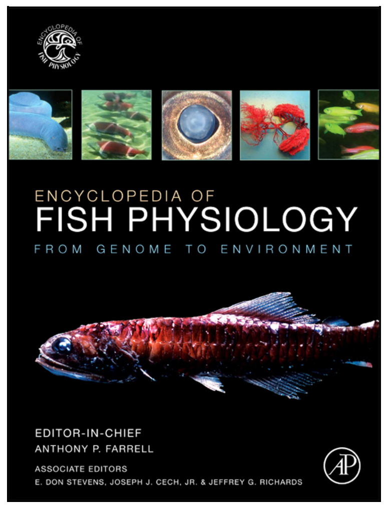

Luczkovich J.J., Sprague M.W., and Krahforst C.S. (2011) Acoustic Behavior. In: Farrell A.P., (ed.), *Encyclopedia of Fish Physiology: From Genome to Environment*, volume 1, pp. 311–320. San Diego: Academic Press.

Acoustic Behavior

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Glossary

Amplitude The maximum pressure deviation from ambient pressure in a sound wave.
Decibel (dB) A logarithmic scale for comparing signal parameters such as sound pressure, particle velocity, voltage, current, etc.

$$\text{Number of decibels} = 20 \log_{10}(a_1/a_0),$$

where a_0 and a_1 are the two signal parameters being compared. Decibels are used in acoustics for sound pressure levels and other measurements.
Frequency The number of wave cycles in a time interval (measured in Hz = 1 cycle s^{-1} or kHz = 1000 cycles s^{-1}).
Interpulse interval Time between two pulses in a sound.
Oscillogram A graph produced from an oscilloscope or sound analysis software that records the pressure of a sound wave along a time axis.
Period The time it takes for one cycle of a sound wave to pass by a point.
Power spectral density The total sound power of a 1-Hz-wide band centered at a given frequency in a sound.
Pulse train A set of sound waves, each pulse due to a single set of sonic muscle contractions, or a single contraction for some species.
Sound pressure level A measurement of the sound pressure in decibels comparing the measured sound pressure (a_1 in the decibel formula above) to a reference pressure (a_0 in the decibel formula above). Underwater sound measurements use 1 μPa as the reference pressure.
Spectrogram (also sonogram) A graph representing the sound frequency and intensity variation over time; useful in identifying fish species by their sounds. Most spectrograms are displayed as two-dimensional plots in which the horizontal (x) axis is time (in s), the vertical (y) axis frequency (in Hz), and the color (z) axis is power spectral density (in dB).

Introduction – Fish Behavior and Underwater Sound

Because the underwater world is often dark and turbid, fishes have evolved to take advantage of sounds (**see also Behavior and Physiology**: Linking Fish Behavior and Physiology: An Introduction). Fishes can hear sounds, some better than others, within a frequency range of 10–1000 Hz for most species. Some fishes can hear much higher frequencies, up to 4000 Hz (or ultrasound >20 kHz in some Clupeids) (**see also Hearing and Lateral Line**: The Ear and Hearing in Sharks, Skates, and Rays and Psychoacoustics: What Fish Hear). Hearing provides fishes with the ability to analyze their auditory scene – their local (~1 m) and long-distance (~10 m to 1 km) acoustic environment (**see also** Biomechanics of the Inner Ear in Fishes).

Fishes also produce sounds in the same frequencies as they hear for communication (**see also Hearing and Lateral Line**: Psychoacoustics: What Fish Hear). Fishes have evolved specialized sound production mechanisms including stridulation of bones and teeth or contraction of sonic muscles to drive gas-filled swimbladders (**see also Hearing and Lateral Line**: Vocal Behavior of Fishes: Anatomy and Physiology). Recordings of many fish sounds can be played at the 'Relevant websites' listed at the end of this article. It appears that sounds are produced by some of the most primitive fishes (i.e., various species of sturgeons (Acipenseridae) and the reedfishes or bichirs, gray bichir *Polypterus senegalus* and West African bichir *P. retropinnus* Polypteridae)) for the purposes of intraspecific communication. Sound production in fishes has also evolved more than once and has become important for communication in codfish (Gadidae), drumfish (Sciaenidae), toadfishes and midshipmen (Batrachoididae), and many other species. Sound production is used by fishes to communicate along with chemical, tactile, and visual signals (**see also Smell, Taste, and Chemical Sensing**: Chemosensory Behavior

Encyclopedia of Fish Physiology: From Genome to Environment, 2011, Vol. 1, 311-320, DOI: 10.1016/B978-0-1237-4553-8.00011-3

and Behavioral Assessment of the Visual Capabilities of Fish).

Fishes produce two different types of sounds: (1) pulsed sounds, in which the sonic muscles contract once to produce each pulse and (2) tonal sounds, in which the sound-producing muscles contract repeatedly to cause a steady-state vibration of the swimbladder. Pulsed sounds, such as the knock produced by silver perch, *Bairdiella chrysoura* (Sciaenidae) (**Figure 1**), have frequencies that depend on the physical properties of the sound-producing mechanism (sonic muscles and swimbladder), and will vary with the size of the individual fish. Tonal sounds, such as the boop produced by oyster toadfish, *Opsanus tau* (Batrachoididae) (**Figure 2**), have frequencies that depend on the vocal pacemaker and muscle contractions, and do not vary with the size of the fish.

The distance that fish sounds travel depends on the loudness of the sound, the loudness of the background noise at the same frequencies as the sound, and the water conditions (e.g., depth, temperature profile, and bottom type). Most sound communication among fishes occurs over short distances, less than 10 m. Although the knock of an individual silver perch can be detected at a maximum distance of 316 m in quiet conditions, the biologically relevant propagation distance is closer to 2 m, especially when background sounds are loud from other fish that are calling nearby. However, the combined sounds of aggregations of fish in the open ocean can be detected by hydrophones at distances of 1–8 km. Conversely, the maximum detection distance can be significantly shorter (<1 m) in shallow streams and ponds where turbulence, wave noise, bottom depth, and the shore limit the sound propagation distances.

