Symbiotic Behavior among Fishes from Temperate Ocean Waters

Abstract. *Symbiotic cleaning among Atlantic coastal fishes has been observed under laboratory conditions. The cleaning phenomenon may be commonplace in the natural environment along the Atlantic seaboard. The black sea bass,* Centropristes striatus *(Linn.), parasitized by the copepod,* Lernaeenicus radiatus *(Le Sueur), was cleaned by a topminnow,* Fundulus heteroclitus *(Linn.). The behavior was recorded by cinematography and analyzed.*

Limbaugh (*1*) reported extensive field observations of symbiotic cleaning among fishes. It appears to be an important biological phenomenon. The symbiotic cleaners included 26 species of fish, 6 species of shrimp, and Beebe's crab. Limbaugh stated that, "the phenomenon appears to be more highly developed in clear tropical waters than in cooler regions of the sea." We report here a symbiotic relationship occurring under laboratory conditions, analysis of which indicates that cleaning may be widespread in temperate ocean waters. The conditions in these waters are not as favorable for underwater observations as those described by Limbaugh, consequently the symbiosis may go unnoticed.

A cylindrical glass tube, 365 cm long and 10.2 cm in diameter, was being used as a closed chamber with aeration and pressure control equipment for studies of pressure sensitivity and buoyancy reflexes in marine fishes. Among these fishes was the black sea bass, *Centropristes striatus* (Linn.), a predatory fish readily caught near the laboratory. According to Migdalski (*2*), "this sea bass is a strictly salt water species distributed along the Atlantic coastal waters from northern Florida to Cape Cod with strays to Maine."

Live topminnows, especially *Fundulus heteroclitus* (Linn.), were provided as food for bass in the sealed chamber. Breder (*3*) reported that *Fundulus* ranges from the Gulf of St. Lawrence to the Gulf of Mexico, in the same waters as where the sea bass is found. Both species are abundant throughout this range; moreover they follow the same seasonal inshore-offshore migration patterns.

Fishes to be studied were kept singly in the chamber where each was given several days of conditioning and preliminary testing before the experiments were begun. One bass was infected with minute, threadlike parasites, *Lernaeenicus radiatus* (Le Sueur) (*4*). The bass seemed normal when tested for behavior, reflexes, and buoyancy responses. The parasites went unnoticed until the beginning of the actual experiments.

Lernaeenicus radiatus, a copepod, is found in the North Atlantic and in North American coastal waters (*5*). It is 35 to 45 mm long and less than 2 mm in diameter; it has a globular head with radiating horns and both the head and horns are buried in the flesh of the host; its threadlike neck is about half the length of the whole animal. The neck and trunk may protrude freely when the parasite is attached, but they may be retracted. This parasite has been found on 11 species of fish (*5*), including the topminnow (*Cyprinodon variegatus*). Copepod infestations are more common among fishes kept in aquaria than among those freshly caught. *Lernaeenicus radiatus* is a ubiquitous species and shares the same range as the sea bass and *Fundulus*.

In fishes, stereotyped behavior patterns which may be identified in their responses to changes in pressure are also involved in cleaning symbiosis. One of these patterns is a state of generalized motor inhibition. The sea bass, like pinfish (*6*), show this "immobilization

