The Pacific Tuna Pole-and-Line and Live-Bait Fisheries

HOWARD O. YOSHIDA, RICHARD N. UCHIDA, and TAMIO OTSU[1]

ABSTRACT

The pole-and-line and live-bait fisheries of the eastern, central, and western Pacific Ocean are reviewed, including landing trends of tunas and catch and effort statistics on the fisheries for the tuna baitfishes. It was estimated that landings of tuna by the live-bait, pole-and-line fisheries contributed about 35% of the total Pacific landings of tunas in 1970. Also included were gross comparisons of the relative effectiveness of the live bait used in the various fisheries and discussions of the factors that may affect the relative effectiveness. The mean catch of tuna in metric tons per metric ton of bait was estimated at 7.5 in the eastern Pacific, 9.8 in the Japanese fishery, and 23.1 in the Hawaiian pole-and-line fishery. Thus, in terms of the catch per unit of bait, the Hawaiian fishery was 3.1 times more efficient than the eastern Pacific fishery and 2.3 times more efficient than the Japanese pole-and-line fishery.

The Japanese anchovy, *Engraulis japonicus*, is the most important bait species used in the Japanese pole-and-line fishery. In the eastern Pacific fishery the more important bait species are the anchoveta, *Cetengraulis mysticetus*; northern anchovy, *E. mordax*; California sardine, *Sardinops caerulea*; Galapagos sardine, *S. sagax*; and southern anchovy, *E. ringens*. The Hawaiian skipjack tuna fishermen primarily use nehu, *Stolephorus purpureus*.

INTRODUCTION

The total landings of skipjack tuna, *Katsuwonus pelamis*; yellowfin tuna, *Thunnus albacares*; albacore, *T. alalunga*; and bigeye tuna, *T. obesus*, in the Pacific Ocean by all methods of fishing amounted to an estimated 702,600 t in 1970 (FAO 1971). It is estimated that of these total landings, 243,800 t were made by the pole-and-line fishing method using live bait. The landings by the pole-and-line fisheries represent about 35% of the total landings by all methods of fishing.

Purse seine fishing for tropical tunas in the eastern Pacific was not very successful during the years prior to 1957. During the period from 1931 to 1956 the fishery for yellowfin tuna and skipjack tuna was dominated by bait boats, and purse seiners produced less than 15% of the yellowfin tuna and about 13% of the skipjack tuna catch (Broadhead 1962). However, beginning in 1957, the development of several technological innovations helped to reverse the trend, so that by 1960, the purse seine fleet had displaced the bait boats as the major producer of tunas in the eastern Pacific Ocean (Alverson 1963).

Because of the success of purse seining as practiced in the eastern Pacific, attempts were recently made to utilize this method on skipjack tuna in the central Pacific ([Hawaii.] Division of Fish and Game and Bumble Bee Seafoods [1970?]). The experiments were partially successful. In the western Pacific the Japanese have also been trying this method (Watakabe 1970) but, like the Hawaiian experiments, they have not been an unqualified success (Hester and Otsu 1973). Thus, in spite of its highly successful use in the eastern Pacific, the purse seine method with all of its technological advancements still requires more improvement for successful use in the central and western Pacific. Consequently, pole-and-line fishing with live bait is still the dominant method of fishing for tunas at the surface in the central and western Pacific.

Although the fishery in the eastern Pacific is now dominated by purse seiners, pole-and-line fishing with live bait is still practiced. In 1972 there were 52 bait boats of U.S. registry operating in the eastern Pacific (IATTC 1973). In the western Pacific, the Japanese have a highly viable pole-and-line fishery for skipjack tuna and albacore. And in the central Pacific a small but important pole-and-line fishery for skipjack tuna exists in Hawaii.

The purpose of this report is to present descriptions of the pole-and-line and live-bait fisheries in the eastern, central, and western Pacific, to review the historical catch and effort statistics on the fisheries for tuna baitfishes, and to compare the relative effectiveness of the live bait used in the three representative fisheries mentioned above. We will also discuss the factors that may contribute to the relative effectiveness of bait in terms of the volume of tuna produced. The material for this paper was taken almost entirely from published papers and reports.

EASTERN PACIFIC FISHERY

As noted earlier, the eastern Pacific tropical tuna fishery at present is essentially a purse seine fishery but,

[1]Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

prior to 1957, was predominantly a live-bait fishery. In 1948, of 118,752 t of skipjack tuna and yellowfin tuna landed by the eastern Pacific fleet, about 84% was caught by bait boats. By 1960, the proportion had dropped to about 40% as the "purse-seine revolution" launched a mass conversion of bait boats to seiners. In recent years, only about 10% of the tunas has been landed by bait boats.

The geographical extent of the eastern Pacific pole-and-line fishery for yellowfin and skipjack tunas, as given by Shimada and Schaefer (1956) is shown in Figure 1. This figure shows the extent of the fishery in 1954, and includes purse seiner operations. During the period prior to 1957, when the bait boats dominated the fishery, they ranged over a large area in the eastern Pacific, from Cedros Island, Mexico (lat. 28°N), to northern Peru (about lat. 10°S). Except for the offshore islands and banks, most of the tuna catches were made within a few hundred miles of the coastline (Alverson 1959). By 1963, as noted in the Annual Report of the Inter-American Tropical Tuna Commission (IATTC 1964), many of the larger bait boats had been converted to purse seiners and the remaining bait boat fleet was composed of vessels of less than 170 tons capacity which generally operated north of the Gulf of Tehuantepec (ca. lat. 15°N).

Alverson (1959) discussed the seasonal nature of the eastern Pacific fishery for yellowfin and skipjack tunas during the period from 1952 to 1955. During this 4-yr period the catches of yellowfin tuna and particularly skipjack tuna were poorest in the first quarter (January-March). The catches of both species improved in the second quarter and continued good in the third. Alverson believed that the fourth quarter would have been the best of the year had it not been for some economic factors, including strikes and slow unloading of vessels. It should be pointed out that the seasonal nature of the fishery as described above is an oversimplification. The geographical extent of the fishery is large and there are variations in abundance in various localities in any one season.

Beginning in 1966, because of the use of increasingly efficient purse seine vessels, management procedures were implemented on the yellowfin tuna. These procedures were in the form of restricted fishing periods. In recent years the season of unrestricted fishing has grown increasingly short and in 1972 was only about 4 mo

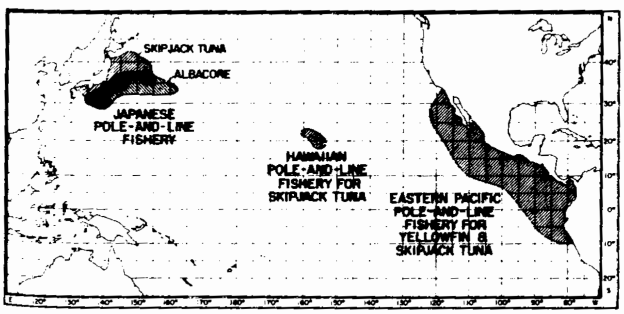

Figure 1.—Geographical location of the eastern Pacific, Hawaiian, and Japanese pole-and-line fisheries for tunas.

(IATTC 1972). The skipjack tuna stocks in the eastern Pacific are still not under management.

Bait Species Utilized

Nearly all the species of fish used as live bait in fishing for tunas in the eastern Pacific belong to the herring and anchovy families (Alverson and Shimada 1957). These fishes are usually small and school in shallow waters nearshore. In 1946-58, the anchoveta, *Cetengraulis mysticetus*, composed from 29.6 to 59.5% of the bait taken by the bait boats, but in 1959, it represented only 21.8% of the bait taken (Table 1). In 1960-69, the percentage of the catch consisting of anchoveta varied between 10.0 and 34.9% and averaged slightly more than one-fifth of the bait catch.

Among the qualities that made anchoveta highly desirable as a baitfish were its wide distribution, wide range of temperature tolerance, and ability to survive for long periods in the baitwells (Alverson and Shimada 1957).

A species that has become important only since the 1960's is the northern anchovy, *Engraulis mordax*. Table 1 shows that in 1946-60, less than 19% of the catch consisted of this species. In 1961-69, however, the northern anchovy gradually replaced the anchoveta as the predominant bait species (Fig. 2). While the 1961 catch of anchoveta composed 32.5% of the total bait catch, the northern anchovy and California sardine, *Sardinops caerulea*, represented 27.5% and 16.3% of the total bait catch, respectively, both relatively higher than in 1960 (IATTC 1962). By 1963, the northern anchovy had become the predominant species in the catch. The change from anchoveta to northern anchovy as the predominant bait species reflected the shift in the composition of the tuna fleet from one consisting predominantly of bait boats to one of purse seiners. As noted earlier, after the mass conversion from bait boats to seiners, the majority of the remaining bait boats were small vessels of under 150-ton capacity that usually fished north of the Gulf of Tehuantepec where northern anchovies were more common.

Baiting Areas

Alverson and Shimada (1957) listed the anchoveta, the California sardine, the Galapagos sardine, *Sardinops sagax*, the northern anchovy, and the southern anchovy, *Engraulis ringens*, as the most important baitfishes in the eastern Pacific. The principal baiting areas for these five major species are given in Table 2 and their locations are shown in Figure 3.

Catch and Baiting Effort

Alverson and Shimada (1957) noted that the fishery for baitfish, a subordinate but integral part of the eastern Pacific tuna fishery, is not predisposed to the easy collection of reliable catch records. The only source of information is the detailed accounts of baiting kept by fisher-

Table 1.—Estimated amounts, in thousands of scoops and percentages of kinds, of baitfishes taken from 1946 to 1969 by bait boats (excludes bait caught by vessels fishing out of Latin American ports and that by a few small vessels fishing out of California).

	Anchoveta, *Cetengraulis mysticetus*		California sardine, *Sardinops caerulea*		Galapagos sardine, *Sardinops sagax*		Northern anchovy, *Engraulis mordax*		Southern anchovy, *Engraulis ringens*		California sardine and northern anchovy mixed		Herring, *Opisthonema*, *Harengula*		Salima, *Xenocys jessiae*		Miscellaneous and unidentified		Total catch
Year	**Scoops**	**%**	**Scoops**	**%**	**Scoops**	**%**	**Scoops**	**%**	**Scoops**	**%**	**Scoops**	**%**	**Scoops**	**%**	**Scoops**	**%**	**Scoops**	**%**	**Scoops**
1946	398	29.6	389	28.9	28	2.1	132	9.8	—	—	203	15.1	23	1.7	126	9.4	45	3.3	1,344
1947	836	39.5	405	19.1	97	4.6	141	6.7	—	—	250	11.8	62	2.9	259	12.2	66	3.1	2,116
1948	964	32.3	416	13.9	753	25.2	147	4.9	—	—	349	11.7	42	1.4	217	7.3	95	3.2	2,983
1949	1,079	39.3	514	18.7	570	20.7	138	5.0	—	—	217	7.9	40	1.5	117	4.3	73	2.6	2,748
1950	1,700	47.6	318	8.9	959	26.9	239	6.7	—	—	187	5.2	45	1.3	32	0.9	90	2.5	3,570
1951	1,708	63.5	366	13.6	130	4.8	143	5.3	—	—	13	0.5	137	5.1	118	4.4	76	2.8	2,691
1952	2,542	59.5	286	6.7	596	14.0	577	13.5	—	—	53	1.2	124	2.9	51	1.2	40	0.9	4,269
1953	1,618	37.2	413	9.5	1,145	26.3	814	18.7	36	0.8	168	3.9	88	2.0	31	0.7	36	0.8	4,349
1954	1,820	46.3	203	5.2	590	15.0	604	15.4	553	14.1	65	1.7	49	1.2	23	0.6	20	0.5	3,927
1955	1,321	51.0	541	20.9	247	9.6	159	6.2	214	8.3	9	0.4	49	1.9	21	0.8	25	0.9	2,586
1956	1,667	45.6	362	9.9	152	4.2	594	16.2	355	9.7	38	1.0	368	10.1	27	0.7	95	2.6	3,658
1957	2,070	55.8	290	7.8	38	1.0	547	14.8	410	11.1	30	0.8	193	5.2	17	0.5	112	3.0	3,707
1958	1,515	34.0	601	13.5	141	3.2	736	16.5	1,169	26.3	57	1.3	102	2.3	16	0.4	110	2.5	4,447
1959	649	21.8	290	9.7	110	3.7	190	6.4	1,484	49.8	30	1.0	75	2.5	24	0.8	128	4.3	2,980
1960	416	34.9	110	9.2	82	6.9	212	17.8	214	17.9	6	0.5	64	5.4	15	1.2	74	6.2	1,193
1961	211	32.5	106	16.3	8	1.2	179	27.5	88	13.5	2	0.3	26	4.0	14	2.2	16	2.5	650
1962	123	29.6	89	21.4	34	8.2	110	26.5	25	6.0	2	0.5	16	3.9	7	1.7	8	1.9	414
1963	56	23.2	19	8.0	29	12.1	101	41.8	—	—	8	3.3	22	9.2	1	0.4	5	2.2	241
1964	37	16.5	54	24.1	74	33.0	41	18.3	—	—	1	0.4	8	3.6	4	1.8	5	2.2	224
1965	34	11.0	41	13.3	33	10.7	147	47.7	—	—	2	0.7	34	11.0	10	3.3	7	2.3	308
1966	49	17.3	68	23.9	22	7.7	106	37.3	—	—	3	1.1	24	8.4	9	3.2	3	1.1	284
1967	61	25.6	56	23.5	14	5.9	94	39.5	—	—	—	—	8	3.4	4	1.7	1	0.4	238
1968	37	13.7	54	19.9	18	6.6	148	54.6	—	—	1	0.4	10	3.7	2	0.7	1	0.4	271
1969	25	10.0	40	16.1	10	4.0	153	61.5	—	—	1	0.4	16	6.4	0	0.0	4	1.6	249

men in their logbooks. Based on data collected from about 85% of the bait boats based in California ports, scientists at the IATTC have been able to estimate the amounts and kinds of baitfish taken by all California bait boats operating in the eastern Pacific.

