A Summary of Sightings of Fish Schools and Bird Flocks and of Trolling in the Central Pacific

SPECIAL SCIENTIFIC REPORT---FISHERIES No. 154

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

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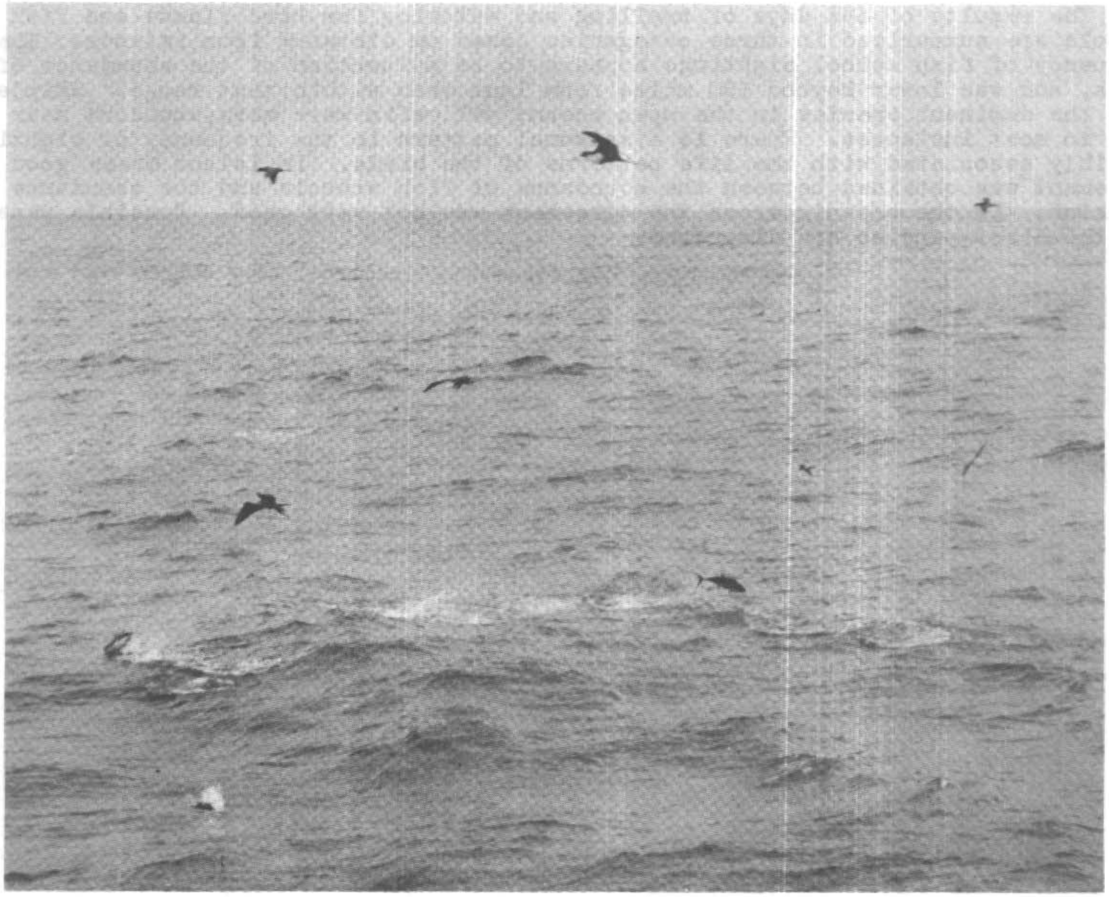

A SUMMARY OF SIGHTINGS OF FISH SCHOOLS AND BIRD FLOCKS AND OF TROLLING IN THE CENTRAL PACIFIC

By

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Special Scientific Report: Fisheries No. 154

WASHINGTON: JUNE 1955

ABSTRACT

The results of 546 days of trolling and watching for bird flocks and fish schools are summarized in three categories based on distance from islands. The frequency of fish school sightings appears to be a function of the abundance of birds, and was lower beyond 180 miles from land than within that range. Skipjack were the dominant species in the open ocean; yellowfin were more abundant near land in most instances. There is a seasonal pattern in the frequency of sightings, possibly associated with the life patterns of the birds. In island areas good agreement was obtained between the abundance of fish schools and the abundance of plankton. In the oceanic areas the agreement was not very good. Possible reasons for the discrepancies are discussed.

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There are three important types of tuna fisheries in the Pacific, two of which operate by finding and catching the fish on or near the surface. The third, long-line fishing, widely practiced by the Japanese in the western Pacific, operates by catching the large deep-swimming tunas that rarely appear at the surface and are never seen prior to capture. On the other hand, livebait fishing and purse seining, the former important both off Japan and the Americas, and the latter important only off the Americas, involve locating schools of fish before capturing them. As the extent of the resources of these surface and deep-swimming tunas in the central equatorial Pacific was little known, the Pacific Oceanic Fishery Investigations (POFI) has attempted to evaluate their fishery potential by studying their abundance and their relation to the oceanic circulation and productivity. This report, one of several resulting from these investigations, deals with the abundance and distribution of surface schools of tuna in the central equatorial Pacific.

Because of the vastness of the area to be explored and the small number of vessels available for the various types of fishing and oceanographic cruises that had to be made, it has been possible to cover only the most promising parts of the region with cruises expressly planned to locate and fish for surface schools. In order to secure information from a much broader area, systematic searching for visible indications of tuna schools and trolling to detect the presence of fish have been done routinely during all daylight runs of POFI vessels, whatever the primary objectives of the cruises on which they were engaged. This method of surveying essentially parallels the scouting techniques of the commercial surface fisheries, for most schools fished by purse-seine and livebait boats are located by seeing the fish in the water, by noting the presence of birds and other animals known to associate with tuna, or by capturing tuna on trolling lines.

This report is a biological evaluation of all the observations on surface tunas from the inception of the program in 1950 to April 1953 with the exception of the observations currently accumulating from a study around the Hawaiian Islands (Royce and Otsu 1955). The results significant to commercial trolling and livebait fishing have already been reported (Bates 1950, Ikehara 1953) and this aspect is not reconsidered here. In essence, we summarize and interpret what was seen from the bridge and what was caught from the stern during 546 days when research vessels were under way through the tropical and subtropical waters of the central Pacific.

The observations on fish schools and bird flocks are arranged to furnish comparisons among the various island groups in the central Pacific and comparisons between the vicinity of land and the open ocean, and to estimate variations in abundance associated with different periods of the year. The results of trolling are organized in the same manner as the sighting records. Finally, the resulting estimates of tuna abundance around certain islands and in limited portions of the open ocean are compared with the standing crop of plankton, in order to investigate the hypothesis that a larger supply of basic food should be associated with a larger population of animals farther up the food chain.

The recording of the numbers and types of fish schools and birds seen while the vessels were under way has usually been a duty of the wheel watch under the guidance of the scientist in charge, and credit is due the officers and fishermen of the research vessels John R. Manning, Hugh M. Smith, Charles H. Gilbert, and the charter vessel Cavalieri for the keen observation and the systematic recording of what they saw. Surface trolling and the maintenance of appropriate records of this operation have been the responsibility of the various scientific field parties.

The following lists include the birds and fishes sighted or caught during the period of observation. The first vernacular names are used in this report. The second, when given, are in common use in Hawaii. Birds are not dealt with specifically or as family groups because it was not always possible to identify them.

Fish:

Yellowfin tuna - ahi - Neothunnus macropterus (Temminck and Schlegel)
Skipjack - aku - Katsuwonus pelamis (Linnaeus)
Little tunny - kawakawa - Euthynnus affinis (Cantor)
Wahoo - ono - Acanthocybium solandri (Cuvier)
Dolphin - mahimahi - Coryphaena hippurus (Linnaeus)
Black marlin - a'u - Makaira mazara (Jordan and Snyder)
Barracuda - kaku - Sphyraena sp.
Red snapper - opakapaka - Lutianus sp.
Rainbow runner - kamani - Elagatis bipinnulatus (Quoy and Gaimard)
Needlefish - Belonidae
Jack - ulua - Caranx sp.

