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Changes to an urban marina soundscape associated with COVID-19 lockdown in Guadeloupe☆

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A B S T R A C T
In 2020, the COVID-19 pandemic led to government-enforced limits on activities worldwide, causing a marked reduction of human presence in outdoors environments, including in coastal areas that normally support substantial levels of boat traffic. These restrictions provided a unique opportunity to quantify the degree to which anthropogenic noise contributes to and impacts underwater soundscapes. In Guadeloupe, French West Indies, a significantly lower number of motor boats were recorded in the vicinity of the major urban marina during the peak of the first COVID-19 lockdown (April–May 2020), compared with the number recorded post-lockdown. The resumption of human activities at the end of May was correlated with a maximum increase of 6 decibels in the ambient noise level underwater. The change in noise level did not impact daily sound production patterns of vocal fishes, with increased activity at dusk seen both during and after the lockdown period. However, during the lockdown vocal activity was comprised of a reduced number of sounds, suggesting that anthropogenic noise has the potential to interfere with vocalization behaviours in fishes.

1. Introduction

In 2020, the COVID-19 pandemic led to widespread government directives that forced people to isolate or restrict their movement to slow and contain the virus (Newland, 2020). By April 2020, half of the world’s population underwent some form of lockdown, with more than 3.9 billion people in more than 90 countries ordered to stay at home by their governments (Sandford, 2020). These actions corresponded with a marked reduction of human presence in public spaces, urban areas, and centers of tourism. With decreased movement, air pollution levels reduced (European Space Agency, www.esa.int), and daily CO2 emissions declined globally by an average of 17 % by April 2020 compared with the mean 2019 levels (Le Quéré et al., 2020). In addition, changes to other sources of anthropogenic pollution, such as the noise generated as a result of human activities (i.e. anthropophony) (Slabberkooorn et al., 2010; Kight and Swaddle, 2011; Francis and Barber, 2013) were also observed (e.g. Asensio et al., 2020; Banu et al., 2021; Čurović et al., 2021; Leon-Lopez et al., 2021; Mostafa et al., 2021). The reduction of anthropogenic noise should make the natural soundscape, and particularly sounds produced by animals, i.e. the biophony (Pijanowski et al., 2011a, 2011b; Heenehan et al., 2017) more noticeable.

Underwater soundscapes can be defined as the spatial, temporal, and frequency attributes of ambient sound, and the sources of noise contributing to the sound field (ISO, 2017). The nature of underwater soundscapes are rapidly changing worldwide due to declines of sound-producing animals (biophony), changes to geophysical processes

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such as storms (geophony), and increases in human-associated noise (anthropophony) (Duarte et al., 2021). Sounds produced by human activities, termed ‘noise pollution’, are present in many marine environments and can affect a wide range of taxa, from small invertebrates such as shrimps and bivalves, to fish and mammals (Duarte et al., 2021; Ferrier-Pagés et al., 2021). For this reason, underwater noise pollution is now the focus of greater research interest as activities and uses of the marine environment change and intensify (Slabbekoorn et al., 2010; Williams et al., 2015). At a large scale, commercial operations such as offshore oil and gas installations and international shipping are known to produce substantial levels of noise pollution (e.g. Erbe et al., 2013; Southall et al., 2017). However, even less intensive activities in coastal areas, such as tourism and recreational boating have had an identifiable effect on underwater soundscapes, including those associated with tropical coastal reefs (e.g. McDonald et al., 2006; Dinh et al., 2018; McCormick et al., 2018, 2019; Hermannsen et al., 2019). In the recent past, dramatic reductions in human activities have seen significant flow on effects on levels of noise pollution. For instance, after the events of September 11, 2001, levels of international shipping traffic rapidly declined. In the Bay of Fundy, Canada, this was correlated with a decrease in underwater noise by 6 dB, with a significant reduction below 150 Hz (Rolland et al., 2012). This noise reduction positively impacted Northern right whales (Eubalaena glacialis), which showed decreased levels of stress-related faecal hormone metabolites (Rolland et al., 2012).