Table 3 gives the annual catches of all species of baitfish caught by bait boats in 1946-69. The annual catches, measured in scoops holding 4 kg (8 lb) of bait (Shimada and Schaefer 1956), varied from 224,000 scoops in 1964 to 4,447,000 scoops in 1958. At the height of the bait boat era, annual catches of 3.5-4.0 million scoops were not uncommon. From 1946 to 1959, when the bait boats dominated the fishery, the annual catches averaged 3,241,000 scoops. In 1960-69, the average annual catch reached only 407,000 scoopes, about one-eighth of the pre-1960 catches.

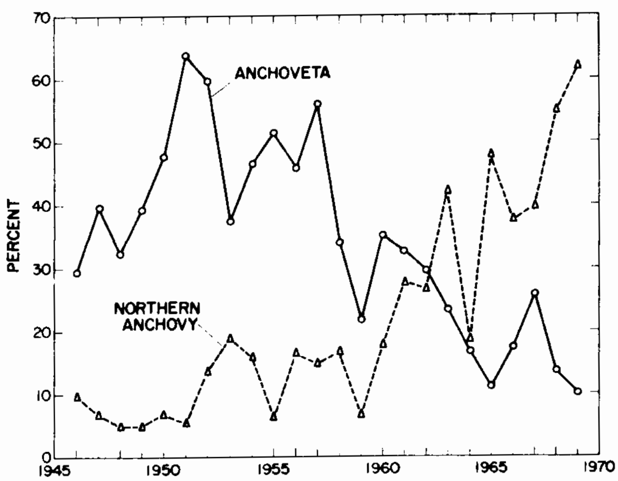

Figure 2.—Percentage of anchoveta and northern anchovy in the baitfish catches of bait boats in the eastern Pacific tuna fishery, 1946-69.

Data on baiting effort are not usually published in the annual reports of the IATTC. For 1939-51, Peterson (1956) gave the recorded and estimated catches and baiting effort for anchovetas, herring, and other miscellaneous species in the Gulf of Nicoya (Table 4). Alverson and Shimada (1957) also published catch and baiting effort data giving the catch per standard day's baiting, estimated total catch, and calculated baiting intensity for anchovetas in several of the major baiting grounds. Their data are reproduced in Table 5.

HAWAIIAN FISHERY

The Hawaiian pole-and-line fishery for skipjack tuna is conducted within 90 mi of the main islands of Hawaii, Oahu, Maui, Kauai, and Molokai (Fig. 1). Skipjack tuna are taken throughout the year, but the bulk of the catch is made between May and September. Smaller fish from 1.8 to 2.3 kg (4 to 5 lb) are taken all year long, but during the months of peak catches large fish ranging from 5.9 to 11.3 kg (13 to 25 lb) are also taken. These larger fish constitute a large percentage by weight of the total annual catch (Uchida 1967).

Unlike the eastern Pacific tuna fishery, where the demand for live bait has declined since 1960, catches of live bait are becoming increasingly important in other areas

Table 2.—Major baiting localities for five of the most important bait species used by eastern Pacific bait boats (compiled from Alverson and Shimada 1957).

Species	Major baiting grounds	Season
Anchoveta *Cetengraulis mysticetus*	Ranges from central Baja California to northern Peru. Important baiting grounds are Almejas Bay in Baja California, Guaymas and Ahome Point in the Gulf of California, and Gulf of Fonseca and Gulf of Panama in Central America.	Caught in appreciable numbers at one season or another throughout the year.
California sardine *Sardinops caerulea*	Ranges from San Diego, Calif., along outer coast of Baja California and along western side of Gulf of California as far north as Santa Catalina Island. Important grounds are at Cedros Island, Santa Maria Bay, and Magdalena Bay in Baja California and San Jose Island in Gulf of California.	July to November.
Galapagos sardine *Sardinops sagax*	Galapagos Islands.	September through February.
Northern anchovy *Engraulis mordax*	From San Diego, Calif., to Cape Falso at southernmost extremity of Baja California. Important grounds are at Turtle Bay, Santa Maria Bay, and Magdalena Bay; San Quentin Bay and Abreojos Point in some years.	June through November.
Southern anchovy *Engraulis ringens*	Cape Blanco, Peru to about lat. 10°S.	September through January.

of the Pacific. The Hawaiian fishery for skipjack tuna is small compared with those in the eastern and western Pacific, but it is the only commercial pole-and-line fishery in the midst of what is believed to be a vast resource of skipjack tuna extending throughout the tropical and subtropical central Pacific.

Bait Species Utilized

In Hawaii, a small, fragile anchovy locally called nehu, *Stolephorus purpureus*, is captured day and night and constitutes roughly 95% of the baitfish used for skipjack

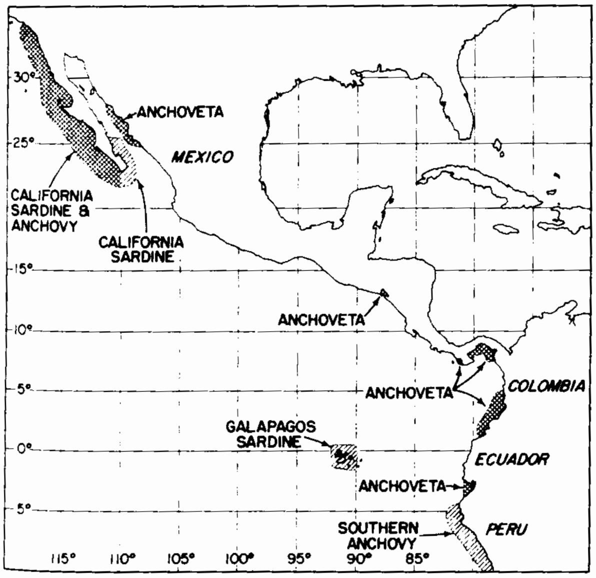

Figure 3.—Principal baiting areas of the California live-bait fishery for yellowfin and skipjack tunas (from Alverson and Shimada, 1957).

Table 3.—Annual catches of live bait in the eastern Pacific (all species), Hawaiian (nehu), and Japanese (anchovy) fisheries for bait.

Year	Eastern Pacific[1] (scoops)	Hawaii[2] (buckets)	Japan[3] (metric tons)
1946	1,344,000	25,860	—
1947	2,116,000	30,750	—
1948	2,983,000	42,036	—
1949	2,747,000	39,558	—
1950	3,570,000	39,638	—
1951	2,691,000	40,491	—
1952	4,269,000	29,807	—
1953	4,349,000	37,682	—
1954	3,927,000	43,737	—
1955	2,586,000	49,712	—
1956	3,653,000	40,864	—
1957	3,707,000	30,638	18,468
1958	4,447,000	33,303	18,109
1959	2,980,000	37,637	16,304
1960	1,193,000	22,849	15,916
1961	650,000	37,092	15,604
1962	414,000	34,256	15,526
1963	241,000	32,670	16,067
1964	224,000	30,606	14,915
1965	308,000	36,352	27,568
1966	284,000	31,603	22,262
1967	238,000	31,832	18,320
1968	271,000	35,535	20,771
1969	249,000	30,096	21,606
1970	—	33,596	21,264
1971	—	42,098	20,848
1972	—	38,970	—

[1]Data for 1946-69 are from IATTC (1956, 1962, 1968, 1970).

[2]Data for 1946-53 are from Yamashita (1958); data for 1954-72 are unpublished data courtesy of the Hawaii Division of Fish and Game. (Data for 1960-72 have been adjusted after correcting errors in catch reports.)

[3]Data from [Japan.] Ministry of Agriculture and Forestry, Statistics and Survey Division (1958-62, 1964-73).

Table 4.—Recorded and estimated catches in scoops and number of days of fishing for anchovetas, *Cetengraulis mysticetus*, and other baitfishes taken by California-based tuna clippers from the Gulf of Nicoya from 1939 to 1951. On the left side of the table are the recorded or actual catches and actual number of days of fishing obtained from logbooks made available to the commission by a segment of the fleet. Estimates for the entire fleet are shown to the right. Also shown is the average catch of anchovetas per day of fishing (from Peterson 1956).

	Recorded catch and days fishing					Estimated catch and days fishing					
Year	Anchoveta	Herring	Miscel-laneous	Total	No. days fishing	Anchoveta	Herring	Miscel-laneous	Total	No. days fishing	Catch of anchovetas per day of fishing
1939	23,902	—	—	23,902	49.0	220,756	—	—	220,756	486.0	454
1940	1,958	—	—	1,958	12.0	25,310	—	—	25,310	152.5	166
1941	11,704	—	—	11,704	58.0	89,590	—	—	89,590	449.5	199
1942	2,438	—	—	2,438	9.5	19,249	—	—	19,249	74.5	258
1943	7,600	—	—	7,600	16.0	54,688	—	—	54,688	116.0	471
1944	2,917	—	—	2,917	18.5	23,539	—	—	23,539	143.0	165
1945	6,148	357	—	6,505	47.0	29,282	2,156	—	31,438	232.5	126
1946	35,408	58	667	36,133	115.0	90,190	554	5,848	96,592	323.5	279
1947	23,420	4,647	1,821	29,888	233.5	57,536	14,978	4,984	77,498	628.0	92
1948	3,473	7,920	5,272	16,665	82.5	7,123	15,090	10,432	32,645	163.5	44
1949	683	53	—	736	11.0	1,157	89	—	1,246	19.5	59
1950	—	4,181	1,547	5,728	26.0	—	6,615	2,449	9,064	51.5	0
1951	—	—	—	—	2.0	—	—	—	—	2.0	0

Table 5.—Catch per standard day's baiting, estimated total catch, and calculated fishing intensity for anchovetas in Almejas Bay, Guaymas, Ahome Point, Gulf of Fonseca, and Gulf of Panama, 1946-54 (Alverson and Shimada 1957).

	Almejas Bay			Guaymas			Ahome Point			Gulf of Fonseca			Gulf of Panama		
Year	Catch per standard day's baiting scoops/class 4 day	Estimated total catch in scoops	Calculated fishing intensity, in class 4 days	Catch per standard day's baiting scoops/class 4 day	Estimated total catch in scoops	Calculated fishing intensity, in class 4 days	Catch per standard day's baiting scoops/class 4 day	Estimated total catch in scoops	Calculated fishing intensity, in class 4 days	Catch per standard day's baiting scoops/class 4 day	Estimated total catch in scoops	Calculated fishing intensity, in class 4 days	Catch per standard day's baiting scoops/class 4 day	Estimated total catch in scoops	Calculated fishing intensity, in class 4 days
1946	283.4	28,847	102.0	520.0	184,192	354.0	404.8	47,705	110.5	334.7	39,896	119.0	300.0	5,999	20.0
1947	289.4	100,594	347.5	424.9	325,503	766.0	313.8	149,186	475.5	220.6	36,020	163.5	355.6	143,445	403.5
1948	410.8	218,728	532.5	—	0	0	502.0	331,539	660.5	29.9	972	32.5	456.7	395,563	886.0
1949	291.4	236,293	811.0	76.4	949	12.5	751.6	278,166	370.0	118.1	3,336	28.0	679.1	513,973	757.0
1950	583.6	498,558	854.3	819.9	481,470	587.0	676.8	81,830	121.0	355.0	18,669	52.5	355.7	183,378	515.5
1951	526.1	246,077	467.5	618.6	433,088	700.0	711.5	419,033	589.0	478.8	172,062	359.5	597.7	204,479	352.0
1952	451.5	374,115	828.5	627.8	584,706	931.5	360.6	72,460	201.0	526.2	286,148	544.0	616.8	925,689	1,501.0
1953	599.4	347,016	578.9	748.9	355,580	475.0	753.3	165,491	219.5	148.9	5,435	36.5	421.5	623,290	1,478.5
1954	613.8	101,754	166.0	829.0	439,903	530.5	892.1	114,133	128.0	527.0	47,793	90.5	530.8	760,564	1,433.0

tuna fishing. Nehu is preferred above all others by the skipjack tuna fishermen because it possesses most of the qualities of a good baitfish. But nehu is also extremely fragile and during seining and transferring from seines to baitwells, many fish are injured and die of their injuries. Annually, an average of about 22% of the nehu die before they can be used in tuna fishing.