Birds:

Terns - Fam. Sternidae
Boobies - Fam. Sulidae
Bos'n birds - Fam. Phaethontidae
Albatrosses - Fam. Diomedeidae
Frigate birds - Fam. Fregatidae
Petrels and shearwaters - Fam. Procellariidae

VISUAL OBSERVATIONS ON FISH SCHOOLS AND BIRDS

Birds are considered with fish schools because about 85 percent of all fish schools sighted were accompanied by birds, and were located by first sighting the birds. The relation between fish and birds is probably more apparent in the central Pacific than along continental shores because the choppy seas characteristic of the subtropical Pacific nearly always preclude sighting a school of fish not accompanied by birds, unless the school is within a few hundred feet of the vessel. Although the difficulty of sighting birdless fish schools may tend to overemphasize the association between birds and fish schools, it has the obvious biological basis that both birds and fish have a common prey, the feeding fish often driving small fish and squid to the surface, where they are easy prey for birds. Thus we consider birds and surface schools together because they are associated in nature and because they are virtually inseparable in our observations.

Observational Procedure

For the recording of sightings of birds and fish the wheel watch is provided with a daily log (fig. 1), and is occasionally assisted by someone from the scientific party except during livebait fishing and purse seining, when a scientist is almost constantly on the bridge. Despite the constant effort to systematize the observations, a number of irregularities occur. For example, if a fisherman records a fish school near the end of his watch, that same school might be recorded a second time by the man who relieves him. Also, if a fish school or bird flock[1] crosses and recrosses the path of the vessel, that same school or flock might be recorded a number of times. Another difficulty is that the observations are not quantitative. That is, not all of the birds or fish actually in a given range from the vessel are recorded, and the proportion varies among observers and under various sea conditions. Such relative errors were not specifically considered, but their effect was minimized by pooling several days' observations.

1/ The term "bird flock" refers to a working flock of birds, that is, a group of birds that are feeding or searching for food more or less as a unit. Such aggregations generally consist of 10 or more birds, and may or may not accompany a school of fish. The term "fish school" refers only to instances of detecting fish in the water, with or without birds.

OCCURRENCE OF TUNA SCHOOLS, BIRDS, AND AQUATIC MAMMALS B6.1.1

M/V ______ Cruise ______ Date ______ Noon Position ______

At/on route from ______ to ______

Time: Began Watch

(LST) Ended Watch

Observer's Name

		TIME (LST)
Tuna Schools	Kind (if obvious)	yellowfin
		skipjack
		little tuna
		unidentified
	Size of school	small
		medium
		large
		undetermined
	Est. size of fish (lbs.)	
	No birds with school	
Bird Flocks	Size of flock	10 or less
		11 - 50
		50 or more
	Kinds in flock	terns
		boobies
		bo'sun birds
		frigate birds
		petrels or shearwaters
		other
	No tuna in evidence	
Scattered birds	Give number for each kind	albatross
		petrels or shearwaters
		boobies
		terns
		frigate birds
		bo'sun birds
		storm petrels
Porpoise	Give number	
	No tuna in evidence	
Other Animals		

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Figure 1.--The form used to record surface observations on POFI vessels. This log, introduced in January 1953, calls for essentially the same information as earlier editions.

Whenever possible, a positive identification was made of the fish making up the schools. Most of the identifications were made by skilled fishermen on the wheel watch, and such identifications are usually based on the type of birds working over the schools and the general behavior of the birds and fish. Generally, when a positive identification followed, the fishermen's judgement was confirmed. Positive identifications were possible only when the fish broke water near the boat, or when one or more were caught on the trolling lines. This happened so seldom that most of the records lack positive verification. However, we believe that the errors are few.

Scope and Organization of the Sightings

The fish and bird sightings were gathered from an area of approximately 8 million square miles (fig. 2). Over this area there were 546 days of observation during the period October 17, 1950, to April 4, 1953. The intensity of sampling is adequate to give a general picture of the distribution of birds and fish but in many instances is not adequate for defining seasonal and geographical variations in abundance for subareas.

Summarization of the sightings was facilitated by classifying the observations according to rectangles 1 degree of latitude by 1 degree of longitude, based on the ship's noon position. This could result in assigning an observation to a locality as much as 60 miles from its true occurrence, because of the distance travelled during the day. This is of little consequence in areas far from land, where the environment changes slowly, but may cause distortion close to land. All of the observations were entered on punchcards and further coded by month and year.

After coding, the observations were divided into three groups for study and analysis. The "island" observations consist of those made on days during which the noon position of the ship was within a 1° square a portion of which is within 60 miles of land (fig. 2). A second group, termed the "semioceanic" observations, is made up of sightings made on days when the noon position of the ship was within a 1° square a portion of which is between 60 and 180 miles from land. The balance comprises the "oceanic" observations. It will be realized upon reference to figure 3 that these limits are not perfectly realized because the configuration of the island shorelines necessitated a number of compromises.

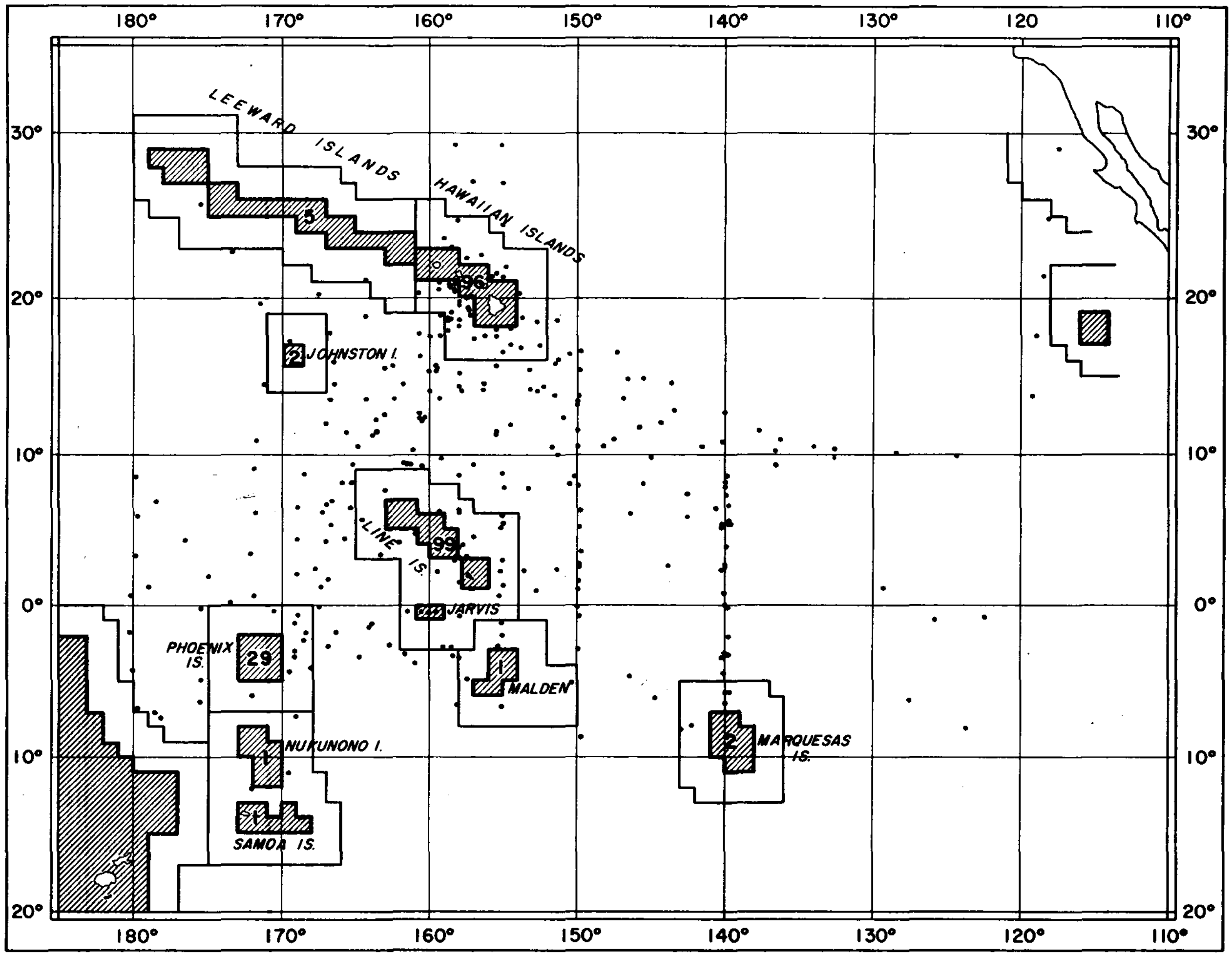

Figure 2.--Map of the central Pacific Ocean showing the demarcation into "island," "semioceanic," and "oceanic" provinces. Each dot represents the noon position for a day's observation in the semioceanic and oceanic areas. The number of days' observations in each island area is shown by the figures.

