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DISTRIBUTION AND ABUNDANCE OF SKIPJACK IN THE HAWAII FISHERY, 1952–53

By HERBERT H. SHIPPEN

FISHERY BULLETIN 188

From Fishery Bulletin of the Fish and Wildlife Service

VOLUME 61

Published by the U.S. Fish and Wildlife Service • Washington • 1961

Printed at the U.S. Government Printing Office, Washington, D.C.

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. - Price 20 cents

Library of Congress catalog card for the series, Fishery Bulletin of the Fish and Wildlife Series:

U.S. *Fish and Wildlife Service.*
Fishery bulletin. v. 1–
Washington, U.S. Govt. Print. Off., 1881–19

v. in illus., maps (part fold.) 23–28 cm.

Some vols. issued in the congressional series as Senate or House documents.
Bulletins composing v. 47– also numbered 1–
Title varies: v. 1–49, Bulletin.
Vols. 1–49 issued by Bureau of Fisheries (called Fish Commission, v. 1–23)

1. Fisheries—U. S. 2. Fish-culture—U. S. I. Title.

SH11.A25 639.206173 9–35239 rev 2*

Library of Congress [r55e¾]

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ABSTRACT

Commercial catch records of the Hawaii skipjack fishery for 1952 (a poor year) and 1953 (a good year) are summarized by area and time of catch and by size composition. A unit of fishing effort and its appropriateness are discussed. Geographical distribution of the catch and effort is determined and the two years are compared. Movements of skipjack throughout the fishery are analyzed. The usefulness of the raw catch and the catch per unit of effort as indexes of abundance are considered, and some conjectures as to the nature of the population supporting the fishery are offered.

DISTRIBUTION AND ABUNDANCE OF SKIPJACK IN THE HAWAII FISHERY, 1952–53

BY HERBERT H. SHIPPEN, *Fishery Research Biologist,*
BUREAU OF COMMERCIAL FISHERIES

A study of the environmental factors that may influence the availability of the skipjack (*Katsuwonus pelamis*) to the Hawaii fishery was begun by the staff of the U.S. Fish and Wildlife Service Biological Laboratory (Honolulu, Hawaii). Because the index of availability is to be based on records of commercial skipjack landings, an analysis of these records is an essential part of this study.

HAWAII SKIPJACK FISHERY

The skipjack, or aku, is the most important commercial species of fish in Hawaii, both in terms of quantity landed and dollar value. The 11 million pounds caught and sold for $1,260,000 in 1956 constituted about 70 percent of the total catch of marine species and 40 percent of the value received by Hawaii fishermen during that year. Most of the catch is canned, but a small amount, estimated at less than 10 percent, is sold fresh.

June (1951) and Yamashita (1958) have described the fishery in some detail. Since World War II, the skipjack fleet has consisted of approximately 15 to 20 sampans based in Honolulu, with a few boats based at the islands of Kauai, Maui, and Hawaii. A sampan usually carries a crew of 8 to 15 men. The fishermen rely on the presence of flocks of wild birds to locate skipjack schools. The fish are caught on pole-and-line after being attracted to the boat by chumming with live bait.

The fishery is seasonal with large catches generally occurring in the summer and small catches in the winter months. Catches have fluctuated widely in recent years (fig. 1). The skipjack taken weigh from 2 to 30 pounds. The most sought after size is the 17- to 22-pound fish, known to the fishermen as "season fish." Brock (1954, p. 96) estimates these to be either in their second or third year of life. The reason for the seasonal fluctuation in the catch appears to be the migration of season fish into and out of the area of the fishery, but the direction and significance of this migration in the life history of the species are largely unknown.

NOTE.—Approved for publication February 24, 1961. Fishery Bulletin 195.

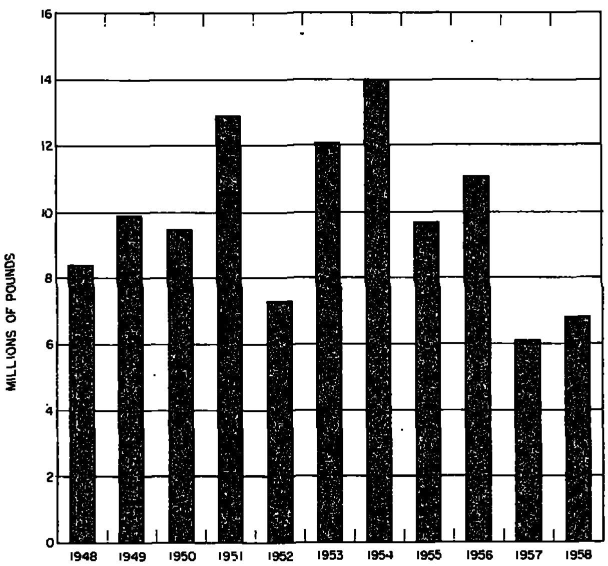

FIGURE 1.—Annual Hawaii skipjack catch, 1948–58.

PURPOSES OF THIS STUDY

The purposes of this study are (1) to examine the raw catch data and the catch per unit of effort as measures of the apparent abundance of skipjack; (2) to search the data for differences between good and poor years in the fishery; (3) to study movements of skipjack within the fishery during the course of the season; (4) to examine the distribution of pounds of skipjack caught, catch per unit of effort, total effort, and size composition of the catch throughout the fishery.

I wish to thank the staff of the Hawaii Division of Fish and Game who collected the fish-catch reports that form the basis of this study. Vernon E. Brock and Tamotsu Shimizu made their data available for study. Additional information was received from Saul Price of the U.S. Weather Bureau who furnished the data on small craft warnings. Peter Wilson of Hawaiian Tuna Packers, Ltd., was instrumental in obtaining the logbooks from two fishing sampans; and Dr. Robert Riffenburgh suggested certain useful statistical procedures.

UTILIZATION OF DATA

The fish-catch reports (fig. 2), completed by the fishermen, were used in this study. Items in these reports are treated as follows:

Time of catch.—The interval from the beginning of 1952 through 1953 was divided into biweekly periods (table 1). Catch reports were grouped by periods according to date of landing.

TABLE 1.—*Biweekly periods in 1952 and 1953*

Period	1952	1953
1	Jan. 1–12	Dec. 28–Jan. 10.
2	Jan. 13–26	Jan. 11–24.
3	Jan. 27–Feb. 9	Jan. 25–Feb. 7.
4	Feb. 10–23	Feb. 8–21.
5	Feb. 24–Mar. 8	Feb. 22–Mar. 7
6	Mar. 9–22	Mar. 8–21.
7	Mar. 23–April 5	Mar. 22–April 4.
8	April 6–19	April 5–18.
9	April 20–May 3	April 19–May 2.
10	May 4–17	May 3–16.
11	May 18–31	May 17–30.
12	June 1–14	May 31–June 13.
13	June 15–28	June 14–27.
14	June 29–July 12	June 28–July 11.
15	July 13–26	July 12–25.
16	July 27–Aug. 9	July 26–Aug. 8.
17	Aug. 10–23	Aug. 9–22.
18	Aug. 24–Sept. 6	Aug. 23–Sept. 5.
19	Sept. 7–20	Sept. 6–19.
20	Sept. 21–Oct. 4	Sept. 20–Oct. 3.
21	Oct. 5–18	Oct. 4–17.
22	Oct. 19–Nov. 1	Oct. 18–31.
23	Nov. 2–15	Nov. 1–14.
24	Nov. 16–29	Nov. 15–28.
25	Nov. 30–Dec. 13	Nov. 29–Dec. 12.
26	Dec. 14–27	Dec. 13–26.

Area of catch.—The catch reports were sorted and reported according to statistical area (fig. 3). For reasons discussed under Sources of Error, the statistical areas have been summarized in terms of zones and regions (fig. 4).

Pounds caught.—This figure was used exactly as recorded in the catch reports.

Average size of skipjack caught.—The total weight was divided by the estimated number caught to arrive at the average weight per fish in the catch. Catches were then classified according to the following categories: (1) small fish (average weight 10 pounds or less), (2) large fish (average weight greater than 10 pounds), or (3) catches for which no size estimate was possible, because the number of fish caught was omitted from the report.

Estimate of total number of skipjack caught in each size group.—A simple proportion, utilizing the known weights and numbers, was used to estimate the numbers of small and large skipjack in the total catch. For example, if the summary of data from the fish-catch reports for a particular region and period yields the following information:

Weight and number of fish	Small skipjack	Large skipjack	No size data	Total
Pounds	30,000	50,000	40,000	120,000
Number	6,000	2,500	(1)	(1)

[1] Unknown.

then, the estimated total number of small skipjack caught is $\frac{(6{,}000)\cdot(120{,}000)}{80{,}000}=9{,}000$, and the estimated total number of large skipjack caught is $\frac{(2{,}500)\cdot(120{,}000)}{80{,}000}=3{,}750$.

Unusable fish-catch reports.—A small number of reports was set aside and not used, except to accumulate gross totals of pounds caught. If a report fell into one or more of the following categories, it was classified as unusable: (*a*) no statistical area was given on catch report, or area number given did not appear on Division of Fish and Game Chart (fig. 3); (*b*) several statistical area numbers were given so that assignment of the catch to any single zone or region was impossible; (*c*) several trips were apparently grouped on one catch report so that estimates of fishing effort would be erroneous.

All other reports were considered usable.

CHOICE OF UNIT OF FISHING EFFORT

The fish-catch report gives no direct information on the amount of effort. There are no data to indicate the number of fishermen making the catch, the time in terms of scouting and fishing, the number of unreported trips with no catch, or any of the other factors which might be pertinent. The fish-catch reports provide, insofar as the determination of effort is concerned, a listing of dates on which fish were unloaded from the vessel. It is from this list, and other data, that fishing effort was estimated.

Each usable catch report was assumed to describe the results of a single trip of the vessel. Each boat has an official number-of-crew, which is reported to the U.S. Customs (Yamashita, 1958, table A–1). This figure, a constant for each vessel, was assigned as a weight to each usable catch report to represent the amount of effort expended in

TERRITORY OF HAWAII
BOARD OF COMMISSIONERS OF AGRICULTURE AND FORESTRY
DIVISION OF FISH AND GAME

FISH CATCH REPORT

Name of Permittee...Boat Permit No.....................

Name of Boat... FG No.....................