Other small fish are also used for bait. Almost all the remainder of the bait catch in Hawaii is composed of silverside or iao, *Pranesus insularum*, and small round herring or piha, *Spratelloides delicatulus*.

Baiting Areas

Nearly 79% of the live bait captured in the Hawaiian Islands comes from the island of Oahu. Two of the major baiting grounds are Kaneohe Bay and Pearl Harbor, which together contribute about 71% of the State's bait catch. Other areas of less importance are Kalihi-Keehi Lagoon and Honolulu Harbor.

On the neighboring islands, baiting grounds appear to have diminished in importance, probably due to a reduction in the number of vessels based there. Good baiting areas on Maui are the Maalaea Bay region (including Kihei), Lahaina, and Kahului. On the island of Hawaii, the vessels usually catch bait in Hilo Bay, Kawaihae, Mahukona, and Kona. Kauai has Port Allen, Nawiliwili, Hanalei, and Hanapepe as baiting areas. Infrequent attempts are made to bait at Lanai and at Kaunakakai, Molokai.

Catch and Baiting Effort

In Hawaii, bait catches are reported to the State on the same form as that used for reporting skipjack tuna catches. The form has undergone several revisions over

Table 6.—Catch, effort, and catch per effort in the fishery for nehu in Hawaii, 1960-72.

Year	Nehu - day: Catch (buckets)	Nehu - day: Effort days (no.)	Nehu - day: Catch per day (buckets)	Nehu - night: Catch (buckets)	Nehu - night: Effort nights (no.)	Nehu - night: Catch per night (buckets)	Nehu - day and night: Catch (buckets)	Nehu - day and night: Effort days and nights (no.)	Nehu - day and night: Catch per effort (buckets)	Other species - day and night: Catch (buckets)	Other species - day and night: Effort days and nights (no.)	Other species - day and night: Catch per effort (buckets)	Totals: Annual catch (buckets)	Totals: Effort days and nights (no.)	Totals: Catch per effort (buckets)
1960	15,735	1,001	15.7	3,069	408	7.5	2,489	297	8.4	1,556	145	10.7	22,849	1,851	12.3
1961	25,309	940	26.9	7,804	639	12.2	2,150	130	16.5	1,829	102	17.9	37,092	1,811	20.5
1962	23,544	823	28.6	7,819	623	12.6	1,585	126	12.6	1,308	83	15.8	34,256	1,655	20.7
1963	21,832	817	26.7	7,731	851	9.1	1,414	95	14.9	1,693	124	13.6	32,670	1,887	17.3
1964	18,454	774	23.8	9,618	1,003	9.6	1,547	82	18.9	987	63	15.7	30,606	1,922	15.9
1965	19,972	839	23.8	14,251	1,424	10.0	1,142	50	22.8	987	52	19.0	36,352	2,365	15.4
1966	20,696	781	26.5	10,242	1,011	10.1	480	20	24.0	185	19	9.7	31,603	1,831	17.2
1967	22,432	740	30.3	9,201	914	10.1	—	—	—	199	12	16.6	31,832	1,666	19.1
1968	30,148	1,055	28.6	4,911	544	9.0	96	4	24.0	380	17	22.4	35,535	1,620	21.9
1969	25,650	870	29.5	4,164	374	11.1	65	2	32.5	217	25	8.7	30,096	1,271	23.7
1970	30,332	1,017	29.8	2,654	288	9.2	112	3	37.3	498	24	20.8	33,596	1,332	25.2
1971	38,786	1,334	29.1	2,776	288	9.6	30	1	30.0	506	38	13.3	42,098	1,661	25.3
1972	36,503	1,171	31.2	2,187	206	10.6	30	1	30.0	250	15	16.7	38,970	1,393	28.0
Total	329,393	12,162		86,427	8,573		11,140	811		10,595	719		437,555	22,265	
Mean	25,338	936	27.1	6,648	659	10.1	928	68	13.7	815	55	14.8	33,658	1,713	19.6

the years, but in all the various versions used, the fishermen have reported date of catch, locality, amount of bait caught, and amount used. More recently, the forms have also included spaces for recording zero-catches, the amount of bait that died, and the amount of bait left over after fishing. Unlike commercial fish catches that are published and distributed monthly by the Hawaii Division of Fish and Game, bait catches are not published.

The annual catches of live bait in the Hawaiian Islands are given in Table 3 (see also Uchida 1977). In 1946-72, the bait catches ranged from a low of 22,849 buckets in 1960 to 49,712 buckets in 1955 and averaged 35,528 buckets. Yamashita (1958) estimated that a bucket holds about 3.2 kg (7 lb) of nehu.

Data on catch, baiting effort, and catch per effort of nehu taken in 1960-72 are given for day and night baiting in Table 6. Also included in the table are nehu catches for which the bait reports gave no time of capture, and catches of other species. Data on effort have not been corrected for variations in bait catches due to differences in efficiency among the different-sized fishing vessels.

Of particular interest were the opposite trends of day and night catches of nehu. Table 7 gives the baiting effort expended during the day and at night and their percentages of the total effort in 1960-72. A distinct pattern was obvious. Whereas 71% of the baiting effort in 1960 was expended in day operations, only 37% was expended during the day in 1965. A change in the ratio of day to night baiting in 1966, however, carried day effort back to the 1960 level and by 1972, 85% of the baiting effort expended was during the day. The change in emphasis in day and night baiting in 1960-72 is reflected in the catches of day and night bait shown in Figure 4.

JAPANESE POLE-AND-LINE FISHERY

In Figure 1 can be seen the geographical extent of the Japanese pole-and-line fishery for skipjack tuna and albacore. The figure for skipjack tuna was taken from

Table 7.—The amounts, percentages, and means of day and night effort expended in the bait fishery for nehu in Hawaii, 1960-72.

Year	Baiting effort: Day	Percent	Night	Percent	Day and night total effort
1960	1,001	71	408	29	1,409
1961	940	60	639	40	1,579
1962	823	57	623	43	1,446
1963	817	49	851	51	1,668
1964	774	44	1,003	56	1,777
1965	839	37	1,424	63	2,263
1966	781	44	1,011	56	1,792
1967	740	45	914	55	1,654
1968	1,055	66	544	34	1,599
1969	870	70	374	30	1,244
1970	1,017	78	288	22	1,305
1971	1,334	82	288	18	1,622
1972	1,171	85	206	15	1,377
Total	12,162		8,573		20,735
Mean	936		659		1,595
Percent		59		41	

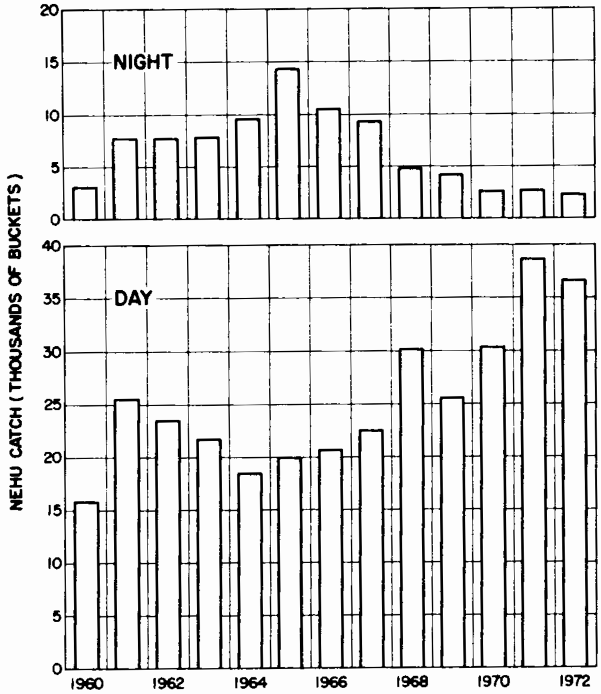

Figure 4.—Annual catches in the day and night fishery for nehu in Hawaii, 1960-72.

Rothschild and Uchida (1968) and that of albacore from Otsu and Uchida (1963). The albacore fishery extends over a thousand miles offshore whereas the skipjack tuna fishery tends to be more coastal.

Generally, over 75% of the annual catch of skipjack tuna is made from May through September. However, variations to this general rule occur in the sector of the fishery north of about lat. 35°N. Here the fishery may begin as early as April or as late as July and may end as early as August or as late as October. The seasonal development of the albacore fishery is somewhat similar to that of the skipjack tuna. Small catches of albacore are usually made in March or April and between the latter part of April and the end of May the first large catches are made. The season peaks in June and by the end of July the season is virtually over. Fishing for skipjack tuna and albacore are interrelated in that most of the pole-and-line fleet seek out skipjack tuna except during the brief period when the albacore are most abundant (Van Campen 1960).

Japanese vessels harvest about two-thirds of the world's skipjack tuna catch, which annually reaches about 300,000 t (Kawasaki 1972). The bulk of the catch is made by the traditional method using pole-and-line and live bait, although since 1964 the Japanese fishing industry has been actively engaged in experimental fishing with purse seines to capture skipjack tuna (Watakabe 1970; Yabe 1972).

Despite the fact that the skipjack tuna fishery has a long history and is well established among Japanese commercial fishing enterprises, pressure has been mounting in recent years to expand and develop this fishery even further. In 1970, realizing that the deep-swimming larger tunas were already being fished at or near the maximum level by the far ranging longline fleet, the Japanese Fisheries Agency turned its attention to further development of the skipjack tuna resource in southern waters (Suisan Shūhō 1973). Automatic fishing poles installed on pole-and-line fishing vessels proved successful and will probably help in significantly reducing future manpower needs (Suzuki Tekkojo Kabushiki Kaisha 1970). But skipjack tuna fishing has not developed as rapidly as expected. Two of the most pressing needs at present are to develop methods of transporting live bait to distant fishing grounds and to capture live bait in areas outside foreign territorial waters (Suda 1972).

Bait Species Utilized

About 97% of the live bait used in Japan today is an anchovy, *Engraulis japonicus*, known as katakuchi iwashi in Japanese (Katsuo-Maguro Nenkan 1971). Imamura (1949) listed various other species that have been used as bait in the past. Among them were maiwashi or sardines, *Sardinops melanosticta*; muroaji or scad, *Decapturus muroaji*; and the juveniles of masaba or mackerel, *Scomber japonicus*. Cleaver and Shimada (1950) published an extensive list of fishes that were used as live bait in the pre-World War II fisheries in Japan, the Ryukyu Islands, and the South Seas (Table 8).

Katakuchi iwashi was not always the predominant bait species in Japan. Imamura (1949) listed maiwashi as the predominant species in the immediate post-World War II period. Maiwashi, he stated, was more resistant to injury and excitement, whereas katakuchi iwashi was resistant to oxygen deficiency.

Baiting Areas

There are more than 60 baiting areas for anchovy in Japan (Katsuo-Maguro Nenkan 1971). These areas are given in Table 9. During a visit to Japan in 1974, one of the coauthors (T. Otsu) made firsthand observations on the bait fisheries in Shizuoka Prefecture (Ajiro, Usami), Oita Prefecture (Tsukumi), and Nagasaki Prefecture (Segawa). The areas are representative of the Kanto and Kyushu baiting areas (central and southwestern Japan, respectively). Following are some of the observations made during that visit.

There is considerable demand for live bait in Shizuoka Prefecture, which is the leading skipjack tuna fishing prefecture in Japan. Because the prefectural baiting areas periodically experience shortages, several bait-transport vessels are now in operation carrying fish purchased from Kyushu baiting areas to Shizuoka Prefecture. Most of the anchovy in Shizuoka Prefecture are taken by one-boat or two-boat purse seines. In addition to the seiners, a baiting unit includes a fish-finder vessel, a small scouting vessel, and a tugboat to tow the bait receivers to and from the fishing grounds.

Table 8.—Some baitfishes used by the Japanese skipjack tuna fishery (from Cleaver and Shimada 1950).