These three groupings were made to correspond roughly with elements in the habits of the birds and the fish which might affect their occurrence. We wished to ascertain whether waters in the immediate vicinity of land might not afford an environment of a special character, perhaps supporting denser populations of tuna than the offshore waters, for Reintjes and King (1953) have shown that the food of yellowfin tuna captured near islands differs qualitatively from that of yellowfin taken in the open ocean. The semioceanic zone (60 to 180 miles from land) is beyond the immediate influence of islands, judging by the stomach contents of the yellowfin, but is within reasonable flight range for island-based birds. And finally, since birds are the chief indicator of fish, it was thought that some difference in apparent abundance might be noted between the semioceanic zone and the truly oceanic areas beyond the possible daily flying range from islands, i.e., more than 180 miles from land.

Island Observations

The observations from the vicinity of islands were subdivided by islands or island groups (fig. 2) and tabulated by four periods of the year roughly corresponding to the temperate-zone seasons (table 1). The Hawaiian Islands group includes Hawaii, Lanai, Molokai, Maui, Oahu, Kauai, and Niihau. The balance of the Hawaiian Archipelago is designated as the Leeward Islands in table 1. For the purposes of this discussion the Line Islands comprise Christmas, Fanning, Palmyra, Washington,

Table 1.--Summary of island observations on fish schools and bird flocks

Locality	Period	Number of days		Yellowfin		Skipjack		Mixed[1]		Unidentified		Total fish schools		Bird flocks	
		Fishing and scouting	Running	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day
Line Is.	Mar.-May	26	6	16	0.5	0	0.0	2	0.1	15	0.5	33	1.0	33	1.0
	June-Aug.	4	3	13	1.9	1	0.1	4	0.6	3	0.4	21	3.0	27	3.9
	Sept.-Nov.	22	11	20	0.6	12	0.4	4	0.1	55	1.7	91	2.8	108	3.3
	Dec.-Feb.	8	19	7	0.3	4	0.1	3	0.1	24	0.9	38	1.4	71	2.6
Total and average[2]		60	39	56	0.8	17	0.2	13	0.2	97	0.9	183	2.1	239	2.7
Phoenix Is.	Mar.-May	-	3	0	0.0	0	0.0	0	0.0	2	0.7	2	0.7	6	2.0
	June-Aug.	3	4	8	1.1	6	0.9	0	0.0	5	0.7	19	2.7	26	3.7
	Sept.-Nov.	0	2	3	1.5	2	1.0	0	0.0	2	1.0	7	3.5	1	0.5
	Dec.-Feb.	3	14	3	0.2	1	0.1	0	0.0	5	0.3	9	0.5	13	0.8
Total and average[2]		6	23	14	0.7	9	0.5	0	0.0	14	0.7	37	1.9	46	1.8
Hawaiian Is.	Mar.-May	0	9	0	0.0	7	0.8	0	0.0	7	0.8	14	1.6	18	2.0
	June-Aug.	33	15	4	0.1	81	1.7	0	0.0	20	0.4	105	2.2	100	2.1
	Sept.-Nov.	4	31	0	0.0	17	0.5	0	0.0	21	0.6	38	1.1	47	1.3
	Dec.-Feb.	0	4	1	0.2	1	0.2	0	0.0	1	0.2	3	0.8	3	0.8
Total and average[2]		37	59	5	0.1	106	0.8	0	0.0	49	0.5	160	1.4	168	1.6
Leeward Is.	Mar.-May	1	4	1	0.2	3	0.6	0	0.0	25	5.0	29	5.8	47	9.4
Jarvis I.	June-Aug.	1	0	2	2.0	0	0.0	0	0.0	1	1.0	3	3.0	4	4.0
	Dec.-Feb.	1	1	0	0.0	0	0.0	0	0.0	3	1.5	3	1.5	4	2.0
Malden I.	Sept.-Nov.	1	0	0	0.0	2	2.0	0	0.0	4	4.0	6	6.0	6	6.0
Starbuck I.	Dec.-Feb.	1	0	0	0.0	3	3.0	0	0.0	0	0.0	3	3.0	3	3.0
Johnston I.	Mar.-May	0	2	0	0.0	0	0.0	0	0.0	5	2.5	5	2.5	8	4.0
Marquesas Is.	June-Aug.	0	2	0	0.0	2	1.0	0	0.0	0	0.0	2	1.0	3	1.5
Samoa Is.	Dec.-Feb.	0	1	0	0.0	2	2.0	0	0.0	7	7.0	9	9.0	9	9.0
Nukunono Is.	Dec.-Feb.	0	1	0	0.0	0	0.0	0	0.0	1	1.0	1	1.0	1	1.0

1/ Yellowfin and skipjack.

2/ Unweighted averages.

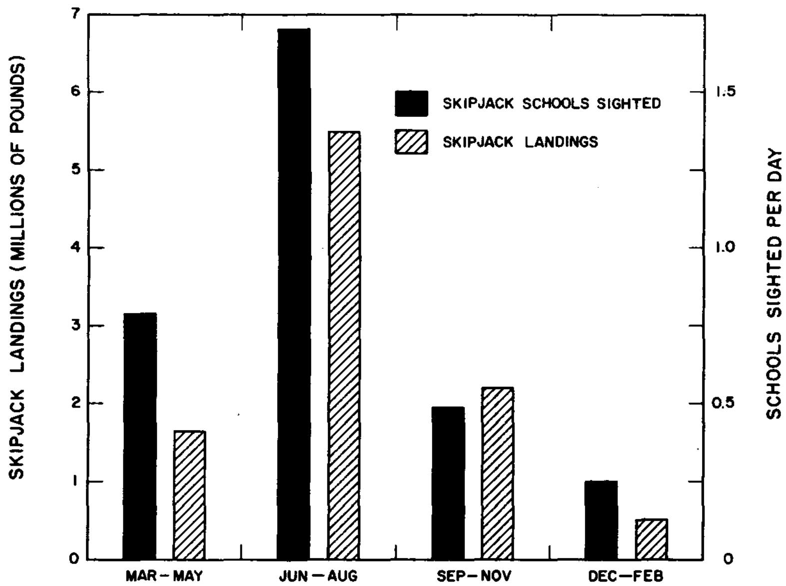

Figure 3.--Comparison between average Hawaiian skipjack landings (1950-1952) and POFI surface sightings of skipjack schools in the Hawaiian Islands area.

and Kingman Reef; the Phoenix Islands are Hull, Canton, Sidney, Phoenix, Birnie, Enderbury, Gardner, and McKean.

For the Hawaiian Islands it is possible to examine the reliability of sightings as a measure of relative abundance by comparing our sightings of skipjack with the commercial landings of skipjack in Hawaii. The same seasonal trends are evident in both the sightings and landings (fig. 3). Discrepancies are minor and occur only in the details. For instance, commercial landings (expressed in pounds) treble in passing from the March-May period to the June-August period, while the number of schools sighted only doubles. Because the fishing fleet is usually larger in summer and the size of skipjack is also larger, the greater increase in landings than in sightings is not surprising. It is clearly evident that the relatively sparse surface sightings from POFI vessels furnished a description of seasonal variation in skipjack occurrence that is very similar to the description one gets from the catching activity of a much larger number of commercial fishing vessels.