Type of Fishing......................................☐ Fishing Gear.......................................☐

FORM C-1 S-B 93859 10M SETS-7-51

Area of Catch......................................☐ Date of Landing.................. .... 19.......
(See Fisheries Chart No. 2) Mo. Day

	SPECIES CAUGHT		No. CAUGHT	LBS. CAUGHT	LBS. SOLD	VALUE*
TUNAS 001	Aku (Skipjack)	002				
	Ahi (Yellowfin) (Shibi)	003				
	Ahipalaha (Albacore) (Tombo-shibi)	004				
	Japanese Bluefin (Black Tuna) (Maguro)	005				
	Big-eye (Menpachi-shibi) ("Bluefin")	006				
	Kawakawa	007				
SWORDFISHES (A'U) 008	Striped Marlin	009				
	Black Marlin	010				
	Short-nose Marlin	107				
	Silver Marlin	108				
	Broadbill Swordfish	011				
	Au lepe (Sailfish)	012				
Mahimahi		013				
Ono		014				

BAIT REPORT

BAIT FISH		DATE TAKEN	TIME TAKEN† DAY	TIME TAKEN† NIGHT	LOCALITY TAKEN	QUANTITY TAKEN	QUANTITY USED
Nehu	**41**					**buckets**	**buckets**
Iao	**42**					**buckets**	**buckets**
Opelu	**20**					**fish**	**fish**
Sardines	**07**						**pounds**

* Value represents the amount of money Received by the fisherman for total pounds of fish sold. Do not record price per pound.
† Check one to indicate whether baiting was done at day or at night. Applies to livebaiting only.

The above reports are true, correct, and complete to the best of my knowledge and belief.

Signature.. Port of Landing..............................☐
Permittee or Authorized Agent

Island..

FIGURE 2.—Hawaii Division of Fish and Game, Fish Catch Report (1950–54).

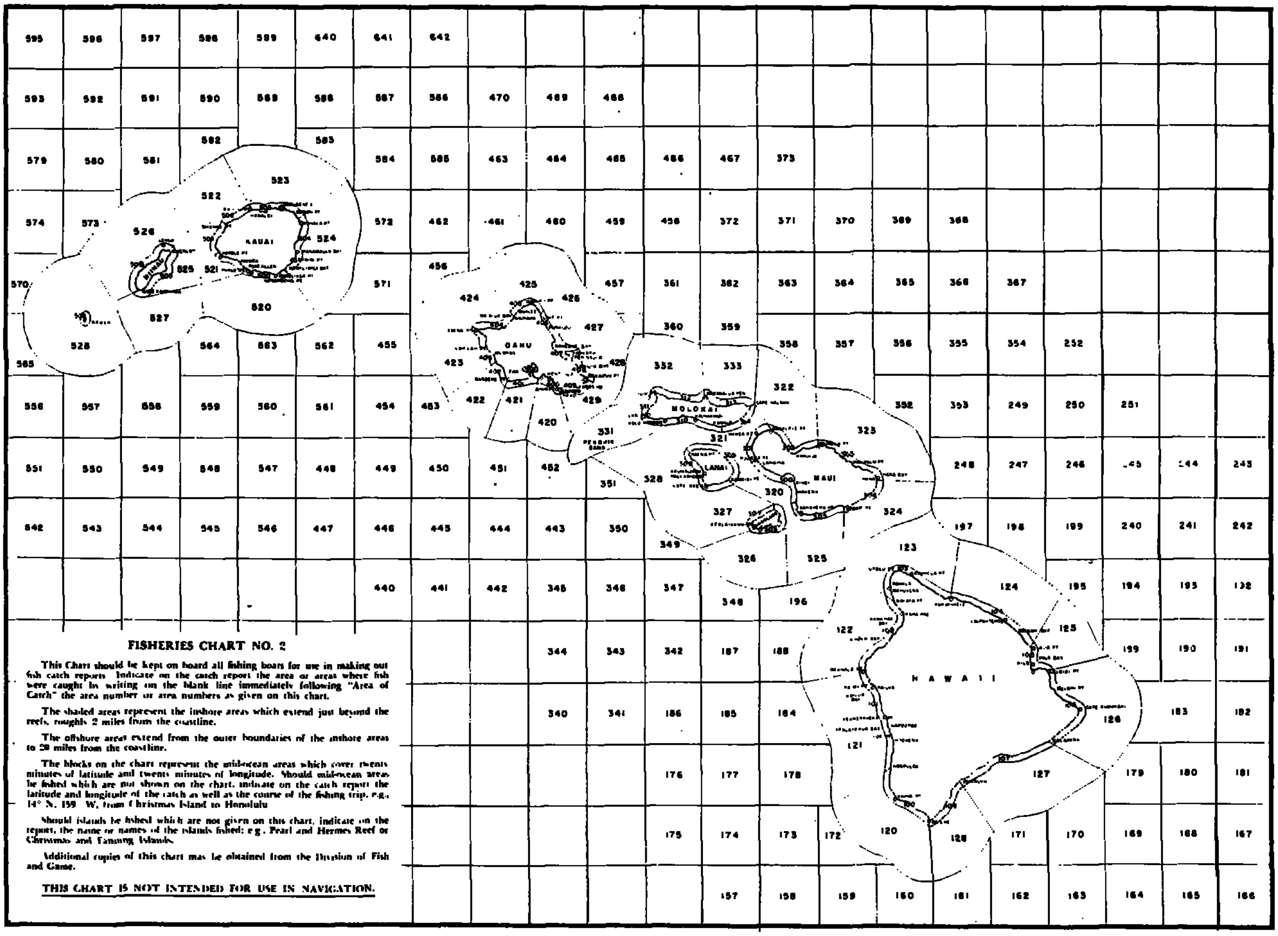

FIGURE 3.—Hawaii Division of Fish and Game, Fisheries Chart No. 2, Statistical Areas.

TABLE 2.—*Fishing effort in 1952 and 1953 for two Honolulu-based skipjack boats*

1	2	3	4	5	6	7	8	9	10	11
Boat and period	Number biweekly periods with fishing	Number trips	Number productive trips	Number non-productive trips	Percent non-productive trips	Average number trips per biweekly period	Number days fishing (includes scouting)	Average number days fishing per biweekly period	Average number trips per days fishing	Average number productive trips per days fishing
BOAT *A* (*1952*)										
Jan. 1–May 31; Oct. 5–Dec. 27	9	42	37	5	12	4.7	51	5.7	0.82	0.78
June 1–Oct. 4	9	61	56	5	8	6.8	66	7.3	.92	.85
Jan. 1–Dec. 27, 1952	18	103	93	10	10	5.7	117	6.5	.88	.79
BOAT *A* (*1953*)										
Dec. 28, 1952–May 30, Oct. 4–Dec. 26	15	82	74	8	10	5.5	85	5.7	.96	.87
May 31–Oct. 3	9	58	55	3	5	6.4	59	6.6	.98	.93
Dec. 28, 1952–Dec. 26, 1953	24	140	129	11	8	5.8	144	6.0	.97	.90
BOAT *B* (*1952*)										
Jan. 1–May 31; Oct. 5–Dec. 27	11	29	22	7	24	2.6	55	5.0	.53	.40
June 1–Oct. 4	9	33	31	2	6	3.7	55	6.1	.60	.56
Jan. 1–Dec. 27, 1952	20	62	53	9	14	3.1	110	5.5	.56	.48
BOAT *B* (*1953*)										
Dec. 28–May 30; Oct. 4–Dec. 26	16	69	60	9	13	4.3	91	5.7	.76	.66
May 31–Oct. 3	9	50	47	3	6	5.6	65	7.2	.77	.72
Dec. 28, 1952–Dec. 26, 1953	25	119	107	12	10	4.8	156	6.2	.76	.69

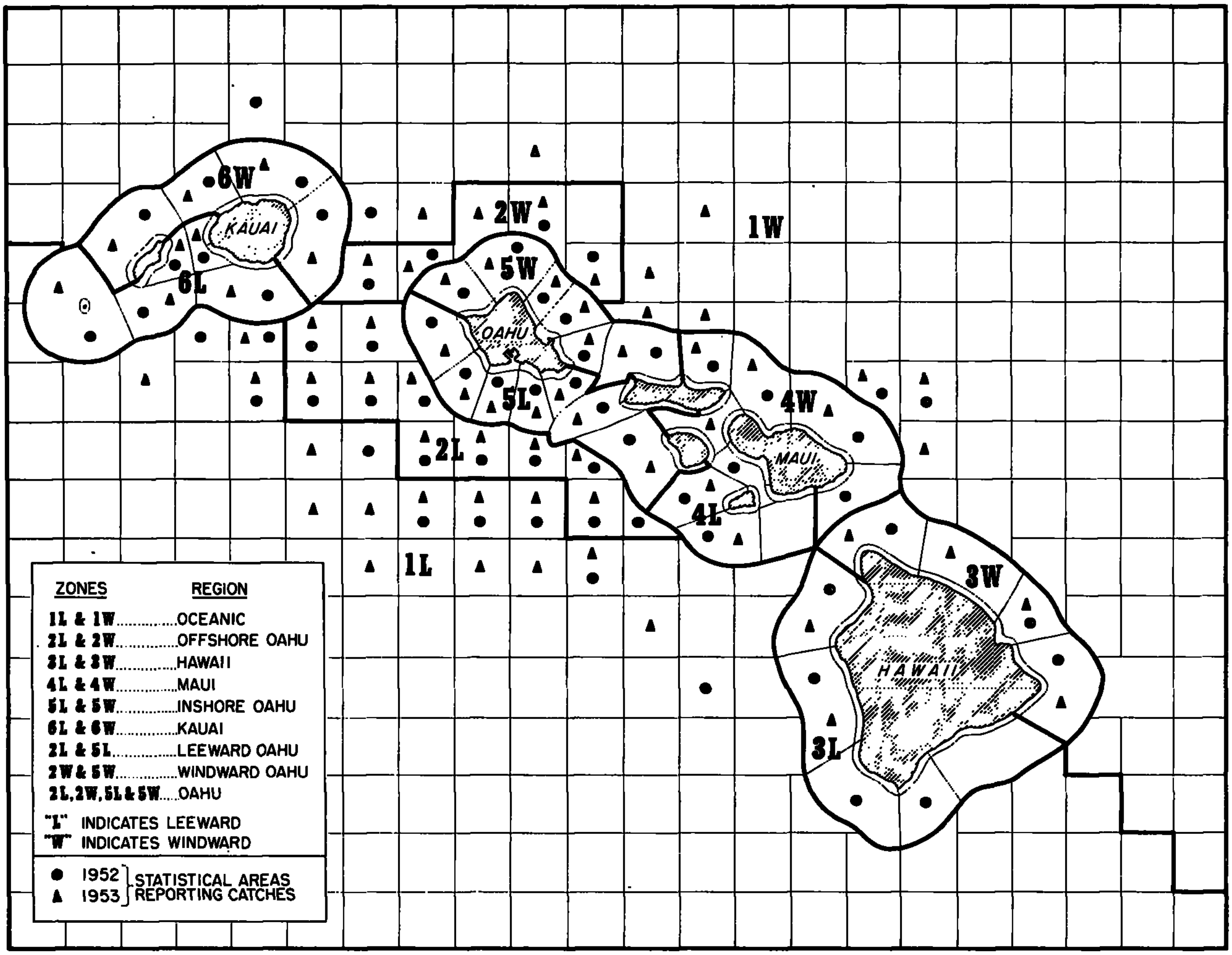

FIGURE 4.—Hawaii skipjack fishery fishing zones and regions and the extent of fishing in 1952 and 1953.

making the catch. The number of fishermen is used as a factor in the computation of fishing effort because it seems reasonable that in pole-and-line fishing the efficiency of a vessel is more or less directly related to the number of men hooking fish. No adjustments were made for differences in trip time or for deviations from the official number of fishermen. Inasmuch as a fish-catch report is required only if fish are caught, the unit of effort employed in this study is the productive fisherman-trip. Thus, if a vessel with a registered crew of 10 men reported a catch of 20,000 pounds, the effort is considered to be 10 units and the catch per unit of effort is 2,000 pounds. If two or more catch reports were combined, the sum of the catches was divided by the sum of the effort to obtain the catch per unit of effort.

