ACOUSTIC COMMUNICATION IN A NOISY UNDERWATER WORLD: INSIGHTS FROM THE INTERTIDAL ROCK-POOL BLENNY

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Far from '*The silent world*' described by Cousteau & Dumas in 1953 [1], the underwater world is in fact rather noisy. Rasping fish, snapping shrimps, and echo-locating whales all add to the drone of wind, waves, and water currents and the whirling whoosh of tidal movements [2]. In addition, over the last century, anthropogenic noise has invaded almost all aquatic environments and typically adds significant power to overall ambient noise levels [3, 4]. The already historical but still growing presence of a continuous hum of accumulating motorized vessels are more and more accompanied by extreme sound pulses. Seismic air guns used for geological surveys, pile-driving in and around the water, and sonar for sub-bottom profiling and seabed scanning have changed the underwater soundscape dramatically. Offshore windmill parks are just another recent addition to the human-generated cacophony.

We are slowly becoming aware of the potential impact of noise above water [5], but natural and anthropogenic noise may have particularly dramatic impact on animal life under water [6, 7]. Noise may be categorized into relatively short, but very loud sounds that may harm, distress, and even kill animals, and more continuous, but moderate sounds that may disturb and interfere with natural behaviour. In this paper, we focus on the latter category and address the impact of ubiquitous but moderate noise levels on fish. It is therefore necessary to first consider the importance of sounds and hearing in the life of fish in general.

Sounds and hearing can be critical to fish survival and reproduction in a variety of ways (Figure 1). Biologically relevant sounds may concern sounds made by conspecifics or biotic or abiotic sounds from the environment. Many species of fish communicate with calls during aggressive interactions and courtship [8, 9, 10]. Sounds produced in distressful events may warn group members or startle potential predators [11]. Acoustic cues are also likely to be exploited by predators to localize and chase prey, while prey can depend on the same modality to detect and avoid predators. Furthermore, all sound events and more continuous sound gradients present in water may be helpful in guiding aquatic animals to places of interest for feeding, hiding, or reproducing [6, 12]. Fish larvae may for example respond phonotactically to sounds of snapping shrimps, which indicate the presence of suitable reef habitat, a behaviour covered by the phenomenon labelled as 'soundscape orientation' [13].

Noisy conditions make auditory perception of biologically relevant sounds more difficult [14]. Therefore, masking noise may have fitness consequences that can affect individuals and populations. Fish species that have evolved communicative sounds, hunting or localizing strategies, complete with the required perceptual sensitivity, may find themselves lost when their traditional habitat has gone through a rapid acoustic make-over with all sorts of artificial sounds. A better understanding of communication in fish under naturally fluctuating noise conditions may shed light on the detrimental potential of anthropogenic noise pollution.

We studied acoustic communication in the rock-pool blenny, *Parablennius parvicornis*, on the rocky shores of Faial, one of the central, volcanic islands of the Azores, Portugal (Figure 2). Nest-guarding male blennies produce calls which are allometrically related to their body size, and therefore could affect female mate choice decisions [10]. We investigated the female response to male vocalisations and the potential for noise interference in the temporal and spectral domain due to incoming waves throughout the tidal cycle [15]. Males called at the moment of female entrance, or shortly after, and calling sometimes continued in the following period, in which the female could stay for a variable amount of time. Males were not always calling when a female entered their burrow: we recorded one or more male calls in only about a third of all female visits. These visits with calls were distinct in terms of female behaviour. Females stayed much longer with calling males as compared to silent males. More importantly: we confirmed egg deposition in four out of 11 visits with male calls, but only once out of 28 visits without male calls [15].

We collected ambient noise recordings at several locations in the rock-pool breeding sites of the Azorean blennies [15]. Sampling throughout tidal cycles revealed dramatic spatial and temporal variation in noise levels. Most energy was in the lowest frequencies, which effectively overlaps with the peak frequency of male vocalisations. Blenny calls can be heard up to a distance of approximately 25 cm under optimal noise conditions. This audible range drops quickly to a few or zero cm under the extreme noise conditions of spectrally overlapping tidal water turbulence. This means that blenny vocalisations are not suitable for 'long distance' communication for an important period of the day: during upcoming high tide, which coincides with the influx of new gravid females into the pool. This may have affected the typical occurrence of acoustic activity in this species. Unlike in the closely related gobies [16, 17], male blennies seem to produce calls exclusively to stimulate females to spawn when they are already at very close range, entering or within their burrow. No calls are produced to attract females over a longer distance, and depending on the tidal cycle, chances would be high that masking noise would render them inaudible anyway.

We hypothesize that restrictions on acoustic communication due to ambient noise during potentially critical periods in the life cycle, such as suggested by the blenny case, may apply to many other fish as well. Furthermore, in the context of noise pollution, fish species that live, feed or reproduce in historically silent backwaters can be severely hampered by invasive anthropogenic noise in a similar way. Generally speaking, still too little is known for too few species about the use of sounds and its importance for survival of individuals. The same is true for the negative impact of noise pollution on population health. We need more investigations into many aspects, for example into the human-activity related noise cycles (daily and seasonal) and the overlap between periods of high masking potential with acoustically critical periods for fish. We are aware of the fact that benefits to the economy go often at the expense of ecology. And we can only dream of the more *Silent world* under water of the old days. Nevertheless, we think it is important that we at least assess the ecological price that we pay for our noisy economy.

