Anchored Fish Aggregating Devices in Hawaiian Waters

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ABSTRACT—Fish aggregating devices (FAD's) made of 55-gallon oil drums and wooden rafts were moored in Hawaiian waters off the islands of Oahu, Lanai, and Hawaii from May 1977 through July 1979. The FAD's successfully attracted numerous pelagic fishes, including large schools of skipjack and small yellowfin tunas. Commercial tuna pole-and-line boats benefited greatly by taking large catches of tunas from around the FAD's. Fishing around the FAD's resulted in reduced fuel and baitfish expenses. Trolling boats also benefited as they experienced a reduction in the number of zero-catch days. The success of the FAD experiment encouraged the State of Hawaii to implement its own FAD system involving 26 fish aggregating devices around seven major islands.

Introduction

Tunas have long been known to aggregate around floating objects such as logs, masses of drifting seaweed, debris, and other flotsam. Both Japanese and American fishermen have utilized this knowledge and routinely seek such objects while fishing for skipjack tuna, *Katsuwonus pelamis*, and yellowfin tuna, *Thunnus albacares*, in the eastern and western Pacific (Uda, 1933; Kimura, 1954; McNeely, 1961; Inoue et al., 1963, 1968).

In recent years, the Japanese began seining for skipjack and small yellowfin tunas in the western equatorial Pacific. The Pacific Tuna Development Foundation (PTDF) also began similar operations in the western Pacific with chartered American seiners (PTDF, 1979). In both operations the success of seining for tunas depended largely upon schools associated with drifting logs. The ratio of successful sets in the PTDF operations was well over 4:1 in favor of sets made around drifting logs as compared with sets made on schools independent of logs.

While the value of drifting logs to successful seining has been well demonstrated by these questions, such logs, which abound in the western equatorial Pacific, especially in waters north of Papua New Guinea, are only seldom found around islands in the central Pacific. Moreover, whenever an occasional log is encountered in the latter areas, it is available to the local fishermen only for a short time before it drifts off beyond the range of their boats. Thus, to benefit from this type of fishing in areas where drifting logs are scarce, it may be necessary for man to turn to anchored devices.

This has been done in the Philippines in recent years where purse seining for tunas around large bamboo rafts (7 × 36 feet) anchored in very deep waters (2,000-3,000 fathoms) has developed into a sizable tuna fishery (Matsumoto[1]). The anchored rafts, numbering in the hundreds and spaced 4-8 miles apart, have successfully attracted large quantities of tunas and enabled the seiners to operate continuously for 6 months or more at a time. The success of this fishery has been mainly due to the availability of vast areas of protected waters in the Philippines where the seas are exceptionally calm.

The Honolulu Laboratory of the National Marine Fisheries Service (NMFS) Southwest Fisheries Center and the PTDF embarked on a joint project to test anchored fish aggregating devices in Hawaiian waters in May 1977. The project was funded largely by PTDF with additional support from NMFS. This report covers the procedures and results of the project.

Objectives

The primary objectives of the project were to: 1) Develop and test anchored fish aggregating devices (hereafter called buoys) in open ocean areas and 2) determine their effect upon the skipjack tuna pole-and-line fishery in Hawaii. Secondary objectives were to determine the effects of buoy placement relative to distance from land, depth, and bottom topography.

Procedure

Buoy Construction

Two types of buoys were used in the experiment. The first type (Fig. 1, 2) consisted of a buoy made of two 55-gallon steel oil drums filled with polyurethane foam and held together in a frame of 3- × 3-inch angle iron. The frame was extended below to form V's at the front and rear and wooden slats were bolted to the V sections to form a haven for small fish. This also provided additional stability to the buoy. A pyramid made of angle iron and plywood

[1]Matsumoto, W. M. Seine fishing around payaos in the Philippines. Honolulu Laboratory, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812. Manuscr. in prep.

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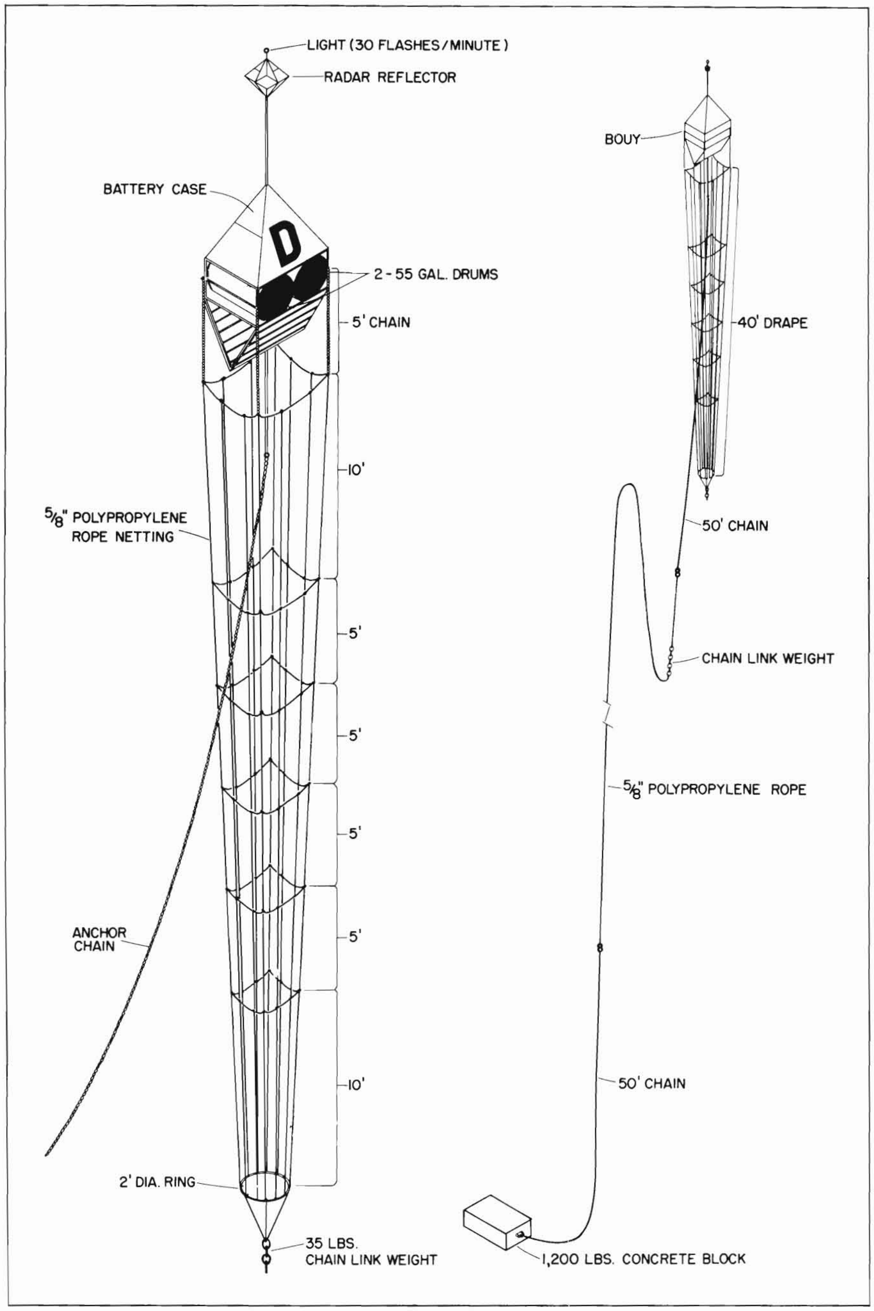

Figure 1.—Fish aggregating device, buoy type.

was welded over the drums and a radar reflector and a navigational warning light were mounted above the pyramid. Details of the buoy and radar reflector are shown in Figures 3 and 4.

A battery compartment was built into the upper half of the pyramid, which was painted in alternate orange and white horizontal bands and marked A, B, C, etc. The light, which was equipped with a photosensor and flashed 32 times per minute, was visible at 0.75 mile. It was energized by three 6-V lantern batteries encased in a length of 3-inch

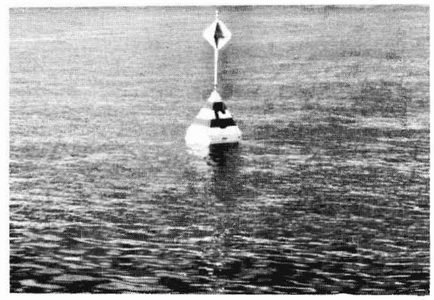

Figure 2.—Fish aggregating device in place off Oahu, Hawaii.

polyvinyl chloride (PVC) pipe. The battery pack provided energy for up to 5 months.

