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Use of Threadfin Shad, *Dorosoma petenense*, as Live Bait During Experimental Pole-and-Line Fishing for Skipjack Tuna, *Katsuwonus pelamis*, in Hawaii

ROBERT T. B. IVERSEN

SEATTLE, WA.
August 1971

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By

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ABSTRACT

The effectiveness of threadfin shad as a live bait for skipjack tuna fishing in Hawaii was compared with the normal anchovy bait (nehu) during experimental fishing on 37 schools of skipjack tuna during 1967 and 1968 aboard the research vessel Charles H. Gilbert. Threadfin shad proved about as effective as nehu in (1) luring skipjack tuna to the stern of the vessel, (2) concentrating the skipjack tuna at the fishing station, and (3) catch rate of skipjack tuna. Underwater observations of threadfin shad and nehu indicate a general similarity in behavior during fishing. Bait-sized threadfin shad occur in freshwater impoundments in Hawaii during the peak months of skipjack tuna fishing. They are hardy, easily acclimated to salt water, and readily handled in large numbers.

INTRODUCTION

Reducing the time now required to catch live bait has been suggested as a major step to increase the fishing effort of the pole-and-line fishery for skipjack tuna, Katsuwonus pelamis, in Hawaii (Brock and Uchida, 1968; Shang, 1969). For several years, developing a new live bait which could be obtained from a bait station by Hawaiian fishermen has been a goal of the National Marine Fisheries Service, Hawaii Area Fishery Research Center.

Threadfin shad, Dorosoma petenense, is one baitfish (Figure 1) that has been extensively investigated. Any new baitfish must meet three basic requirements: It should be effective under fishing conditions, capable of mass production, and hardy. I here report on the ability of shad to fulfill one of these requirements—effectiveness during experimental pole-and-line fishing aboard a research vessel. Observations on the behavior and hardiness of bait are also included.

The fishing methods and catch statistics of the Hawaiian fishery for skipjack tuna have been described by Uchida (1967) and by Brock and Uchida (1968). The fishery produces an average catch of about 5,000 tons of skipjack tuna each year. Each vessel catches its own live bait that is taken to sea in baitwells and chummed into the water to lure skipjack to the stern of the vessel and within range of the fishermen's hooks. A small, silvery anchovy called nehu, Stolephorus purpureus (Figure 2), occurs in several bays in Hawaii and makes up 92% of the bait catch. It is a delicate fish and sometimes in short supply. Bait catching takes place during the day and night. Day baiting is a time-consuming activity, making up about 32% of the total time devoted by the boats to scouting, fishing, and day baiting. Reduction in the time spent day baiting should result in more

Figure 1.--Threadfin shad, Dorosoma petenense.

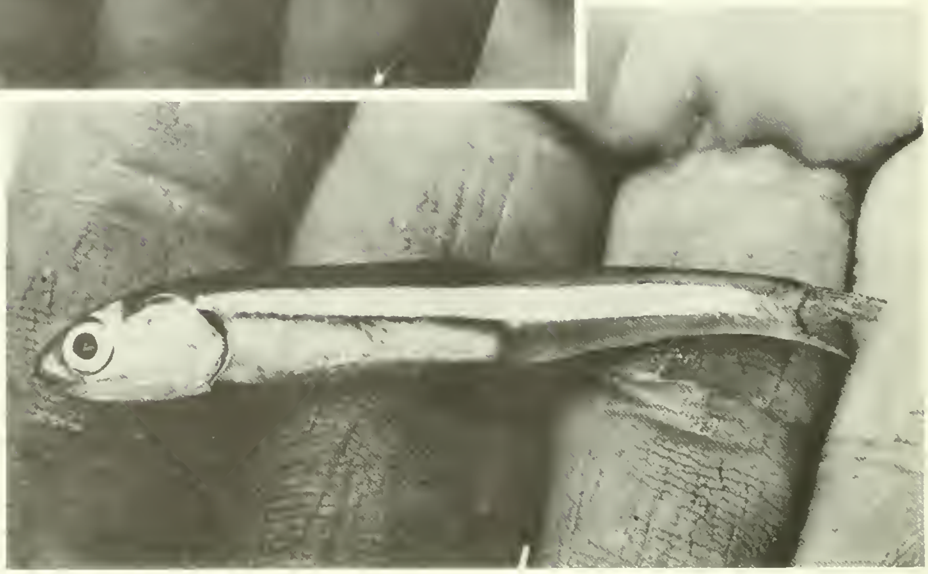

Figure 2.--Nehu, Stolephorus purpureus.

actual fishing time and should increase the overall catch of the fishermen.

