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Land-based noise pollution impairs reef fish behavior: A case study with a Brazilian carnival

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ABSTRACT

Anthropogenic sounds have spread across the biosphere, with threats from individual welfare to ecosystem health. Sounds are important to animals in both terrestrial and aquatic environments and detrimental effects have been shown across a wide range of taxa. Despite the ever-growing transformation of coastal lands by human activities, pollutant effects of sounds that propagate from land into coastal water (across realms) have been largely overlooked. We here show that the Brazilian carnival of Salvador, annually taking place along a coastal boulevard, elevated underwater sound pressure levels by more than 30 dB re 1 μPa^2. We used remotely operated cameras to measure individual abundance and feeding activity of the Brazilian damsels (*Stegastes fuscus*) and we measured its flight-initiation distance to a model predator. Brazilian damsels did not abandon their reef territories, but their feeding activity and fleeing distance were significantly reduced under elevated noise levels, compared to the ambient control conditions at the same site and at a spatial control site. Apparently, carnival sounds emitted from land affected underwater behavior in our reef fish species. The behavioral effects may be critically important for individual fitness, and the detrimental impact of land-based noise pollution in coastal waters may also apply to other fish and invertebrate species. Humanity is claiming coastlines at a faster rate than any other habitat, and conservation concerns should extend to nearby coastal ecosystems and the possible impacts of underwater sounds emanating from land.

1. Introduction

Noise pollution has become a growing global concern. This stressor can detrimentally affect the health and survival of individual animals, but may also cause ecological shifts in natural communities and entire ecosystems (Buxton et al., 2017; Francis et al., 2012; Goines and Hagler, 2007; Shannon et al., 2015; Slabbekoorn et al., 2010). The impaired ability to exploit communicative or other biologically relevant ambient sounds, emergence of mal-adaptive behaviors, site abandonment, physiological stress, and developmental abnormalities, are but some of the deleterious consequences that sound pollution imposes on fauna across taxa (Buxton et al., 2017; Cox et al., 2018; Francis et al., 2012; Goines and Hagler, 2007; Shannon et al., 2015; Slabbekoorn et al., 2010). This situation challenges the integrity of natural ecosystems and requires community wide attention of societal parties working in science, animal welfare, conservation, legislation, and even human health.

Several decades of research have provided pivotal insights into the propagation and impacts of anthropogenic sounds in air and water (Buxton et al., 2017; Francis et al., 2012; Goines and Hagler, 2007; Shannon et al., 2015; Slabbekoorn et al., 2010). However, while humans

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are transforming the planet's landscape, the intensity at which this process occurs is by far greatest in coastal areas (Creel, 2003; Kummu et al., 2016; Small and Nicholls, 2003). Presently, population densities in low-elevation, coastal areas are five times that of the global mean (Neumann et al., 2015), including most of the world's megacities (Seto et al., 2011). Near-future estimates point out that over half of humanity will live within 100 km from a coast; an area constituting less than 10% of all terrestrial land (Creel, 2003). While this implies the continued transformation of coastal soundscapes (Buxton et al., 2017; Shannon et al., 2015; Slabbekoorn et al., 2010; Slabbekoorn and Peet, 2003), the potential spillover effects of terrestrial sound pollution into seas and oceans have received limited attention (Bugnot et al., 2019). This is worrisome because coastal ecosystems provide many irreplaceable services whose permanence is already threatened by an array of human disturbances (Andrades et al., 2017; Buxton et al., 2017; Halpern et al., 2008; Shannon et al., 2015; Worm et al., 2006).

Here, we present the results of observations and an experiment to test whether anthropogenic sounds emitted from land have measurable impacts on the adjacent underwater soundscape at a 500 m-long shallow reef, and to examine whether there are deterrence or disturbance effects on local reef fish. This study took place during one of the world's biggest street festivals, the Brazilian carnival in the city of Salvador. The festivities last for over a week and are concentrated along a coastal boulevard and provides a natural 'before-during-after' study design, with temporal controls at the exposed reef system, and with a nearby spatial control coastal reef system unexposed to the carnival sounds. Based on insights from within-realm observations and experiments (i.e., intrinsic noise pollution pressure, sensu Bugnot et al., 2019; Cox et al., 2018; Kunc et al., 2016), we posited that if land-based sound emissions penetrated the coastal marine ecosystem, fish during the noisy period at the noisy reef, may flee, reduce foraging and show slower response to a predator threat, compared to fish during the quiet periods and at the quiet (i.e., control) reef.

2. Material and methods

2.1. Study locations

The city of Salvador (Fig. 1) hosts a weeklong carnival that is world renowned for involving the participation of millions of people, along with hundreds of 'sound trucks', locally known as *Trios Elétricos* (Fig. 2). These sound trucks act as moving stages, travelling (speed of approximately ≤ 3 km h^{-1}) from mid-afternoon until daybreak along a road located within 50 m from a rocky reef. The intensity of the amplified music these trucks emit may be exceedingly loud, reaching over 125 dBA (re 20 μPa). We conducted our sampling at a site near the carnival (thereafter referred to as Carnival reef), and a very similar but unexposed site as spatial control (Control reef). Both of these rocky reefs are separated by approximately 2400 m and adjacent to the coastal city of Salvador (i.e., within 100 m from shore; Fig. 1). These two reef locations are characterized by their maximum depth of ~2 m, the benthic species composition is similar and fish richness has been shown to reach 77 species (Ferreira et al., 2015). During our study, horizontal visibility was at least seven meters and sea surface temperature ranged between 28 and 30 °C. Wave action was negligible, given the protection offered by the outer reef. Both reefs are characterized by a complex but similar geomorphological formation (Ferreira et al., 2015; Leão et al., 2003).

Fig. 2. Example of a sound truck during the carnival of Salvador, locally referred as a *Trio Elétrico* (Electric Trio). These trucks act as moving stages that are equipped with a powerful sound system, including amplified speakers on all four sides (details in inset panel A). On at least six consecutive days during carnival, sound trucks follow each other at 15–20 minute intervals, from ~14:00 to ~04:00 and undertake a 3 km course, of which approximately 800 m are near a shallow reef ecosystem occurs (e.g., inset panel B). At a distance of 1 m from a sound truck, the sound pressure level may exceed 125 dB(A) re 20 μPa.
Photo credits: Manu Dias, 2018.