The graphic summary of the observations made at the three principal island groups (fig. 4) reveals a considerable difference in the species composition of the tuna schools between the Hawaiian Islands on the one hand and the Line and Phoenix islands on the other. The skipjack is by far the most commonly sighted tuna in the Hawaiian Islands. This species also is by far the dominant one in the catch of the commercial fishery (June 1951). In the Line and Phoenix islands skipjack form a substantial part of the surface sightings, but they are considerably outnumbered by the yellowfin (Ikehara 1953). This difference between the Line and Hawaiian islands is also found in the populations of subsurface tunas detected by longline fishing. In the Line Islands, where surface yellowfin are abundant, subsurface yellowfin are also abundant (Murphy and Shomura 1953a). In the Hawaiian Islands, where surface yellowfin are scarce in relation to skipjack, the subsurface yellowfin are less than one-fourth as abundant as in the Line Islands. These differences may well be caused by differences in basic productivity or by combinations of ecological factors that tend to favor one or the other species of tuna in each of the localities.

In contrast to the differences in species composition among the three island areas, the general patterns of seasonal abundance are surprisingly similar (fig. 4). Each of them shows a peak in abundance of skipjack, yellowfin, and all species combined during the period June to November. Minor differences among island groups are to be expected in view of the small number of observations during some of the periods in some areas. This similarity of seasonal pattern suggests that common factors are operating in the three areas. It is difficult to suggest common factors that might affect fish abundance in all three island areas simultaneously, since they are widely separated in space and are in different current systems. Possibly these seasonal cycles are merely apparent changes in abundance brought about by fluctuations in the bird populations, for, as has been shown, most fish schools are located by birds.

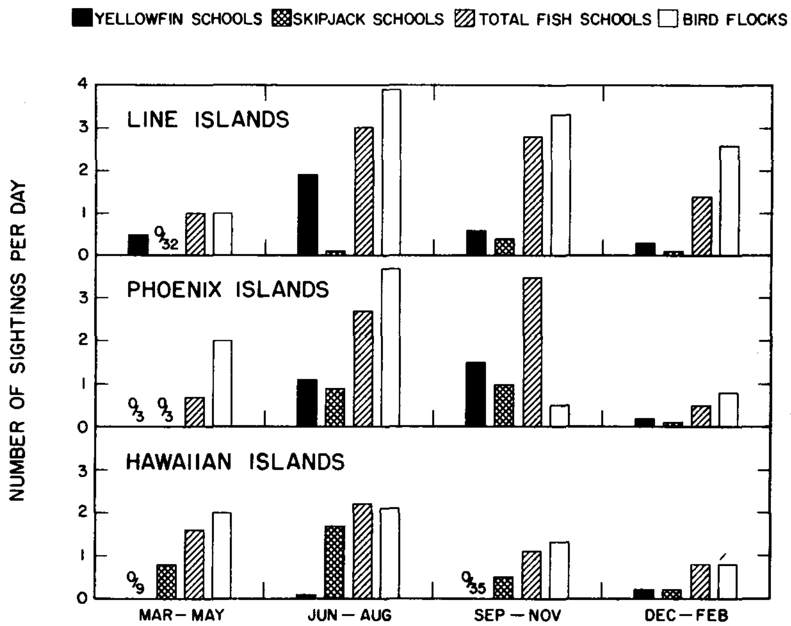

Figure 4.--Seasonal distribution of tuna school sightings in the Line, Phoenix, and Hawaiian islands. (Total fish schools per day includes unidentified schools as well as yellowfin and skipjack, table 1. The figures on the graph, such as 0/32, indicate a number of days of scouting, in this case 32, during which no schools were seen.)

Semioceanic Observations

The semioceanic sightings, made between 60 and 180 miles from land, are treated somewhat differently from the island observations in that the numbers of birds sighted are listed in addition to the numbers of flocks. This was possible because the estimates of the size of the smaller flocks in the areas farther from land were reasonably accurate.

Comparison of the semioceanic fish sightings (table 2) and the island sightings (table 1) shows that yellowfin schools are more abundant close to land. In the Line and Phoenix islands yellowfin predominated near land and skipjack dominated the semioceanic zone. In the Hawaiian area all yellowfin noted were close to the islands, although skipjack predominated there as well as offshore. Thus it appears that in the central Pacific surface schools of yellowfin are rather closely associated with land; however, this is not true of the deep-swimming yellowfin (Murphy and Shomura 1953a).

Although the composition of the fish schools is different farther from land, the abundance, disregarding kind, appears to be nearly as great in the semioceanic as in the island areas (1.3 versus 1.8 per day, tables 1 and 2). If the number of schools sighted is taken as an index, it can be concluded that the area immediately surrounding these small islands (0 to 60 miles from land) has about the same productivity as the outlying zone (60 to 180 miles from land), but the ecology of the waters immediately around the islands favors surface schools of yellowfin tuna and that of more distant waters favors schools of skipjack.

Oceanic Observations

Oceanic observations are considered to be those made farther than 180 miles from land. Rather than associate them with any particular island group they were tabulated by areas of the ocean 10 degrees of latitude high and 10 degrees of longitude wide (table 3). The bird sightings were tabulated by number only, because the occurrence of flocked birds is a rarity at these distances from emergent land.

It has already been inferred that there are fewer birds in the open ocean than in the island and semioceanic areas. This is very pointedly shown in table 3, for the mean number of birds sighted per day for all oceanic observations is only 37.2, whereas 135.6 were seen per day in the semioceanic areas (table 2). Fish schools were sighted at the rate of only 0.5 per day in the oceanic area as against 2.3 per day in the semioceanic areas. Thus it appears that the reduction in the fish schools sighted is almost exactly proportional to the reduction in numbers of birds. This, coupled with the acknowledged difficulty of locating schools of fish unless they are accompanied by birds, leads us to question whether the actual abundance of fish is any less in the open ocean than it is nearer to land.

Table 2.--Summary of semioceanic[1] observations associated with particular island groups

Locality	Period	Number of days: Fishing and scouting	Number of days: Running	Yellowfin: Number	Yellowfin: Number per day	Skipjack: Number	Skipjack: Number per day	Unidentified: Number	Unidentified: Number per day	Total fish schools: Number	Total fish schools: Number per day	Bird flocks: Number	Bird flocks: Number per day	Number of birds[3]: Number	Number of birds[3]: Number per day
Line Is.	Mar.-May	0	1	0	0.0	1	1.0	0	0.0	1	1.0	1	1.0	30	30.0
	June-Aug.	0	2	0	0.0	0	0.0	0	0.0	0	0.0	1	0.5	37	18.5
	Sept.-Nov.	0	3	1	0.3	2	0.7	6[2]	2.0	9	3.0	12	4:0	162	54.0
	Dec.-Feb.	0	17	0	0.0	10	0.6	21	1.2	31	1.8	36	2.1	959	56.4
Total and average[4]		0	23	1	0.1	13	0.6	27	0.8	41	1.4	50	1.9	1188	39.7
Phoenix Is.	Mar.-May	0	4	0	0.0	1	0.2	4	1.0	5	1.2	8	2.0	310	77.5
	June-Aug.	0	2	2	1.0	3	1.5	1	0.5	6	3.0	13	6.5	615	307.5
	Sept.-Nov.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dec.-Feb.	0	4	0	0.0	0	0.0	0	0.0	0	0.0	1	0.2	43	10.8
Total and average[4]		0	10	2	0.3	4	0.6	5	0.5	11	1.4	22	2.9	968	131.9
Hawaiian Is.	Mar.-May	0	10	0	0.0	3	0.3	5	0.5	8	0.8	12	1.2	558	55.8
	June-Aug.	1	8	0	0.0	4	0.4	10	1.1	14	1.6	19	2.1	1212	134.7
	Sept.-Nov.	0	16	0	0.0	10	0.6	7	0.4	17	1.1	16	1.0	1283	80.2
	Dec.-Feb.	0	7	0	0.0	1	0.1	1	0.1	2	0.3	3	0.4	144	20.6
Total and average[4]		1	41	0	0.0	18	0.4	23	0.5	41	1.0	50	1.2	3197	72.8
Leeward Is.	Mar.-May	0	2	0	0.0	2	1.0	1	0.5	3	1.5	3	1.5	85	42.5
Jarvis I.	Sept.-Nov.	0	1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	35	35.0
	Dec.-Feb.	0	2	0	0.0	2	1.0	0	0.0	2	1.0	8	4.0	352	176.0
Malden I.	June-Aug.	0	1	0	0.0	1	1.0	0	0.0	1	1.0	3	3.0	94	94.0
Starbuck I.	Sept-Nov.	0	1	0	0.0	0	0.0	2	2.0	2	2.0	2	2.0	86	86.0
	Dec.-Feb.	0	5	0	0.0	2	0.4	17	3.4	19	3.8	22	4.4	1172	234.4
Johnston I.	Mar.-May	0	1	0	0.0	1	1.0	0	0.0	1	1.0	2	2.0	11	11.0
Marquesas Is.	Mar.-May	0	1	0	0.0	0	0.0	0	0.0	0	0.0	1	1.0	16	16.0
	June-Aug.	0	4	0	0.0	1	0.2	3	0.8	4	1.0	5	1.2	309	77.2
Samoa - Nukunono Is.	Dec.-Feb.	0	3	0	0.0	0	0.0	2	0.7	2	0.7	2	0.7	12	4.0