Threadfin shad were first introduced into freshwater impoundments and streams in Hawaii in 1958 and by 1960 had become established in several reservoirs (Hida and Thomson, 1962). Among the attributes of threadfin shad which led to their investigation as a new baitfish are: tolerance to both salt and fresh water, hardiness, silvery color, size, swimming behavior, and low mortality during mass handling. Also, the use of threadfin shad would not require any major changes in the methods used by skipjack tuna fishermen in Hawaii. In recent years threadfin shad in Wahiawa Reservoir, Oahu, have become sufficiently abundant to make large-scale fishing tests possible.

METHODS AND MATERIALS

Experimental Fishing

Fishing took place during five different cruises of the research vessel Charles H. Gilbert in Hawaiian waters in 1967 and 1968 (Table 1). Nehu, the regular skipjack tuna bait, were used as a control, and fishing data were collected from 37 of 101 schools of skipjack tuna encountered. On the first three cruises both threadfin shad and nehu were chummed alternately for 3- to 5-min periods on each of nine schools of skipjack tuna fished. On the latter two cruises the two bait species were alternated among 28 schools of skipjack tuna, except on three occasions when operational problems prevented alternation of bait.

Fishing was carried out in the following manner. Upon arrival on the fishing grounds, scouting commenced for bird flocks, which usually signify the presence of skipjack tuna schools. When approaching a fish school, the bait supplies were readied and the chummer, fishermen, and observers took their places. As the vessel crossed the head of the school, the chummer began broadcasting the bait until the school was brought to the stern and fishing started. If the attempt was unsuccessful, the ship would then return for another "pass" and the process was repeated. Several passes were usually made on each school until either the school was successfully fished or until it became obvious the school was not going to respond and was abandoned.

The first sign that fishing would probably be successful was a surface break or splash made by the skipjack tuna feeding on bait near the stern of the vessel. When this occurred, the vessel would slow to fishing speed (ca. 2 knots), the fishermen would enter the racks, and water sprays would be turned on and directed to the sea surface just behind the vessel. Water sprays are used by the commercial skipjack tuna fishermen in Hawaii in order to improve the catch rate (Yuen, 1969). Two scientific observers helped coordinate the experiment and recorded data. One observer, stationed on the afterdeck near the chummer, recorded the number of skipjack tuna caught and the time that each bait species was used during fishing. He was in communication by telephone with the second observer, who was stationed in an underwater observation chamber located on the

Table 1.--Dates of experimental fishing and number of skipjack tuna schools fished aboard the *Charles H. Gilbert*.

Cruise no.	Month	Year	No. of skipjack tuna schools fished	Method of chumming
105	Oct.	1967	1	Shad and nehu alternated at intervals of 3 to 5 min.
106	Nov.	1967	4	Do.
108	Mar.-Apr.	1968	4	Do.
109	May-Aug.	1968	22	Shad and nehu alternated among schools.
110	Aug.-Sept.	1968	6	Do.

Figure 3.--Underwater observation chamber used for viewing baitfish and skipjack tuna.

portside of the ship, just forward of the propeller and below the fishing racks (Figure 3). Four experienced fishermen were in the racks during fishing and were usually the same four men during each cruise. Fishing terminated when bait was exhausted or when the school sounded, stopped biting, or bit too slowly to justify further expenditure of live bait.

