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Potential for acoustic masking due to shipping noise in the European lobster (*Homarus gammarus*)

Jézéquel Youenn [1, 2, *], Bonnel Julien [3], Chauvaud Laurent [1]

[1] Laboratoire des Sciences de l'Environnement Marin (LEMAR), UMR 6539 UBO/CNRS/IRD/Ifremer, Plouzane, France
[2] Woods Hole Oceanographic Institution, Biology Department, Woods Hole, MA 02543, USA
[3] Woods Hole Oceanographic Institution, Applied Ocean Physics and Engineering Department, Woods Hole, MA 02543, USA

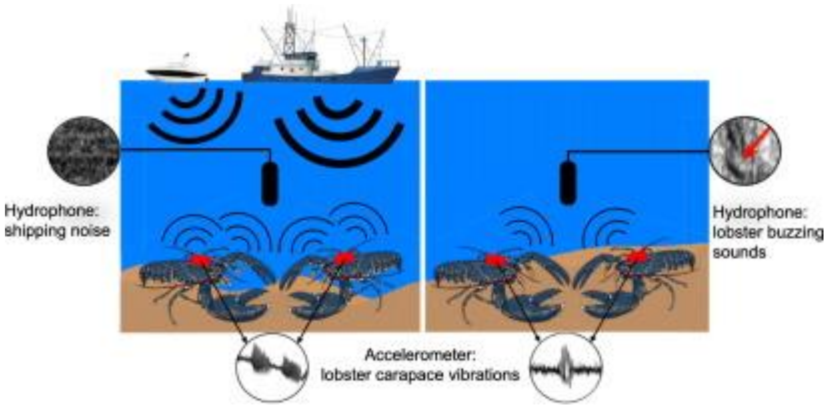
* Corresponding author : Youenn Jézéquel, email address : youen93@hotmail.fr

jbonnel@whoi.edu ; laurent.chauvaud@univ-brest.fr

Abstract :

Marine traffic is the most pervasive underwater anthropogenic noise pollution which can mask acoustic communication in marine mammals and fish, but its effect in marine invertebrates remains unknown. Here, we performed an at sea experiment to study the potential of shipping noise to mask and alter lobster acoustic communication. We used hydrophones to record buzzing sounds and accelerometers to detect lobster carapace vibrations (i.e. the buzzing sounds' sources). We demonstrated that male individuals produced carapace vibrations under various ambient noise conditions, including heavy shipping noise. However, while the associated waterborne buzzing sounds could be recorded under natural ambient noise levels, they were masked by shipping noise. Additionally, lobsters significantly increased their call rates in presence of shipping noise, suggesting a vocal compensation due to the reduction of intraspecific communication. This study reports for the first time the potential acoustic masking of lobster acoustic communication by chronic anthropogenic noise pollution, which could affect ecologically important behaviors.

Graphical abstract



Highlights

► Shipping noise is a widespread source of chronic underwater pollution. ► Lobsters produce underwater sounds, both in absence and presence of shipping noise. ► Shipping noise is louder than lobster sounds (i.e. acoustic masking). ► Lobsters significantly increased their call rates in presence of shipping noise. ► The potential impacts of noise pollution on marine invertebrates cannot be ignored.

Keywords : Noise Pollution, Bioacoustics, Acoustic communication, Marine invertebrates, Crustaceans, Passive acoustics

1 | INTRODUCTION

The oceans are becoming noisier worldwide due to anthropogenic noise sources, which are now considered as major underwater pollutants (Duarte et al. 2021). Seismic surveys and marine construction activities generate high impulsive (i.e. intermittent) noise that have various impacts on all marine taxa, from temporary changes in animal behaviors to lethal impacts (Madsen et al. 2006; Slabbekoorn et al. 2010; Jones et al. 2020). In marked contrast, far less studies have adressed the impacts of lower-level but permanent noise pollution, such as noise produced by marine traffic (Clark et al. 2009).