1/ Semi-oceanic observations were considered to be from 60 to 180 miles from the islands.
2/ 2 schools of little tunny.
3/ Includes scattered birds.
4/ Unweighted averages.

Table 3.--Summary of oceanic observations of fish schools and birds. The sightings are summarized by rectangles bounded by 10° of latitude and 10° of longitude and identified by coordinates of the southeast corner

Location	Number of days	Number of birds	Fish schools: Yellowfin	Skipjack	Unidentified	Total
20°N - 110°W	2	6	-	-	-	-
20°N - 150°W	5	17	-	-	-	-
20°N - 160°W	1	7	-	-	-	-
20°N - 170°W	1	-	-	-	-	-
10°N - 110°W	2	147	-	-	2	2
10°N - 120°W	1	234	-	-	3	3
10°N - 130°W	5	321	1	-	2	3
10°N - 140°W	16	970	-	1	8	9
10°N - 150°W	32	1,395	-	7	12	19
10°N - 160°W	29	171	-	1	-	1
Q - 120°W	2	34	-	-	-	-
Q - 130°W	12	286	1	1	2	4
Q - 140°W	18	800	1	5	5	11
Q - 150°W	9	780	1	3	8	12
Q - 160°W	22	645	-	-	8	8
Q - 170°W	11	100	-	-	1	1
Q - 180°	1	3	-	-	-	-
10°S - 120°W	4	316	-	3	6	9
10°S - 130°W	4	46	-	-	-	-
10°S - 140°W	9	187	-	-	1	1
10°S - 150°W	2	12	-	1	-	1
10°S - 160°W	9	975	1	8	8	17
10°S - 170°W	8	182	-	-	4	4
Total	205	7,634	5	30	70	105

As in the semioceanic areas, the dominant fish species in the oceanic area is the skipjack. This lends further weight to the conclusion that surface schools of small yellowfin are principally associated with land in the central Pacific, although they have been observed far from land.

There is some indication of seasonality in the frequency of sightings of oceanic fish schools and birds. As shown in figure 5, there were more schools sighted from June to November than during the rest of the year. This seasonal pattern is similar to that of the Line and Phoenix islands (fig. 5), but is divergent from the Hawaiian Islands (the island group for which we have the most sightings), as shown in figure 6.

The differences between the Hawaiian and oceanic sightings may be the result of the nesting cycles of the birds. The peak in Hawaiian sightings (March-August) occurs during what is presumably the peak in the nesting cycles of the birds (Richardson and Fisher 1950), when their daily flying range tends to be restricted to the vicinity of the nesting sites. On the other hand, the peak in the oceanic cycle appears to occur at the season when nesting is reduced (September-November) and the birds are free to fly greater distances from land.

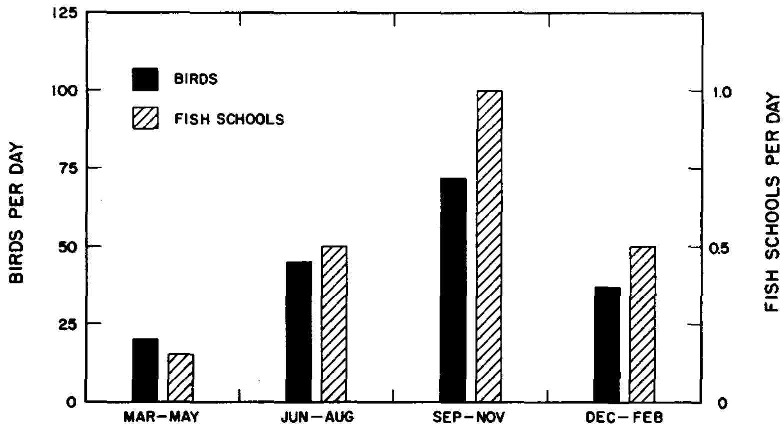

Figure 5.--Seasonal distribution of oceanic fish school and bird sightings.

It is evident from the sighting records in table 3 that there was great variation in the numbers of birds and fish schools seen in different parts of the oceanic zone. It is impossible to examine this variation to determine longitudinal trends, but sampling in the central portion of the area (140° to 170°W. longitude) is adequate to permit study of latitudinal variation. Considerable interest is attached to latitudinal variation because the sightings were made over the three current systems of the equatorial Pacific: the North Equatorial Current, lying roughly north of 10°N. latitude, the Countercurrent between 5° and 10°N. latitude, and the South Equatorial Current south of the Countercurrent.

The rate of sighting birds and fish schools varied considerably among the different current systems (fig. 7) and within current systems. In the North Equatorial Current, north of 20°N., abundance is very low, though of course the sample is inadequate. Between 10° and 20°N. abundance is greater, though still of a rather low order of magnitude. In the Countercurrent abundance is high, an observation first made by Brooks (1934), who noted that birds were more abundant in that region than to the north or south during a crossing from San Francisco to Tahiti near 140°W. longitude. Birds and fish schools are relatively scarce in the South Equatorial Current between the Equator and 5°N. latitude. South of the Equator our observations suggest a large population of birds and fish (fig. 7), but examination of the field records shows that nearly all of the schools of fish were sighted during one week of February 1952, and very few sightings were made during the balance of the year (the observations were distributed through seven months). This is not typical of the information from the other areas, for the field records show that the fish schools and birds noted were well distributed in time and space. Thus we are inclined to the view that the high rate of sighting south of the Equator (fig. 7) is in part a sampling accident, and that the information is not strictly comparable with that obtained north of the Equator.

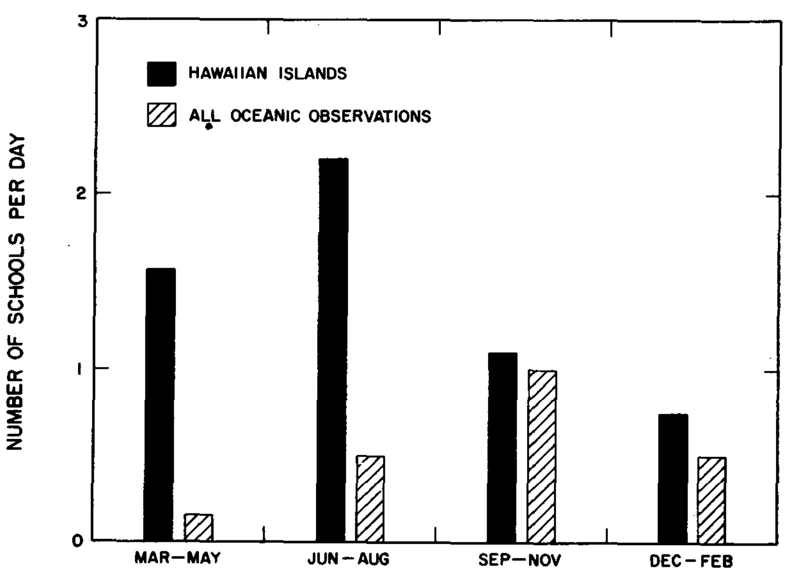

Figure 6.--Comparison of number of schools sighted per day in Hawaiian waters and oceanic waters.