Initially, a 1 × 3 × 30-foot raft made of 1½-inch PVC pipes bolted onto metal frames with floats at both ends was tethered to the buoy. Six to eight coconut palm fronds attached to a 50-foot cable were suspended from the end of the raft. The palm fronds were soon found to be too fragile to withstand the prevailing wave action, and the raft itself was prone to excessive damage because it collided with the buoy in rough seas. Consequently, both raft and fronds were removed from the buoy and a drape made of polypropylene rope was suspended directly from the buoy (Fig. 1).

The second type was a raft (Fig. 5), 4 × 12 feet, made of 2- × 6-inch wooden planks on top and bottom and bolted to four 4- × 4-inch crosspieces. The space between the top and bottom layers of planks was filled with polyurethane foam. A superstructure identical with that used on the buoy was mounted on the raft and a drape, made of 1-inch mesh nylon netting, was hung from the rear third of the raft. These rafts were used only off Kona, Hawaii.

Anchor and Mooring Method

The anchor consisted of a 1,200-pound block of concrete, reinforced with steel bars, and fitted with a ¾-inch galvanized eyebolt at one end.

The anchor line consisted of 50-foot

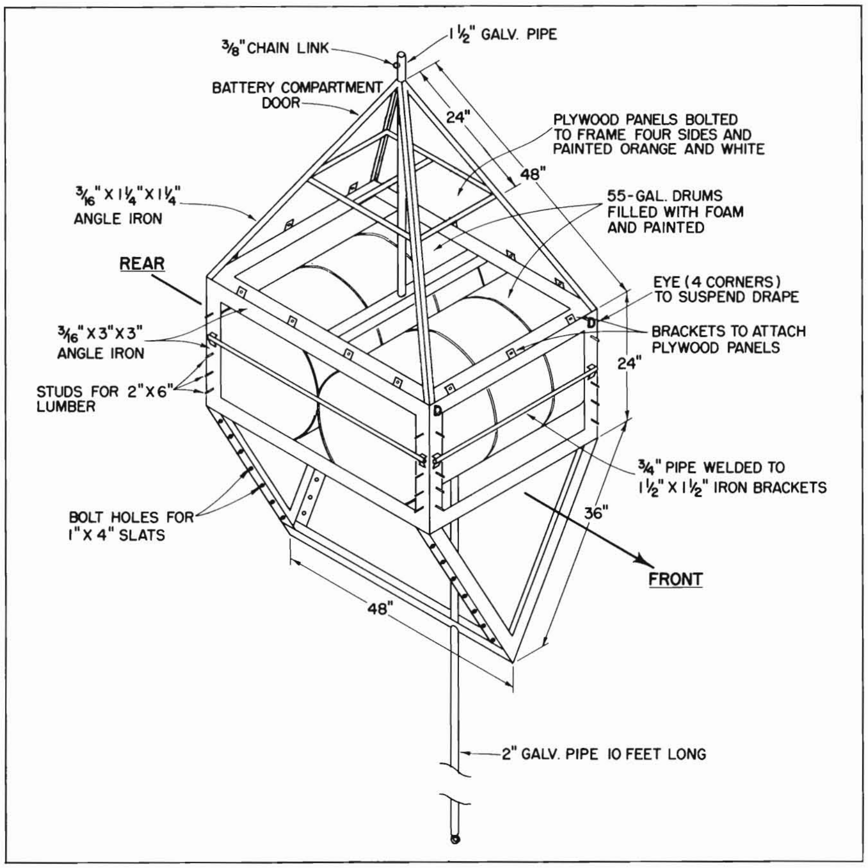

Figure 3.—Details of two-drum buoys.

345 fathoms. Buoys A and D were situated within 2 miles of the 500- to 1,000-fathom slope, whereas buoys B and C were 14 and 6 miles, respectively, from the slope.

The first three buoy sites were fully exposed to the northeast trades, which predominated in all seasons, and to occasional south winds, often accompanied by storms. The buoys were thus buffeted by winds from 15 to 25 knots, often approaching gale force. The seas were generally from 4 to 12 feet but exceeded 20 feet during storms. Site D was relatively calmer, with seas generally ranging from 2 to 4 feet. During stormy periods, however, the seas ranged as high as 10 feet.

Subsequently, on 22 March 1978, two raft-type devices were moored off Kona, Hawaii, in relatively calm waters. The first, F, was placed 4.5 miles west of Kaiwi Point at a depth of 1,250 fathoms and the second, G, was placed 6 miles offshore and 8 miles north-northwest of Keahole Point at a depth of 220 fathoms. The latter was situated 3.5 miles shoreward from the 1,000-fathom slope. Both of these sites were in proven fishing areas for tunas and billfishes.

lengths of ½-inch galvanized chain at the top and bottom and a main section of ⅝-inch twisted polypropylene rope. The scope or ratio of anchor line to depth was between 1.65:1 and 1.80:1. Such a large scope, together with the positive buoyancy of the polypropylene rope, caused large sections of anchor line to float at the surface periodically during changes in the tidal current and thereby posed a hazard to navigation. To correct this, a chain link weight was added to the upper one-fourth to one-third of the anchor line to keep the excess line submerged at all times. The position and size of the weight varied from one buoy to the next, depending upon the length of the anchor line and the depth of the anchoring site. The weight was linked into the line to prevent it from chafing the anchor line.

The simplest method was used in mooring the buoys. The buoy was first set on the water at the selected site, the anchor line was payed out as the vessel moved slowly in a circular path around the buoy, and the anchor was released in a free fall to the bottom.

Location of Buoys

Four buoys were initially moored off Oahu and Lanai (Fig. 6) on 9 and 10 May 1977. Buoy A was placed 16 miles south-southwest of Kewalo Basin (lat. 12°04′N, long. 158°00.4′W), Oahu, at a depth of 308 fathoms; buoy B was placed 18 miles southeast of Kewalo Basin and 1 mile off Penguin Bank (lat. 21°00.5′N, long. 157°43.7′W) at a depth of 242 fathoms; buoy C was moored 27 miles south-southeast of Kewalo Basin and 1.1 miles off the tip of Penguin Bank (lat. 20°51′N, long. 157°45′W) at a depth of 246 fathoms; and buoy D was moored 10.5 miles southwest of Lanai (lat. 19°20′N, long. 157°10′W) at a depth of

Monitoring Buoys and Catches

Monitoring and maintenance of the buoys off Oahu and Lanai were scheduled on a monthly basis, with additional visits at the height of the skipjack tuna fishing season. All visits could not be made as planned, however, due to prolonged periods of rough sea conditions.

On all monitoring trips, troll fishing was done at each buoy site and on runs between buoys. Sightings of bird flocks, fish schools, and scattered birds were recorded and the areas immediately around the buoys were scanned with a depth recorder to detect subsurface fish schools.

Fish catch data from commercial tuna pole-and-line boats visiting the buoys were obtained through catch forms supplied to each boat and from interviews with boat operators. Catch data from commercial and recreational trolling boats were obtained from interviews once or twice each week and were limited to boats based at Kewalo Basin,

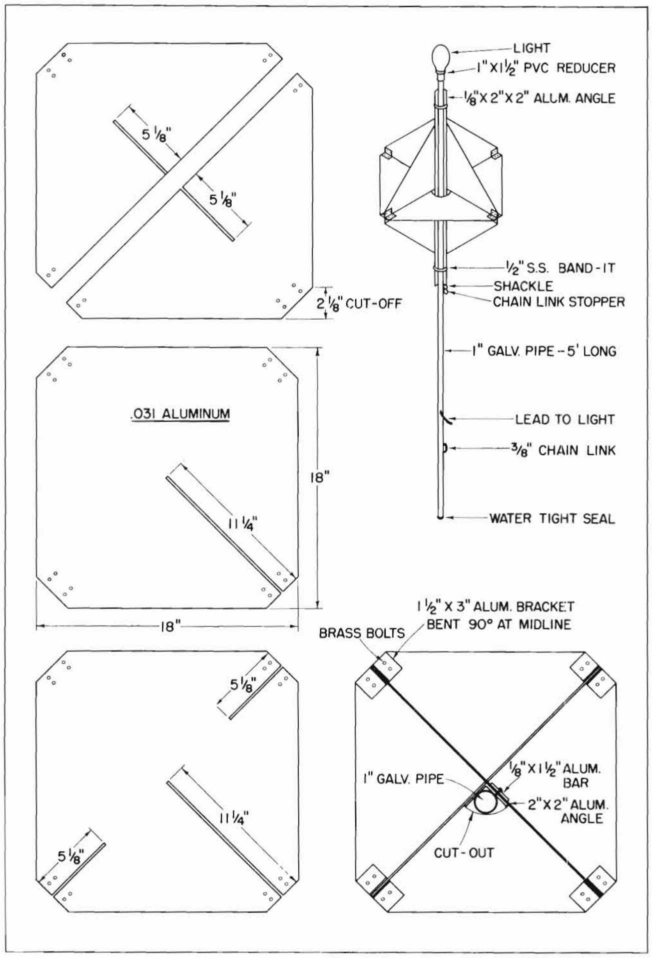

Figure 4.—Details of radar reflector.

