BEHAVIOR OF BLUEFIN TUNA SCHOOLS IN THE EASTERN NORTH PACIFIC OCEAN AS INFERRED FROM FISHERMEN'S LOGBOOKS, 1960-67[1]

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ABSTRACT

Fishermen's records of 8,059 purse-seine sets made on *Thunnus thynnus* (bluefin tuna) were examined for the period 1960-67. A total of 3,538 sets were identified as to school type. The majority of these sets were made within 90 miles of the beach off southern and Baja California from lat 23°N to 34°N. The region was divided into a northern and southern area on the basis of biological and oceanographic factors.

Significant differences were observed in the occurrence of the six most common school types between the northern and southern most areas of the fishery. The difference in occurrence of the jumping, boiling, and shining schools was related to the relative absence of red crabs (*Pleuroncodes planipes*) in the northern area and to differences in the foraging behavior of *T. thynnus* on baitfish and red crabs.

Differences in vulnerability to capture and catch per successful set were noted among the five most common daytime schools as well as with respect to time of day.

Purse-seine sets made with the assistance of airborne spotters had larger catches and a greater percentage success than did unassisted sets. In addition the percentage of a particular school type taken with aircraft assistance was inversely proportional to the visibility of the schools from the mast.

The existence of different school types in scombroid fishes has been noted by several authors. In 1931, Suzaki (as cited by Uda, 1933) recognized five types of skipjack tuna (*Katsuwonus pelamis*) schools in the western tropical Pacific. Kimura (1954) listed six types of skipjack tuna schools. To these Inoue (1959) added three additional types based on behavior and association of the tuna with animals and inanimate objects. Ogilvie (1949)[4] described 10 types of tuna schools commonly encountered in the eastern tropical Pacific. McNeely (1961) stated that the California tuna fishermen recognized several different school types for yellowfin (*Thunnus albacares*), skipjack, and bluefin tuna (*T. thynnus*). Scott (1969) described 16 different school types for the eastern Pacific tunas, listed fishermen's synonyms, and placed them into two major groups and five lesser categories on the basis of time of day, depth of occurrence, and association with other animals and floating objects.

Various attempts have been made to correlate the type of school with fishing success. Uda (1933) and Uda and Tukusi (1934) attempted to show an "index of biting" for the different school types as did Kimura (1954). Inoue (1959) correlated the percentage success of the Japanese purse seiner fleet with school types for yellowfin, skipjack, and bluefin tuna in the western tropical Pacific. Inoue's data indicated that possible differences in school size and vulnera-

[1] This work was initiated while both authors were employed in the Tuna Resources Laboratory of the Bureau of Commercial Fisheries (now the National Marine Fisheries Service, Southwest Fisheries Center) under the direction of Dr. Richard R. Whitney, then leader of the Tuna Behavior Program.

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[4] Ogilvie, H. 1949. Description of various types of tuna schools, of behavior, methods of fishing and production possibilities in relation to pole and line fishing encountered in Central America. Inter-American Tropical Tuna Commission, La Jolla, Calif. 5 p. (Manuscr.)

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bility to capture existed among the various school types as well as between the three species.

MATERIALS AND METHODS

In order to describe the schooling behavior of *T. thynnus* in the eastern North Pacific and to relate this behavior to percentage of successful sets and catch per successful purse-seine set, California fishermen's logbooks were analyzed for the period 1960-67. Abstracts of these logs were made available through the courtesy of the Inter-American Tropical Tuna Commission.

A purse-seine set is defined as that operation in which the net is laid out around a school of fish and the bottom of the net drawn together, capturing the fish, which are then transferred to the vessel (Orange, Schaefer, and Larmie, 1957). A complete description of the fishing operation is given by McNeely (1961). For the purposes of this paper the term "school" will apply to that quantity of fish captured in a successful set of the net. No assumptions as to the configuration of the school nor the orientation of the fish within the school will be made (see Williams, 1964; Breder, 1967).

Orange, Schaefer, and Larmie (1957) made several assumptions in analyzing single set data from fishermen's logbooks, and other workers have followed (Broadhead and Orange, 1960; Whitney, 1969). These assumptions are:

1. A set of the net is made on a single school of fish.
2. Either the entire school is captured or each set captures a constant fraction of the school upon which it is made.
3. Vessel masters can estimate accurately the tonnage from individual sets of the net.

In addition, it is assumed that the schooling behavior described in ship's logs indicated the school type evident when the fish were first observed.

The average size of all schools may actually be smaller than those cited by the fishermen because small schools of 2 tons or less may be passed over by the fishermen in the hope of capturing a larger school later in the day.

In regard to the second assumption, fishermen generally agree that it is extremely difficult to "cut" a tuna school with their nets; it appears to be an all-or-nothing situation. Typically a fisherman will catch ¼ ton or less when the school is missed. These fish usually are entrapped in net folds during the pursing operation and are unable to escape with the main body of the school being set upon. The constant fraction, therefore, approaches zero. That the second assumption does not hold in every case was recognized by the original proponents (Orange, Schaefer, and Larmie, 1957). We have assumed also that the fraction of fish retained in the net from a school escaping capture is the same for all school types, as well as for all times of day; these are factors which need additional study.