Sampling occurred two days before, two days during, and two days after carnival (8th - 15th of 2018) on February 2nd, 7th, 9th, 13th, 16th

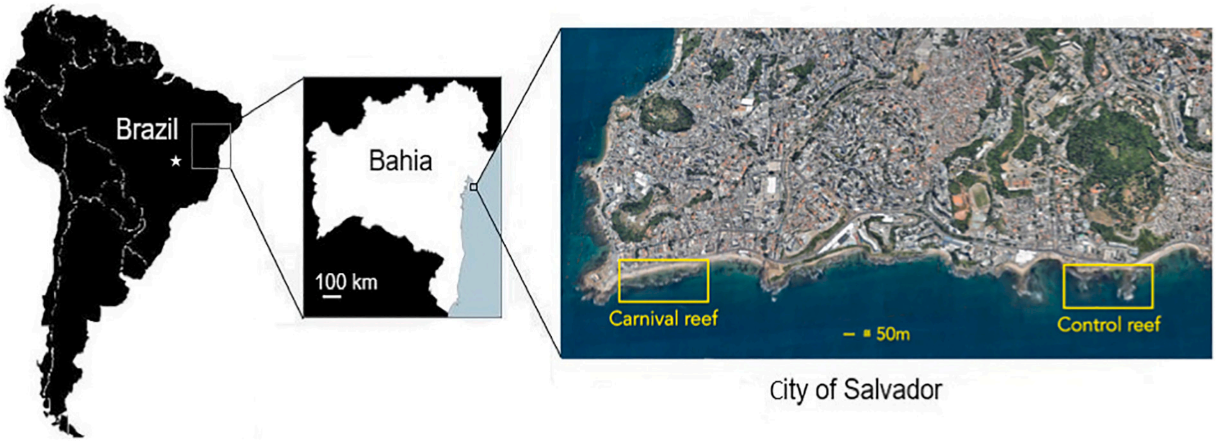

Fig. 1. The location of the carnival and control reefs along the coast of the metropolitan city of Salvador, Bahia State, Brazil. These shallow reefs are within 10-100 m from the coast; approximately 2400 m separate these reefs from each other. The city of Salvador is located within the Brazilian State of Bahia. The white star shows the location of the country's capital, Brasilia.
Source: Google Earth Pro 2018.

and 20th, thereafter corresponding to three periods, namely 'before', 'during' and 'after'. The Carnival reef was located near the emissions of music (i.e., within 100 m), whereas the Control reef was separated from the carnival by at least 2000 m (Fig. 1). Sampling across periods (i.e., before, during and after) at the Carnival reef provided an assessment of exposure conditions with temporal controls within the same site, while sampling at the Control reef on the very same days in adjacent time periods provided a spatial control. This experimental design, was based on similar before, during, and after, pilot sampling at the Carnival reef in a previous year, and should be considered a well-prepared and optimally replicated case study, but is not meant to be a general test of coastal festival impacts on all fish everywhere (c.f. Slabbekoorn and Bouton, 2008; Underwood, 1994).

2.2. Sound recording procedure

We monitored sound regimes, before, during and after the 2018 carnival, which occurred under sunny weather. At these reefs, during each of these three periods, we recorded the aerial and underwater sound levels (detailed below). Recordings were conducted daily from set points on shore, allowing us to compare potential changes in sound intensity associated to the presence of carnival noise (i.e., sound trucks). During carnival, the coastal boulevard is closed to regular car traffic, and at the Carnival reef, sound trucks departed at intervals of approximately 15–20 min. The distance separating our recordings from these sound trucks ranged from ~45 to 115 m (as trucks were in movement), which we estimated using Google Earth Pro (2018). We measured aerial sound pressure levels (dBA re 20 μPa) on the beach, at the low-tide waterline with a sound pressure meter (Skill-Tec™ SKDEC-02, São Paulo, Brazil). We conducted 30-s recordings repeatedly, for a total duration of 5 min, which occurred over a period of approximately 90 min (i.e., the time necessary to conduct the behavioral observations detailed below). During this period, we also recorded 30 min of the underwater sound pressure levels in five-minute bouts. To record underwater sounds, an observer on foot held a hydrophone vertically at a depth of 50 cm, 30 cm above sand-overlaid substrate, at a distance of ~5–7 m from the beach (i.e., ~50–122 m of the sound trucks, as detailed above). To reduce potential sound distortion, recordings were conducted from at least 3 m from any reef structure. The barrier formed by reefs at low tide (which coincided with the time of our recordings) substantially reduced wave action, to nearly no breaking waves during this period. Our recording system consisted of a hydrophone (SQ26, Cetacean Research Technology, Seattle, USA) with a built-in preamp, connected to a digital audio recorder (PCM-M10, 48 kHz sampling rate, Sony Corporation, Tokyo, Japan). To measure sound pressure in absolute units, we determined calibration constants for the audio recorder by recording pure tones of known amplitude at frequencies of 40, 400, 800, and 1000 Hz. We confirmed a flat response across these frequencies using oscilloscope recordings (3425 Differential Picoscope, Pico Technology, Cambridgeshire, UK) and we combined our measurements with the manufacturer-provided hydrophone sensitivity to determine the recording system calibration constant, which allowed conversion of our underwater audio recordings to μPa for analyses. We then imported all recordings to the statistical software R (Core Team R, 2013), allowing us to extract sound pressure levels in third-octave frequency bands using a custom written R-module.

2.3. Behavioral assays and model species

To determine whether carnival-related acoustic changes from music emitted on land could have biological consequences on aquatic fauna, we quantified changes in both abundance and behavior of the Brazilian damsel (detailed below). In situ measures on our model species occurred concurrently with the acoustic measurements detailed above to correlate variation in sound level to variation in fish presence and behavior. Our choice for this fish as model was made on the grounds that it represents an abundant and conspicuousness species in coastal shallow reef habitats of the Western tropical Atlantic (Froese and Pauly, 2017), including the coastline around the city of Salvador (Ferreira et al., 2015). Pomacentridae fish are also known to make and respond to sounds (Egner and Mann, 2005; Leis et al., 2002; Myrberg and Spires, 1980; Parmentier et al., 2009; Popper and Schilt, 2008). Given the relatively high acoustic threshold characterizing *Stegastes* species (Egner and Mann, 2005), we posited that any impact on this species would suggest that many other aquatic organisms could also be afflicted by the noise pollution generated on land. All observations were conducted between 12:00 and 17:00 h, as our model species is diurnal, with peak activity levels from noon until dusk (Ferreira et al., 1998; Osório et al., 2006). During these observations (and the acoustic recordings), there was no nearby boat traffic that could have affected local sound levels.

The Brazilian damsel exhibits distinct territorial behavior, with a mean territory size of 2 m^2 (Ferreira et al., 1998; Osório et al., 2006). This allowed us to conduct observations via remote underwater cameras, which provide better assessments of rapid and repetitive behavior than with direct observations by an observer (Branconi et al., 2019). We used remote cameras (GoPro®, Hero 3+ Black Edition, San Mateo, USA, 24fps and 1080 dpi), each placed 15 cm above the substrate (by a snorkeling observer) at approximately 1.5 m from at least one Brazilian damsel (i.e., target fish), randomly chosen. Each recording lasted 9 min, but we avoided quantifying potential behavioral changes associated with placing and retrieving the camera by excluding the first and last 2 min of each recording from our analysis.