Shipping traffic is the most pervasive and chronic anthropogenic noise at sea, and have been responsible for increasing by 12 dB the low frequencies (below 1 kHz) in ambiant noise spectra worldwide (Hildebrand 2009), a frequency band also used by marine animals for acoustic communication (Duarte et al. 2021). There is emerging evidence that shipping noise can induce both behavioural and physiological changes in marine mammals and fish (e.g. Williams et al. 2014; Mills et al. 2020). Shipping noise can also alter animal communication and orientation by masking biologically important sounds, a common but yet understudied threat (Clark 2009). Acoustic masking results in the reduction of animal communication space as the signal cannot be detected, inducing changes from acoustic behaviours to complete loss of sound communication (Putland et al. 2018; Popper and Hawkins 2019). To date, no study has demonstrated yet whether fish are still vocally active in the presence of shipping noise. Assessing acoustic masking in marine animals is crucial for management of underwater anthropogenic noise (Hawkins et al. 2015). Yet, there is no evidence of acoustic masking effects due to shipping noise in marine invertebrates, even if some crustacean species use sound to communicate.

Among crustaceans, recent studies have demonstrated that lobsters can detect low frequency sounds (~100-200 Hz) in the same frequency band as the buzzing sounds they are known to produce (Jézéquel et al. 2018, 2021). In addition, these buzzing sounds likely play an important role for communicating about dominance status between male lobsters during agonistic encounters to get access to females during the reproduction (Jézéquel et al. 2020a). Considering the low soud level and frequency content of buzzing sounds, there are concerns about the potential effects of anthropogenic noise on lobster acoustic communication. This is particularly true since lobster habitat often overlaps with intense shipping traffic, such as in the Iroise Sea in Brittany (France; Kinda et al. 2017). In addition, the rapid expansion of offshore windfarms in Europe raise now concerns about the potential impacts of noise generated by pile driving, cable lying and shipping during construction and operations, on marine invertebrates (Edmonds et al. 2016). Understanding acoustic masking effects by chronic noise in lobsters is a key for future management of this valuable marine resource of high commercial interest.

The aim of the present study was to provide a first insight of potential acoustic masking due to shipping noise in male European lobsters (*Homarus gammarus*) during agonistic encounters. For this purpose, we combined both hydrophones to record their buzzing sounds underwater about a meter away from the animals, and accelerometers on lobsters to record their carapace vibrations (i.e. the source of the buzzing sounds). We first thought to understand whether lobsters were producing buzzing sounds under different ambient noise levels, including heavy shipping noise. Acoustic masking was assessed when carapace vibrations were produced by lobsters but their associated waterborne buzzing sounds were not recorded by hydrophones due to higher shipping noise levels. Finally, we assessed whether the presence of shipping noise affected the temporal features of lobster buzzing sounds, and discussed the ecological relevance of masking for lobster acoustic ecology.

2 | MATERIALS AND METHODS

2.1 | Animal collection, characteristics and care

For these experiments, we used a total of 9 *H. gammarus* male individuals, with carapace lengths (CLs; measured from the eye socket to the posterior carapace margin for lobsters) between 12.5 and 15 cm (i.e. weights between 2.5 and 3.5 kg). One of these individuals was used for a preliminary sound recordings, and was not used for main experiments (see Section 2.3.1). Lobsters were collected carefully by hand while snorkeling in the Bay of Plougonvelin (Brittany, France) at water depths of between 1 and 10 meters in March and April 2019. We chose to experiment with exceptionnally large lobsters because we expected them to produce higher buzzing sound levels that could be recorded more easily underwater compared to smaller individuals, as it as been shown in spiny lobsters (Jézéquel et al. 2020b).

After capture, they were immediately transferred to an isolated, quiet room in the facilities of the Institut Universtitaire Européen de la Mer in plouzané (France). They were all sperated in 9 identical plastic rectangular tanks filled with 180 L of seawater. All holding tanks were continuously supplied with an independent flow-through seawater system with clean seawater pumped from the Bay of Brest. One air stone was provided in each holding tank to ensure high dissolved oxygen. Animal conditions were controlled twice a day. Animals were fed with defrostred pieces of fish (mackerel, mullet) and cephalopod (squid) *ad libitum*. They were kept under a 12:12 photoperiod, the daylight condition being simulated by one fluorescent light tube above the tanks. A large section of PVC drainage pipe was provided as shelter in each holding tank. Animals were acclimatized at least one month in these conditions before they were used in the experiments.