Changes in human activities may therefore have rapid and measurable effects in underwater environments more broadly, potentially impacting a wide range of associated marine life. The coastal environment of many Caribbean Islands underwent such changes during early 2020 due to government-enforced restrictions on activity related to the COVID-19 pandemic. Due to the decrease in commercial and recreational marine activities, underwater noise pollution is likely to have fallen significantly in these locations (Zambrano-Monserrate et al., 2020). Many studies have suggested positive and indirect effects of reductions in human activities on the environment (Chakraborty and Maity, 2020; Pearson et al., 2020; Rosenbloom and Markard, 2020; Zambrano-Monserrate et al., 2020), and some have provided supporting experimental data (e.g. Cohen, 2020; Molintas, 2020; Kumar et al., 2021; Naqvi et al., 2021). However, few have examined these effects within tropical coastal environments such as coral reefs and seagrass. To this end, the present study aimed to examine the underwater soundscape, i.e. the ambient sound, of a human-impacted coastal area, close to the city of Pointe-à-Pitre in Guadeloupe, French West Indies during and after the island’s COVID-19 lockdown.

2. Material and methods

2.1. COVID-19 lockdown and study site

In France and its overseas departments, a government-imposed lockdown took place from March 16 to May 21, 2020 in an effort to control the COVID-19 virus. In Guadeloupe, all cruise ships left on
March 15 and all flights were cancelled on March 23 which drastically reduced economic activity on the island. Meanwhile, on March 19, all access to public beaches and leisure boating were forbidden. A curfew was set on April 01 from 20:00 to 05:00.

Passive acoustic recordings were performed in the navigation channel of the Marina of Bas-du-Fort (16°22′N; 61°53′W) (Fig. 1). While the Marina is used by leisure boats, it is located less than 400 m from the channel of the harbor of Pointe-à-Pitre where large commercial vessels and cruise ships navigate. The benthic substrate at the site was primarily muddy sand with rare patches of seagrass. High levels of water turbidity prevented visual surveys and description of the local fish community at the time of the recordings. Wind was moderate (4–5 Bf) (https://www.meteoblue.com/fr/meteo/historyclimate/weatherarchive/guadeloupe_guadeloupe_3579144) and sea state was calm during all recording sessions since the channel is located between the mainland shore and a large embankment preventing waves and swell coming from the ocean. Tidal ranges (https://maree.shom.fr/harbor/POINTE-A-PITRE/hlt/0?date=2021-07-15&utc=—4) were 0.25–0.42 m from April 7–9, 0.14–0.28 m from April 20–22 and 0.06–0.40 m from May 21–23. We therefore considered environmental conditions to be relatively stable throughout the recording sessions and any differences detected will not be due to environmental conditions.

2.2. Data acquisition

Recordings were made by using an autonomous SNAP acoustic recorder (Loggerhead Instruments, Sarasota, FL, USA) connected to a HTI-96-min hydrophone (sensitivity: 170 dB re 1 V μPa−1; flat frequency response range: 2 Hz - 30 kHz; High Tech Inc, Long Beach, MS, USA). The device was positioned on a weighted metallic frame placed on the bottom at a depth of 3–5 m by snorkeling and with the help of local fishermen. The device was deployed in the morning between 07:00 and 08:00, and was programmed to record for 1 min every 10 min (sampling frequency of 44 kHz, 16-bit resolution). Recording sessions lasted for 48h and took place from April 7–9, 2020 and from April 20–22, 2020, with both sessions during the lockdown. A third recording session took place from May 21–23, 2020 after the lockdown had ended. Recordings were split into 8 periods of 3 h in order to separate particular daily periods, i.e. dawn (05:00–08:00), daytime (08:00–11:00, 11:00–14:00 and 14:00–17:00), dusk (17:00–20:00) and night-time (20:00–23:00, 23:00–02:00 and 02:00–05:00).