Fishermen identify schools to species with considerable skill, but the system of identification is difficult to describe. Their ability to judge tonnage, however, is very good after the fish are inside the net and in full view of the mastman. The airborne spotters are extremely good at estimating school size.

Bluefin net sets were defined to be: 1) all sets in which 90% or more of the total tonnage landed was *T. thynnus*, 2) all no-catch sets in which *T. thynnus* was clearly identified as the pursued species, and 3) all sets in which it could be determined from location, water temperature, date, time, and previous and later sets by the same or other boats operating nearby that it was *T. thynnus* being sought and/or captured. Using the above criteria, we determined that a minimum of 8,059 sets were made on *T. thynnus* and 65,478 tons landed by the eastern North Pacific high seas purse-seine fleet during the period 1960-67. Of these sets, 43.9% were identified in the logbooks as to school type.

All weight references in this paper are expressed in short ton units.

SCHOOLING BEHAVIOR

The terminology of school types used in this paper is that of Scott (1969) (Table 1). *T. thynnus* exhibited 13 different types of schooling

TABLE 1.—Terms used by southern California purse-seine tuna fishermen to describe various types of tuna schools and associations (from Scott, 1969).

School fish	Associated schools[1]
Surface schools[1]	Fish and mammals[1]
Breezer	Porpoise schools
Finner	Spotters
Jumper	Spinners
Boiler, foamer, smoker, or meatball	Spotters and spinners
	Whitebelly
	Whale schools
Subsurface schools[1]	
	Shark schools
Black spot, dark spot, brown spot, green spot, or black ball	Inanimate object association[1]
	Log school
Shiner	Bait boat
Night schools[1]	
Fireball, ardura, glow spot, white spot, or flare	
Popper	

[1] These terms are used for organization of the table and are not used by the fishermen.

behavior and 12 different combinations of these to the commercial fishermen. There were differences in frequency of occurrence, size of the schools, and vulnerability to capture between the schools (Table 2). Differences in the occurrence of the school types in the northern and southern areas of the fishery were also evident (Table 3).

In order to eliminate possible bias in analyzing school size and percentage success, all sets made with the assistance of airborne spotters have been separated. The effects of airborne spotters on catch data will be discussed later in this paper.

Of the 13 school types observed, only 6 were recorded often enough (50 or more times) to warrant attention.

GEOGRAPHICAL VARIATION

T. thynnus is taken along the coast of Baja California and southern California from lat 23°N to 34°N. Occasionally fish are taken north of this area, especially in warm water years, but they are few, and seiner operations are severely limited by prevailing weather and sea conditions. The greatest percentage of the bluefin catch is made within 90 miles of shore near shoals, banks, reefs, and islands.

We have divided the area of the fishery into two major areas: that area north of lat 28°59′N and the area south of and including that same latitude (Figure 1). There is some biological basis for this division, as Punta Eugenia marks the northernmost extension of the Panamic fauna (Steinbeck and Ricketts, 1941). In addition, oceanographic and meteorological conditions also differ considerably. South of Punta Eugenia, an annual visitation of warm tropical

TABLE 2.—Catch statistics for 13 different bluefin school types and 4 different categories of combined schooling behavior observed.
[All purse-seine sets recording schooling behavior are included.]

School type	Total sets	Successful sets		Total catch (short tons)	Average catch per successful set (short tons)
		Number	Percent		
Breezers	1,871	870	46.5	17,043	19.6
Boilers	221	141	63.8	1,286	9.1
Jumpers	639	414	64.8	2,192	5.3
Black spots	137	61	44.5	1,475	24.2
Shiners	111	67	60.4	776	11.6
Foamers	7	5	71.4	104	20.8
Fireballs	397	293	73.8	4,423	15.1
Finners	7	5	71.4	45	9.0
Log	1	0	0	0	0
Whales	15	6	40.0	91	15.2
Poppers	8	6	75.0	29	4.8
White spots	7	6	85.7	58	9.7
Meatballs	3	2	66.7	40	20.0
Combined schooling behavior recorded for the following					
Breezers	96	45	46.9	837	18.6
Boilers	4	3	75.0	68	22.7
Jumpers	10	8	80.0	68	8.5
Black spots	4	2	50.0	38	19.0
Total	3,538	1,934	54.7	28,573	14.8

TABLE 3.—Catch statistics for all non-aircraft assisted bluefin purse-seine sets recording schooling behavior.