2.2 | Data Recordings

Sounds were recorded using two different calibrated and pre-amplified hydrophones with a flat response from 2 Hz to 50 kHz. We used two HTI-92-WB (High Tech Inc., USA): one with a sensitivity of -155 dB re 1 V μPa^{-1} to characterize low level lobster buzzing sounds, and one HTI-92-SIN (High Tech Inc., USA) with a sensitivity of -165 dB re 1 V μPa^{-1} to characterize high level shipping noise. Both hydrophones were connected and synchronized to a compact autonomous recorder (EA-SDA14, RTSys, France) with gains of 14.7 and 0 dB, respectively. Recordings were made with a sampling frequency of either 44 or 78 kHz at 32-bit resolution.

Lobsters produce buzzing sounds through rapid contractions of internal muscles located at the base of their antennae which cause the carapace to vibrate (Jézéquel et al. 2020a). We therefore added accelerometers on their dorsal carapaces as a means to detect these vibration events (i.e. the sound sources), independently of the hydrophones, using the procedure described in Jézéquel et al. (2020a). Briefly, One small AX-3 data logger (23 × 32.5 × 8.9 mm, mass: 11 g; Axivity Ltd. UK) was glued with 3-minute underwater epoxy to the dorsal carapace of each lobster, near the eye-sockets at the base of the second antennae (Figure 1A). Lobsters were tagged 24h prior the experiments to let them recover from handling. The accelerometers permitted us to validate the buzzing sounds production by lobsters and their detections by the hydrophones.

Video recordings were made during all experiments using one GoPro® HERO3 camera placed at one meter above the experimental cage. The videos were used to confirm the production of agonistic encounters by the lobsters during the experiments.

2.3 | Experiments

2.3.1 | Buzzing sounds recordings under natural and quiet ambiant noise levels

Prior to the agonistic encounter experiments, we recorded lobster buzzing sounds in a quiet area under a natural ambiant soundscape (i.e. without shipping noise) to ensure they could be detected underwater with our hydrophone. One large male lobster (CL = 13 cm) was tagged with an accelerometer device (see Section 2.2) and released underwater in the Bay of St Mathieu (48°20'01.7" N, 4°46'27.2" W) on the 4th October 2018 at a depth of 5 m while snorkeling to. Sound recordings were performed in late afternoon, between 6 and 7 pm, and no boat was present in the area at this .

First, the ambiant noise was recorded for 5 min. Then, the free-moving lobster was gently grasped by hand to imitate its catch by a predator to elicit its buzzing sound production (Jézéquel et al. 2018). The individual was handled underwater at around one m in front of the hydrophone and 50 cm above the substrate. This procedure was repeated five times and lasted 30 seconds per sequence.

2.3.2 | Experimental site description

The experimental site selected to observe agonistic encounters was located in the Bay of Saint Anne de Portzic (48°21'32.951" N, 4°32'59.024" W) in the bay of Brest (Brittany, France), just beneath the facilities of the IUEM where lobsters were held. It is a shallow sandy bottom with depths varying between 15 m during high tide and 9 m during low tide.

This site was chosen for two main reasons. First, previous observations while snorkeling revealed us the presence of lobsters on the rocky artificial dike located at 20 m from the experimental site; as a result the agonistic encounters we forced happened in a location where they naturally occur. Second, it was located at about 100 m outside a marina hosting 120 recreational boats. Thus, this small bay is expected to be highly affected by recreational shipping traffic, especially in spring when the experiments were performed.

2.3.3 | Agonistic encounters

The experiments were performed in May and June 2019 between 10 and 12 am, a time window particularly affected by shipping noise presence. One stainless steel cage (100 × 100 × 50 cm) was placed by two scuba divers on a flat sand floor in the site previously described. Then, the two hydrophones were placed at one meter from the cage on diagonal opposites and at 50 cm from the substrate. Two male lobsters tagged with accelerometers were separately transferred from their holding tanks to the experimental cage. Agonistic encounters in lobsters naturally occur as soon as two male individuals interact between each others (Figure 1B; Atema and Voigt 1995). Then, the two scuba divers returned to the support boat, which slowly (speed < 3 knots) reached a mooring buoy located at 50 m from the cage. The recordings started when the motor was shut down and lasted for one hour. After the experiments, the accelerometers were gently taken off from the lobsters and placed on the bottom of the cage. Then, ten sharp raps were made on the cage that could be used to synchronize all three recording devices (hydrophones, accelerometers and GoPros).