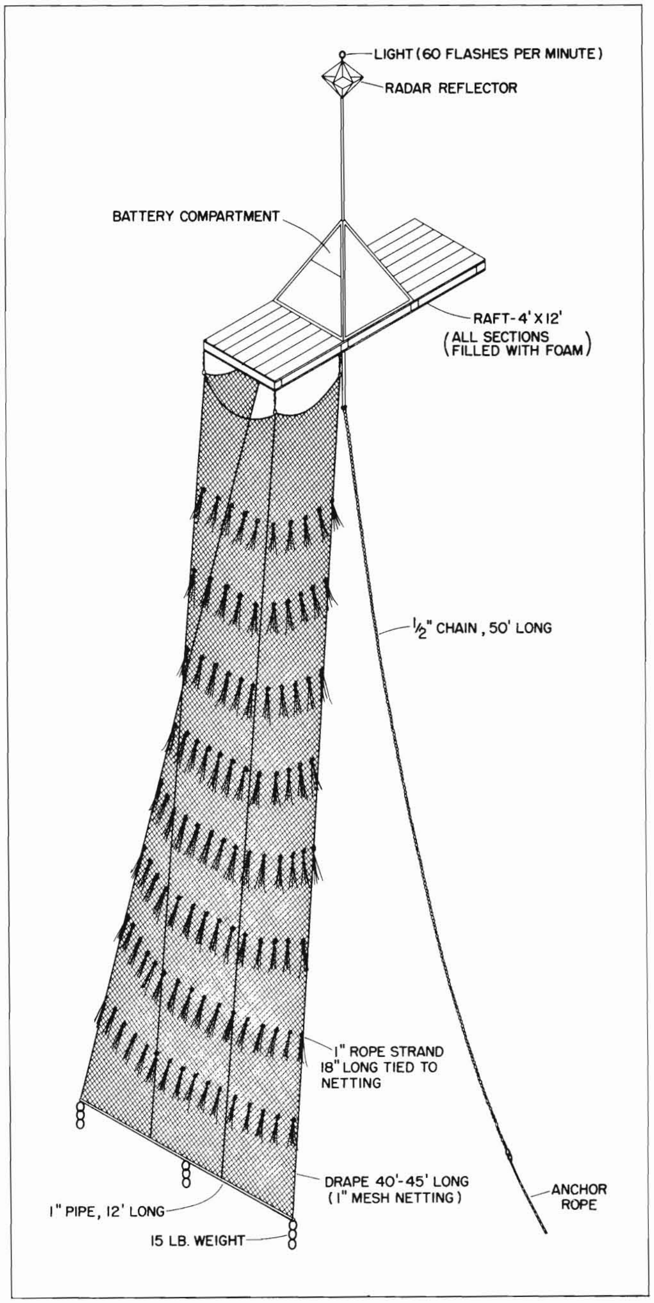

Figure 5.—Fish aggregating device, raft type.

since it was not possible to monitor the numerous trailer boats launched from scattered points on the island. Fish catch forms also were distributed to boats fishing out of Kona and Maui. Underwater observations were made at buoys D and F, both located in calm water.

Results

Buoy Performance

The buoys performed as expected in attracting and holding marketable fish species. The dolphin, *Coryphaena hippurus*, and wahoo, *Acanthocybium solanderi,* were among the first to be caught by trolling around the buoys. These fish appeared from 1 to 3 weeks after the buoys had been anchored. Both species generally appeared in small numbers but sizable catches of 10-20 dolphin were reported on 14 occasions and 20-30 fish on 4 occasions. The two largest single-day catches of this species were 32 and 41 fish.

Schools of tunas, small yellowfin, skipjack, and kawakawa, *Euthynnus affinis*, generally appeared from 2 to 5 weeks after the buoys had been deployed. The early arrivals were small fish weighing from 1 to 4 pounds. These were joined later by larger fish as the tuna aggregations increased around the buoys. Other fish of the families Carangidae, Balistidae, and Kyphosidae often appeared well before the tunas.

As the aggregations of fish built up around the buoys, so did the number of fishing boats. These included commercial bait boats, chartered (sport fishing) and commercial trollers, and trailer boats of assorted sizes. Buoy A attracted as many as 30 boats on a given day, all fishing simultaneously around the buoy and up to a distance of 3 miles. In the calmer waters off Kona, F and G buoys attracted 50 or more boats on a given day.

Buoy losses were experienced at all sites. The four buoys (A-D), initially deployed on 9 and 10 May 1977, broke free in July after 7-10 weeks because of incompatible fittings used in the anchor line. Subsequently, two more buoys were lost at sites A and B and one more each at sites C and D from other causes. At site A, the second buoy was lost after 16.5 months as a result of a storm and the third buoy was lost after 4.5 months, due to cable grip slippage. On this buoy, 100 feet of ⅜-inch cable, secured by three safety cable grips at each end, was used at the top of the anchor line, instead of the usual length of chain. At site B, the second buoy was lost after 3 months as a result of line chafing. The buoy was inadvertently anchored too close to Penguin Bank, and the anchor rope failed to clear the top of the ledge as the buoy swung over the bank during tidal changes. The third buoy was lost after 16.75 months when a shackle pin was lost. At site C, the second buoy was lost after 19.75 months due to undetermined causes, and at site D, the second buoy was lost after 16.5 months after it had been dragged by currents to a shallow ledge where the anchor rope eventually chafed on the bottom. Despite these losses, the buoys at all sites remained in position long enough to demonstrate their effectiveness in attracting and holding fish schools.

The buoy design was adequate at all sites, except D, where unforeseen strong currents occurred twice during the testing period. On both occasions the current forced the buoy to submerge and caused the anchor to be dragged along the relatively flat, mud and silt bottom.

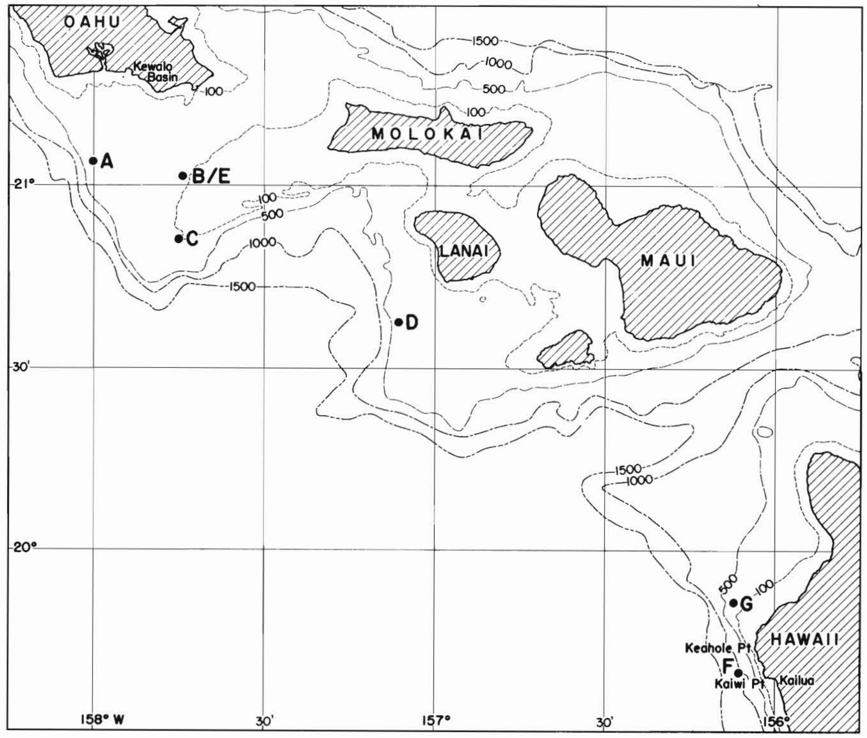

Figure 6.—Fish aggregating devices off Oahu, Lanai, and Hawaii.

