Chapter 91
Does Masking Matter? Shipping Noise and Fish Vocalizations

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Abstract Shipping creates large near-field background noises at levels similar to or higher than fish vocalizations and in the same critical bandwidths. This noise has the potential to "mask" biologically important signals and prevent fish from hearing them; any interference with the detection and recognition of sounds may impact fish survival. The Lombard effect, whereby vocalizations are altered to reduce or exclude masking effects, is an adaptation that has been observed in mammals and birds. Research is needed to establish whether the Lombard effect occurs in fish to gain a better understanding of the implications of noise pollution on fish populations.

Keywords Lombard effect • Anthropogenic • Vessel • Communication

1 Trends in Vessel Noise

The most widespread source of marine anthropogenic underwater noise pollution is from vessels (Firestone and Jarvis 2007; Jensen et al. 2009). Higher levels of marine traffic have led to low-frequency background noise in the ocean increasing 32-fold since the 1950s (Malakoff 2010). Several factors have contributed to this increase. For example, the worldwide commercial fleet, consisting of tankers, dry bulk vessels, container ships, and other large ocean-going vessels, has grown from ~30,000 vessels (~85,000,000 gross tons) in 1950 to 89,899 vessels (~605,000,000 gross tons) in 2003 (Ross 1993; Southall 2005). Worldwide, noncommercial vessels,

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including recreational craft and private boats, have also increased (although actual numbers cannot be stated because no official log exists). Additionally, port turnaround times are shorter, resulting in ships spending more days per year at sea and vessels have greater average speeds, propulsion power, and propeller tip speeds (Ross 1976, 1993; Southall 2005; McDonald et al. 2006). Ross (1976, 1982, 1993) presented data that indicated that sound levels had increased by 15 dB between 1950 and 1975 as a direct result of shipping activities. These trends are certain to continue, posing unique challenges for aquatic animals (Firestone and Jarvis 2007).

2 Masking

The turbid conditions present in much of the underwater environment, e.g., in coastal areas, means that many species rely on sound rather than vision to decipher information about their surroundings. Many fish species use ambient biotic and abiotic sounds emanating from objects to interpret changes in their acoustic environment, creating an "acoustic view" (Bregman 1990). Sound is an ideal means of communication in the aquatic environment because it can be propagated rapidly over great distances (five times faster than in air, 1,560 ms^{-1} at 25 °C) and is not attenuated as quickly as other signals such as light or chemicals (Hawkins and Myrberg 1983; Amoser and Ladich 2003; Andersson 2011). Fish use hearing to perceive and navigate their environment, so the ability to create an auditory scene and correctly interpret the acoustic information gleaned is crucial for survival (Myrberg 2001). Sound can inform an individual as to the whereabouts of food, competitors, predators, and potential mates through the perception of intended and/or unintended acoustic signals in the environment (Myrberg 1978).

When considering noise pollution, "noise" is taken to mean any sound that has the potential to negatively impact marine life (van der Graaf et al. 2012). Noise may be generated for an explicit purpose, such as locating submerged objects or fish shoals or measuring environmental features, or it may be an unwelcome by-product of industrial activities, such as the construction of infrastructure or the movement of vessels. Anthropogenic noise can potentially affect any animal that comes into contact with it and is capable of hearing it (Slabbekoorn et al. 2010). Noise is especially deleterious to fish because it often has frequencies within their hearing thresholds (Scholik and Yan 2002). Both physiological and behavioral changes have been observed in fish as a result of anthropogenic noise sources (Popper et al. 2003). Masking (when the detection of one sound is impaired by the presence of another) has been proven to occur in terrestrial animals (e.g., Fletcher 1940), and it is possible that it is occurring in fish. Shipping creates large near-field background noise at levels similar to those of fish vocalizations and in the same critical bandwidths so noise pollution could directly affect the survival of fish populations by decreasing their ability to hear and respond to biologically important signals.

Over 800 fish species from more than 109 families are known to vocalize, with many more suspected of doing so (Slabbekoorn et al. 2010). Fish, including some key UK commercial species such as cod and haddock, vocalize for a variety of reasons:

- to attract mates (e.g., damselfish, Parmentier et al. 2006; blennies, De Jong et al. 2007; croakers, Connaughton et al. 2002; drums, Locascio et al. 2012);
- to establish territory (e.g., toadfish, McKibben and Bass 1998; minnows, Nicoletto and Linscomb 2007);
- while foraging (e.g., gurnards, Amorim et al. 2004; seahorse, Anderson 2009);
- while competing for food (e.g., cichlids, Lamml and Kramer 2008; piranhas, Kastenhuber and Neuhauss 2011);
- as a fright response (e.g., croakers, Connaughton et al. 2002); or
- to aggregate for spawning and synchronize the release of gametes (e.g., catfish, Papes and Ladich 2011).

Masking from anthropogenic sources can interfere with these vocalizations or reduce the distance at which these biologically important vocalizations can be detected by the fish. This is due to the introduced noise raising the ambient level and decreasing the signal-to-noise ratio, which reduces the signal detection distance and thus causes the detection of a signal to become more difficult (Andersson 2011). This masking effect could make it difficult for the fish to locate and communicate with conspecifics (other members of the same species) and prevent the biologically important sounds associated with successful reproduction from being heard. *Gobius cruentatus* (red-mouthed goby), *Sciaena umbra* (brown meagre), and *Chromis chromis* (Mediterranean damselfish) all significantly increased their detection threshold levels to hear conspecific sounds when exposed to 132-dB cabin-cruiser noise reproduced in the laboratory (Codarin et al. 2009). It has also been shown that wind, temperature gradients, substrate, and foliage can all restrict or enhance the distance over which signals can be used for communication in terrestrial environments (Mann and Lobel 1997). Therefore, anthropogenic sounds may work synergistically with the underwater environment to increase the adverse effects of masking.