2.4 | Data analysis

The lobster carapace vibrations produce clear signals in the accelerometer data, with similar properties as the associated waterborne buzzing sounds: a frequency modulated signal with a frequency band ranging from ~55 to 180 Hz with a duration of ~200 ms (Jézéquel et al, 2020a). This signal is fully different from natural sources of vibration present in the environment, and thus carapace vibrations are simple to identify.

Data from the accelerometers were downloaded using the Open Movement GUI software (version 1.0.0.37). The x-axis data (i.e. along the animal body axis) was manually explored to detect lobster carapace vibrations, following the method from Jézéquel et al.

(2020a). Here, the carapace vibrations were used as a proxy of the buzzing sound production by the lobsters, and were compared with sound recordings. We also calculated the duration of each carapace vibration (in ms).

Sound recording files (.wav) from the two hydrophones (one hour each) were archived at the end of each experiment. They were first visualized over the entire frequency band by using the spectrogram mode in Audacity® (Version 2.1.1; Audacity Team 2015). This permitted us to check for the presence or absence of shipping noise, which usually caused substantial changes to the ambient noise levels and were easily detectable by both visual and aural inspections of spectrograms.

Next, spectrograms were vizualized between 0 and 500 Hz a second time to identify buzzing sounds using custom MATLAB scripts (Version 9.1; 2016b). The buzzing sound detection sequences were compared with the carapace vibrations recorded by the accelerometers following their synchronyzation. Sound recording sequences were cut into 1-min file sequences (60 sequences per recordings) and the sound pressure levels in root-mean-square (SPL_{rms}) were calculated over the 55-1000 Hz frequency band (SPL_{rms}[55-1000 Hz]). An increase in the SPL_{rms}[55-1000] of 6 dB was used to quantify the presence of shipping noise (Merchant et al. 2012). The presence of shipping noise was further confirmed by aural examination of the data, as commonly done in the bioacoustic literature (Kaplan et al. 2015, Dinh et al. 2018). Using these values, we also calculated lobster call rates by dividing the number of carapace vibrations per minute in presence and absence of shipping noise.

Signal-to-noise ratios (SNRs) were calculated as the difference in dB between the SPL_{rms} of the buzzing sound and ambient noise recorded in the two experimental sites. SPL_{rms} were calculated in the band of the buzzing sound (i.e. 55-180 Hz; Jézéquel et al. 2018) using the entire duration of each detected buzzing signal (~200 ms), while the SPL_{rms} for ambient noise in 500 ms snapshot preceding the buzzing sound detection. Ambient noise snapshots were all visually examined to ensure none contained interfering acoustic signal, such as broadband sounds.

2.5 | Statistical analysis

The sound temporal features are considered the most important cues for acoustic communication in the fish bioacoustic literature (Bass and McKibben, 2003, Picciulin et al. 2012). Here, we tested whether the temporal features of lobster buzzing sounds (i.e. call rates and buzzing sounds' durations) were significantly different in absence and in presence of shipping noise. Considering the small number of samples, and assuming that calculated variables for each individual can be assimilated to a random distribution, the non-parametric Mann-Whitney (MW) test was used to determine whether their call rates and buzzing sound durations were identical (significance level, $\alpha = 0.05$).

3 | RESULTS

During all experiments, the wind state ranged between 0 (calm) and 2 (light breeze) on the Beaufort scale, corresponding to speeds between 1 and 6 knots.

3.1 | Detection of the buzzing sounds in a low ambiant noise level

The ambiant noise recorded in the Bay of Saint Mathieu was mainly dominated by broadband transient sounds from unknown sources in the high frequency band from 1 to 2 kHz. Hence, the SPL_{rms}[55-1000 Hz] was low with a mean of 89 ± 0.6 dB re 1 µPa (Figure 2). During the five recording sessions, the handled lobster produced a total of 41 carapaces vibrations. The associated buzzing sounds were all (100%) detected by the hydrophone (Figure 3A, 3B), and the mean experimental SNR was 11.7 dB.