Baiting

Shad captured in Wahiawa Reservoir by bait seine were transported in portable tanks by truck to Kewalo Basin, Honolulu, and acclimated to 100% seawater in 34,850-liter (9,200-gal) holding tanks before being placed in the baitwells of the Gilbert. Nehu were captured by bait seine in Pearl Harbor or Kaneohe Bay, Oahu, and placed directly into the baitwells. Nehu were "rested" overnight in the baitwells prior to departure for the fishing grounds. Shad were acclimated to seawater for 36 to 72 hr before being placed in the Gilbert's baitwells several hours prior to departure. The shad and nehu used as bait ranged from about 40 to 65 mm.

The unit of bait measure in the Hawaiian skipjack tuna fishery is the "bucket," so named because the fishermen use stainless steel buckets to transfer the bait from the bait seine to the baitwells. A bucket is equal to about 3.2 kg of baitfish. However, a bucket of nehu contains more individuals than a bucket of shad because shad are more deep-bodied than the nehu. In general, it was possible to carry a greater number of buckets of shad than nehu in the same sized baitwell because of the greater hardiness of shad.

Recording of Data

On Gilbert cruises 105 and 106 the catch data were recorded by the observer on deck using a hand tally, a stopwatch, and a wristwatch to time the start and end of fishing periods and other events. On cruises 108, 109, and 110, data collecting was automated by the use of an event recorder and a camera to automatically photograph skipjack in the fishing area through the windows of the underwater observation chamber. The catch of tuna and other information concerning fishing were graphically recorded on a 20-channel event recorder. The event recorder received data from a small hand-held control panel operated by the scientist on deck and also data from the automatically run camera in the stern observation chamber. One channel recorded the time each photograph was taken. Photographs were taken to determine if either bait resulted in a greater concentration of tuna near the hooks. A photograph was taken every 10 sec with 16-mm color film in a cinecamera operated in a single frame mode. Shutter speed was 0.03 sec. The film was analyzed by projecting the sequence, one frame at a time, and counting the number of skipjack tuna present in each frame. Only those frames taken during the time fish were actually caught were used to calculate the concentration of skipjack near the hooks.

Behavioral Observations

Observations on the swimming behavior of shad and nehu and their reaction to predation by skipjack tuna were made during fishing on Gilbert cruises 105, 106, 108, 109, and 110, and also during some preliminary trials during 1967 on Gilbert cruises 99, 100, and 102. These observations were made from the stern underwater observation chamber and also by scuba divers. The scientist in the stern chamber made continuous voice tape recordings of his visual observations of shad, nehu, and skipjack tuna. The divers observed bait behavior while swimming in the water adjacent to the stern with the ship stopped. On several occasions the divers observed shad and nehu from an underwater sea sled while it was towed from the stern of the Gilbert.

Statistical Methods

The response of skipjack tuna schools to the pole-and-line fishing method is highly variable and the frequency of various measures of response is not normally distributed (Yuen, 1959). Nonparametric statistical tests were used to analyze the data because they do not require a normal distribution. The Wilcoxon matched-pairs, signed-ranks test and the Mann-Whitney U-test (Siegel, 1956) were used.

RESULTS

Experimental Fishing

Alternating shad and nehu among schools.— Results of experimental fishing on cruises 109 and 110 are summarized in Table 2. These results are presented first because they account for 76% of the schools fished. The basic catch data for each school are given in Table 3. Inspection of Table 2 shows that shad compared favorably with nehu as a live bait, and this is confirmed

Table 2.--Summary of experimental fishing for skipjack tuna with threadfin shad and nehu alternated as bait among schools on Charles H. Gilbert cruises 109 and 110.

Item	Shad	Nehu
Number of schools chummed	28	39
Number of schools fished	14	14
Percent of schools fished	50.0	35.9
Average number of skipjack tuna caught per minute (4 men fishing)	7.5	8.2
Number of skipjack tuna caught	1,428	1,597
Average number of skipjack tuna caught per school	102	114
Total weight (kg) of skipjack tuna caught	4,809	6,788
Average total weight (kg) of skipjack tuna caught per school	344	485
Average catch per minute of skipjack tuna <4.5 kg	10.0	10.0
Average catch per minute of skipjack tuna >4.5 kg	3.0	4.9
Average duration (minutes) of fishing per school	10.8	15.4
Average number of buckets of bait used per school fished	4.0	4.8
Average weight (kg) of skipjack tuna caught per bucket of bait	85	102

Table 3.--Results of experimental fishing with threadfin shad and nehu on Charles H. Gilbert cruises 109 and 110.