Spectrograms and power spectra (Fast Fourier Transform FFT, Hamming window, 1024 points, no overlap) were produced using PAMGuide (Merchant et al., 2015) in RStudio version 1.2.5042 (2020) which allowed the calculation of the relative Power Spectral Density graphics (PSD, dB re: 1 μPa².Hz−1). Spectrograms and power spectra were plotted with a frequency range between 40 and 2500 Hz (low frequency range), and a frequency range between 2500 and 22000 Hz (high frequency range). The low frequency band corresponds to the range in which most teleost fishes vocalize and can hear (Lobel et al., 2010; Tavolga et al., 2012). This band also includes sounds generated by the wind and waves. The high frequency band encompassed the range that is typically dominated by the noise produced by snapping shrimps (Hildebrand, 2009). Boat sounds cover a large frequency band (e.g. Kaplan and Mooney, 2013; Erbe et al., 2019) and may interfere with both bands examined. The Root Mean Square (RMS) levels of the PSD values of each frequency bin were calculated for all 3h-periods to present average power spectra of both frequency ranges for the lockdown and post-lockdown sessions. Recordings performed during the lockdown were merged to produce single averaged spectra.

Not all boats and crafts frequenting the present marina and coastal areas in general are equipped with Automatic Identification System (AIS) (Hermannsen et al., 2019). In addition, during the lockdown the public (including the investigators of this study) could only make short trips of up to 1 h per day and within a maximum radius of 1 km of their home. Visual counting of boats was therefore impossible. Alternatively, the spectrograms (Fast Fourier Transform FFT, 128 points, Hamming window, 75 % overlap) of each 1 min recording were visually and aurally inspected and cross-checked by two investigators using the Avisoft-SASLab Pro software (version 5.2.10). The number of recordings during which at least one sound produced by boats was recorded were counted. Boat noises are long lasting sounds that cover both low and high frequency ranges with a broadband energy dominating at frequencies above several hundred Hertz (Barlett and Wilson, 2002).

Visual and aural inspections of the spectrograms were also performed to detect biotic sounds. The most distinctive of those observed were series of impulsive or grunt-like sounds in the low frequency range (40–2500 Hz) produced by fishes, with these detected over a 24h period for the three sessions. These sounds were tagged using the insert label function of Avisoft-SASLab Pro software.

2.3. Data analysis

The Normality of the Root Mean Square (RMS) levels of the PSD values in the 40–2500 Hz frequency range during and after the lockdown were checked by Shapiro-Wilk tests (W = 0.95–0.99, all P < 10−5). Non-parametric Kruskal-Wallis tests were performed to compare PSD levels (RMS, dB re: 1 μPa².Hz−1) between the 3h-periods for each recording session. Dunn’s multiple pairwise comparisons post-hoc tests with Holm’s adjustment method were subsequently used to identify significant differences.

The differences in the presence of boat between sessions were tested by comparing the proportion (%) of recording files of each 3h-period in which at least one boat sound was detected by means of Binomial exact tests with proportions observed during lockdown conditions as theory proportion. Boat noise here refers to all motor sounds that could be detected, from small crafts to large vessels.

Acoustic analysis was conducted with Avisoft-SASLab Pro software on N = 8–12 sounds from the two most prominent sound types that showed a good signal-to-noise ratio allowing them to be analysed. The following acoustic characteristics were measured from oscillograms: the total duration of sounds (ms), the number of pulses within a sound, the period of pulses (peak-to-peak interval, ms) and the pulse duration (ms). The dominant frequency (Hz) was measured from logarithmic power spectra. The number of biotic sounds did not follow a Normal distribution (Shapiro-Wilk tests, W = 0.52–0.58, all P < 10−5). Non-parametric Kruskal-Wallis tests were then performed to compare the number of sounds detected between the recording sessions and between the 3h-periods. Dunn’s multiple pairwise comparisons post-hoc tests were subsequently used to identify significant differences.

All statistical analysis were performed with RStudio (R version 4.0.3) at the significance level α = 0.05. In addition to probabilities (P-values), effect sizes of statistical measures made to compare PSD levels, and number of biotic sounds were estimated as the difference between medians of data obtained during and after the lockdown using the R package “dabestr” (Ho et al., 2019) before inferences and conclusions were drawn.