3.2 | Influence of shipping on ambiant noise levels at the experimental site

In absence of shipping noise, the mean SPL_{rms}[55-1000 Hz] of the ambient noise level in the experimental site was 102.3 ± 4 dB re 1 µPa. The difference in noise level with the Bay of Saint Mathieu was mainly due to the chains of nearby boats' buoys rubbing against the bottom, as well as the lobsters tapping against the cage walls during agonistic encounters. When these noises were not present, the SPL_{rms}[55-1000 Hz] decreased at 94.9 ± 0.6 dB re 1 µPa and the acoustic spectra showed similar levels compared to the Bay of Saint Mathieu (Figure 2).

During the four lobster agonistic encounters, shipping noise was audible and visible in the spectrograms from 171 out of the 240 1-min long sound sequences (71%). This corresponded to an increase in both SPL_{rms}[55-1000 Hz], with a mean of 118.4 ± 7.7 dB re 1µPa, and acoustic spectra (Figure 2). The contribution to the increase in SPL_{rms}[55-1000 Hz] depended on the distance of the boats according to the experimental cage (Figure 2). For example, during an experiment, one large vessel (used for scallop farming) navigated at 10 meters from the experimental cage, and the maximum SPL_{rms}[55-1000 Hz] reached 146.2 dB re 1µPa (Figure 2).

3.3 | Buzzing sounds produced during lobster agonistic encounters

The video data showed that all 8 lobsters exhibited agonistic encounters during the experiments, even when shipping noise was present (see Figure 1B). During these four different agonistic encounters, the 8 lobsters produced a total of 294 carapace vibrations (as recorded using the accelerometers), which were mostly produced in the presence of shipping noise (93%).

In absence of shipping noise, 10 buzzing sounds out of the 22 carapace vibrations (45 %) were recorded by the hydrophone (Figure 3C, 3D), with a mean SNR of 5.5 dB. This difference in SNR value with the Bay of Saint Mathieu was mainly attributed to a higher ambient noise levels recorded in the experimental site. In marked contrast, in the presence of shipping noise, only 22 buzzing sounds from the 272 carapace vibrations (8 %) were recorded by the hydrophone (Figure 3 E, F), suggesting a potential masking effect (Figure 3 G, H). These 22 buzzing sounds were detected when shipping noise levels were low, with a mean SNR of 4.5 dB.

Finally, lobsters significantly increased their call rates in presence of shipping noise compared to when shipping noise was absent (mean of 1.5 and 0.3 carapace vibrations per minute, respectively; MW, $p < 0.001$). However, the durations of the buzzing sounds in presence and absence of shipping noise were similar (MW, $p > 0.05$).

4 | DISCUSSION

To our knowledge, this field study is the first to highlight the potential masking effect of shipping noise on the acoustic communication of a marine crustacean. Indeed, while all lobsters engaged in agonistic encounters and produced many carapace vibrations, only 8% of the associated buzzing sounds were detected when shipping noise was present. This result raises new concerns about the potential effects of such a chronic noise on lobster acoustic behaviours.

Because no other studies are available on marine invertebrates, we chose to compare our results with the fish bioacoustic literature. To date, most of fish studies have assessed masking of biological sounds from shipping noise either in tanks or in the field using playbacks (e.g. Vasconcelos et al. 2007; Codarin et al. 2009) or when animals were exposed before and after to the noise (e.g. Picciulin et al. 2012; Mackiewicz et al. 2021). However, none of those studies used a tag (or any other technological solution) to assess the fish sound production during shipping noise. Hence, this leaves the following question unanswered: are animals still vocally active in the presence of anthropogenic noise, or do they stop emitting sounds?

While marine mammals produce high sound levels that can be detected even in presence of anthropogenic noise (e.g. Lesage et al. 1999), this is not the case for fish and marine invertebrates (including lobsters) producing lower sound levels. To circumvent this issue, it is necessary to add other recording devices that can record directly the sound sources, i.e. through the animal body vibrations. Here, we used small accelerometers glued on lobsters' carapaces, which aimed to record their vibrations when they produced buzzing sounds. The same recording device was already used in our previous study, and permitted us to counter the high attenuation of the buzzing sounds produced by lobsters during agonistic encounters in an experimental tank (Jézéquel et al. 2020a). In the present study, the accelerometers allowed us to detect the production of buzzing sounds by lobsters even when they were masked by shipping noise and thus could not be recorded by the hydrophone (Figure 3).

