Bull. Southern California Acad. Sci.
97(2), 1998, pp. 76–81

Strategies of Predator Attacks on the Schooling Fish, *Selar crumenophthalmus*, in Academy Bay, Socorro Island, Islas Revillagigedo, Mexico

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Abstract.—One of the main reasons that fish form schools is that it serves to reduce the risk of being eaten. Single predators are most successful at capturing individuals not in schools. For every successful anti-predator strategy by a prey species there is usually a concomitant more successful strategy by the predators. I report here on the behavior of three species of predatory fish and two species of predatory birds toward a school of jacks, *Selar crumenophthalmus* which demonstrate that these predators use a variety of methods to obtain fish from a school.

Fish school for a variety of reasons. The behavior, dynamics, and advantages of fish schools and other similar aggregations in birds, tadpoles, and mammals have been fully described by many authors (Brattstrom 1962, 1989; Breder 1959, 1967; Cushing and Harden Jones 1968; Elliott, et al. 1977; Hamilton 1971; Major 1978, 1979; Partridge 1982; Partridge and Pitcher 1980; Seghers 1974; Shaw 1970, 1978; Webb 1980). One of the main reasons that fish school is that it serves to reduce the risk of being eaten (Breder 1967; Partridge 1982). Single predators are most successful at capturing isolated, individual prey and less successful at capturing individuals in schools (Brattstrom 1989; Major 1978, 1979). Thanks to natural selection, there usually will be a concomitant more successful strategy by the predators for every successful anti-predator strategy by a prey species! Studies on the behavior of the predator in response to schooling fish are diverse (Katzir and Chamhi 1993; Major 1978, 1979; Parish, Strand, and Lott 1989; Schmitt and Strand 1982). The outcome of any interaction between the predator and the prey fish usually depends on three factors: relative performance, maneuvering, and timing (Webb 1980). In addition, Major (1978) showed that while single predators are most successful at capturing isolated prey and less successful at capturing individuals in schools, grouped predators were more successful at capturing schooled prey. Larger predators were also able to break up schools of prey, resulting in increased numbers of prey becoming isolated. These predators then attacked these isolated individuals (Major 1978). I report here on the behavior of three species of predatory fish and two species of predatory birds preying on a school of jacks, *Selar crumenophthalmus*. This behavior shows that these predators have developed diverse strategies to prey on schooling fish.

I observed the predation of three species of fish yellowtail, *Seriola lalanderi*, California needlefish, *Strongylura exilis*, and black-tipped shark, *Carcharhinus limbatus*) and two species of birds (masked booby, *Sula dactylatra*, and great frigatebird, *Fregata minor*) on schooling jacks, *Selar crumenophthalmus*, locally called cabalito.

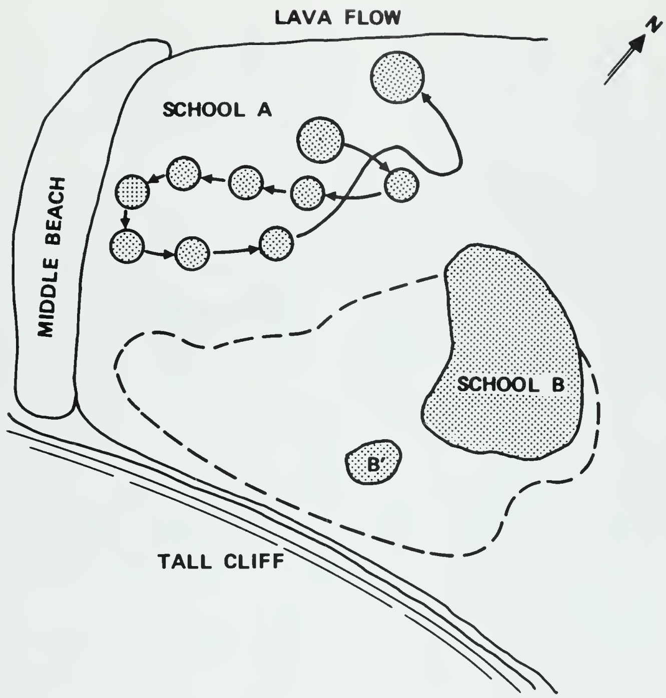

Fig. 1. Diagram of Academy Bay, Socorro Island, Mexico of cliff from which observations were made.

Observations were made from a cliff above Academy Bay, at the north end of Socorro Island, Islas Revillagigedo, Mexico. Socorro Island is 390 km SW of the southern tip of Baja California (see descriptions in Brattstrom 1955, 1963, 1982, 1990; Brattstrom and Howell 1956; Richards and Brattstrom 1959).