Scientific name	Common names
Japan and Ryukyu Islands	
Amia notata	kurohoshi-tenjikudai, ufumi
A. truncata	ufumi
Atherina bleekeri	tōgoro-iwashi
A. tsurugae	aoharara, gin-isō-iwashi
Beryx decadactylus	gasagasa, nanyō-kinmedai
Caesio coerulaureus	saneera, shimamuro-gurukun
C. digramma	gurukun
Caranx djeddeba	gatsun
Engraulis japonicus	katakuchi-iwashi, segurō-iwashi, tarekuchi-iwashi
Harengula zunasi	sappa
Lutjanus vaigiensis	mochinogwa, okifuefuki
Pomacentrus anabatoids	hichigwa, hikigwa
Pseudupeneus sp.	himeji
Sardinella mizun	mizun
Sardinia immaculata	hoshinashi-iwashi, shiira
S. melanosticta	ma-iwashi
Scomber japonicus	ōsabanoko, saba
South Seas	
Amia sp.	akadoro
Apogon sp.	akadoro
Archamia bleekeri	atohiki-tenjikudai
Atherina sp.	kokera, tobi-iwashi, tōgoro-iwashi
Atherina valenciennesii	nanyō-tōgoro-iwashi
Caesio chrysozonus	akamuro, gurukun, saneera, umeiro
Caranx leptolepis	aji
C. malibalicus	shima-aji
Caranx sp.	aji, gatsun
Chilodipterus sp.	akadoro
Dascyllus trimaculatus	montsuki
Decapterus russelli	akamuro
Decapterus sp.	muro, shima-muro
Gazza equulasformis	hiiragi
Harengula molluciensis	ma-iwashi, nanyō-ma-iwashi
Labracoglossa argentiventris	takabe
Mullus sp.	ojisan
Sardinella leiogaster	mangurōbu-iwashi
Scomber kanagurta	saba
Sphyraena obtusata	kamasu
Spratelloides delicatulus	ao-iwashi, baka, nanyō-kibinago, shiira
Trachurops crumenophthalma	me-aji
Trachurus japonicus	ma-aji
Upeneus sp.	ojisan
Upeneus tragula	yomehimeji
Upenoides sp.	ojisan
Stolephorus heterolobus	nanyō-katakuchi-iwashi, tarekuchi
S. japonicus	bakasako, kibiko-iwashi, sururu

The bait fishery at Tsukumi in Oita Prefecture is one of the important baiting areas in Kyushu. It is operated strictly for vessels from outside prefectures since Oita Prefecture does not have a skipjack tuna fishery of its own. Vessels from Shizuoka, Kochi, and Miyazaki Prefectures, among others, come here to purchase bait. The baiting fleet in Tsukumi consists of two 7-ton catcher boats (seiners), a one-boat seiner, a 2-ton lightboat, a transport, and a tugboat.

Bait from the bait fishery in an area in Segawa Bay, Nagasaki Prefecture, is reported to be of excellent quality. It is known as "Sasebo bait" and is taken in Omura Bay, an enclosed bay located between Nagasaki City and Sasebo City. Vessels from various prefectures come here to make purchases. Fishing is largely by purse seining but about a third of the catch is made by beach seining, a method which reportedly produces superior bait.

Table 9.—Baiting areas for anchovy in Japan (Katsuo-Maguro Nenkan 1971).

Prefecture	Baiting areas
Iwate	Miyako, Yamada, Tanohama, Oozuchi, Ofunato, Hirota, Ohno, Takada
Miyagi	Kesennuma, Shizukawa, Takenoura, Onagawa, Sameura, Makinohama, Momoura, Koamigura
Chiba	Tateyama, Tomiura, Katsuyama, Hoda, Kisarazu
Kanagawa	Koajiro, Shimoura, Sajima, Hayama
Shizuoka	Ajiro, Usami, Tago, Mito, Heda, Enoura
Mie	Goza, Hamajima, Shukutaso, Kamimae, Shiroura, Sugari, Mikiura, Nagashima
Wakayama	Kushimoto, Tanabe
Kochi	Asakawa, Shukumo
Ehime	Uwajima
Oita	Tsukumi, Saeki
Miyazaki	Takashima
Saga	Imari
Nagasaki	Sasebo, Imafuku, Hatashita, Takashima, Higashihama, Omodaka, Tawaragaura, Nakura
Kumamoto	Ushibuka, Miyaura, Yokoura
Kagoshima	Ooneshime, Furue, Umigata, Sakurajima, Yamakawa, Oura

Catch and Baiting Effort

Data on the amount of anchovy caught and sold as live bait may be found in the Annual Report of Catch Statistics on Fishing and Aquiculture ([Japan.] Ministry of Agriculture and Forestry, 1958-62, 1964-73). There are, however, no statistical data on the amount of effort expended in catching bait.

Japanese pole-and-line vessels usually purchase bait from bait fishermen. It has been estimated that roughly 10% of the anchovy catch in Japan is actually marketed for use as live bait (Katsuo-Maguro Nenkan 1971). Data on total catch of anchovy and the amount of anchovy sold as live bait in three principal regions of Japan show that in 1968, out of a total catch of 225,348 t of anchovy, 24,027 t or 10.7% was sold as live bait.

In 1957-71, the catch of anchovy as live bait varied from 14,915 t in 1964 to 27,568 t in 1965 (Table 3). The average amount of anchovy sold as live bait annually was 19,103 t.

Although the amount of anchovy sold as live bait is reported in metric tons, the actual unit of measurement that the bait fishermen use in selling bait is the bucket. As in Hawaii, the amount of bait per bucket is quite variable. For example, the bucket in the Kanto (central Japan) baiting areas holds an average of 3.4 kg of baitfish whereas that in the Sanriku (north of Ibaragi Prefecture including the Tohoku area) and the Shikoku-Kyushu areas averages 6-7 kg or more of baitfish. In order to compare bait production from the eastern and western

Pacific, we converted the eastern Pacific catches to metric tons, using 3.6 kg of bait per scoop. The average annual eastern Pacific catch of live bait during the period when bait boats dominated the fishery (1946-59) was 11,760 t, roughly two-thirds of the Japanese bait production.

LANDINGS OF TUNA

The estimated landings of yellowfin and skipjack tunas by bait boats in the eastern Pacific are shown in Figure 5. These estimates were obtained by using the data on the percentage of the total landings made by bait boats as given in the annual reports of the IATTC and the California landings data provided by Frey (1971). The most striking feature of Figure 5 is the sudden drop in the landings of both species starting in 1959. This sudden decline was caused, of course, by the conversion of a large number of the bait boats to purse seiners. It can be seen that, during the period from 1950 to 1958, the bait boats landed between about 37,000 and 68,000 t of yellowfin tuna and 33,000 and 62,000 t of skipjack tuna. In more recent years the bait boat landings have stabilized at a low level with only small fluctuations.

The landings of tuna in the Japanese pole-and-line fishery from 1958 to 1971 are shown in Figure 6. The category "others" in this figure includes yellowfin, bigeye, and bluefin, *Thunnus thynnus*, tunas; and frigate mackerels, *Auxis*. The Japanese pole-and-line fishery appears to be stabilized in that there are no apparent upward or downward trends in the landings. Skipjack tuna landings fluctuated from 70,428 to 212,985 t during this period. The landings of albacore varied between a low of 8,729 and a high of 52,957 t. The landings of other tunas ranged from 9,081 to 28,342 t.

The Hawaiian pole-and-line fishery also did not show any positive or negative trends (Fig. 7). The landings ranged from a low of 2,679 to a high of 7,329 t during the period from 1950 to 1972.

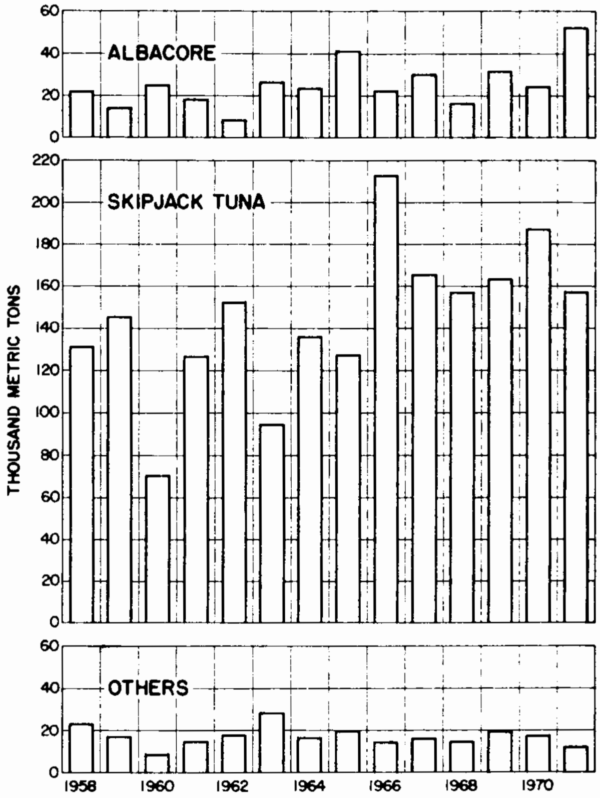

Figure 6.—Landings of tuna in the Japanese pole-and-line fishery.

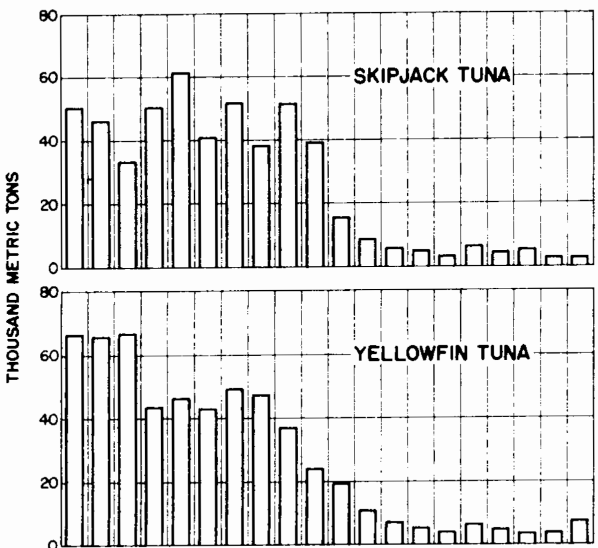

Figure 5.—Estimated landings of yellowfin and skipjack tunas by California-based bait boats in the eastern Pacific fishery.

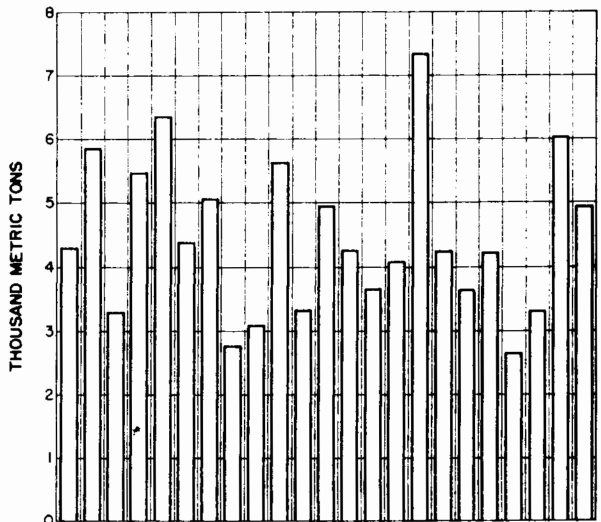

Figure 7.—Landings of skipjack tuna in the Hawaiian pole-and-line fishery.

RELATION OF LANDINGS TO FLEET SIZE

It is interesting to determine, roughly, how the total landings are related to number of boats and to catch per boat, especially in the eastern Pacific where a large number of bait boats were converted to purse seiners. The combined total catch of yellowfin and skipjack tunas, the number of bait boats, and the catch per boat in the eastern Pacific are shown in Figure 8. As noted earlier the conversion of bait boats to purse seiners caused a decline in the number of bait boats in the eastern Pacific tuna fleet. This resulted directly in a decline in the total landings of tuna by the bait boats and also a decline in the mean catch per boat, probably related to the resultant size composition of the bait boat fleet after the mass conversion. It has been shown in the eastern Pacific fishery for tunas that the success of fishing is related to vessel size, the larger vessels being the more efficient (Shimada and Schaefer 1956). Recent data in the annual reports of the IATTC on the size composition of the bait boat fleet show very few boats larger than 182 t (200 short tons) capacity after 1959 (Table 10). Therefore it appears that the eastern Pacific bait boat fleet has been reduced not only in number but also in efficiency.

Similar data on the total catch of tuna, number of boats, and the catch per boat from 1958 to 1971 in the Japanese pole-and-line fishery are shown in Figure 9. The total catch includes all the tunas taken by pole and line and the boats include only those larger than 20 t. Live-bait boats smaller than 20 t number in the thousands but these vessels primarily catch frigate mackerel and contribute only a small amount to the skipjack tuna and albacore landings (Van Campen 1960).

