

Listening Backward: Early Days of Marine Bioacoustics

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In 1953, the eminent undersea explorer Jacques Cousteau published *The Silent World*. This small volume was to become the generator of a huge upwelling of research on life in the ocean. The title, however, was a misnomer. The book came out years after the end of World War II (WWII) and the concomitant release of data and equipment from the Navy on the plethora of sounds produced by marine organisms. Probably the reason Cousteau could not hear the sounds was because the human ear is just not built for underwater hearing. Besides, the small amount of animal sound that got to his ears was masked by the bubbling of his breathing apparatus. In fact, information on sounds of fishes and cetaceans was available long before World War I. Moby Dick-era whalers listened for the songs of humpback whales through the hulls of their wooden ships. Historical details can be found elsewhere (Tavolga 1971a).

Antisubmarine warfare (ASW) was a major effort during WWII and continues to the present day. The techniques have been based primarily on acoustics, and the presence of what were called “biologicals” was often distracting and confusing. As wartime instrumentation became declassified and available, it was discovered that the seas are truly noisy places, with a cacophony of snapping shrimp, spawning fishes, and echolocating dolphins.

A landmark piece of research in the 1950s was the work of Dr. Marie Poland Fish (Fish 1954; Fish et al. 1952). She reported that a large number of fish species were capable of producing sounds. She and her co-workers literally “auditioned” individual fish in aquarium tanks by stimulating them with the equivalent of an electrical cattle prod. Unfortunately, it turned out that many of the sounds emitted were from violent muscle contractions, not sounds that the animals produced during normal behavior. Nevertheless, the basis for further study in marine bioacoustics was established.

The precise relationship of sounds to behavior is not always easy to determine. In some cases, the choruses of spawning fish (mainly sciaenids) can be heard above water, and such events have been known to fishermen since time immemorial. In most cases, however, the behavioral significance of fish sounds has required underwater listening equipment and careful observation. A combined video and audio system was installed off Bimini, Bahamas, in the 1960s by the Rosenstiel Laboratory of the University of Miami, Coral Gables, FL. The combination of visual and acoustic observations contributed a large body of data on sonic fishes (Cummings et al. 1964; Steinberg and Koczy 1964). In my own studies on the frill-finned goby (*Bathygobius soporator*), I found that

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successful courtship and spawning involved a complex of acoustic, visual, and chemical stimuli (Tavalga 1956, 1958).

Of all marine animals, dolphins were (and still remain) most prominent in bioacoustic research. When the first captive and trained dolphins were exhibited in the 1940s at Marineland in Florida, all were immediately intrigued by the huge variety of sounds they produced, from high-pitched whistles to low buzzes. One well-known physiologist even proposed that dolphins could imitate human speech and had a vocal language of their own (Lilly 1961). The careful research by Schevill (1964) and Norris (1964) eventually separated the communication whistles from the trains of clicks that were used in echolocation.

The echolocating pulses of dolphins were found to be highly directional, and this was discovered to be a function of the oil-filled bulbous forehead, the so-called “melon” (Norris and Evans 1967; Norris et al. 1961). Norris’s research, however, was preceded by a series of unpublished tests using dolphin heads and primitive audio equipment. The credit for these tests and the original idea for echolocation and melon function should go to the late F. G. Wood, Jr., then of Marineland in Florida. Indeed, the directional character of echolocation in dolphins is responsible for the high resolving power and range of this remarkable facility.

Echolocation was first discovered in bats and subsequently in several other mammalian species, including delphinid cetaceans. Short pulse length and high (ultrasonic) frequency enables the finest resolution and identification of targets. However, low-frequency sounds can serve an echolocation function also. Evidence was presented to demonstrate that the low-pitched sound bursts in the sea catfish (*Arius felis*) could serve both a social function in schooling and a coarse version of echolocation (Tavalga 1971b, 1976).

An interesting case was that of the curious very low pitched sounds detected by ASW stations. These were powerful pulses with a dominant frequency of ~20 Hz. The sound sources could be tracked and were immediately classified as top secret. The military minds were quick to blame an adversary, possibly a Russian submarine with a secret device. These 20-Hz sounds had been recorded and publically puzzled over off the Canadian east coast for many years but became designated as secret south of the 54°40′ parallel. Although known since the 1940s, these sounds were declassified during the Marine Bioacoustics Conference in Bimini in 1963, and their source was identified as a large cetacean, probably the fin whale (*Balaenoptera physalus*) (Patterson and Hamilton 1964; Schevill et al. 1964; Walker 1964).

In proposing to investigate the function of acoustics in the behavior of fishes, obvious experimental procedures involve the playback of sounds, natural and artificial. How loud should the stimulus sounds be? What about pitch and timbre? The question of how well can fish hear has to be addressed first. Lacking an external ear, it was assumed that fish were essentially deaf, but sporadic reports began to appear in the early 1900s. A dramatic and convincing demonstration was when the eminent Karl von Frisch trained catfish in his backyard pond to come when he whistled (von Frisch 1923). These early studies on fish hearing have been adequately reviewed elsewhere (Kleerekoper and Chagnon 1954; Moulton 1963; Tavalga and Wodinsky 1963). However, few of these reports contained any quantitative data. An attempt to put absolute values on hearing thresholds in fishes was a report using avoidance conditioning (Tavalga and Wodinsky 1963), and subsequent attempts to demonstrate masking and frequency discrimination (Tavalga 1967; Tavalga and Jacobs 1968). Current techniques using electrophysiological auditory brain stem response (ABR) have confirmed much of the data derived from behavioral conditioning (Fay 1988). In this way, the first evidence for ultrasound detection in fish was established (Mann et al. 1997). We are now capable of testing fragile species such as herring and anchovies. Indeed, we were able to demonstrate that a clupeid fish, the menhaden (*Brevoortia*), was capable of detecting sound frequencies from 40,000 to at least 80,000 Hz (Mann et al. 2001).

In goldfish (*Carassius auratus*) hearing, thresholds obtained by behavioral techniques and electrophysiological measurements were not significantly different (Fay 1988). This may not always be

the case. Field observations on the bonefish (*Albula vulpes*) show the fish to be very sensitive and responsive to noises, yet laboratory tests of their hearing reveal thresholds not significantly different from those of other species in the same areas. In other words, some fish “listen” better but may not actually have better hearing (Tavolga 1974).

A few words here about a good friend and colleague, the late Arthur Myrberg. Art was a true ethologist and was a student with Konrad Lorenz. He and I spend many hours, far into the night, over a bottle of wine, arguing about “releasers,” instinct, and innate behavior. He was a keen observer and a fine scientist, and his studies on behavior of reef fishes are true classics (Myrberg 1972). He bemoaned the fact that so little research was being done on acoustic behavior in fish. With all the advances we have made in the areas of acoustic reception in fishes over the past 10–15 years, our behavioral advances have lagged far behind. Armed with our understanding of audition, we should now be able to pursue the operation of acoustics at the higher levels of organization, e.g., behavior, ethology, and sociobiology. We now have the tools of psychophysics, and we have a substantial database on the acoustic sensory system in fishes and marine mammals. We should use this information to learn more about how these animals use this acoustic sense to survive. Here is an example. The ubiquitous freshwater catfish (*Ameiurus*) and carp (*Carassius*; the ancestor of the domesticated goldfish) possess a highly specialized hearing system of Weberian ossicles, yet produce no sounds of their own and appear to live in a quiet neighborhood. What is that fish listening to so intently? What does it need to hear to survive? In other words, how do fish use their bioacoustic properties to make a living?

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