

ASSESSING EFFECTS OF INCREASED NOISE LEVELS ON FISH BEHAVIOUR

Irene Voellmy¹

University of Bristol
School of Biological
Sciences, Woodland Road,
Bristol, BS8 1UG, U.K.

Julia Purser

University of Bristol
School of Biological
Sciences, Woodland
Road, Bristol, BS8 1UG,
U.K.

Stephen Simpson

University of Exeter
Geoffrey Pope Building,
Biosciences, College of
Life and Environmental
Sciences, Stocker Road,
Exeter, EX4 4QD, U.K.

Andrew Radford

University of Bristol
School of Biological
Sciences, Woodland Road,
Bristol, BS8 1UG, U.K.

ABSTRACT

Man-made noise can affect physiology and behaviour of animals of all taxa, including fish. However, there is not much known about effects of increased noise levels on anti-predator and foraging behaviour, which are both essential for survival and reproduction. In our laboratory study, we investigated effects of increased noise levels on these behaviours in two sympatric fish species, three-spined sticklebacks (*Gasterosteus aculeatus*) and European minnows (*Phoxinus phoxinus*), which differ in their anti-predator defences and likely in their hearing capabilities. Our study indicated that both behavioural contexts were affected by increased noise levels, but effects differed between species. Sticklebacks responded to a visual predatory stimulus sooner when exposed to additional noise playbacks than in control conditions, whereas minnows were not affected by the noise treatments. In foraging experiments, both fish species consumed fewer water fleas, but the reasons fish decreased food consumption seemed species specific: sticklebacks increased the number of foraging errors, whereas minnows tended to decrease their foraging effort by interacting socially more often and more individuals were inactive during increased noise level conditions. To allow for controlled comparative experiments, our studies were conducted in the laboratory. Complementary field experiments ensuring natural acoustic conditions will be necessary to investigate whether species differences can translate into community effects and whether these effects differ between different kinds of noise, such as drilling, pile driving and energy device operation noise. Expanding research to commercially important fish and quantification of particle motion in addition to sound pressure as most fish, and likely invertebrate species, perceive particle motion rather than sound pressure, would further deliver valuable knowledge for industry, policy makers and fisheries managers about how marine renewable energy devices may interfere with the marine environment.

INTRODUCTION

Growing numbers of human activities in marine areas, including the use of marine renewable energy

devices, have increased the necessity to investigate the environmental impact and to consider sustainable ways to interact with our environment [1]. One aspect of potential negative interference is noise emitted by human activities [2]. A growing body of studies has shown that man-made noise can affect physiology and behaviour of animals of all taxa [1, 3]. To date, the majority of behavioural studies examining effects of noise emitted by human activities have focussed on acoustic communication and movement patterns, which can be difficult to translate into ultimate fitness consequences [3, 4]. Moreover, most studies considered only a single species, even though marine organisms are highly diverse. In this laboratory project, we investigated whether increased noise levels affect anti-predator and foraging behaviour of two sympatric fish species [5], which differ in their anti-predator defences and likely in their hearing capabilities: three-spined sticklebacks (*Gasterosteus aculeatus*) and European minnows (*Phoxinus phoxinus*). Effects of additional noise levels were tested in the contexts of anti-predator and foraging behaviour, because any impacts of increased noise levels could lead to fitness consequences. Fish species possessing body armour have been shown to remain longer in exposed feeding locations, initiate predator avoidance behaviour at shorter flight distances and hide less often and for shorter time periods than fish without body armour [6-8]. Moreover, species can vary in their response and sensitivity to stressors [9], and thus most likely to danger in general. Since sticklebacks possess body armour, in contrast to minnows, minnows may show more risk-adverse [10], and thus more stress-related behaviour in general. Additional noise treatments may thus have greater impacts on minnows than on sticklebacks. If species differ in hearing capabilities, and thus perception of noise treatments, this may also cause species differences in behavioural responses to noise treatments.

METHODOLOGY

Noise playback preparation

Recordings from eight different cargo ships from three British harbours were used for playbacks of additional noise. For anti-predatory experiments, playbacks for control conditions were created in addition from nine different recordings of ambient

¹ Corresponding author: Irene.Voellmy@bristol.ac.uk

noise without passing vessel noises at the same sites (see [11] for details). For foraging experiments, silent tracks were created as control playbacks (see [12] for details). Sound tracks were played back using an underwater loudspeaker as wav files through an Aqua30 underwater loudspeaker (Aqua30 DNH; effective frequency range 80–20 000 Hz) positioned behind opaque tank partitions (width: 4mm) out of sight of the fish (see [11, 12] for more details).