3. Results

3.1. Soundscape’s characteristics

During the lockdown, power spectrum density levels (RMS, dB re: 1 μPa².Hz−1) did not show significant diel variations in the frequency range below 1000 Hz (Kruskal-Wallis test, Χ² = 2.84, P = 0.89) (Fig. 2A). Even if a ca. 5 dB (re: 1 μPa².Hz−1) decrease could be observed between recordings performed at night (74.1 ± 1.2 dB from 20:00 to 08:00, mean ± S.D) and during day-time (79.0 ± 1.4 dB from 08:00 to 20:00) (Fig 3). In other words, there were no diel differences in PSD levels during the lockdown period. In contrast, following the lockdown the acoustic analysis of the 40–2500 Hz frequency range showed a marked diel pattern in the spectra (Fig. 3), with higher levels being
recorded during the day, likely owing to the resumption of human activities. Most variability occurred below 1000 Hz (Kruskal-Wallis tests, $\chi^2_7 = 68.60, P < 10^{-3}$). The significantly highest Power Spectral Density (PSD) levels below 1000 Hz were obtained during the 17:00–20:00 period with an average value of 85.2 ± 3.6 dB (Table 1). Periods showing the lowest PSD levels were recorded during night-time (from 20:00 to 05:00). Both the 23:00–02:00 and 02:00–05:00 periods showed the lowest PSD levels in the frequency range below 1000 Hz with $77.5 \pm 3.7$ dB and $78.2 \pm 3.4$ dB respectively (Dunn tests, $Z = 3.12–6.04$, all $P < 0.05$) (Table 1).

Comparison of PSD levels indicated that night-time periods (20:00–05:00) possessed the same levels during and post-lockdown, with differences of $0.7–1.4$ dB (Fig. 2B, Table 1). However, recordings made during day-time (05:00–20:00) had higher levels after the

Fig. 3. – Average power spectra in the 40–2500 Hz frequency band for each 3h-period during (red dashed lines) and after lockdown (blue lines). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1 – Average power spectrum density levels (RMS, dB re 1 $\mu$Pa$^2$.Hz$^{-1}$) calculated as the mean of all frequency bins below 1000 Hz for each 3h-period during and after lockdown (values are mean ± S.D). Effect sizes are calculated as the median differences between levels recorded after and during the lockdown.

| Time          | 02:00–05:00 | 05:00–08:00 | 08:00–11:00 | 11:00–14:00 | 14:00–17:00 | 17:00–20:00 | 20:00–23:00 | 23:00–02:00 |
|---------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| During        | 78.4 ± 3.5  | 78.5 ± 3.1  | 78.9 ± 2.2  | 78.3 ± 2.2  | 78.2 ± 2.2  | 79.2 ± 2.3  | 78.9 ± 3.5  | 78.5 ± 3.2  |
| After         | 78.2 ± 3.4  | 81.8 ± 2.4  | 84.3 ± 3.0  | 83.7 ± 3.7  | 82.2 ± 3.8  | 85.2 ± 3.6  | 80.8 ± 3.0  | 77.5 ± 3.7  |
| Effect size   | -0.7        | 2.7         | 5.2         | 5.1         | 3.6         | 6.0         | 1.4         | -1.3        |
| 95 % CI       | -3.9–3.0    | 0.1–5.9     | 3.1–7.1     | 3.7–6.7     | 2.3–5.2     | 3.9–7.9     | -1.4–5.2    | -4.5–2.4    |
lockdown (Fig. 2B, Table 1). Recordings showed a maximum difference (effect size) of 6.0 dB in frequencies below 1000 Hz between 17:00 and 20:00 (95% CI = 3.93–7.97) (Fig. 2B, Table 1). PSD levels differences during the remaining 3h-periods varied from 2.7 dB (05:00–08:00) to 5.2 dB (08:00–11:00) (Fig. 2B, Table 1).

Lastly, spectra in the higher frequency range (from 2500 to 22000 Hz) showed no differences with no diel variations between recordings performed during or post-lockdown (Supplementary Material 1).