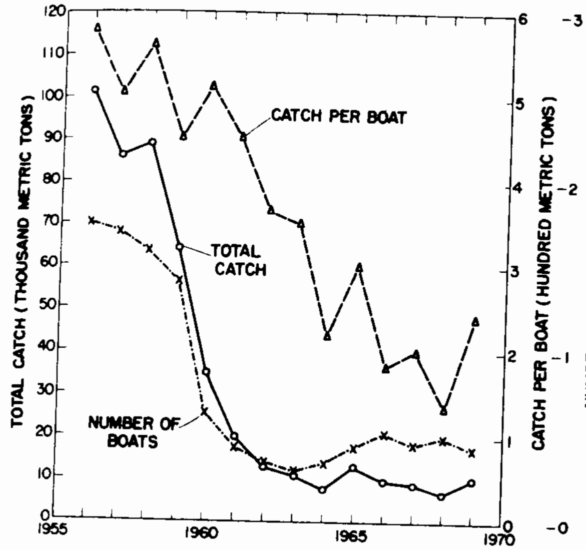

Figure 8.—Total catch of yellowfin and skipjack tunas, number of bait boats, and catch per boat in the eastern Pacific pole-and-line fishery.

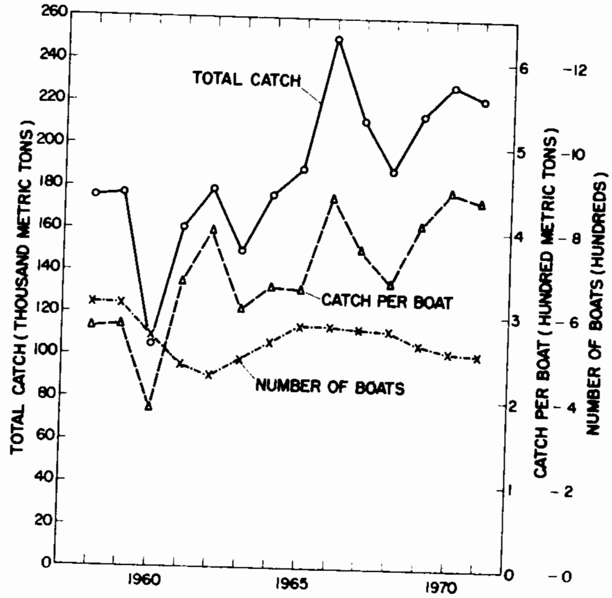

Figure 9.—Total catch of tunas, number of boats, and catch per boat in the Japanese pole-and-line fishery. (Original data from [Japan.] Ministry of Agriculture and Forestry. Statistics and Survey Division, 1960-1973.)

Table 10.—The number of bait boats based in U.S. ports (including Puerto Rico) in the pole-and-line fishery in the eastern Pacific (from IATTC 1961, 1966, 1971).

Year	Capacity in metric tons and short tons (in parentheses)						Total
	<46.4 (51)	46.4-90.9 (51-100)	91.8-181.8 (101-200)	182.7-272.7 (201-300)	273.6-363.6 (301-400)	364.5 (≥ 401)	
1956	12	11	43	66	32	11	175
1957	11	11	43	60	35	10	170
1958	12	8	35	56	36	11	158
1959	13	8	31	46	33	10	141
1960	10	7	21	11	17	3	69
1961	11	4	17	1	11	0	44
1962	13	4	12	1	6	0	36
1963	13	4	11	2	0	0	30
1964	16	5	11	2	1	0	35
1965	21	7	12	3	1	0	44
1966	25	9	11	5	2	0	52
1967	21	9	10	4	2	0	46
1968	23	11	10	4	2	0	50
1969	17	12	9	4	1	0	43

Because catches of boats smaller than 20 t, but not number of boats, were included in the computations, the catches per boat as shown in Figure 9 are probably higher than the actual catches. However, this should not mask any trends that may be present.

The number of boats in the Japanese pole-and-line fishery has fluctuated between 451 and 623 from 1958 to 1971. Although, as it was pointed out earlier, there was no trend apparent in the landings of the various tuna species, it appears that the total tuna landings are increasing. The catch per boat also appears to be on a slight upward trend. There has been a change in the size composition of the Japanese pole-and-line fleet in that since 1967 the number of vessels in the 200- to 500-t class has been increasing (Table 11). If size is also related to efficiency in the Japanese pole-and-line fishery, then the increase in the catch per boat could be accounted for by the increasing number of larger boats in the fleet.

The number of boats in the Hawaiian pole-and-line fishery has been declining steadily since 1950 (Fig. 10). It is interesting that in spite of this the landings have not declined correspondingly. The catch per boat showed large annual fluctuations, but appeared to be at a higher level after 1963 than before. Except for the addition of one new vessel in December 1971, the composition of the Hawaiian fleet has remained unchanged for many years. Thus, although the new addition to the Hawaiian fleet is a larger vessel with a greater fish-carrying capacity and range than the average Hawaiian boat, this fact alone cannot account for the apparent increase in efficiency. Among other things, a change in fishing techniques has been suggested as a factor in the improved efficiency of Hawaiian pole-and-line vessels (Uchida 1967).

Table 11.—The number of pole-and-line boats in various size categories (metric tons) in the Japanese fishery (from [Japan.] Ministry of Agriculture and Forestry 1959-62, 1964-73).

Year	20-30	30-50	50-100	100-200	200-500	>500	Total
1958	19	68	239	273	24	—	623
1959	18	80	234	262	26	—	620
1960	11	98	179	229	28	—	545
1961	19	122	132	178	26	—	477
1962	13	173	111	126	28	—	451
1963	33	207	111	112	29	—	492
1964	40	251	103	106	32	—	532
1965	14	284	91	148	35	—	572
1966	14	285	71	167	34	—	571
1967	12	284	54	173	41	—	564
1968	5	271	60	170	54	1	561
1969	4	244	71	156	53	—	528
1970	2	218	91	140	61	—	512
1971	2	163	133	129	83	—	510

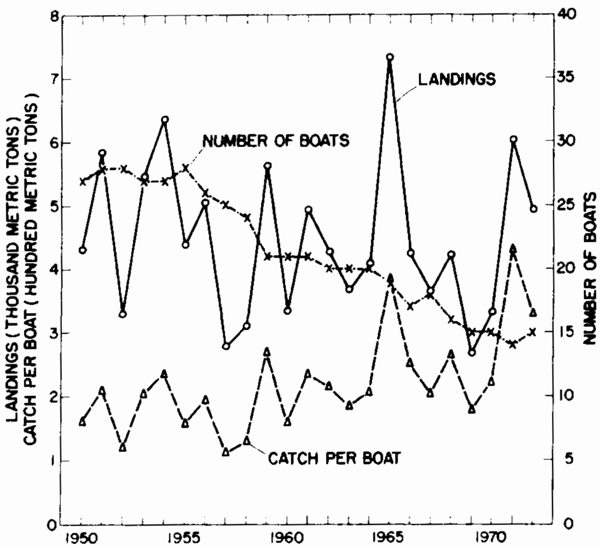

Figure 10.—Landings of skipjack tuna, number of boats, and catch per boat in the Hawaiian pole-and-line fishery. (Original data from Hawaii Division of Fish and Game.)

BAIT AND TUNA CATCHES

The catch of tuna and the amount of bait used in the Japanese pole-and-line fishery from 1957 to 1971 are shown in Table 12. Although skipjack tuna and albacore are the most important species of tuna caught in the pole-and-line fishery, as noted earlier appreciable amounts of other species are also taken with live bait. These include frigate mackerel and bluefin, bigeye, and yellowfin tunas (listed under "others" in Table 12). In analyzing the relative effectiveness of the Japanese anchovy in the pole-and-line fishery the total catch of all species should be considered. This must be done because although the statistics published by the Japanese Government lists all the species caught by the pole-and-line method, no breakdown is given on the amount of bait expended to catch each species. In addition to the tunas, species of mackerel are actively fished with live bait and pole and line. These catches will not be included in the discussion, but it should be borne in mind

Table 12.—Catch of tunas and bait (metric tons) in the Japanese pole-and-line fishery (from [Japan.] Ministry of Agriculture and Forestry, Statistics and Survey Division 1958-62, 1964-73.)

Year	Skipjack tuna	Albacore	Others[1]	Total	Japanese anchovy[2]	Tuna catch per unit of bait
1957	92,156	49,500	20,675	162,331	18,468	8.8
1958	131,441	22,190	22,778	176,409	18,109	9.7
1959	145,447	14,252	17,058	176,757	16,304	10.8
1960	70,428	25,156	9,081	104,665	15,916	6.6
1961	127,011	18,636	14,914	160,561	15,604	10.3
1962	152,387	8,729	18,111	179,227	18,526	9.7
1963	94,757	26,420	28,342	149,519	16,067	9.3
1964	136,081	23,858	16,827	176,766	14,915	11.8
1965	127,436	41,491	19,821	188,748	27,568	6.8
1966	212,985	22,830	14,718	250,533	22,262	11.2
1967	165,492	30,481	16,431	212,404	18,320	11.6
1968	157,340	16,597	15,021	188,958	20,771	9.1
1969	163,455	31,912	19,641	215,008	21,606	10.0
1970	187,438	24,263	17,391	229,092	21,264	10.8
1971	157,380	52,957	12,327	222,664	20,848	10.7
Total				2,793,642	286,548	
n				15	15	
Mean				186,243	19,103	9.7

[1] Includes *Auxis*, bluefin, bigeye, and yellowfin tunas.
[2] *Engraulis japonicus*.

that an undetermined amount of bait and effort is expended towards the catch of these nontuna species.

The total landings of tuna from 1957 to 1971 in the Japanese pole-and-line fishery ranged from 104,665 to 250,533 t with an expenditure of 14,915 to 22,262 t of bait. The tuna catch per unit of bait (CPUB) ranged from 6.6 to 11.8 t per metric ton of bait. The mean values for the 14-yr period were 186,243 t for the total annual catch of tuna, 19,103 t for the annual catch of anchovy, and 9.7 t of tuna per metric ton of bait for the mean annual CPUB.

Table 13 gives the estimated landings of skipjack and yellowfin tunas and the amount of bait caught from 1950 to 1969 by bait boats based in California ports. The bait data were given in terms of "scoops" in the IATTC annual reports, and these were converted to metric tons.

The total bait boat landings of skipjack and yellowfin tunas ranged from 6,811 to 117,369 t and averaged 54,602 t. The total bait catch ranged from 813 to 16,138 t and averaged 7,304 t. The CPUB of yellowfin and skipjack tunas ranged from 5.5 to 12.2 t per metric ton of bait and averaged 7.5 t per metric ton of bait.

As noted earlier, several different species of fish are used as bait in the eastern Pacific bait boat fishery. However, there is nothing in the literature on a comparison of the relative effectiveness of the various species of bait used in this fishery. Although figures are available on the catch of baitfishes by species (Table 1), no figures are available on the catch of tunas by the use of the various species of bait. Thus the CPUB figures given in Table 13 are based on the total catch of all species of bait.

The catch of skipjack tuna and the amount of bait caught from 1950 to 1972 in Hawaii are given in Table 14. The bait catch statistics provided by the Hawaii Division of Fish and Game, which are given in terms of buckets, were converted to metric tons using a factor of 5.4 kg (12 lb) per bucket. In the past, the bucket was assumed to be equivalent to about 3.2 kg (7 lb) of fish (Yamashita 1958). However, more recent data indicate that this figure is an underestimate (T. S. Hida, Southwest Fisheries Center, Honolulu, HI 96812, pers. commun.).

The skipjack tuna catch ranged from 2,679 to 7,324 t from 1950 to 1972. The catch of bait ranged from 124 to 270 t and the skipjack tuna CPUB ranged from 16.3 to 37.0 t per metric ton of bait. The mean values were 4,478 t of skipjack tuna, 194 t of bait, and 17.2 t of skipjack tuna per metric ton of bait.

The relative effectiveness of the bait used in these fisheries in terms of CPUB is summarized in Table 15. It can be seen that the mean annual CPUB for the Hawaiian fishery at 23.1 was higher than the Japanese and eastern Pacific fisheries. In terms of the CPUB then, the Hawaiian pole-and-line fishery is 3.1 times more efficient than the eastern Pacific fishery and 2.3 times more efficient than the Japanese fishery.

Table 13.—Estimated landings (metric tons) of yellowfin and skipjack tunas by bait boats based in California ports.

