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Distribution, Relative Abundance, and Movement of Skipjack Tuna, *Katsuwonus pelamis*, in the Pacific Ocean Based on Japanese Tuna Longline Catches, 1964-67

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ABSTRACT

Catch data of the Japanese tuna longline fishery from 1964 to 1967 were analyzed to determine the distribution, abundance, and movement of skipjack tuna, *Katsuwonus pelamis*, in offshore waters of the Pacific Ocean.

Large skipjack tuna, as well as larvae, were found to be concentrated mainly in the east central equatorial Pacific. Movement of skipjack tuna stocks was determined by following the shifting of high-CPUE (catch per unit effort) cells from one quarter to the next. The apparent movement of skipjack tuna stocks in the Pacific appeared to coincide with the circulation of the major ocean currents; counterclockwise in the southern hemisphere and clockwise in the northern hemisphere, except in the eastern Pacific where the current flow is counterclockwise. The movement patterns of high-CPUE suggested that skipjack tuna adults or their progeny could move from one area to the next. The movement pattern was used also to determine the probable migratory routes followed by skipjack tuna tagged in the eastern Pacific and recovered near the Hawaiian and Christmas islands.

INTRODUCTION

Skipjack tuna, *Katsuwonus pelamis*, are taken near the surface and at moderate depths in the Pacific Ocean, but the surface fisheries, utilizing pole and line and purse seine, account for about 99% of the catch. For various reasons, most of the catches throughout the major fisheries are made within 320 km (ca. 200 miles) of shore (Fig. 1). Consequently, although much has been learned about the skipjack tuna within the surface fisheries, knowledge of their distribution and movements in mid-oceanic areas is limited.

In an attempt to determine the population structure and migration of the skipjack tuna in mid-oceanic areas, Miyake (1968) examined the longline catch data of Japanese commercial (1956-64) and research (1949-65) vessels. He did not draw any conclusions from his study because he believed the data were inadequate.

Kasahara (1968) also examined the Japanese longline catch data to determine the distribution and centers of abundance of skipjack tuna in the Pacific Ocean. His report included hypothetical migratory routes of skipjack tuna as postulated by Naganuma (unpublished manuscript[2]) based on the catches and monthly variations in length frequencies of skipjack tuna taken by the Japanese longline fishery (year not given). Certain aspects about the routes postulated by Naganuma require clarification; for example, no return routes toward the equator are given for fish in the central and western North Pacific, and the direction of movement of skipjack tuna in the central South Pacific differs from the results of my study.

My study also is based upon the Japanese tuna longline catch data to determine centers of skipjack tuna abundance and, by tracing the seasonal shifting of high catch-rate areas, to derive the migration paths of skipjack tuna in the Pacific Ocean. As might be expected in studies of this kind, some degree of subjectivity was involved in the analyses. Nevertheless, models such as this are necessary first step in advancing our knowledge about the oceanwide movement of the skipjack tuna.

LONGLINE CATCH DATA

Source of Data

Several sources of tuna longline data are available, but the data are not all equally useful. Miyake (1968) gives a detailed account of the nature of these data. The best data are those published in the annual report of effort and catch statistics by area in the Japanese tuna longline fishery beginning with the year 1962 (Fisheries Agency of Japan, Research Division, 1965, 1966, 1967a, 1967b, 1968, 1969). However, because the Japanese Government's requirement that all fishing vessels submit copies of their fishing logbooks at the termination of each trip did not go into effect until 1963 and because the extent of longline fishing coverage in the eastern and southern Pacific was poor through the first quarter of 1963 (Miyake 1968), data for 1962 and 1963 are not included in this study.

Evaluation of Longline Data

The tuna longline is a passive gear designed to catch large fish about 70 to 145 m below the surface (Yoshihara 1954). Its design and fishing characteristics are not ideal for catching skipjack tuna, but in the absence of