Scientists use hydrophones (underwater microphones) to record fishes in the wild and when held captive in aquaria to identify the sound-producing species involved (**Figure 3**). Hydrophones have been attached to remotely operated vehicles (**Figure 4**), submarines, and autonomous sound-recording equipment to capture short- and long-term variations of acoustic fish behavior. Sound recordings are then correlated with biological measurements (size, sex, spawning condition, and gamete production) taken at the same time.

What Species Make Sound?

Many fishes make sounds, including (in addition to the families already noted above) catfishes (multiple families in the order Siluriformes), sculpins (Cottidae), Siamese fighting fishes (Osphronemidae), sea robins and gurnards (Triglidae), pearlfishes (Carapidae), elephant-nose fishes (Mormyridae), damselfish (Pomacentridae), wrasses (Labridae), grunts (Haemulidae), porgies (Sparidae), seabasses and groupers (Serranidae), sunfish (Centrarchidae), cichlids (Cichlidae), and gobies (Gobiidae). This is not an exhaustive list of

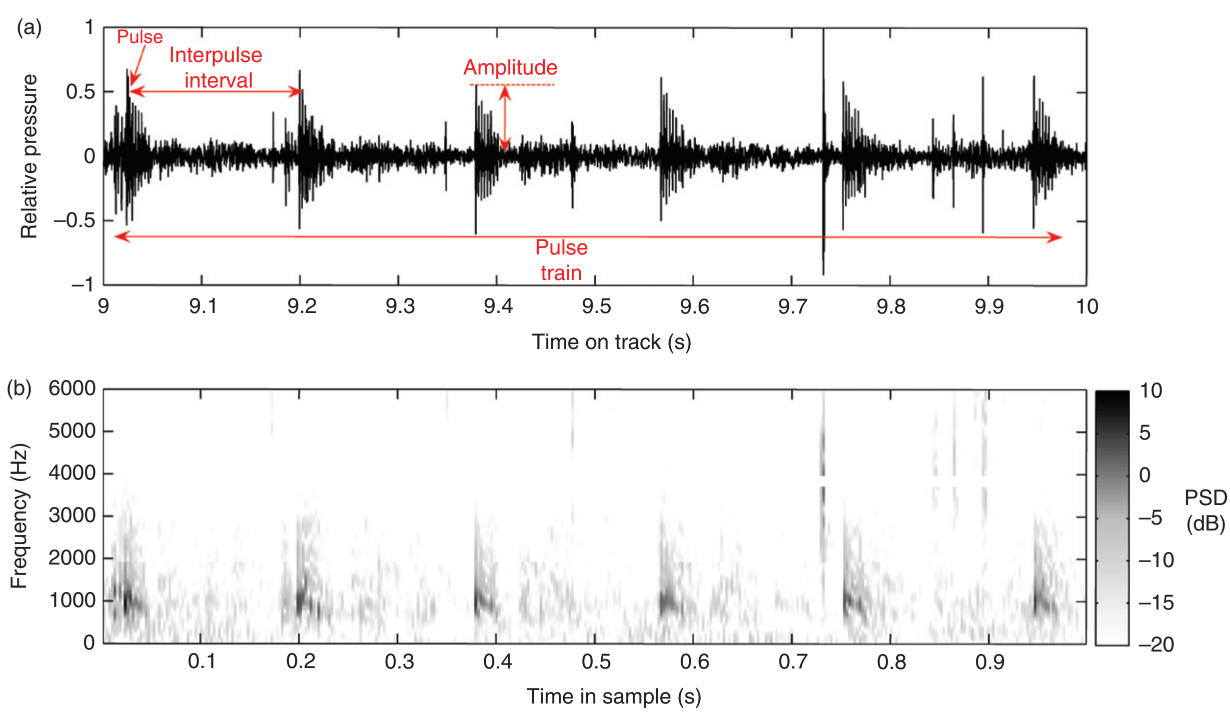

Figure 1 Spectral characteristics illustrated for silver perch, *Bairdiella chrysoura*, pulsed sounds: (a) oscillogram and (b) spectrogram or sonogram.