The distribution of surface schools and birds (fig. 7) is different from the distribution of subsurface or deep-swimming fishes, particularly the yellowfin tuna, as noted by Murphy and Shomura (1953a, b). These papers report the results of systematic longline fishing across the equatorial current systems. The yellowfin catches summarized in figure 8 show that, on the average, abundance is zero in the North Equatorial Current,

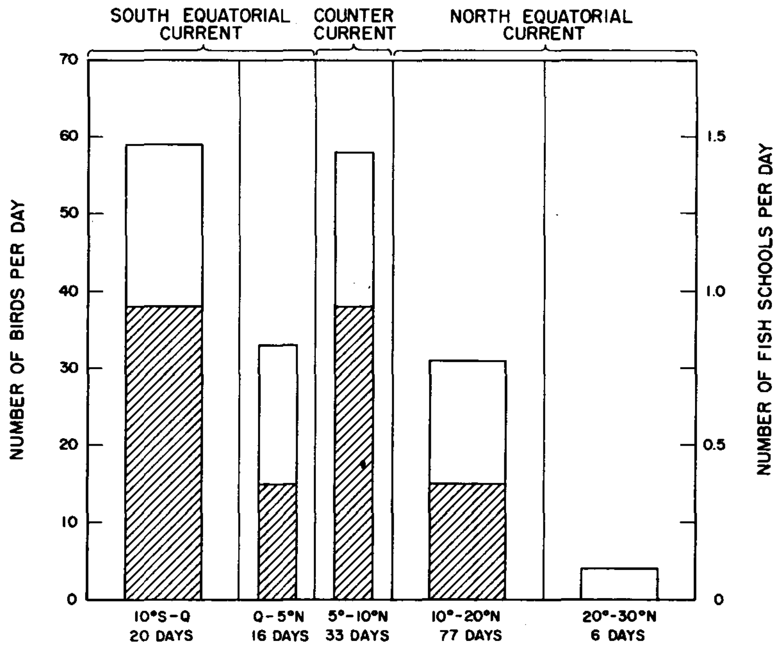

Figure 7.--Oceanic sightings between 140°W. longitude and 170°W. longitude summarized by latitude. The height of the bar represents the average bird count per day, and the shaded portion the average number of fish schools per day, whether or not they were accompanied by birds. The number of days' observations is shown below each bar. The zone between the Equator and 10° N. has been considered in two portions because the Countercurrent lies between 5° and 10°N. North of the Countercurrent is the North Equatorial Current and south of it flows the South Equatorial Current.

moderate in the Countercurrent, greatest in the South Equatorial Current between the Equator and 5°N., where surface fish schools were scarce, and relatively low south of the Equator.

The difference between surface sightings and longline catches may be related to the difference in the species of fish involved, for the longline takes mostly yellowfin and to a lesser extent bigeye tuna and the surface sightings are predominantly skipjack. These species undoubtedly have different ecological requirements, and so there is little reason to expect their distributions to be coincidental.

TROLLING

Trolling represents a method of directly sampling the surface populations of fishes. It is a direct measure inasmuch as the location of fish is not so dependent on some associated phenomenon such as flocks of birds. For this reason it potentially provides an independent check on the relative abundance of fish as determined by sightings. There were two types of trolling carried out on POFI vessels, secondary and primary trolling.

Secondary trolling is conducted as a routine activity whenever vessels are under way during daylight hours unless it would interfere with more important missions. The speed of the vessel is not adjusted to facilitate trolling, and no attempt is made to fish in favorable locations or to work the schools of fish encountered. The usual cruising speed of the POFI vessels (7 to 10 knots) does not preclude hooking fish, but there have been occasions when hooked fish were lost because of the difficulty of handling them from a rapidly moving vessel. After January 1952 the method of surface trolling was standardized. Two 25-fathom lines were fished, one from each side of the stern. One line was equipped with a 6-ounce leadhead jig with white and Plymouth Rock feathers and a 9/0 double hook. The second line had a red bone jig with a 9/0 double hook. Before that time two lines of varying lengths and a variety of lures had been used, but we doubt that these variations had a significant effect on the catch.

On a number of occasions the primary type of trolling has been done, particularly in the vicinity of islands. In contrast to secondary trolling, the ship's speed is brought down to about 6 knots and attempts are made to work favorable areas and the schools of fish encountered. Usually 4 to 6 lines were fished from the stern of the vessel, and various lures were used. These lures were of the same general type and size as those used in secondary trolling. (For details of primary trolling see Bates 1950.)

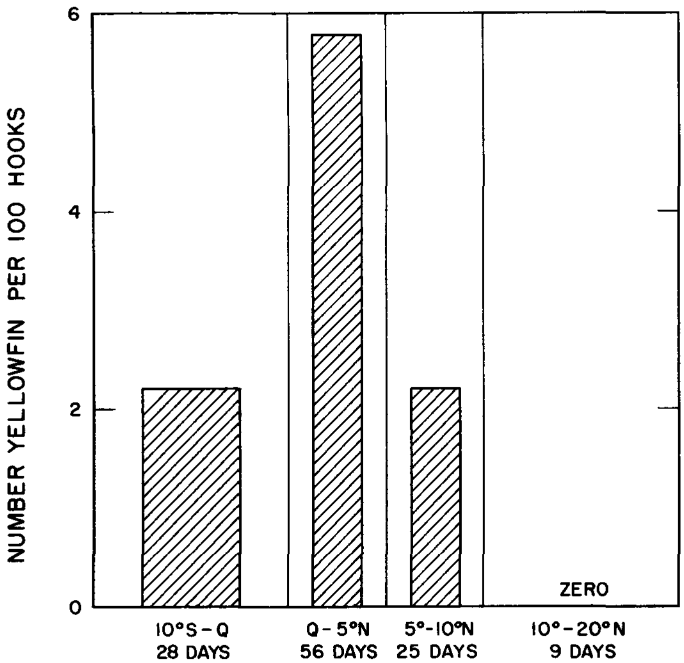

Figure 8.--Results of longlining between 140°W. and 170°W. longitude during 1950-52.

The results of the 8,937 line-hours of secondary and primary trolling have been organized geographically in the same manner as the surface sightings, the two types of trolling being treated separately. These data will be examined for information on the distribution of tuna and will be compared with the surface sightings for consistency between the two measures of abundance. The seasonal distribution of the troll catches will not be analyzed because of the paucity of data.

It should be noted particularly that trolling, both secondary and primary, fails to sample skipjack as efficiently as it samples yellowfin. It is commonplace to troll through visible concentrations of skipjack without strikes, whereas yellowfin are nearly always taken when there are indications of their presence. In the Hawaiian area Welsh (1950) reported capture of approximately one yellowfin for each two skipjack by trolling, a ratio in close agreement with POFI secondary trolling in the Hawaiian area. But contrasted with this, commercial landings by the Hawaiian livebait fishery are less than 1 yellowfin for 100 skipjack, showing that trolling takes a far smaller proportion of skipjack than livebait fishing does. Paralleling these observations, the results of surface sightings discussed in earlier sections indicate, for all areas, a greater relative abundance of skipjack than was shown by the troll catches, leading to the conclusion that skipjack are relatively more abundant in most areas than is indicated by trolling.

Island Trolling

One of the earliest published reports on island tuna trolling in the central Pacific (Chapman 1946) indicated an abundance of skipjack and yellowfin in the vicinity of the Line and Phoenix islands. Welsh (1950) has published the results of a general trolling survey of the Hawaiian Islands, indicating that skipjack and little tunny predominated in that area. Bates (1950), reporting on a portion of the POFI trolling in the Line Islands, suggested that the island populations of yellowfin there were abundant enough for commercial trolling.