To gain some knowledge of the reliability of the productive trip as a factor in the unit of effort, the logbooks of two Honolulu-based skipjack fishing sampans were analyzed to determine the ratio of productive trips to the actual number of days spent fishing; i.e., the time spent in scouting for and catching skipjack. The results of this analysis appear in table 2. Boat *A* is typical of the fleet as a whole in that it makes frequent trips of seldom more than a single day. Boat *B*, on the other hand, is probably the most atypical in the fleet since it ventures far afield and may remain at sea for as many as 4 days, especially when skipjack are relatively scarce. The differences between the two boats are apparent in the number of trips per biweekly period (col. 7) and the number of trips per day's fishing (col. 10).

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Each year is divided into the more productive and less productive parts; for convenience these are called summer and winter, respectively (rows 1 and 2 for each boat and year). The number of trips per biweekly period (col. 7) and number of day's fishing per biweekly period (col. 9) are greater during summer, but the ratio of trips to day's fishing (col. 10) is not markedly different in the two seasons, although trips are somewhat longer in winter.

Nonproductive trips (col. 5) occur with greater frequency (col. 6) in winter than in summer, and there is a tendency for the number of productive trips per day's fishing to be greater in summer. Differences in the number of productive trips per day's fishing are also apparent between years, as in 1953 there were generally more productive trips per day's fishing than in 1952.

To summarize the performances of the two boats, it appears that the ratio of productive trips to the number of day's fishing is greater during times of good fishing and smaller during times of poor fishing. Since trips are shorter when the fishing is good and there are also fewer nonproductive trips, the actual effort in terms of day's fishing will usually be underestimated during the periods of poor fishing as compared with periods of good fishing.

Variations from the official number of crew will also affect the accuracy of the estimate of fishing effort. The official number is a maximum and variations will usually mean that fewer than the official number are aboard. In the Hawaiian skipjack fleet, boats ordinarily carry the maximum number of crew during the summer season, after which some men leave to find other employment. In this study, since the official (maximum) number of crew has been used throughout the year as a weight for the individual trip, the "fisherman" factor in the productive fisherman-trip is probably overestimated during the times of poor fishing.

Thus, the biases in the productive fisherman-trip between times of good and poor fishing tend to cancel each other because during the winter season and years of generally poor fishing, longer trips and the increased frequency of nonproductive trips cause an underestimation of the actual time spent fishing while, at the same time, the actual number of fishermen on the boat is likely to be fewer than the official number. The converse will hold true during the summer season and in years when good fishing attracts the maximum number of fishermen to the fleet.

Information is not available to permit the examination of the actual variations in the number of fishermen and the extent to which they offset the bias introduced by nonproductive trips, but if boat *A* is assumed to represent the average situation, the number of productive trips per day's fishing (col. 11) appears to be about 10 percent greater in summer than in winter. Since the crew of the average skipjack boat is about 10 men, the absence of one of these men on the average during the winter season represents a 10-percent overestimation of the number of fishermen. Thus, the absence of one fisherman per boat during the winter season would be sufficient to equalize the bias in the productive trip factor introduced during the winter season.

SOURCES OF ERROR

Unreported catches or forms containing incomplete or inaccurate information are an obvious source of error. Yamashita (1958, p. 258) estimates that the reported portion of the 1952 catch included 94 percent of the pounds, but only 88 percent of the trips, indicating a bias in favor of the reporting of large catches. Since small catches are most likely to occur in the slack part of the year, there may be a tendency for an estimate of the fishing effort, which is a function of the number of trips, to be correspondingly reduced.

Inaccurate information is difficult to detect without data from other sources with which to compare the catch records. On the basis of interview records, Yamashita (1958, p. 258) estimates that only 45 percent of the statistical areas indicated in the 1952 catch reports were reasonably accurate. By means of broad geographical divisions to summarize the data (fig. 4), it is assumed that the effects of such erroneous information will be minimized.

ERROR IN DETERMINATION OF FISH SIZE

Dividing the total weight caught by the estimated number as indicated in the catch report, yields the average size of fish caught, but provides no indication of the range or variability of sizes. Since the entire catch is assigned to either the small or large category on the basis of the average weight per fish, a certain amount of error will result from mixed catches of small and large fish; this error should distribute itself more or less randomly, however, so that neither size group is consistently favored.

ERROR IN ESTIMATION OF FISHING EFFORT

There is no way to determine from the catch records the actual effort, i.e., the fisherman-days whether productive or not, put forth on a skipjack boat. In this study only positive fishing results (catch reports) are available, and the productive fisherman-trip is of necessity used in lieu of the fisherman-day. Sources of error in the productive fisherman-trip have been discussed in the section, Choice of the Unit of Fishing Effort, and on the basis of the performance of two skipjack boats for which logbooks are available, it appears to be a reasonable substitute.

OTHER SOURCES OF ERROR

The weight of the catch of skipjack taken in the Hawaiian live-bait fishery is affected by complex factors which present sources of error that are difficult to estimate. Among these factors are variations in bait supply, response of skipjack to chum, behavior and number of birds in the flocks which serve to locate schools, the size and behavior of the skipjack schools, selection by the fishermen, and probably several others.

Yamashita (1958, p. 270) has discussed the problem of ascertaining the influence of variations in bait supply on the skipjack catch in terms of annual production and suggests that in certain years, when skipjack have been plentiful, the availability of bait may be a limiting factor in the fishery. Royce and Otsu (1955) have investigated many aspects of behavior of skipjack schools and birds; Yuen (1959) has studied the response of skipjack to live bait.

In the present study no attempt has been made to evaluate the sources of error introduced by the factors considered above. Information available is not adequate to discern which of these may be important at any particular time. It seems reasonable that most of these factors act relatively independent of one another so that over a period of time their combined effects should not introduce bias. However, it is just as plausible that at certain times several of these elements may act in unison resulting in considerable deviation from the normal state. The investigation of the role of these factors in the fishery awaits a more sophisticated study than is attempted here or is possible with the present sources of information.

CONCLUSIONS ON SOURCES OF ERROR

None of the sources of error appears to be so extensive as to destroy the usefulness of the catch report as the basis for a study of distribution and abundance. Some of the sources of error tend to reduce the bias introduced by others. With respect to time, geography, and size, the categories employed in this study have deliberately been made broad. Were the study concerned with only a few vessels, very short time periods, or several size groups, the probability of error would be increased, but as only the most general of categories are used, the influence of error on the results should be slight.

RESULTS AND DISCUSSION

There are small discrepancies between the official total catches for 1952 and 1953 as listed by Yamashita (1958, table 2) and the totals obtained in the present study (table 3). These differences amount to 1 percent and are probably the result of catch reports, which were turned in too late to be included in official summaries and to records lost or misplaced during the interval of storage. The proportion of unusable data in 1953 was greater than in 1952 (table 4), largely because of the poor

TABLE 3.—*Comparative data from 2 studies of the Hawaiian skipjack catch for 1952 and 1953*

Year	Pounds skipjack caught		Difference	Percent difference
	Yamashita [1]	Shippen [2]		
1952	7,291,851	7,390,882	99,031	1.3
1953	12,059,406	11,928,965	−130,441	−1.1

[1] Source: Yamashita (1958, table 2).
[2] Figures adjusted to correspond with calendar year.

TABLE 4.—*Usability of 1952 and 1953 catch report data*

	1952		1953	
	Pounds	Percent	Pounds	Percent
Usable	7,270,990	98.6	11,345,013	95.0
Unusable	105,453	1.4	598,391	5.0
Total	7,376,443	100.0	11,943,404	100.0

reports from the master of one sampan who consistently summarized his catches by weeks throughout much of the year.

GEOGRAPHICAL DISTRIBUTION OF 1952 AND 1953 CATCHES

Despite the large differences in total landings in 1952 and 1953, the geographical distribution of catch and effort (table 5, fig. 5) is much the same. In both years the leeward Oahu and Hawaii regions furnished approximately 50 and 16 percent of the total catch, respectively, and the oceanic region and Maui were relatively unimportant with less than 8 percent in the aggregate. The combined windward Oahu and Kauai regions contributed about 25 percent of the total catch in each year, but in 1953 a much larger proportion of this came from windward Oahu.

Within the vicinity of Oahu, the distribution of effort appears to be related to the distance from the home port; the amount of effort expended in the zones decreases as their distance from Honolulu increases. This is probably because of the fragile nature of the nehu (*Stolephorus purpureus*), the most important bait species.