School type	North of lat 28°59'N					South of lat 28°59'N					Northern and southern areas combined				
	Total sets	Successful sets		Catch per successful set (short tons)		Total sets	Successful sets		Catch per successful set (short tons)		Total sets	Successful sets		Catch per successful set (short tons)	
		Number	Percent	Median	Range		Number	Percent	Median	Range		Number	Percent	Median	Range
Breezers	475	206	43.4	10.5	0.3-100.0	1,037	492	47.5	14.0	0.5-145.0	1,512	698	46.1	12.0	0.3-145.0
Boilers	191	114	59.7	4.0	0.3- 73.0	13	7	53.9	25.0	4.0-106.0	204	121	59.3	4.0	0.3-106.0
Jumpers	572	363	63.5	2.0	0.2- 25.0	23	16	69.6	5.0	1.0- 44.0	595	379	63.7	2.0	0.2- 85.0
Black spots	17	5	29.4	9.0	4.0- 30.0	70	31	44.3	15.0	2.0-200.0	87	36	41.4	15.0	2.0-200.0
Shiners	39	29	74.4	8.0	1.0- 55.0	28	10	35.7	5.0	1.0- 15.0	67	39	58.2	7.0	1.0- 55.0
Fireballs	296	220	74.3	8.0	5.0-140.0	94	68	72.3	12.0	0.3- 65.0	390	288	73.9	9.0	0.3-140.0
Total	1,590	937	58.9			1,265	624	49.3			2,855	1,561	54.1		

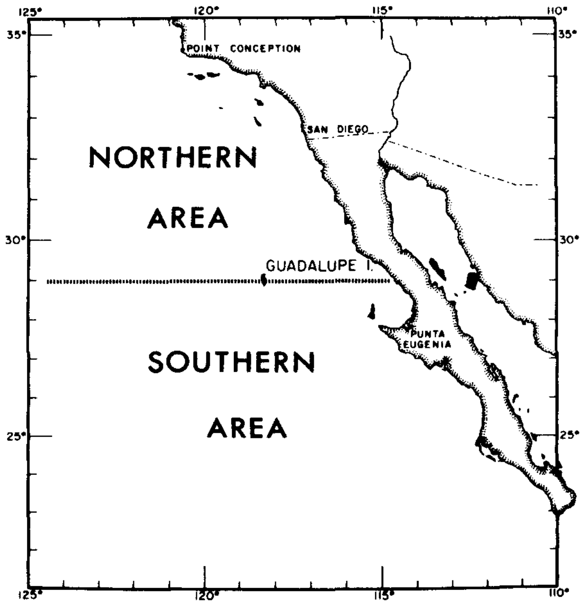

FIGURE 1.—Area of the eastern north Pacific bluefin tuna fishery.

waters occurs (except for a narrow band of very cold, rich upwelled water near shore south to San Juanico). Red crabs (*Pleuroncodes planipes*) are abundant in this area. Winds and weather are generally favorable for purse-seine operations after mid-June, but in April and May strong northwest winds severely restrict fishing.

From Punta Eugenia to Point Conception, the southern California offshore area typically exhibits the warm Catalina Gyre in association with cold, upwelled water centered off Ensenada and to the north of Point Conception. Hydrographic conditions in this region favor good filter feeding for bait fishes, and winds and weather improve in late July through September. Seldom is this district too warm for bluefin.

The occurrence of the various school types in the northern and southern areas of the fishery is nonrandom (chi square 985.20, $P<0.001$). Perhaps the most striking difference is the almost complete lack of jumping and boiling schools in the southern area and the predominance of breezers in this same area (Table 3). These differences may reflect differences in the feeding behavior of *T. thynnus* on different prey species. McHugh (1952) and Alverson (1963) found differences in the stomach contents of albacore, yellowfin, and skipjack tuna in different geographical areas. McHugh noted that red crabs were the dominant food item for albacore off the Baja California coast, while anchovies and other baitfish dominated in fish stomachs taken from southern California waters. Blunt (1958) noted that of 168 *T. thynnus* taken off California in 1957, 70% had been feeding on anchovies. Longhurst (1967) observed that during normal years the distribution of *P. planipes* reaches from the area of Cedros Island south, while the range extends farther north during warm water years. This distributional pattern includes the entire area from which jumpers and boilers were almost entirely absent. While baitfish, like anchovies, are found in the southern area, previously cited studies indicate that red crabs may be the preferred food item. Since *P. planipes* is a relatively weak swimmer and occurs in very dense concentrations off southern Baja California, a modified filter feeding such as Sette (1950) described for Atlantic mackerel (*Scomber scombrus*) might be employed by *T. thynnus* while feeding on red crabs. On the other hand, the vigorous pursuit by scombroids feeding on forage fish is well known (Magnuson, 1963; Whitney, 1969).

The lack of jumping and boiling schools in the southern area also may be due to differences in the behavior of *T. thynnus* feeding on *P. planipes* and baitfish and a preference for the former when available. Comparisons of stomach contents of *T. thynnus* from the three school types would provide the necessary test of this hypothesis, but such information is not available. However, analyses of stomach contents for yellowfin from an area in which *P. planipes* was the dominant food item and from a second area in which fish were the dominant item have been made (Alverson, 1963). Yellowfin sets, which were from these same two areas (but at different times in 1965) and which were identified as to school type, showed significant differences (chi square 17.27, $P<0.01$) in the occurrence of jumping, boiling, and breezing schools (Table 4). Greater numbers of jumping and boiling schools and reduced numbers of breezers occurred in the area in which fish were the dominant food item, whereas the opposite was true in the area where red crabs were the dominant item. This lends support to our hypothesis that these school types reflect behavioral differences in the feeding patterns of *T. thynnus* and other tunas on red crabs and baitfish.