Cruise no.	Station	Time fished		Total skipjack tuna catch				Average skipjack tuna weight		Amount of bait used		Average skipjack tuna catch per minute	
		Shad	Nehu	Shad	Nehu	Shad	Nehu	Shad	Nehu	Shad	Nehu	Shad	Nehu
		Minute		Number		Kg		Kg		Bucket		Number	
109	7	1.1	-	1	-	9.7	-	9.7	-	3.0	-	0.9	-
	8	-	16.0	-	58	-	323.5	-	5.6	-	3.5	-	3.6
	11	5.6	-	11	-	648.5	-	5.9	-	3.5	-	2.0	-
	14	7.4	-	53	-	326.9	-	6.2	-	3.0	-	7.1	-
	15	-	6.2	-	66	-	281.4	-	4.3	-	3.0	-	10.6
	26	3.0	-	17	-	39.3	-	2.3	-	2.5	-	5.6	-
	27	-	18.0	-	102	-	222.0	-	2.2	-	3.0	-	5.7
	28	18.0	-	153	-	388.6	-	2.5	-	7.0	-	8.5	-
	29	-	5.2	-	33	-	320.3	-	9.7	-	4.0	-	6.3
	31	12.4	-	84	-	129.5	-	1.5	-	3.5	-	6.8	-
	32	-	11.5	-	217	-	334.6	-	1.5	-	5.0	-	18.9
	35	1.5	-	1	-	5.1	-	5.1	-	2.0	-	0.6	-
	36	-	12.4	-	105	-	390.5	-	3.7	-	3.5	-	8.5
	42	11.0	-	93	-	215.1	-	2.3	-	2.5	-	8.5	-
	43	-	20.7	-	312	-	622.6	-	2.0	-	10.0	-	15.1
	44	7.9	-	32	-	68.2	-	2.1	-	2.0	-	4.1	-
	46	-	5.5	-	67	-	118.5	-	1.8	-	2.5	-	12.2
	47	1.5	-	20	-	30.8	-	1.5	-	2.0	-	13.6	-
	48	23.6	-	464	-	799.6	-	1.7	-	7.0	-	19.7	-
	52	-	20.8	-	184	-	1,368.5	-	7.4	-	8.5	-	8.9
	53	16.8	-	312	-	905.6	-	2.9	-	6.5	-	18.6	-
	70	-	13.4	-	106	-	182.7	-	1.7	-	3.0	-	7.9
110	6	-	38.2	-	165	-	1,878.2	-	11.4	-	9.0	-	4.3
	7	25.6	-	114	-	1,096.0	-	9.6	-	10.0	-	4.4	-
	12	-	17.3	-	70	-	241.3	-	3.4	-	5.0	-	4.0
	13	16.3	-	73	-	145.7	-	2.0	-	2.0	-	4.5	-
	14	-	18.4	-	29	-	218.3	-	7.5	-	2.5	-	1.6
	31	-	12.4	-	83	-	286.1	-	3.4	-	4.0	-	6.7
	Totals	151.7	216.0	1,428	1,597	4,808.6	6,788.5	4.0	4.7	4.0	4.8	7.5	8.2

by the results of the statistical analyses (see Table 4). All tests indicated no significant differences between shad and nehu at the 0.05 probability level.

Alternation of both shad and nehu on the same school.— Results of experimental fishing during cruises 105, 106, and 108 are summarized in Table 5. The basic catch data for these three cruises are given in Table 6. These results also show shad compared favorably with nehu as live bait. Analysis of the skipjack tuna catch per minute showed no significant difference between either shad or nehu as bait (see Table 4). Additional statistical tests were not made because further stratification of the data would have considerably reduced the sample size. Information on the amount of shad and nehu chummed at each station was not collected because this would have required temporarily suspending chumming at the end of each period with the result that the school of skipjack tuna probably would have sounded and fishing ended.