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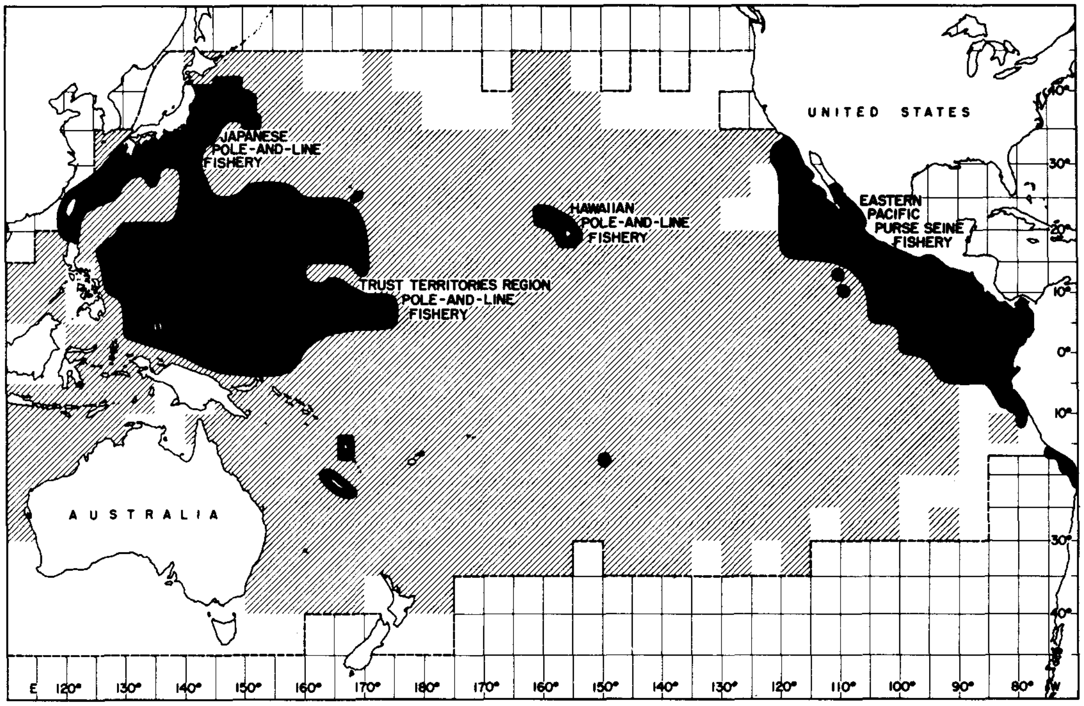


Figure 1.—Geographical locations of skipjack tuna fisheries in the Pacific Ocean. The dark shaded areas denote surface fisheries; the the light shaded areas denote areas where skipjack tuna have been taken by the Japanese tuna longline fishery. The broken lines indicate the northern and southern limits of the longline fishery.

adequate catch data from mid-oceanic areas using other means, the longline data can be helpful in providing clues to the distribution of skipjack tuna on an ocean-wide basis. The extensive use of longlines geographically (Fig. 1) and in all months of the year makes the data especially useful for this purpose.

Certain characteristics of the longline gear affect the catch and catch data, and these should be cited so that conclusions drawn from the data are viewed in the proper perspective. First, the catches of skipjack tuna by this gear are extremely small. In the years 1962-66, for example, the catch of skipjack tuna in the Japanese commercial tuna longline fishery averaged 1,180 metric tons per year, as compared with an average of 130,000 metric tons caught by the pole-and-line fishery. The smallness of the catch reflects the inefficiency of the gear for taking this species, but, because of the wide areal coverage by this gear, these data should be useful for determining areas of high or low relative abundance.

Second, longlines tend to catch the large fish, although there is evidence that shows this gear to be capable of catching smaller ones also. Miyake (1968) examined the lengths of skipjack tuna caught by longline and by pole and line from the Japanese mother ship *Tenyo Maru* off the Solomon Islands and found that fish taken by longline were significantly larger than those taken by pole and line. Length-composition data for longline-caught skipjack tuna from other areas in the Pacific also show this tendency toward larger fish (Fig. 2), but in the U.S. Trust Territory of the Pacific Islands, for example, the longline catches were composed mainly of fish less than 65 cm, the same group that makes up the bulk of the pole-and-line catch. Longline catches of fish less than 55 cm (3.5 kg) are not uncommon, and the smallest skipjack tuna recorded by scientists of the National Marine Fisheries Service, Honolulu Laboratory measured only 35 cm (Murphy and Shomura 1955).

Third, although the Japanese Government issued regulations in 1963 requiring all tuna fishing vessels to submit copies of their fishing logbooks after each trip, it may be that not all longline-caught skipjack tuna were recorded, since this species is of minor economical importance to the longline fishery and is taken incidentally to other tunas. Failure to do so by these longliners is suspected from the low proportion (expressed as percentages) of skipjack tuna recorded compared to those landed (Table 1). In Table 1, the number of skipjack tuna recorded was converted to weight, using 6.88 kg as the mean weight of skipjack tuna taken on longlines. The mean weight was obtained by converting the mean fish length from four areas of the Pacific Ocean (Fig. 2, panel B), using the length to weight relationship, $\text{Log}_{10} W = -8.342 + 3.368 \text{ Log}_{10} L$, developed by the Honolulu Laboratory (the length to weight relationship is based on 1,298 skipjack tuna caught in Hawaiian waters, including both males and females measuring from 32.7 to 87.7 cm). In early years, 1962-64, the proportion of skipjack tuna recorded was extremely low, averaging 21.3%, but in later years, 1965-67, it rose to an average of 60.5%.