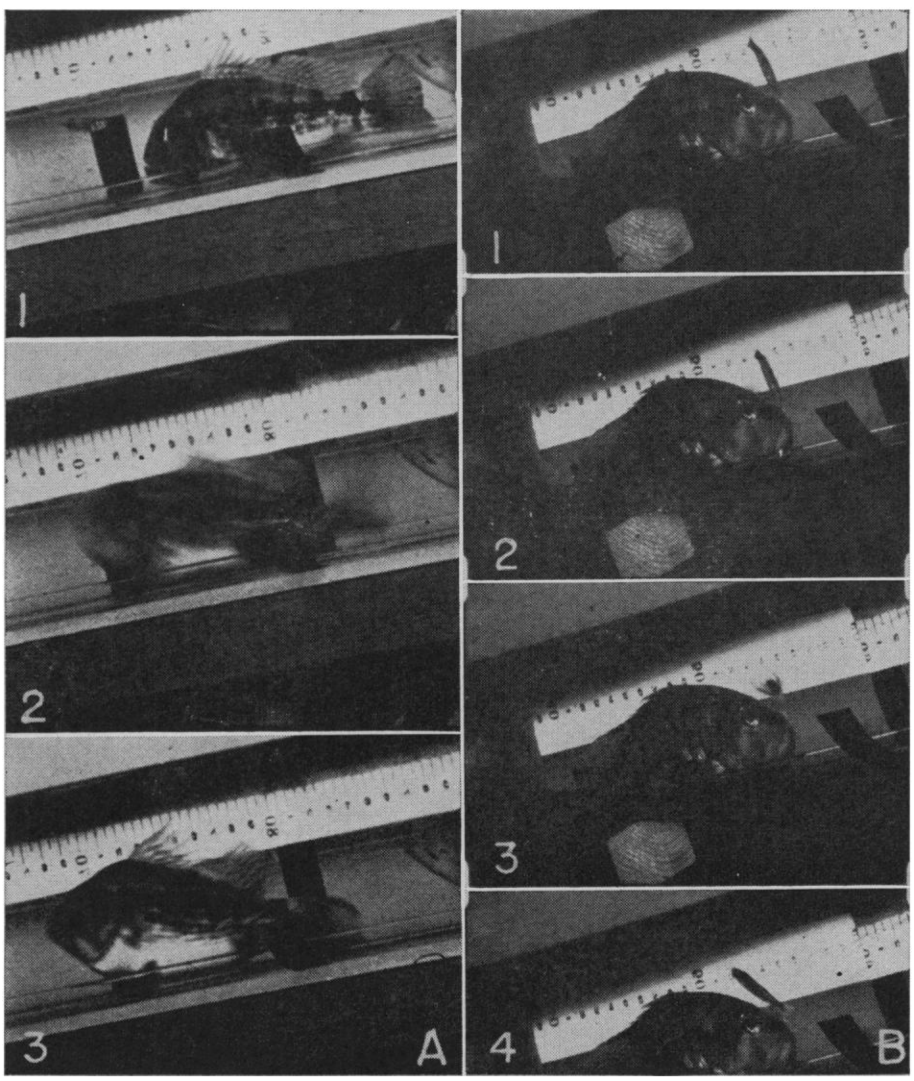

Fig. 1. Predatory and symbiotic relationships between a black sea bass and a *Fundulus*; successive frames at 16 per second. (*A*) *1*, Fundulus swimming past a bass; *2*, bass engulfing the *Fundulus*; *3*, bass swallowing the *Fundulus*. (*B*) *1*, *Fundulus* approaching a copepod parasite on the head of the bass; *2*, *Fundulus* seizing the copepod; *3*, *Fundulus* tearing away a piece of the copepod; *4*, *Fundulus* swallowing as it circles back to the bass.

pattern" in response to strong aversive stimuli. These fishes also become immobile periodically when adjusting for imposed buoyancy displacement (*7*). Another behavioral pattern is marked erection of the dorsal fin (Fig. 1*A*). This display is a common "alarm reaction" in a fish when other animals encroach on its position, or when defensive-aggressive action is imminent. The same fin erection may be found among the reflexes for buoyancy adjustment of swimbladder volume.

A bass which is stationary, or in the immobile state, is approached by topminnows as though it were an inanimate object. One topminnow may swim by within a few centimeters if the bass remains still. Topminnows are always alert to any fish when it makes a fin display or moves, but these topminnows showed no strong aversive reactions to the bass even though it is a predator. However, no topminnow remained beside or touched a normal bass; a marked contrast to their symbiotic behavior with the parasitized fish.

