**Animal communication in a human-dominated world: a comment on Radford et al.**

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Humans have caused widespread changes to environments worldwide. Such changes can impair animal communication by interfering with every stage of the communication process—from the way signals are produced and transmitted through the environment to how they are perceived and evaluated by receivers (Rosenthal and Stuart-Fox 2012). Critically, due to the pervasive nature of anthropogenic disturbance, few (if any) of the sensory modalities used by animals to communicate are likely to be immune. Changes that affect communication, in turn, can profoundly impact on animal reproduction and survival because of the vital role communication plays in mediating behaviors, such as foraging, predator avoidance, and mate selection (Candolin and Wong 2012). Not surprisingly, there has been considerable interest in trying to understand how human-induced environmental changes affect animal communication. Yet, despite this, much of our research attention remains focused narrowly on only a handful of taxa and sensory modalities. As a result, significant knowledge gaps remain. Radford et al. (2014) provides a timely reminder of why a more expansive approach is warranted.

**BEYOND BIRDS**

In the context of human disturbance and acoustic communication, most of what we know has come from studies carried out in terrestrial environments, with a heavy emphasis on birds and, to a lesser extent, frogs. In aquatic environments, studies have focused largely on marine mammals. However, as Radford et al. (2014) point out, many species of fish also use sound to communicate with each other. Indeed, the use of acoustic signals may be far more widespread in fish than is currently appreciated (Slabbekoorn et al. 2010). Thus, like birds, frogs, and marine mammals, acoustic communication in fish is also susceptible to anthropogenic noise and other human disturbances (Slabbekoorn et al. 2010; van der Suijs et al. 2011). Unfortunately, detailed empirical studies of anthropogenic impacts on acoustic communication in fish are desperately lacking. Given the dearth of research, work on other taxa can certainly help provide insights and inform the kinds of questions that need to be addressed (Slabbekoorn et al. 2010; Radford et al. 2014). However, taxonomic differences in the mechanisms of sound production and detection, as well as differences in the transmission properties of sound in water and air, mean that the impacts of anthropogenic noise may not always be directly comparable. For instance, sound is able to travel further at higher amplitudes in aquatic environments, which has implications for acoustic communication—as well as the potential for anthropogenic noise to affect organisms at longer distances—in aquatic environments (Slabbekoorn et al. 2010). Such differences underscore the necessity for more direct testing of anthropogenic impacts in taxonomic groups that have, to date, been largely neglected.

**AND A BIT MORE SENSE**

Another important challenge will be to overcome our own sensory predilections. To date, researchers interested in understanding the effects of human disturbance on animal communication have focused almost exclusively on visual, acoustic, and olfactory communication at the expense of other sensory modalities and their interactions (Rosenthal and Stuart-Fox 2012). Such a narrow approach can severely underestimate the impact of human activities on animal communication (Heuschele et al. 2009; Candolin and Wong 2012). Not only do many animals communicate using sensory channels that are dissimilar to our own (e.g., electrocommunication), but even in cases where the same sensory modalities are employed, perceptual abilities are often strikingly different (e.g., capacity to see ultraviolet signals or hear infrasound). Yet, despite all this, our knowledge of how such systems are affected by anthropogenic change remains rudimentary. Because communication typically involves multiple sensory modalities, impairment of any one (or combination) of these can have largely unexplored and underappreciated effects that are likely to depend on environmental context, the relative importance of the different sensory modalities, and the information being communicated (Candolin and Wong 2012; Rosenthal and Stuart-Fox 2012; Radford et al. 2014). Future advancements, in this regard, will require a research effort that is better informed by sensory ecology and far less encumbered by our own perceptual biases (Lim et al. 2008).

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**Fish struggle to be heard—but just how much fin waving is there? A comment on Radford et al.**

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Anthropogenic noise is an issue of growing concern for conservation (Brumm 2010; McGregor et al. 2013) but compared with other
vertebrates, very little is known about the effects of noise pollution on acoustic communication in fishes. In their review, Radford et al. (2014) have made a strong case for the need for more studies on the effects of human-made noise on fish communication, and I second this call. In addition, I would like to add a few points that I feel may be relevant for the further study of this topic and I will stress some issues that the target article only briefly addresses.

