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Analysis of the Operations of Seven Hawaiian Skipjack Tuna Fishing Vessels, June-August 1967

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ABSTRACT

Analysis of operational data collected from seven Hawaiian skipjack tuna fishing vessels in the summer of 1967 showed that the vessels expended 38 percent of their day-baiting effort at Kaneohe Bay, which yielded 14.7 buckets of bait per set. Keehi Lagoon was, by far, the most productive night-baiting ground; it received 84 percent of the night effort and yielded 10.4 buckets per set.

On fishing trips which averaged 15.5 hours, 31 percent of the time was devoted to traveling to and from the fishing grounds, 62 percent was occupied by scouting, and only 7 percent was actually spent fishing. The vessels chummed 83 percent of the schools sighted, successfully fished 57 percent of the schools chummed, and used an average of 12.8 buckets of bait per trip. Most often seven men fished per school. Fishing duration among the vessels ranged from 1 to 155 minutes, but most schools were fished only for short periods.

Schools of large skipjack tuna (7 kg. or more), which dominate the summer catch, were usually fished further offshore.

About half of the schools sighted were in waters to the west of Oahu. Sightings increased from daybreak to a peak at 0801-0900, dipped at 1001-1100, then rose to a second peak at 1301-1400. The vessels caught 62 percent of their day's catch after 1200. Cloud cover and wave height at the time of fishing had no effect on the success or failure in fishing the school. Although the predominant species of bird associated with the school was not a good indicator of fishing success, size of the bird flock differed significantly among those schools with and without catches. Among schools yielding catches, the vessels found most associated with 50 or more birds; among those unsuccessfully fished, the vessels found most associated with 11-50 birds.

Data on support activities showed that it usually took nine men one-half hour to unload about 3.4 metric tons of skipjack tuna. The rate of unloading depended largely on the size of the fish. Loading ice required 6.6 minutes.

Comparison of data from high- and low-producing vessels showed that a high-producing vessel chummed the schools longer, used more bait in fishing, tended to remain with the school longer, and was successful in fishing a higher percentage of the schools it sighted.

INTRODUCTION

Since the early 1900's when the fishery for skipjack tuna, Katsuwonus pelamis, or aku, as it is locally called, began, the Hawaiian skipjack tuna fishermen have been modifying their vessels to increase their fishing power. They replaced scull or sail power with engines to increase the vessels' operating range, added a flying bridge to extend the vessels' scouting range, redesigned the hulls to improve the vessels' speed, stability, and maneuverability in rough channel waters around the islands, and increased the carrying capacities of the vessels' fuel tanks, ice holds, and baitwells.

The NMFS (National Marine Fisheries Service) (formerly the Bureau of Commercial Fisheries) in Honolulu also has attempted to improve fishing efficiency in the skipjack tuna fishery. Realizing that fishing with pole and line was often seriously hampered by a shortage of live bait, the NMFS tried purse seines (Murphy and Niska, 1953) and gill nets (Matsumoto, 1952; Shomura, 1963), but these attempts were unsuccessful in catching commercial quantities of skipjack tuna.

Until new means of catching skipjack tuna can be found, the Hawaiian tuna fishermen must rely on pole and line and live bait; therefore, the NMFS decided to try to improve the pole-and-line operation. This study of the operations of the fishery provides some basic information which is necessary for suggesting improvements. In addition, the information is potentially useful for obtaining the best possible index of abundance of the fish for biological studies.

SOURCE OF DATA

The captains and crewmembers of seven vessels participated in this study. NMFS technicians, who were permitted to remain aboard the vessels for 5-6 days a week, collected data on baiting, fishing, and supporting activities from June through August 1967.

When baiting, the technicians reported on the species and quantity caught, the mortality incurred in transporting the bait from catch site to the vessel, and the time required for the entire operation.

On fishing trips, the technicians recorded the time of departure and return and the start and end of scouting. For each school, they recorded the time of sighting, the start of chumming, and the start and end of fishing. They estimated the amount of bait used per school, noted the number of men that fished, counted the number of fish caught, and obtained the average weight of the fish in the school from a sample consisting of 10 fish selected at random. While pursuing the schools they estimated the amount of sky covered by clouds, the height of the waves, the number of birds in the flock, and identified the predominant birds associated with the school. After fishing and at 2-hour intervals while scouting, the technicians checked surface water temperatures and collected water samples for salinity determination. When possible, the technicians also approximated the positions of schools sighted and of schools fished by taking compass bearings from the vessel to recognizable landmarks. When landmarks were not visible, the captain estimated the position after considering the ship's course and approximate distance or hours from land.

In port, the technicians recorded time and number of men required to unload the catch and to load ice.

ANALYTICAL PROCEDURES

We summarized data on baiting, fishing, and supporting activities first by vessel, then collectively for all vessels over the 3 months. In examining the relation between any two variables, however, we separated the data into appropriate units, within which we summarized all other information important to our analysis. For example, in examining catch in relation to the number of men fishing, we separated the schools by number of men fishing; then, for each group (1, 2, 3,...10 men fishing) we summarized the catch per school and other information such as the amount of bait used and fishing duration.

We used data from incomplete logs in some of our analysis, but only after we established that the data would not bias the results. For example, on one vessel, a newly hired technician failed to record data on all schools sighted and chummed; therefore, his data were used only in summaries dealing with catch and not in summaries of schools sighted and chummed. The result was that although we could use the catch data from 244 trips, we were able to use the data on schools sightings from only 231 trips.

Catches of species other than skipjack tuna were infrequent (only about 0.8 percent, by weight); therefore, they were tabulated with the skipjack tuna catch. We considered that all fishing effort was expended with the primary purpose of catching skipjack tuna regardless of the species actually caught.

We agreed with the captains that the data collected would not be traçeable to individual vessels so as to preserve anonymity; therefore we grouped the data or identified them with vessel code letters.

BAITING

The generalized block diagram in figure 1 shows the sequence of events which leads to a catch of skipjack tuna by a vessel. Basically, it begins with a period of baiting. ("Bait" and "baiting" are colloquial terms which refer to the catching of bait.) Day baiting usually starts at dawn and ends when sufficient bait has been captured. If little or no bait is caught during the day, the vessel may attempt night baiting; if that proves unproductive, day baiting is resumed.

Within the Hawaiian Islands, there are several baiting grounds, but two of the major ones, which provide roughly two-thirds of the State's

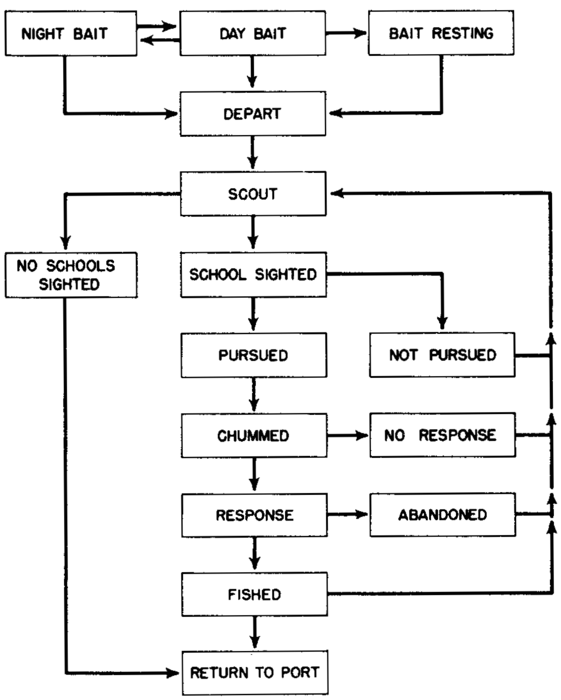

Figure 1.--Block diagram of baiting and fishing operation.

bait production (Yamashita, 1958), are on Oahu. There is Kaneohe Bay on the windward side of the island and Pearl Harbor on the leeward (fig. 2). A third site of some importance, particularly for night baiting, is Keehi Lagoon, also on the leeward side.

Having baiting grounds on windward and leeward Oahu has certain advantages. When fishing intensifies in windward Oahu waters, the vessels bait at Kaneohe Bay and return there after fishing to unload their catches, which are trucked to leeward Oahu where the markets and cannery are located. When fishing intensifies in leeward waters, the vessels bait at Pearl Harbor and at Keehi Lagoon and return after fishing to Kewalo Basin, home port of Oahu vessels and the site of the cannery.

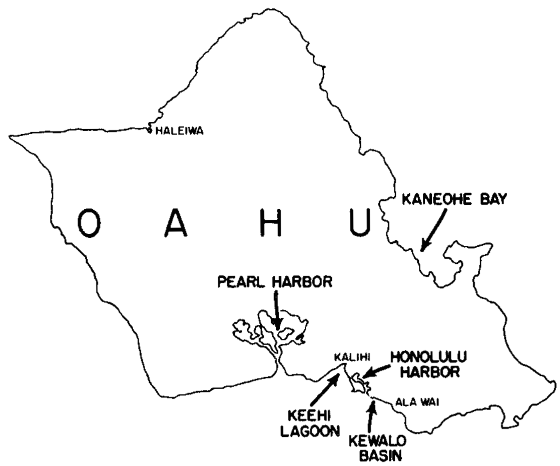

Figure 2.--Baiting areas on Oahu.

In 1948-66, bait production ranged from 23,622 to 49,712 buckets with an average of 36,465 buckets annually. Contributing 93 percent of the bait catch, the small (40-60 mm.), fragile Hawaiian anchovy locally called nehu, Stolephorus purpureus, is captured day and night and is the species preferred above all others by the skipjack tuna fishermen because it possesses most of the qualities of a good baitfish. Almost all the remainder of the bait catch is made up of silverside or iao, Pranesus insularum; other species sometimes used as bait constitute less than 1 percent of the bait catch.

Day Baiting

Day baiting, which usually begins at daybreak, frequently lasts for about 3 hours. The fishermen use an outboard skiff loaded with a surround net to scout for baitfish that school in shallow waters of bays and harbors or near river mouths. Having located a school, the fishermen surround it and then partially "dry up" the net to form a bag to hold the school. To avoid killing the bait, the fishermen "swim" the net-enclosed baitfish back to the vessel and transfer them into baitwells. Several sets may be required to obtain enough bait to justify fishing. We considered a set as a unit of baiting effort in this study. For additional information on baiting in Hawaiian waters, see June (1951).

Prior to 1968, Pearl Harbor was primarily a day-baiting ground for the Hawaiian tuna fleet. In June-August 1967, the seven vessels baited there 36 times and caught 1,093 buckets of bait in 108 sets or an average of 10.1 buckets per set (table 1). Mortalities at the time of capture were low, averaging 1.3 percent, and the amount released--either back into the water or transferred to another vessel because of an excess in catch--was 4.1 percent. Day baiting in Pearl Harbor usually lasted a little over 3 hours. Figure 3 shows that area 08, near the mouth of the Waiawa Stream in Middle Loch, was highly productive.

A ground for both a day and a night fishery for bait, Kaneohe Bay is usually the most productive baiting ground in the State. Catches in 41 days of baiting totaled 2,040 buckets of day bait in 139 sets or an average of 14.7 buckets per set, which is roughly 50 percent larger than the catch per set at Pearl Harbor (table 1). Mortalities, however, averaged about three times as much at Kaneohe Bay as at Pearl Harbor with roughly 3.8 percent of the total catch dead from various causes on the baiting grounds. The data also show that whereas bait released averaged 1.2 buckets for each day baited at Pearl Harbor, bait released at Kaneohe Bay averaged 3.9 buckets per day of baiting or roughly three times more than at Pearl Harbor. In time spent baiting, there appeared to be little difference between the two grounds. High producing areas in Kaneohe Bay can be seen in figure 3--area 47 off Waiahole and area 58 off Heeia had catches of 795 and 304 buckets, respectively.