Year	Landings: Yellowfin tuna	Landings: Skipjack tuna	Total	Catch bait	Tuna catch per unit of bait
1950	66,655	50,714	117,369	12,956	9.0
1951	66,000	46,626	112,626	9,766	11.5
1952	67,018	33,435	100,453	15,492	6.5
1953	43,797	50,374	94,171	15,782	6.0
1954	46,524	61,235	107,759	14,251	7.6
1955	43,157	41,041	84,198	9,384	9.0
1956	49,363	51,940	101,303	13,257	7.6
1957	47,524	38,403	85,927	13,453	6.4
1958	37,173	51,511	88,684	16,138	5.5
1959	24,332	39,215	63,547	10,814	5.9
1960	19,664	15,690	35,354	4,329	8.2
1961	10,965	8,900	19,865	2,359	8.4
1962	7,257	5,972	13,229	1,502	8.8
1963	5,468	5,215	10,683	874	12.2
1964	3,988	3,656	7,644	813	9.4
1965	6,604	6,649	13,253	1,118	11.8
1966	4,812	4,728	9,540	1,031	9.2
1967	3,692	5,587	9,279	864	10.7
1968	3,748	3,063	6,811	983	6.9
1969	7,409	2,936	10,345	904	11.4

Table 14.—Catch of nehu and skipjack tuna (metric tons) in the Hawaiian pole-and-line fishery.[1]

Year	Nehu catch	Skipjack tuna catch	Skipjack tuna catch in metric tons per metric ton of nehu
1950	216	4,312	20.0
1951	220	5,863	26.6
1952	162	3,308	20.4
1953	205	5,470	27.1
1954	238	6,360	26.7
1955	270	4,397	16.3
1956	222	5,050	22.7
1957	167	2,781	16.6
1958	181	3,100	17.1
1959	205	5,631	27.5
1960	124	3,338	26.0
1961	202	4,942	24.3
1962	186	4,271	22.7
1963	178	3,674	20.6
1964	166	4,093	23.5
1965	198	7,329	37.0
1966	172	4,257	24.8
1967	173	3,647	21.0
1968	193	4,228	21.9
1969	164	2,679	16.3
1970	183	3,314	18.2
1971	229	6,023	26.3
1972	212	4,930	23.1

[1]Original data courtesy Hawaii Division of Fish and Game.

Table 15.—The relative effectiveness of live bait used in the eastern Pacific, Japanese, and Hawaiian pole-and-line fisheries.

Area and period	Mean annual catch of tuna (metric tons)	Mean annual catch of bait (metric tons)	Mean annual catch of tuna per unit of bait (metric tons)
Eastern Pacific (1950-69)	54,602	7,304	7.5
Japan (1957-71)	186,243	19,103	9.7
Hawaii (1950-72)	4,478	194	23.1

FACTORS AFFECTING CPUB

The CPUB in terms of the weight of tuna caught in a pole-and-line fishery can be affected by many variables including the size and species of fish caught, the number of men fishing, the number of fish in a unit weight of bait, and, less directly, the apparent abundance of the fish caught.

The size of the fish would affect the CPUB in that, assuming that fish up to a certain maximum size, i.e., one-pole size fish, are caught at the same rate, the catch in weight would be greater if the fish caught were larger. If the fish are so large as to require a two-pole rig, then the effective fishing power would be reduced because it would require two men to bring in one fish. However, it may happen that the fish are large enough to balance out or even exceed the difference caused by the loss of fishing power in using a two-pole rig. In the eastern Pacific fishery, one pole is used on fish up to 13.6 kg (30 lb). For fish from 13.6 to 27.2 kg (30 to 60 lb) two-pole rigs are used. With fish larger than 27.2 kg, a three-pole rig is used (Godsil 1938). In the Japanese pole-and-line fishery albacore fishing is done with two-pole rigs and one-pole rigs are used on skipjack tuna (Van Campen 1960).

Another important variable affecting the CPUB is the number of fish in a unit weight of bait. Obviously, the size of the fish will affect the number in a unit weight of bait: the larger the fish, the fewer per unit. Presumably, the greater the number of fish per unit weight of bait, the greater would be the "fishing power." The length-frequency distribution of the baitfishes used in the three fisheries is shown in Figure 11. For the eastern Pacific fishery, the length distribution of two of the more important baitfishes, the anchoveta and the northern anchovy, is shown. If it is assumed that these size distributions are representative of the bait in the three fisheries, it can be seen that the bait used in the Hawaiian fishery is generally the smallest and that used in the eastern Pacific the largest. The Japanese anchovy is intermediate in size between the Hawaiian and the eastern Pacific baitfishes. It can be deduced, then, that the fishing power of a unit weight of bait in the Hawaiian fishery is greater than that in the eastern Pacific and Japanese pole-and-line fisheries.

Finally, the apparent abundance of the tunas in any one year may have an influence on the mean annual

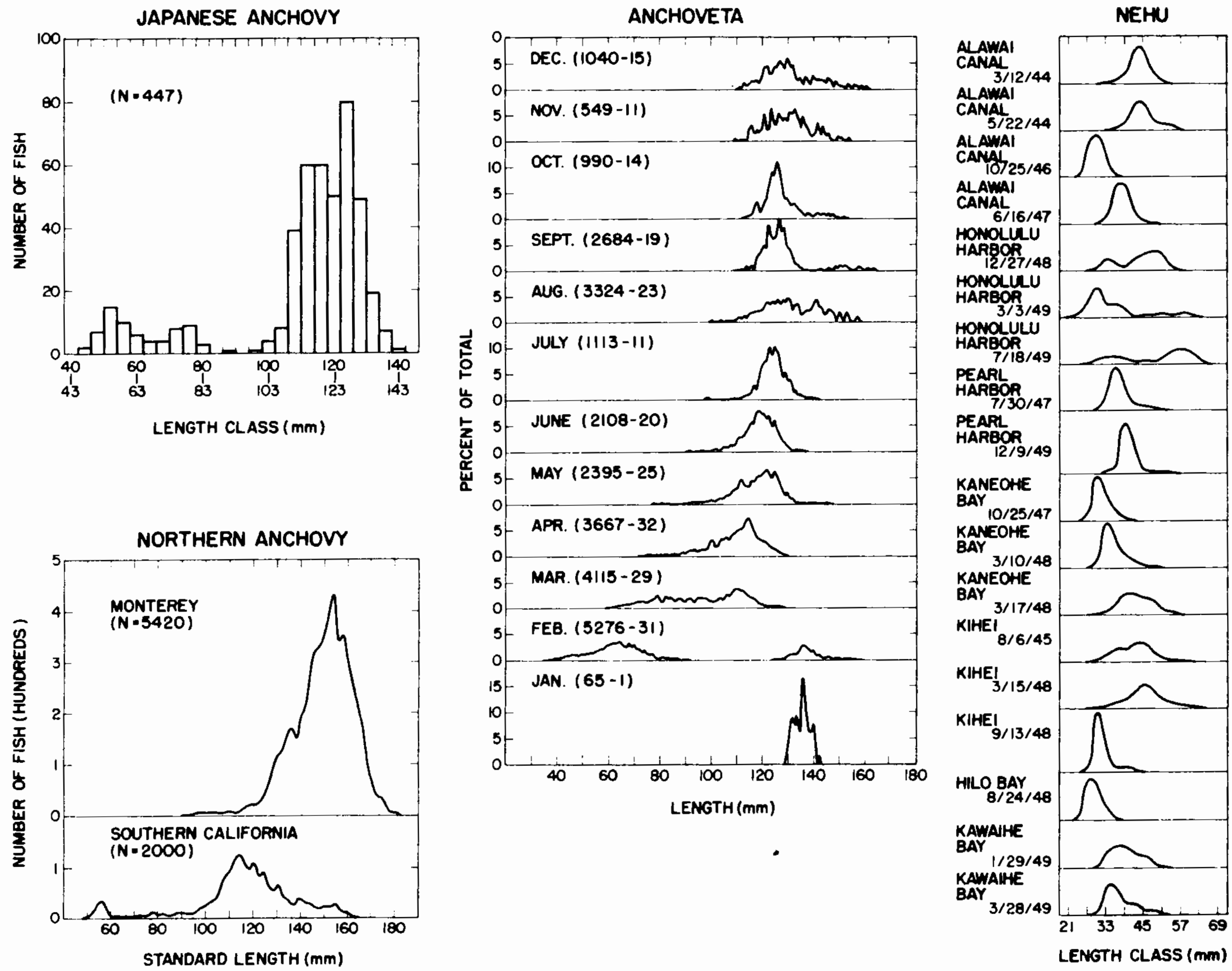

Figure 11.—Length-frequency distribution of Japanese anchovy, anchoveta, northern anchovy, and nehu. (From Clark and Phillips 1952; Tester and Hiatt 1952; Mie Prefectural Fisheries Experiment Station 1953; Howard and Landa 1958.)

CPUB: if the apparent abundance is higher, it may be expected that the mean annual CPUB will be greater. Figure 12 shows the relation between the mean annual CPUB and the mean annual apparent abundance for skipjack tuna in the Hawaiian fishery, and Figure 13 shows the mean annual CPUB and the mean annual apparent abundance of yellowfin and skipjack tunas in the eastern Pacific fishery. For the eastern Pacific figure, the apparent abundance is expressed in terms of the mean catch of yellowfin and skipjack tunas per day's fishing. The data for 1950-58 are based only on bait boat operations and the data for 1959-69 are means based on bait boat and purse seiner operations. The basic data were taken from the annual reports of the IATTC.

For the Hawaiian pole-and-line fishery figure, apparent abundance is simply represented by the total annual catch. Uchida (1967) found that the apparent abundance of skipjack tuna expressed as the catch per standard effective trip was correlated with the total catch of skipjack tuna from 1952 to 1962. He stated, therefore, that the total catch may be used as an index of apparent abundance during 1952-62. Although he cautioned against the use of the total catch as an index of apparent abundance for other years, we assumed that it was reliable for other years also.

It can be seen that CPUB was positively related to the apparent abundance of tuna in the eastern Pacific and the Hawaiian fisheries. In years when the apparent abundance was high the CPUB was also high. The coefficient of correlation was computed for the data for both fisheries. The results (eastern Pacific fishery, r = 0.556; df = 19; P<0.01; Hawaiian fishery, r = 0.839; df = 22; P<0.01) indicated that the mean annual CPUB was highly correlated with the apparent abundance of tuna.

Higgins (1966) examined the size distribution of the various tunas caught in the Pacific and noted fundamental differences in the sizes caught in the different areas. For example, he noted that larger skipjack tuna are caught around the Hawaiian Islands than in the eastern Pacific or near Japan. Obviously, it would be expected that differences in size would exist among the different species of tuna. The albacore caught by pole and line in the Japanese fishery are larger than the skipjack tuna caught by the same method. The yellowfin tuna taken by pole and line in the eastern Pacific are larger than the skipjack tuna. Thus CPUB is not only influenced by differences in sizes within the same species among the different fisheries, but also by the species of fish taken.

The number of men fishing per unit of bait expended also affects the CPUB. In the eastern Pacific fishery the size of the crew on a bait boat ranged from 12 to 20 men (Godsil 1938). The average number of crewmen on a Japanese pole-and-line boat ranged from 29 on 20- to 50-ton boats to 54 on 100- to 200-ton boats (Van Campen 1960). In the Hawaiian pole-and-line fishery from 1950 to 1960, Uchida (1967) indicated that, depending on the size of the vessel, an average of 6.7 to 10.4 fishermen fished on each trip. However, the relation between the number of men fishing and the amount of bait expended is not very clear. Generally, it is likely that more men fishing would require a greater use of bait. In the Japanese pole-and-line fishery bait is chummed at the stern, amidships, and forward (Van Campen 1960). In the eastern Pacific fishery, the smaller boats have one chummer and the larger ones usually have two (Godsil 1938). The Hawaiian pole-and-line boats usually have only one chummer.

SUMMARY

This report reviews the pole-and-line and live-bait fisheries of the eastern, central, and western Pacific Ocean including historical catch and effort statistics on

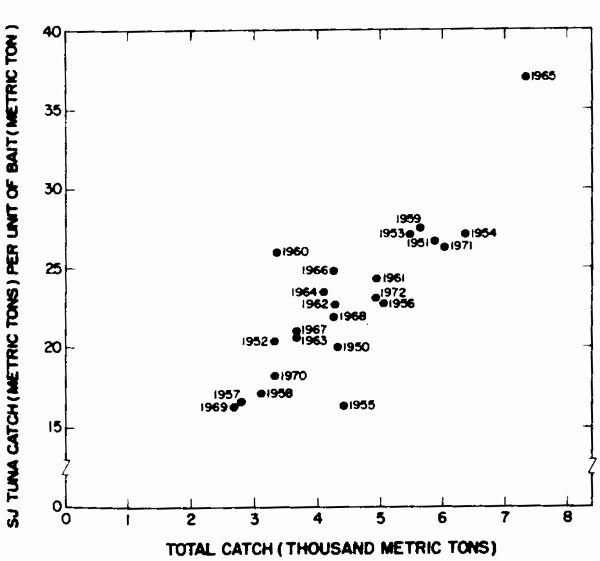

Figure 12.—Relation between total catch of skipjack tuna and catch per unit of bait in the Hawaiian pole-and-line fishery, 1950-72.