CATCH PER UNIT OF EFFORT IN THE HAWAII SKIPJACK FISHERY

If the regions of the fishery from Hawaii in the southeast to Kauai in the northwest are arranged in sequential order (fig. 6), there is some suggestion of an increasing catch per unit-of-effort in the direction of Kauai, but the inequities in the distribution of effort and certain known differences in the local fisheries make it doubtful that the apparent trend is of biological significance. The Hilo (Hawaii) fishermen usually make short trips and land each day's catch on the day it was made,

TABLE 5.—*Geographical distribution of the 1952 and 1953 usable catch data*

[See fig. 4 for location of zones; C/E=catch/effort]

Regions and zones	1952					1953				
	Catch		Effort		C/E	Catch		Effort		C/E
	Pounds	Percent	Units	Percent		Pounds	Percent	Units	Percent	
Oceanic:										
1L	183,729	2.5	244	1.2	753	274,358	2.4	439	1.7	625
1W	128,458	1.8	348	1.8	369	191,531	1.7	236	0.9	812
Total	312,187	4.3	592	3.0	527	465,889	4.1	675	2.6	690
Hawaii:										
3L	252,659	3.5	1,073	5.4	235	485,317	4.3	1,572	6.2	309
3W	881,673	12.1	2,869	14.6	307	1,288,967	11.4	3,676	14.4	351
Total	1,134,332	15.6	3,942	20.0	288	1,774,284	15.6	5,248	20.6	338
Maui:										
4L	115,113	1.6	119	0.6	967	25,257	0.2	62	0.2	407
4W	139,939	1.9	463	2.4	302	179,291	1.6	452	1.8	397
Total	255,052	3.5	582	3.0	438	204,548	1.8	514	2.0	398
Inshore Oahu:*										
5L	2,259,734	31.1	7,350	37.3	307	3,365,538	29.7	9,116	35.7	369
5W	719,780	9.9	1,952	9.9	369	1,742,242	15.3	3,266	12.8	534
Total	2,979,514	41.0	9,302	47.2	320	5,107,780	45.0	12,382	48.5	413
Offshore Oahu:*										
2L	1,486,181	20.4	3,519	17.9	422	2,656,150	23.4	5,022	19.7	529
2W	157,854	2.2	361	1.8	437	415,346	3.7	674	2.6	616
Total	1,644,035	22.6	3,880	19.7	424	3,071,496	27.1	5,696	22.3	539
Oahu region subtotals:*										
L	3,745,915	51.5	10,869	55.2	345	6,077,707	53.6	14,242	55.8	427
W	877,634	12.1	2,313	11.7	379	2,212,112	19.5	3,990	15.6	554
Region total	4,623,549	63.6	13,182	66.9	351	8,289,819	73.1	18,232	71.5	455
Kauai:										
6L	284,845	3.9	560	2.8	509	217,722	1.9	373	1.5	584
6W	661,025	9.1	844	4.3	783	392,751	3.5	462	1.8	850
Total	945,870	13.0	1,404	7.1	674	610,473	5.4	835	3.3	731
Grand total	7,270,990	100.0	19,702	100.0	369	11,345,013	100.0	25,504	100.0	445

*The Oahu region includes inshore and offshore Oahu, 2L, 5L, 2W, and 5W. For 1953, a few additional catches were made across zone boundaries within the Oahu region.

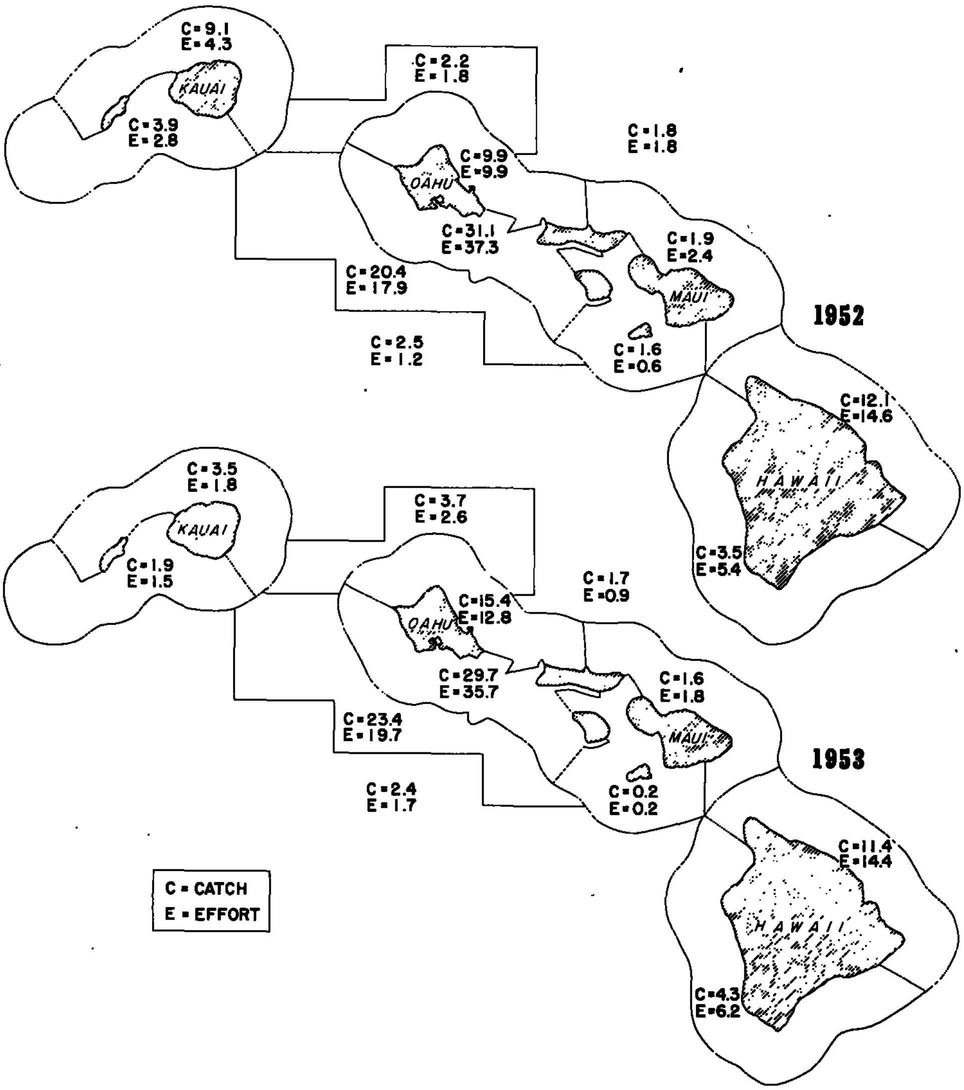

FIGURE 5.—Geographical distribution of catch and effort in the Hawaiian skipjack fishery, 1952 and 1953.

whereas the trips by Honolulu-based fishermen to the vicinity of Kauai are longer than a single day; therefore, the differences in time-of-trip between the two areas are probably significant.

Similarly, catch per unit of effort tends to increase with increasing distance from shore (fig. 7). Only a fraction of the total effort was expended in the oceanic region as compared with the effort inshore, and a few good catches of large fish may have produced an index far out of proportion to the actual apparent abundance. Royce and Otsu (1955, p. 18), however, report sighting more tuna schools per day's scouting beyond 19 miles from shore than were seen within 19 miles of shore.

SIZE OF SKIPJACK AND POUNDS CAUGHT PER UNIT OF EFFORT

There is a positive correlation (fig. 8) between the average size of skipjack caught in zones of the fishery during the year (table 6) and corresponding catch per unit of effort (table 5). Zones with less than 5 percent of the total annual effort are not included in the analysis because they are unlikely to represent fishing conditions throughout the year. This correlation appears to substantiate the observation that the larger skipjack usually can be caught more efficiently than the smaller, up to the size at which individuals must be gaffed in landing and the efficiency drops.

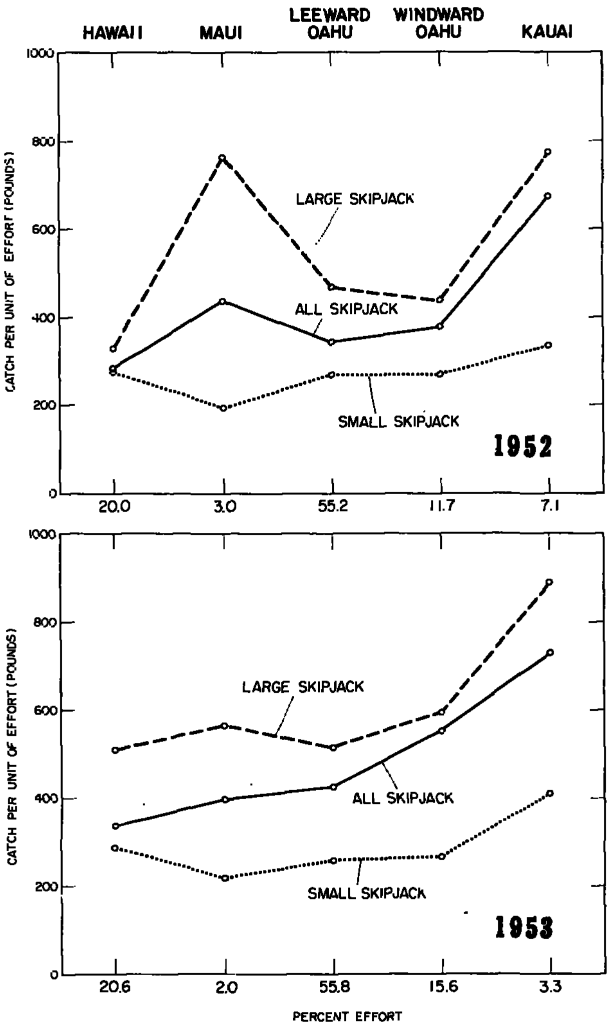

FIGURE 6.—Pounds caught per unit of effort by island regions.

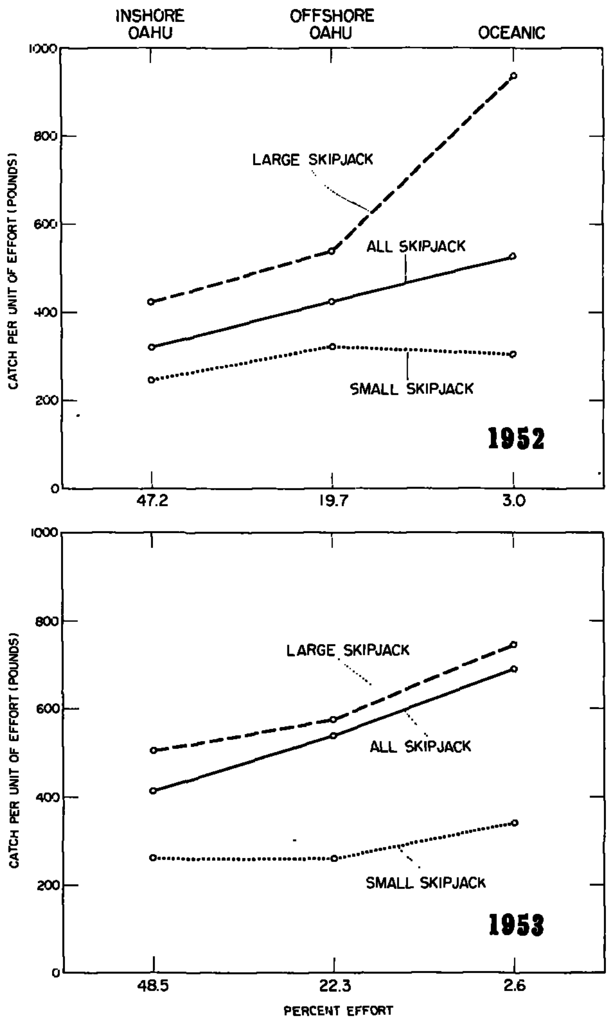

FIGURE 7.—Pounds caught per unit of effort by distance from shore.