There has been no primary trolling by POFI in Hawaiian waters, but data of Welsh (1950) are available for comparison with the various island areas. He reported on 307 hours of trolling with 7 lines, the total catch amounting to 548 fish: 46 skipjack, 23 yellowfin, 350 little tunny, 101 dolphin, 8 jacks, and 20 wahoo. The survey was made during the period March 1948 to June 1949, and most of the trolling was done around Oahu. In terms of catch per 100 line-hours, the average for all tunas was approximately 19.5. By species it was 1.1 yellowfin, 2.1 skipjack, and 16.3 little tunny. These catches are lower than those reported by Tester (1952) (about 27 tuna per 100 line-hours), but his fishing was all done in a particularly productive area off Kaneohe Bay, Oahu.

Primary trolling by POFI vessels in the Line Islands (table 4) indicated a much higher catch rate than in the Hawaiian Islands, and the catches were dominated by yellowfin. There were 890 line-hours of trolling with a catch of 241 yellowfin, 5 skipjack, 171 wahoo, 11 jacks, 8 rainbow runners, and 24 miscellaneous fish. The average for tuna was 27.6 per 100 line-hours, practically all yellowfin. The sizes of the yellowfin ranged from 13 to 69 pounds. It is probable that larger yellowfin

Table 4.--Results of trolling in island areas

Species	Number caught, by locality											
	Line Islands	Phoenix Islands	Hawaiian Islands	Leeward Hawaiian Islands	Malden Island	Starbuck Island	Jarvis Island	Samoa Islands	Marquesas Islands	Nukunono Island	Johnston Island	Total
Primary trolling:												
TUNAS												
Yellowfin	241	34	-	1	7	11	29	-	-	-	-	323
Skipjack	5	0	-	0	0	0	0	-	-	-	-	5
Little tunny	0	0	-	0	0	0	0	-	-	-	-	-
Total	246	34	-	1	7	11	29	-	-	-	-	328
MISCELLANEOUS												
Dolphin	0	0	-	0	0	0	0	-	-	-	-	-
Wahoo	171	7	-	0	3	8	12	-	-	-	-	201
Jacks	11	0	-	0	1	0	0	-	-	-	-	12
Rainbow runner	8	0	-	0	0	0	0	-	-	-	-	8
Others	24	0	-	0	1	0	0	-	-	-	-	25
Total	214	7	-	0	5	8	12	-	-	-	-	246
Grand Total	460	41	-	1	12	19	41	-	-	-	-	574
Line hours	890	79	-	13	14	20	12	-	-	-	-	1,028
Tuna/100 line hours	27.6	43.0	-	7.7	50.0	55.0	241.7	-	-	-	-	31.9
All species/100 line hours	51.5	51.8	-	7.7	85.6	95.0	341.7	-	-	-	-	55.8
Secondary trolling:												
TUNAS												
Yellowfin	34	1	3	0	0	0	0	0	0	0	3	41
Skipjack	1	0	6	0	0	0	0	0	0	0	0	7
Little tunny	0	0	1	7	0	0	0	0	0	0	0	8
Total	35	1	10	7	0	0	0	0	0	0	3	56
MISCELLANEOUS												
Dolphin	0	0	11	2	0	0	0	1	0	0	0	14
Wahoo	17	3	2	1	0	0	0	0	0	0	0	23
Jacks	1	0	0	0	0	0	0	0	0	0	0	1
Rainbow runner	2	0	0	0	0	0	0	0	0	0	0	2
Others	2	0	0	0	0	0	0	0	0	0	0	2
Total	22	3	13	3	0	0	0	1	0	0	0	42
Grand total	57	4	23	10	0	0	0	1	0	0	3	98
Line hours	739	339	930	173	8	10	46	29	22	32	56	2,384
Tuna/100 line hours	4.7	0.3	1.1	4.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4	2.3
All species/100 line hours	7.7	1.2	2.5	5.8	0.0	0.0	0.0	3.4	0.0	0.0	5.4	4.1

were not as well represented in the catches as they were in the population since the largest fish hooked were most frequently lost.

Trolling surveys in the Phoenix Islands indicate an even higher catch rate than in the Line Islands (table 4), but the sample is somewhat smaller and may not be as reliable. The Phoenix Island catches closely resembled in species composition those from the Line Islands, with a catch of 43.0 tuna per 100 line-hours, all of them yellowfin.

The amount of primary trolling at other island areas in the central Pacific (table 4) was inadequate for an evaluation of abundance, but very good catch rates for yellowfin were experienced during the few hours of trolling performed at Malden, Starbuck, and Jarvis islands.

The secondary trolling (table 5) is less reliable than the primary trolling as an index of relative abundance among the several island groups because tuna trolling in all the island areas, possibly excluding the Hawaiian Islands, is particularly productive in very specialized locations, usually near reefs. Inasmuch as these locations were only occasionally and unsystematically traversed during secondary trolling the catches do not afford unbiased estimates for the several island areas. The records will, however, be useful later in the discussion.

Oceanic and Semioceanic Trolling

The 5,525 line-hours of secondary oceanic and semioceanic trolling resulted in a very low tuna catch. Only 70 fish were landed: 7 skipjack, 8 yellowfin, 40 dolphin, 12 wahoo, 1 little tunny, 1 black marlin, and 1 barracuda (table 5). This is an average of 1.3 fish per 100 line-hours, 0.3 of which were tuna.

Table 5.--Results of semioceanic and oceanic trolling

	Semioceanic	Oceanic
Line-hours	1,834	3,691
Skipjack	3	4
Yellowfin	3	5
Little tunny	-	1
Wahoo	3	9
Black marlin	-	1
Barracuda	-	1
Dolphin	20	20
Total catch	29	41
Catch/100 line-hours	1.6	1.1

It is of particular interest to note that the nearly equal catches in the oceanic and semioceanic trolling (table 5) are at variance with the number of surface schools, which were seen 5 times as frequently in the semioceanic zone (page 7). Thus it appears likely that the greater relative number of sightings in the semioceanic areas is mainly a reflection of the greater abundance of birds within 180 miles of islands. This confirms the surmise in the previous section that the fish school sightings decreased when passing from the semioceanic to the oceanic provinces because the bird population decreased.

The secondary trolling in the semioceanic zone resulted in smaller tuna catches (0.3 per 100 line-hours) than the secondary trolling in the combined island zones (2.3 per 100 line-hours) (tables 4 and 5), suggesting differences in abundance that were not evident from the sightings. Actually, the higher troll catch in the island zones probably does not represent a difference in general tuna abundance but in the main reflects the higher relative populations near land of easily captured yellowfin. In addition, the reef areas, known to harbor concentrations of yellowfin, are occasionally traversed during secondary trolling, erratically increasing the results of insular secondary trolling.

DISCUSSION

The sightings and trolling catches suggest several generalizations on the distribution of surface tunas in the central Pacific. First, close to the reefs there appear to be concentrations of tunas dominated by the yellowfin. Beyond the immediate vicinity of the reefs the presence of land does not seem to affect the abundance of tuna but does affect the species composition. Yellowfin schools are sighted more frequently in the island than in the semioceanic and oceanic zones, where skipjack dominate. This may indicate that the presence of land alters the ecology in such a way that yellowfin can exist in larger numbers in the adjacent waters. Skipjack, on the other hand, dominate the semioceanic and oceanic zones, being almost completely replaced by yellowfin in the island zones of the Line and Phoenix islands, and to a limited degree of the Hawaiian Islands.

Since it appears that the mere presence of land does not alter the density of the tuna population, except in limited areas, we should consider the possibility that the different levels of abundance (disregarding species) in different island and oceanic areas are a function of different levels of general productivity of the oceanic waters. To examine this hypothesis, it is necessary to suppress variation in the tuna population associated with different seasons, either by comparing different areas in the same season or by making comparisons between areas having representation throughout the year. The latter course appears the sounder, because we do not have the information on homologous seasons, and if comparisons are limited to segments of the year there is danger of comparing one area at its peak with another area at an "off season." Finally, comparisons must be restricted to areas or zones equally accessible to aquatic birds, because most schools are overlooked unless working birds advertise their presence.