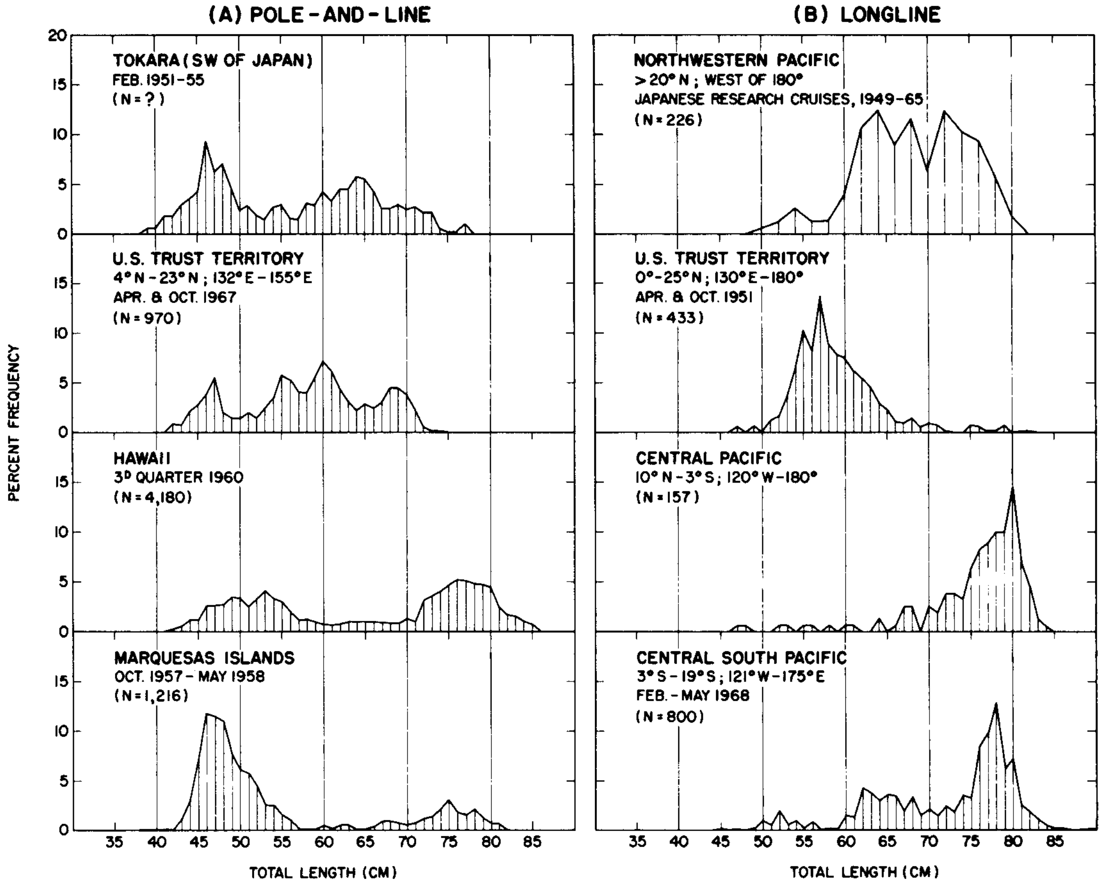


Figure 2.—Length compositions of skipjack tuna taken with pole-and-line and longline gear in various parts of the Pacific Ocean. [Source of data: Panel A—Tokara from Kawasaki (1965); U.S. Trust Territory from Tohoku Regional Fisheries Laboratory (n.d.); Hawaii from Rothschild (1965); Marquesas Islands from Wilson, Nakamura, and Yoshida (1958). Panel B—Northwestern Pacific from Miyake (1968); U.S. Trust Territory from Murphy and Otsu (1954); central Pacific from Murphy and Shomura (1953, 1955); and Shomura and Murphy (1955); central South Pacific from files NMFS Honolulu Laboratory.]

Table 1.—Estimated ratio of skipjack tuna recorded to skipjack tuna landed in the Japanese longline fishery, 1962-67.

Year	Skipjack recorded[1]		Total skipjack landed[2]	Proportion of skipjack recorded	Average proportion of skipjack recorded
	Number	*Metric ton*	*Metric ton*	*Percent*	*Percent*
1962	20,000	137.6	1,175	11.7	
1963	52,000	357.6	1,082	33.0	21.3
1964	42,000	289.0	1,505	19.2	
1965	105,000	722.4	1,170	61.7	
1966	97,000	667.4	1,175	56.8	60.5
1967	94,000	646.7	1,025	63.1	

[1]Data from Fisheries Agency of Japan, Research Division (1969).
[2]Data from Japan, Ministry of Agriculture and Forestry. Statistics and Survey Division (1963, 1964, 1966, 1967, 1968, 1969).

