Chapter 20
Singing Fish in an Ocean of Noise: Effects of Boat Noise on the Plainfin Midshipman (*Porichthys notatus*) in a Natural Ecosystem

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Abstract When it comes to hearing and vocal communication in fishes, the plainfin midshipman (*Porichthys notatus*) is perhaps best understood. However, distinctly lacking are studies investigating communication of *P. notatus* in its natural ecosystems and the effects of noise on wild fish populations. Here, an exploratory look into both is discussed. By monitoring a population of wild *P. notatus* off British Columbia, Canada, call patterns were distinguished, the function of communicative sounds was identified, and midshipman vocalizations in agonistic encounters with natural predators were evaluated. A preliminary investigation into the effects of boat noise on wild midshipman is also described.

Keywords Vocalization • Predator–prey interactions • Communication • In situ

1 Introduction

Ship traffic along the Pacific northwest coast is substantial (Halpern et al. 2008) and is only set to increase (Heise and Alidina 2012). Already, marine transport has contributed significantly to ocean noise. "Shipping is probably the most extensive source of noise in the oceans, especially along major shipping channels (e.g., from Alaska to California for supertankers carrying oil)" (Popper 2003). The Pacific Northwest is also the coastal habitat range for many distinct fish species, including those that depend on sound to communicate and derive information from their auditory scene (Popper and Hastings 2009b). One such species is the plainfin midshipman (*Porichthys notatus*; Arora 1948; see Fishbase.org), a highly vocal fish whose call frequency overlaps that of boat noise (e.g., from large ships); this makes

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apparent the potential for boats to mask or impede fish communication, which could, in turn, have cascading effects up and down the food chain, including impacts on predators (see Slabbekoorn et al. 2010).

1.1 Fish and Ships

Until relatively recently, the vast majority of research on the effects of anthropogenic noise on marine life has focused on the impacts on marine mammals (e.g., Barrett-Lennard et al. 1996; Ford et al. 2000; Kastak et al. 2005; Mulsow et al. 2011). Over the last few years, however, more studies have emerged documenting the potential impacts of noise on other marine life, including crustaceans, cephalopods, and even coral (Department of Fisheries and Oceans Canada 2004; Vermeij et al. 2010; André et al. 2011; Simpson et al. 2011; Wale et al. 2013). In particular, anthropogenic noise as it affects fishes, noting their wide range, abundance, and diversity, is currently being explored (McCauley et al. 2003; Anderson et al. 2011; Holles et al. 2013). Potential impacts of noise on fish are now known to extend from direct physical harm, including stress and hearing loss (Amoser and Ladich 2003; McCauley et al. 2003), to indirect results such as altered group formations and spatial distributions (e.g., schooling behavior; Pearson et al. 1992; Slotte et al. 2004; Sarà et al. 2007) and masked communication (Vasconcelos et al. 2007); such effects are not limited to the adult forms (see Simpson et al. 2004; Wright et al. 2008; Radford et al. 2011) and could impact fitness (e.g., Sarà et al. 2007). Human-induced noise in the ocean encompasses acute sources like pile driving and sonar as well as more continuous noise such as from shipping (Popper and Hastings 2009b). Recent articles stress the importance of understanding the less studied and lower intensity noise produced from shipping because it is both chronic and globally widespread (Popper 2003; Halpern et al. 2008; Slabbekoorn et al. 2010; Ellison et al. 2012).

1.2 Predators and Prey

Predator–prey interactions increase the stability of ecosystems (Allesina and Tang 2012). However, the difficulties of assessing such dynamics in the wild are many, especially within multipredator scenarios (Lima 2002; Handegard et al. 2012). Although data are limited, when it comes to the effects of noise on fish and predator–prey relationships, some studies suggest that noise can affect fish both as predators and as prey; as predators, noise could impede their foraging competence (Purser and Radford 2011) and as prey, fish could alter their vocalizing behavior in the presence of nearby predators (Remage-Healey et al. 2006). Studies on other organisms show evidence for increased vulnerability to predation under boat noise conditions (Chan et al. 2010). More research on fish is needed, however, because, “Data are completely lacking in fish, but based on insight from very few and very different animal species, we believe that anthropogenic masking effects on predator–prey relationships could be widespread” (Slabbekoorn et al. 2010).

1.3 A Singing Fish

The plainfin midshipman, also known as talkative fish, singing fish, and canary fish (Kasumyan 2009), is found along the Pacific coast of North America and belongs to the family Batrachoididae, a highly vocal group of fish collectively known as toadfish. These fish produce sounds by contracting a pair of sonic muscles attached to their gas-filled swim bladders (Bass 1996; Sisneros 2009a). *P. notatus* has two adult male morphs, type I (alpha male) and type II (sneaker male), which vary in vocal abilities among other characteristics (Bass 1996; Sisneros 2012). Type I males produce several agonistic sounds, including the grunt (also produced by females), the grunt train (a sequence of short repetitive grunts), and the growl (Bass et al. 1999). Of most interest and currently best understood, however, is the hum, a distinct and prolonged vocalization emitted only by alpha males and associated with reproduction (Brantley and Bass 1994; Bass 1996; McKibben and Bass 1998; Sisneros and Bass 2005; Sisneros 2009b). All documented vocalizations produced by midshipman have fundamental frequencies at or just below 100 Hz (Weeg et al. 2002).