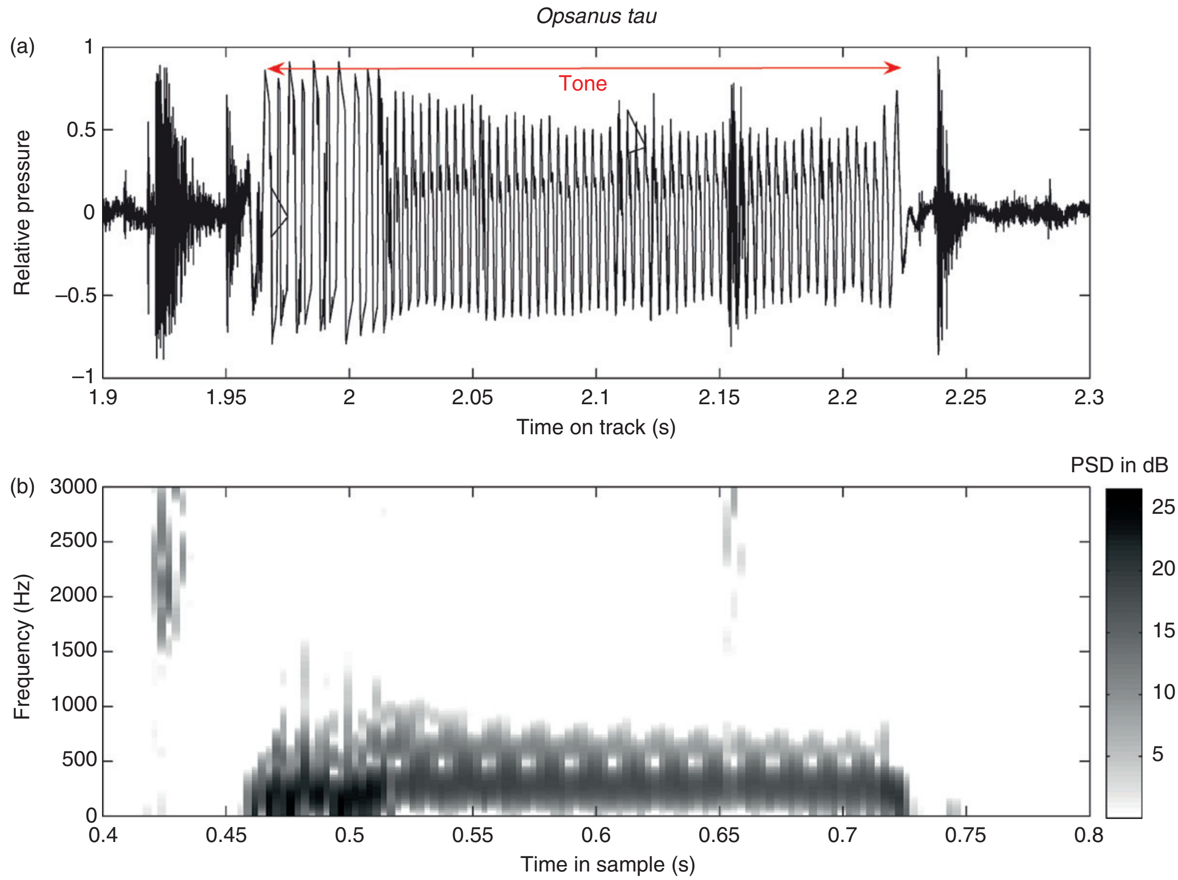

Figure 2 Spectral characteristics of a tonal sound, the oyster toadfish, *Opsanus tau*, boop sound: (a) oscillogram and (b) spectrogram.

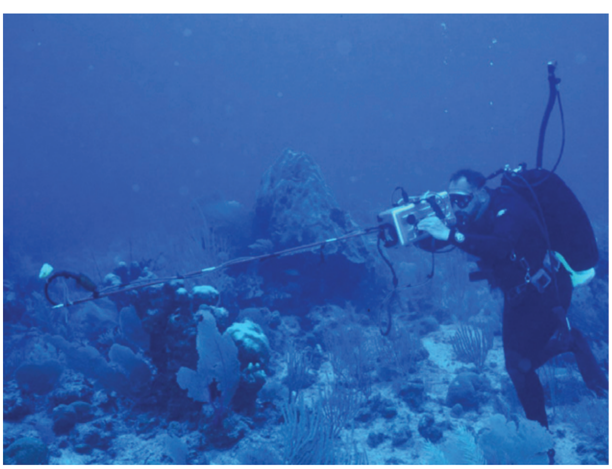

Figure 3 Recording sound and video underwater using a hydrophone mounted on a boom. Photo by Lisa Kerr Lobel. Reproduced from Lobel PS (2001) Sounds produced by spawning fishes. *Marine Technology Society Journal* 35: 19–28.

sound-producing fish families, and at least 700 species are known to make sounds; many species likely to produce sounds have not been studied (**see also Hearing and Lateral Line**: Psychoacoustics: What Fish Hear).

Why Do Fishes Make Sound?

Fishes produce sound for a variety of reasons. These include: (1) incidental sounds produced while swimming and feeding and (2) sounds produced intentionally for communication during aggression, predatory attack (alarm calls), feeding, reproduction, and possibly produced for echolocation. Examples of each type of sound are provided in the subsections below.

Incidental Sounds

Some sounds are incidental and are produced by body movements such as swimming. Anecdotal evidence suggests that these hydrodynamic sounds can be detected by prey fish avoiding predatory fishes. Many fishes are also known to produce sounds incidentally during feeding. These feeding sounds can be simple, like the scraping of teeth on coral as parrotfish, *Sparisoma* sp. and *Scarus* sp. (Scaridae), feed on algae. Other fishes produce sounds when chasing or capturing prey. For example, seahorses, *Hippocampus* sp. (Syngnathidae), make clicking sounds as their skull hits vertebrae when catching prey. Margate, *Haemulon album* (Haemulidae), make both pop and burst

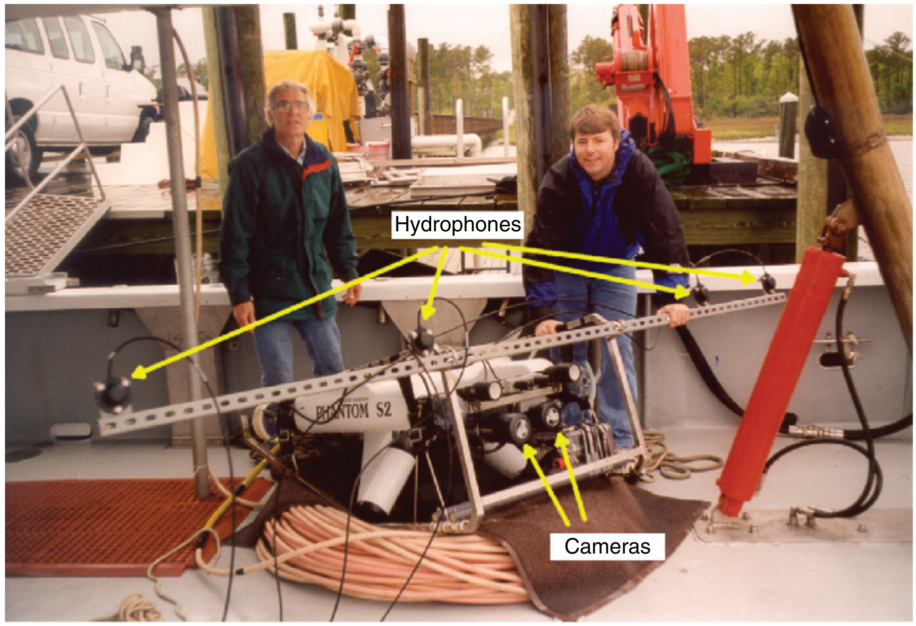

Figure 4 Phantom S2 remote operated vehicle (ROV) with hydrophone boom and integral camera. Photo by Joseph J Luczkovich. Reproduced from Sprague MW and Luczkovich JJ (2004) Measurement of an individual silver perch *Bairdiella chrysoura* sound presure level in a field recording. *Journal of the Acoustical Society of America* 116: 3186–3191.

sounds depending on their feeding mechanism. Popping sounds are made as the fish propels its body forward after plankton, while burst sounds accompany the act of expelling sand from their mouth and opercular openings after a benthic feeding.