Referred to frequently by the fishermen as "Kalihi" and understood to mean waters off the district of Kalihi in Honolulu, area 64 was the most productive in the Keehi Lagoon-Honolulu Harbor baiting grounds (fig. 3). Keehi Lagoon day bait catches--combined with those from Honolulu Harbor--totaled 506 buckets or about half the amount caught at Pearl Harbor (table 1). In 22 days of baiting, 51 sets yielded an average of 9.9 buckets per set or roughly the same amount per set as at Pearl Harbor. Baiting at Keehi Lagoon usually lasted a little longer than at any of the other baiting grounds for some unknown reason. Of the total bait caught,

Table 1.--Number of days or nights baited, catches, mortalities and releases, time spent baiting, and catch rates in baiting grounds fished by seven Hawaiian skipjack tuna vessels, June-August 1967

Baiting	Days baited	Bait transferred to well	Bait died	Bait released	Total catch	Total time	Mean baiting time	Catch per hour	Total sets	Catch per set	Catch per day	Catch per night
	Number	Bucket	Bucket	Bucket	Bucket	Minute	Minute	Bucket	Number	Bucket	Bucket	Bucket
Day:												
Pearl Harbor	36	1,034	14	45	1,093	5,870	190	11.2	108	10.1	30.4	-
Kaneohe Bay	41	1,803	77	160	2,040	7,868	192	15.6	139	14.7	49.8	-
Keehi Lagoon	22	457	13	36	506	4,427	201	6.8	51	9.9	23.0	-
Other areas	9	292	6	6	304	1,703	189	10.7	21	14.5	33.8	-
Total	108	-	-	-	3,943	-	-	-	319	12.4	36.5	-
Night:												
Kaneohe Bay	13	170	0	0	170	7,227	556	1.4	18	9.4	-	13.1
Keehi Lagoon	101	1,092	11	15	1,118	47,621	471	1.4	108	10.4	-	11.1
Other areas	3	24	0	0	24	1,220	407	1.2	3	8.0	-	8.0
Total	117	-	-	-	1,312	-	-	-	129	10.2	-	11.2

2.6 percent died at the baiting ground, whereas 7.1 percent were released. Areas 64-66 had good catches.

The vessels expended very little effort baiting at other areas such as Ala Wai and Haleiwa on Oahu and at grounds on neighboring islands. Nine days of baiting yielded 304 buckets in 21 sets or 14.5 buckets per set.

Collectively, the vessels had day catches totaling 3,943 buckets and averaging 36.5 buckets per day, enough to fill the baitwells on an average-sized vessel. In 319 sets or an average of 3.0 sets per day, the vessels averaged 12.4 buckets of bait per set.

Not all the bait caught reached the fishing grounds. The skipjack tuna catch reports of the Hawaii Division of Fish and Game show that about 25 percent of the bait die before use. We estimated that about 3 percent of the losses occurred on the baiting grounds during transport and transfer. The bulk of the losses, however, occurred between the time that the bait was safely aboard and arrival at the fishing grounds, but we are unable to give a reliable estimate of this loss because of insufficient data.

Night Baiting

In night baiting, there is no active scouting for schools of baitfish. Rather, a submerged light attracts the baitfish to the anchored or moored vessel. Usually just before daybreak, the fishermen set the net around the school and transfer the bait into the baitwells. So that they may have enough sleep, the fishermen rarely set the net more than once during the night. Night baiting frequently started at 1901-0100 and in 90 percent of the operations ended at 0501-0600; it usually lasted about 8 hours.

In recent years, the fishermen have found the baiting grounds at Keehi Lagoon (and Honolulu Harbor) very productive and attributed the good catches to increased nehu production in recently dredged areas. Actually, Keehi Lagoon accounted for only 16 percent of all day-baiting effort, but had 84 percent of all night-baiting effort, which totaled 129 sets. The reason is that until 1968, the U.S. Navy prohibited fishing

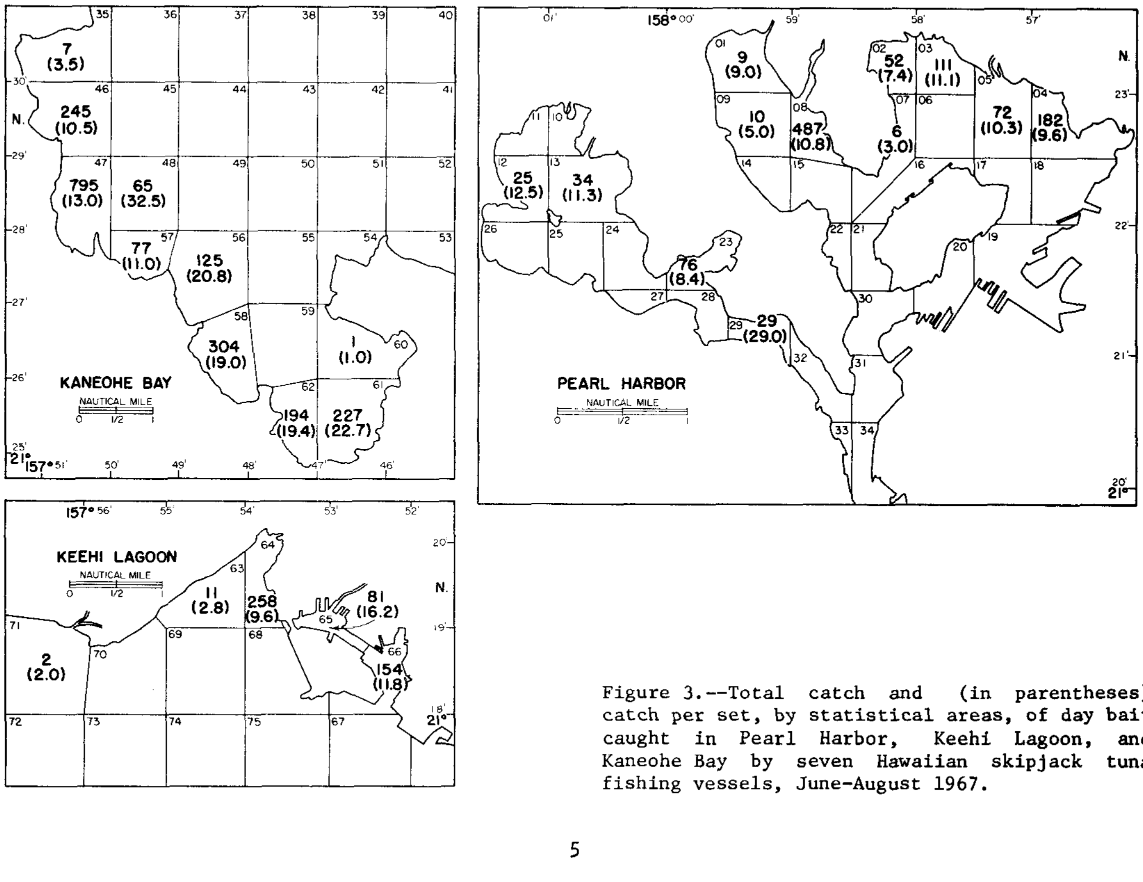

Figure 3.--Total catch and (in parentheses) catch per set, by statistical areas, of day bait caught in Pearl Harbor, Keehi Lagoon, and Kaneohe Bay by seven Hawaiian skipjack tuna fishing vessels, June-August 1967.

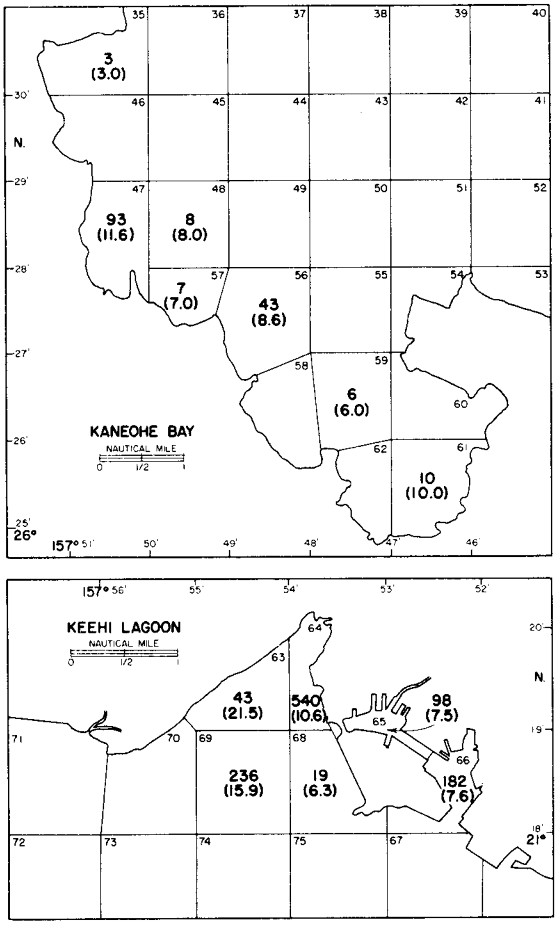

Figure 4.--Total catch and (in parentheses) catch per set, by statistical areas, of night bait caught in Kaneohe Bay and Keehi Lagoon by seven Hawaiian skipjack tuna fishing vessels, June-August 1967.

vessels from baiting at night at Pearl Harbor, the only other leeward baiting ground with any significant bait production. In 108 sets at Keehi Lagoon, the vessels caught 1,118 buckets or an average of 10.4 buckets per set (table 1). Figure 4 shows that areas 64 and 69 were highly productive night-baiting grounds.

The only other night-baiting ground of any importance was Kaneohe Bay. In 18 sets, the total catch reached 70 buckets or an average of 9.4 buckets per set (table 1). Like day baiting, night baiting was most productive in area 47 off Waiahole. The vessels spent only three nights catching bait from other baiting areas.

Collectively, in 117 nights of baiting, 129 sets produced 1,312 buckets of bait. Obviously, a few vessels made more than one set per night as evidenced by the difference in the number of nights baited and number of sets made. We calculated catch per set at 10.2 buckets, whereas catch per night reached 11.2 buckets. Frequently, catches of bait at night were insufficient for a day's fishing and the vessel spent additional time baiting during the day.

In night baiting, loss of bait through handling was minimal and amounted to less than 1 percent for all vessels over the 3-month period. Excess bait, which was released or shared with other vessels, amounted to about 1 percent of the total catch.

THE FISHING TRIP

The fishing trip starts only after sufficient bait is aboard to justify fishing. To be on the fishing grounds by sunrise, the fishermen usually restrict traveling to darkness, when they neither scout nor fish. From data on time of departure and return to port, we found that most trips originated between 0200 and 0600, with 41 percent originating at 0501-0600 (table 2). The vessels usually returned to port between 1800 and 2200, although there were a few trips that ended earlier or much later. Trips ending at 2001-2100 were most frequent (17 percent), but there were almost as many trips that ended at 1901-2000 (16 percent). By taking the difference in time between the length of the trip and the time expended in scouting and fishing, we calculated that traveling time on 231 trips averaged 4.8 hours or about 31 percent of an average trip of 15.5 hours. The average traveling time of individual vessels ranged widely from 3.6 to 6.5 hours per trip.

A fishing trip of a Hawaiian skipjack tuna vessel usually lasts 1 day, and has been used as the unit of effort in past studies on apparent abundance (Yamashita, 1958; Shippen, 1961; Uchida, 1966, 1967). In the section that follows, we discuss scouting, fishing, and catch per trip.