3.2. Temporal variation of boat presence

A low occurrence of boat sounds was detected during the lockdown in the marina of Bas-du-Fort (Supplementary Material 2). In the recording sessions performed during the lockdown, the most regular occurrence of boat sounds appeared from 09:30 to 12:00 (Fig. 4A) and from 12:00 to 15:30 (Fig. 4B). Boat sounds were absent from 19:00 and 20:00, likely due to the imminent curfew (20:00–05:00). Boat sounds were rarely detected during the night, until either 05:00 (Fig. 4A) or 06:00 (Fig. 4B). The highest proportion of recordings in which at least one boat could be detected was from between 08:00 to 11:00, with 51% of recordings containing boat sounds (Table 2). After the lockdown (May 21 to May 23) recordings were characterized by increased and sustained boat traffic in the marina of Bas-du-Fort. The proportion of recordings with at least one boat sound were significantly higher (Binomial tests, all P values < 0.05) for all time periods except between 02:00 and 05:00, reaching a maximum of 100% and 89% of recordings containing boat sounds during 08:00–11:00 and 11:00–14:00 respectively (Table 2). The presence of boat sound was almost continuous, occurring during a longer period than during the lockdown, from 05:00 to 19:00 (Fig. 4C). Even though boat sound presence decreased at night (Fig. 4C), the proportion of recordings with at least one boat sound varied from 11% to 20% compared to only 3%–7% during the lockdown (Table 2).

3.3. Temporal variation of fish sounds

Sounds from biological sources were recoded both during and post-lockdown, identified as originating from fishes. These primarily consisted of short, low frequency sounds that were produced either as isolated units or in series. The first type of sound that was often detected was defined as ‘growls’ (Fig. 5A). These sounds lasted 280 ± 173 ms (mean ± SD, N = 8 sounds analysed) and had a dominant frequency of 158 ± 64 Hz (Supplementary Material 3). The second defined type of sound consisted of a series of ‘knocks’ produced in chorus (Fig. 5B). These series (N = 12 series analysed) had a duration of 533 ± 193 ms.
and were made of $6 \pm 2$ pulses. Pulses lasted $24 \pm 5$ ms with a period of $107 \pm 5$ ms and a dominant frequency of $471 \pm 47$ Hz (Supplementary Material 4). These series of knock sounds drastically increased in number at night from 20:00 to 23:00 while they were rarely detected during the day. Other less common sound types consisted of fast series of low frequency pulses and higher pitched stridulations.

In total, 434 and 588 biological sounds were detected over 24h respectively during and after the lockdown. The diel pattern of biological sound detection appeared similar with a maximum of 9 sounds.min$^{-1}$ from 02:00 to 17:00 both during and after the lockdown, followed by an increase following the onset of night, primarily driven by knocking sounds, to a maximum of 35 sounds.min$^{-1}$ and 4 sounds.min$^{-1}$ from 20:00 to 02:00, before and after the lockdown respectively (Kruskal-Wallis test, $\chi^2 = 14.20-21.69$, all $P < 10^{-3}$; Dunn tests, $Z = 2.37-4.20$, all $P < 0.05$) (Fig. 6A). No significant difference between the recordings made during and after the lockdown was observed from 02:00 to 20:00 with differences ranging from $-1.5$ to $1.5$ sounds.min$^{-1}$ (Fig. 6B).

4. Discussion

The COVID-19 crisis was an unprecedented social and economic catastrophe, resulting in millions of deaths worldwide. The resulting

| Table 2 |
| --- |
| Proportion of recordings with at least one boat sound detected during and after the lockdown. Confidence intervals (C.I.) and $P$ values are the results of exact Binomial tests comparing proportions after the lockdown with during lockdown’s theoretical proportions. N.S. = non-significant difference. |
| 02:00-05:00 | 05:00-08:00 | 08:00-11:00 | 11:00-14:00 | 14:00-17:00 | 17:00-20:00 | 20:00-23:00 | 23:00-02:00 |
| During | 5/72 (7%) | 16/72 (22%) | 37/72 (51%) | 32/80 (40%) | 30/72 (42%) | 20/72 (28%) | 3/72 (4%) | 2/72 (3%) |
| After | 6/54 (11%) | 24/47 (51%) | 36/36 (100%) | 43/48 (89%) | 43/54 (79%) | 35/54 (65%) | 11/54 (20%) | 6/54 (11%) |
| 95% C.I. | 4%-23% | 36%-66% | 90%-100% | 77%-96% | 66%-89% | 51%-77% | 11%-33% | 4%-23% |
| $P$ values | N.S. | $<10^{-3}$ | $<10^{-3}$ | $<10^{-3}$ | $<10^{-3}$ | $<10^{-3}$ | $<10^{-3}$ | 0.005 |