Observations were made throughout the day of 14 April, 1978 by me and other members of the Carnegie Museum/Sea World, 1978 Expedition to the Islas Revillagigedo. Notes and photographs (35 mm slides, 16 mm color film) were made of the schooling jacks (Fig. 1, 3). Predation by the fish was observed in the clear shallow water from the cliff (Fig. 1), predation by the birds was observed from the cliff, beach, and aboard the expedition ship anchored in Academy Bay. The temperature of the water in the bay as taken from under the ship was 25°C.

Following Breder (1959), I define a school as a behavior in which the fish are oriented in the same direction and are more or less one fish-length apart, a Pod as a group of fish that are in contact, a Pod I (or "ball") when the fish show no orientation and a Pod II when the fish show orientation.

The jacks were in two, large schools (Fig. 1), each estimated to contain tens of thousands of fish. These schools would often spontaneously change into a Pod I or Pod II. Even when the fish were oriented in one direction, the entire school or pod did not really move very far. Instead, the entire school or pod seemed to slowly "float" about the bay. School B (see Fig. 1) once divided in two and then recombined. The two main schools never joined, even though at one time they were within 3 m of each other.

The behavior of the fish in the school changed as the school approached the shore (Fig. 2; beach effect). Here the waves and/or the shallow water caused the fish nearest the shore to form a Pod II (dots in Fig. 2). This pod formation spread until the whole group was in a pod. This pod slowly moved away from the shore and switched back to a school.

Three species of predatory fish were also observed in the bay and each attempted to feed on the jacks in a different way. Groups of from two to 12 yellowtail swam around the bay always some distance from the jacks. They would circle both schools or swim back and forth in front of the beach or below the cliff. Now and then, and very suddenly, the group would turn toward the school and swim side by side straight into the school of jacks (Fig. 2, top). The fish in the school would immediately form a Pod I or Pod II at the edge of the school where the yellowtail were attacking. With the continued forward movement of the yellowtail, a ripple-like effect of school changing into pod occurred until finally all the fish were in a ball or Pod I. As the predators left, the pod would change back into a school formation as diagrammed in Fig. 2. I could not determine if the yellowtail actually caught any of the jacks, though this strategy is usually successful (Major 1978). Cooperative foraging in yellowtail has also been documented by Schmitt and Strand (1982).

Two black-tip sharks were also swimming in the bay. Now and then a shark would circle around a school of jacks, moving closer and closer to the school as it circled (Fig. 2). When the shark was about 3 m from the school, the jacks on the outer edge of the school would begin to contact each other. As the shark got closer the pod formation continued from outside toward the center until all fish were in a Pod I or ball. At that time the shark turned directly into the ball, mouth opening and closing (Fig. 2).

A single needlefish also occurred in the bay. It usually swam just below the tall cliff on which I was standing. It appeared not to notice the schooling fish, yet (and I saw this happen many times) the needlefish would turn, suddenly, directly toward the school. It swam fast, and just before reaching the school, would jump out of the water and almost sail, like a flying fish. It would land in the water in the middle of the schooling jacks with its mouth opening and closing (Fig. 2). Again, I could not determine if the needlefish was successful in obtaining a prey fish, but the density of jacks would suggest that there was a high degree of success.

The schooling jacks were also preyed upon by two sea birds. For most of the day a single frigatebird and a single masked booby flew over the bay. Both fed on the jacks by plunging down on the fish from above (Fig. 2). Both birds were successful in catching fish. The booby, for example, caught three fish in three dives over a six minute period from 1432–1458 hrs. The school/pod concentration of the prey made escape responses of the fish less effective (Katzir and Camhi 1993) and presumably therefore increased the success of the birds.

While schooling behavior in fishes may have many causes and advantages, the most documented advantage is, of course, the group effect against predators (Breder 1967; Partridge 1982). It is usually the individual, isolated or separated from the herd, flock, or school, that is taken by predators (Brattstrom 1989). Yet the mere presence of this school in this bay allowed the feeding on the school by these predators. In addition, two of the predators manipulated the school into a