Intentional Sounds

Aggressive sounds

There are many examples of fish sounds used in aggressive interactions between individuals of the same species or in territory defense. When several grey gurnard, *Eutrigla gurnardus* (Triglidae), are given food in a laboratory, there is a significant increase in both visual and acoustic displays, with different sound types indicating feeding, fighting, and warning (**Figure 5**). These signals prevent other fish from feeding in the same area. Bicolor damselfish, *Stegastes partitus* (Pomacentridae), are well known for their acoustic and visual displays when approached by an intruder (e.g., SCUBA diver). Bicolor damselfish produce popping sounds with an increasing repetition rate as the intruder approaches their nest. If the intruder is not deterred by the acoustic and visual displays and continues to approach, the damselfish engages in physical battle, biting, and even ramming the intruder.

Alarm calls

Alarm calls denote behaviors alerting conspecifics to predators in the area. For example, longspine squirrelfish, *Holocentrus rufus* (Holocentridae), grunt or make staccato sounds when an intruder, such as another longspine squirrelfish, a bluestriped grunt, *Haemulon scirus*

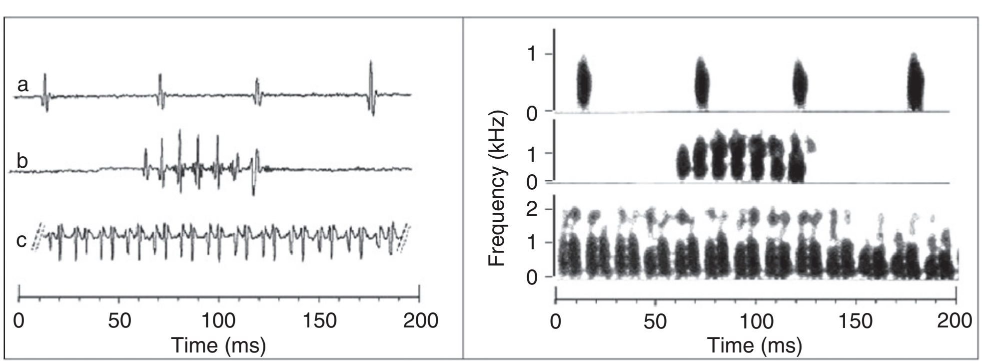

Figure 5 Oscillogram (left) with spectrogram (right) representation of the three types of acoustic signals emitted by grey gurnards *Eutrigla gurnardus* (Triglidae): (a) knocks (feeding); (b) grunts (fighting); and (c) growls (warning). Modified from Amorim MCP, Stratoudakis Y, and Hawkins AD (2004) Sound production during competitive feeding in the grey gurnard. *Journal of Fish Biology* 65: 182–194.

(Haemulidae), a mullet, *Mugil* sp. (Mugilidae), or a spotted moray eel, *Gymnothorax moringa* (Muraenidae), enters their territory. Longspine squirrelfish produced longer staccatos when spotted moray eels were introduced experimentally into their territories compared with the introduction of nonpiscivorous mullet and grunt, suggesting that the longer staccatos may be an alarm call. These squirrelfish alarm calls have been recorded when moray eels and groupers hunt together cooperatively on reefs. These alarm sounds are examples of altruistic behaviors that may facilitate escape behaviors for closely related individuals.

In contrast, longspine squirrelfish have been observed to become silent when the low-frequency (<10 kHz) component of bottlenose dolphin, *Tursiops truncatus*, echolocation sounds was played back. Similarly, a chorus of silver perch (Figure 6(a)) was silenced by the sounds of their predator (Figure 6(b)). This acoustic avoidance effect was demonstrated by playback experiments using bottlenose dolphin signature whistles, which caused a drop in silver perch sound production of 15 dB (Figure 6(c)), but this did not happen when a control sound (700-Hz tone) was played back (Figure 6(d)). It is unclear if warning sounds were produced by the silver perch and longspine squirrelfish prior to the silences in these cases.

Spawning/advertisement call

The most well-described fish calls are associated with spawning and reproductive behavior. Sound production, when associated with spawning, is common in turbid water or dark environments, and often occurs during nocturnal spawning events. Generally, only male fishes make spawning sounds as advertisement calls. Acoustic signals may be the mechanisms for female fishes to locate spawning-ready male conspecifics, especially in dark waters. Nocturnal sound production by males is commonly associated with pelagic eggs produced by females in field hydrophone surveys of fishes in the family Sciaenidae: silver perch; weakfish, *Cynoscion regalis*; spotted seatrout, *C. nebulosus*; and red drum, *Sciaenops ocellatus* (Figure 7).

In aquarium observations, male red drum used acoustic, visual, and tactile cues during courtship. Males call females with increasingly rapid sounds as spawning approaches, first with two to four short pulse trains, then with rapid drum rolls. When a female responds to the sounds of a male, she begins swimming off the bottom. The male then uses visual (e.g., color change) or tactile (nudging near the female's vent) cues to initiate egg release.