Number of skipjack tuna in the fishing area.— Estimates of the concentration of skipjack tuna in the fishing area near the hooks are given in Table 7. Mean values for cruises 108, 109, and 110 ranged from 1.7 skipjack tuna per photograph with nehu during cruise 108 to 5.0

Table 4.--Summary of analyses made to compare the effectiveness of threadfin shad with nehu as a live bait during Charles H. Gilbert cruises 105, 106, 108, 109, and 110. All tests indicated no significant differences between shad and nehu at the 0.05 probability level.

Cruise no.	Statistic compared, shad versus nehu	Analysis used	N	Value calculated	Probability of occurrence
109, 110	Skipjack tuna catch per minute	Mann-Whitney U-test	28	U = 86	>0.10
	Skipjack tuna <4.5 kg, catch per minute	do.	18	U = 39	>0.10
	Skipjack tuna >4.5 kg, catch per minute	do.	10	U = 8	≥0.42
	Number of skipjack tuna caught per school	do.	28	U = 70.5	>0.10
	Duration of fishing per school	do.	28	U = 68	>0.10
	Total weight of skipjack tuna caught per school	do.	28	U = 59	>0.05
105, 106, 108	Skipjack tuna catch per minute	Wilcoxon matched-pairs, signed-ranks test	18	T = 16	>0.05

Table 5.--Summary of experimental fishing for skipjack tuna with both threadfin shad and nehu alternated as bait on the same school during Charles H. Gilbert cruises 105, 106, and 108.

Item	Shad	Nehu
Number of schools first chummed with	25	9
Number of schools responding to first bait chummed	3	[1]5
Percent of schools responding to first bait chummed	12.0	55.6
Number of schools fished with both baits	9	9
Total number of fishing periods for each bait	37	38
Average number of skipjack tuna caught per minute (4 men fishing)	9.1	7.7
Number of skipjack tuna caught	1,248	998
Total weight (kg) of skipjack tuna caught	4,147	2,823
Average number of skipjack tuna caught per school	139	111
Average total weight (kg) of skipjack tuna caught per school	461	314
Average catch per minute of skipjack tuna <4.5 kg	10.0	9.0
Average catch per minute of skipjack tuna >4.5 kg	7.3	5.7

[1]One school was first chummed with shad, but did not respond until nehu was chummed.

Table 6.--Results of experimental fishing with threadfin shad and nehu on *Charles H. Gilbert* cruises 105, 106, and 108.

Cruise no.	Station	Fishing periods		Time fished		Total skipjack tuna catch				Average skipjack tuna weight	Average skipjack tuna catch per minute	
		Shad	Nehu	Shad	Nehu	Shad	Nehu	Shad	Nehu		Shad	Nehu
		Number		Minute		Number		Kg		Kg	Number	
105	4	2	3	6.0	9.0	42	55	91.4	119.7	2.2	7.0	6.1
106	5	4	3	18.5	14.5	128	90	725.6	510.2	5.7	6.9	6.2
	6	3	3	9.0	8.5	143	65	531.8	241.7	3.7	15.9	7.6
	8	5	5	15.5	14.5	158	32	895.7	181.4	5.7	10.2	2.2
	9	1	1	9.0	3.0	42	26	259.0	160.4	6.2	4.7	8.7
108	11	6	6	17.8	18.2	191	168	389.8	342.9	2.0	10.7	9.2
	12	9	9	26.8	26.3	435	383	986.4	868.5	2.3	16.2	14.6
	15	3	4	8.8	12.0	31	82	38.0	112.7	1.2	3.5	6.8
	20	4	4	11.0	12.1	78	97	229.0	285.9	2.9	7.1	8.0
	Totals	37	38	122.4	118.1	1,248	998	4,146.7	2,823.4	3.5	9.1	7.7

Table 7.--Number of skipjack tuna photographed in the fishing area.