TABLE 6.—*Average weight of skipjack caught in each zone of the fishery*

Zone	1952 Average weight (pounds)	1953 Average weight (pounds)	Zone	1952 Average weight (pounds)	1953 Average weight (pounds)
1L	15.5	18.2	4L	14.5	12.1
1W	7.9	14.7	4W	11.9	13.0
2L	*9.0	*13.9	5L	*8.2	*11.2
2W	17.2	15.9	5W	*9.2	*12.8
3L	*4.8	*7.7	6L	6.7	11.5
3W	*4.8	*7.5	6W	12.8	8.1

*Indicates zones receiving more than 5 percent of the total fishing effort during the year.

Each year the small fish are caught in Hawaii (zones 3L and 3W); the larger fish are from inshore windward Oahu (5W), and offshore leeward Oahu (2L). The association of small fish with

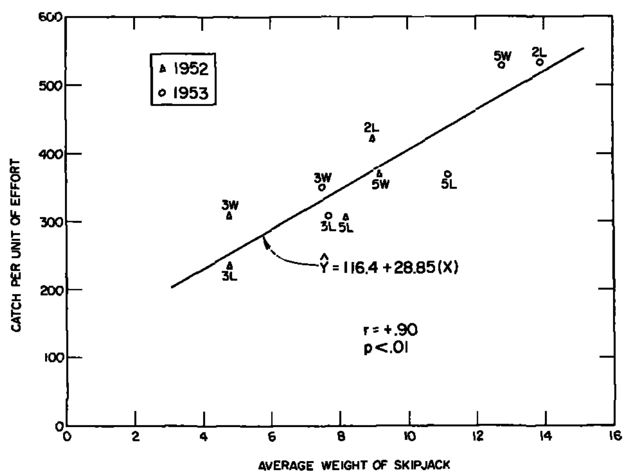

FIGURE 8.—Regression of catch per unit of effort on average weight of fish caught.

Hawaii may be explained by the nature of the fishery there, which is based largely on semiresident populations of small skipjack. Other populations of small fish are known to occur in inshore areas of leeward Oahu (5L), and these are usually exploited when the large skipjack are in low abundance and produce the intermediate average weight for zone 5L. Zones 5W and 2L are more remote from Honolulu than is 5L, and it seems probable that the fishery in these zones may be biased in favor of periods when large skipjack are available, which could account for the relatively greater average weight per fish in these zones of the fishery.

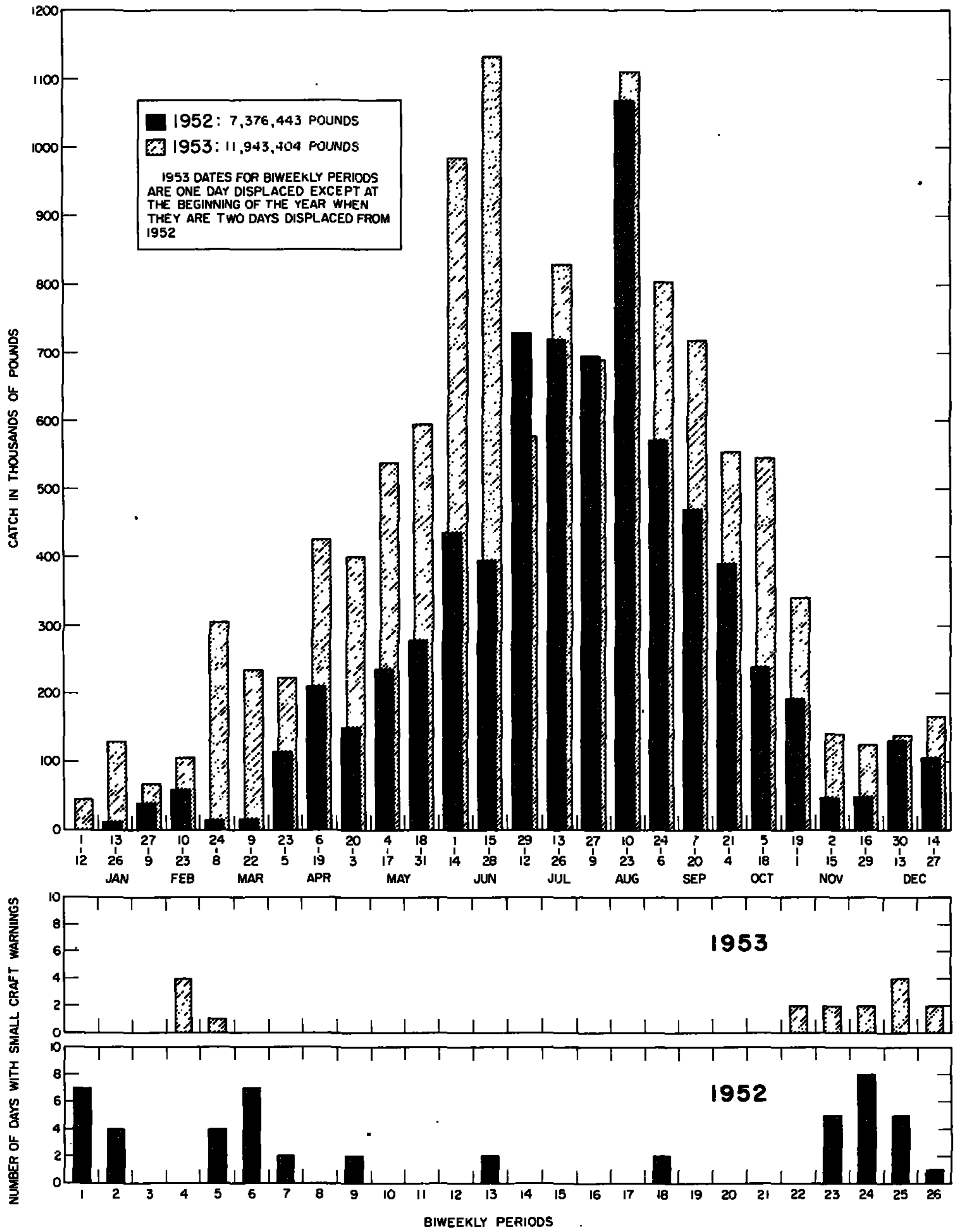

FIGURE 9.—Catches (pounds) of the Hawaii skipjack fishery, 1952–1953, by biweekly periods. Periods of small craft warnings are shown below.

DISTRIBUTION OF 1952 AND 1953 CATCHES BY BIWEEKLY PERIODS

Catches for the Entire Fishery

Only during July and August (periods 14–17) and briefly in December (period 25) did the 1952 skipjack catches reach the magnitude of the 1953 totals (fig. 9). In particular, the spring of 1953 and, to a lesser extent, the autumn months provided much larger catches than occurred in 1952.

Effects of Small Craft Warnings

There were 49 days with small craft warnings during 1952 and 17 during 1953 (fig. 9), but only 6 of these fell in the interval from April through September in 1952 and none in 1953. The effects of rough weather, therefore, appear to be relatively minor in comparison with the seasonal fluctuation in the availability of skipjack.

The immediate effects of poor weather may be indicated by the relatively small catches made during periods 1, 2, 5, 6, 23, and 24 of 1952, each of which had several days with small craft warnings. Period 25, on the other hand, shows an increase in catch despite 5 days of poor weather.

MOVEMENTS OF SKIPJACK WITHIN THE FISHERY

Local changes in the skipjack catch within the entire range of the fishery may result from changes in the amount of fishing effort or from changes in availability. The latter may include horizontal movement of the fish into or out of a particular area or, within an area, a change in the vertical distribution or behavior such that the catch rate by live bait fishing is affected. The records of the fishery, however, provide no means by which one or the other cause may be determined, and it is therefore assumed for the purposes of this discussion that all changes in the catch are caused by movements of fish from one area to another. Thus, errors, if any, are likely to be on the side of postulating a horizontal movement of fish when there has been a change in vertical distribution, behavior, or fishing effort. This approach seems to be the most reasonable one, because tagging experiments show that individual skipjack travel the length and breadth of the fishery, while knowledge of changes in availability and fishing effort, particularly if nonproductive, remains quite limited.

Large Skipjack

After an interval of low abundance throughout the islands during the early part of 1952, large skipjack (fig. 10) appeared simultaneously in small numbers in leeward Oahu and Kauai in period 8. In period 10 the fish arrived in windward Oahu and Hawaii. This sequence suggests an approach from the west. In period 12, a concentration centered in windward Oahu occurred; it appears to have shifted northward to Kauai by periods 15 and 16. In period 17, however, the catches of large skipjack ceased in Hawaii and began to dwindle in Kauai, but at the same time the largest catches of the year were being made in leeward Oahu. All these changes seem to indicate that the large skipjack had returned to the leeward side of the island chain. The gradually diminishing catches from Kauai and leeward Oahu in periods 18 through 20 indicated the withdrawal of season fish to the westward. After period 20, the numbers of large skipjack in the catch returned to the state of low variable abundance which characterizes the off-season of the fishery.

During the interval from period 25 (1952) until period 4 (1953) the number of large skipjack taken in all regions of the fishery was uniformly low, a condition typical of the winter season. In period 5, however, a sharp increase occurred in the catch of large skipjack in the leeward Oahu region. To judge from the variation in average weights (fig. 12), these fish were 1952-season fish, being somewhat heavier than 1953-season fish which entered the fishery in period 9. These 1952-season fish appeared in the catches during periods 5, 7, 8, and 9 and were the cause of the apparent early beginning of the "season" in 1953 (fig. 9).

In period 9 of 1953, the season fish were present throughout most of the fishery (note the declining average weights in periods 9 and 10, fig. 12) but the large catches in leeward Oahu in periods 10 through 12 suggest that the direction of the approach of the main body of fish was from the leeward. As in the previous year, a peak occurred early in the season in windward Oahu (period 12, 1952; period 13, 1953), and in succeeding periods the fish dispersed southward to leeward Oahu and Hawaii where large catches were made in periods 15–17. Following the excellent catches of period 17, the best of the year, a gradual decrease in catch occurred, and by period 23 the season was over.