The buoys off Kona (F and G) were not part of the original buoy project. Consequently, wooden rafts that were available from a prior experiment were used instead of the steel-drum buoys. These rafts remained operative for 10 months before breaking apart during the same series of storms that caused the losses of A and D buoys. The winds off Kona exceeded 40 knots during this storm.

The drapes of fine-mesh netting used on F and G buoys were very effective in attracting fish; however, they also gilled numerous mackerel scad, *Decapterus punctatus* (Fig. 7), and were torn to shreds from sharks feeding on the gilled fish.

Monitoring Trips

Visits to the buoys were interrupted at various times, either because of rough sea conditions or loss of buoys (Table 1). Sixteen visits were made to A, 13 to B, 13 to C, and 10 to D. The catch by trolling on these trips was generally low at all the buoys. The total catch consisted of 29 fish at A (1.8 fish per visit), 11 at B (0.8 fish per visit), 3 at C (0.2 fish per visit), and 7 at D (0.7 fish per visit). The low catch was largely due to fishing by trollers prior to the arrival of the monitoring vessel. Consequently, determination of the presence of fish around the buoys were made from fish and bird flock sightings and fish-finder observations. Fish were present at A and 13 of 16 visits (81.2 percent), at B on 8 of 13 visits (61.5 percent), at C on 6 of 13 visits (46.2 percent), and at D on 9 of 10 visits (90.0 percent). Thus, buoys A and D, because of their locations (see Discussion), were more effective in attracting fish than B and C.

To determine the effectiveness of the buoys statistically, controlled fishing by trolling was done within 0.5 mile and at distances of 3 to 5 miles from the buoys

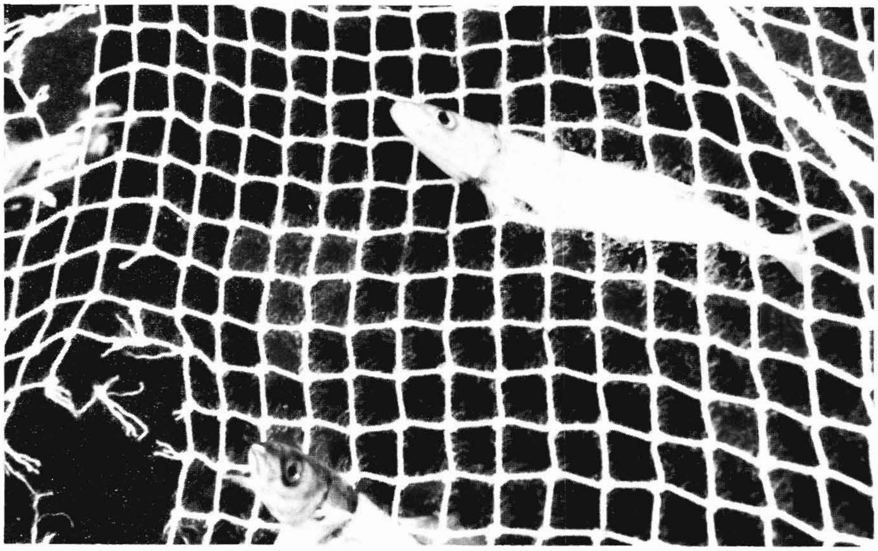

Figure 7.—Mackerel scad gilled on netting hung from fish aggregating device. Torn sections caused by shark attacks on gilled fish.

by a commercial trolling boat and vessels used in monitoring the buoys. Because of differences in fishing duration and in number of lines fished by different vessels, catch-per-line-hour was used in comparing the effect of the buoys in the two areas. Sixteen pairs of observations were obtained in March, April, and August 1978. Of these, fish were caught within 0.5 mile of the buoy on nine occasions, between 3 and 5 miles on one occasion, and in both areas on one occasion. No fish was caught in both areas on five occasions. There were 10 positive differences in the catch rates in favor of the buoy area, 1 negative difference, and 5 with no difference.

The randomized test for matched pairs (Siegel, 1956) indicated that catch rates within 0.5 mile of the buoys were significantly greater ($P = 0.00097$, one-tailed) than in areas 3 to 5 miles away. The test, thus, indicated that the buoys were successful in aggregating fish.

Pole-and-Line Fishing

The buoys were first deployed in May, at the beginning of the skipjack tuna fishing season. The anticipated visits to the buoys by pole-and-line boats during the fishing season did not occur because of the unexpected loss of all four buoys in July and because the buoys could not be reinstalled before the end of the fishing season. All four buoys were reinstalled between August and October, and visits by pole-and-line boats began in December. Initially, the few boats that fished around the buoys were reluctant to report their visits and catches because they did not want other boats to visit the buoys also. The reporting of visits and catches improved with time, however, as the effectiveness of the buoys became common knowledge throughout the fishing fleet.

Several of the smaller bait boats visited the buoys more often than the others. These boats usually left port well before daybreak in order to be at the buoy site by sunrise. They began fishing at the buoys at daybreak and pursued the schools as the latter departed from the immediate area of the buoys. As fishing slacked off, the boats departed the area to seek schools of larger fish. Depending on the day's catch, these boats visited the buoys again in late afternoon before returning to port. Occasionally when fishing around the buoys was exceptionally good, these boats returned to port well before noon with catches of 10,000 pounds, or more.

During 1978, the number of known visits increased from a low of 9 in January to 80 in May (Table 2), representing 5.6 and 46.8 percent, respectively, of the total monthly fishing trips made by the fleet of 12 pole-and-line boats. The ratio of visits to total trips peaked in April, decreased sharply in June, and remained low throughout the remainder of the year. This was reflected in the total monthly catches around the buoys. The sharp increase in catch at the buoys in April corresponded with the start of the fishing season when season fish (medium and large skipjack tuna) entered the fishery. The significant drop in the monthly catches around the buoys in June, July, and August was due to reduced visits to the buoys as a result of the presence of these season fish in areas away from the buoys. Because these fish commanded two and three times more per unit price of small fish which predominated in the catch around the buoys, they drew the boats away from the buoy sites.

The high catches of 424,897 pounds in April and 431,129 pounds in May represented 58.4 and 43.3 percent of the respective total cannery landings. During this period, there were 23 catches of over 10,000 pounds, 2 catches of over 20,000 pounds, and 2 catches of over 30,000 pounds. (One boat reported catches of nearly 60,000 pounds in a 3-day period.) The average catch per visit was 7,326 pounds in April and 5,389 pounds in May.

Fish species taken by pole-and-line boats at the buoys (Table 3) included skipjack tuna (89.7 percent), yellowfin tuna (9.3 percent), kawakawa (0.6 percent), and dolphin (0.3 percent). The skipjack tuna ranged in size from 2 to 12 pounds, with occasional catches of large fish above 20 pounds. Small yellowfin tuna and kawakawa ranged in size from 2 to 12 pounds and dolphin from 10 to 30 pounds. Skipjack tuna were taken at all four sites, but mostly at A and D. The single recorded visit to B consisted of a catch from one skipjack tuna school. Yellowfin tuna were taken mostly at D, with a fair amount at A, and a small amount at C. Kawakawa were taken at these three sites also, but the bulk of the catches were made at C.

The pattern of visits and catches in 1979 did not follow that of the previous

Table 1.—Visits and observations at monitored buoys.