Cruise no.	Bait	No. of schools	No. of photos	No. of skipjack tuna	Average no. of skipjack tuna per photograph
108	Shad	4	389	1,159	3.0
	Nehu	4	419	730	1.7
109	Shad	11	588	2,777	4.7
	Nehu	8	517	2,149	4.2
110	Shad	2	233	839	3.6
	Nehu	4	535	2,677	5.0
Totals	Shad	17	1,210	4,775	3.8
	Nehu	16	1,471	5,556	3.6

skipjack tuna per photograph with nehu during cruise 110. The mean value for all three cruises was 3.8 skipjack tuna per photograph with shad and 3.6 skipjack tuna per photograph with nehu.

The number of skipjack tuna counted per photograph should be considered only as rough indications of the concentration of skipjack in the fishing area because of certain inherent variables associated with the photography. These included the rolling motion of the vessel, skipjack tuna being obscured by bubbles, changes in lighting conditions caused by clouds and vessel maneuvers, and the relatively slow camera shutter speed.

Behavior of Bait

Generally speaking, threadfin shad and nehu had similar swimming behavior when used as chum for skipjack tuna fishing. Some differences occurred in their behavior, however, and were marked enough to allow an experienced observer to usually determine which species was being chummed.

Upon entering the water, both species dove downward to escape the skipjack. The diving angle of nehu varied up to 90°, but typically was 45° to 90°. They appeared to dive faster than shad and exhibited marked dodging in their escape attempts. If several nehu landed in the water in the same vicinity, they often formed a school a few feet below the surface and tried to dive downward and escape en masse. The diving angle of shad also varied up to 90°, but was usually about 45° to 65°, generally not as steep as that of nehu. They did not appear to swim as fast as nehu, nor dodge quite as vigorously. Shad also formed small schools while diving. During fishing, shad were often eaten by the skipjack tuna before they had a chance to get much deeper than 3 to 4 m, while nehu often reached depths of 6 to 8 m before being eaten. This sometimes resulted in the skipjack tuna swimming deeper when nehu was being chummed than on those schools when the bait species were alternated.

Both baits, however, can dive to considerable depths. From a sea sled we have observed nehu swim as deep as 18 m. They were still heading downward when lost to view. On one occasion scuba divers followed two shad and one Tilapia mossambica down to 23 m before breaking off the pursuit.

One difference between the two baits is their visibility. Shad are deeper bodied than nehu and have a greater portion of their sides covered with silvery scales. The result is a larger silvery reflecting surface. To the underwater observer, shad is more visible than nehu. Shad scales are highly deciduous and create a pattern of small silvery points of reflected light in the water. On one occasion, observers on the sea sled 23 m astern of the Gilbert were able to determine when a switch in bait from nehu to shad occurred just by watching for the silvery glints in the water from the shad scales.

Both shad and nehu have been observed to return to the surface when pursued by skipjack and to flee to the side of the vessel and swim along beside it. Whether this occurs more frequently when using shad or nehu is not known. Both shad and nehu are avidly eaten by skipjack; we have found skipjack stomachs gorged with shad, nehu, and both.

DISCUSSION

Bait Characteristics

The basic characteristics necessary for a live bait to be effective in the Hawaiian skipjack tuna fishery are the ability to: (1) lure skipjack to the stern of the fishing vessel, (2) concentrate the skipjack at the stern in sufficient numbers, and (3) produce a good catch rate. If the bait can be easily obtained, is hardy, and is readily handled, its effectiveness should increase.

Threadfin shad satisfy the three basic characteristics, and are also hardy and readily handled. During Gilbert cruises 109 and 110, shad were more successful than nehu in luring skipjack tuna to the stern of the vessel, since 50.0% of the schools chummed with shad were successfully fished and 35.9% of the schools chummed with nehu were fished. On cruises 105, 106, and 108, nehu were more successful than shad: 55.6% of the schools initially chummed with nehu were successfully fished and 12.0% of the schools initially chummed with shad were successfully fished. With the exception of shad on cruises 105, 106, and 108, these percentages are roughly comparable to those reported by Royce and Otsu (1955), who found that only 43% of Hawaii skipjack tuna schools are successfully fished, and Yuen (1959), who reported a 48% response to nehu. The low percentage response to shad on cruises 105, 106, and 108 was due to the necessity of initially chumming shad on successive schools in order to conserve low supplies of nehu. Had nehu been chummed on alternate schools, the percent response for both baits probably would have been similar.