TABLE 4.—Comparison of breezing, jumping, and boiling yellowfin schools from the Gulf of Guayaquil and Baja California.[1]

Area	Breezers		Boilers		Jumpers	
	Number	Percent	Number	Percent	Number	Percent
Baja California[2]	183	91.5	1	0.5	16	8.0
Gulf of Guayaquil[3]	121	77.1	11	7.0	25	15.9
Total	304		12		41	

[1] Schooling data are for 1965 (Inter-American Tropical Tuna Commission, unpublished data).
[2] Stomach contents: fish, 19.4%; red crabs, 78.1% (Alverson, 1963)
[3] Stomach contents: fish, 76.9%; red crabs, 0.0% (Alverson, 1963) red crabs do not occur in the Gulf of Guayaquil.

If, in fact, many of the breezing schools in the southern area of the fishery are feeding upon red crabs, one would expect to find a greater percentage of successful sets on breezing schools in this area when compared with breezing schools taken in the northern area of the fishery. However the observed differences are not significant (chi square 2.18, $P>0.20$). It might be that if feeding breezers and nonfeeding breezers were compared that differences in percentage success between the two areas would be found.

The greater number of fireball schools observed in the northern area of the fishery may reflect a difference in the distribution of bioluminescent organisms. However, persistent stratus overcast in the southern California offshore zone during summer results from upwelled water coursing southward from Point Conception. As a result of this stratus overcast, the fishermen's ability to see fireballs at night may be significantly enhanced by eliminating background illumination from the moon and stars. The phenomenon requires further study.

VULNERABILITY TO CAPTURE

There were significant differences in vulnerability to capture, as indicated by percentage of successful sets (Table 2), among the five most common daytime schools (chi square 62.32,

$P<0.001$). These differences in vulnerability are most likely related to behavioral differences which affect a school's ability to avoid capture. Other factors such as water clarity, depth of thermocline, and water temperature also may be important. Two of the three most vulnerable school types were jumpers and boilers, both of which can be described as violently active schools in which individual fish are often in pursuit of baitfish. Shiner schools were also highly vulnerable to capture, yielding success rates of over 58%. It may be that shiners are subsurface feeding schools in which the "shines" are reflections of the operculum or of the lateral or ventral surfaces of the fish as they twist and turn in pursuit of their prey (Scott, 1969).

Three factors may be responsible for the greater vulnerability of these "feeding" schools: 1) feeding schools lack the organization of nonfeeding schools; 2) individual fish in feeding schools are less aware of threatening stimuli than are nonfeeding fish, and 3) feeding schools are more likely to remain in a localized area. The first two factors would increase a school's vulnerability to capture by delaying the time at which the fish are aware of potential danger and also by increasing the elapsed time before the fish react as a unit to this danger. The third factor would make it easier for the fisherman to anticipate the position of the school when he sets upon it. Another factor which should be mentioned is that a greater percentage of actively feeding schools may be located in areas of upwelling where cold, nutrient-laden waters generally result in decreased visibility. The effect of water clarity on percentage success has been discussed by Hester and Taylor (1965).

Breezing schools are generally schools moving in a single direction, often making sudden changes in depth, which makes it difficult for fishermen to anticipate the position of the school relative to the boat before setting. Greater cohesiveness is apparent among breezing schools, and it appears that there is a greater awareness of potential danger than in feeding schools.

Blackspots are subsurface schools which are difficult to locate and to catch. The very nature of this school type suggests that a greater number of them might be expected to be found in areas with a deep thermocline and clear surface waters. Green (1967) has shown that schools encountered in areas with a deep thermocline are less vulnerable to capture than are schools found in areas with a shallow thermocline. In addition, the deeper a school is in the water column, the closer it is to one possible route of escape: the bottom of the net. All of these factors would contribute to the greater rate of escapement observed for black spots.

We have omitted from this section any consideration of fireball schools. The reasons for the greater vulnerability of nighttime schools (discussed in a later section) are equally applicable to fireballs.

CATCH PER SUCCESSFUL SET

There were significant differences in the mean size of the six most common schools (Figure 2). Black spots and breezers were the two largest school types. The three feeding school types, jumpers, boilers, and shiners, were the smallest. The disruption of schooling behavior during feeding activity (Magnuson, 1963; Whitney,

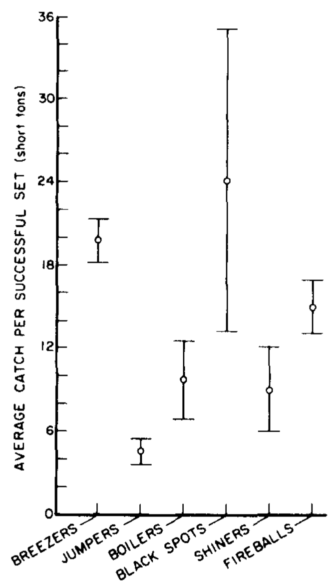

FIGURE 2.—Average catch (short tons) of each of the six most common bluefin tuna school types.