Date	A							B						
	Time	Line hours trolled	Catch	Catch per line hour	Fish seen[1]	Bird flock (No. birds)	Fish finder[2]	Time	Line hours trolled	Catch	Catch per line hour	Fish seen[1]	Bird flock (No. birds)	Fish finder[2]
1977														
May 26	1600	0.50	0	0.00	1	0	—	0845	0.33	1	3.03	0	20	—
June 14-15	0828	1.42	0	0.00	3	0	F-15	1103	1.42	1	0.72	3	0	0
July 2-3				Buoy lost 1 July				1130	1.50	1	0.67	0	0	F-20
July 17								1025	2.25	0	0.00	1	0	0
Aug.				Replaced 8 Aug.							Buoy lost 20 July			
Sept. 12	1015	0.67	0	0.00	1	250	S-15, 25				Replaced 27 Sept.			
Oct. 19	1026	0.60	0	0.00	0	0	F-16	1256	0.27	0	0.00	0	0	—
Nov. 19-20	1235	1.50	0	0.00	1	15	0	1535	0.95	0	0.00	0	0	0
Dec. 15-16	1325	1.15	0	0.00	0	0	0				Buoy lost 2 Dec.			
1978														
Jan. 23	0926	1.00	0	0.00	0	0	0							
Feb.				No visit[3]							Buoy lost 2 Dec.			
Mar. 21-23	0738	1.15	1	0.87	0	0	—				Replaced 20 March			
Apr. 13-14	0700	4.00	6	1.50	TS	1,000	—	0835	1.67	0	0.00	0	15	0
May 30-31				No visit				0925	0.67	0	0.00	2	0	—
June 1	0735	1.33	0	0.00	1	150	—				No visit			
July				No visit[3]							No visit[3]			
Aug. 17-18	1030	2.50	0	0.00	0	0	—	1010	4.58	7	1.53	0	25	—
Sept. 20-21	0825	0.75	0	0.00	TS	10	—	0950	0.75	0	0.00	1	0	—
Oct.				No visit[3]							No visit[3]			
Nov.				No visit[3]							No visit[3]			
Dec.				Buoy lost 26 Dec.							No visit[3]			
1979														
Jan.				Buoy lost							No visit[3]			
Feb.				Buoy lost							No visit[3]			
Mar. 6				Replaced 31 Mar				1005	0.67	0	0.00	0	0	—
Apr 11				No visit				0752	0.50	0	0.00	0	0	—
May				No visit							No visit			
June 1	0750	2.33	2	0.86	TS	300	S-15				No visit			
June 29	0700	3.50	6	1.71	TS	200	0				No visit			
July 10	0615	2.67	13	4.87	0	0	0				No visit			
July 10				No visit				0805	5.33	1	0.19	0	0	0
July 31	1700	8.00	1	0.13	0	20	—				No visit			
Aug.				Buoy lost 8 Aug (terminated)							Buoy lost 8 Aug. (terminated)			

Date	C							D						
	Time	Line hours trolled	Catch	Catch per line hour	Fish seen[1]	Bird flock (No. birds)	Fish finder[2]	Time	Line hours trolled	Catch	Catch per line hour	Fish seen[1]	Bird flock (No. birds)	Fish finder[2]
1977														
May 26	1100	0.50	0	0.00	4	50	—				No visit			
June 14-15	1304	1.33	0	0.00	1	60	—	0630	1.25	0	0.00	3	0	0
July 2-3	0700	1.40	0	0.00	2	40	0	0815	4.50	6	1.33	18	45	0
July 17	1200	1.25	0	0.00	7	0	0				No visit			
Aug.				Buoy lost 20 July							Buoy lost 20 July			
Sept. 12														
Oct. 19				Replaced 19 Oct.							Replaced 19 Oct.			
Nov. 19-20	0700	0.85	0	0.00	0	0	0	1330	1.10	0	0.00	6	0	S-10
Dec. 15-16	1450	1.00	0	0.00	0	0	0	0640	1.70	0	0.00	TS	100	—
1978														
Jan. 23	1230	0.93	0	0.00	0	0	0	1750	0.67	0	0.00	0	0	0
Feb.				No visit[3]							No visit[3]			
Mar. 21-23	0612	1.40	1	0.71	0	0	—	1537	0.65	0	0.00	10	75	—
Apr. 13-14	1810	1.25	0	0.00	0	0	0	1341	2.00	0	0.00	TS	25	—
May 30-31	1043	0.80	0	0.00	0	0	—	1445	2.33	0	0.00	TS	50	—
June 1				No visit							No visit			
July				No visit[3]							No visit[3]			
Aug. 17-18	0735	2.50	1	0.40	0	0	—	1715	6.25	1	0.16	0	100	—
Sept. 20-21	1210	1.25	0	0.00	0	0	—	1652	1.50	0	0.00	TS	30	—
Oct.				No visit[3]							No visit[3]			
Nov.				No visit[3]							No visit[3]			
Dec.				No visit[3]							No visit[3]			
1979														
Jan.				No visit[3]							No visit[3]			
Feb.				No visit[3]							Buoy lost 26 Feb. (terminated)			
Mar. 6	1145	0.75	0	0.00	0	0	—	—	—	—	—	—	—	—
Apr 11	0938	0.33	1	3.03	0	0	—	—	—	—	—	—	—	—
May				No visit				—	—	—	—	—	—	—
June 1				Buoy lost 10 June (terminated)				—	—	—	—	—	—	—
June 29	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[1]TS=tuna school.
[2]Scattered fish (F) or school (S) at stated depth in fathoms.
[3]No visits to buoys due to rough seas.

Table 2.—Monthly catches (in pounds) of tuna by pole-and-line boats during fish aggregating device experiment.

Year/ month	Buoy A Catch	Buoy A Visit	Buoy B Catch	Buoy B Visit	Buoy C Catch	Buoy C Visit	Buoy D Catch	Buoy D Visit	Totals Catch	Totals Visit	Catch per visit	Landings by fleet	Trips by fleet	Catch per trip	Percent buoy visit	Percent buoy catch
1977																
Dec.	10,000	1	—	—	—	—	25,200	2	35,200	3	11,733.3	226,622	126	1,798.6	2.4	15.5
1978																
Jan.	9,000	2	—	—	18,600	3	13,938	4	41,538	9	4,615 3	410,210	160	2,563.8	5.6	10.1
Feb.	7,849	7	—	—	1,396	2	40,085	20	49,330	29	1,701.0	143,522	111	1,292.9	26.1	34.4
Mar.	9,718	6	—	—	—	—	22,872	14	32,590	20	1,629.5	142,646	69	2,067.3	29.0	22.8
Apr	86,738	14	5,110	1	88,734	9	224,315	34	424,897	58	7,325.8	727,933	109	6,678.3	53.2	58.4
May	208,288	48	—	—	—	—	222,841	32	431,129	80	5,389.1	996,312	171	5,826.4	46.8	43.2
June	31,503	7	—	—	—	—	—	—	31,503	7	4,500.4	909,456	183	4,969.7	3.8	3.5
July	28,109	9	—	—	—	—	—	—	28,109	9	3,123.2	869,491	166	5,237.9	5.4	3.2
Aug.	—	—	—	—	—	—	23,170	5	23,170	5	4,634.0	571,981	125	4,575.8	4.0	4.1
Sept.	—	—	—	—	—	—	30,725	9	30,725	9	3,413.9	251,363	80	3,142.0	11.2	12.2
Oct.	—	—	—	—	—	—	22,882	9	22,882	9	2,542.4	341,885	97	3,524.6	9.3	6.7
Nov.	—	—	—	—	—	—	34,162	12	34,162	12	2,846.8	471,969	107	4,410.9	11.2	7.2
Dec.	—	—	—	—	—	—	—	—	—	—	—	218,450	76	2,874.3	—	—
Total	381,205	93	5,110	1	108,730	14	654,990	139	1,150,035	247	4,656.0	6,055,218	1,454	4,164.5	17.0	19.0
1979																
Jan.	Buoy lost		—	—	—	—	—	—	—	—	—	113,050	47	2,405.3	—	—
Feb.			—	—	—	—	—	—	—	—	—	220,540	74	2,980.3	—	—
Mar			—	—	—	—	Buoy lost		—	—	—	258,607	74	3,494.7	—	—
Apr	Buoy replaced		—	—	—	—			—	—	—	280,668	109	2,574.9	—	—
May	10,500	5	—	—	—	—			10,500	5	2,100.0	1,045,667	176	5,941.3	2.8	1.0
June	18,841	5	—	—	Buoy lost				18,841	5	3,768.2	827,293	187	4,424.0	2.7	2.3
July	4,200	3	—	—					4,200	3	1,400.0	1,012,239	184	5,501.3	1.6	0.4
Aug.	Buoy lost		Buoy lost						—	—	—	—	—	—	—	—
Total	33,541	13	—	—	—	—	—	—	33,541	13	2,580.1	3,758,064	851	4,416.1	1.5	0.9

Table 3.—Fish species caught (in pounds) by pole-and-line boats around fish aggregating buoys during 1978.