The ability of shad to produce catches comparable to nehu is shown in the summaries given in Tables 2 and 5. On cruises 109 and 110, shad produced a catch rate of 7.5 skipjack tuna per minute, slightly less than the nehu catch rate of 8.2 skipjack tuna per minute. On cruises 105, 106, and 108, the catch rate averaged 9.1 skipjack tuna per minute with shad, slightly better than that of 7.7 skipjack tuna per minute with nehu.

The major differences between shad and nehu during cruises 109 and 110 were in the total weight of skipjack tuna caught and in the duration of fishing. The higher weight of skipjack tuna caught with nehu on cruises 109 and 110 was due to large skipjack tuna being heavily fished from several schools when nehu were used as bait, such as station 52, cruise 109, and station 6, cruise 110. Since the bait species were switched on each school, and there is no prior way of knowing what size skipjack tuna are in successive schools, it appears the difference is due to chance. The lower duration of fishing with shad (10.8 min) is due to the effects of two schools (cruise 109, stations 7 and 35) when only one skipjack tuna was caught from each. If data from these two schools are removed, the mean duration of fishing with shad for both cruises becomes 12.4 min, compared with nehu at 15.4 min.

The amount of bait necessary to produce a good skipjack tuna catch is another important factor in developing an alternate live bait. Here shad also appear promising. During cruises 109 and 110, an average of 4.0 buckets of shad and 4.8 buckets of nehu were used on each school successfully fished. These amounts were calculated from the chummer's estimate of how much bait had been used, the estimate being made just after fishing ended.

In considering bait requirements, the effects of mortality must also be taken into account. Brock and Uchida (1968) found that nehu usually averaged about 25% mortality a day after being placed in the baitwells. I have no exactly comparable data for shad, since the shad were not placed directly into the baitwells but were placed first into 2,350-liter (620-gal) portable transfer tanks and then into the larger 34,850-liter (9,200-gal) holding tanks for several days prior to being placed into the baitwells. However, it was not unusual to place about 10,000 to 15,000 shad in a 2,350-liter oxygenated tank, transport them for 37 km from the reservoir to the larger holding tanks and find less than 50 dead shad on arrival. In placing shad aboard several vessels using a variety of transfer methods on other occasions, the average mortality the following day was 16% (Iversen and Puffinburger[1]). Assuming optimum transfer conditions, a mortality rate of 10% by the following day appears attainable. During Gilbert cruise 116, 113 buckets of shad were carried in the ship's baitwells and 30 buckets in portable tanks on deck a distance of 4,300 km southeast of Hawaii for use as live bait in skipjack tuna fishing (Hida, 1970). Although mortalities in the portable tanks were about 50% due to bait being lost through open seams in the tank covers, mortalities in the regular baitwells were negligible.

Use of a live bait with a lower mortality rate than nehu could result in a reduced overall bait requirement, but only if the fishing effort remained unchanged. A reduced bait requirement is unlikely to happen because the purpose of developing a substitute bait is to increase fishing effort. What is more likely to happen is that use of a hardy bait will allow fishermen to increase the number of trips, fish farther offshore, or possibly increase the duration of each fishing trip. Presently most trips last 1 day and the boats rarely fish more than 170 km from the islands (Uchida, 1967). The net result could well be an increase in the total amount of bait needed.