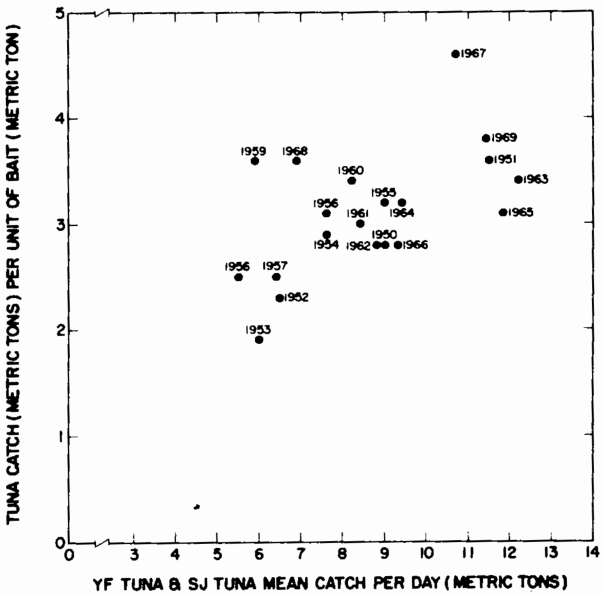

Figure 13.—Relation between the mean apparent abundance (catch per day's fishing) of yellowfin tuna and skipjack tuna and the catch per unit of bait in the eastern Pacific, 1951-69.

the fisheries for tuna baitfishes. Included in the report are comparisons on the relative effectiveness of the live bait used in the fisheries and a discussion of the factors that may contribute to the relative effectiveness.

Although the eastern Pacific fishery for yellowfin and skipjack tunas is now dominated by the purse seiners, bait boats are still active in that fishery. In Japan, the pole-and-line technique of catching albacore and skipjack tuna is still one of the important methods of fishing for tuna. And in Hawaii, the pole-and-line fishery for skipjack tuna is the most important fishery in the State.

In the Japanese pole-and-line fishery, the Japanese anchovy, *Engraulis japonicus*, is the most important bait species used. The more important bait species utilized in the eastern Pacific fishery are anchoveta, *Cetengraulis mysticetus*, northern anchovy, *E. mordax*, California sardine, *Sardinops caerulea*, Galapagos sardine, *S. sagax*, and southern anchovy, *E. ringens*. The Hawaiian skipjack tuna fishermen primarily use an anchovy called nehu, *Stolephorus purpureus*.

In the eastern Pacific it was seen that landings of yellowfin and skipjack tunas by the bait boats dropped suddenly starting in 1959 owing largely to the reduced number of bait boats in the fleet following the conversion of many of them to purse seiners. It was also seen that there was a downward trend in the catch per boat, which was attributed to a reduction in efficiency of the remaining bait boat fleet.

Landings of tuna by species in Japan did not show any important trends, although the total catch of all tuna species combined appeared to be increasing. The catch per boat also appeared to be on a slight upward trend. A change in the composition of the fleet by the addition of larger vessels may have contributed to the increasing catch per boat.

Landings of skipjack tuna in the Hawaiian pole-and-line fishery did not show any significant trends. However, the number of boats in the fleet has been steadily declining since 1950. The fact that the landings did not decline correspondingly suggested an improved efficiency in the operation of the Hawaiian pole-and-line fleet.

In terms of tuna catch per unit of bait, the Hawaiian fishery appeared to be the most efficient among the three tuna fisheries considered. Catch per unit of bait, however, is affected by many variables including size of tuna, number of men fishing, the number of fish in a unit weight of bait, and the apparent abundance of tuna.

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Catch Statistics and Abundance of Nehu, *Stolephorus purpureus*, in Kaneohe Bay

JERRY A. WETHERALL[1]

ABSTRACT

Catch and nominal effort statistics from the Kaneohe Bay day-baiting fishery for nehu, *Stolephorus purpureus*, were used to explore hypotheses concerning two sources of variation in baiting success: 1) nehu stock abundance, and 2) abiotic environmental variables. Baiting success was found to be positively correlated with streamflow in a major tributary to Kaneohe Bay, but was unrelated to nominal baiting effort. However, the assumptions underpinning the analyses cannot be accepted with confidence, because the available nominal effort data do not provide a good measure of effective baiting effort. A definitive understanding of nebu stock dynamics will require changes in data collection practices of the Hawaii Division of Fish and Game. In particular, detailed information on catch per set of the bait seine and on size composition of the nehu stock and catch are needed.

INTRODUCTION

The high cost of acquiring bait from the natural stocks of nehu, *Stolephorus purpureus*, has been a major obstacle to the full development of Hawaii's fishery for skipjack tuna, *Katsuwonus pelamis*. Accordingly, it has stimulated government research programs spanning a quarter of a century, seeking to develop cheaper and more reliable substitutes.

Successful creation of alternative bait supplies requires a two-pronged research effort: 1) technical development of new bait sources at unit costs permitting substitution, and 2) practical demonstration of the effectiveness of new baits and building of confidence in their use among skipjack tuna fishermen. Current status reports on research related to several alternative bait substitution schemes are presented elsewhere in this publication. Until effective substitutes are developed, skipjack tuna fishermen will continue to favor the traditional baiting practices and abundance of nehu will be of central concern to the fishing industry.

One concern is apt to be that baiting success or nehu abundance is affected by fishing pressure. The question of overfishing of Oahu nehu stocks was posed early by Hiatt and Tester (1950),[2] but the data available to them did not permit a conclusive study. Even now, details of nehu population dynamics are largely unknown, and the customary approach to nehu stock assessment has been to study an index of abundance, such as catch per unit of fishing effort. This was done by Bachman (1963), who examined the relationship between average catch per day of baiting and the number of days of baiting for several nehu fisheries, using data covering the period from 1948 through 1960. He found no evidence that fishing had diminished the stocks.

In this paper I will summarize the results of some analyses similar to Bachman's which I conducted recently. I will first show that the available unit of nominal fishing effort is probably not a good measure of effective effort, i.e., not proportional to the fishing mortality it generates. In particular, fluctuations in effective fishing effort over a wide range are severely dampened in construction of the catch per nominal effort statistics.

With the shortcomings of the available data clearly in mind, I will explore two analyses using catch statistics from the day fishery of Kaneohe Bay, one of the key baiting grounds of the Hawaii skipjack tuna fleet. The first analysis assumes that the catch of nehu per day of baiting effort is proportional to nehu abundance, and the second assumes that abundance of nehu is relatively constant and that variations in the catch per day reflect changes in catchability or availability of nehu. Results of both analyses should be viewed circumspectly.

CONSTRUCTING AN INDEX OF ABUNDANCE

For the Kaneohe Bay baiting operations, records of nehu catch (in buckets) for each trip to the baiting grounds are available. During a baiting session a boat may make as many as 10 sets of its seine before sufficient nehu are captured to support a trip for skipjack tuna. When nehu are abundant one set may be enough.

If we assume that availability of nehu and effectiveness of the fishing operation (catchability) are constant, a good measure of abundance might be the average catch per set. Unfortunately the number of sets is not recorded. The best one can do is to calculate a provisional index of abundance as the average catch of nehu per "day" of fishing, i.e., per trip to the baiting grounds.

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[1] Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

[2] Hiatt, R., and A. Tester. 1950. The supply of nehu. Univ. Hawaii, Mar. Lab. News Circ. 6, 3 p. [Processed.]

Separate records are available for each boat in the fleet. Four vessels, about one-third of the fleet, had fairly continuous records from 1966 to 1972. Data for the analyses were taken from these four boats. One of the vessels was selected as a standard boat, and the fishing power of each vessel relative to the standard was estimated. The average standardized catch of nehu per day of baiting (CPU) was then computed on a monthly basis, giving an 84-mo sequence.

The Hawaii Division of Fish and Game records for Kaneohe Bay also give the catch of nehu taken in the night-light operations and by users other than skipjack tuna fishermen. Thus, estimates of the total monthly nehu harvest for the Bay are available. These figures were divided by the standard index of nehu abundance to give estimates of total fishing effort, measured in standard boat days (Tables 1, 2; Fig. 1).

A major difficulty in using CPU as a measure of abundance is that skipjack tuna boats generally stay on the baiting grounds until a certain quantity of nehu is captured. This amount is determined largely by the capacity of the vessel's baitwells. A demonstration of this is given in Figure 2, for the four selected vessels, where relative fishing power or catch per day is plotted against average baitwell capacity. This shows clearly that the

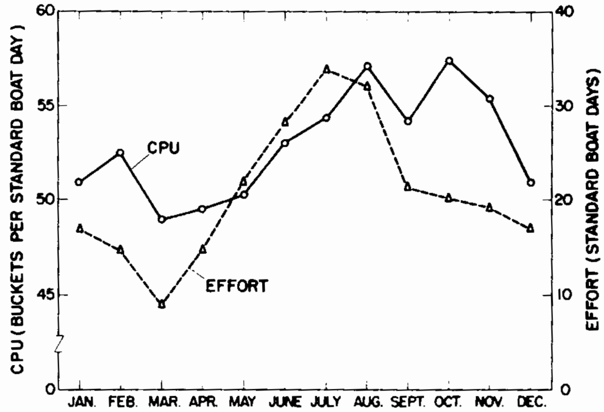

Figure 1.—Monthly average of CPU and effort, computed over 7-yr period (1966-72), for Kaneohe Bay nehu.

average catch per day is not a particularly good index of abundance, even if the number of sets per day does not vary.

During periods when nehu are abundant, the boats will easily fill their baitwells in a trip to the Bay, and the index of abundance will be truncated. Figure 3 shows the relationship between the index of abundance and abun-

Table 1.—Average catch rate of Kaneohe Bay nehu, in buckets per standard boat day, 1966-72.

	Year							
Month	1966	1967	1968	1969	1970	1971	1972	Mean
Jan.	48.57	57.60	56.37	39.96	56.42	50.10	47.39	50.92
Feb.	50.73	65.67	53.94	42.78	47.96	53.27	52.61	52.42
Mar.	55.23	49.97	37.53	51.16	46.66	51.16	50.65	48.91
Apr.	50.82	43.41	54.16	44.91	52.10	53.03	48.01	49.49
May	52.55	45.18	55.65	58.02	47.57	42.88	50.03	50.27
June	48.55	54.90	56.84	51.45	51.64	49.48	58.34	53.03
July	52.88	58.64	56.56	65.11	59.91	34.78	52.57	54.35
Aug.	57.48	57.65	53.81	58.66	61.23	50.95	59.83	57.09
Sept.	56.55	62.14	35.27	62.83	54.79	51.79	55.84	54.17
Oct.	59.03	60.41	49.84	64.42	54.18	55.92	58.04	57.40
Nov.	57.75	59.16	57.20	58.09	47.72	49.38	58.64	55.42
Dec.	62.33	50.75	33.05	57.75	47.42	50.00	55.25	50.94
Mean	54.37	55.46	50.02	54.60	52.30	49.40	53.93	52.87

Table 2.—Average baiting effort in standard boat days, Kaneohe Bay, 1966-72.

	Year							
Month	1966	1967	1968	1969	1970	1971	1972	Mean
Jan.	9.88	12.08	29.23	24.88	9.59	22.93	9.83	16.92
Feb.	12.77	6.59	17.02	6.68	22.89	23.28	11.20	14.35
Mar.	15.15	11.23	11.94	2.15	14.36	0.59	7.26	8.95
Apr.	16.23	10.94	13.44	7.99	18.77	14.29	18.64	14.33
May	24.05	14.59	22.14	15.03	16.38	37.78	22.90	21.84
June	21.01	22.35	28.74	26.70	32.69	39.59	25.50	28.08
July	36.63	26.75	37.99	22.27	37.19	52.72	23.93	33.92
Aug.	21.68	27.79	45.88	27.29	36.81	25.04	39.88	32.05
Sept.	12.25	14.63	18.32	19.38	36.45	14.67	32.86	21.22
Oct.	19.91	9.73	19.28	24.28	30.34	9.67	27.62	20.12
Nov.	19.72	21.37	26.94	19.73	29.52	2.37	14.70	19.19
Dec.	15.58	26.56	24.05	15.31	17.29	1.68	18.52	17.00
Mean	18.74	17.05	24.58	17.64	25.19	20.38	21.07	20.66

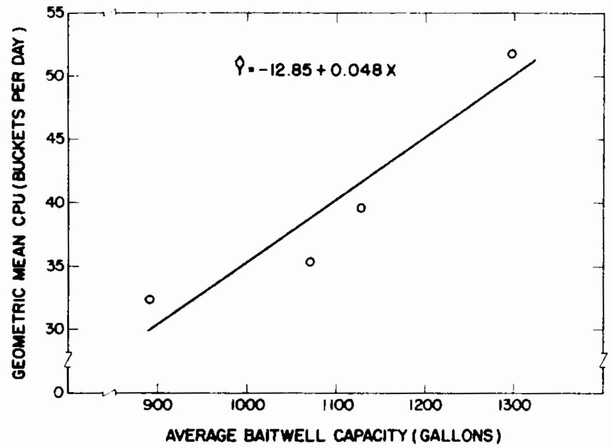

Figure 2.—Relationship between average nehu CPU and baitwell capacity for selected skipjack tuna vessels, Kaneohe Bay.

