15.1.6: Animal Acoustics

Note

Much of the information about animal perception in this chapter and in Chapters 10 and 14 comes from the excellent book *Engineering Animals: How Life Works* by Mark Denny and Alan McFadzean.

Animals use sounds to communicate to others in their species, to navigate and to find prey. As mentioned previously, small animals tend to make and use high frequency sound to communicate whereas larger animals tend to use lower frequencies but there are exceptions. The size of an animal also affects which of the methods in the previous section it might use to detect the source of a sound. Animals with small heads tend to use phase difference to locate a sound source because the timing difference is too small if your ears are closer together.

Under normal circumstances low frequencies travel larger distances with less ***attenuation*** or loss. Elephants use this fact to communicate over distances of a few kilometers using ***infrasound*** (frequencies below 20 Hz). Woodpeckers use hollow trees to create lower sounds than they sing in order to attract mates and establish territory over longer distances. There is some evidence that pigeons can use the infrasound acoustic signatures of particular land features for long distance migration. Because higher frequencies attenuate sooner than low frequencies, particularly in forests, the timbre of a birdsong will change depending on the distance from the source to the listener. Some birds appear to be able to make use of this fact to locate mates and competitors in places where visibility is limited.

Water carries low frequencies much better than air and whales and dolphins use low frequency sounds to communicate. In the ocean the speed of sound is affected by temperature, salinity and pressure. Temperature decreases with depth but pressure increases with the result that there is a layer of the ocean at a depth of about 0.7 km where the speed of sound is the slowest. At this particular depth, called the Sound Fixing and Ranging channel (SOFAR), the speed of sound is about 1480 m/s (compared to as much as 1540 m/s at other temperatures and pressures). The layer acts as a wave guide; sound that tries to leave the layer refracts back into the layer because of total internal reflection, just like light trying to exit a fiber optic cable at a small angle. Because sound is trapped in this layer it can travel long distances with very little attenuation. The navy has investigated the SOFAR channel as a potential way to detect sounds of enemy submarines at large distances. Some whales appear to be able to communicate over hundreds of kilometers by emitting low frequency sounds in the SOFAR layer.

Most birds do not emit sound signals to navigate or find prey but instead use intensity, phase difference or timing differences of ambient sounds as described in the previous section. The ears of owls are located asymmetrically at different heights on the head. Owls can also change the orientation of the feathers around the ears to get slightly different phase information from a sound source. Based on laboratory experiments we know some owls use timing to establish the azimuthal (up and down) angle to a prey but they use phase shifts to determine the horizontal location of a sound source. This probably gives them something like a two dimensional picture of what is around them using sound instead of light.

A few birds navigate by ***echolocation***, emitting signals and listening for their return. Oilbirds and swiftlets can navigate by timing how long a signal takes to return, the least sophisticated form of echolocation. This allows them to find their nests in dark caves where they nest and avoid collision with other birds but they do not use echolocation to find prey.

Bats and toothed whales are best at echolocation. Higher frequencies have shorter wavelengths which increase accuracy so most echolocating animals use high frequency chirps or clicks to echolocate. Because sound attenuation in water is less than in air, whales can echolocate over much larger distances than bats. Bats use sound to communicate with others of their own species over distances of 50 m to 100 m but must be within about 5 m to use echolocation to hunt prey.

About 800 species of bats echolocate and some have abilities beyond what humans can do with radar or other electronic forms of echolocation. Bats often have unusual face and nose shapes in order to funnel the emitted sound into a narrow beam which helps avoid spurious echoes from background sources. They also have sophisticated brain circuitry which can measure the Doppler shift (Chapter 7) to not only locate their prey but also determine how fast and in which direction the prey is traveling. There is some evidence that some bats can even use the very small Doppler shift from the flapping of the wings of a moth to identify which kind of moth is present. Things are not all bad for the moths, however. Tiger moths can detect the signals emitted by its bat predator and take evasive action and they can even emit a 'jamming' signal to confuse the bat.

Whales and dolphins emit higher frequency clicks, chirps and other sounds which they use for echolocation in addition to lower frequency sounds for communication. It has been shown that dolphins can emit clicks of around 50 micro seconds in duration which gives them up to a $1 \mathrm{~cm}$ resolution at a distance of $100 \mathrm{~m}$. Many of these marine mammals have structures in their foreheads which focus the sounds into a beam pointing forward. When dolphins are closer to their prey they change the frequency of the chirps which gives them a $0.5 \mathrm{~mm}$ resolution at a distance of $1 \mathrm{~m}$. Because some of these sounds penetrate into the fish they are hunting it is very likely dolphins can identify the type of fish present by forming basically a three dimensional picture of the fish, including its skeleton and inner organs using only sound.

One might wonder how it is that echolocators don't deafen their delicate ears with the sounds they emit. We know sound intensity dies off as an inverse square law (Chapter 8) so by the time a signal returns after reflecting off a prey it must be very weak, in fact as much as 10^{20} times weaker. The bat or whale wants to maximize the output signal but have ears as sensitive as possible for the return signal. How is this possible? Most echolocators have mechanisms that mechanically disconnect their hearing apparatus when they are emitting signals.