Using the video-recording approach, we quantified species' abundance, and thereby tested for the potential impact of spatial deterrence or elevated predation risk caused by high noise levels (Simpson et al., 2015; Purser and Radford, 2011). We counted the maximum number of individuals appearing on a single frame of a given 5-minute recording (N per period per reef = 32–52), which provided a conservative estimate of abundance by avoiding multiple counts of a single individual. Although noise pollution emanating from aquatic sources can interfere with feeding in fish (Purser and Radford, 2011), it remained unknown whether feeding intensity of aquatic animals is compromised by emissions of noise from land. We thus measured foraging activity by counting the number of feeding attempts of the Brazilian damsel, which we derived by considering each pecking motion toward the substrate or at a floating particle in the water column (Barneche et al., 2009; Nunes et al., 2013). To analyze these videos, we trained an observer, who remained naïve to treatments (i.e., reefs or periods) and watched without audio. We collected a total of 242 video recordings. A typical field of view from our cameras is presented in Supplementary material Fig. S1.

In addition to potential effect of spatial deterrence and feeding led by these land-based acoustic emissions, anthropogenic sounds of marine origin can interfere with prey fish's ability to respond to a predation threat. We thus gauged anti-predation using the flight initiation distance (FID) approach, which consists of measuring the distance at which a prey flees from an approaching predation threat (Blumstein, 2003; Gotanda et al., 2009; Januchowski-Hartley et al., 2015; Nunes et al., 2013). FID reflects an animal's detection and perception of threat and is critical for its chances to escape (Blumstein, 2003; Gotanda et al., 2009; Quadros et al., 2019), thereby allowing us to compare the Brazilian damsel's response to a predation threat under two distinct conditions, namely with and without the presence of additional sound emanating from land. As a predation threat, we used a realistic-looking 30-cm fiberglass model predator grouper (*Epinephelus* genus, Supplementary material, Fig. S2; following the approach used by Gotanda et al., 2009; Januchowski-Hartley et al., 2015; Quadros et al., 2019). During our experimental test, this life-size model of a common local predator was manipulated by a snorkeling observer and approached toward a Brazilian damsel at a steady speed. Manipulation of the model was done via a one-meter rod, which allowed the observer to stay further back, thereby reducing its conspicuousness. Starting from a distance of approximately three meters, the observer approached a randomly chosen target fish, at a speed of approximately 1 m per second, in prone position relative to the substrate, i.e., at the same depth as the target fish. Following the flight of the target fish, the negatively buoyant model predator was laid onto the substrate and the horizontal distance separating its snout from the last position of the escaped fish was measured with a measuring tape (following the general methods of Gotanda et al., 2009; Januchowski-Hartley et al., 2015; Quadros et al., 2019). All target fish fled from their initial approach position. To avoid recording the same fishes multiple times, we conducted daily measurements in different reef sections and separated observations by a minimum of four meters. We measured the FID of 252 individual fish.

2.4. Statistical analysis

We predicted that land-based acoustic interferences would occur at the Carnival reef during the period of carnival, henceforth modifying the behavior of the Brazilian damsel. We used separate Generalized Linear Models with Poisson error distribution for the dependent variables 'abundance' and 'FID', and a Generalized Linear Model with negative binomial error distribution, with a log link, to test for differences in 'number of feeding attempts'. Our main model for the dependent variables 'abundance' and 'FID' included the factors 'reef' and 'period'. However for the dependent variable 'number of feeding attempts', we also included the covariate 'abundance', as higher fish abundance should increase the propensity of observing this behavior. We ensured the parameters used in our models best fitted our data by using Akaike Information Criterion (AIC) scores in a model selection process. For each of the three dependent variables, we conducted pairwise tests from our Generalized Linear Models, comparing the distinct periods of each reef, as our goal was to test for within-site effects associated with the different periods (i.e., noise) of the carnival. These statistical analyses were conducted with the software IBM SPSS Statistics (v.20).

3. Results

At Carnival reef, during the period of carnival, the aerial soundscape measured at the waterfront was more than 30 dB(A) re 20 μPa louder than before or after this period, while no such difference existed at the Control reef (Fig. 3, insets). The carnival sounds emitted on land also propagated into the underwater soundscape. During carnival, low frequency sounds (30–400 Hz) reached a peak increase of 30 dB re 1 μPa^2 sound pressure, compared to baseline conditions or the Control reef (Fig. 3). These results highlight that anthropogenic sounds generated on land transformed the acoustic underwater seascape of nearshore habitats.

Based on the AIC scores, the retained model for the dependent variable 'abundance' and 'FID' contained the interaction "reefs × periods". For the dependent variable 'number of feeding attempts', the final model included the interaction "reefs × periods" with "abundance" as covariate ("reefs × periods + Abundance"; Supplementary material, Table S1). Throughout the study, the abundance of the Brazilian damsel did not significantly differ between reefs or among periods (Likelihood Ratio Chi-Share = 8.984, df = 5, $P = 0.110$). Thus, this territorial fish did not appear to have fled the reef (nor died) as a result of the fluctuations in