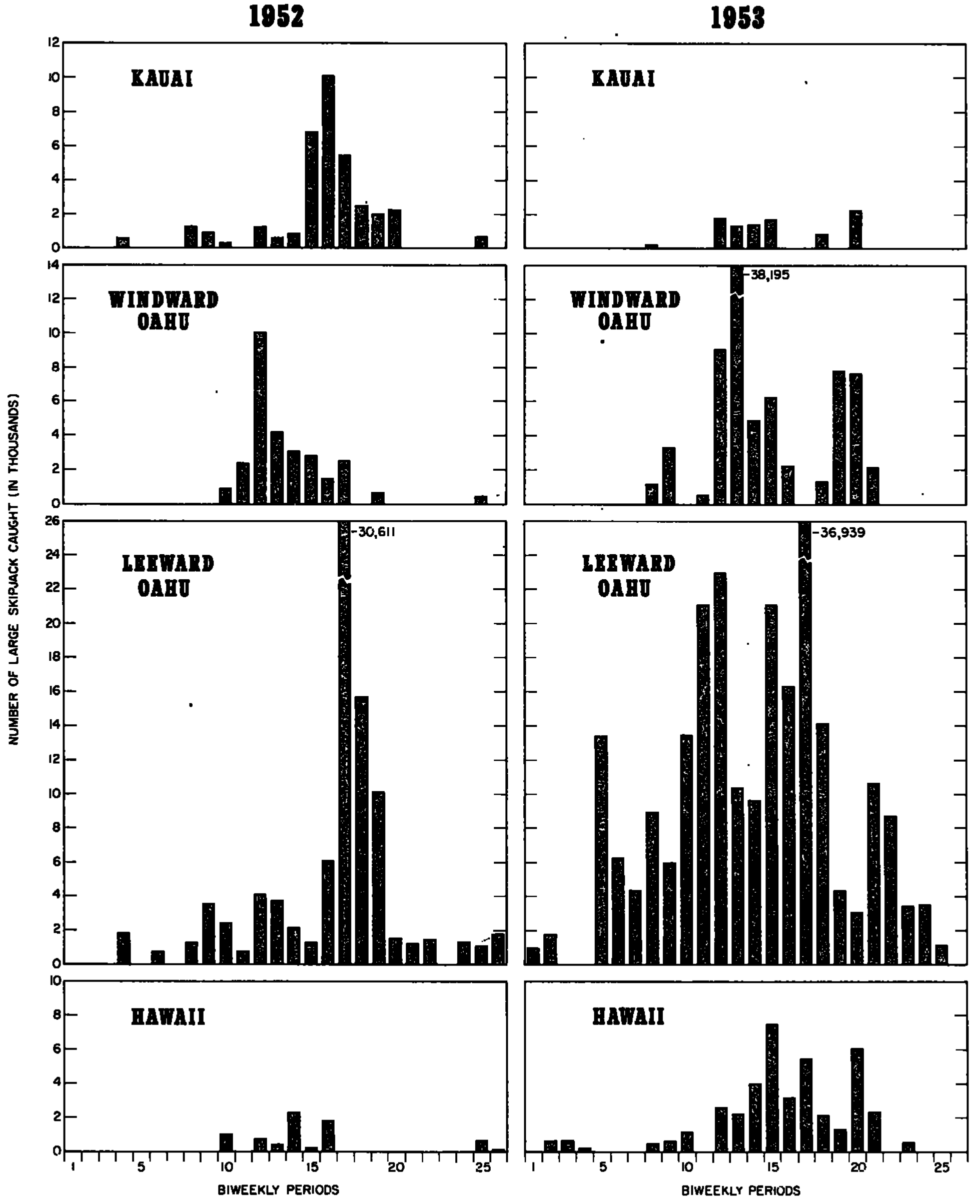

FIGURE 10.—Number of large skipjack caught (1952–53); biweekly periods.

Certain features common to both years are to be noted: (1) the approach of the large fish at the start of the season, apparently from the leeward; (2) the concentrations on the windward and leeward sides of Oahu in June and August, respectively; and (3) the final disappearance of fish to the leeward. Differences in the 2 years are as follows: (1) the appearance in the early part of 1953 (period 5) of large skipjack, and (2) the direction of movement of the season fish between the time of the windward Oahu peak catches (periods 12–13) and the leeward Oahu peak (period 17). In 1952 the fish went northward to Kauai and thus close to the limit of the fishery. In 1953 they returned to leeward Oahu and Hawaii to remain well within the range of the Honolulu and Hilo based vessels.

In general, the movements of large skipjack, as indicated by their occurrence in the commercial catch, do not suggest an orderly migration along the island chain. The reason for this may be in the direction of approach of the migrating schools, which appears to be perpendicular rather than parallel to the barrier formed by the islands. The relative speed with which schools travel, which may reach 15 knots (Royce and Otsu, p. 18), may be such that a period of 2 weeks is too long to discern a migratory pattern within an area as small as that encompassed by the Hawaiian skipjack fishery.

Small Skipjack

Examination of the numbers of small skipjack caught and the corresponding catch per unit-of-effort data revealed no discernible pattern of movement within the fishery. Large skipjack are the prime objective of the fishery and the smaller sizes are usually taken as a second choice. The number of small skipjack in the catch, therefore, tends to be a function of the number of large fish available. The relationships between the numbers of large and small fish in the catch are discussed under the section, Size Composition.

OAHU SKIPJACK FISHERY, 1952 AND 1953

STATISTICAL COMPARISONS

The comparative statistics for 1952 and 1953 in the Oahu region are summarized in table 7. In almost every way, 1953 reflects the greater availability of skipjack than in the previous year, as evidenced by (1) a much larger catch, (2) almost half as much fishing effort, and (3) a larger catch per unit of effort. The number of small skipjack caught (4b) and pounds caught per unit of effort (3b) are not markedly different between years, but the catch of large fish, both in absolute numbers (4a) and on a relative basis (3a), is considerably greater in 1953. Most of the differences between the 2 years can be attributed to the abundance of this size group in the fishery.

Independently of size considerations, the number of fish taken per biweekly period in 1953 was larger than the corresponding number in 1952 (5 and 6). The relative abundance of large and small skipjack in the 2 years is indicated by the number caught per unit of effort (7) which is greater for the small fish in 1952 and for the large fish in 1953. The importance of the abundance of large fish to the success of the fishery may be measured by the comparative number of biweekly periods in the various categories (8).

TABLE 7.—*Comparative statistics for the Oahu fishery, 1952 and 1953*

	1952	1953	1953/1952
1. Total pounds caught	4,623,549	8,715,958	1.89
(Percent of total for skipjack fishery)	(63)	(73)	
a. Large skipjack only	2,058,921	6,366,336	3.09
b. Small skipjack only	2,564,628	2,349,622	.92
2. Total productive effort	13,182	19,169	1.45
a. Large skipjack, percent	34	55	
b. Small skipjack, percent	66	45	
3. Pounds caught per unit of effort, all usable catches	351	455	1.30
a. Large skipjack only	462	533	1.15
b. Small skipjack only	270	261	.97
4. Total number of fish caught	521,500	677,000	1.30
a. Large skipjack only	123,500	330,500	2.67
b. Small skipjack only	398,000	346,500	.87
5. Average number caught per biweekly period	20,577	26,038	1.27
6. Median number of skipjack caught in each year for the 26 biweekly periods	18,044	25,833	1.43
7. Number of fish caught per unit of effort	40	35	.88
a. Large skipjack only	28	31	1.11
b. Small skipjack only	46	40	.87
8. Number of biweekly periods with—			
a. more than 300,000 pounds catch	5	14	2.80
b. more than 800 units fishing effort	5	11	2.20
c. more than 400 pounds catch per unit of effort	5	14	2.80

RELATIONSHIPS BETWEEN CATCH STATISTICS

The population indices derived from the catch reports are the raw catch and the relative catch; i.e., catch per unit of effort. Either index may be in terms of weight or number of fish and may be calculated for the entire catch or for limited categories. Since 1954, however, no information on the number or size of fish in the catch has been included in the catch report, so the only indices which may be considered for recent years in the fishery are the pounds caught and the catch per unit of effort without respect to size categories.

The biweekly statistics for pounds caught, catch per unit of effort, and effort within the Oahu region for 1952 and 1953 are plotted in figure 11. Of particular interest here is the relation between the raw catch and the catch per unit of effort, for if the two show essentially the same variation, there is little or no advantage to be gained in employing catch per unit of effort as the index of apparent abundance.

It is obvious from figure 11 that there is much similarity in the fluctuations of all three indices; each has a seasonal variation on which lesser fluctuations are superimposed. Additionally, there is a secular trend from 1952 to 1953. The catch curve tends to change gradually and peak sharply, while the effort curve changes rapidly at the start and close of the season, with little trend during midyear.

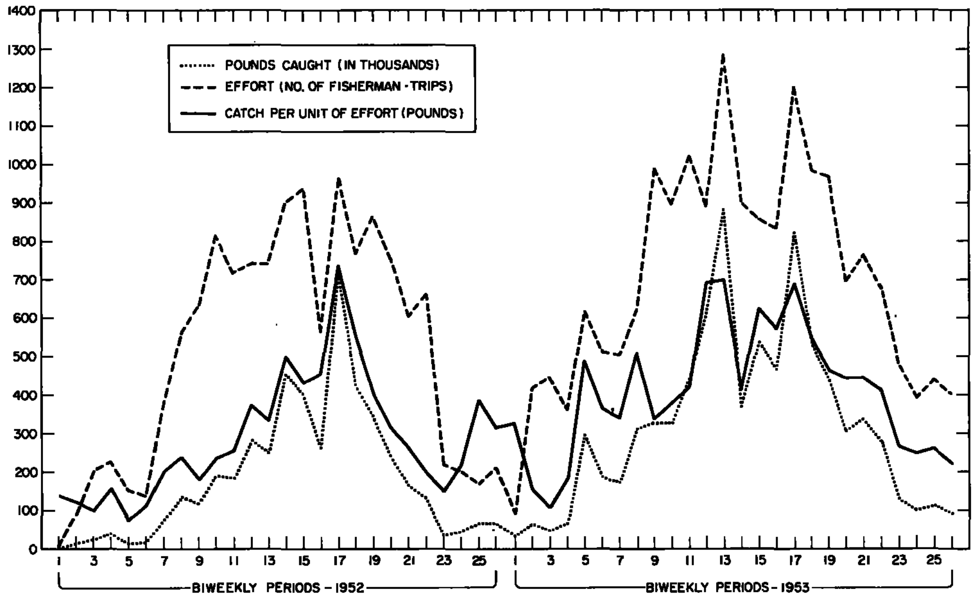

FIGURE 11.—Oahu region catch statistics, 1952 and 1953, biweekly periods.

The results of these tendencies in catch and effort curves on the catch per unit-of-effort curve are as follows: (1) During midyear when effort tends to be constant, the catch per unit of effort will closely follow the fluctuations in catch. (2) During the onset and decline of the season, effort is changing more rapidly than catch and the catch per unit of effort will change at an intermediate rate. Random fluctuations in the catch per unit-of-effort at this time may be somewhat at variance with those in the catch, as occurred in the interval from period 24, 1952, to period 3, 1953.