Scouting

Scouting, which averaged 9.7 hours or 62 percent of the time on an average fishing trip, is an essential part in fishing surface schools of tuna with either pole and line or purse seine and, therefore, is a major component of effort expended to catch fish. Usually, scouting started at daybreak; in 51 percent of the trips by 0600 and in 83 percent by 0700. On those trips where scouting started after 0700, the vessels usually spent part of the morning catching bait. Scouting continued until sunset, but rough weather, mechanical trouble, the need to unload the catch before spoilage, or the need to replenish the baitwells curtailed some trips. Scouting ended between 1700 and 1900 in 60 percent of the trips; most (36 percent) ended at 1801-1900.

Fishermen have long been aware of the association of sea birds with schools of fish. In Hawaii, the fishermen locate fish schools by relying almost exclusively on birds, large numbers of which flock and feed on prey driven to the surface by the skipjack tuna. Among the birds most frequently associated with fish schools are sooty tern, Sterna fuscata; noddy tern, Anous stolidus; wedge-tailed shearwater, Puffinus pacificus; and petrel, family Procellariidae, subfamily Hydrobatinae. In addition, other species which usually do not flock, but frequently associate with fish schools are the great frigate bird, Fregata minor; boobies, Sula spp.; and bo'sun (tropic birds), Phaethon spp.

In this report, we make the assumption that a fish school was associated with each bird flock sighted. This assumption appears justified. On two scouting cruises of the research vessel, Charles H. Gilbert, during the spring of 1953, Royce and Otsu (1955) found that "every one of 253 fish schools sighted was accompanied by birds and was found by means of birds." Although no mention is made of the number of flocks not associated with fish schools, we believe that most of the flocks sighted are associated with fish schools, because the fishermen can usually distinguish by observing the birds' behavior whether a school is nearby. Numbers of birds flying together in the same direction and not quartering back and forth or diving are usually regarded as scattered birds.

Bird flock sightings on 231 trips totaled 1,249 flocks or an average of 5.4 schools per trip. Vessel B, sighting 158 schools on 36 trips, averaged the least, with 4.4 schools per trip, whereas vessel E, sighting 320 schools on 51 trips, averaged the most, with 6.3 schools per trip (table 3). Trips with no sightings reached 2 percent. From the data in table 4 and figure 5, we found that 5 schools were sighted on one

Table 2.--Number and percentage of trips tabulated by time the vessels departed, started and ended scouting, and returned to port, Hawaii, June-August 1967

Time	Departure		Scouting started		Scouting ended		Returned to port	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
0001-0100	9	3.7	-	-	-	-	9	3.8
0101-0200	10	4.1	-	-	-	-	7	3.0
0201-0300	31	12.8	-	-	-	-	2	0.8
0301-0400	27	11.1	-	-	-	-	4	1.7
0401-0500	37	15.2	6	2.5	-	-	1	0.4
0501-0600	99	40.7	117	48.3	-	-	1	0.4
0601-0700	7	2.9	79	32.6	1	0.4	-	-
0701-0800	9	3.7	25	10.3	1	0.4	-	-
0801-0900	5	2.1	6	2.5	1	0.4	1	0.4
0901-1000	3	1.2	6	2.5	1	0.4	-	-
1001-1100	-	-	2	0.8	5	2.1	1	0.4
1101-1200	1	0.4	1	0.4	6	2.5	-	-
1201-1300	-	-	-	-	6	2.5	2	0.8
1301-1400	-	-	-	-	3	1.2	4	1.7
1401-1500	-	-	-	-	11	4.5	7	3.0
1501-1600	-	-	-	-	15	6.2	10	4.2
1601-1700	-	-	-	-	20	8.2	10	4.2
1701-1800	-	-	-	-	56	23.1	9	3.8
1801-1900	-	-	-	-	78	36.4	28	11.9
1901-2000	-	-	-	-	28	11.6	38	16.1
2001-2100	3	1.2	-	-	-	-	40	17.0
2101-2200	-	-	-	-	-	-	29	12.3
2201-2300	2	0.8	-	-	-	-	23	9.8
2301-2400	-	-	-	-	-	-	10	4.2
Totals	243	-	242	-	242	-	236	-

Table 3.--Average number of schools sighted, chummed, and fished; average time spent pursuing, chumming, and fishing the schools; average amount of bait used per trip and per school; average number of men fishing; and catch per trip, per bucket of bait used, and per school for seven Hawaiian skipjack tuna vessels, June-August 1967

Vessel	Schools per trip			Time per school			Bait used		Men fishing	Catch		
	Sighted	Chummed	Fished	Pursued	Chummed	Fished	Per trip	Per school		Per trip	Per bucket of bait used	Per school
	Number	Number	Number	Minute	Minute	Minute	Bucket	Bucket	Number	Metric ton	Kg.	Metric ton
A	4.9	4.6	3.1	13.5	11.6	31.2	22.6	5.0	7.6	4.1	179.3	1.3
B	4.4	3.8	1.8	17.4	11.9	36.7	14.0	3.7	6.9	2.4	174.6	1.4
C	5.7	3.8	2.1	31.5	7.7	30.2	10.9	3.1	7.1	2.9	262.0	1.4
D	5.2	4.3	2.7	13.9	5.6	22.1	12.8	3.0	5.5	3.1	238.7	1.1
E	6.3	5.3	2.6	11.0	13.2	29.4	11.4	2.3	6.4	2.7	234.8	1.0
F	5.2	4.4	2.9	8.6	4.6	15.6	9.0	2.3	6.5	2.0	225.3	0.7
G	5.6	5.4	3.1	9.4	9.2	15.5	11.1	2.1	7.7	2.4	217.3	0.8
All	5.4	4.5	2.5	15.0	9.4	26.0	12.8	3.0	6.8	2.8	216.1	1.1

Table 4.--Number, percentage, and cumulative percentage of trips of seven Hawaiian skipjack tuna fishing vessels, tabulated by numbers of schools sighted, chummed, and successfully fished per trip, June-August 1967 (excludes August data for vessel F)

Schools per trip	Trips								
	Sighted			Chummed			Successfully fished		
Number	Number	Percent	Cumulative percent	Number	Percent	Cumulative percent	Number	Percent	Cumulative percent
0	4	1.7	1.7	5	2.2	2.2	22	9.5	9.5
1	8	3.5	5.2	17	7.4	9.6	41	17.7	27.2
2	16	6.9	12.1	22	9.5	19.1	60	25.9	53.1
3	27	11.7	23.8	42	18.2	37.3	49	21.2	74.3
4	31	13.4	37.2	43	18.6	55.9	33	14.3	88.6
5	46	19.9	57.1	32	13.9	69.8	15	6.5	95.1
6	34	14.7	71.8	29	12.6	82.4	7	3.1	98.2
7	20	8.7	80.5	18	7.8	90.2	2	0.9	99.1
8	17	7.4	87.9	10	4.3	94.5	2	0.9	100.0
9	12	5.2	93.1	7	3.0	97.5	-	-	-
10	7	3.0	96.1	1	0.4	97.9	-	-	-
11	4	1.7	97.8	2	0.9	98.8	-	-	-
12	1	0.4	98.2	-	-	-	-	-	-
13	2	0.9	99.1	2	0.9	99.7	-	-	-
14	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-
16	1	0.4	99.5	1	0.4	100.0	-	-	-
17	-	-	-	-	-	-	-	-	-
18	1	0.4	100.0	-	-	-	-	-	-
Totals	231	-	-	231	-	-	231	-	-

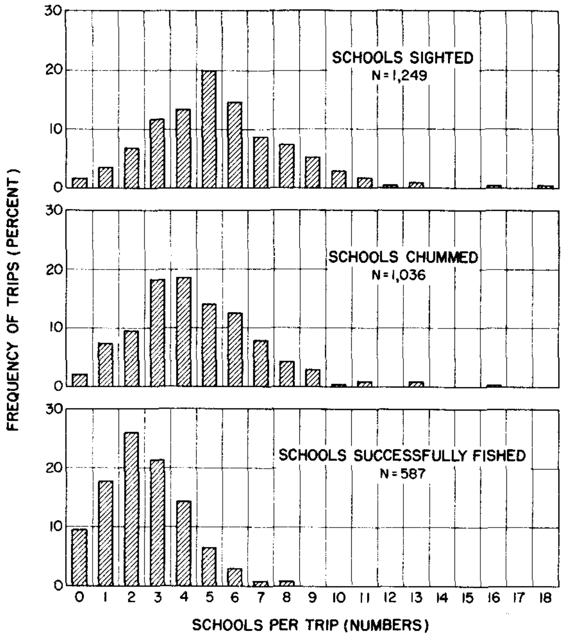

Figure 5.--Percentage frequency of trips tabulated by the number of schools sighted, chummed, and successfully fished per trip by seven Hawaiian skipjack tuna fishing vessels, June-August 1967.

out of five trips, that from one to five sightings were reported on more than half of the trips (57 percent), and that 18 schools were the most sighted on one trip.

When a flock is sighted, the vessel pursues it in an attempt to head off the school and begin chumming. The interval between sighting and the start of chumming, which we called pursuit time, varied widely among the vessels. Considered an integral part of scouting time because scouting continues even when the vessel is pursuing a school, pursuit time is obviously influenced by the vessel's speed and its distance from the school at the time of sighting. Some elements, however, prolong pursuit time; for example, when schools are scarce on the fishing grounds, a captain may feel compelled to chase a nonbiting school longer than usual, or to drift and wait up to an hour for schools that have sounded to return to the surface.

The frequency distribution of pursuit time, tabulated by 5-minute intervals, was strongly skewed toward short intervals (table 5 and fig. 6). Pursuit time ranged from 1 to 105 minutes, but the mode in the distribution occurred at 6-10 minutes. The vessels pursued about 80 percent of the schools for 20 minutes or less, 15 percent from 21 to 40 minutes, and 5 percent longer than 40 minutes. Among the vessels, pursuit time averaged from 9.4 minutes for vessel G to 31.5 minutes for vessel C with a grand mean of 15.0 minutes (table 3).

Table 5.--Number, percentage, and cumulative percentage frequencies of schools pursued and chummed by seven Hawaiian skipjack tuna fishing vessels, tabulated by pursuit and chumming time in 5-minute intervals, June-August 1967

Time	Pursuit time			Chumming time		
Minute	Number	Percent	Cumulative percent	Number	Percent	Cumulative percent
<1	-	-	-	25	4.1	4.1
1-5	228	22.2	22.2	357	58.1	62.2
6-10	254	24.7	46.9	81	13.2	75.4
11-15	217	21.1	68.0	47	7.6	83.0
16-20	117	11.4	79.4	22	3.6	86.6
21-25	64	6.2	85.6	22	3.6	90.2
26-30	56	5.4	91.0	19	3.1	93.3
31-35	25	2.4	93.4	9	1.5	94.8
36-40	10	1.0	94.4	14	2.3	97.1
41-45	14	1.4	95.8	5	0.8	97.9
46-50	7	0.7	96.5	4	0.6	98.5
51-55	5	0.5	97.0	1	0.2	98.7
56-60	9	0.9	97.9	-	-	-
>60	21	2.1	100.0	8	1.3	100.0
Totals	1,027	-	-	614	-	-

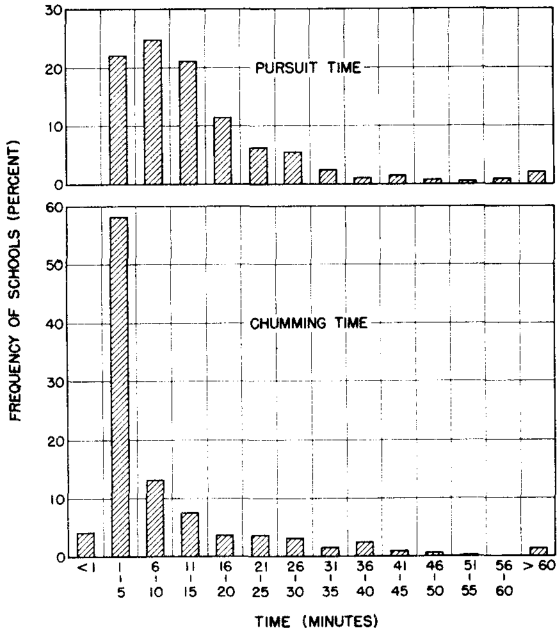

Figure 6.--Frequency of pursuit time and chumming time per school for seven Hawaiian skipjack tuna fishing vessels, June-August 1967.