The availability of bait-sized shad must also be considered. Landings of skipjack tuna in Hawaii are highest during the months of June through August, lowest in November through March, and intermediate in the remaining months (Brock and Uchida, 1968). In Hawaii shad begin to spawn in the late winter and early spring, with the heaviest spawning apparently occurring in February and March. In about 10 to 12 weeks the young shad grow to 40 to 50 mm and are large enough to use as bait. The availability of bait-sized shad thus coincides with the heaviest demands for bait from the fishermen during the summer. Bait-sized shad must also be abundant enough to meet needs. In recent years, the annual catch of nehu has averaged about 24,500 buckets (Uchida, 1967). It is not known how large an impoundment would be required to produce that many buckets of shad. During 16 days of baiting in Wahiawa Reservoir between February 18 and June 15, 1970, we captured 1,025 buckets of shad, an average of 64 buckets per day. More could have been captured, for the amount removed was limited by the carrying capacity of our portable tanks. Wahiawa Reservoir probably contains at least 5,000 buckets of shad in the summer. The reservoir has a surface area of 122 ha (302 acres) at high water. Thus it may be possible to culture enough shad in a pond or impoundment approaching the size of Wahiawa Reservoir to satisfy a significant percentage of the fleet's total bait requirements, providing the cost of culturing, capturing, and acclimatizing the shad is economically feasible.

What Remains to be Done?

On a short-term basis, the next logical step is a comprehensive sea test under actual commercial conditions. Providing enough shad to one or more commercial boats so that they could fish exclusively with shad during all or part of the peak fishing months would produce information on fishing effort and catches due to the use of a substitute live bait. More precise information is also needed on the amount of shad that can be cultured in ponds of different sizes and on the costs of shad culture. The results of a comprehensive commercial fishing test and cost estimates for culturing shad should lead to a rational decision on the economic feasibility of using shad as a substitute live bait for nehu.

On a long-term basis, biological investigations are needed to determine if the shad's reproductive cycle can be manipulated to produce earlier spawning and if it is possible to raise shad on a large scale in a bait hatchery.

SUMMARY

1. In order to compare the effectiveness of threadfin shad with the anchovy (nehu) normally used as live bait for skipjack tuna fishing in Hawaii, 37 schools of skipjack tuna were fished

[1] Iversen, Robert T. B., and Jay O. Puffinburger. Capture, transportation, and pumping of threadfin shad, Dorosoma petenense. Unpublished MS.

with the two baits during 1967 and 1968 aboard the research vessel Charles H. Gilbert. Threadfin shad and nehu were alternated among 25 of 28 skipjack schools fished and alternated every 3 to 5 min on each of the other 9 skipjack schools.

2. When bait was alternated among schools, the following catch data were recorded. Average number of skipjack tuna caught per minute: shad - 7.5; nehu - 8.2. Number of skipjack tuna caught: shad - 1,428; nehu - 1,597. Average number of skipjack tuna caught per school: shad - 102; nehu - 114. Average weight of skipjack tuna caught per school: shad - 344 kg; nehu - 485 kg. Average duration of fishing per school: shad - 10.8 min; nehu - 15.4 min. Percent of schools chummed that were successfully fished: shad - 50.0; nehu - 35.9.

3. When bait was alternated on the same school, the following catch data were recorded. Average number of skipjack tuna caught per minute: shad - 9.1; nehu - 7.7. Number of skipjack tuna caught: shad - 1,248; nehu - 998. Average number of skipjack tuna caught per school: shad - 139; nehu - 111. Average weight of skipjack tuna caught per school: shad - 461 kg; nehu - 314 kg. Percent of schools responding to first bait chummed: shad - 12.0; nehu - 55.6.

4. Nonparametric statistical tests showed no significant differences between threadfin shad and nehu in the following categories of catch data: skipjack tuna catch per minute, catch per minute of skipjack tuna < 4.5 kg, catch per minute of skipjack tuna >4.5 kg, number of skipjack tuna caught per school, duration of fishing per school, and weight of skipjack tuna caught per school.

5. Underwater photographs taken automatically indicated shad concentrated skipjack tuna in the fishing area equally as well as nehu.

6. Threadfin shad and nehu have similar swimming behavior when used as chum for skipjack tuna fishing.

7. Bait-sized threadfin shad occur in Hawaiian freshwater impoundments during the peak months of skipjack tuna fishing. They are hardy, readily handled in large numbers and easily acclimated to salt water.

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