Buoy	Visits	Skipjack tuna Catch	Skipjack tuna Catch per visit	Yellowfin tuna Catch	Yellowfin tuna Catch per visit	Kawakawa Catch	Kawakawa Catch per visit	Dolphin Catch	Dolphin Catch per visit	Total Catch	Total Catch per visit
A	92	357,044	3,880.4	22,682	246.5	1,479	16.0	854	9.3	382,031	4,152.5
B	1	5,110	5,110.0	0	0.0	0	0.0	0	0.0	5,110	5,110.0
C	14	103,037	7,359.8	1,475	105.4	4,218	301.3	0	0.0	108,730	7,766.4
D	139	573,106	4,123.1	80,183	576.9	1,706	12.3	3,034	22.6	658,029	4,734.0
Total	246	1,038,297	4,220.7	104,340	424.1	7,403	30.0	3,888	15.8	1,153,900	4,690.6
Percent of total catch		89.73		9.28		0.64		0.34		99.99	

year for several reasons. First, the presence of large skipjack tuna in the fishery in late fall and winter kept the boats from returning to the buoys in the off-season; second, the December-January period was beset with inclement weather, including several periods of gale-force winds that reduced fishing activity considerably; and third, the loss of buoys A in December 1978 and D in March resulted in the elimination of the two buoys that were most productive of tunas. By the time A was restored in April and the 2-5 weeks necessary for it to become effective had gone by, the regular skipjack tuna fishing season was at hand, and the pole-and-line boats had already turned their attention to large fish away from the buoy areas.

Troll Fishing

Table 4 lists the visits and catches obtained from interviews with trolling boat operators. Only visits to A, B, and C are shown because D, located off Lanai, was beyond the usual 1-day charter range of most trollers based at Kewalo Basin, and because no firm reports were received from boats fishing at this buoy out of Maui and Lanai. Since most of the boats at Kewalo Basin fished irregular schedules and since it was not always possible to interview all boats daily, the number of visits and resultant catches may be greatly understated.

Visits to the buoys generally remained low (8.3 visits per month) during the last half of 1977 due to interruption of fishing caused by buoy losses, rough sea conditions, and poor initial response in reporting by the trollers. Buoy visits increased to 22 visits per month in 1978 and to 44 visits per month in 1979.

During the 26-month period of fishing around the buoys, a total of 2,087 fish, estimated at 29,351 pounds, were taken by trolling boats. The catch rate for the period was 3.44 fish per visit. Although the amount of fish taken was not overwhelming, the buoys, nevertheless, substantially reduced the number of zero-catch days (interviews with boat operators). From April through July 1978, the period of greatest fish concentration around the buoys, trollers caught 876 fish (estimated weight 11,288 pounds) at a catch rate of 10.55 fish per visit. The concentrations of fish around the buoys were not as great during the same period in 1979. Only 546 fish (estimated weight 10,156 pounds) were caught at a catch rate of 2.92 fish per visit. Both catch and catch rate were affected greatly by reduced fishing at A, the most productive buoy, which was lost in December 1978 and was not replaced until March 1979.

Fishing effort varied at the different buoy sites. Buoy A was visited most often (51.0 percent of all buoy visits) and yielded the most catch (61.5 percent of total buoy catch). Buoy B received 26.4 percent of all visits and yielded 17.7 percent of the total buoy catch, and buoy C recorded 22.6 percent of all visits and yielded 20.8 percent of the catch. Although buoys B and C were not productive of tunas, they were ideally placed to attract dolphin from nearby Penguin Bank. Several boats that preferred trolling for dolphin made regular visits to these sites. The catch rate of dolphin at these two sites averaged 1.87 fish per visit, as compared with 0.70 fish per visit to A.

Twelve species of fish were taken by trollers around the buoys (Table 5). Dolphin comprised the largest group (37.0 percent), followed by yellowfin tuna (25.9 percent), and skipjack tuna (23.0 percent). Of the 772 dolphin taken, nearly 72 percent were from sites B and C in roughly equal amounts; and of the 481 skipjack tuna and 540 yellowfin tuna taken, nearly 88 and 90 percent, respectively, were from site A. Kawakawa represented 9.0 percent of the total catch, with roughly 41 percent taken from A, 36 percent from B, and 23 percent from C. Marlins, *Makaira nigricans* and *Tetrapturus audax*, and

Table 4.—Fish caught by trolling boats based at Kewalo Basin.

	A			B			C			All buoys			
Year/ month	Visit	No. of fish	Wt. (lb)	Visit	No. of fish	Wt. (lb)	Visit	No. of fish	Wt. (lb)	Visit	No. of fish	Wt. (lb)	Catch per visit
1977													
June	8	18	475	3	0	0	4	1	5	15	19	480	1.26
July	—	—	—	5	57	335	1	11	55	6	68	390	11.33
Aug.	2	0	0	—	—	—	—	—	—	2	0	0	0.00
Sept.	2	4	25	—	—	—	—	—	—	2	4	25	2.00
Oct.	12	89	187	7	22	170	1	0	0	20	110	357	5.55
Nov.	2	1	10	2	3	40	1	0	0	5	4	50	0.80
Dec.	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	26	112	697	17	82	545	7	12	60	50	206	1,302	4.12
1978													
Jan.	9	52	327	—	—	—	7	61	439	16	113	766	7.06
Feb.	9	29	216	—	—	—	7	3	26	16	32	242	2.00
March	6	6	272	—	—	—	5	3	50	11	9	322	0.82
April	14	236	2,499	3	5	84	6	38	395	23	279	2,978	12.13
May	19	294	4,083	8	23	363	9	129	992	36	446	5,438	12.39
June	6	35	431	4	32	452	4	33	591	14	100	1,474	7.14
July	7	45	1,340	1	2	16	2	4	42	10	51	1,398	5.10
Aug.	11	14	327	1	7	42	5	17	148	17	38	517	2.24
Sept.	5	17	1,001	1	2	38	—	—	—	6	19	1,039	3.17
Oct.	31	26	953	8	9	152	12	6	105	51	41	1,210	0.80
Nov.	37	33	210	8	10	135	6	6	165	51	49	510	0.96
Dec.	3	10	250	8	1	6	6	2	15	17	13	271	0.76
Total	157	797	11,933	42	91	1,288	69	302	2,944	268	1,190	16,165	4.44
1979													
Jan.	—	—	—	11	18	189	10	21	205	21	39	394	1.85
Feb.	—	—	—	37	69	1,705	15	18	322	52	87	2,027	1.67
March	10	4	51	16	15	180	12	4	48	28	19	228	0.68
April	10	4	51	7	11	144	8	14	171	25	29	366	1.16
May	59	189	2,582	15	36	594	15	61	2,076	89	286	5,252	3.21
June	27	136	1,551	6	22	434	1	3	60	34	161	2,045	4.74
July	30	45	1,315	9	25	257	—	—	—	39	70	1,572	1.79
Total	126	374	5,499	101	196	3,503	61	121	2,882	288	691	11,884	2.40
Total for period	309	1,283	18,129	160	369	5,336	137	435	5,886	606	2,087	29,351	3.44
Percent of all FAD totals	51.0	61.5	61.8	26.4	17.7	18.2	22.6	20.8	20.0				

Table 5.—Species and number of fish caught by trolling boats around fish aggregating buoys, May 1977-July 1979.