When the parasitized bass had been in the cylinder 48 hours, live topminnows were added as food. Two of these, including a *Fundulus*, were eaten within 3 hours. Feeding behavior did not involve extensive pursuit. The bass usually remained at a "fix position" (*6*) until a topminnow swam to within a few centimeters of it. The bass then advanced slightly; poised, as the topminnow hesitated; then lunged, mouth agape, to eat the topminnow. This was typical feeding behavior for all bass (Fig. 1*A*).

Symbiotic cleaning was first noticed on the day after topminnows were placed in the cylinder. The bass seemed to be paralyzed or insensitive. A *Fundulus* attacked the fins and the velum of the opercular margins. The bass rested on the bottom in an awkward posture, in slightly negative hydrostatic buoyancy. The topminnow sometimes wrested those parts it was biting with enough force to lift the bass bodily from its place. The bass remained completely passive and parasites were suspected. It did retain normal eye reflexes. Since the attacks of the topminnows seemed to focus on parasites the bass was kept in the cylinder so that the behavior of the animals and their interrelationships could be studied and recorded by cinematography. Cleaning activity occurred at intervals of an hour or more and lasted a few minutes. Each of three remaining topminnows in the cylinder participated during the 3-day period of observation. All topminnows and most parasites had been eaten before the 4th day. The bass and parasites were examined post-mortem (*4*).

Before the topminnows showed this cleaning behavior, the bass had usually remained stationary, but not immobile, at its "fix position" for 10 minutes or more. If it was moving, it became stationary as a topminnow approached with a series of darts and pauses. At the beginning of the approach, the bass sometimes exhibited a transient alarm reaction. As the approach continued, the bass settled to rest on the bottom with fins fully relaxed. This state of generalized motor inhibition is comparable to the "immobilization pattern" of buoyancy displacement.

The topminnow then explored about the surface of the bass, tearing off pieces of copepods. Biting around the head disturbed the bass no more than biting at the fins (Fig. 1*B*). If the topminnow worked about an opercular margin, that operculum would gape sufficiently for the topminnow to reach its inner surface. If a wresting action displaced the body of the bass or tilted it, there was usually no compensating fin action. When the topminnow eventually moved away, the bass returned to its normal orientation. The postural reflexes and buoyancy responses of this bass always responded normally to hydrostatic manipulation (*6, 7*).

Mutuality and cooperation in the cleaning relationship is emphasized by the fact that the bass exposed vulnerable gill regions. This "host" behavior is like exposure of the open mouth for cleaning, which Limbaugh reported (*1*). He saw, in the natural habitat, that gobies entered the mouths of groupers, hogfishes the mouths of barracuda; and while blacksmiths were being cleaned by señoritas they "would remain motionless in the most awkward positions—on their sides, head up, head down or even upsidedown."

There are three possibilities to explain the bass-*Fundulus* symbiosis: (i) the specific relationship was a natural one to which the bass was habituated; (ii) a behavioral background for symbiotic cleaning already existed through independent conditioning in both species; or (iii) a spontaneous, new, facile interaction developed under the experimental conditions. The third possibility seems the least probable. Such a complex behavioral interaction, reversing an established predator-prey relationship and becoming complete within 12 hours after the animals came together, supports the hypothesis of previous conditioning. Whether black sea bass and *Fundulus* are in fact symbiotic in their usual environment is unknown. Their established distribution and natural history, together with the observations here reported, make natural symbiosis probable.

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References and Notes

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Electroencephalograms of Sharks

Abstract. *Patterns of electrical potentials recorded from the brains of sharks exhibit definite relationships to chemical and visual stimuli. Forebrain potentials reflect olfactory processes. Both restrained and free-swimming sharks exhibit mesencephalic responses to light and neural triggering of respiratory reflexes from the medulla. Early evolution of typical vertebrate brain functions, with emphasis upon chemoreception, is indicated.*

Patterns of electrical potentials from the brains of sharks are of interest from two main standpoints. First, the elasmobranchs illustrate more primitive features in the evolution of the vertebrate brain than any other examples which have been subjected, thus far, to electroencephalographic (EEG) study. Consequently, EEG analysis might reveal features of brain function established some 350 million years ago, during the Devonian Period (*1*). Second,