Correlation analysis between raw catch and catch per unit-of-effort data yields a coefficient of +0.92. It was necessary to use rank correlation methods (Snedecor, 1956, p. 190) because the distribution of catches is skewed toward small catches. In order to determine the amount of agreement between the random fluctuations in the two indices, the first differences were correlated and yielded a coefficient of +0.79. Conventional methods were used here because the first differences are distributed more normally than the original series. The probability that correlation coefficients this large would occur by chance is less than 0.01.

The variate-difference technique (Kendall, vol. II, p. 387–390) was used to obtain an estimate of the variance in the random component of each index compared to the variance of the original series. The values obtained for the random components were 24 percent for the raw-catch series and 18 percent for the catch per unit-of-effort series. Since it exhibits a smaller random component, the catch per unit-of-effort series appears to be somewhat more reliable than the catch as an index of skipjack availability, but only slightly so.

In summary, the raw catch is almost as accurate as the catch per unit of effort in indicating the seasonal variation in skipjack abundance in the Hawaiian fishery. During the middle of the year the raw catch is in good agreement with the random fluctuations in catch per unit of effort, but during the off-season of the fishery, when effort and catch are either declining rapidly or are at a low level, random fluctuations in catch per unit of effort may not vary in agreement with fluctuations in catch. For most purposes, total catch would appear to be as useful an indicator of availability as the catch per unit of effort, especially in problems where the seasonal trend in the fishery is apparent.

USE OF CATCH RECORDS TO DETERMINE POPULATION COMPOSITION

The catch statistics of the Hawaiian fishery are the only continuous source of information which provides a means of assessing the nature of the skipjack population which supports the fishery. Inferences about this population must be made with caution, however, because the fishery is limited geographically to the immediate island area (fig. 4). Furthermore, the catches are also influenced by availability, fishing effort, and selectivity on the part of the fishermen, which may not be constant throughout the year. Brock (1954, p. 100–103) has shown, by means of sex ratios, that the availability of female skipjack is not constant. He suggests that spawning activity may be the crucial element. The cyclical nature of fishing effort has been shown previously (fig. 11), and the fact that the fishermen are selective in the schools they fish is common knowledge. These biases appear to have an annual cycle and between-year comparisons may not be affected by them to the extent of within-year comparisons.

Fluctuations in the Catch of Large Skipjack in the Oahu Region

The growth rate of Hawaiian skipjack has been studied by Brock (1954, pp. 96–97) by means of length frequency distributions. During the summer there are two distinct modes, one at about 45 cm. (4 pounds) and one at about 70 cm. (18 pounds).[1] The mode of large skipjack represents season-fish and presumably a smaller number of the previous year's season-fish. It is this mode that is considered here as large skipjack. The time of year when a mode, which Brock assumes to be a year class, passes through the weight (10 pounds) which separates small and large fish in this study, is apparently winter or early spring. During the period from May to October, it may be assumed with reasonable certainty that the small skipjack are a year younger than the large skipjack.

In 1952 there appears to be little consistency in the average weight for large skipjack (fig. 12), which fluctuates widely from one biweekly period to the next. By contrast, 1953 has an interval from May 3 through October 3 (periods 10–20) with a regularly increasing weight for large fish. The rate of this increase, 0.25 pound per week, is in agreement with Brock's curve for skipjack growth, which yields a linear weight increase of 0.25 pound per week. The coincidence of the season of greatest productivity (as indicated by the

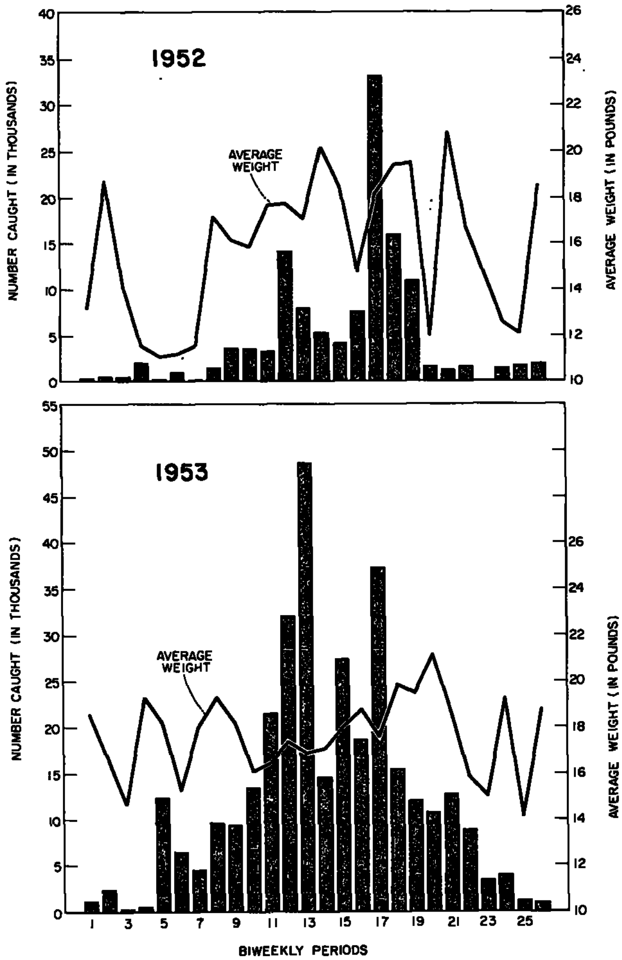

FIGURE 12.—Catch of large skipjack in the Oahu region, 1952 and 1953.

number of large fish caught) with the interval of uniform weight increase suggests that in 1953 a single population of season skipjack was available to the fishery, but the erratic fluctuation in the numbers taken indicates that variations in this availability were quite marked.

Period 5 of 1953, with its unusual numbers of very large fish, must consist of skipjack greater in size than the 1953-season fish. It seems probable that these very large skipjack are 1952-season fish, which were present only briefly that year. The relatively high average weights during other periods of early 1953 imply that 1952-season fish may have been generally present during that time. In early 1952, on the other hand, few of the previous year's season fish were present, as judged by the average weights during periods 4 to 7.

[1] Conversions of length (millimeters) to weigh (pounds) were made according to the formula: Log weight $= -8.2755 + 3.34913$ log total length.

Size Composition

Small skipjack are usually sought by the fishermen only when they are unable to locate larger fish. One would expect, therefore, that the occurrence of small fish in the catch would be inversely related to the presence of the larger skipjack, and this does seem to be the situation. The numbers of large and small skipjack taken in the Oahu fishery in each biweekly period of the 2 years under study is plotted in figure 13. In 28 biweekly periods (1952, 8–20; 1953, 8–22) when large skipjack were generally present, a tabulation was made to see how frequently the changes in the number of one size group were associated with similar or opposite changes in the other. Opposite trends, e.g., the number of large skipjack decreases from the preceding period while the number of small skipjack increases, occur in 22 periods while similar trends occur in 6. The probability of obtaining such a distribution if the numbers of large and small fish in the catch fluctuate independently of one another is less than 0.01.

Size composition appears to be important in the determination of the general level of catch (fig. 14) and the pounds caught per unit-of-effort (fig. 15). Both increase rapidly with an increasing proportion of large fish up to a ratio of 1 large fish for 1 small fish. Above this ratio the total catch continues to increase at a fairly rapid rate, but catch per unit of effort increases at a slower rate.

The likelihood of catches of large numbers of individuals seems to be loosely linked with the size composition. During the interval included in this study, the largest numbers of skipjack were taken either when small fish were especially numerous and very few large fish were available or when large skipjack were in a majority (fig. 16). When small fish outnumber the large, but are less than 10 times as numerous, there seem to be factors that work against the capture of a large number of individuals. These factors, if they exist, are probably related to the distribution of the various size groups in the population which supports the fishery. A hypothesis concerning the structure of this population is offered below.

Conjecture

In order to account for the variations in apparent abundance of particular size groups in the catches, it is necessary to hypothesize a skipjack population consisting of at least three and possibly one additional element. In the approximate order of their importance to the success of the fishery in 1952–53, these are as follows:

Group A: "Season fish," approximately 17–22 pounds in weight, which Brock assumes to be in either their second or third year of life. This group is migratory.

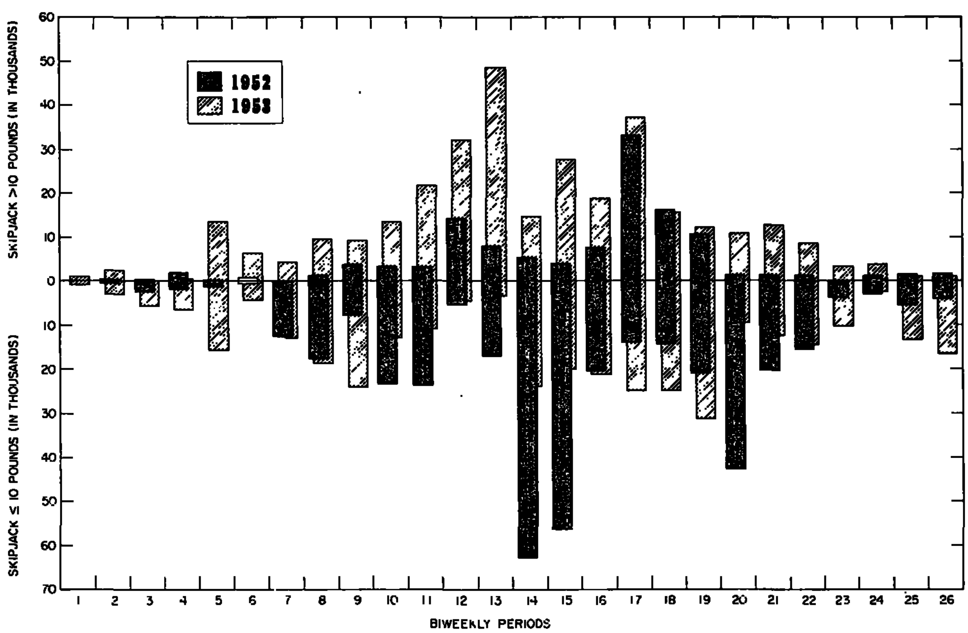

FIGURE 13.—Estimated numbers of large and small skipjack taken in the Oahu fishery, 1952–53, by biweekly periods.