Anti-predatory experiment

Trials were conducted in a 150 x 30 cm glass tank (water depth: 25 cm; wall thickness: 4 mm). A seagull model was used as predatory stimulus and presented during playback of recordings of either ambient noise with no ship traffic (ambient-noise treatment) or of an individual ship passing (additional-noise treatment). Each fish (35 sticklebacks and 27 minnows) was tested twice in a repeated-measures design (one for each sound treatment). Each trial series was separated by at least 30 min. Noise treatments were randomly assigned to a trial series in counterbalanced order. Each experiment involved a familiar companion fish in addition to the focal fish placed in an adjacent tank section to minimise adverse responses to the experimental procedure. The response of the focal animal to the predatory stimulus was digitally video-recorded (Sony Handycam HDR-XR155E at 25 frames per second). Response latency (time elapsed between release of the predatory stimulus to first response) of the focal fish was assessed from the videos with randomly assigned identification numbers and muted sound (see [11] for details).

Foraging experiment

Experimental trials were conducted in a 10 l plastic tank (34 x 20 cm; water depth: 16 cm; wall thickness: 2 mm) and followed the protocol of [13]. Each trial lasted for five minutes during which either additional noise or silent control playbacks were played. Every 20 s, live *Daphnia magna* were delivered singly using a plastic Pasteur pipette. Fish received only one trial (either additional noise or silent playback) in an independent-measures design (15 sticklebacks tested in additional noise treatment, 14 sticklebacks in silent control treatments, 14 minnows tested in each noise treatment, respectively). For every trial, a companion fish was transferred into a mesh cylinder in the centre of the test tank (ca. 7 cm in diameter), to minimise adverse responses of the focal fish to the experimental setup. Focal fish were allowed to move freely in the test tank (see [12] for details).

For each trial, the following data were recorded from the focal fish (definitions following [13]): 1) Feeding behaviour: number of strikes directed towards *Daphnia* and non-food items (movements directed towards an object while expanding mouth) and numbers of *Daphnia* consumed. Since *Daphnia* were delivered manually, more than one *Daphnia* were sometimes produced per feeding event

resulting in slightly different amounts of total food available between trials, the proportion of consumed *Daphnia* versus total available *Daphnia* was calculated. To assess foraging errors, the number of unsuccessful feeding attempts was calculated by the sum of (a) strikes towards *Daphnia* not resulting in their consumption and (b) strikes towards non-food items. 2) Stress-related behaviour: number of events of inactivity (when the focal fish ceased moving). 3) Social behaviour: for minnows, events of social interaction behaviour (focal fish swimming in close proximity to the separating cylinder oriented towards the companion fish) were recorded in addition, whereas sticklebacks rarely exhibited this behaviour ([13]; IKV, personal observation).

RESULTS

Anti-predatory experiment

There was a significant difference how noise treatments affected response latency depending on fish species. Minnows were not significantly affected by noise treatment, whereas sticklebacks responded significantly sooner to the predatory stimulus during additional noise treatment than during control conditions (see [11] for details).

Foraging experiment

Feeding behaviour

Both species consumed a significantly lower proportion of *Daphnia* during playbacks of additional noise than during control conditions (see [12] for more details). However, the effect of noise treatments on the number of strikes performed against food and non-food items differed between the two species: minnows tended to show less strikes during playbacks of additional noise than during silent controls, whereas sticklebacks did not change the amount of strikes in response to noise treatments (see [12] for more details). The effect of additional noise on number of foraging errors (strikes resulting in missed or loss of *Daphnia* and strikes against non-food items) showed a strong tendency to differ between species: sticklebacks tended to perform more unsuccessful strikes during additional-noise playbacks than in silent control conditions, while minnows were not significantly affected by noise (see [12] for more details).

Stress-related and social behaviour

Effects of noise treatments on inactive behaviour differed between species: more minnows were inactive during additional-noise playbacks than in silent control conditions, whereas the number of inactive sticklebacks was not significantly affected by noise treatment. Minnows also showed a tendency to interact socially more often with their companion fish during additional-noise playbacks compared to silent controls (see [12] for more details).