1969) may account, in part, for the reduced size of these schools. However, the observed disruptions have occurred within a relatively small area and were in response to an immediately available food source. It seems unlikely that the area involved would exceed that area normally encircled by a purse seine. We believe that the reduced size of the actively feeding daytime schools is the result of the relatively larger nighttime schools separating into smaller foraging schools with the rapid onset of higher light intensities at dawn.

Various mathematical treatments have shown the advantages of schooling to predator and prey alike (Brock and Riffenburgh, 1960; Olson, 1964). Olson contends that the swept path of an individual predator, and hence its chances of encountering a prey species, would be greatly increased if it traveled in a school rather than singly. In addition, we suggest that there is an optimum school size (number of individuals within the school) for feeding. Beyond this size, there may be increasing duplication of individual visual fields, making it more efficient for the fish to break down into a number of smaller schools in order to increase the area covered and thereby increase their chances of encountering and capturing prey. It may be also that individuals in schools beyond a certain size obtain less energy than those foraging in smaller schools. This school size would be dictated by a number of factors, such as visual acuity of the predator, type of prey, and prey density. A patchy distribution of a relatively fast moving schooling prey (e.g., anchovies) and a relatively uniform distribution of a slow moving prey (e.g., red crabs) within a localized area require different hunting and feeding strategies. Other factors may also be important (see Shaw, 1962; Breder, 1967).

TIME OF DAY

Fishermen recorded time of day for a total of 4,925 sets. Of these, 4,144 were made without aircraft assistance. The number of sets varied with time of day (Figure 3), as did the catch per successful set (Figure 4), percentage of suc-

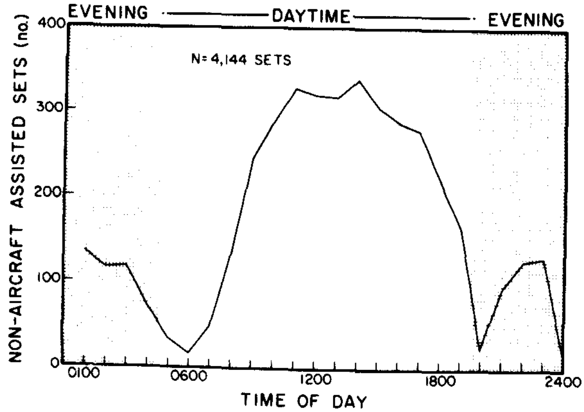

FIGURE 3.—Variation of the number of purse-seine sets on bluefin tuna in relation to time of day.

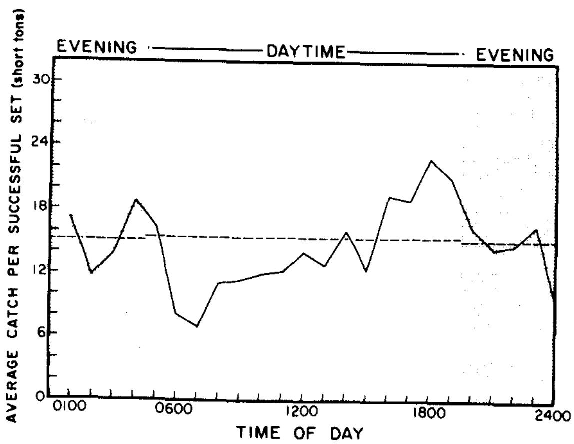

FIGURE 4.—Average catch per successful purse-seine set (short tons) on bluefin tuna in relation to time of day. (Not assisted by aircraft. Grand average catch for daylight and evening hours is indicated by the dashed lines.)

cessful sets (Figure 5), and occurrence of the various school types (Figure 6).

The percentage of successful sets on bluefin schools was significantly greater during the evening hours than it was during the day (chi square 126.56, $P<0.001$).

Whitney (1969) suggested that the greater vulnerability of tuna to capture at night was due to decreased visibility of the net and decreased activity of the fish. Recent laboratory work using *Engraulis mordax* has shown a diel rhythm

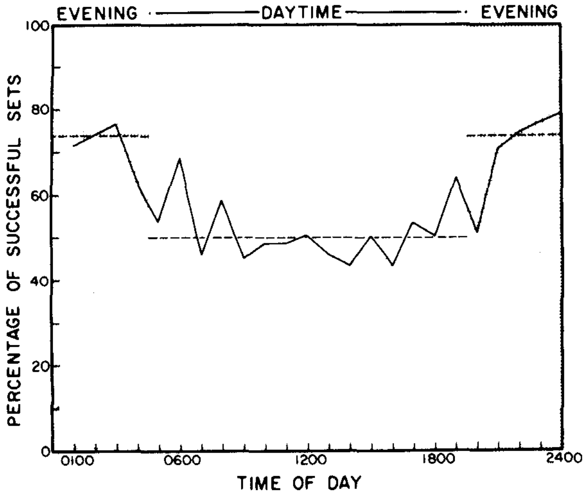

FIGURE 5.—Variation of percentage success of purse-seine sets on bluefin tuna in relation to time of day. (The grand average percentage success for daylight and evening hours is indicated by the dashed lines.)