Chumming starts as soon as the vessel crosses the head of the school and if the fish start to bite, the chummer throws more bait to bring the school near the stern so fishing can start. If there is no response, chumming stops temporarily, marking the completion of a "pass." Usually, then, the vessel is swung around for another pass. We defined chumming time as the interval from the start of chumming to the landing of the first fish and calculated it only for those schools with catches because we did not record the time that a nonresponsive school was abandoned.

The distribution of chumming time, which varied from less than a minute to 141 minutes, was strongly skewed; chumming lasted less than a minute in 4 percent of the schools, 1-5 minutes in 58 percent, 6-10 minutes in 13 percent, and 11 minutes or more in 25 percent (table 5 and fig. 6). Chumming time, which varied widely, reflects the biting behavior of schools; some bit readily, whereas others responded slowly. Vessel F chummed an average of only 4.6 minutes per school, the least among the vessels; it probably abandoned nonresponsive schools early (table 3). Vessel E chummed the longest, spending an average of 13.2 minutes per school before catching any fish. Chumming time of all vessels averaged 9.4 minutes per school.

We estimated that collectively on 231 trips the vessels chummed 1,036 schools out of 1,249 schools sighted or about 83 percent. Table 4 and figure 5 show that the distribution of trips, tabulated by the number of schools chummed, was moderately skewed, that the number of schools chummed per trip ranged from 1 to 16, and that trips on which the vessels chummed three or four schools were most frequent. Reference to individual vessels showed that the percentage of schools chummed varied widely from 66 percent for vessel C to 97 percent for vessel G, which incidentally chummed 5.4 schools per trip, the highest average among the vessels. Vessels B and C, both with the lowest rates, averaged 3.8 schools per trip. The grand mean was 4.5 schools per trip (table 3).

Sometimes, a vessel will pass up a school or abandon one even before catching fish. There were 653 schools which were not fished for reasons given in table 6. About half of the schools did not respond to chum and were abandoned, 28 percent sounded or moved too fast to overtake, 18 percent were composed of fish too small for canning or marketing, and 4 percent were passed up so that the vessels could fish other schools.

Table 6.--Number and percentage of 653 schools not fished by the seven Hawaiian skipjack tuna fishing vessels, tabulated by their reasons for abandoning the schools, June-August 1967

Reasons for not fishing	Schools	
	Number	Percent
Chummed but no response	322	49.3
School sounded or moving too fast	182	27.9
Fish too small	120	18.4
Chummed another school close by	29	4.4

Fishing

In fishing skipjack tuna schools with pole and line and live bait, the vessels usually fish only a few minutes and catch a variable fraction of the fish from each school. Fishing time per trip, the sum of the time spent fishing each school, averaged 68 minutes (1.1 hours), which is only about 7 percent of the average trip time. There was, however, a wide variation--

from 46 to 96 minutes--in the average fishing time per trip of the vessels.

The catch from a skipjack tuna school is the outcome of complex and interacting components. For example, the fishermen can control the number of men fishing and to some degree have control over fishing duration, the amount of bait used, and size of fish they will catch, but have no control over the school's biting behavior which adds to the complexity of producing a catch. Furthermore, skill and experience of crewmembers are part of this complex system, but these components are difficult or impossible to quantify.

In Hawaiian waters, the probability that a vessel will catch one or more fish from a school is roughly 50 percent. Royce and Otsu (1955), who examined scouting data over a period of 10 months, reported 43 percent success, whereas Yuen (1959), who had data for the fishing season from May to September, reported 48 percent success among the schools chummed. Collected at the peak of the fishing season in June-August, our data showed that the vessels chummed 1,036 schools (August data for vessel F not included) and caught one or more fish from 587 schools or 57 percent. Individually, vessel A was most successful, fishing 68 percent of the schools it chummed; vessel B was least successful, fishing only 48 percent. In the section that follows, we discuss various components as they relate to fishing.

Amount of bait used.--The amount of bait caught or used in the fishery is measured in units of a "bucket," which holds varying amounts of bait, but usually about 3.6 kg. In the beginning, we attempted to keep an accurate, daily record of the quantity of bait in each baitwell and the subsequent rate at which that bait was used or died at sea, but found the procedure impractical on commercial fishing vessels. We did, however, obtain data on amount of bait used on each school, some of which required more than a bucket, others less. We used one bucket as a minimum, even though on some schools only a few handfuls or some fraction of a bucket were used in chumming. The amount of bait used, therefore, may be overestimated, but we believe any error to be reasonably small.

We compared our estimate of bait used per trip, which averaged 12.8 buckets (table 3), and an earlier estimate made by Uchida (1967) and found them similar. Uchida showed that in 1952-62, small vessels used 12.3 buckets and large vessels used 15.4 buckets of bait per trip, whereas our data showed that, individually, the

Table 7.--Number of schools with and without catches, and averages of catch per school, number of men fishing per school, fishing duration per school, and size of fish per school, tabulated by the amount of bait used per school by seven Hawaiian skipjack tuna vessels, June-August 1967

Bait used per school	Schools		Catch per school		Men fishing	Fishing duration	Fish size
	With catches	Without catches					
Bucket	Number	Number	Number	Metric ton	Number	Minute	Kg.
1	108	383	42.0	0.1	6.1	8.6	3.4
2	111	18	81.6	0.4	6.9	15.3	5.4
3	99	8	110.8	0.7	6.8	21.0	6.6
4	75	1	158.0	1.1	6.7	25.4	6.7
5	76	3	164.6	1.2	6.8	30.3	7.6
6	43	-	203.6	1.7	6.8	37.5	8.2
7	26	-	205.8	1.8	7.5	41.1	8.8
8	27	-	187.4	2.0	7.3	44.8	10.9
9	8	-	259.9	3.0	7.4	53.6	11.4
10	18	-	251.9	2.3	6.9	53.0	9.2
11	4	-	771.8	1.8	7.5	93.2	2.3
12	8	-	680.8	3.3	8.0	66.6	4.9
13	6	-	421.2	4.4	7.8	69.7	10.4
14	2	-	323.0	3.7	8.0	92.5	11.5
15	4	-	433.8	5.2	8.0	72.0	12.0
>15	7	-	583.7	5.0	7.8	98.3	8.5

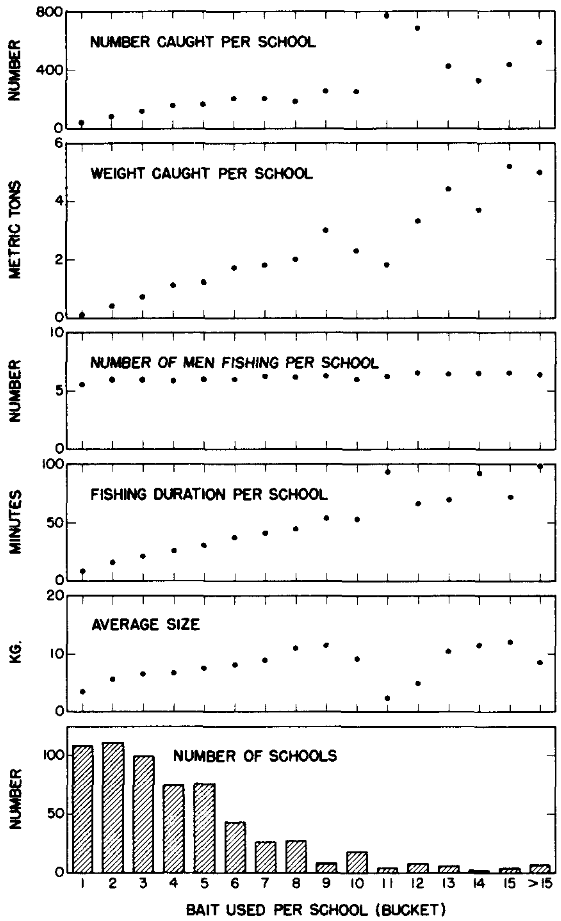

Figure 7.--Relation between amount of bait used per school and average values of catch per school, number of men fishing per school, fishing duration per school, and size of fish per school, June-August 1967.

vessels used from 9.0 to 22.6 buckets per trip. Fully loaded, most vessels carry at least 36 buckets of bait, and sometimes much more, per trip.

A vessel with a full load of bait can fish 2-3 days, provided the bait does not die or is not used up rapidly because of good fishing. That chummers generally used bait sparingly is reflected in the data in table 7, which shows that among nonresponding schools, the vessels chummed 93 percent with only one bucket and the remainder usually with two to five buckets of bait. Even among responding schools, the vessels fished 75 percent with up to only five buckets of bait (table 7 and fig. 7). The average amount of bait used per school, by vessel, ranged from 2.1 to 5.0 buckets per school. Collectively, the average was 3.0 buckets per school (table 3).

Figure 7 shows the averages of the catch per school, number of men fishing, fishing duration, and fish size, plotted by the amount of bait used per school. To show the mutual relationship between the variables examined, we calculated and tested the correlation coefficients, using a hypothesis of $\rho = 0$. We found all the correlation coefficients differing significantly from the hypothesis (table 8). We concluded that the amount of bait used, therefore, contributed significantly to the average number and weight of fish caught per school. It is also evident that on schools requiring more bait, the average fish size was larger and fishing duration longer. Usually, more men fished those schools that required more bait.

To measure the fleet's efficiency in the production of skipjack tuna relative to the bait supply, two indices are occasionally used--catch per bucket of bait caught and catch per bucket of bait used (Yamashita, 1958; Brock and Uchida, 1968). Because we did not collect data for all baiting and fishing operations, we could not calculate the catch per bucket of bait caught; instead, we calculated the catch per

Table 8.--The correlation coefficients calculated for the relation between bait used, men fishing, fishing duration, and fish size and the averages per school of the number and weight of fish caught, amount of bait used, men fishing, fishing duration, and fish size. A single asterisk denotes probabilities between 0.05 and 0.01; two asterisks denote probabilities equal to or less than 0.01

Components of catch	Bait used	Men fishing	Fishing duration	Fish size
Number caught	0.744**	0.956**	0.979**	-0.456
Weight caught	0.939**	0.940**	0.960**	0.852**
Bait used	-	0.977**	0.946**	0.813**
Men fishing	0.899**	-	0.753**	0.300
Fishing duration	0.934**	0.822**	-	0.592*
Fish size	0.510*	0.705	0.847**	-
Degrees of freedom	13	6	10	10

bucket of bait used (table 3). We found that a high-producing vessel does not necessarily have the highest catch rate per bucket of bait used. Vessel A, which ranked first in catch per trip with 4.1 metric tons and third in catch per school with 1.3 metric tons, ranked sixth with a catch of 179.3 kg. per bucket of bait used, whereas vessel F, which ranked lowest in both catch per trip with 2.0 metric tons and catch per school with 0.7 metric ton, ranked fourth or better than average with a catch of 225.3 kg. per bucket of bait used. The averages of the other vessels varied from 174.6 to 262.0 kg.

