Pa (e.g., Bertucci et al., 2016) and as most fishes have a detection
87 threshold of 90 dB rel 1 μ Pa, it is likely most fishes detected the earthquake. Seismometers
88 also registered two other earthquakes on the same day, one at 09:14 of magnitude 2.1 and one
89 at 12:43 of magnitude 2.3. None of these earthquakes was detectable among the ambient reef
90 noise on the sounds recorded by our cameras and fish did not show any change in behavior at
91 those exact times.

92

93 The Comoros archipelago, including Mayotte, the oldest island of the archipelago, was
94 formed through volcanism that started 20 million years ago. The last volcanic activity
95 probably occurred about 4,000 years ago (Zinke et al., 2003) and few earthquakes were
96 recorded in the area before 2018. Since then, the rise of a submarine volcano on the seafloor
97 50 km East of Mayotte island (Cesca et al., 2020) has markedly increased seismic activity in
98 the area, producing hundreds of earthquakes including 35 with magnitude >5 (REVOSIMA -
99 IPGP 2021). Hence, reef fishes from Mayotte have been subjected to earthquakes for 2 years

100 when the studied earthquake occurred which could explain why they quickly recovered
101 behaviors they were doing prior to the quake after the vibrations ended. The lack of visible
102 reaction of fishes to the later low magnitude earthquakes suggest fishes may not be able to
103 detect small foreshocks before large earthquakes (Woith et al., 2018).

104

105 Sea habitats contain diverse underwater noises from natural and anthropogenic sources
106 (Hildebrand 2009). Earthquakes are characterized by low-frequency, medium-intensity and
107 short durations, especially compared to seismic surveys of seafloor with air-guns that
108 produced repeated powerful shots (Carroll et al., 2017). Effect of earthquake on fish
109 behaviors have been very scarcely investigated, the only report being a marked decrease in
110 the catch of lacustrine cichlids for a week after two earthquakes of magnitude 5.7 and 6.5 in
111 the deep parts of Lake Malawi in March 1989 (Tweddle & Crossley, 1991). The increasing
112 use of remote underwater cameras to survey fishes in coastal ecosystems for various purposes
113 (e.g., assessing species abundance and roles) can serendipitously record fish behavior during
114 different types of earthquakes (depth, magnitude, distance) and under a variety of
115 environmental conditions (depth, type of seafloor). For instance, assessing fish reaction to
116 earthquakes on reefs that experience more frequent magnitude 5 earthquakes, such as in
117 Indonesia or Japan, will allow testing whether exposition to such high seismic activity
118 decreases reaction to each earthquake. Remote stereo-camera would even allow recording the
119 3D trajectory of each individual thus to measure change in swimming speed and direction
120 within and across species. Acoustic surveys using calibrated hydrophone will further help
121 unravel which threshold of frequencies and intensity of acoustic signal produced by
122 earthquakes determine the reaction of each fish species.

123

124

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140 and will be applied to all subsequent versions up to the Author Accepted Manuscript arising
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142



143 **AUTHOR CONTRIBUTIONS**

144 Sébastien Villéger, Camille Magneville and Thomas Claverie designed the video-based
145 survey of fish biodiversity, set up the underwater cameras and managed the recorded videos
146 and associated metadata. Fany Roncin, Camille Magneville and Sébastien Villéger annotated
147 behavior of all fish individuals on all videos. Sébastien Villéger analyzed data.
148 Lise Retailleau provided the seismograms. Sébastien Villéger and Camille Magneville led the
149 writing and all authors contributed to the final version.

150

151 **CONFLICT OF INTEREST**

152 The authors declare no conflict of interest.

153

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182 lagoon of Mayotte associated with the Holocene transgression. *Sedimentary Geology* 160:
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184 **FIGURE CAPTIONS**

185 Figure 1: Still frames of the video recorded by a remote underwater camera on N’Gouja
186 fringing reef, before (top), during (center) and after (bottom) the magnitude 5.3 earthquake in
187 Mayotte (10 November 2020, 12:19:39 local time). Images created by Sébastien Villéger,
188 taken from videos available in Villéger et al. (2023).

189

190 Figure 2: Reaction of fishes to earthquake. Left: Proportion of fish that show a fleeing
191 behavior during 10 s slots before (‘be.’), during (‘Earthq.’) and after (‘af.’) earthquake (left).
192 Right: Feeding activity of *Ctenochaetus striatus* measured as number of bites per individual
193 during 10 s slots before (‘be.’), during (‘Earthq’) and after (‘af.’) earthquake (right).
194 Size of point is proportional to the number of fish seen during the 10 s slot from each video.