When white seabass, *Atractoscion nobilis* (Sciaenidae), were observed with underwater video and hydrophones in semi-natural oceanic enclosures, a single female spawned with multiple males (up to nine individual males), while the males made sounds variously described as drum rolls, thuds, and a chanting chorus of sounds. During courtship, the males would swim alongside the female with their vents in close proximity to the female's vent (Figure 8(a)), making low-frequency (30–200 Hz) pulse trains of sounds (Figure 9(a)), some of which were identified as drum rolls and thuds (Figure 9(b)). The female exhibited vertical color bars during courtship and spawning, which provided a visual cue to the males

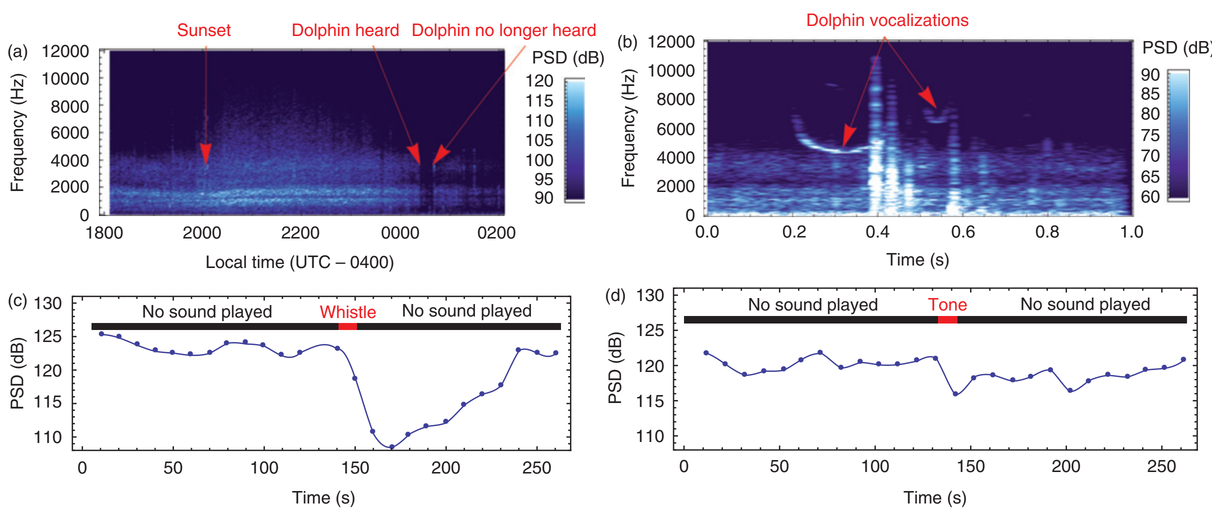

Figure 6 Silver perch, *Bairdiella chrysoura*, acoustic avoidance of bottlenose dolphin, *Tursiops truncatus*, whistles. Power spectral densities (PSDs) given in dB re 1 $\mu Pa^2\ Hz^{-1}$. (a) Composite sonogram showing a silver perch chorus with a sudden quiet period at time 00:24 (24 min after midnight). (b) Sonogram of bottlenose dolphin whistles recorded during the silver perch quiet period in (a). (c) Variation of silver perch loudness, measured by the peak of the power spectrum between frequencies 950 and 1200 Hz, before and after a bottlenose dolphin whistle was played through an underwater speaker. (d) Same measurement as (c) before and after a 700-Hz tone was played through an underwater speaker. Reproduced from Luczkovich JJ, Daniel HJ III, Hutchinson M, et al. (2000) Sounds of sex and death in the sea: Bottlenose dolphin whistles silence mating choruses of silver perch. *Bioacoustics* 11: 323–334.

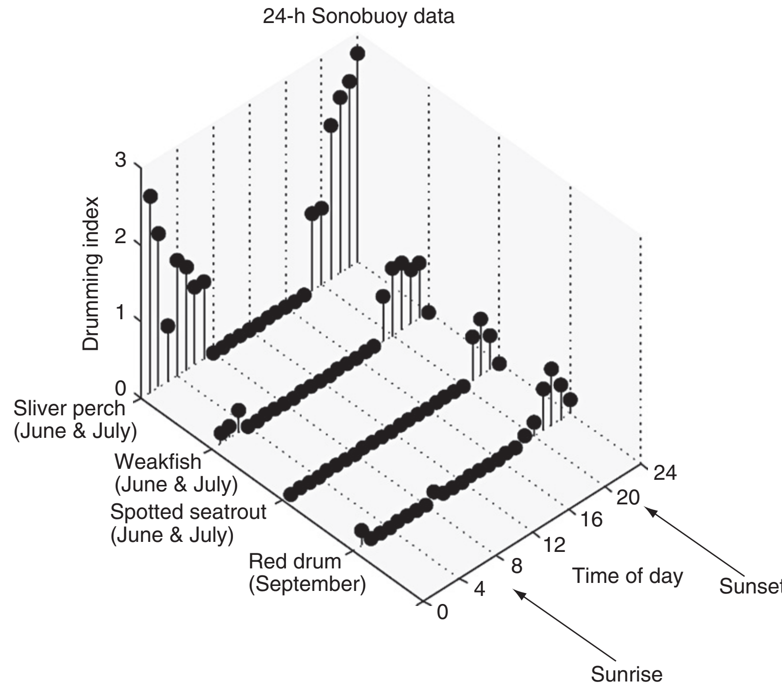

Figure 7 An index of sound production during spawning (drumming index) showing nocturnal and seasonal sound production patterns exhibited by silver perch, *Bairdiella chrysoura*; weakfish, *Cynoscion regalis*; spotted seatrout, *C. nebulosus*; and red drum, *Sciaenops ocellatus*, in Pamlico Sound, North Carolina, USA. An index of 0 corresponds to no fish sound detected, 1 to an individual call detected, 2 to several individual calls detected, and 3 to a chorus of sounds too loud to distinguish individual calls. Reproduced from Luczkovich JJ, Pullinger RC, Johnson SE, and Sprague MW (2008) Identifying sciaenid critical spawning habitats by the use of passive acoutics. *Transactions of the American Fisheries Society* 137: 576–605.

indicating the willingness of the female to spawn. During spawning, a long trail of gametes was observed as the spawning pack swam toward the surface producing a continuous chant (**Figure 9(c)**) during gamete release (**Figure 8(b)**). In this sciaenid species, sound production was made before and during spawning events, and the sound was continuous and loudest during the gamete release.