	Buoy												
	A			B			C			Total			
Species	Visit	Catch	Catch/ visit	Visit	Catch	Catch/ visit	Visit	Catch	Catch/ visit	Visit	Catch	Catch/ visit	Percent of total
Skipjack tuna	309	423	1.37	160	3	0.02	137	55	0.40	606	481	0.79	23.0
Yellowfin tuna		484	1.57		12	0.08		44	0.32		540	0.89	25.9
Bigeye tuna		11	0.04		0	0.00		10	0.07		21	0.04	1.0
Kawakawa		77	0.25		68	0.42		43	0.31		188	0.31	9.0
Dolphin		217	0.70		275	1.72		280	2.04		772	1.27	37.0
Wahoo		30	0.10		8	0.05		2	0.02		40	0.07	1.9
Blue marlin		15	0.05		3	0.02		1	0.01		19	0.03	0.9
Striped marlin		2	0.01		0	0.00		0	0.00		2	<0.01	0.1
Spearfish		3	0.01		0	0.00		0	0.00		3	<0.01	0.1
Rainbow runner		16	0.05		0	0.00		0	0.00		16	0.03	0.8
Greater amberjack		3	0.01		0	0.00		0	0.00		3	<0.01	0.1
Barracuda		2	0.01		0	0.00		0	0.00		2	<0.01	0.1
Total	309	1,283	4.15	160	369	2.31	137	435	3.18	606	2,087	3.44	

shortbill spearfish, *T. angustirostris*, represented 1.2 percent of the total catch. Nearly all (83.3 percent) were taken at site A. All other fish, including bigeye tuna, *Thunnus obesus*; wahoo; rainbow runner, *Elagatis bipinnulata*; amberjack, *Seriola dumerili*; and barracuda, *Sphyraena argentea,* comprised 3.9 percent of the total catch. All bigeye tuna, except 10, were taken at A. The billfishes were generally taken about 0.5 to 1.5 miles away from the buoy, whereas the skipjack and yellowfin tunas were caught all the way from the buoy up to 3-5 miles away. Most of the other species were taken within 200-300 yards of the buoy.

Occasional reports from Maui indicated heavy fishing activity around buoy D, where individual boat catches of 300-700 pounds of skipjack (8-10 pound size) and yellowfin (30-50 pound size) tunas, and 100 pounds of dolphin per weekend were commonly made in April 1978.

Reports from Kona indicated the success of the buoys placed there. Buoy F, in particular, which had been placed at the edge of an outstanding fishing area, was teeming with skipjack and yellowfin tunas within 5 weeks after deployment. Trollers were able to catch small skipjack tuna for marlin bait in 10-15 minutes, compared with half a day or more before the buoy was in place. During the height of the summer marlin run, many trollers who took advantage of the accessibility of bait-size skipjack tuna at buoy F reported catches of three and four marlin a day. One boat reported catching 11 marlin in a period of 10 consecutive days of fishing, while another caught 20 marlin in 20 days.

Table 6. — Underwater observations of fish at fish aggregating buoys off Lanai and Kona, Hawaii.

Date	Buoy	Locality	Fish observed	Estimated number	Est. fish size (lb)	Depth range (m)
1977 15 Dec.	D	Lanai	Dolphin	14-16	15-20	0-35
			Sea chub, *Kyphosus cinerascens*	50-100		N.s.[1]
			Scrawled filefish, *Aluterus scriptus*	2	1	N.s.
1978 30 May	D	Lanai	Yellowfin tuna	800-1,000	6-8	0->50
			Dolphin	10-12	10-15	0->35
			Rainbow runner	15-20	<1	0->35
			Rough triggerfish, *Canthidermis maculatus*	80		N.s.
			Porpoises	12		
27 July	F	Kona	Skipjack tuna	200-300	2-10	0->70
			Yellowfin tuna	6		>50
			Bigeye tuna	1		
			Wahoo	3	15-20	15
			Rainbow runner	6		0-35
			Mackerel scad	>5,000		0->70
			Freckled driftfish, *Psenes cyanophrys*	50		N.s.
			Rough triggerfish	4		N.s.
			Pilotfish, *Naucrates ductor*	2		N.s.
12 Aug.	F	Kona	Skipjack tuna	Many 1,000's	2-10	0->70
			Bigeye tuna	3	20-30	>35
			Rainbow runner	12		0-70
			Mackerel scad	Many 1,000's		0-70
			Freckled driftfish	200-300		N.s.
			Rough triggerfish	12		0-35
1979 10 Aug.	F	Kona	Wahoo	2	10-15	0-35
			Rainbow runner	4		0-35
			Mackerel scad	1,000		0-35
			Greater amberjack	5	Juvenile	N.s.
			Rough triggerfish	60		N.s.

[1]N.s. = near surface

Other Types of Fishing

The buoys off Kona also attracted many commercial skiff fishermen using the "drop-stone" method to fish for 50-200 pound yellowfin tuna usually accompanying porpoise schools. The gear is essentially a handline using 10- to 12-inch mackerel scad as bait. The hooked bait is laid on a smooth stone weighing about 2 pounds together with a package of mackerel scad chopped up and wrapped in a chum bag. Both bait and chum bag are bound to the stone by a few turns of the mainline and secured with a slipknot. The stone is lowered 30-60 fathoms and is jerked free to expose the bait and chum. Fishing was done by positioning the skiff in the path of a porpoise school and dropping the line as the school approached the skiff. The buoys enabled fishing during periods when porpoise schools were absent from the area.

One report in June 1978 indicated that up to 50 trolling and handline boats fishing at G brought in 35,000 pounds of yellowfin tuna and marlins on one weekend and that the drop-stone skiffs averaged from three to four yellowfin tuna per day.

Underwater Observation

Observations by divers were made on five occasions, twice at D and three times at F (Table 6). Dives were made generally to depths of 100 or 150 feet. Tuna schools were seen on one dive at D and two dives at F.

A yellowfin tuna school observed at D (Fig. 8), composed of 6-8 pound fish, roamed from beneath the buoy to distances of 0.5 mile or more repeatedly. Its roaming behavior may have been induced by the presence of porpoises. The school became more compact and moved about more rapidly each time a porpoise approached it.

The skipjack tuna schools observed at F behaved differently. On the first dive, 27 July 1978, groups of several hundred skipjack tuna rose to within 100 feet of the surface from below. The major skipjack tuna school was situated at depths beyond 250 feet beneath the buoy, beyond the visibility of the divers. On the second dive, 12 August 1978, many thousands of skipjack tuna were constantly in view of the divers and on several occasions, part of the school was seen to pursue baitfish (mackerel scad) to the surface within 30 feet of the buoy.

Discussion

The study provided information concerning buoy design, tuna schools attracted to fish aggregating devices, and the influence these devices had in modi-

Figure 8.—Yellowfin tuna school accompanied by porpoise beneath fish aggregating device.

fying the established fishing routine in Hawaiian waters.

Buoy Design

For the most part, the buoys, as designed, performed adequately. However, the intermittent submerging and shifting of buoy D during periods of unusually strong tidal current indicated that the design was inadequate for that particular site. To prevent similar mishaps, the buoy should be enlarged to three steel drums and the anchor weight should be increased to 2,000-3,000 pounds. Other modifications include the relocation of the anchor line attachment to the apex of the forward V section and the addition of a 40-50 pound weight to the ballast pipe to prevent the buoy from leaning over.

The importance of the drape cannot be overemphasized. Although small fish of 2-5 inches tended to remain as close to the buoy as possible, and often strayed inside of the V section, it was mainly because of the drape that large fish remained at the buoy site over prolonged periods. The reduction of fish aggregations and catches at buoys that had lost the drapes were quickly noticed by the fishermen, who clamored for immediate restoration.

The drape should be made of material that can withstand the stresses of currents and heavy wave action. The drape made of ⅝-inch polypropylene rope was effective in attracting fish, as well as being long lasting; however, the drape need not encircle the buoy, as in our experiment. Five to seven lengths of rope hung vertically and seized onto horizontal bamboo crosspieces, spaced 3-5 feet apart, and short pieces of loosened rope strands attached at intervals of 24 inches to each length of rope, should make an adequate drape.

The buoy, as designed, was adequate for trolling and pole-and-line fishing. For purse seine fishing, however, the drape should be lengthened to about 100 feet, the chain at the top of the mooring line should be 120 feet long, and the position of the weight on the mooring line should be adjusted so that the upper loop of the buoyant rope will remain at a depth of 100 fathoms or more at all times.

Tuna Aggregations Around Buoys

Distribution by Size

The fish aggregating devices attracted all sizes of tunas ranging from below 2 to over 20 pounds. Small fish below 3-4 pounds (skipjack tuna, yellowfin funa, kawakawa, and a few bigeye tuna) generally remained in the immediate vicinity of the buoys and ranged in depth from the surface to over 250 feet. Larger fish, mainly skipjack and yellowfin tunas, roamed over wider areas from 0.25 to 3 miles or more from the buoys during the day. These fish apparently returned to the buoys at night since the day's first catches by bait boats were invariably made at the buoys at daybreak. The bait boats moved away from the buoys after sunrise as they continued to fish the schools.

Medium-sized yellowfin tuna, 30-50 pounds or more, and often exceeding 100 pounds, were caught on baited lines by either deep trolling at reduced speed or by handlining while drifting. These fish were caught anywhere within 1 mile of the buoys.