The question of whether or not fish can compete with anthropogenic noise is indeed a pressing one. Before one tries to answer this question, however, it might be prudent to first find out just how much competition with noise fish actually face, or in other words, how much of a problem is noise pollution for fish communication?

I completely agree with Radford et al. (2014) that more controlled, systematic experiments are needed—a plea that has been raised repeatedly for more than 10 years (e.g., Popper 2003; Fay and Popper 2012; Ladich 2013). In particular, there is a major lack of field experiments addressing acoustic communication in fishes, which makes it difficult to assess whether or not noise pollution impairs signal exchange in this group of animals. But even if such an impairment can be established, the crucial question is: how much does it matter? In terms of conservation, the answer to this question hinges on the function of the particular signals, and especially whether these signals are obligate for reproduction, and thus whether successful signal exchange will affect fitness and ultimately population dynamics.

COMMUNICATION DISTANCES

It is important to bear in mind that the active space of sounds produced by fishes is much smaller than that of most other vertebrates. This has important implications for the potential effects of noise pollution on fish communication. Many fishes only exchange acoustic signals over distances of less than 1 m and, in many cases, probably only over a distance of a few centimeters (reviewed in Ladich 2013). If these short communication ranges are mainly determined by low source amplitudes, then anthropogenic noise rising above ambient noise will indeed further reduce communication distances. In this case, putative changes in signal structure or performance, as described by Radford et al. (2014), can mitigate acoustic masking. On the other hand, if the strikingly short transmission ranges of fish sounds are foremost the result of low sound propagation (due to physical constraints such as frequency-cutoff phenomena in shallow waters, see Ladich 2013), then anthropogenic noise would reduce communication distances only to a much lesser degree, or not at all.

To clarify this issue, one must make measurements of signal-to-noise ratios in the field within the typical communication ranges of fish sounds in both ambient noise conditions and during exposure to anthropogenic noise. Without such data, it is difficult to draw firm conclusions about the potential hazards of noise pollution for fish communication.

ROLE OF OTHER SIGNAL MODALITIES

The particularly small active space of fish calls raises another point that is independent of sound transmission but directly related to the function and usage of the sound signals. Given the very short communication distances, it is conceivable that fishes use their acoustic signals in combination with visual ones. This is quite the opposite of what is found in anurans, birds, and marine mammals, in which sound is often used to communicate over much longer distances than could be covered by visual signals. Thus, an impairment of the acoustic channel may be less problematic in fishes, provided that redundant messages are conveyed by visual signals (or electric or chemical ones). The way forward would be to establish the relative importance of sounds in what may be a multicomponent signaling system in fishes.

As reviewed by Radford et al. (2014), there is some evidence from captive fish that suggests that sound production affects mating success. In the context of potential multicomponent signaling, it would be quite interesting to find out whether sounds in wild fish are indeed essential for reproduction. In natural fish habitats, which are inevitably noisy (Ladich 2013), visual signals might be sufficient to successfully mate when acoustic signaling is disrupted. There is a caveat, though: in cases in which vision is also impaired (e.g., during the night, in turbid waters, when fish call from crevices), a loss of acoustic information can of course not easily be compensated by visual signals. Admittedly, the notion of multicomponent signaling is speculation but the issue has far-reaching implications. If variation in the efficiency of acoustic signal transmission has only minor fitness consequences, noise pollution would be less likely to affect population viability through acoustic masking. Yet through other physiological or behavioral effects (Popper and Hastings 2009; McGregor et al. 2013) it certainly can.

Let us be mistaken as overly critical: Radford et al. (2014) have written a timely and insightful review. Hopefully, their article will encourage researchers to tackle the many unresolved issues in this field so that we will eventually understand how much anthropogenic noise matters for acoustically communicating fish, and if the fish can make any signal adjustments that alleviate acoustic masking.

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