Number of men fishing.--In pole-and-line fishing, each fisherman uses a stout bamboo pole with a line and a lure consisting of a barbless hook to which feathers and a soft, plastic skirt are attached. Simulating a live baitfish, the lure is slapped on the water and moved over the surface, which is rippled by water sprays from the vessel to enhance the feeding frenzy. When a fish strikes, the fisherman quickly leans back on the pole, taking advantage of the fish's initial thrust to lift it out of the water and "flip" it onto the deck in one continuous motion. By relaxing the tension on the pole, the fisherman allows the fish to become unhooked then returns the freed hook to the water.

On Hawaiian vessels, the "good hookers" fish at the stern where fishing is usually best while others fish along the gunwales near the stern. Every crewmember fishes except the chummer. On some vessels, however, the captain, engineer, and perhaps one fisherman fish only intermittently so they were counted as fishing only if they fished more than half of the fishing duration.

Although the number of men fishing per school ranged from 1 to 10, it was very unusual to have fewer than 3 men fishing (table 9). All the fishermen may not be in their positions at the stern when the school starts biting; those who are may catch a few fish before biting stops. In counting the number of men fishing, we included only those fishermen in position at the time of fishing. Usually, between six and eight men fished; most often, there were seven men fishing (fig. 8).

Catch increased as the number of men fishing increased, but not proportionally. For example, table 9 shows that four men caught an average of 0.4 metric ton, whereas eight men averaged 1.3 metric tons or about three times as much. Plots of the data in table 9 showed positive upward trends of all the variables as the number of men hooking increased; all except one of the correlation coefficients differed significantly when tested against the hypothesis $\rho = 0$ (table 8). The exception was that for the correlation between fish size and number of men fishing. The test of the coefficient against the hypothesis showed a probability very close to 0.05, the level of rejection; however, we accepted the hypothesis on the basis of the summary, by fish size, to be presented in a later section. We conclude from our tests that when the vessels made large catches, they usually had more men fishing, used more bait, and fished the schools longer.

Table 9.--Number of schools and averages of catch per school, amount of bait used per school, fishing duration, and fish size, tabulated by the number of men fishing per school on seven Hawaiian skipjack tuna vessels, June-August 1967

Men fishing per school	Schools	Catch per school		Bait used per school	Fishing duration	Fish size
Number	Number	Number	Metric ton	Bucket	Minute	Kg.
1	4	1.0	<0.1	1.5	5.0	10.0
2	-	-	-	-	-	-
3	7	8.1	<0.1	1.0	3.3	3.3
4	16	76.3	0.4	2.1	11.2	5.7
5	64	109.9	1.0	3.8	22.3	9.0
6	152	140.0	0.9	3.8	27.4	6.3
7	188	143.2	1.1	4.2	27.8	7.6
8	138	180.2	1.3	5.0	29.1	7.0
9	41	194.4	1.6	5.9	32.2	8.4
10	9	306.7	2.6	7.3	29.4	8.5

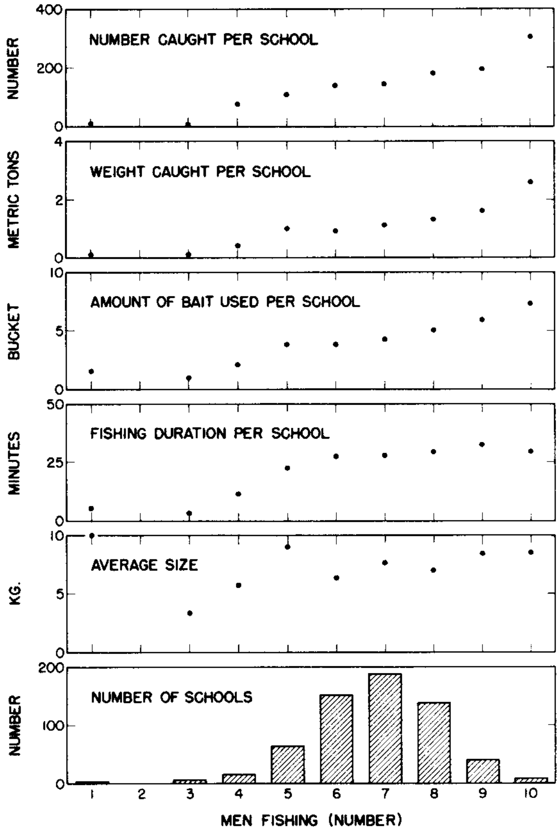

Figure 8.--Relation between number of men fishing per school and average values of catch per school, amount of bait used per school, fishing duration per school, and size of fish per school, June-August 1967.

Fishing duration.--Fishing ends either when the captain decides to abandon the school or when the school breaks away from the vessel. We defined fishing duration as the elapsed time from the landing of the first fish to the end of fishing and for 617 schools found that, although ranging widely from 1 to 155 minutes, it was usually short. The distribution of fishing duration (table 10 and fig. 9), grouped into 5-minute intervals, peaked at 6-10 minutes, with progressively fewer schools fished at longer durations.

Biting behavior has a strong influence on fishing duration. The captains abandoned 42 percent of the schools after fishing started, because biting slowed to a point where they could no longer justify further expenditure of time and live bait (table 11). Moreover, they abandoned an almost equally large percentage--40 percent--of the schools after biting stopped, whereas they abandoned only 8 percent because the schools sounded and failed to return to the surface. In the remaining 11 percent of the schools, the captains quit fishing when they learned that the schools consisted of small fish, when predators--shark or billfish--attacked and dispersed the school, or when bait was exhausted.

It follows that biting behavior influences not only fishing duration, but also the amount of bait chummed to hold the school near the vessel and the catch. Table 10 and figure 9 show that the vessels usually used more bait and caught more fish from good-biting schools that

Table 10.--Number of schools and averages of catch per school, amount of bait used per school, number of men hooking per school, and fish size, tabulated by fishing duration per school for seven Hawaiian skipjack tuna vessels, June-August 1967

Fishing duration	Schools	Catch per school		Bait used per school	Men hooking	Fish size
Minute	Number	Number	Metric ton	Bucket	Number	Kg.
1-5	63	29.3	0.1	1.5	6.2	3.2
6-10	88	62.3	0.3	2.1	6.6	4.2
11-15	82	106.7	0.5	2.7	6.9	4.7
16-20	70	122.0	0.8	3.5	6.9	6.9
21-25	68	140.0	0.9	3.8	6.8	6.4
26-30	59	151.1	1.3	4.9	6.9	8.5
31-35	39	187.8	1.4	5.2	6.7	7.6
36-40	37	220.7	1.9	5.7	6.9	8.7
41-45	20	222.1	2.3	6.8	6.9	10.5
46-50	17	204.9	1.7	5.7	6.8	8.2
51-55	11	257.6	2.5	8.3	7.1	9.8
56-60	11	277.7	2.2	6.4	7.3	7.9
>60	52	379.8	2.9	10.4	7.3	7.8

stayed with the vessel longer. Excluding fishing duration of longer than 60 minutes, we calculated còrrelation coefficients for the data in table 10 and found that they differed significantly from $\rho = 0$. Figure 9 shows that the average number and weight of fish caught per school were larger with more time spent fishing the schools. It also turned out that the vessels usually had more men fishing those schools that bit longer, possibly because the captains and engineers spent more time fishing and were, therefore, included in the effort. Our data showed that the vessels usually caught larger fish from schools that bit longer.

Table 11.--Number and percentage of 585 schools fished by seven Hawaiian skipjack tuna fishing vessels, tabulated by reasons cited for abandoning successfully fished schools, June-August 1967

Reason for abandoning schools	Schools	
	Number	Percent
Biting slowed	244	41.7
Biting stopped	232	39.6
School sounded	46	7.9
Other reasons (small fish, presence of predators, no bait left)	63	10.8

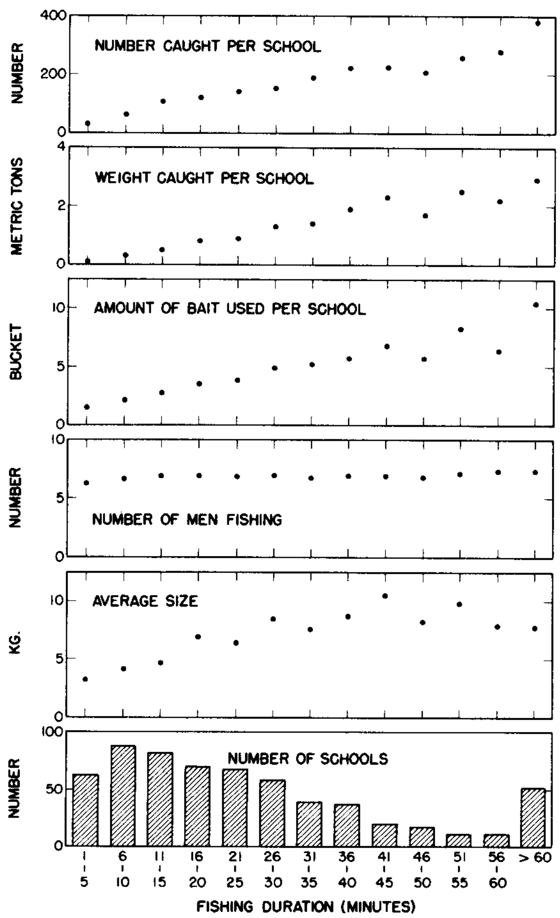

Figure 9.--Relation between fishing duration and average values of catch per school, amount of bait used per school, number of men fishing per school, and size of fish per school, June-August 1967.

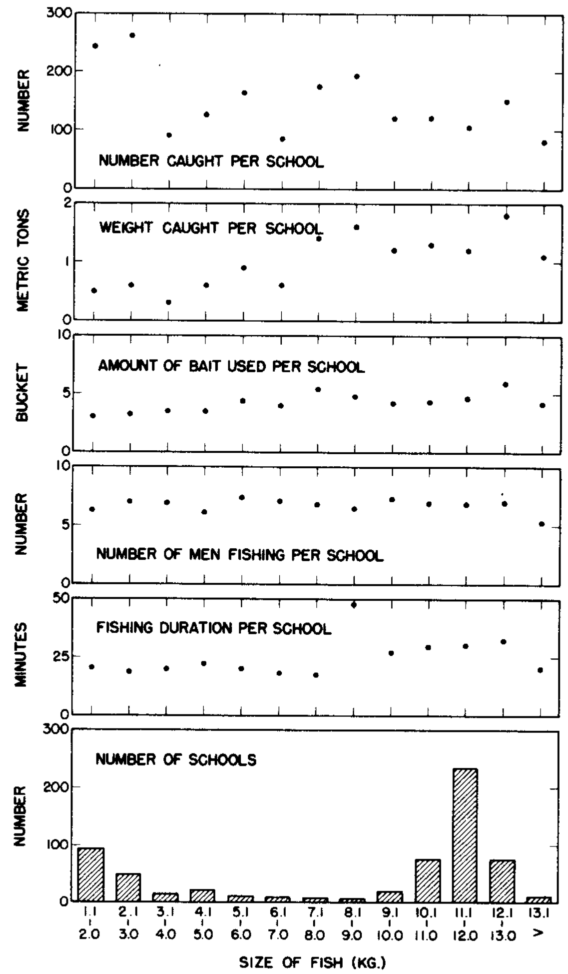

Figure 10.--Relation between size of fish and average values of catch per school, amount of bait used per school, number of men fishing per school, and fishing duration per school, June-August 1967.