In order to compare the relative abundance of fish schools with productivity we shall use the standing crop of zooplankton, the level of which has been shown to be related to the oceanic circulation (Cromwell 1954, King and Demond 1953, Sette MS, etc.), as an index of relative oceanic productivity. Considering the three island areas, King and Demond (1953) provide data indicating that the relative order of island groups with respect to zooplankton abundance is Hawaiian Islands, Phoenix Islands and Line Islands in ascending order. If these same groups of islands are listed according to the apparent abundance of fish schools, using the average of the unweighted average quarterly sighting rates from table 1 (1.4, 1.9, 2.1), their order remains unchanged. A similar comparison of fish-school abundance using the semioceanic sightings (table 2) gives the same order, though the comparison is less precise because of poor stratification in time.

In the oceanic area the abundance of surface fish and birds does not conform to the abundance of plankton as well as in the insular areas. King (MS) indicates that north of 10°N. the abundance of zooplankton is relatively low as is also the abundance of birds and fish schools. In the Countercurrent he reports considerably more zooplankton than to the north, and here surface schools are also relatively abundant. In the South Equatorial Current between the Equator and 5°N. latitude he reports even more zooplankton than in the Countercurrent, but fish schools are only about as abundant as in the zooplankton-poor region north of the Countercurrent. South of the Equator (0° to 10°S.) there is somewhat less zooplankton than in the Countercurrent, but fish schools are slightly more abundant than in any of the zones under consideration, though there is reason to suspect that the sampling south of the Equator has not been adequate.

The discrepancies between fish schools and plankton in the oceanic area may not be in serious conflict with the general idea that the size of the population of animals (fish and birds) at one trophic level is related to the size of the population at lower levels (plankton), for we are here considering only one element of the fish population (surface schools that are mostly skipjack). It was pointed out that the distribution of surface schools does not correspond with the distribution of subsurface or deep-swimming tunas (mostly yellowfin). The fact that deep-swimming yellowfin tuna are most abundant in regions of few surface tuna schools

(0 to 5°N. lat.) suggests that if it were possible to consider quantitatively the higher vertebrate fauna as a whole, there might be better agreement in the horizontal distribution of the groups of organisms at different trophic levels.

However, the question still remains: Why does the zone with low numbers of surface skipjack schools coincide with the zone of high numbers of deep-swimming yellowfin tuna? Sampling is, of course, always suspect, particularly in this instance, when the critical region (0° to 5°) is represented by only 16 days, though these were well distributed in time and space. The possibility of competition with other species was inferred above. An alternative hypothesis is that the vertical distribution of food organisms in the region of low surface sightings differs in such a way that the fish do not spend as large a fraction of their life at the surface as they do in the adjacent areas to the north. Or, even if differences in the vertical distribution of food organisms do not affect fish, the differences might affect the density of aquatic birds, thus altering the apparent abundance of surface schools of fish.

SUMMARY

1. During the period October 17, 1950, to April 4, 1953, there were 546 days during which surface trolling and bird and fish watches were maintained on POFI vessels in the central Pacific. These observations have been separated into "island" (0 to 60 miles from land), "semioceanic" (60 to 180 miles from land), and "oceanic" (more than 180 miles from land) provinces.

2. The seasonal pattern of frequency of daily sightings in the Hawaiian Islands area closely resembles the seasonal pattern of landings of the commercial tuna fishery. The frequency of fish sightings appears to be a function of the abundance of birds.

3. The seasonal patterns in the Hawaiian, Line, and Phoenix islands are similar, with greater frequency of sightings during the period June to November.

4. Skipjack dominate the surface schools in the Hawaiian area, and yellowfin dominate in the Line and Phoenix islands.

5. The frequency of sightings in semioceanic areas is approximately the same as in the island areas.

6. The frequency of sightings in the oceanic areas in general was lower than in island and semioceanic areas.

7. Skipjack are evidently the dominant surface tuna in the oceanic and semioceanic areas, and surface yellowfin, if not dominant, at least are relatively more abundant close to land.

8. There is an indication of seasonality in the abundance of surface schools in the oceanic area, probably differing from the seasonal pattern in island and semioceanic areas.

9. Trolling indicated a relatively high abundance of tunas, particularly yellowfin, in the near proximity of islands, with a uniformly low abundance in the semioceanic and oceanic areas.

10. The evidence indicates that the abundance of surface schools near islands in the central Pacific is a function of the standing crop of plankton. In the oceanic area the abundance of surface schools and birds does not closely parallel the abundance of plankton.

APPENDIX

Table 6.--List of cruises during which the data used in this report were gathered

Vessel	Cruise number	Cruise period	Primary mission	Captain of vessel	Field party chief
Hugh M. Smith	7	Oct. 17 to Nov. 30, 1950	Longline fishing	O. J. Heggem	F. C. Cleaver
"	8	Jan. 14 to Mar. 14, 1951	Hydrographic	O. J. Heggem	J. E. King
"	9	May 5 to July 2, 1951	Livebait fishing	A. K. Akana	F. C. June
"	10	July 19 to July 31, 1951	Hydrographic	R. L. Johnson	J. E. King
"	11	Aug. 20 to Oct. 6, 1951	Longline - hydrographic	R. L. Johnson	T. Cromwell
"	12	Oct. 23 to Nov. 3, 1951	Hydrographic	R. L. Johnson	H. J. Mann
"	14	Jan. 23 to Mar. 13, 1952	Hydrographic	R. L. Johnson	G. I. Murphy
"	15	May 21 to July 1, 1952	Hydrographic	G. L. Wilkinson	J. E. King
"	16	July 23 to Aug. 29, 1952	Hydrographic	R. L. Johnson	T. Cromwell
"	17	Sept. 5 to Sept. 15, 1952	Hydrographic	R. L. Johnson	J. E. King
"	18	Oct. 7 to Nov. 22, 1952	Longline - hydrographic	R. L. Johnson	G. I. Murphy
"	19	Jan. 8 to Feb. 12, 1953	Longline - hydrographic	R. L. Johnson	J. E. King
"	20	Feb. 25 to April 4, 1953	Hydrographic	R. L. Johnson	T. Cromwell
John R. Manning	4	Oct. 26 to Dec. 6, 1950	Purse seining	H. Olsen	T. J. Roseberry
"	5	Jan. 11 to Mar. 2, 1951	Purse seining	H. Olsen	J. E. Rawlings
"	6	Mar. 30 to May 17, 1951	Purse seining	H. Olsen	T. J. Roseberry
"	7a	June 5 tq June 18, 1951	Purse seining	H. Olsen	E. L. Niska
"	7b	July 21 to Aug. 15, 1951	Purse seining	J. Vilicich	G. I. Murphy
"	7c	Aug. 21 to Sept. 8, 1951	Purse seining	J. Vilicich	G. I. Murphy
"	8	Sept. 23 to Oct. 19, 1951	Gillnet fishing	G. L. Wilkinson	W. M. Matsumoto
"	9a	Nov. 13 to Nov. 19, 1951	Plankton sampling	G. L. Wilkinson	J. E. King
"	9b	Nov. 26 to Nov. 27, 1951	Plankton sampling	G. L. Wilkinson	J. E. King
"	11	Jan. 24 to Mar. 19, 1952	Longline fishing	G. L. Wilkinson	G. I. Murphy
"	12	Aug. 6 to Sept. 15, 1952	Longline fishing	G. L. Wilkinson	W. F. Royce
"	13	Oct. 16 to Dec. 6, 1952	Longline fishing	G. L. Wilkinson	T. Otsu
"	14	Jan. 22 to Mar. 25, 1953	Longline fishing	G. L. Wilkinson	W. G. Van Campen
Charles H. Gilbert	1	May 20 to June 21, 1952	Longline fishing	R. L. Johnson	W. G. Van Campen
Cavalieri	1a	June 11 to July 1, 1952	Longline fishing	R. E. K. D. Lee	D. L. McKernan
"	1b	Aug. 13 to Sept. 27, 1952	Longline fishing	R. E. K. D. Lee	D. L. McKernan

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