in their direction of escape from a net cylinder (Scott, 1970). The tendency of *E. mordax* to use the bottom escape route during the day and to be random in their direction of escape at night would increase their vulnerability to capture at night by bottom-closing nets. If this same pattern is found in *T. thynnus* and other tunas, it would help to explain the observed differences in percentage success.

There were significant differences also in percentage success during the daylight hours (chi square 37.12, $P<0.01$). This is in contrast to the lack of significant variation in percentage success during the day reported by Whitney (1969).

The distribution in time of the five most common daytime school types is nonrandom (chi square 259.15, $P<0.001$). The three actively feeding schools were most common from 0700 to 1100 (Figure 6). During this period, these school types account for more than 42.2% of the identified school types.

The greater number of feeding schools in the early morning hours reflected in an increased percentage success during the early morning hours (0500-0800) when all school types are combined (Figure 5). The decrease in percentage success at 0700 is accounted for by a decrease in the percentage success of nonfeeding schools rather than a decrease in the number of feeding schools or a decrease in the vulnerability of feeding schools to capture. While the number of feeding schools increases until 1100, this is not reflected in an increase in the overall percentage success because of an accompanying increase in the number of nonfeeding schools (Figure 6). There appears to be a slight increase in the percentage of feeding schools during the late afternoon hours (1600-1900) (Figure 6B,C,D) which suggests that there may be two peaks in feeding

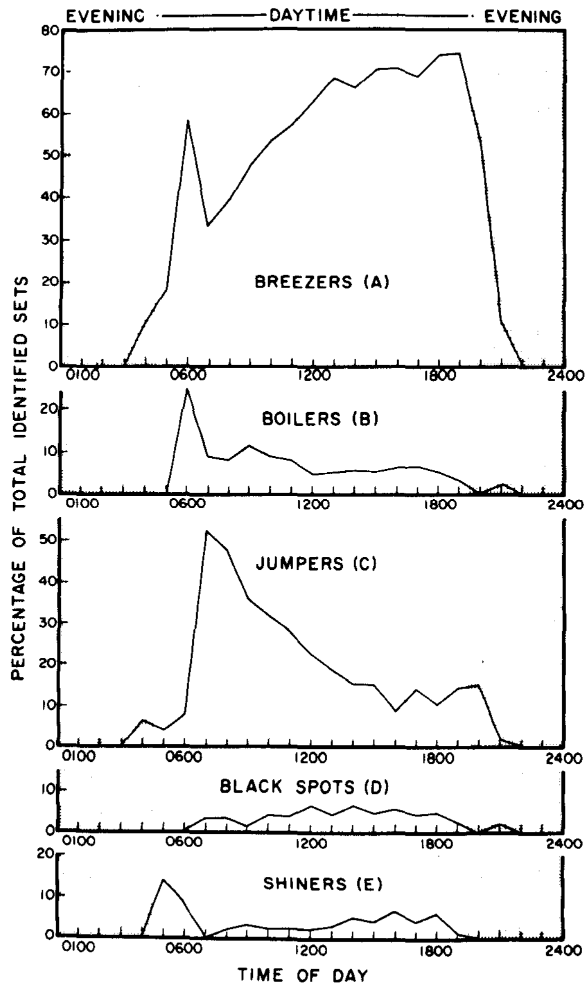

FIGURE 6.—Variation of occurrence of the five most common bluefin tuna school types in relation to time of day.

activity for *T. thynnus,* as has been shown for albacore (Iversen, 1962), bonito (Suyehiro, 1938), and yellowfin tuna (Uda, 1940; Waldron and King, 1963). However, the late afternoon increase in feeding activity is a minor one.

The percentage success does not vary significantly with respect to time of day in the four most common school types: breezers, jumpers, boilers, and fireballs (Figure 7). However, there is an increase in percentage success during the late afternoon hours for the three daytime schools, suggesting that the observed increase in percentage success during the late afternoon hours is due to the environmental factors cited by Whitney (1969). Additional data are needed for the late afternoon hours in order to further clarify this question.

The differences in school size between daytime (14.8 tons) and nighttime sets (14.4 tons) were not significant. However, there were differences noted in distribution of sets by 5-ton intervals (chi square 18.80, $P<0.05$) with fewer small schools (5 tons or less) being taken at night. The reduced percentage of small schools could be the result of a greater number of these schools being passed up by the fishermen at night, possibly because of reduced visibility to the mastman. We have no evidence to suggest a real decrease in the number of small schools during night hours as opposed to daytime.