Table 12.--Number of schools and averages of catch per school, amount of bait used per school, number of men fishing per school, and fishing duration per school, tabulated by size of fish caught by seven Hawaiian skipjack tuna vessels, June-August 1967

Fish size	Schools	Catch per school		Bait used	Men fishing	Fishing duration
Kg.	Number	Number	Metric ton	Bucket	Number	Minute
1.1-2.0	93	242.4	0.5	3.0	6.3	20.5
2.1-3.0	49	261.9	0.6	3.2	7.0	18.5
3.1-4.0	15	91.3	0.3	3.5	6.9	19.8
4.1-5.0	22	122.7	0.6	3.5	6.1	22.1
5.1-6.0	11	164.3	0.9	4.4	7.4	20.0
6.1-7.0	9	85.1	0.6	4.0	7.1	18.0
7.1-8.0	8	173.8	1.4	5.4	6.8	17.5
8.1-9.0	6	192.3	1.6	4.8	6.5	47.7
9.1-10.0	19	120.4	1.2	4.2	7.3	27.1
10.1-11.0	74	121.0	1.3	4.3	6.9	29.6
11.1-12.0	233	105.2	1.2	4.6	6.8	30.4
12.1-13.0	74	149.9	1.8	5.9	7.0	32.3
>13.0	10	81.7	1.1	4.2	5.3	20.2

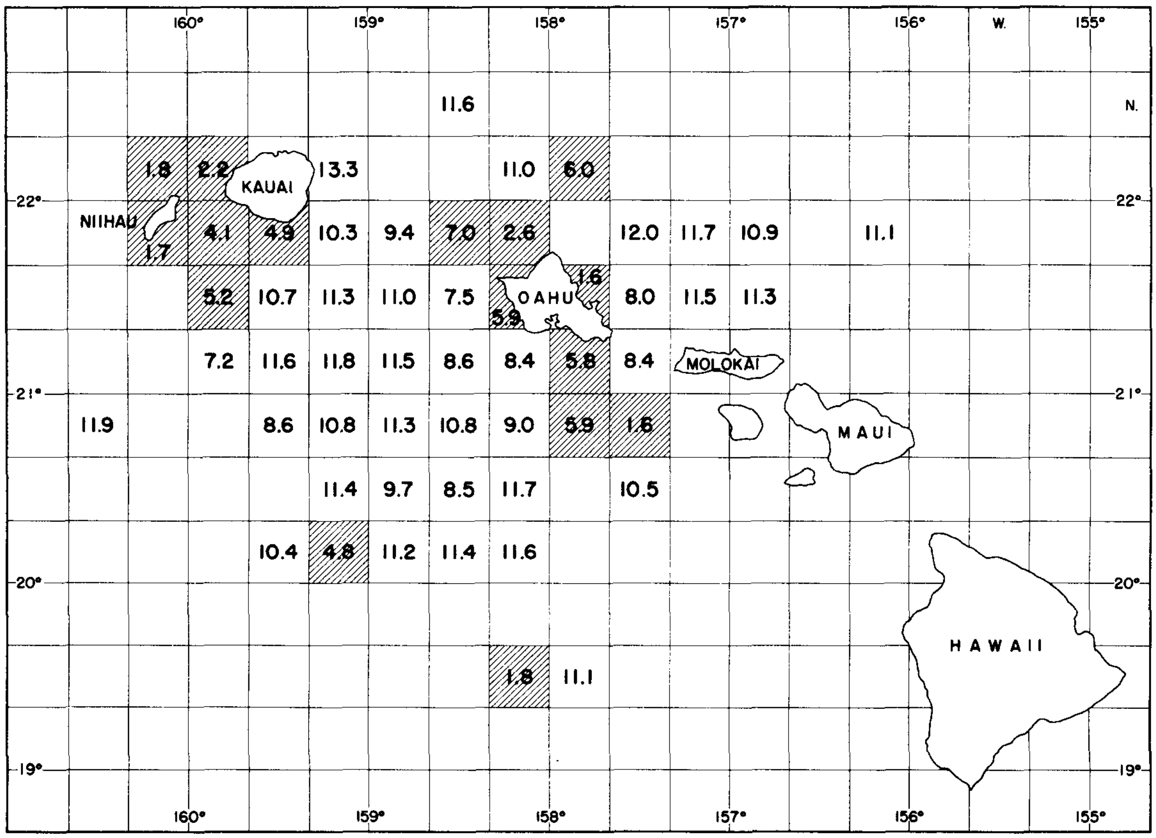

Figure 11.--Average size (kg.) of skipjack tuna caught in 20-minute areas of longitude and latitude by seven Hawaiian skipjack tuna fishing vessels, June-August 1967. Areas in which skipjack averaged 7 kg. or less are shaded.

Size of fish.--The size of skipjack tuna caught in Hawaiian waters is an important factor in the success of a fishing season. The influx of large numbers of "season" fish in the fishery marks the height of the fishing season, usually from May to September, and these fish constitute a major portion of the landings annually.

There appear to be four size groups in the catch: < 4 kg. = small; 4-7 kg. = medium; 7-10 kg. = season; and > 10 kg. = extra large. Because large fish bring better prices, the Hawaiian tuna fishermen usually pass up schools of small and sometimes medium fish for large "season" fish. In table 12 and figure 10, which show the size of fish caught by the seven vessels in June-August 1967, we noted that "season" fish were rather scarce in the catch, constituting only about 5 percent of the schools fished. Much more frequent were schools of extra-large fish (63 percent), which are usually not as frequently encountered as schools of "season" fish, and schools of small fish (25 percent), with schools of medium fish only slightly more frequent in the catch than schools of "season" fish. We also plotted the averages of catch per school, amount of bait used per school, number of men hooking per school, and fishing duration, by fish size, and found that some tended to increase whereas one decreased as fish size increased; only two of the correlations, those for the number of fish caught per school and for the number of men fishing per school with size of fish, did not differ significantly (table 8). The fact that the correlation coefficient of the average number of men fishing and fish size did not differ significantly led us to our earlier conclusion that variation in the number of men fishing did not contribute to variation in average fish size.

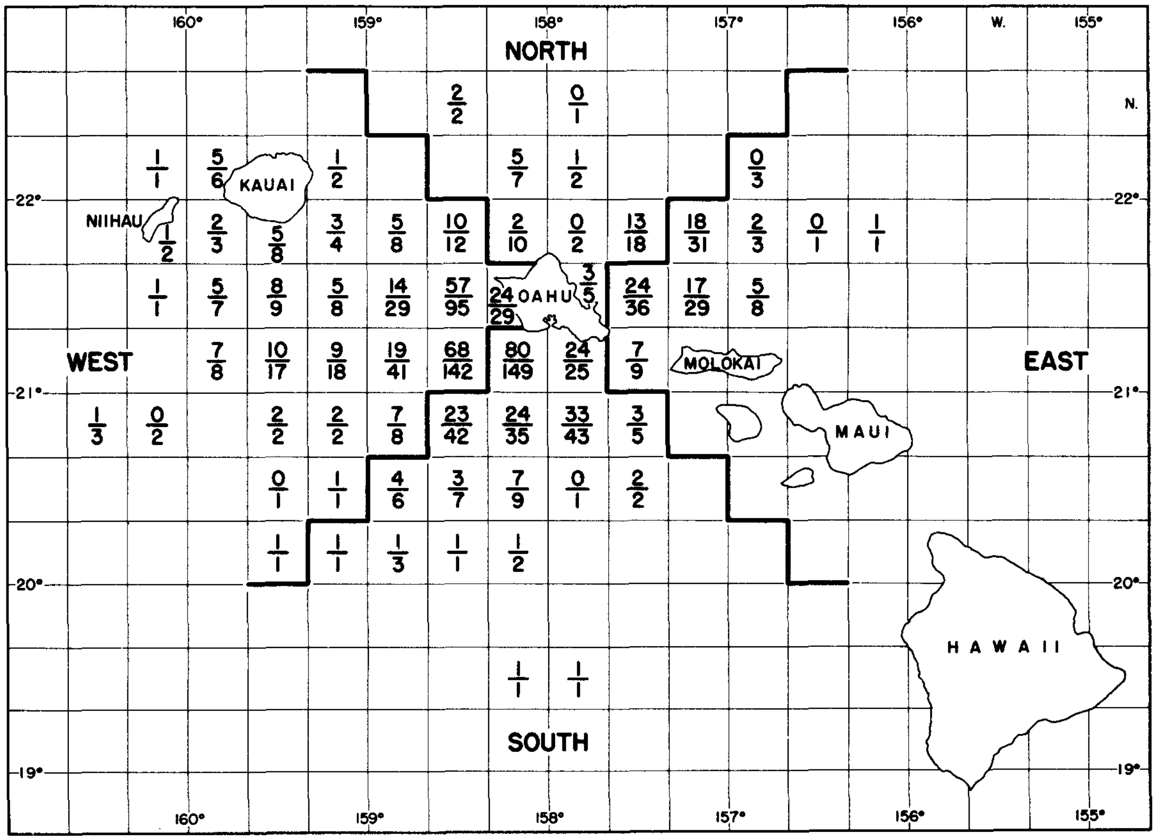

Figure 12.--Ratio of the number of schools successfully fished (upper figure) to the number of schools sighted (lower figure), by 20-minute areas of longitude and latitude in Hawaiian waters, June-August 1967.

A plot of fish size by area of catch showed that larger fish were usually caught farther offshore. Separating the fish sizes into two categories, we found fish averaging smaller than 7 kg. concentrated in six 20-minute areas near Niihau and Kauai, in eight areas around Oahu, and in only two isolated, offshore 20-minute areas south of Kauai and Oahu (fig. 11). Most of the areas with fish averaging larger than 7 kg. were far offshore.

Spatial and temporal distributions of sightings and catches.--The vessels, concentrating their fishing in those areas where skipjack tuna showed the greatest tendency to aggregate in the past, obtain a major portion of the skipjack tuna catch each year from waters to the southwest of Oahu. Commonly called "shitaba" (which means lower ground in Japanese) by the fishermen, this leeward fishing ground off Oahu is calm almost year-round and close to the home port of Oahu-based vessels as well as to Pearl Harbor, one of two major baiting grounds in the Hawaiian Islands. We arbitrarily divided the fishing grounds around Oahu into four sectors and found that out of 971 sightings for which positions were recorded, nearly half were in waters to the west of Oahu, 34 percent to the south, about 13 percent to the east, particularly north of Molokai, and only 5 percent to the north (fig. 12).

Sightings varied not only by geographic location, but also by time of day. The number of sightings in relation to time of day increased rapidly from daybreak to a peak at midmorning (0801-0900), followed by a slight dip at 1001-1100 and a second peak at 1301-1400 (table 13 and fig. 13). We believe that reduced scouting intensity during mealtimes may have caused the slight dip at midday. Data on mealtime aboard the seven vessels showed that on nearly half of the trips, the crewmembers ate lunch at 1001-1100, which coincided with the slump in sightings (table 14). Undoubtedly, insufficient light and scarcity of birds at 0501-0600 and at 1801-1900 affected sightings, but the time taken for breakfast and dinner also may have had some effect on scouting intensity.