Fig. 5. – Spectrograms (top) and oscillograms (bottom) of A. a single low frequency growl and B. a series of pulsed sounds detected in the study area (made with R-studio using the Seewave package, Sueur et al., 2008).
government-imposed lockdowns provided an unprecedented opportunity to investigate the impact of noise pollution worldwide and to quantify how the world may sound with minimal human activity. The present study showed that the reduction in human activities during the first COVID-19 lockdown of 2020 resulted in a reduction in ambient noise during the day-time at the studied marina. Changes in the level of noise and boat traffic did not change the acoustic diel activity of fishes. However, more sounds were detected after the lockdown, following the resumption of boat activities.

Reductions in human activities can rapidly lead to behavioral changes in associated wildlife. For instance, during the 2020 lockdown many wild species, including Sika deer in Japan, monkeys in Thailand, and harbor dolphins in Italy, were observed exploring urban spaces where they were usually rare (Arora et al., 2020). However, our results suggest that reductions in noise pollution during the day due to less boat traffic did not result in variation in the diel patterns of fish vocal activity at our study site (Nedelec et al., 2016; Currie et al., 2020; Staaterman et al., 2020). Diel patterns of vocalization may be minimally affected by changes to day-time boat noise as the species present at the study site primarily vocalize during the night when human activity and boat traffic was consistently low.

Many teleost fishes produce and hear social sounds between 20 Hz and 3 kHz (Lindseth and Lobel, 2018; Ladich, 2019; Popper and Hawkins, 2019) which falls into the frequency range that is mostly occupied by boat noise. Particularly, large vessels may generate noise levels up to 188 dB re: 1 \( \mu \)Pa at 1m (McKenna et al., 2013) which may then radiate over wide distances in the ocean. Smaller boats also increase local sound intensities in shallow waters over a wider frequency range, from 5 to 1000 Hz (Holles et al., 2013; Nedelec et al., 2016; McCormick et al., 2019), potentially interfering with the acoustic communication range of both fishes and other marine species (Slabbeekorn et al., 2010). High levels of boat noise have therefore been proposed to have a masking effect, giving the impression that fishes produce less sound overall (Luczkovich et al., 2016) or reduce their sound production in loud environments. However, in the present study a lower absolute number of signals was detected during the two recording sessions performed during the lockdown, suggesting that environments with less noise pollution may reduce the need to produce as much sound to communicate information (Picciulin et al., 2012). Without elevated anthropogenic noise, sounds could potentially more easily reach receivers, increasing communication efficiency.

However, the opportunistic nature of the study, the relatively short duration of the lockdown in Guadeloupe, the lack of data from previous years, and the potential seasonality in acoustic behaviour did not enable us to fully qualify the effect of noise pollution on sound production by fishes at the study site. In addition, while human activities resumed at the end of the lockdown period, these were still reduced compared to prior to the COVID 19 pandemic. Local economic activity remained lower than in previous years due to the continued lack of international tourists and subsequent restrictions on movement. Future investigations should include temporal replicates and associated playback experiments in order to confidently link the reduction of boat presence and associated noise to changes in fish sound production.

The fishes responsible for the production of the main sound types used in temporal comparisons remain to be fully identified. The series of pulses produced in chorus, i.e. by large number of individuals concurrently at night, were the primary contribution to the observed biophony. Their percussive nature, together with their dominant frequency, would suggest that these sounds were produced by drumfish (Scliniidae) (Lagardère and Mariani, 2006; Parmentier et al., 2014; Parmentier et al., 2017). The two species found in Guadeloupe, the spotted drum Equetus punctatus (Bloch & Schneider 1801) and the Jack-knifefish Equetus lanceolatus (L. 1758) are therefore good candidates although their vocalizations have yet to be formally described. While the chorousing nature of this vocal activity suggests the presence of several individuals in the study area, we were unable to estimate the number of the sound producers.

These results clearly illustrate how quickly anthropogenic noise pollution can be reduced in marine environments when activity is restricted. Our findings could persuade local stakeholders to evaluate the impacts of noise associated with human activities in coastal environments and the importance of considering noise mitigation in spatial planning and management of such anthropised areas.