Female fishes may be able to interpret acoustic signals as a measure of male fitness and use the sounds to choose an appropriate male to fertilize the eggs. The best-studied example of mate choice based on sound production is the plainfin midshipman, *Porichthys notatus* (Batrachoididae). Each summer on the US Pacific coast, plainfin midshipman migrate from deep water to tidepools in the intertidal zone to mate. Males produce a tonal humming sound of 100 Hz with duration lasting from a few minutes to hour-long calls to attract mates. Laboratory experiments have demonstrated that the females are attracted to recorded 100-Hz hums played back alternatively through two underwater speakers. Playback experiments using artificial humming sounds of the same frequency also attract females. When presented with pure tones of various frequencies near the hum frequency, female midshipman showed a preference for 100-Hz tones.

Male damselfishes (Pomacentridae) produce sounds to warn competing males to keep away from their territory and to initiate courtship behavior with a female. In the bicolor damselfish (*Stegastes partitus*), sound playback experiments on a natural reef using males' recorded chirp sounds demonstrated that males use the sound as a warning to other males to keep out. Territory holders can discriminate between neighboring males based on sounds, which carry size-related information (larger damselfish have lower-frequency chirps). Females can also discriminate between males' chirps of different frequencies, choosing the largest males. Male Hawaiian dominos, *Dascyllus albisella*, had significantly longer pulse durations during mating events than when males only were present. During mating, males also complete a signal jump in which they swim upward and then move up and down while producing pulses of sound. Signal jumps differ in interpulse interval, period, pulse duration, and amplitude compared with male aggressive encounters. Signal jumps are related to male vigor and fitness, allowing females to assess a mate using both visual and auditory cues.

Researchers have observed and recorded spawning haddock, *Melanogrammus aeglenus* (Gadidae), in aquaria. Males were observed to participate in several complicated behavioral acts during spawning and courtship, many of which have specific sounds associated with them

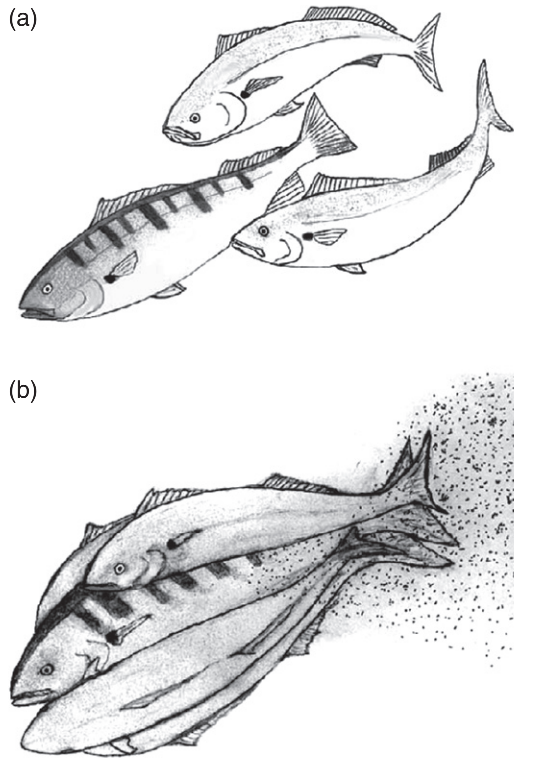

Figure 8 Illustrations of (a) two courting white seabass, *Atractoscion nobilis*, males shadowing and nudging a darkly barred gravid female and (b) a spawning pack of four males and a barred female simultaneously releasing gametes during a broadcast spawning event. Reproduced from Albers SA and Drawbridge MA (2008) White seabass spawning behavior and sound production. *Transactions of the American Fisheries Society* 137: 542–550.

(**Figure 10**). Researchers hypothesized that the associations of distinct sounds with these complicated behaviors are because haddock spawn at depths of over 100 m, where there is little light. Thus, the sounds enhance the visual displays.

Other examples of fishes that produce sound during courtship and mating include the parrotfish, groupers, hamlets, and gobies. In the butter hamlet, *Hypoplectrus unicolor* (Serranidae), both members of a spawning pair are simultaneous hermaphrodites, and both make sounds. The butter hamlet individual acting in the male spawning role (producing spermatozoa) produces an initial courtship sound, a series of 500-Hz pulses. The other individual, acting in the female role (producing eggs), also produces a sound during egg release, which is a frequency-modulated downward sweep (between 600 and 200 Hz), followed by a longer broadband sound (350–1350 Hz). Individuals will then immediately reverse in their mating roles, making the appropriate sounds for their sex role. In striped parrotfish, *Scarus iseri* (Scaridae), group spawning occurs in association with sound production. A spawning rush or upward swimming group of 5–30 individuals of both the sexes produces a low-frequency (30–1200 Hz) broadband sound during the entire spawning event. Grass gobies, *Zosterisessor ophiocephalus* (Gobiidae) are sound producers, having grunting and staccato sounds associated with territorial defense, courtship, and reproduction. Males produce these sounds prior to mating. The frequencies (~330 Hz) of these transient sounds are inversely related to fish size.

Navigation and echolocation

Fishes may use sounds, produced by themselves or other species, as a way of finding their way around. For example, there is evidence that more larval damselfish and cardinalfish (Apogonidae) are attracted to artificial reefs that have sounds of reef animals (fishes, snapping shrimp, and urchins) played through underwater speakers than are attracted to control sites that do not have reef sounds. Larval reef fishes also swim toward the sounds of a coral reef played back through a speaker. Because coral reef sounds can be heard by larvae over a long distance (~100 m), planktonic larval fishes can possibly use sounds as a navigation cue to locate suitable settlement habitats.