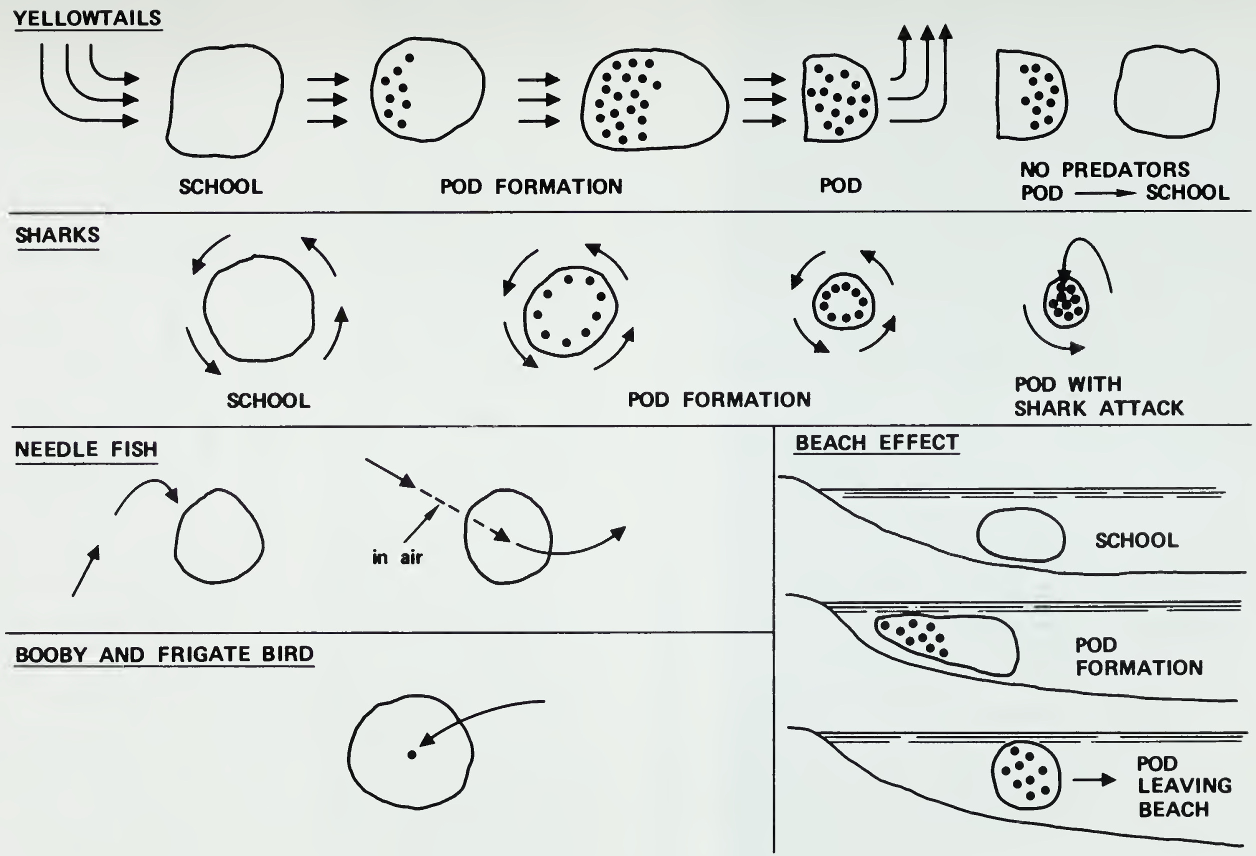

Fig. 2. Diagrams showing behavior of several predators, response of the jacks to those predators, and response of the jacks to the beach. Irregular outline shows the shape and size of the school; black dots indicate when and where the school is changing into a pod formation.

Fig. 3. Photograph of a school of jacks, *Selar crumenophthalmus*, in Academy Bay, Socorro Island, Mexico. Photograph by Robert Pitman.

pod formation where it would be expected that nearly any bite by a predator would be assured of striking a fish. Parrish, Strand, and Lott (1989) showed that while predation was highest on isolated stragglers, predation on a school of flat-iron herring, *Harengula thrissina*, due to predator strategies, was about equal on peripheral and central fish in the school. Thus, while there is an advantage to schooling by fish, there are also predators that take advantage of that schooling behavior. In addition, cooperative hunting can circumvent the schooling advantage to prey species (Schmitt and Strand 1982).

Acknowledgments

The 1978 trip to the Islas Revillagigedo was aboard the R/V Sea World and was sponsored by the Carnegie Museum of Philadelphia and Sea World of San Diego under the leadership of Drs. Kenneth Parkes and Joe Jehl and was specifically designed to study aspects of the biota of Socorro and allow me to continue my studies of the effect of Barcena Volcano, 1952 on the biota of San Benedicto Island (Brattstrom 1963). I am very thankful to those gentlemen and their institutions for support. Identifications of fish were made by Dr. Richard Rosenblatt, Scripps Institution of Oceanography and an early draft of the manuscript was read by Dr. Michael Horn. Figure 1 was photographed by Robert Pitman and the copy made by Alan Fugleberg. The drawings were made by Mark Zolle with funds from the Department of Biology, California State University, Fullerton.

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Accepted for publication, 26 June, 1997.