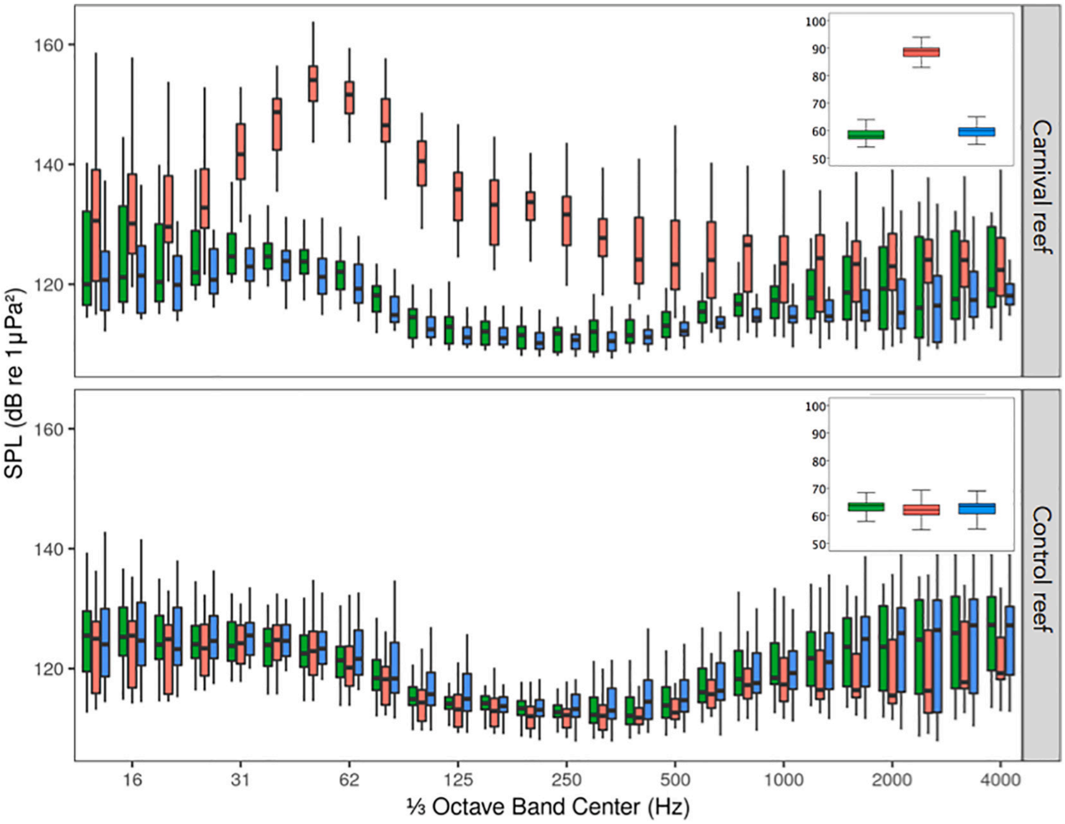

Fig. 3. Sound pressure level (SPL; dB re 1μPa^2) in third octave frequency bands (Hz), measured within the carnival and control reefs (top and bottom panel, respectively). The light-blue boxplots correspond to measurements done ahead (i.e., 6 and 2 days before) and following (i.e., 2 and 6 days after) the period of carnival (respectively). Measurements conducted concurrently with the period of carnival (i.e., second and penultimate days) are in dark-red and dark-blue for the carnival and control reefs, respectively. The carnival and control reefs were each distanced by 50-150 m and >2000 m from the emissions of music, respectively. At the carnival reef, mid- to low-frequency sounds were louder during carnival; when compared to baseline conditions, sound levels are significantly higher across the frequencies of 30–400 Hz, with a peak increase of 30 dB in 1/3 octave banded sound pressure level. No such difference was observable at the control reef. The inset figures represent the mean aerial sound pressure level (SPL; dB(A) re 20 μPa) measured at the waterline for each of these three periods. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

acoustic conditions (Table 1a; Fig. 4). By contrast, our statistical model revealed a significant effect of reef and period on the number of feeding attempts (Likelihood Ratio Chi-Share = 96.514, df = 6, $P < 0.001$). At the Carnival reef, during the period of carnival, average feeding values were reduced by 29% and 44% compared to before and after this period (respectively), whereas at the Control reef, feeding did not significantly vary among periods (Table 1b; Fig. 4). Furthermore, our statistical model also revealed a significant change in the FID of the Brazilian damsel among reefs and periods (Likelihood Ratio Chi-Share = 140.472, df = 5, P < 0.001). At the Carnival reef, during the period of carnival, the FID was reduced by nearly half, but again, no significant difference occurred at the Control reef (Table 1c, Fig. 4).

4. Discussion

Our acoustic measurements demonstrated considerable elevation of underwater ambient noise levels in a coastal reef system located alongside a coastal boulevard during carnival festivities involving exceedingly loud music. Our monitoring data indicated that the Brazilian damsel, a common resident reef fish, is not leaving the area prior, during or after the carnival-related sound exposures. Our behavioral observations and experimental results, however, revealed that foraging and escaping from a simulated predator could be compromised by the noisy conditions.

4.1. No evidence for deterrence

The Brazilian damsels did not avoid the elevated sound levels by fleeing the reef during the carnival period, which may appear surprising given the substantial behavioral effects to feeding and anti-predation. A rare investigation into the potential effects of anthropogenic noise emitted from bridge crossings on freshwater soundscapes revealed masking probability for acoustic communication in fish for entire watersheds (Holt and Johnston, 2015). In the freshwater case, fishes may not be able to avoid detrimental masking anywhere, while in our coastal marine situation, fishes may be able to flee to deeper water or to similar but more quiet reef habitat along the coastline, but they apparently do not. While several reasons may explain our findings, detrimental effects

Table 1
Pairwise tests of separate Generalized Linear Models, comparing periods (before, during, after) of each respective reefs (carnival, control), for mean fish abundance a), number of feeding attempts b) and flight initiation distance c). Shown are the mean difference (±SE) for each comparison, degree of freedom (df) and significance. Bold numbers indicate a statistically significant difference for the comparison.

Site × period	Site × period	Mean difference (±SE)	df	Significance
a) Abundance				
Carnival, during	Carnival, before	0.26 (±0.42)	1	0.539
Carnival, during	Carnival, after	0.55 (±0.30)	1	0.742
Carnival, before	Carnival, after	0.81 (±0.89)	1	0.083
Control, during	Control, before	0.18 (±0.45)	1	0.696
Control, during	Control, after	0.62 (±0.46)	1	0.180
Control, before	Control, after	0.80 (±0.42)	1	0.056
b) Number of feeding attempts				
Carnival, during	Carnival, before	5.63 (±1.98)	1	**0.017**
Carnival, during	Carnival, after	10.51 (±2.95)	1	**0.002**
Carnival, before	Carnival, after	4.88 (±3.10)	1	0.162
Control, during	Control, before	0.58 (±1.59)	1	0.709
Control, during	Control, after	3.17 (±1.57)	1	0.096
Control, before	Control, after	2.59 (±1.52)	1	0.175
c) Flight initiation distance				
Carnival, during	Carnival, before	8.21 (±1.24)	1	<**0.001**
Carnival, during	Carnival, after	6.10 (±1.25)	1	<**0.001**
Carnival, before	Carnival, after	2.12 (±1.32)	1	0.109
Control, during	Control, before	1.60 (±1.57)	1	0.312
Control, during	Control, after	1.31 (±1.55)	1	0.399
Control, before	Control, after	0.29 (±1.49)	1	0.848