Other fish such as marlin and spearfish were usually taken by trollers at distances of up to 1.5 miles from the buoys, whereas dolphin were usually taken well within 100 feet of the buoys and up to 0.5 mile away.

Multiple Schools at Buoys

It was evident from the daily catch reports by bait boats that more than one tuna school was present around a buoy at the same time. During the height of fishing activity around the buoys (April and May 1978), from two to six bait boats reported catches from the same buoy on 30 separate days. It is likely that some of the catches were made at different times of the day, but because the best fishing usually occurred at sunrise, it was not uncommon for more than one boat to be at a buoy site well before daybreak and for all of them to commence fishing at sunrise. This was corroborated by trolling boat operators who repeatedly witnessed two or more bait boats fishing simultaneously, each on separate schools spaced up to 3 miles apart.

Length of Time at Buoys

In the absence of tagging effort, it was not possible to determine how long a tuna school or individual tuna remained at a buoy site. Catches made on consecutive days at the same buoy, however, indicate roughly the length of time fish school(s) remained around a buoy and were thus available to the fishermen.

Catches on consecutive days in 1978, the year visits to the buoys were most prevalent, are shown in Table 7. Nearly all of the 2 and 3 consecutive-day

Table 7. — Tunas caught on consecutive days at buoys A, C, and D during 1978.

	A			C			D		
Month	Consecutive days	Visits	Catch per day	Consecutive days	Visits	Catch per day	Consecutive days	Visits	Catch per day
Jan.	—	—	—	—	—	—	2	2	1,439
Feb.	2	2	1,172	—	—	—	5	7	3,252
	3	3	1,256	—	—	—	6	11	3,564
March	3	4	2,080	—	—	—	2	2	1,267
April	—	—	—	—	—	—	2	2	2,775
	—	—	—	—	—	—	2	2	3,188
	—	—	—	—	—	—	3	3	2,417
	3	7	26,016	4	5	11,201	2	3	4,160
	2	3	1,192	—	—	—	9	21	23,341
May	5	9	9,690	—	—	—	9	26	23,141
	2	3	3,813	—	—	—	2	2	2,796
	13	32	10,602	—	—	—	—	—	—
	3	5	5,378	—	—	—	—	—	—
June	2	2	6,366	—	—	—	—	—	—
	2	3	5,689	—	—	—	—	—	—
July	2	2	3,256	—	—	—	—	—	—
	2	2	1,186	—	—	—	—	—	—
	2	2	2,919	—	—	—	—	—	—
Aug.	—	—	—	—	—	—	—	—	—
Sept.	—	—	—	—	—	—	4	4	2,730
Oct.	—	—	—	—	—	—	2	2	3,657
Nov.	—	—	—	—	—	—	4	4	3,570
	—	—	—	—	—	—	5	5	2,691
	—	—	—	—	—	—	2	2	2,901
December (no visits)									

catches listed represent visits to buoys made in anticipation of good catches. Visits usually ended after a couple of days whenever the catches were less than anticipated. Longer consecutive-day catch periods of 4-6 days indicate a continuation of visits due to good catches resulting from the presence of a large school or the accumulation of schools around the buoy. This occurred twice in February at buoy D, prior to the start of the fishing season, once in May at A, after the start of the fishing season, and once in September and twice in November at D, after the end of the season. During the early part of the season, when fish schools were abundant, the period of consecutive days fished extended to 13 days at buoy A and 18 days at D.

Thus, although the length of stay of individual tuna schools at a buoy site cannot be determined from these data, the arrival and accumulation of schools around the buoys enabled the fishing boats to fish continuously for periods of up to 2 and 3 weeks at a time.

Effect of Buoy Location

Pole-and-line catches at the different buoy sites varied considerably (Table 1). Buoys A and D, which were anchored in deep water within 2 miles of the 1,000-fathom ledge were particularly successful in attracting tuna schools. They commanded 93.9 percent of all reported visits in 1978 and yielded 90.1 percent of all tunas caught around the buoys.

Buoy C, anchored off the tip of Penguin Bank and located 6 miles away from the 1,000-fathom ledge, was only moderately successful. Most of the tuna catches there were made during a span of 1 week in both January and April.

Buoy B, anchored off Penguin Bank and 15 miles shoreward of the 1,000-fathom ledge, fared poorly, as it was fished only on one occasion. Since only visits resulting in catches were reported by bait boats, it is likely that more visits may have been made to B and C, as well as to A and D. Nevertheless, both B and C received little attention from these boats since they were located too close to Penguin Bank where schools of tunas were known to appear only occasionally.

Trolling boats based at Kewalo Basin which visited A, B, and C also recorded low catches of tunas at B and C (Table 5). Verbal reports of troll fishing at the two buoys placed off Kona indicated similar results. Buoy F, which was anchored at a depth of 1,250 fathoms, attracted large concentrations of skipjack and yellowfin tunas, but buoy G, which was anchored at a depth of 220 fathoms and 3.5 miles away from the 1,000-fathom ledge, was not as successful in attracting skipjack tuna schools.

The superior catches of skipjack tuna at buoys A, D, and F were apparently due to their placement at or near the 1,000-fathom depth contour. This was not surprising since we had known through interviews with both pole-and-line and troll fishermen prior to our selecting the buoy sites that large yellowfin tuna generally followed the 1,000-fathom contour in moving north and south along the leeward coasts of the islands. We suspected that schools of skipjack tuna would follow the same pattern.

Influence on Fishing Routine

Pole-and-Line Fishing

The usual fishing routine followed by bait boats was to spend 1 day, occasionally 2, fishing for baitfish and 1 or 2 days, sometimes 3, fishing for skipjack tuna. Consequently, 30-50 percent of the time was lost to baiting operations. Additional time was lost at sea due to scouting for tuna schools.

The introduction of the buoys eased the stringent demands on the supply and condition of baitfish and eliminated scouting time and time lost in pursuing schools. Night baiting often was sufficient to provide baitfish for a day's fishing. Consequently, fishing routine was reduced to baiting at night and fishing the next day. If the catch was sufficiently large, the boats would return to port well before noon and prepare for night baiting. Following this routine, many boats were able to fish 5 or 6 days a week. One boat fished 8 days during a 9-day period. On numerous occasions vessels visited buoy A with less than the minimum amount of baitfish normally required for a day's fishing, and with baitfish in slightly weakened condition because of the short distance from port, and fishing around it required less intensive chumming.

Troll Fishing

Trolling boats also modified their daily routine. They headed directly for the buoys in the morning and again on their way into port. Some trollers even changed their fishing method by either trolling deep with live bait at very low speed or drifting and fishing with light tackle or handlines.

Handline Fishing

In Kona, Hawaii, where handlining (drop-stone fishing) for medium to large yellowfin tuna has been going on for a number of years, the introduction of the buoys provided an additional dimension to fishing. In the past, daylight fishing for large yellowfin tuna accompanying porpoises was done by dropping lines in the midst of a school of porpoises. The porpoise schools usually passed through the area within a day or so. With the installation of the buoys, however, the porpoise schools remained in the area for many days at a time, circling the buoys at distances of 4-6 miles all day long.

A similar type of fishing called ikashibi fishing, is done off Hilo, Hawaii, where squid is used as bait, supplemented by mackerel scad (Yuen, 1979). Because live squid is used as the principal bait, fishing is done usually at night. The fishery, which began in 1973, shows promise of becoming an important segment of Hawaiian fisheries. The catch, consisting of bigeye and yellowfin tunas and, occasionally, albacore, increased from 89.0 t in 1973 to 154.6 t in 1975. This fishery could benefit from fish aggregating devices.

Buoy Benefits

It is not possible to determine precisely what the total pole-and-line catch might have been without the buoys in 1978, nor to what extent the buoys had increased the off-season catches because both monthly and year-to-year catches of the fishery fluctuate widely. There is no question, however, that the buoys were a boon to the pole-and-line fishermen, particularly with respect to more economical use of baitfish, to a reduction of time lost to baiting and searching for tuna schools, and to reduced fuel costs.

The buoy test, which was aimed primarily to aid the skipjack tuna fishery, resulted in two important side benefits. One was the heavy use of the buoys by trolling boats, the other was the utilization of the buoys by drop-stone commercial fishermen, who were able to extend the fishing of porpoise-associated tunas from one to several days and enabled fishing in the absence of porpoise schools.

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