During the late spring and summer months, *P. notatus* migrates up into the intertidal zone from hundreds of meters deep to lay eggs and nest (Arora 1948; Sisneros 2012). Thus, it makes a particularly convenient research subject for in situ predator–prey studies; when exposed at low tides, *P. notatus* can be accessed with relative ease (Brantley and Bass 1994; McKibben and Bass 1998) and, being highly territorial, alpha males do not leave their nests, which helps in documenting predator visits (e.g., through a stationed camera).

2 Study

"Finally, and perhaps most importantly, there is a need for behavioral studies that actually examine the responses of wild fish to anthropogenic sounds. Almost all studies to date have involved caged fish" (Popper and Hastings 2009a). The purpose of this investigation was to analyze vocal communication of *P. notatus* within its natural ecosystem and to explore the effects of boat noise on wild populations.

2.1 Methods

The study site for this research was located in a small bay on the east coast of Quadra Island in the Strait of Georgia, off the north Pacific coast of Canada. Although the bay itself is relatively protected, the Strait of Georgia is an area highly impacted by human activities, including shipping (Ban et al. 2010). From late April to late August 2012, continuous underwater recordings were taken with a hydrophone (HTI-96 MIN; www.hightechincusa.com) secured to the bottom of the ocean floor near nesting midshipman at tidal depths varying between 1 and 20 ft. Baseline information on vocalizations and call patterns of midshipman as well as salinity and temperature data over an entire breeding season was then collected. The following year, between 7 and 27 June 2013, 15 distinct *P. notatus* nests, each guarded by an alpha male, were monitored and recorded over the course of 15 days. Midshipman nests were chosen at the lowest daytime tides and based on the presence of a nest-guarding midshipman, eggs, and accessibility. This experiment was unique in that, by using two cameras simultaneously, the effects of boat noise on prey and on predators could be observed concurrently; a "drop camera" (created for this research and fitted with LED lights and red light filters) was positioned in front of each nest (Rubow and Bass 2009) along with a microvideo camera, also fitted with LED lights and red light filters (MVC2120WP-LED; www.microvideo.ca), which was set up for observing *P. notatus* underneath rocks (Lee and Bass 2006). This double-camera setup allowed clear, simultaneous viewing of *P. notatus* in its nest as well as predator appearances outside the nest. Two hydrophones (HTI-96-MIN) were also set near nests, one synced with the drop camera and the other recording audio independent (see Fig. 20.1 for the experimental setup.) Live audio and video data were streamed through waterproof cables back to a proximate research station (e.g., Wardle et al. 2001), where they were recorded onto external hard drives. All cables of video cameras and hydrophones were at least 300 ft long to accommodate reaching from nest sites to research station.