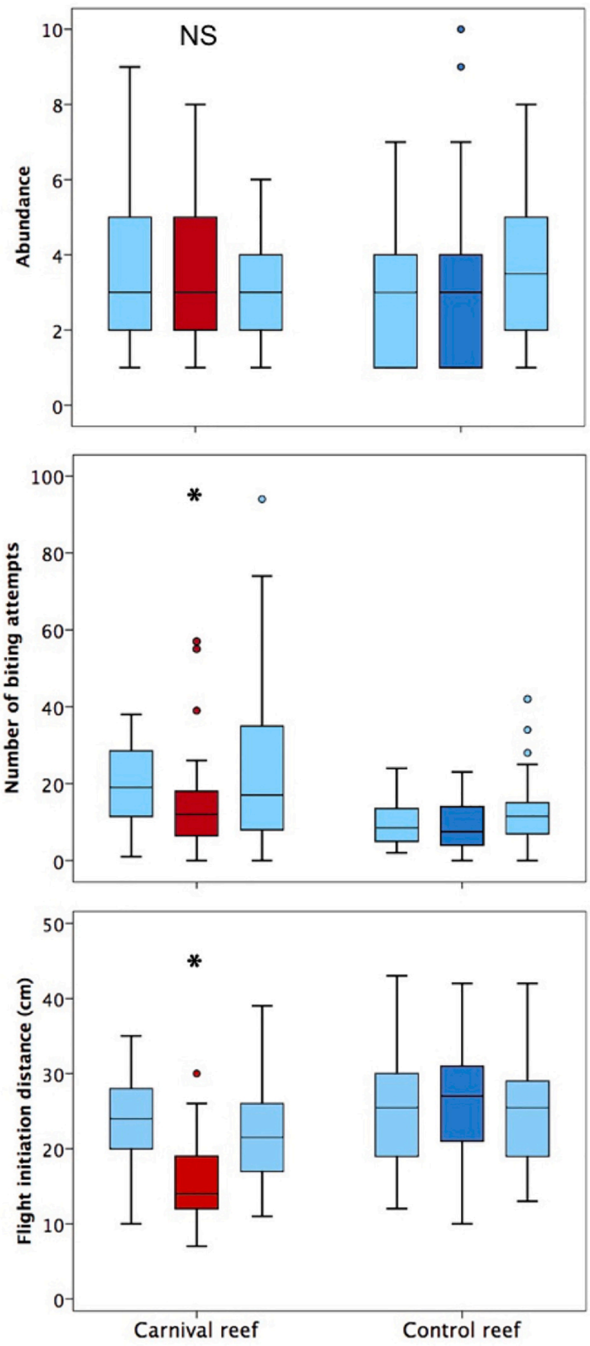

Fig. 4. Measurements on the Brazilian damsel (*Stegastes fuscus*) conducted before, during and after the 2018 carnival of Salvador. Light-blue boxplots correspond to measurements taken before and after carnival, whereas dark-red and dark-blue boxplots are measurements taken during carnival, at the carnival and control reefs, respectively. The boxplot lines are the median for the measured parameters, the boxes range from the 25th to the 75th percentile, whiskers are 1.5 IQR, circles are outliers and asterisks denote statistically-significant differences. The mean abundance of this fish did not vary significantly (NS) among periods nor between sites ($n = 243$; a). At the carnival reef, however, during the period of carnival, feeding of the Brazilian damsel, measured in number of feeding attempts ($n = 243$; b) and its flight initiation distance (cm) to an approaching model predator ($n = 252$; c) were significantly reduced. No such differences were observable at the control reef. The carnival and control reefs were distanced by 50 - 150 m and over 2000 m (respectively) from the musical emissions. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

for fishes that remain in the noisy area are likely to exist (Popper and Hawkins, 2019; Wright et al., 2007). In fact, many species, particularly territorial ones, are unable or unwilling to relocate and thereby are forced to tolerate a stressor with potential ramifications for survival and fitness (Albuquerque et al., 2014; Gill et al., 2001). Distress by sound exposures often induces freezing behavior or general inactivity (Cox et al., 2018; Sabet et al., 2016a), which may also further reduce the tendency for displacements. Furthermore, fishes in noisy conditions may not be able to assess whether it is quieter elsewhere, and in what direction they would need to swim to escape noise exposures (Sabet et al., 2016b).

4.2. *Behavioral effects with potential fitness consequences*

The effects of land-based noise pollution on behavior, as reported here, are likely biologically relevant, as foraging and escaping predation are critical for individual growth, maturation and survival, and thereby fitness (Slabbekoorn et al., 2019; Soudijn et al., 2020). Our results are in line with other studies in which noisy conditions, both in air and in water, affect foraging effort in several taxonomic groups (e.g., birds: Ware et al., 2015; bats: Luo et al., 2015; crabs: Hubert et al., 2018), while there is also evidence for reduced foraging efficiency in fish (Purser and Radford, 2011; Sabet et al., 2016b). Furthermore, impaired anti-predator responses behavior to noisy conditions have also been reported, for instance, in hermit crabs (Chan et al., 2010) and fish (Simpson et al., 2015; Spiga et al., 2017; Voellmy et al., 2014), with reduced survival in a related Indo-Pacific reef fish species (Simpson et al., 2016). Demonstration for whether the behavioral changes related to foraging and anti-predation also lead to negative fitness consequences in our damselfish will require further investigations.

The diurnal timing of the noisy conditions measured herein appear to create disturbances in our test fish, which may increase its vulnerability to visual predators from impaired risk-sensitivity (Neo et al., 2018; Vera et al., 2014). Noisy activities conducted offshore, (e.g., pile driving, seismic surveys, commercial vessel traffic) are typically continuous or without a regular diurnal pattern (De Jong and Ainslie, 2008; Frisk, 2012; Slabbekoorn et al., 2019). Contrastingly, the onshore carnival activities of our study do have a regular diurnal rhythm, specifically starting in the early afternoon, continuing throughout evening and well into the night. We conducted our observations during the afternoon, which is typically when daily feeding rates peak for our study species (i.e., ~2.5 bites min $^{-1}$, compared to <1.5 min $^{-1}$ in morning hours; Ferreira et al., 1998). Thus, the reduction in feeding rate, when the land-based acoustic emissions prevailed, is likely to significantly disturb this fish's diurnal activity patterns and daily food intake. Although we do not believe feeding or predator escape responses play a significant role during the evening or night time, we can also not exclude additional impacts in these dark hours due to behavioral (Neo et al., 2018) or physiological impacts (Vera et al., 2014).

4.3. *Conservation concerns for coastline habitat*

Coastal ecosystems face the impacts of many land-based disturbances (Halpern et al., 2008, 2009; Seitz et al., 2014; Smith, 2003), a situation that becomes particularly acute in urbanized areas (Bugnot et al., 2019; Todd et al., 2019). Fish assemblages are often impoverished in coastal areas facing high human demographic pressure (Drew et al., 2015). For example, in urbanized areas of Papua New Guinea, the number of reef fish species may be less than half of the number of coastal reefs in rural areas (Drew et al., 2015). Sound pollution generated by human activities on land may contribute to these patterns of coastal habitat degradation and local biodiversity loss. However, noise pollution across realms (i.e., from land to water) is only starting to be formally considered a stressor of conservation relevance for aquatic species (Bugnot et al., 2019; Crovo et al., 2015; Holt and Johnston, 2015).