There was a marked variation in average school size within the daylight hours; the size of schools steadily increased from 6.9 tons at 0700 to 22.5 tons at 1800 hours (Figure 5). This pattern is not apparent in the jumping and boiling schools, however (Figure 8).

The early morning decrease in school size initially may be a response to increased light and feeding activity as suggested by Whitney (1969); subsequently the relatively large nighttime schools break down into several smaller foraging schools and begin their search for food. The time elapsed between the reduction in school size and subsequent occurrence of large numbers of feeding schools might thus be the time required to encounter prey and begin to feed. We believe that the reduction in the number of feeding schools after 1100 hours reflects an increasing number of fish whose hunger is sated.

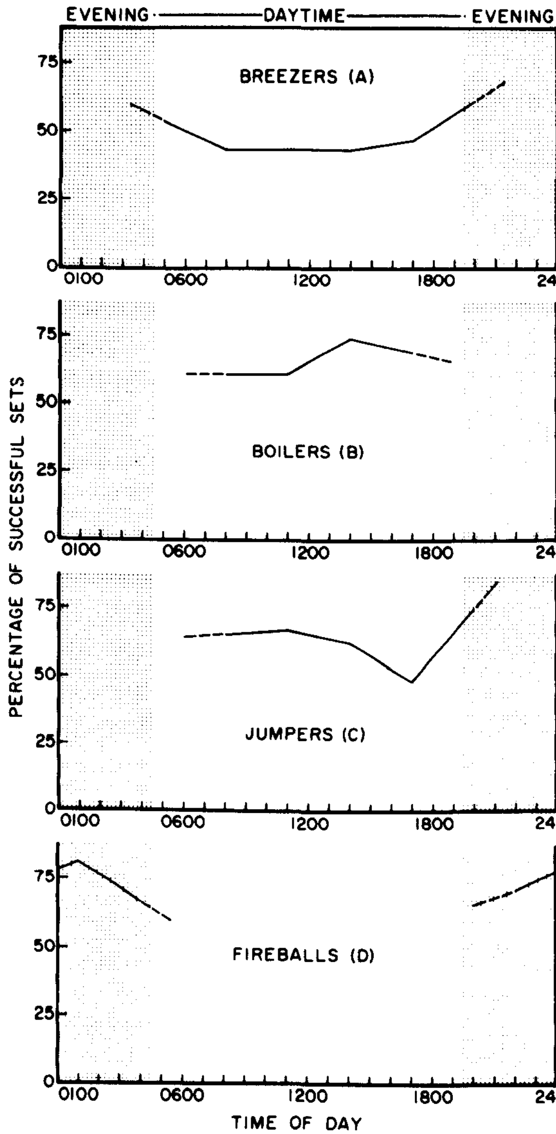

FIGURE 7.—Variations of percentage success on the four most common bluefin tuna school types in relation to time of day.

The gradual increase in school size during the daylight hours may be due to regrouping of the smaller schools through random encounters as suggested by Whitney (1969). The reduction in school size in the late afternoon cannot be accounted for by an increase in the number of

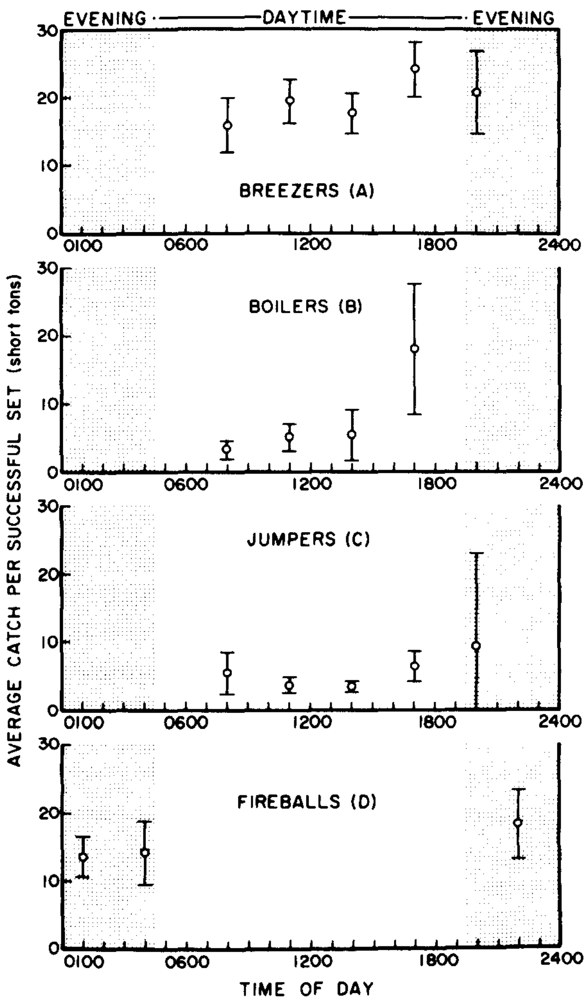

FIGURE 8.—Variation in the average catch per successful set on the four most common bluefin tuna school types in relation to time of day. (Catch in short tons grouped by 3-hr intervals.)

feeding schools and is most likely due to a reduction in available light (Whitney, 1969).