Acoustic masking is defined as a psychophysical measure quantifying the change of sound perception due to the presence of another sound (i.e. anthropogenic noise; Reviewed in Erbe et al. 2016). For example, it is relatively standard for marine mammals perceiving sound pressure to estimate masking from decrease in in-band SNRs by incorporating temporal and spectral integration of the auditory system (Jensen et al. 2009). Here, we recorded both lobster buzzing sounds and shipping noise using hydrophones, thus the difference in SNR was assessed in sound pressure (see Results). Since marine invertebrates mostly rely on particle motion rather than pressure (Popper and Hawkins 2018), further studies are now required to assess lobster capacities to detect buzzing sounds when shipping noise is present through the quantification of particle motion SNR.

Masking of biologically import sounds often results in a vocal compensation due to the reduction of intraspecific communication, which increases the energy consumption of marine animals, and can have long term detrimental effects on their reproductive success. For example, marine mammals have been found to sing longer songs (Miller et al. 2000) and even increase their call levels (Holt et al. 2009) when exposed to shipping noise. After repetitive shipping noise exposures, brown meagres increased their vocalization rates (Picciulin et al. 2012). Interestingly, we also found that lobsters produced five times more carapace vibrations in presence of shipping noise, which result suggests a vocal compensation due to acoustic masking of buzzing sound by shipping noise.

Lobster acoustic behaviour has received little attention within the bioacoustic litterature. To date, buzzing sounds have been shown to be used for both inter- and intraspecific communication. First, lobsters use sounds to deter fish predators (Watson et al. 2011). Hence, acoustic masking could alter lobsters' ability to deter predators, increasing their risks of predation. Secondly, male lobsters produce sounds towards conspecifics, likely to assess dominance statues during agonistic encounters (Jézéquel et al. 2020a). The ability to recall the outcome of past encounters help individuals to avoid additional fights, lowering their future risks of injury (Atema and Voigt 1995). Agonistic encounters are a crucial behaviour in lobsters as only male dominants gain access to females during the reproduction (Atema and Voigt 1995). Thus, if a lobster cannot detect the sounds produced by a nearby conspecific, it may use more energy to perform additionnal fights to assess dominance statues, which could affect lobster reproduction, as it has been shown in fish (de Jong et al. 2018). It is to note that the acoustic behaviours of both juvenile and female lobsters are not known yet.

Theoretically, lobster acoustic communication may occur only within short distances (i.e. less than few meters; Breithaupt 2002), similarly to fish species (Ladich 2013). Considering their low levels and frequency contents, lobster buzzing sounds can likely be masked by higher shipping noise levels that occur in the same frequency band (see Figure 2). Most of the shipping noise recorded during our experiments corresponded to small recreationnal boats. However, large commercial ships are known to produce higher noise levels, with noise propagating over kilometers underwater (Duarte et al. 2021). These large commercial ships will dramatically increase in the next decade (Kaplan and Solomon 2016). The Iroise Sea where the present study was performed is an important transition zone for commercial ships, representing a heavy shipping noise area (Kinda et al. 2017). Hence, there are clear concerns about their high potentials to mask lobster acoustic communication in this area.

5 | CONCLUSION

This study provides first insights about the potential masking effects of a chronic anthropogenic noise on the acoustic communication of lobsters. In the presence of shipping noise, lobsters tended to increase their call rates, suggesting a vocal compensation due to acoustic masking of their buzzing sounds. However, lobster hearing abilities toward their buzzing sounds and shipping noise are now required to fully assess this acoustic masking effect. We also highlight the importance of evaluating anthropogenic activities on coastal marine invertebrates, an ecologically important but yet understudied group.

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CONFLICTS OF INTEREST

The authors declare no competing interests.

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FIGURE CAPTION

Figure 1: Photos from field experiments showing a large tagged male lobster with an accelerometer (A), prior engaging in agonistic encounters with another conspecific despite the presence of shipping noise at the same time (B). White arrows indicate the location of the accelerometers. © Erwan Amice.