In the near future, noise pollution in coastal areas is not like to go down, given the prevalence of noisy human activities on and in the water, as well as on land. Given the current popularity of coastal tourism and leisure, hundred of millions of people yearly are found at seashores (Davenport and Davenport, 2006; Hall, 2001). Coastal festivities, such as various festivals, carnivals, and beach parties are also becoming more popular and almost always involve excessive sound levels (Ballesteros et al., 2015; Sánchez-Sánchez et al., 2015). In Brazil, for example, nearly all major cities and coastal tourist destinations host similar festivities, with often poorly regulated sound emissions of amplified music. Aside from amplified music, an array of noise-generating activities (e.g., terrestrial and aerial transport, industrial processes, construction activities) typically transform natural soundscapes completely (Buxton et al., 2017; Shannon et al., 2015). We therefore believe it is important to monitor, and when possible mitigate noise pollution on land adjacent to sensitive aquatic ecosystems. Such approach should become an explicit part of conservation strategies to protect marine habitat.

In conclusion, our results clearly highlight the need to consider human activities on land as relevant sources of noise pollution to the underwater soundscape of coastal habitat. During carnival, a coastal reef system adjacent to a coastal boulevard was exposed to elevated underwater sound levels, which affected a local reef fish's foraging behavior and escape responsiveness to a predator threat. Further studies are necessary to understand the ecological ramifications of such effects; the current insights with respect to noise pollution effects on individual fitness and potential consequences at population and ecosystem levels are such that we should worry. Nearshore waters provide irreplaceable habitats as foraging and nursery grounds to many aquatic species (reviewed in Seitz et al., 2014) and many of these shallow water species are typically well-coupled with the substrate sensitive to low frequencies, (Popper and Hawkins, 2018, 2019) and may therefore be particularly vulnerable to acoustic disturbances emitted from land. Future studies should encompass a wider range of sound sources, propagation conditions and coastal geology, but it is clear that land-based sounds may impose pervasive, yet not well-quantified, fitness consequences to aquatic fauna, which could have implications for marine conservation, coastal management and policy.

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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CRediT authorship contribution statement

The work is original. All authors have contributed substantially to this work and agree with the contents of the manuscript and its submission to the journal.

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Appendix A. Supplementary data

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References

Albuquerque, T., Loiola, M., Nunes, J.A.C.C., Reis-Filho, J.A., Sampaio, C.L.S., Leduc, A.O.H.C., 2014. *In situ* effects of human disturbances on coral reef-fish assemblage structure: temporary and persisting changes are reflected as a result of intensive tourism. Mar. Freshw. Res. 66, 23–32. https://doi.org/10.1071/MF13185.

Andrades, R., Joyeux, J.-C., Gasparini, J.L., Reis-Filho, J.A., Macieira, R.M., Giarrizzo, T., 2017. Fringe on the brink: intertidal reefs at risk. Science 357, 261. https://doi.org/10.1126/science.aao0403.

Ballesteros, M.J., Fernández, M.D., Ballesteros, J.A., 2015. Acoustic evaluation of leisure events in two mediterranean cities. Appl. Acoust. 89, 288–296. https://doi.org/10.1016/j.apacoust.2014.09.022.

Barneche, D.R., Floeter, S.R., Ceccarelli, D.M., Frensel, D., Dinslaken, D.F., Màrio, H.F.S., Ferreira, C.E.L., 2009. Feeding macroecology of territorial damselfishes (Perciformes: Pomacentridae). Mar. Biol. 156, 286–299. https://doi.org/10.1007/s00227-008-1083-z.

Blumstein, D.T., 2003. Flight-initiation distance in birds is dependent on intruder starting distance. J. Wildl. Manag. 67, 852–857.

Branconi, R., Wong, M.Y.L., Buston, P.M., 2019. Comparison of efficiency of direct observations by scuba diver and indirect observations via video camera for measuring reef fish behaviour. J. Fish Biol. 94, 489–497. https://doi.org/10.1016/j.anbehav.2012.07.013.

Bugnot, A.B., Hose, G.C., Walsh, C.J., Floerl, O., French, K., Dafforn, K.A., Hanford, J., Lowe, E.C., Hahs, A.K., 2019. Urban impacts across realms: making the case for inter-realm monitoring and management. Sci. Total Environ. 648, 711–719. https://doi.org/10.1016/j.scitotenv.2018.08.134.

Buxton, R.T., McKenna, M.F., Mennitt, D., Fristrup, K., Crooks, K., Angeloni, L., Wittemyer, G., 2017. Noise pollution is pervasive in U.S. protected areas. Science 356, 531–533. https://doi.org/10.1126/science.aah4783.

Chan, A.A.Y.H., Giraldo-Perez, P., Smith, S., Blumstein, D.T., 2010. Anthropogenic noise affects risk assessment and attention: the distracted prey hypothesis. Biol. Lett. 6, 458–461. https://doi.org/10.1037/h0022681.

Core Team R, 2013. R: A Language and Environment for Statistical Computing. [WWW Document]. R Foundation for Statistical Computing, Vienna, Austria (URL (accessed 7.18.19)).

Cox, K., Brennan, L.P., Gerwing, T.G., Dudas, S.E., Juanes, F., 2018. Sound the alarm: a meta-analysis on the effect of aquatic noise on fish behavior and physiology. Glob. Chang. Biol. 24, 3105–3116. https://doi.org/10.1007/s10162-004-4043-4.

Creel, L., 2003. Ripple Effects: Population and Coastal Regions. Population Reference Bureau, Measure Communication, Washington, pp. 1–8.

Crovo, J.A., Mendonça, M.T., Holt, D.E., Johnston, C.E., 2015. Stress and auditory responses of the Otophysan fish, *Cyprinella venusta*, to road traffic noise. PLoS ONE 10, e0137290. https://doi.org/10.1371/journal.pone.0137290.s003.

Davenport, J., Davenport, J.L., 2006. The impact of tourism and personal leisure transport on coastal environments: a review. Estuar. Coast. Shelf Sci. 67, 280–292. https://doi.org/10.1016/j.ecss.2005.11.026.

De Jong, C.A.F., Ainslie, M., 2008. Underwater Radiated Noise Due to the Piling for the Q7 Offshore Wind Park. Acoustics 08 Paris, pp. 277–282.

Drew, J.A., Amatangelo, K.L., Hufbauer, R.A., 2015. Quantifying the human impacts on Papua New Guinea reef fish communities across space and time. PLoS One 10, 1–11. https://doi.org/10.1371/journal.pone.0140682.

Egner, S.A., Mann, D.A., 2005. Auditory sensitivity of sergeant major damselfish *Abudefduf saxatilis* from post-settlement juvenile to adult. Mar. Ecol. Prog. Ser. 285, 213–222.

Ferreira, C.E.L., Gonçalves, J., Coutinho, R., Peret, A.C., 1998. Herbivory by the dusky damselfish *Stegastes fuscus* (Cuvier, 1830) in a tropical rocky shore: effects on the benthic community. J. Exp. Mar. Biol. Ecol. 229, 241–264.