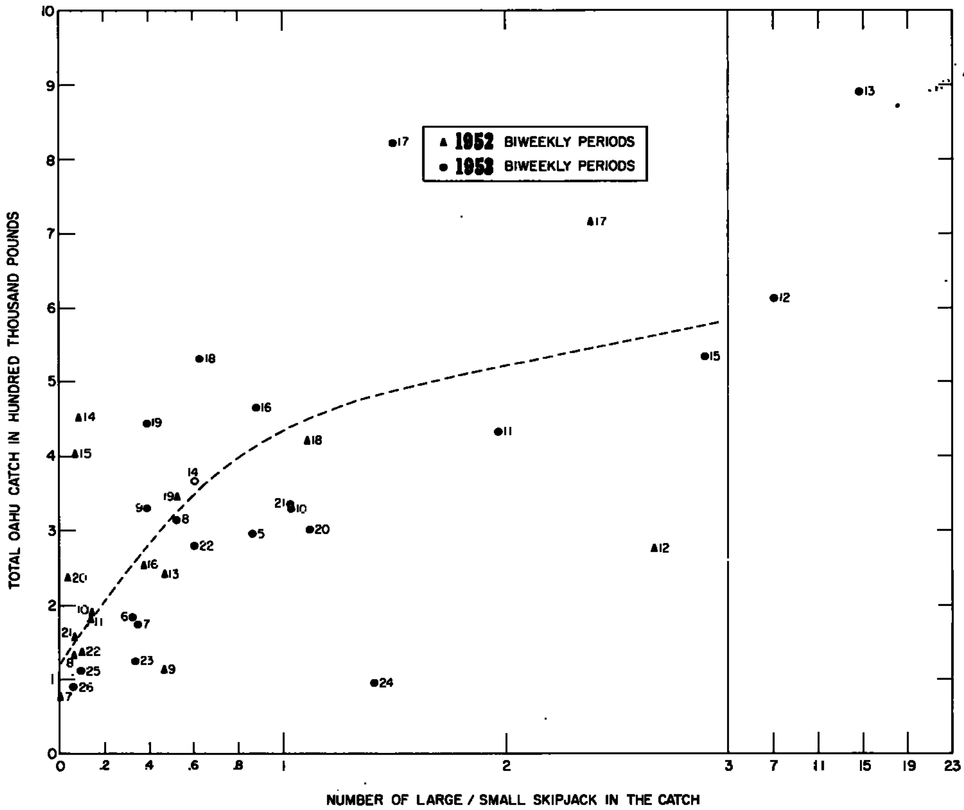

FIGURE 14.—Size composition and the total catch in the Oahu skipjack fishery, 1952–53.

Group B: Nonmigratory small fish, which during the summer months are about 4 to 8 pounds in weight. These fish occur in semi-permanent aggregations which are to be found in certain localities, usually near shore, where presumably oceanographic conditions are suitable for the concentration of food organisms. These fish, according to Brock's hypothesis, are a year younger than the season fish. This group serves as the main source of supply for some of the fishermen, but in general it functions as a reserve supply where most of the fishermen can use their bait, when larger fish are not available.

Group C: Large migratory skipjack, 28–32 pounds, which may be a year older than the season fish. This group seems to have been abundant during the first part of 1953 and accounts for the apparent early begining of the season in that year.

Group D: Migratory small skipjack. The existence of this group is not well established; however, the large numbers of small fish which appear suddenly in the fishery in periods 14, 15, and 20 of 1952 suggests that there may be a migratory group of small fish as well as the semiresident group.

In figure 16, catches of large skipjack numbering in excess of 15,000 were all made when season fish (group A) were apparently dominant in the fishery; the large catches of small skipjack, those in excess of 40,000, are presumed to result from the presence of migratory small fish (group D). The sharp decline in the number of periods with catches of small skipjack greater than 25,000 may indicate that this number is about the maximum number of nonmigratory fish (group B), which are available during a biweekly period. Except for period 17, 1953, the number of small fish in the catch declines as the number of large fish increases, which is consistent with the assumption that the number of small fish caught is inversely related to the availability of large fish. The extra-large migratory fish (group C) are distinguished by their greater average weight relative to the season fish, and not, at least during 1952–53, by their unusually large numbers. At the time of

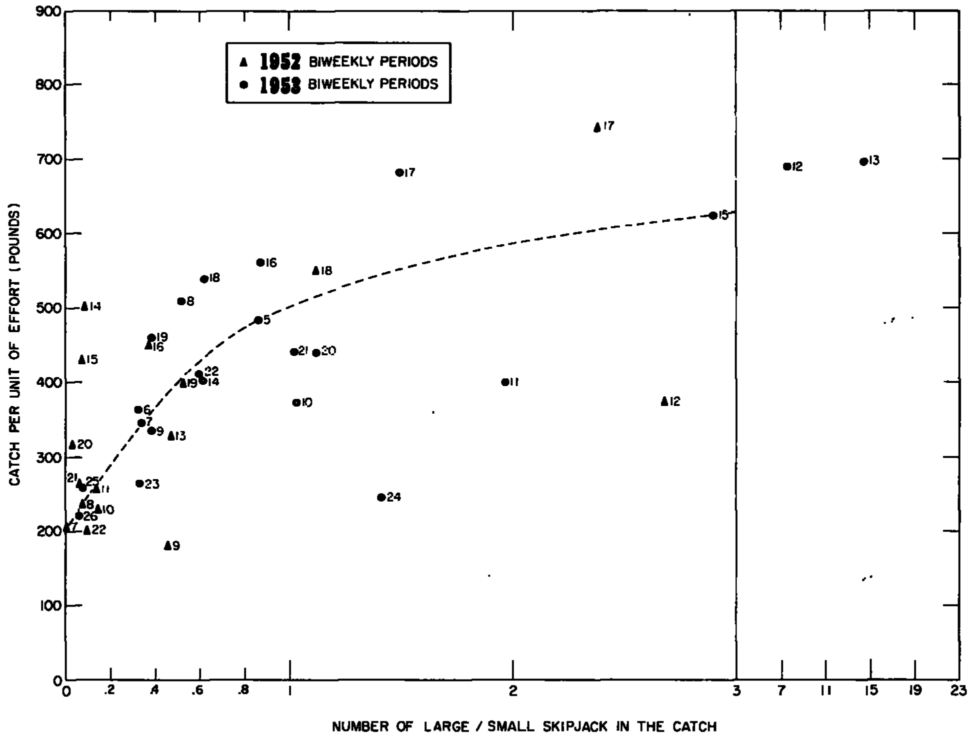

Figure 15.—Size composition and catch per unit-of-effort in the Oahu skipjack fishery, 1952–53.

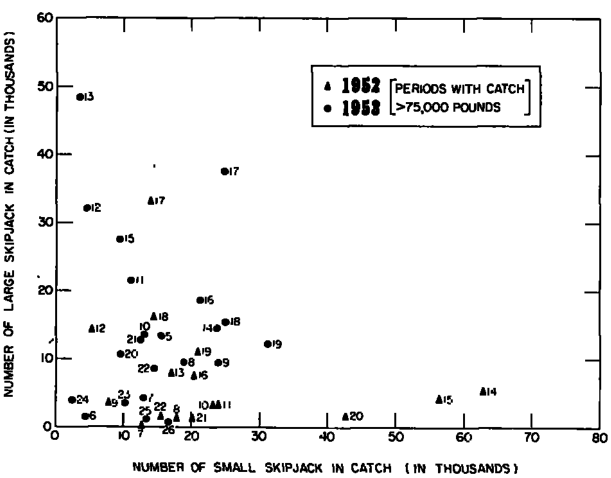

Figure 16.—Size composition and the number of skipjack caught in the Oahu fishery, 1952–53.

their appearance in the catch during periods 5 and 7–9, 1953 (fig. 12), they were associated with fairly large numbers of the nonmigratory small fish.

The fact that the three migratory groups seem to occur at different times suggests that there is little overlap in their distribution, but the catch records do not show this with certainty, for (see Sources of Error) the average weight of fish in the catch is a none too adequate index of size composition. The actual distribution of small skipjack is not defined by their appearance in the catch. It is possible that during the periods when the catch consists predominantly of large fish, small skipjack are also available, but have been rejected by the fishermen. In order to obtain information as to the quantity of small fish actually present, a method such as maintenance of logbooks in which the fishermen could record their observations of all fish sighted, whether fished or not, would be required.

The catch records provide little means of determining the relations between the four groups of skipjack which seem to make up the population exploited by the Hawaii fishery. It is quite probable that the small fish in both the migratory and semiresident groups furnish recruits for the season fish. The season fish of a given year may be the large fish of the next year. The long-term recovery of tagged specimens would appear to offer the best means of ascertaining the relations between these different groups of fish.

SUMMARY

1. The staff of the Honolulu Biological Laboratory is trying to determine the environmental conditions which influence the local availability of skipjack. Commercial catch records are a source of information.

2. Methods and sources of error are considered. Fish catch reports for 1952 (a poor year) and 1953 (a good year) were summarized by areas of the fishery and biweekly fishing periods. The unit of fishing effort, the productive fisherman-trip, is discussed.

3. The distribution of catches and effort in the 2 years was generally similar, with leeward Oahu contributing one-half the catch. Hawaii, windward Oahu, and Kauai fell well below leeward Oahu in productivity, while Maui and the oceanic region contributed insignificant proprotions.

4. Pounds caught per unit of effort increased from southeast to northwest in the fishery and from inshore to offshore, but these trends may result from differences in the fishery rather than to distribution of fish.

5. There was a positive correlation between the average weight per skipjack caught in various zones of the fishery and catch per unit of effort.

6. Catches (in pounds) during the fishing periods of 1953 were, with few exceptions, larger than those made during the corresponding periods of 1952.

7. In comparison with the seasonal trend in the fishery, the effects of rough weather (as indicated by periods of small craft warnings), were unimportant.

8. Large skipjack, from their appearance in the catches, seemed to have arrived first in leeward areas, and at the end of the season they last appeared in catches from leeward areas. In June and August of both years, concentrations of season fish occurred in windward Oahu and leeward Oahu, respectively.

9. The numbers of small fish taken by the Oahu fishery in 1952 and 1953 were approximately equal, but almost three times as many large fish were caught in 1953. In the Oahu region, there was almost one and one-half times the fishing effort in 1953 in comparison with 1952, and a much larger proportion was directed toward catching large skipjack.

10. Catch, effort and catch per unit of effort indexes have similar seasonal variations. The positive correlation between catch and catch per unit-of-effort is so close that there is little to be gained in using the catch per unit-of-effort as an index of apparent abundance in the fishery.

11. During the middle of 1953, the average weight of large skipjack increased at 0.25 pound per week, the growth rate for Hawaii skipjack estimated by Brock. This suggests that fish of the same age were constantly available to the fishery during this period.

12. The number of small skipjack in the catch varied inversely with the number of large fish.

13. A hypothesis for the structure of the skipjack population supporting the fishery is offered. The population has four groups: (1) season fish and (2) extra-large fish, both of which are migratory, and (3) a semiresident and (4) a migratory group of smaller skipjack.

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U. S. GOVERNMENT PRINTING OFFICE : 1962 O - 596500