Wollerman and Wiley (2002) suggested that noisy conditions can interfere with mate selection. Mating calls masked by unnatural noise means that only the loudest individual or an individual displaying a certain pitch will be heard and, therefore, mate successfully. This could ultimately lead to a decrease in the genetic diversity of the population. When heterospecific vocalizations are masked, foraging is energetically more costly because prey are harder to locate and predation risks are higher as warning sounds from approaching predators are missed. Moreover, nonvocal species may use the vocalizations of other species as an aid to navigation; sharks monitor the sounds of struggling fish to locate and capture them as prey (e.g., Myrberg et al. 1976). Any excess noise in the environment can, therefore, decrease the shark's chances of successful foraging.

The larval stage is a crucial time for development and survival in the life cycle of many marine animals (Ohs et al. 2009). Larvae are much more susceptible to predation because their ability to swim is limited. Noise pollution from anthropogenic sources can interfere with larval settlement and recruitment processes because some larvae use the ambient ocean noise to orientate and locate desirable habitats (different habitats have distinct acoustic signatures [Montgomery et al. 2006; Radford et al. 2010]). Larvae unable to locate a suitable site in which to settle will die from lack of food or predation; this will impact on the species' population if it should happen to multiple individuals in the same year or spawning cycle. Reef-associated larvae are especially at risk because vessel noise is commonplace around reefs and can impede the detection and selection of the appropriate settlement habitats of many species (Holles et al. 2013).

Furthermore, masking can cause problems for parents tending their young. The adults need to hear the begging calls of progeny or cues will be missed and the offspring's survival may be compromised (Kilner and Hinde 2008). Territoriality can also be affected by masking because many fish, such as the *Abudefduf saxatilis* (sergeant fish), are known to mark and defend their territory using sound (Maruska et al. 2007). The red-mouthed goby was observed to reduce territoriality in the presence of boat noise, and the resultant increased aggressive contests had a subsequent detrimental effect on reproduction (Sebastianutto et al. 2011). In response to anthropogenic noise, some marine mammals have simply stopped vocalizing altogether (Weilgart 2007). The lack of signals between conspecifics means that behavior necessary for a population's survival may not naturally occur.

3 The Lombard Effect

Throughout the paleontological record, there are examples of species having evolved to overcome the perturbations they faced. However, the rapid rate at which noise is increasing in the ocean may not allow such mechanisms to evolve as quickly as is necessary. Currently, over 77 fish species for which audiograms exist are known to have hearing thresholds within the same frequency range as the noise produced by vessels. The exact frequency spectrum of the noise is altered depending on the type of vessel. Individuals may compensate for the increase in vessel noise by changing the amplitude (Scheifele et al. 2005; Holt et al. 2009), duration (Foote et al. 2004), repetition rate, and/or frequency of the sounds they produce. This effect, which has the potential to overcome the effects of masking, is known as the Lombard effect, the automatic and involuntary change in the intensity of vocalizations in the presence of background noise needed to maintain a constant signal-to-noise ratio (Coffey 2012). To date, the Lombard effect has not been greatly studied in fish, but other animals have shown that this effect can help overcome problems caused by masking (Table 91.1).

Research is needed to determine whether the Lombard effect occurs in fish. If this phenomenon does occur, then serious concerns regarding the effects of vessel noise on vocalizing fish populations may be unfounded. However, altering vocalizations may be metabolically expensive and necessitates that a fish's communication range is not already maximized (Jensen et al. 2009). Furthermore, it has been hypothesized that fish vocalizations are dependent on the size of the fish and individuals may not physically possess the ability to alter their vocalizations.

Table 91.1 Studies that show evidence of the Lombard effect being used to overcome masking

Class	Taxa	Observed effects	Reference
Birds	*Luscinia megarhynchos* (free-ranging nightingale)	Males were recorded singing at higher sound levels when in noisier locations	Brumm (2004)
Arthropods	*Schizocosa ocreata* (ground-dwelling wolf spider)	Females, who communicate via vibrations, showed changes in courtship behavior, receptivity, and mating success when exposed to white noise	Gordon and Uetz (2012)
Mammals	*Delphinapterus leucas* (St. Lawrence River beluga)	Increased the intensity of vocalizations in the presence of boat noise	Scheifele et al. (2005)
	Orcinus orca (killer whales)	Respond to vessel noise by increasing their vocalizations by 1 dB for every 1-dB increase in background noise	Holt et al. (2009)
Amphibians	*Litoria ewingii* (brown tree frogs)	Altered the pitch of their advertisement calls in the presence of traffic noise	Parris et al. (2009)
	Crinia signifera (common eastern froglets)	Altered the pitch of their advertisement calls in the presence of traffic noise	Parris et al. (2009)

The occurrence of the Lombard effect may differ according to species and/or individual differences, the type of sound source, its frequency and intensity, or other factors such as season and topography. Studies to determine whether the Lombard effect occurs in fish should seek to assess a range of environmental conditions under which the effect may occur and relate these to fish life-cycle stages. Primarily, any masking problems encountered during reproductive phases need to be addressed to ascertain whether or not there could be implications for population survival.

If it can be proven that fish species do alter the pitch, intensity, or duration of their vocalizations to remain audible to conspecifics, then behaviors such as aggregated migration, courtship, and spawning can occur unhindered in the presence of underwater noise pollution. However, if the Lombard effect is not observed in fish, then the masking of vocalizations by anthropogenic noise should be regarded as a serious threat to vocalizing fish species.

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