Ferreira, C.M., Cavalcanti Coni, E.O., Medeiros, D.V., Sampaio, C., Reis-Filho, J.A., Barros, F., Loiola, M., Nunes, J.A.C.C., 2015. Community structure of shallow rocky shore fish in a tropical bay of the southwestern Atlantic. Braz. J. Oceanogr. 63, 83–99.

Francis, C.D., Kleist, N.J., Ortega, C.P., Cruz, A., 2012. Noise pollution alters ecological services: enhanced pollination and disrupted seed dispersal. Proc. R. Soc. B Biol. Sci. 279, 2727–2735. https://doi.org/10.2193/2006-224.

Frisk, G.V., 2012. Noiseonomics: the relationship between ambient noise levels in the sea and global economic trends. Sci. Rep. 2, 437. https://doi.org/10.2202/1534-6005.1228.

Froese, R., Pauly, D., 2017. Fishbase. World Wide Web Electronic Publication. www.fishbase.org.

Gill, J.A., Norris, K., Sutherland, W.J., 2001. Why behavioural responses may not reflect the population consequences of human disturbance. Biol. Conserv. 97, 265–268. https://doi.org/10.1016/S0006-3207(00)00002-1.

Goines, L., Hagler, L., 2007. Noise pollution: a modern plague. South. Med. J. 100, 287–294.

Gotanda, K.M., Turgeon, K., Kramer, D.L., 2009. Body size and reserve protection affect flight initiation distance in parrotfishes. Behav. Ecol. Sociobiol. 63, 1563–1572. https://doi.org/10.1016/S0065-3454(08)60192-8.

Hall, M.C., 2001. Trends in ocean and coastal tourism: the end of the last frontier? Ocean & Coastal Management 44, 601–618.

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R., Watson, R., 2008. A global map of human impact on marine ecosystems. Science 319, 948–952. https://doi.org/10.1126/science.1149345.

Halpern, B.S., Ebert, C.M., Kappel, C.V., Madin, E.M.P., Micheli, F., Perry, M., Selkoe, K.A., Walbridge, S., 2009. Global priority areas for incorporating land-sea connections in marine conservation. Conserv. Lett. 2, 189–196. https://doi.org/10.1111/j.1755-263X.2009.00060.x.

Holt, D.E., Johnston, C.E., 2015. Traffic noise masks acoustic signals of freshwater stream fish. Biol. Conserv. 187, 27–33. https://doi.org/10.1016/j.biocon.2015.04.004.

Hubert, J., Campbell, J., van der Beek, J.G., Haan den, M.F., Verhave, R., Verkade, L.S., Slabbekoorn, H., 2018. Effects of broadband sound exposure on the interaction between foraging crab and shrimp – a field study. Environ. Pollut. 243, 1923–1929. https://doi.org/10.1016/j.envpol.2018.09.076.

Januchowski-Hartley, F.A., Graham, N.A.J., Cinner, J.E., Russ, G.R., 2015. Local fishing influences coral reef fish behavior inside protected areas of the Indo-Pacific. Biol. Conserv. 182, 8–12. https://doi.org/10.1016/j.biocon.2014.11.024.

Kummu, M., de Moel, H., Salvucci, G., Viviroli, D., Ward, P.J., Varis, O., 2016. Over the hills and further away from coast: global geospatial patterns of human and environment over the 20th–21st centuries. Environmental Resources Letters. 11, 034010 https://doi.org/10.1088/1748-9326/11/3/034010.

Kunc, H.P., McLaughlin, K.E., Schmidt, R., 2016. Aquatic noise pollution: implications for individuals, populations, and ecosystems. Proc. R. Soc. B Biol. Sci. 283, 20160839 https://doi.org/10.1016/j.anbehav.2013.12.029.

Leão, Z.M., Kikuchi, R.K.P., Testa, V., 2003. Corals and coral reefs of Brazil. Latin American Coral Reefs 9–52.

Leis, J.M., Carson-Ewart, B.M., Cato, D.H., 2002. Sound detection in situ by the larvae of a coral-reef damselfish (Pomacentridae). Mar. Ecol. Prog. Ser. 232, 259–268.

Luo, J., Siemers, B.M., Koselj, K., 2015. How anthropogenic noise affects foraging. Glob. Chang. Biol. 21, 3278–3289. https://doi.org/10.3389/fphys.2013.00065.

Myrberg, A.A., Spires, J.Y., 1980. Hearing in damselfishes: an analysis of signal detection among closely related species. J. Comp. Physiol. 140, 135–144.

Neo, Y.Y., Hubert, J., Bolle, L.J., Winter, H.V., Slabbekoorn, H., 2018. European seabass respond more strongly to noise exposure at night and habituate over repeated trials of sound exposure. Environ. Pollut. 239, 367–374. https://doi.org/10.1016/j.envpol.2018.04.018.

Neumann, B., Vafeidis, A.T., Zimmermann, J., Nicholls, R.J., 2015. Future coastal population growth and exposure to sea-level rise and coastal flooding - a global assessment. PLoS One 10, e0118571. https://doi.org/10.1371/journal.pone.0118571.s004.

Nunes, J.A.C.C., Sampaio, C.L.S., Barros, F., 2013. How wave exposure, group size and habitat complexity influence foraging and population densities in fishes of the genus Halichoeres (Perciformes: Labridae) on tropical rocky shores. Mar. Biol. https://doi.org/10.1007/s00227-013-2233-5.

Osório, R., Rosa, I.L., Cabral, H., 2006. Territorial defence by the Brazilian damsel *Stegastes fuscus* (Teleostei: Pomacentridae). J. Fish Biol. 69, 233–242. https://doi.org/10.1111/j.1095-8649.2006.01095.x.

Parmentier, E., Lecchini, D., Frederich, B., Brie, C., Mann, D., 2009. Sound production in four damselfish (Dascyllus) species: phyletic relationships? Biol. J. Linn. Soc. 97, 928–940.

Popper, A.N., Hawkins, A.D., 2018. The importance of particle motion to fishes and invertebrates. Journal of Acoustic Society of America 143, 470–487.

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. https://doi.org/10.1016/j.biocon.2005.10.020.

Popper, A.N., Schilt, C.R., 2008. Hearing and Acoustic Behavior: Basic and Applied Considerations. Fish Bioacoustics. Springer, New York, pp. 17–48.

Purser, J., Radford, A.N., 2011. Acoustic noise induces attention shifts and reduces foraging performance in three-Spined sticklebacks (*Gasterosteus aculeatus*). PLoS One 6, e17478. https://doi.org/10.1371/journal.pone.0017478.g005.

Quadros, A.L.S., Barros, F., Blumstein, D.T., Meira, V.H., Nunes, J.A.C.C., 2019. Structural complexity but not territory sizes influences flight initiation distance in a damsel fish. Mar. Biol. 1–6. https://doi.org/10.1007/s00227-019-3508-2.