CONCLUSIONS

Our study showed that different behavioural contexts can be affected by increased noise levels, but effects can vary between species and behavioural

contexts. When exposed to additional noise playbacks, sticklebacks showed decreased latencies to respond to a visual predatory stimulus compared to control conditions, whereas noise treatments had no effect on minnow anti-predator responses. In foraging experiments, both fish decreased food intake, but underlying mechanisms seemed to depend on species: while sticklebacks increased the number of foraging errors, minnows tended to interact socially more often and spent more time inactive, decreasing foraging effort. Since these experiments were conducted in the laboratory to ensure detailed behavioural observation and high levels of experimental control, but not representing natural acoustic conditions, it needs to be shown in complementary field experiments whether these species differences will translate into species-specific susceptibilities to noise exposure and ultimately to changes on population and species community levels. In order to move forwards and to deliver important information for industry and policy makers working in the renewable energy sector, a number of additional research issues need to be addressed. Different kinds of man-made noise, such as drilling, pile driving and energy device operation noise vary substantially in intensity and duration [2]. Thus, it is important to investigate whether these noise variations translate into different effects in animals. Assessment of minimum noise levels eliciting effects in organisms is also needed to evaluate spatial extents of potential interference with wildlife. For fisheries industries, research should be extended to investigating effects on economically important fish species, such as salmon, eel, trout, seabass, cod or haddock. Most fish mainly perceive particle motion, but only some perceive sound pressure [1]. Thus, measures of particle motion should be included to assess actual sound levels experienced by fish species of interest in most cases. We think that with this combined approach, valuable insights can be generated for industry, policy makers and fisheries managements to assess and ultimately minimise potential interference of the emerging marine renewable energy industry with the aquatic environment.

ACKNOWLEDGEMENTS

We are grateful to Meesh Cole for fish care, Innes Cuthill for statistical advice, Sophie Holles, Tony Hawkins, Paul Lepper, Michael Ainslie and members of the Bristol Bioacoustics and Behavioural Ecology group for invaluable discussions, and Daniel Robert and Neil Metcalfe for manuscript comments. IKV was supported by the University of Bristol and Basler Stiftung für Biologische Forschung; JP, SDS and ANR received funding from Defra, IKV and SDS from NERC.

REFERENCES

[1] Normandeau Associates Inc. (2012) Effects of noise on fish, fisheries, and invertebrates in the U.S. Atlantic and Arctic from energy industry sound-generating activities. A literature synthesis for the

U.S. Dept. of the Interior, Bureau of Ocean Energy Management. Contract # M11PC00031. pp. 153.

[2] Popper AN and Hastings MC (2009) The effects of human-generated sound on fish. *Integrative Zoology* 4: 43-52.

[3] Morley EL, Jones G and Radford AN (2014) The importance of invertebrates when considering the impacts of anthropogenic noise. *Proc R Soc B* 281: 20132683.

[4] Read J, Jones G and Radford AN (2014) Fitness costs as well as benefits are important when considering responses to anthropogenic noise. *Behav Ecol* 25: 4-7.

[5] Joint Nature Conservation Committee and Centre for Ecology and Hydrology (2011) National Biodiversity Networks Gateway Interactive Map. Available at: www.data.nbn.org.uk. Last accessed: 2 May 2013.

[6] Abrahams MV (1995) The interaction between antipredator behaviour and antipredator morphology: experiments with fathead minnows and brook sticklebacks. *Can J Zool* 73: 2209-2215.

[7] Krause J, Cheng DJS, Kirkman E and Ruxton GD (2000) Species-specific patterns of refuge use in fish: the role of metabolic expenditure and body length. *Behaviour* 137: 1113-1127.

[8] McLean EB and Godin J-GJ (1989) Distance to cover and fleeing from predators in fish with different amounts of defensive armour. *Oikos* 55: 281-290.

[9] Pottinger TG (2010) A multivariate comparison of the stress response in three salmonid and three cyprinid species: evidence for inter-family differences. *J Fish Biol* 76: 601-621.

[10] Hoogland R, Morris D and Tinbergen N (1957) The spines of sticklebacks (*Gasterosteus* and *Pygosteus*) as means of defence against predators (*Perca* and *Esox*). *Behaviour* 10: 205-236.

[11] Voellmy IK, Purser J, Simpson SD and Radford AN (In review) Increased noise levels have contrasting impacts on anti-predator behaviour in two sympatric fish species. Last draft: 18 March 2014.

[12] Voellmy IK, Purser J, Flynn D, Kennedy P, Simpson SD, et al. (2014) Acoustic noise reduces foraging success via different mechanisms in two sympatric fish species. *Anim Behav*: In press.

[13] Purser J and Radford AN (2011) Acoustic noise induces attention shifts and reduces foraging performance in three-spined sticklebacks (*Gasterosteus aculeatus*). *PLoS ONE* 6: e17478.