Figure 2: Acoustic spectra (55 – 1000 Hz) of the two ambient noise levels (1-min each) recorded in the Bay of Saint Mathieu (grey) and in the Bay of Saint Anne du Portzick (black) without anthropogenic noise. Several shipping noises were recorded during the experiments passing at different distances from the cage: a fishing boat passing at ~1 km (magenta), a recreational boat getting into the marina of Sainte Anne du Portzic at ~100 m (green), and a large boat from scallop farming navigating just above the experimental cage at ~10 m (red). The *x*-axis is in logarithmic scale. PSD: power spectral density (calculated with the pwelch function). Note that the presence of shipping noise increased the noise level in the same frequency band as lobster buzzing sounds (i.e. 100-200 Hz).

Figure 3: Synchronized data of accelerometers (A, C, E, G) placed on lobster carapaces and the hydrophone (B, D, F, H) during different recordings in the Bay of Saint of Saint Mathieu (A, B), and in Saint Anne du Portzic without shipping noise (C, D) with low shipping noise level (E, F) and with high shipping noise level (G, H). The red arrows highlight the carapace vibrations and the associated buzzing sounds. The horizontal color bar scales of the spectrograms are in dB re. 1 μPa^2 Hz^{-1}. Note that when shipping noise level was high (i.e. boat passing near the experimental cage), lobsters still produced carapace vibrations during agonistic encounters (G), but the associated buzzing sounds could not be recorded by the hydrophone (H), showing a potential masking effect. The horizontal color bar scales of the spectrograms are in dB re. 1 μPa^2 Hz^{-1}.

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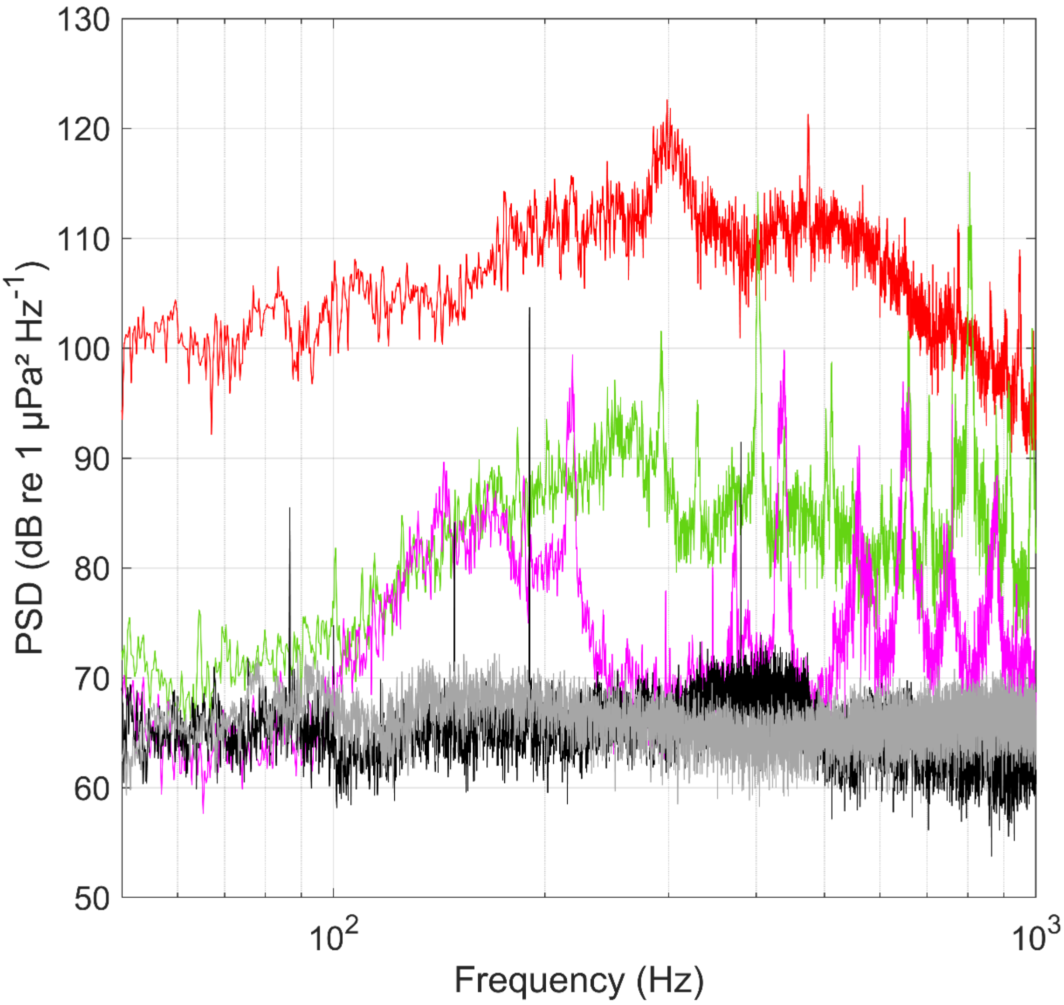