Sabet, S.S., Van Dooren, D., Slabbekoorn, H., 2016a. Son et lumière: sound and light effects on spatial distribution and swimming behavior in captive zebrafish. Environ. Pollut. 212, 480–488. https://doi.org/10.1016/j.envpol.2016.02.046.

Sabet, S.S., Wesdorp, K., Campbell, J., Snelderwaard, P., Slabbekoorn, H., 2016b. Behavioural responses to sound exposure in captivity by two fish species with different hearing ability. Anim. Behav. 116, 1–11. https://doi.org/10.1016/j.anbehav.2016.03.027.

Sánchez-Sánchez, R., Fortes-Garrido, J.C., Bolívar, J.P., 2015. Characterization and evaluation of noise pollution in a tourist coastal town with an adjacent nature reserve. Appl. Acoust. 95, 70–76. https://doi.org/10.1016/j.apacoust.2015.02.004.

Seitz, R.D., Wennhage, H., Bergström, U., Lipcius, R.N., Ysebaert, T., 2014. Ecological value of coastal habitats for commercially and ecologically important species. ICES J. Mar. Sci. 71, 648–665. https://doi.org/10.1093/icesjms/fst152.

Seto, K.C., Fragkias, M., Güneralp, B., Reilly, M.K., 2011. A meta-analysis of global urban land expansion. PLoS One 6, e23777. https://doi.org/10.1371/journal.pone.0023777.

Shannon, G., McKenna, M.F., Angeloni, L.M., Crooks, K.R., Fristrup, K.M., Brown, E., Warner, K.A., Nelson, M.D., White, C., Briggs, J., McFarland, S., Wittemyer, G., 2015. A synthesis of two decades of research documenting the effects of noise on wildlife. Biol. Rev. 91, 982–1005. https://doi.org/10.3161/150811010X537918.

Simpson, S.D., Purser, J., Radford, A.N., 2015. Anthropogenic noise compromises antipredator behaviour in European eels. Glob. Chang. Biol. 21, 586–593. https://doi.org/10.1016/j.aquaculture.2007.07.225.

Simpson, S.D., Simpson, S.D., Radford, A.N., Nedelec, S.L., Ferrari, M.C.O., Chivers, D.P., McCormick, M.I., Meekan, M.G., 2016. Anthropogenic noise increases fish mortality by predation. Nature Communications 21, 10544. https://doi.org/10.1038/ncomms10544.

Slabbekoorn, H., Bouton, N., 2008. Soundscape orientation: a new field in need of sound investigation. Anim. Behav. 76, e5–e8. https://doi.org/10.1016/j.anbehav.2008.06.010.

Slabbekoorn, H., Peet, M., 2003. Ecology: birds sing at a higher pitch in urban noise. Nature 424, 267. https://doi.org/10.1038/424267a.

Slabbekoorn, H., Bouton, N., van Opzeeland, I., Coers, A., Cate ten, C., Popper, A.N., 2010. A noisy spring: the impact of globally rising underwater sound levels on fish. Trends Ecol. Evol. 11, 305–313. https://doi.org/10.1016/j.tree.2010.04.005.

Slabbekoorn, H., Dalen, J., Haan, D., Winter, H.V., Radford, C., Ainslie, M.A., Heaney, K. D., Kooten, T., Thomas, L., Harwood, J., 2019. Population level consequences of seismic surveys on fishes: an interdisciplinary challenge. Fish Fish. 20, 653–685. https://doi.org/10.1242/jeb.064998.

Small, C., Nicholls, R.J., 2003. A global analysis of human settlement in coastal zones. J. Coast. Res. 19, 584–599.

Smith, V.H., 2003. Eutrophication of freshwater and coastal marine ecosystems: a global problem. Environmental Science and Pollution Research 10, 126–139. https://doi.org/10.1065/esor2002.12.142.

Soudijn, F.H., van Kooten, T., Slabbekoorn, H., de Roos, A.M., 2020. Population-level effects of acoustic disturbance in Atlantic cod: a size-structured analysis based on energy budgets. Proc. R. Soc. B Biol. Sci. 287, 20200490 https://doi.org/10.1016/j.biocon.2009.10.007.

Spiga, I., Aldred, N., Caldwell, G.S., 2017. Anthropogenic noise compromises the anti-predator behaviour of the European seabass, *Dicentrarchus labrax* (L.). Marine Pollution Bulletin 122, 297–305. https://doi.org/10.1016/j.marpolbul.2017.06.067.

Todd, P.A., Heery, E.C., Loke, L.H.L., Thurstan, R.H., Kotze, D.J., Swan, C., 2019. Towards an urban marine ecology: characterizing the drivers, patterns and processes of marine ecosystems in coastal cities. Oikos 128, 1215–1242. https://doi.org/10.1007/s12237-012-9559-y.

Underwood, A.J., 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. Ecol. Res. 4, 3–15.

Vera, L.M., Montoya, A., Pujante, I.M., Pérez-Sánchez, J., Calduch-Giner, J.A., Mancera, J.M., Moliner, J., Sánchez-Vázquez, F.J., 2014. Acute stress response in gilthead sea bream (*Sparus aurata* L.) is time-of-day dependent: physiological and oxidative stress indicators. Chronobiol. Int. 31, 1051–1061. https://doi.org/10.1016/j.ygcen.2011.01.010.

Voellmy, I.K., Purser, J., Simpson, S.D., Radford, A.N., 2014. Increased noise levels have different impacts on the anti-predator behaviour of two sympatric fish species. PLoS One 9, e102946. https://doi.org/10.1371/journal.pone.0102946.s001.

Ware, H.E., McClure, C.J.W., Carlisle, J.D., Barber, J.R., 2015. A phantom road experiment reveals traffic noise is an invisible source of habitat degradation. Proc. Natl. Acad. Sci. 112, 12105–12109. https://doi.org/10.3354/meps07979.

Worm, B., Barbier, E., Beaumont, N., Duffy, J., Folke, C., Halpern, B., Jackson, J., Lotze, H., Micheli, F., Palumbi, S., 2006. Impacts of biodiversity loss on ocean ecosystem services. Science 314, 787.

Wright, A.J., Soto, N. tacha A., Baldwin, A.L., Bateson, M., Beale, C.M., Clark, C., Deak, T., Edwards, E.F., Fernández, A., Godinho, A., Hatch, L.T., Kakuschke, A., Lusseau, D., Martineau, D., Romero, L.M., Weilgart, L.S., Wintle, B.A., Notarbartolo-di-Sciara, G., Marin, V., 2007. Anthropogenic noise as a stressor in animals: a multidisciplinary perspective. Int. J. Comp. Psychol. 20, 250–273.