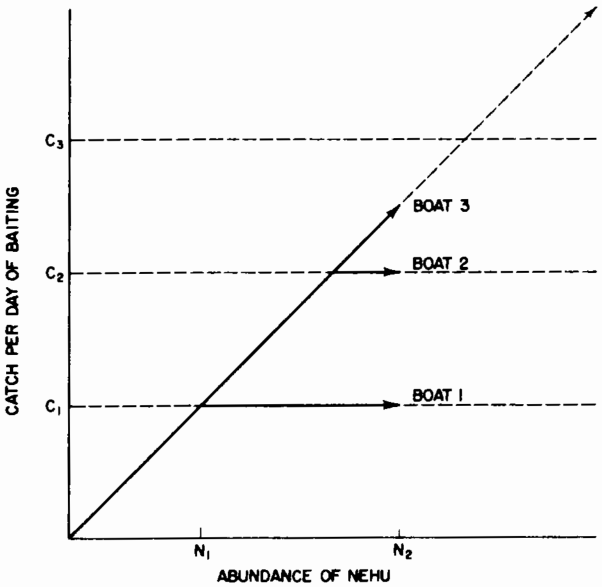

Figure 3.—Catch per day of baiting as a function of nehu abundance for hypothetical vessels with different baitwell capacities (C_1, C_2, C_3).

dance, where there are three vessels with varying baitwell capacities. In this hypothetical situation the catch per day of all three boats is a good measure of abundance as long as abundance does not exceed N_1. If the abundance increases to N_2, only the boat with the largest baitwell capacity, C_3, will still provide a comparable measure of abundance. All this assumes that the number of sets per day is constant. This is patently unrealistic as long as abundance varies.

Thus it is clear that the average catch per day has at least two serious weaknesses when used as an index of abundance: 1) the number of sets per day varies, there tending to be more sets made when nehu are relatively scarce, and 2) baitwell capacity obviously determines an upper limit to catch per day, and, since the objective is to get a full load of bait if possible, baitwell capacity tends to establish a lower bound to catch per day as well The net result is that the CPU will "underestimate" abundance when nehu are plentiful and "overestimate" it when the fish are scarce.

SOME ANALYSES

It should be recognized at the outset that any analysis of nehu abundance using the CPU rests on a set of assumptions almost certainly violated. In the following exploratory treatments of the data, I put on the blinders and assume that changes in CPU reflect similar changes in abundance of nehu with reasonable fidelity. Catchability and availability are assumed to be constant.

The empirical relationship between CPU and standardized effort was used to indicate the response of the nehu resource to fishing pressure. Since the average age of nehu in the exploited stock is believed to be only a few months, the data were first averaged by quarters of the year, producing a series of 28 points assumed to represent equilibrium conditions. If the assumptions are correct, the relationship (Fig. 4) clearly indicates no significant effect of fishing effort on average nehu abundance, over the effort levels observed. This result, not surprisingly, is the same as Bachman's.

In the analysis just discussed the only factor explicitly set out as a determinant of stock abundance was fishing effort. Effort was regarded as the input to a "black box" production process with CPU (abundance) as output. An alternative approach is to do a regression analysis in which the other factors of production, such as natural mortality and recruitment are also modeled explicitly. We may begin as before by assuming that

$$U_i = q D_i$$

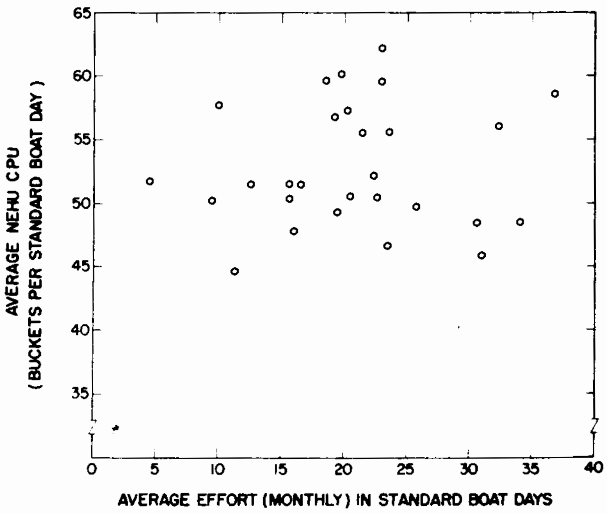

Figure 4.—Relation between quarterly average nehu CPU and standardized effort for the Kaneohe Bay bait fishery, 1966-72.

where U_i = CPU during period (month) i
D_i = average abundance of exploited stock during period i (number of nehu)
q = constant catchability coefficient.

As a first approximation,

$$U_i = U_{i-1} \exp\left\{-\left(M + \frac{f_{i-1} + f_i}{2} q\right)\right\} + q R_i$$
$$= U_{i-1} S \exp\left\{-q\left(\frac{f_{i-1} + f_i}{2}\right)\right\} + q R_i$$

where M = instantaneous natural mortality rate (monthly)
S = monthly survival rate in absence of fishing mortality
f_i = standard units of fishing effort during period i
R_i = average number of newly recruited fish in exploited stock during period i.

The recruitment process may be modeled by a simple Ricker-type function, e.g.,

$$R_i = a D_{i-\delta} \exp\left\{-b D_{i-\delta}\right\}$$

where for nehu we set δ equal to 2 mo. This may be linearized by expanding the exponential in a Taylor series to obtain

$$R_i = a D_{i-2} - \frac{ab}{2} D^2_{i-2} + \ldots$$

Alternatively, R_i may be represented by a more general polynomial in D_{i-2} without a constant term,

$$R_i = \gamma_1 D_{i-2} + \gamma_2 D^2_{i-2} + \gamma_3 D^3_{i-2} + \ldots$$

Further, since fishing mortality is assumed to be insignificant, we let

$$\exp\left\{-q\left(\frac{f_{i-1} + f_i}{2}\right)\right\} \approx 1 - q\left(\frac{f_{i-1} + f_i}{2}\right).$$

Finally, combining these assumptions we have a linear regression model, in the usual notation,

$$Y_i = \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \ldots$$

where $Y_i = U_i$ $\beta_1 = S$
$X_{1i} = U_{i-1}$ $\beta_2 = -qS$
$X_{2i} = U_{i-1}\left(\frac{f_{i-1} + f_i}{2}\right)$ $\beta_3 = \gamma_1$
$X_{3i} = U_{i-2}$ $\beta_4 = \gamma_2$
$X_{4i} = U^2_{i-2}$
.
.
.

This regression model is a nonequilibrium form and was fitted to the monthly CPU data with i = 3, 4, ..., 84. In the recruitment component terms through the fourth degree were allowed. The concoction was fitted using a stepwise regression program. The first term accepted by the stepwise procedure was the natural mortality term. This gave $\hat{S}$ = 0.34 or $\hat{M}$ = 1.07 on a monthly basis. The second term accepted was the first degree recruitment term, with positive sign. Next was the second degree recruitment term with negative sign. Finally came the third degree term with positive sign. As expected, the fishing mortality term was insignificant. So was the fourth degree recruitment term.

The regression model accounted for only 20% of the variation in CPU. Still, the estimates of the coefficients have the proper signs and the estimate of M is consistent with our best guess of the life-span of nehu, judged tentatively to be about 6 mo. Bayliff (1967) studied the relationship between maximum age (Tmax) and instantaneous total mortality rate (Z) for six species of engraulids. On an annual basis his result was Z = 6.384/Tmax. Using this relation for nehu we set Tmax = 0.5 and obtain $\hat{Z}$ = 12.768. Assuming that fishing mortality is negligible ($M \approx Z$) *we have* M = 1.06 on a monthly basis, compared with M = 1.07 from the regression analysis. The astounding correspondence between these estimates must be judged with due regard for the battery of assumptions made in each case. At best we might infer that the CPU data trace the general trend of nehu abundance, but even this conclusion is tenuous.

The preceding analysis was based on the assumption that CPU is proportional to nehu abundance, with catchability and availability constant. An alternative point of departure is to regard abundance as being relatively constant and to assume that variations in CPU are due to fluctuations in catchability or availability. A simple statement of these conditions is

$$U_i = q D A_i$$

where the new symbols are

A_i = overall availability during the ith time period
$= \prod_j A_{ij}$
A_{ij} = availability due to factor j during period i $(0 \le A_{ij} \le 1)$.

Assuming a single availability process is causing variation in CPU, we factor this out (say the kth one) and take logs to obtain

$$\ln U_i = \theta + \ln A_{ik}$$

where $\theta = \ln(q D \prod_{j \neq k} A_{ij})$ = constant.

In the bait fishery of Kaneohe Bay one factor suspected of influencing catchability or availability (it makes no difference in the analysis which process is involved) is turbidity of the water near the mouths of streams where nehu congregate. Fishermen often do not attempt to catch nehu during periods of heavy rainfall, when turbidity increases due to the boost in runoff.

An index of runoff into Kaneohe Bay is the average discharge of a major tributary such as Kamooalii Stream, which flows (via Kaneohe Stream) into the southern sector of the Bay near the city of Kaneohe. Appropriate discharge data, in cubic feet per second, are available in reports of the U.S. Geological Survey (1966-72).

Denoting the availability factor by A_i, we may write

$$A_i = \exp\left\{-\beta[d_i - d_0]\right\}$$

where d_i = Kamooalii Stream discharge in period i (cfs)

d_0 = minimum discharge level such that as $d_i \rightarrow d_0$, $A_i \rightarrow 1$.

Combining this with the previous equation we obtain

$$\ln U_i = \theta' - \beta d_i$$

where $\theta' = \theta + \beta d_0$.

This linear regression model was fitted to log CPU and monthly average discharge data for each year, 1966 through 1972. Logs to base 10 were used. Only two of the regressions were significant, at the 1% level. The other five were not significant. However, six of the seven correlation coefficients were negative, as expected, with values ranging from −0.16 to −0.86. The model was also fitted to all 84 data points, yielding a highly significant regression and a correlation of −0.36.

Finally, the availability model was fitted to the log of the geometric mean of CPU, and the average discharge, with the means computed over the 7 yr (Fig. 5). The regression is highly significant with a correlation coefficient of −0.71. If the assumptions of this analysis are correct, we may take this as evidence that availability, catchability or both are reduced during periods of high rainfall (January through April) and enhanced when streamflows drop (June through October).

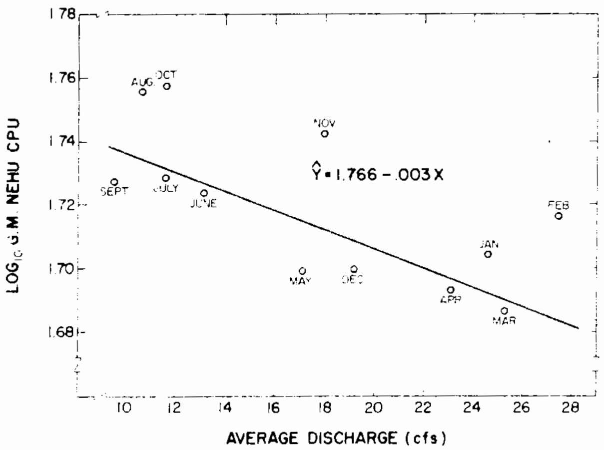

Figure 5.—Regression of log CPU on the average discharge of Kamooalii Stream at Kaneohe. Monthly data averaged over 1966-72.

THE NEED FOR BETTER DATA

The last analysis above suggests that variations in catch per unit of baiting effort may be due largely to changes in availability or catchability arising from exogenous abiotic variables such as runoff, turbidity, etc. If this is so, we can have little confidence that catch and effort statistics, taken alone, will provide useful measures of nehu abundance, particularly when short-term changes are of interest. This applies equally to measures based on catch per set and those based on catch per day. Still, the results of the exploratory analyses presented here are based on assumptions not easily accepted. While the first analysis indicated no long-term effect of baiting effort on nehu abundance, it is quite possible that there are important short-term effects of baiting effort which are erased from the CPU index in the smoothing processes discussed earlier.

A more definitive analysis of nehu stock dynamics and the relative importance of baiting effort and environmental variables in the regulation of baiting success requires a much stronger data base than is now available. At the minimum, reporting requirements for statistics on nominal baiting effort should be extended to include information on the number of sets made each day by each vessel. In addition, catches of nehu should be sampled systematically and frequently to determine size and age composition, so that more detailed modeling can be done. The responsibility for data collection in the nehu fisheries rests jointly with the Hawaii Division of Fish and Game and with members of the aku fishing industry.

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