It has been suggested that fishes make sounds as a way of learning about the environment around them from the echoes that reflect from the bottom or objects in the sea (**see also Hearing and Lateral Line**: Sound Source Localization and Directional Hearing in Fishes). For example, the sea catfish, *Arius felis* (Ariidae), has been shown experimentally to find its way through a maze with transparent walls, never hitting the walls and all the while making popping sounds; individuals that had been muted by surgically cutting their sonic muscles did not make sounds and did not easily navigate the maze, bumping into the transparent plastic walls (**Figure 11**). Blinded sea catfish were also able to navigate the maze, but did so while making sounds. Deep-sea fishes (families Macrouridae and Moridae) have sonic muscles, unusual inner ear structures with large otoliths, and can produce sounds at great depths (3900 m), loud enough to be detected near the surface by a hydrophone. Sound production by these deep-sea fishes may be used to echolocate in total darkness. Whether fishes actually use sound in this way remains speculative, but is an area of considerable interest.

Sound Production and Ontogeny, Sex Differences

Although fishes produce sounds, this does not occur equally at all life stages or in both sexes. Most studies have identified mature males producing sound, but not females or juveniles. For example, in the drumfish family, weakfish, and spotted seatrout, males produce advertisement calls associated with spawning, but females and immature males do not have enlarged drumming muscles

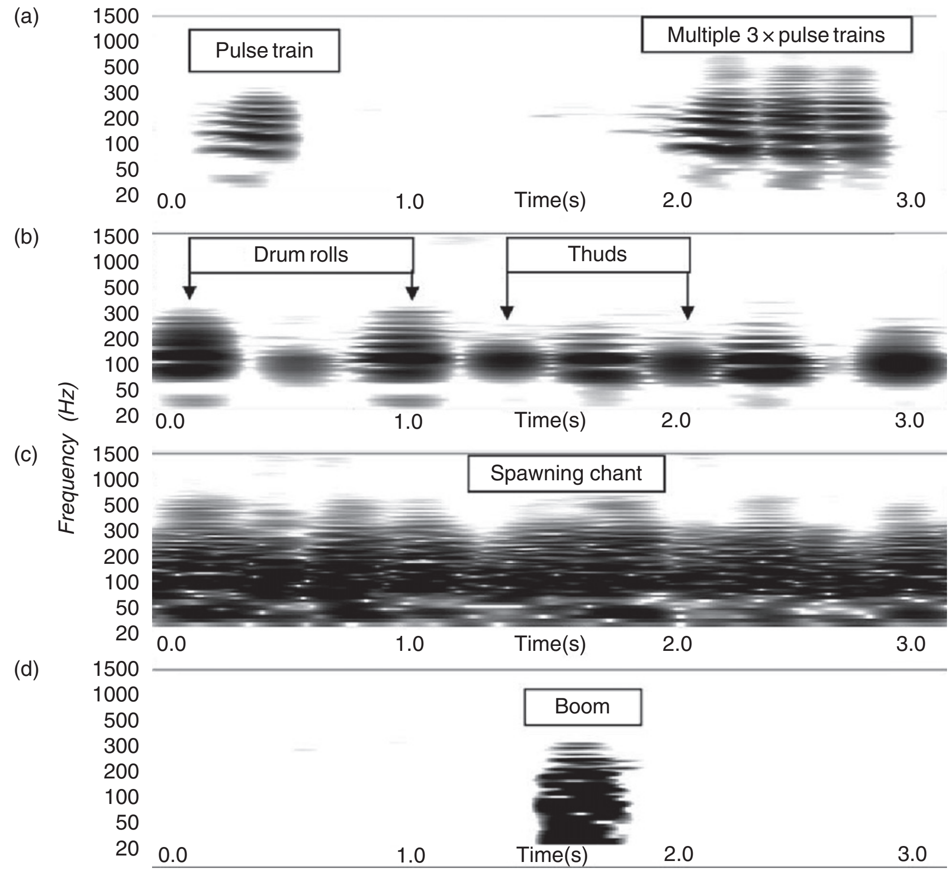

Figure 9 Sonograms displaying: (a) white seabass, *Atractoscion nobilis*, courtship sounds, including single and multiple (33) pulse trains; (b) drumroll and thud sounds produced in rapid succession at the beginning of a spawning event; (c) spawning chant of continuous, overlapping drumroll and thud sounds; and (d) hydrodynamic boom. Sounds recorded from fish held in a net pen in Catalina Harbor, California. Reproduced from Albers SA and Drawbridge MA (2008) *Transactions of the American Fisheries Society* 137: 542–550.

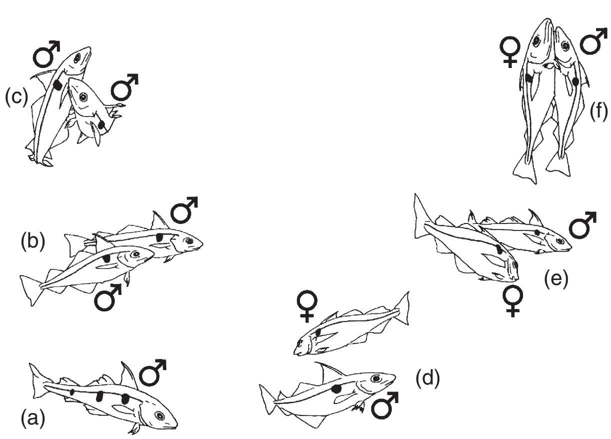

Figure 10 Behavior shown by haddock during courtship: (a) solitary display by a male; (b) lateral display by one male to another; (c) circling of two males in lateral display; (d) lateral display by a male to a female; (e) flicking by a male to a female; (f) mating embrace between male and female, with synchronous release of eggs and milt. From Hawkins AD and Amorim MC (2000) Spawning sounds of the male haddock *Melanogrammus aeglefinus*. *Environmental Biology of Fishes* 59: 29–41.

that are necessary for sound production. This is an example of sexual dimorphism.