Data collected during a research cruise of the Charles H. Gilbert in April 1953 showed similar variations in sightings, by time of day (Royce and Otsu, 1955). Sightings, recorded by fishermen maintaining a continuous watch, dipped at midday and peaked at 0700-0800 and at 1400-1600. Royce and Otsu stated that there

Table 13.--Number and percentage of schools sighted and of schools with catches, tabulated by time of sighting and start of fishing, for seven Hawaiian skipjack tuna vessels, June-August 1967

Time	Schools			
	Sighted		With catches	
	Number	Percent	Number	Percent
0001-0100	-	-	-	-
0101-0200	-	-	-	-
0201-0300	-	-	-	-
0301-0400	-	-	-	-
0401-0500	-	-	-	-
0501-0600	11	0.9	1	0.2
0601-0700	60	4.7	21	3.4
0701-0800	119	9.4	36	5.8
0801-0900	144	11.3	66	10.6
0901-1000	130	10.2	67	10.8
1001-1100	112	8.8	50	8.1
1101-1200	121	9.5	60	9.7
1201-1300	122	9.6	70	11.3
1301-1400	124	9.8	56	9.0
1401-1500	91	7.2	62	10.0
1501-1600	97	7.6	46	7.4
1601-1700	72	5.7	42	6.8
1701-1800	52	4.1	26	4.2
1801-1900	16	1.2	17	2.7
1901-2000	-	-	-	-
2001-2100	-	-	-	-
2101-2200	-	-	-	-
2201-2300	-	-	-	-
2301-2400	-	-	-	-
Totals	1,271	-	620	-

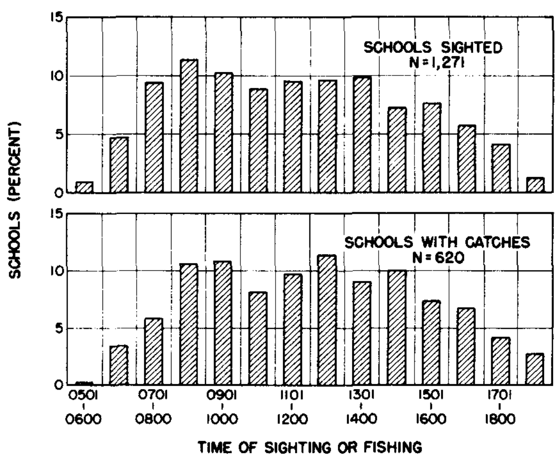

Figure 13.--Frequencies of school sightings and schools with catches, by time of day for seven Hawaiian skipjack tuna fishing vessels, June-August 1967.

is a general belief among the Hawaiian skipjack tuna fishermen that more bird flocks are sighted early in the morning and late in the afternoon. In contrast, another research cruise in June 1953 encountered a peak in sightings at 1100-1200 with a fairly large number of bird flocks sighted at all hours between 0700 and 1700. The lack of consistency among cruises also suggests that the dips and peaks in sightings result from changes in bird or fish behavior.

The spatial distribution of catches was similar to that of sightings (fig. 12). The percentage of schools with catches relative to sightings varied widely among the individual 20-minute areas of longitude and latitude, but the percentages calculated for larger sectors--east, west, north, and south of Oahu--varied little. It should be mentioned that the observers did not record the positions of some of the schools sighted, particularly those schools they encountered during their first week or two of sea duty. The reasons they gave were that they were seasick, were too far offshore, or were experiencing poor weather conditions which interfered with making a reasonably accurate estimate of the school's position. The recording of school positions improved as the observers became accustomed to sea life and learned to work closely with the captain and the fishermen.

In our calculations, we used only schools with positions recorded; therefore, the percentages are overestimates and are of value only in comparing one sector with another. Data presented in figure 5 showed that collectively, the percentage of schools with catches relative to sightings was only 47 percent, but by using only those schools with positions, we calculated that 60 percent of the schools sighted yielded catches. In sectors to the south and east of Oahu, the vessels caught fish from 62 and 61 percent, respectively, of the schools sighted, whereas in sectors to the west and north, they caught fish from 58 and 55 percent of the schools, respectively. Catch per school data from all four sectors ranged from 0.8 metric ton in the north to 1.2 metric tons per school in the west with intermediate values of 1.0 metric ton in the south and 1.1 metric tons in the east.

Table 14.--Number and percentage of trips tabulated by time meals were eaten aboard the seven Hawaiian skipjack tuna vessels, June-August 1967

Time	Breakfast		Lunch		Dinner	
	Number	Percent	Number	Percent	Number	Percent
0001-0100	-	-	-	-	-	-
0101-0200	-	-	-	-	-	-
0201-0300	-	-	-	-	-	-
0301-0400	-	-	-	-	-	-
0401-0500	9	6.9	-	-	-	-
0501-0600	103	79.2	-	-	-	-
0601-0700	18	13.9	-	-	-	-
0701-0800	-	-	-	-	-	-
0801-0900	-	-	-	-	-	-
0901-1000	-	-	15	8.7	-	-
1001-1100	-	-	83	48.0	-	-
1101-1200	-	-	42	24.3	-	-
1201-1300	-	-	21	12.1	-	-
1301-1400	-	-	9	5.2	-	-
1401-1500	-	-	3	1.7	-	-
1501-1600	-	-	-	-	1	0.9
1601-1700	-	-	-	-	8	7.6
1701-1800	-	-	-	-	33	31.1
1801-1900	-	-	-	-	46	43.4
1901-2000	-	-	-	-	16	15.1
2001-2100	-	-	-	-	2	1.9
2101-2200	-	-	-	-	-	-
2201-2300	-	-	-	-	-	-
2301-2400	-	-	-	-	-	-
Totals	130	-	173	-	106	-

The success of fishing in relation to the time of day followed a pattern similar to that seen for sightings relative to time of day (table 13 and fig. 13). Following a rapid increase in fishing success from daybreak to a peak at 0901-1000 and a dip at 1001-1100, there were two other peaks--one at 1201-1300 and another at 1401-1500.

There is also evidence that the vessels caught a large proportion of the day's catch, by weight, usually after 1200 (table 15). Dividing the day's total catch aboard each vessel by schools and by time of day, we found that usually the vessels had only 11 percent of the day's catch aboard by 0900, had less than half--37 percent--of the day's catch aboard by noon, then averaged 31 percent of the day's catch in both the third (1201-1500) and fourth (after 1501) quarters of the fishing day.

Cloud cover and wave height.--Fishing vessels usually operate under various weather conditions. Data collected at the time of fishing revealed that the vessels operated on days that were cloudless, cloudy, overcast, and rainy, and in seas varying from calm to very rough. We were, however, interested primarily in learning whether cloud cover or wave height had any effect on the biting behavior of skipjack tuna. Imamura (1949) reported that Japanese skipjack tuna fishermen experienced better fishing on cloudy days, but Yuen (1959) found that weather had no significant effect on biting behavior of skipjack tuna found in Hawaiian waters.

For June-August 1967, we found that for nearly 50 percent of the schools chummed, cloud cover at the time of fishing was three-tenths or less (table 16). Dividing the data into categories of schools with and without catches, we tested the probability of success in fishing relative to cloud cover and found that the ratios--success to failure--did not vary by more than chance ($\chi^2 = 10.60$; d.f. = 9; $p > 0.25$). We concluded that very cloudy, overcast, or rainy days probably affected fishing only by reducing the fishermen's chances of sighting schools.

Table 15.--Percentage of the day's total catch aboard the vessels in the first (by 0900), second (0901-1200), third (1201-1500), and fourth (after 1501) quarters of the fishing day for seven Hawaiian skipjack tuna fishing vessels, June-August 1967

Vessels	Quarters of the fishing day			
	First	Second	Third	Fourth
	Percent	Percent	Percent	Percent
A	3.3	31.5	42.4	22.8
B	15.5	15.3	35.4	33.8
C	17.0	20.2	23.7	39.1
D	9.2	24.9	35.2	30.7
E	7.1	41.6	28.5	22.8
F	7.2	40.9	33.3	18.6
G	16.4	10.3	21.0	52.3
All	10.8	26.4	31.4	31.4
Cumulative	10.8	37.2	68.6	100.0

Table 16.--Number and percentage of 619 schools with catches and 443 schools without catches, fished by seven Hawaiian skipjack tuna fishing vessels and tabulated by cloud cover at the time of fishing, June-August 1967

Cloud cover	Schools					
	With catches		Without catches		Total	
	Number	Percent	Number	Percent	Number	Percent
Cloudless	23	3.7	31	7.0	54	5.1
1/10 or less	128	20.7	91	20.5	219	20.6
2/10 and 3/10	146	23.6	89	20.1	235	22.1
4/10	83	13.4	67	15.1	150	14.1
5/10	63	10.2	49	11.1	112	10.5
6/10	60	9.7	28	6.3	88	8.3
7/10 and 8/10	42	6.8	35	7.9	77	7.3
9/10 and 9/10 plus	39	6.3	28	6.3	67	6.3
10/10	23	3.7	17	3.8	40	3.8
Rain	12	1.9	8	1.8	20	1.9

The height of the waves also had little effect on fishing. Our data showed that most fishing occurred in waters with moderate wave height; only nine schools were chummed in waters considered very rough (table 17). Testing the ratios of the number of schools with catches to those without, relative to the height of the waves at the time of fishing, we found that they were reasonably constant, with the exception of those schools chummed in very rough waters ($\chi^2 = 0.42$; d.f. = 2; $p > 0.75$).

Predominant birds and size of bird flocks.--While pursuing a school, skipjack tuna fishermen rely heavily on the behavior, species, and number of birds in the flocks to give them information about the species, size, and movement of the fish. For example, Japanese tuna fishermen know from the birds' wild horizontal flights that a school is near the surface, and from the birds' slow flight, high above the water, that the school is swimming deep (Imamura, 1949).

In examining the relationships of catches with predominant birds and with bird flock size at the time of fishing, we found that petrels and shearwaters were most frequently associated with skipjack tuna schools. Of 1,235 flocks identified to predominant species, petrels and shearwaters predominated in 963 flocks or 78 percent, whereas terns predominated in only 235 flocks or 19 percent. Small flocks of boobies or frigate birds predominated infrequently. Using only data for schools chummed (table 18), we found that the predominant species associated with the school at the time of fishing was not a good indicator of success in fishing ($\chi^2 = 2.25$; d.f. = 3; $p > 0.50$).

Rather than predominant species, the size of the bird flock associated with the school appeared to be a good indicator of fishing success. Bird flocks accompanying fish schools varied in size from fewer than 10 to several hundred birds, so to simplify estimation we used only three categories: 10 or fewer, 11 to 50, and 50 or more birds. Size estimates of 1,249

Table 17.--Number and percentage of 620 schools with catches and 442 schools without catches, fished by seven Hawaiian skipjack tuna fishing vessels and tabulated by the height of the wave at the time of fishing, June-August 1967

Wave height	Schools					
	With catches		Without catches		Total	
	Number	Percent	Number	Percent	Number	Percent
Calm (<0.3 m.)	34	5.5	32	7.2	66	6.2
Moderate (0.3-1.5 m.)	471	75.9	331	74.9	802	75.5
Rough (1.5-3.7 m.)	107	17.3	78	17.7	185	17.4
Very rough (>3.7 m.)	8	1.3	1	0.2	9	0.9

Table 18.--Number and percentage of 613 schools with catches and 437 schools without catches, fished by seven Hawaiian skipjack tuna fishing vessels and tabulated by types of predominant birds in the flock associated with the schools at the time of fishing, June-August 1967

Predominant birds	Schools					
	With catches		Without catches		Total	
	Number	Percent	Number	Percent	Number	Percent
Tern	120	19.6	78	17.8	198	18.8
Petrel-shearwater	470	76.7	349	79.9	819	78.0
Booby	17	2.8	7	1.6	24	2.3
Bo'sun bird	2	0.3	3	0.7	5	0.5
Frigate bird	1	0.2	-	-	1	0.1
Other birds	3	0.4	-	-	3	0.3

flocks showed 700 (56 percent) consisted of 50 or more birds, 458 (37 percent) had 11-50 birds, and 91 (7 percent) had 10 or fewer birds. Tabulating only those schools chummed, by size of the flock, we tested the ratios of the number of schools with catches to those without and found them differing significantly ($\chi^2 = 66.60$; d.f. = 2; $p < 0.01$). Table 19 shows that of 617 schools with catches, most had 50 or more birds (68 percent), whereas of 437 schools without catches, most had only 11-50 birds (47 percent). Actually, of 607 schools associated with 50 or more birds, 7 out of 10 schools yielded catches.