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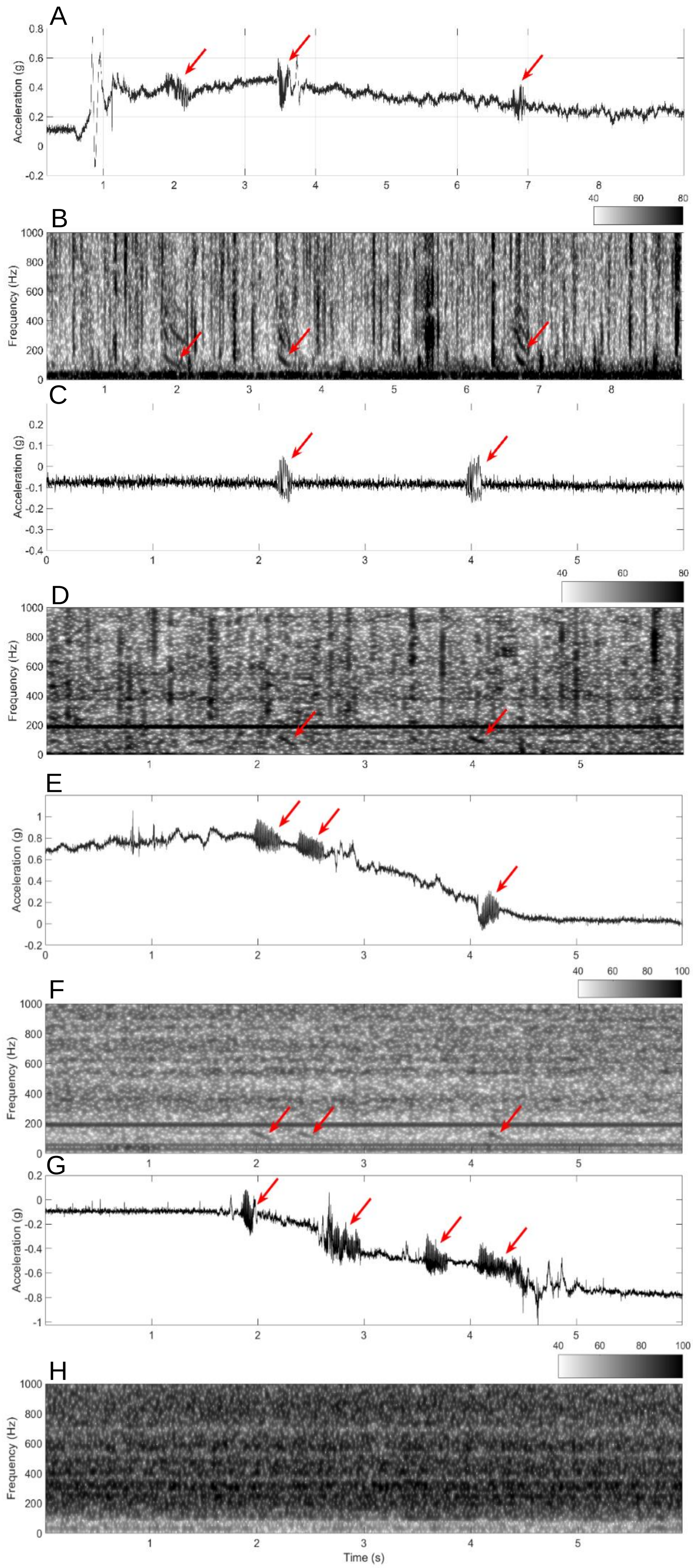
A
B
C
D
E
F
G
H
Acceleration (g)
Frequency (Hz)
Time (s)

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