The lack of significant variation in either percentage success or catch per successful set within a single school type suggests that the observed variations in these two factors when all school types are considered together is due more to differences in the occurrence of the various school types within the daylight hours than it is to environmental factors such as daylight. However, the increased vulnerability of breezing and jumping schools during the late afternoon hours may be due to reduced light intensity during that period. Unfortunately it is the early morning and late afternoon hours for which we have the fewest data.

EFFECT OF AIRCRAFT ASSISTANCE

Aircraft assistance on bluefin tuna sets gave a significantly greater percentage of success than unassisted sets (chi square 8.69, $P<0.01$). The average catch in assisted sets also was consistently larger than in unassisted sets (Table 5). These differences have also been shown for yellowfin and skipjack tuna. The reasons for the greater size and vulnerability of schools set upon with aircraft assistance have been discussed elsewhere (Schaefer, 1962). In addition, however, the greater average size of assisted sets may be due to the disproportionately fewer small schools (jumpers and boilers) and a greater number of large schools (black spots and shiners) captured with aircraft assistance.

The two most visible schools, jumpers and boilers, have the smallest percentage of assisted sets (Table 6). The greater height of the air-

TABLE 5.—Effect of aircraft assistance on purse-seine sets for bluefin tuna, 1960-67.

Year	Percentage of sets assisted by aircraft	Percentage success		Catch per successful set (short tons)	
		Assisted	Unassisted	Assisted	Unassisted
1960	2.5	75.0	47.3	65.7	29.3
1961	14.5	79.0	63.8	17.7	12.6
1962	12.6	72.2	65.7	17.1	9.8
1963	20.4	45.8	41.2	20.5	21.2
1964	12.1	62.8	59.5	13.3	9.3
1965	20.2	43.4	48.0	19.3	14.7
1966	13.9	60.5	46.6	22.5	15.9
1967	11.5	51.5	43.1	23.6	19.5
Average	15.3	54.9	53.0	19.3	14.2

TABLE 6.—Comparison of effectiveness of aircraft assistance by school type for purse-seine sets on bluefin tuna, 1960-67.

School type	Number of sets	Aircraft assisted sets	
		Number	Percent
Boilers	221	17	7.7
Jumpers	639	44	6.9
Breezers	1,871	359	19.2
Shiners	111	44	39.6
Black spots	137	50	36.5
Totals	2,979	514	17.3

TABLE 7.—Comparison of average catch per successful set and percentage success for assisted and unassisted sets on the four most common daytime bluefin tuna school types.

School type	Average catch per successful set (short tons)		Percentage success	
	Assisted	Unassisted	Assisted	Unassisted
Jumpers	29.1	4.7	87.5	63.7
Breezers	21.3	19.8	47.9	46.2
Shiners	15.2	9.0	63.6	58.2
Black spots	23.0	25.0	50.0	41.4

craft and, therefore, the greater area and depth of visibility to an airborne spotter would increase the possibility of spotting the subsurface schools which otherwise might not be visible to observers aboard a vessel (Green, 1966).

However, there are differences in both catch per successful set and percentage success between assisted and unassisted sets in the same school type (Table 7). All of the schools show increased percentage success with aircraft assistance, and all but black spots exhibit larger school size with aircraft assistance. This indicates that the larger size and greater vulnerability of schools set on with aircraft assistance is the result not only of the unequal distribution of the various school types between assisted and unassisted sets but also due to the skill of the airborne spotter in locating larger schools, and by his ability to increase the ship's chances of capturing the school.

MULTIPLE SCHOOLING CHARACTERISTICS

Almost every possible combination of the 13 different school types occurred. However, schools recorded as showing two or more behavioral types made up a very small percentage of the total sets made. Whether this is indicative of the actual occurrence of these types or the propensity of the fishermen to record them and the log abstractor to copy them is unknown. The problem of multiple schooling types has been discussed elsewhere (Scott, 1969).

Bluefin were captured in sets with yellowfin, skipjack, and albacore. Bluefin were also observed schooling with whales (Table 1). In spite of large amounts of flotsam and jetsam occurring in the fishing area, only two reports of this school type were logged. No porpoise-associated schools were reported. This is probably due to the absence of porpoise in the areas in which bluefin are generally found. Further data are needed before meaningful conclusions can be drawn with respect to the occurrence or lack of porpoise-associated schools in the bluefin fishery.

DISCUSSION

Striking differences in catchability, size, and geographical distribution have been demonstrated for the various types of bluefin schools. Suggestions as to possible reasons for these differences are offered but in most instances additional behavioral information is needed. We hope that definitive field and laboratory behavioral studies will be made in order to further strengthen or disprove interpretations which we have drawn from the logbook data. Studies on other scombroids would also be valuable for comparative purposes. The possibility that there are two or more types of breezing schools should be studied in detail, and the percentage success of sets on breezing schools known to be feeding compared with nonfeeding schools should also be investigated.

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