In other species (including striped cusk-eel, *Ophidion marginatum* (Ophidiidae), Atlantic croaker, *Micropogonias undulatus* (Sciaenidae), grey gurnards, multiple species of toadfish, midshipmen, and haddock), both sexes produce sound, although differences in anatomy and sound characteristics are apparent. For example, both male and female croaking gouramis, *Trichopsis vittata* (Osphronemidae), produce sounds, but the sounds differ in loudness and spectral characteristics when mating and in agonistic encounters. Female croaking gouramis initiate courtship by producing low-intensity purring sounds, the only species documented to do this.

Sound production in juvenile fishes has not been well studied. Juvenile Lusitanian toadfish, *Halobatrachus didactylus* (Batrachoididae), can produce territorial sounds when they have reached 38 mm in standard length. Atlantic croakers have been shown to have sonic muscles at a standard length of 45 mm and the ability to produce sounds prior to maturity. It has been shown that sounds become louder and lower in frequency as these fishes

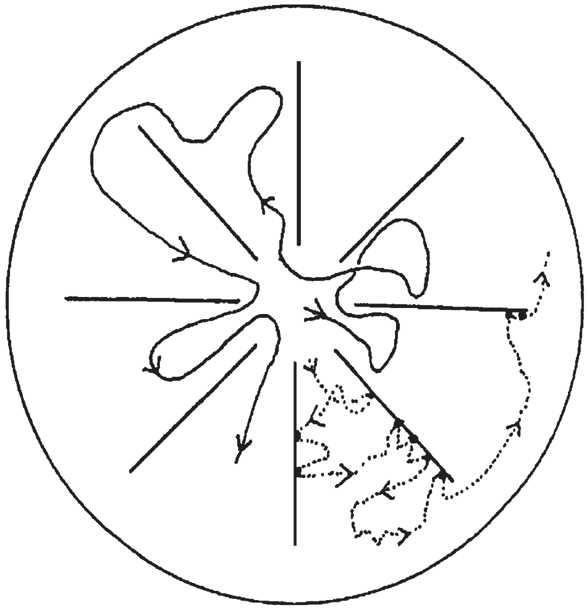

Figure 11 The maze-swimming behavior of sea catfish, *Arius felis*, a normal, sound-producing individual (solid line), and one of a group of eight muted individuals (dashed line). Reproduced from Fig. 6 in Tavolga WN (1976) Acoustic obstacle detection in the sea catfish (*Arius felis*). In: Schuijf A and Hawkins AD (eds.) *Sound Reception in Fishes*, pp. 185–204. Amsterdam: Elsevier, with permission from Elsevier.

grow. There are also differences in the rates of pulsing between juveniles and adults of the same species. These acoustic differences by different life stages may be indicative in changes of behavior (e.g., fighting vs. mating) for these species.

Sound production can vary within a species and sex. Two types of males occur in plainfin midshipman (types I and II), each having different vocal patterns and reproductive strategies. Type I males make the 100-Hz humming sound as an advertisement call to attract females to a spawning nest. Type II males do not make these humming advertisement sounds. Both types of males produce grunts, which are used in agonistic encounters. Instead of initiating courtship behaviors through the hums, type II males will instead employ a sneaker strategy in that they enter the nest of a type I male and spawn with the female, while the type I male is engaged in territorial defense with another type I male. Thus, sound production in midshipman depends upon genetic factors and the physiological state of the males (types I and II, spawning or fighting). Grass gobies also exhibit differences in sound production associated with the alternative reproductive strategies of males: small sneaker males had small dorsal fins, higher frequency (415 Hz), and quieter sounds, while large territory defenders had elongated second dorsal fins, lower-frequency sounds (299 Hz), and louder (by 10 dB) sounds.

Sound Production as a Fishery Management Tool

Scientists have used hydrophones and sound recorders to locate spawning grounds by documenting fishes making sound in the natural environment. Many such studies have been done in association with routine biological sampling, such as egg and larval fish collections using plankton nets, or adult fishes captured by trawl nets and angling. The results of such studies suggest that economically important fishes in the families Sciaenidae, Serranidae, and Gadidae make sound primarily in spawning periods and that sounds can be used as a proxy for spawning behavior. Pelagic egg abundance and sound production of fishes are correlated, both increasing during the mating period. For example, weakfish along the US Atlantic Coast has been shown to increase its sound production during mating periods in May through July each year, when their gonadal development stages are greatest. In addition, the drumming muscles in the male weakfish were also highly developed at that time, due to increased blood levels of testosterone. These results suggest that spawning activities are associated with sound production by male weakfish.

Conclusion

Sound production plays an important role in the survival, social organization, mating success, and navigation capabilities of fishes in dark and turbid aquatic environments. There is a need for more studies linking sound production and specific behaviors in species known to make sound and many more undescribed sound-producing species. Various types of sounds (pulsed and tonal) are produced in association with specific behavior by over 700 species of fishes. Different sounds are produced at different maturity and life stages, with pulsed sound frequencies declining as an individual gets larger. Although most sound producers are males, in some species both sexes make sounds that differ in characteristics.

New technologies based on digital sampling hydrophones connected to automated sound recorders are being used to assess variation in sound production during the day and seasonally, allowing spawning times to be determined remotely. Use of passive acoustic monitoring, combined with active sonar and traditional methods of sampling, can help assess habitat use, size of individuals, and the spawning stock size for economically important sound-producing species and improve fisheries management practices. Scientists now regularly listen to fishes and can identify the species making the sound, their size, and something about their natural behaviors, even when the conditions prevent visual observations. The use of sound by fishes is essential for their survival; humans now appreciate this importance and use it as an aid in conservation of fishes.

See also: **Behavior and Physiology:** Linking Fish Behavior and Physiology: An Introduction. **Hearing and Lateral Line:** Biomechanics of the Inner Ear in Fishes; Psychoacoustics: What Fish Hear; Sound Source Localization and Directional Hearing in Fishes; The Ear and Hearing in Sharks, Skates, and Rays; Vocal Behavior of Fishes: Anatomy and Physiology. **Smell, Taste, and Chemical Sensing:** Chemosensory Behavior. **Vision:** Behavioral Assessment of the Visual Capabilities of Fish.

Further Reading

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