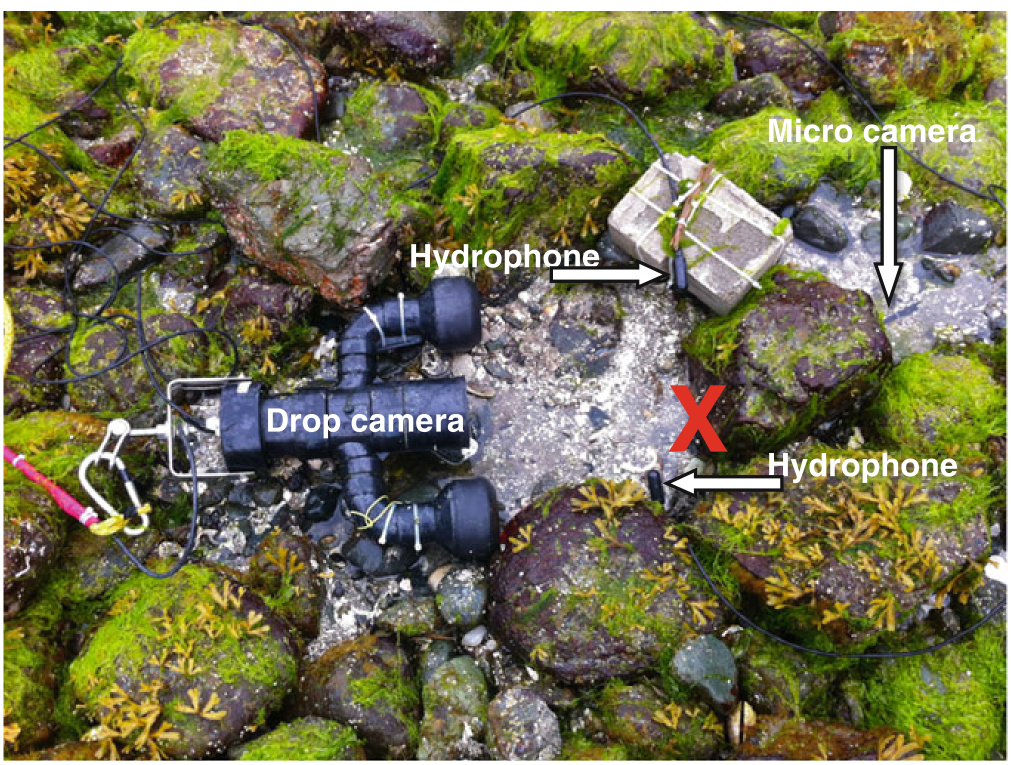

Fig. 20.1 Field setup. X denotes nest entrance

Boat noise experiments were conducted over the same 15 days in 2013, and each experiment lasted under 1 h. At 5 pm on experiment days, trials began; the treatments were boat noise, boat (engine off), and control. The treatments were randomized and lasted 16 min each. Boat noise was provided by a 14-ft aluminum boat with a 9.9-hp engine driven in real time by a research volunteer near the field site (i.e., within 100 ft of the nest). After the trials were completed, video and audio data collection continued until the following morning to keep documenting fish behaviors and ecosystem dynamics along with any potential longer term effects from noise (Picciulin et al. 2010).

3 Preliminary Findings

Although data analysis is currently still in progress, preliminary findings include

(1) an extremely high diversity and abundance of *P. notatus* predators in natural ecosystems. Midshipman predators ranged from crustaceans to fish to pinnipeds. Predator visits occurred continuously throughout the day and night. Most predators were interested in *P. notatus* eggs, although some, e.g., birds, otters, mink, actively hunted *P. notatus* adults;

(2) a *P. notatus* defense, which often included lunging and vocalizing concurrently, that was highly effective across most species of predators. Although grunts and growls are thought to be agonistic sounds emitted by *P. notatus* when threatened by other conspecifics (Brantley and Bass 1994; Bass and McKibben 2003), the use of such vocalizations against heterospecifics has not been documented before;

(3) *P. notatus* predators that might be affected by boat noise. Early investigations point to a possible change in visitation patterns by certain species of midshipman predators under boat noise conditions;

(4) the effects of boat noise on guarding alpha male *P. notatus* that are not obvious. Further assessment, including statistical analysis, is needed;

(5) continuous nest guarding by male *P. notatus* that is essential for egg survival. Multiple video recordings revealed that the absence of a guarding midshipman male, even for a few minutes, resulted in the rapid decimation of egg clutches by predators; and

(6) new insights into wild calls. Discoveries corresponding to natural vocalization patterns included evidence that growls and grunts occur during the day (in contrast to previous studies, e.g., Rice et al. 2011), and other findings (e.g., high maximum grunt numbers/train; see Maruska and Mensinger 2009).

4 Importance of Field Studies: Looking at the Ecosystem

Over the last few decades, studies describing the neural hearing mechanisms of *P. notatus* and how it responds to sound, both pressure and particle motion, have been undertaken (e.g., Weeg et al. 2002; Sisneros and Bass 2003; Bass and Ladich 2008; Sisneros 2009b; Suk et al. 2009; Zeddies et al. 2010, 2012; Alderks and Sisneros 2011). Yet what we know scientifically about this fish is almost entirely derived from laboratory work; data on the natural life history and ecology of *P. notatus* are startlingly few. This is concerning because data collected in the lab could be contradicted by those collected in situ (Myrberg and Spires 1972). "Most importantly, it is not possible to extrapolate in any way from studies of caged fish to wild animals" (Popper and Hastings 2009a).

Laboratory studies are infinitely easier to perform than field studies. Controlling all factors in the wild is near impossible, not to mention the added complexity of temperate marine ecosystems. Yet it is precisely because of these complicated, interwoven factors found only in the ocean that we must observe systems as they are found, in the wild. More research in the field would help fill in knowledge gaps and guide us toward more appropriate hypotheses.

5 Ongoing Work/Future Studies

Data analysis for this study is still in progress, yet the role of sound in predator–prey interactions under both natural and boat noise conditions is already apparent. Although *P. notatus* is known to have many predators, both underwater (otters, seals) and on land (herons, gulls, eagles, mink; DeMartini 1988; Elliott et al. 2004; Love 2011), this will be the first attempt to quantify the diversity and abundance of such predators. Furthermore, this research provides the first evidence that *P. notatus* vocalizes agonistically against heterospecific predators; correlations between midshipman vocalization type and predator type will be further investigated and success rates of predators will be determined, all under natural conditions and when exposed to boat noise. Vocalizations and sounds obtained from long-term acoustic datasets (e.g., for seasonal patterns and anthropogenic noise disturbances and including a comparison of vocalizations of *P. notatus* populations in low and high boat traffic environments) will continue to be analyzed. Finally, field studies on other fish species in other natural ecosystems, using similar coupled acoustic-optic setups (see Rountree et al. 2006), would yield highly informative data and should be pursued.

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