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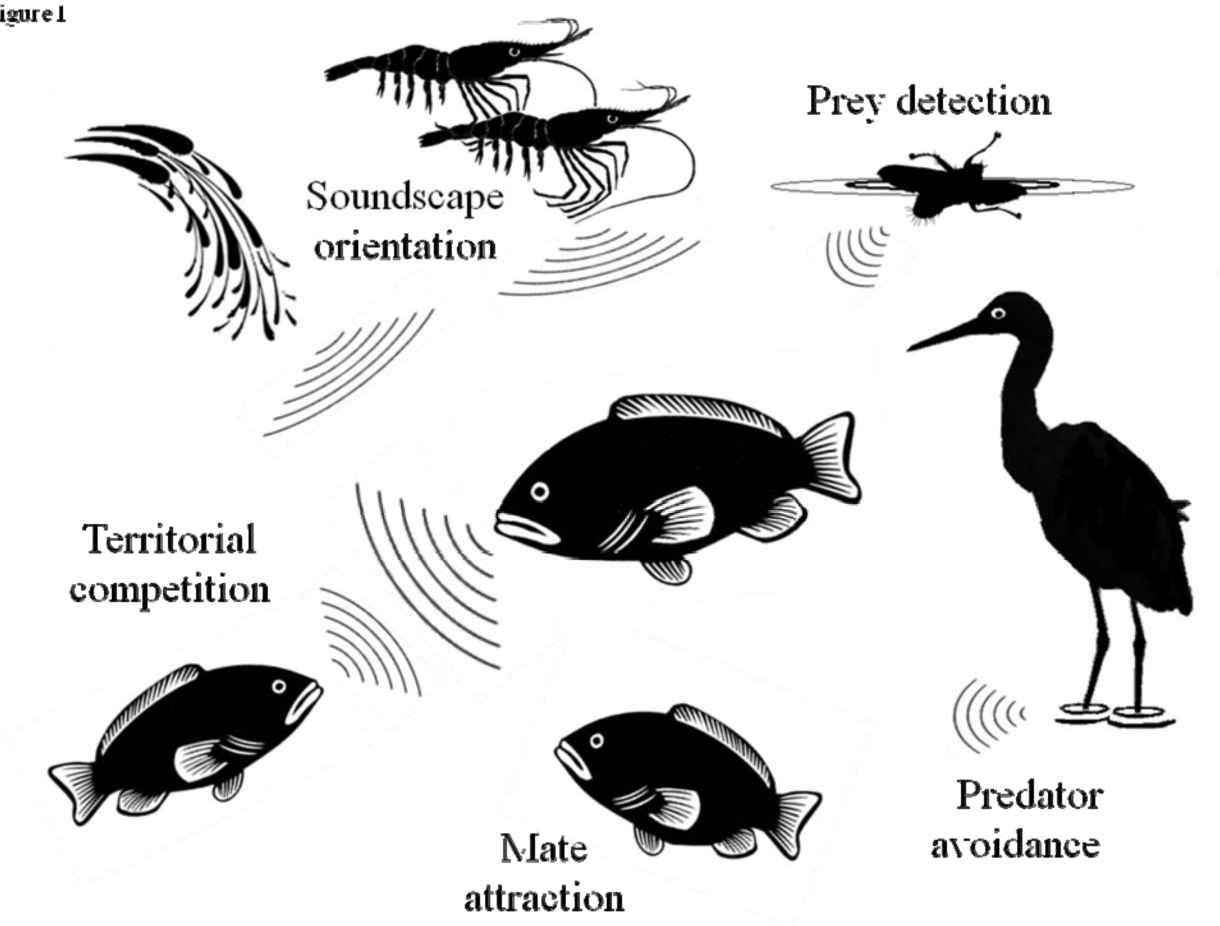
Figure 1. Schematic representation of sound use by fishes. A limited number of fishes is capable of producing sounds, but for virtually all fishes sounds are critical for survival and reproduction. Calls may play a role in agonistic interactions, and may affect mate choice decisions based on female eavesdropping on male-male interactions or based on calls generated in association with male courtship displays. Abiotic (e.g. waterfall, top-left) and biotic (e.g. snapping shrimps) sound sources may provide cues for soundscape orientation, while sounds probably also play a dominant role in many predator-prey interactions.

Figure 2. A map with the geographic location of the Azores in the Atlantic Ocean, in which the arrow depicts the research area on the island of Faial. The pictures concern a portrait of the rock-pool blenny, *Parablennius parvicornis*, and its rocky-shore habitat, exposed to a noisy surf (left), while rock pool breeding areas can be quiet at low tide (right).

Figure 1



Prey detection
Soundscape orientation
Territorial competition
Predator avoidance
Mate attraction

Figure 2


PORTUGAL
AZORES
CORVO
FLORES
GRACIOSA
SÃO JORGE
TERCEIRA
FAIAL
PICO
SÃO MIGUEL
AZORES
SANTA MARIA