Authors’ contribution

Frédéric Bertucci: Methodology, Investigation, Formal analysis, Writing - original draft. David Lecchini: Methodology, Writing - review & editing. Céline Greeven: Investigation, Formal analysis. Rohan M. Brooker: Writing - review & editing. Lana Minier: Formal analysis.
Sebastien Cordonnier: Resources. Malikia Rene-Trouillafou: Writing - review & editing. Eric Parmentier: Methodology, Writing - review & editing.

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.

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Appendix A. Supplementary data

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Availability of data and material

All data are fully available upon kind request to the corresponding author.

References

Arora, S., Bhaushaniki, K.D., Mishra, P.K., 2020. Coronavirus lockdown helped the environment to bounce back. Sci. Total Environ. 743, 140572.
Asensio, C., Pavlov, P., Benavides, C., Leal, M.C., Calado, R., Schmid, D.W., Bertucci, F., Lecchini, D., 2021. Editing. Eric Parmentier.

F. Bertucci et al.

Environmental Pollution 289 (2021) 117988

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References

Arora, S., Bhaushaniki, K.D., Mishra, P.K., 2020. Coronavirus lockdown helped the environment to bounce back. Sci. Total Environ. 743, 140572.
Asensio, C., Pavlov, P., Benavides, C., Leal, M.C., Calado, R., Schmid, D.W., Bertucci, F., Lecchini, D., 2021. Editing. Eric Parmentier.
Popper, A.N., Hawkins, A.D., 2019. An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. J. Fish. Biol. 94, 692–713.
Rolland, R.M., Parks, S.E., Hunt, K.E., Castellote, M., Corkeron, P.J., Nowacek, D.P., Wasser, S.K., Kraus, S.D., 2012. Evidence that ship noise increases stress in right whales. Proc R Soc B 279 (1737), 2363–2368.
Roenibloom, D., Markard, J., 2020. A COVID-19 recovery for climate. Science 368 (6490), 447–447.
Sandford, A., 2020. Coronavirus: half of humanity now on lockdown as 90 countries call for confinement. Euronews with AP, AFP. https://www.euronews.com/2020/04/02/coronavirus-in-europe-spain-s-death-toll-hits-10-000-after-record-950-new-deaths-in-24-hour.
Slabbeekoom, H., Bouton, N., van Opzeeland, I., Coers, A., ten Cate, C., Popper, A.N., 2010. A noisy spring: the impact of globally rising underwater sound levels on fish. Trends Ecol. Evol. 25 (7), 419–427.
Southall, B.L., Scholik-Scholmer, A.R., Hatch, L., Bergmann, T., Jasny, M., Metcalf, K., Weigart, A.J., Wright, A.J., 2017. Underwater noise from large commercial ships—international collaboration for noise reduction. Encyclopedia of Maritime and Offshore Engineering 1–9.
Staaaterman, E., Gallagher, A., Holder, P.E., Reid, C.H., Alitieri, A.H., Ogbum, M.B., Rumnner, J.L., Cooke, S.J., 2020. Exposure to boat noise in the field yields minimal stress response in wild reef fish. Aquat. Biol. 29, 93–103.
Sueur, J., Aphin, T., Simonis, C., 2008. Seewave, a free modular tool for sound analysis and synthesis. Bioacoustics 18 (2), 213–226.
Tavolga, W.N., Popper, A.N., Fay, R.R., 2012. Hearing and Sound Communication in Fishes. Springer Science & Business Media.
Williams, R., Wright, A.J., Ashe, E., Blight, L.K., Bruintjes, R., Canessa, R., Clark, C.W., Calles-Sanzá, S., Dukin, D.T., Erbe, C., Hammond, P.S., Merchant, N.D., O’Hara, P.D., Purser, J., Radford, A.N., Simpson, S.D., Thomas, L., Wale, M.A., 2015. Impacts of anthropogenic noise on marine life: publication patterns, new discoveries, and future directions in research and management. Ocean Coast Manag. 115, 17–24.
Zambrano-Monserrate, M.A., Ruano, M.A., Sanchez-Alcalde, L., 2020. Indirect effects of COVID-19 on the environment. Sci. Total Environ. 728, 138813.