Catch Per Trip

The amount of fish caught per school influences the catch per trip, which has been tabulated by weight of fish in table 20. The distribution of catch per trip was skewed and in 244 trips, of which 22 or 9 percent ended in zero catches, most had 0.1-1.0 metric ton. Actually, slightly more than half (55 percent) of the catches were 3.0 metric tons or less per trip. Vessel F, the low producer among the vessels, averaged 2.0 metric tons per trip, whereas vessel A, the high producer, averaged twice as much or 4.1 metric tons (table 3). The grand mean was 2.8 metric tons or about 376 fish per trip.

Strongly skewed toward small catches, the distribution of catch per school in table 21 shows that the vessel usually caught between 0.1 and 0.5 metric ton or between 1 and 100 fish. Actually, catches ranged from 1 kg. to 9.0 metric tons or from 1 to 1,710 fish, and averaged 1.1 metric tons or 148 fish, slightly higher than the positions of the modes in the

Table 19.--Number and percentage of 617 schools with catches and 437 schools without catches, fished by seven Hawaiian skipjack tuna fishing vessels and tabulated by size of bird flocks associated with the schools at the time of fishing, June-August 1967

Size of bird flock	Schools					
	With catches		Without catches		Total	
Number	Number	Percent	Number	Percent	Number	Percent
10 or fewer	26	4.2	42	9.6	68	6.4
11 to 50	172	27.9	207	47.4	379	36.0
50 or more	419	67.9	188	43.0	607	57.6

Table 20.--Number of trips, schools, catch per trip, catch per school, and number of schools fished per trip, tabulated by the weight of fish caught per trip by seven Hawaiian skipjack tuna vessels, June-August 1967

Size of catch	Trips	Schools	Catch per trip	Catch per school		Schools per trip
Metric ton	Number	Number	Number	Number	Metric ton	Number
0	22	-	-	-	-	-
0.1-1.0	53	103	130.6	67.2	0.3	1.9
1.1-2.0	41	113	256.3	93.0	0.6	2.8
2.1-3.0	41	131	503.8	157.7	0.8	3.2
3.1-4.0	26	71	512.2	187.6	1.3	2.7
4.1-5.0	23	73	514.9	162.2	1.4	3.2
5.1-6.0	12	36	847.2	282.4	1.9	3.0
6.1-7.0	12	45	638.3	170.2	1.8	3.8
7.1-8.0	6	18	659.0	219.7	2.5	3.0
8.1-9.0	4	18	830.3	184.5	1.9	4.5
9.1-10.0	1	6	865.0	144.2	1.6	6.0
10.1-11.0	2	6	1,002.5	334.2	3.6	3.0
11.1-12.0	-	-	-	-	-	-
12.1-13.0	1	3	1,015.0	338.3	4.1	3.0

distributions because of the long positive tails. Catch per school ranged among the vessels from 0.7 metric ton per school for vessel F to 1.4 metric tons per school for vessels B and C (table 3).

Another component which influenced catch per trip was the number of schools with catches on a trip. Table 3 shows that vessels A and G were most successful, catching fish from an average of 3.1 schools per trip, that vessel B was least successful, catching from an average of only 1.8 schools, and that on 231 trips, the vessels usually caught fish from 2.5 schools per trip. The distribution of trips, tabulated by the number of schools with and without catches, was skewed toward fewer schools per trip, with the mode at two schools and the range from one to eight schools with catches per trip (table 4 and fig. 5).

The relationship of catch per trip with catch per school and number of schools fished is shown in table 20 and figure 14. We found that usually 1.9 schools yielded catches averaging 0.3 metric ton per school on trips with catches of 0.1 to 1.0 metric ton. The average number of schools fished and the average catch per school tended to increase progressively for larger categories of catch per trip and reached 3.0 schools and 2.5 metric tons per school, respectively, for those trips with catches of 7.1 to 8.0 metric tons. At 8.1 to 9.0 metric tons per trip, the average number of schools increased further to 4.5 schools, but the average catch per school declined to 1.9 metric tons. There were few trips with catches of 9.1 metric tons or more; therefore, although we calculated averages for the number of schools fished and school catches, they were not considered representative and were excluded from the discussion.

SUPPORTING ACTIVITIES

In addition to time spent traveling, baiting, scouting, and fishing, the fishermen also are engaged in unloading the catch, loading ice, and fabricating, repairing, and maintaining their gear and vessels. We collected and analyzed data on two of these operations--unloading the catch and loading ice.

Upon return to Kewalo Basin with the day's catch, the crew unloads by hand if the catch is small or if part of the catch is consigned to the fresh-fish market. After the market fish is unloaded, the crew uses a conveyor to unload the balance into trucks for sale to the cannery. At Kaneohe Bay, however, the crew unloads the entire catch by hand. In calculating the unloading time for each vessel, we made no distinction in the method used in unloading the catch. The vessels usually loaded ice after the baitwells were emptied of fish.

Table 21.--Size of catch, number of schools, and catch per school of seven Hawaiian skipjack tuna vessels, June-August 1967

Size of catch	Schools	Catch per school	Size of catch	Schools	Catch per school
Number	Number	Metric ton	Metric ton	Number	Number
0	449	-	0	449	-
1-100	326	0.4	0.1-0.5	283	54.3
101-200	146	1.2	0.6-1.0	133	145.6
201-300	71	2.1	1.1-1.5	75	204.9
301-400	35	2.5	1.6-2.0	34	224.8
401-500	20	2.8	2.1-2.5	32	243.1
501-600	7	4.6	2.6-3.0	17	401.8
601-700	7	2.3	3.1-3.5	14	393.5
701-800	4	3.5	3.6-4.0	14	322.6
801-900	1	1.5	4.1-4.5	5	342.4
901-1,000	1	1.7	4.6-5.0	6	456.8
1,001-1,100	2	2.1	5.1-5.5	2	451.5
1,101-1,200	-	-	5.6-6.0	3	506.0
1,201-1,300	-	-	6.1-6.5	2	530.5
1,301-1,400	-	-	6.6-7.0	1	535.0
1,401-1,500	-	-	7.1-7.5	-	-
1,501-1,600	1	2.9	7.6-8.0	1	651.0
1,601-1,700	1	3.3	8.1-8.5	-	-
1,701-1,800	1	2.7	8.6-9.0	1	740.0

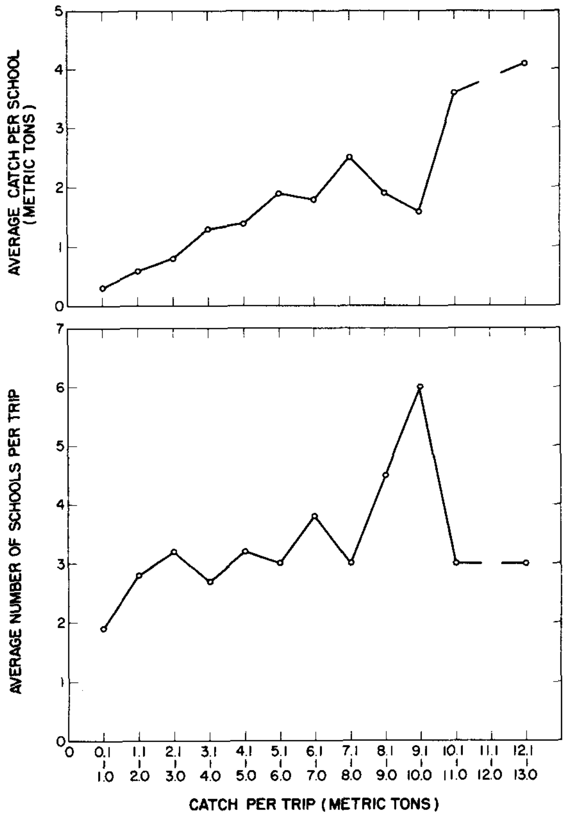

Figure 14.--Relation between catch per trip and average number of schools fished and average catch per school by seven Hawaiian skipjack tuna fishing vessels, June-August 1967.

From data on unloading catch and loading ice, we found that the weight of fish unloaded varied among the vessels from an average of 2.4 to 4.1 metric tons and collectively averaged 3.4 metric tons. In table 3, we noted that catch per trip was 2.8 metric tons, a figure somewhat lower than the average of 3.4 metric tons unloaded at the docks. The discrepancy between the catch per trip and the average catch unloaded occurs because catch per trip was based on a single day's fishing, whereas the unloaded catch included, in some cases, the catches of 2 or more days of fishing.

Usually about 9 men, including crewmembers and shoreside helpers, unloaded the vessel, with a range of 7 to 13 men. Unloading usually required about one-half hour; the average unloading time among the vessels ranged from 26.8 to 33.0 minutes.

The rate of unloading depended largely on the size of the fish. Vessels which caught small fish usually had low unloading rates. On the contrary, vessel B, which had the highest unloading rate per man-minute at 16.8 kg., caught fish which averaged 9.5 kg., the largest average among the vessels.

In loading ice, the vessels averaged from 3.7 to 11.4 minutes with a grand mean of 6.6 minutes. Since loading ice is at a fixed rate, the loading time varied directly with the quantity loaded.

OPTIMUM VESSEL OPERATION

There appears to be a certain pattern to a successful operation in the fishery for skipjack tuna in Hawaiian waters. Using catch, which is convertible into earnings as a measure of success, we found that certain characteristics differ between a high- and low-producing vessel.

There were several aspects of the operations of vessel F, a low producer, which contrasted sharply with those of vessel A, a high producer. Both were below average in pursuit time, but vessel A pursued its schools almost twice as long as vessel F. Vessel A chummed its schools slightly longer than average; vessel F only about half as long as the average of all vessels. In fishing, vessel A, which averaged slightly longer than vessel F in fishing per trip and per school, had values higher than the seven-vessel averages in these categories. In number of men hooking per school, vessel F had six men, which is not dissimilar from the seven-vessel average, but vessel A usually had seven men fishing.

Moreover, vessel A used unusually large amounts of bait at sea, averaging about 23 buckets per trip, whereas vessel F used only about 9 buckets, which is 25 percent less than the average for the seven vessels. A similar difference between these vessels can be seen in the average amount of bait used per school. Vessel A succeeded in fishing 64 percent of the schools it sighted, whereas vessel F succeeded in fishing only 56 percent of its schools.

More time spent pursuing and chumming the schools, more men available for fishing, and more bait used per school undoubtedly contributed to a larger catch per school for vessel A. Averaging 1.3 metric tons per school, vessel A usually caught nearly twice as much per school as vessel F, which averaged only 0.7 metric ton.

Data on catch per bucket of bait used in fishing, however, cast doubt that the operation of vessel A was most successful among the vessels. Vessel A, which ranked among the lowest, caught only 179.3 kg. of skipjack per bucket of bait compared with vessel F, which ranked above average with catches of 225.3 kg. per bucket (table 3).

A vessel with a high catch rate per bucket of bait used may be termed efficient in its bait use, but if the bait conserved dies before it can be used in fishing, then it appears that a vessel with a lower catch rate per bucket of bait is just as efficient if a high percentage of its bait results in production of fish. From examination of the Aku Catch Reports at the Hawaii State Division of Fish and Game, we found that vessel A used 78 percent of the bait it caught, whereas vessel F used only 59 percent. The fact that vessel A had the largest bait capacity among the seven vessels and vessel F the smallest also accounts for the rates at which both vessels used their bait in fishing. Evidently vessel F was too economical with bait and the result was that it had smaller catches and fewer successes in fishing the schools. Overall, the seven vessels used about 66 percent of the bait they caught.

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