Miyake (1968) pointed out the possibility that differences between small and large vessels in reporting skipjack tuna catch data could result in geographical bias of the catches, since smaller vessels (20- to 50-ton class) operate only in near coastal waters, whereas larger vessels (>50-ton class) tend to operate farther away (vessel sizes are in gross metric tons). The data, in fact, show that large vessels fished also in areas fished by small vessels. To determine whether there was any difference in recording by vessel size, the quarterly catch rates (skipjack tuna per 1,000 hooks) of small and large vessels in each 5° area fished by both were compared, using the Wilcoxon matched-pair, signed-rank test (Siegel 1956). The tests were made on the premise that the catch rates of small and large vessels fishing in the same area and same quarter would be comparable, so that any large differences would be attributable to differences in recording. Zero catches by both vessel size categories in the same area were excluded, since it could not be established whether these were due to nonrecording or to absence of fish. The tests indicated that the catch rates, and therefore the recording of skipjack tuna caught, were not significantly different (Table 2) between large and small vessels. Hence, it seems unlikely that smaller vessels fishing only in the western Pacific had biased the catches geographically.

Finally, because longliners are fishing for species of tunas other than skipjack, the selection of fishing sites and competition for hooks could affect the catches of skipjack tuna adversely. Any such effect, however, would lose its importance for this study, since in most areas where other tunas are abundant, skipjack are also present, and competition with other tuna species would occur throughout the range of skipjack tuna distribution.

In summary, although the longline catch data for skipjack tuna are affected by certain characteristics of the gear and of the fishery, they appear adequate for my purpose.

Table 2.—Probabilities (two-tailed) of differences in recording skipjack tuna caught on longline between small (20-50) and large (50-200) vessels by quarters (vessel sizes in gross metric tons). The numerals in parentheses indicate vessels having recorded significantly more skipjack tuna: (1) small vessels, (2) large vessels.

Year	First quarter	Second quarter	Third quarter	Fourth quarter
1963	0.3628	—	0.0588	0.8026
1964	0.3370	0.6872	0.0404(1)	0.7948
1965	0.3168	0.4472	0.0602	0.0022(2)
1966	0.8258	0.0014(1)	0.0750	0.8494
1967	0.5156	0.6892	0.2984	0.8966

DISTRIBUTION OF EFFORT

Rothschild (1966) published a summary of effort of the Japanese longline fishery for 1953-63, in which each year's distribution of effort in each 20° area was given as a percentage of that year's total effort. His report shows a gradual eastward expansion of the fishery, and although fishing had approached the coastal waters of North, Central, and South America by 1962, it was not until the following year that adequate coverage was attained in the eastern Pacific. In my study the quarterly effort in numbers of hooks for each 5° area was averaged for 1964-67 and contour lines were drawn at 100,000-hook intervals (Fig. 3).

The figure shows that heavily fished areas are located near Japan in all four quarters, off southeastern Australia in the second and third quarters, and in the eastern Pacific in the first, third, and fourth quarters. Near Japan, the concentration of effort is not only the highest, but remains high throughout the year because the area is accessible to large vessels as well as small ones that make repeated trips during the year. The concentration of high effort shifts from south of Japan in the first and second quarters to east of Japan in the third and fourth quarters, reflecting the seasonal movement of the albacore, *Thunnus alalunga*, (Van Campen 1960) and the bigeye tuna, *T. obesus*, which are the main species of tunas fished by the longliners in this region. Both the route and time of the shift generally agree with that of skipjack tuna caught by surface gear within the area (Kimura 1949). The heavy effort off Australia in the second, third, and perhaps the fourth quarters is expended mainly for southern bluefin tuna, *T. maccoyii*, and albacore (appendix figures 2 and 5; Fisheries Agency of Japan, Research Division, 1967a, 1967b, 1968, 1969); while in the eastern Pacific, fishing is concentrated off the northern coast of South America in the first and fourth quarters for bigeye tuna and striped marlin, *Tetrapturus audax*, and off Baja California in the third and fourth quarters for striped marlin (Kume and Joseph 1969).

The effort is more evenly distributed, though at lower levels, over the equatorial region between lat. 20°N and 20°S. Moderate fishing prevails in an almost continuous band along the equator from the eastern to the western Pacific for the greater part of the year. This band is interrupted over a relatively short distance only during the last quarter.

RELATIVE ABUNDANCE OF SKIPJACK TUNA

Distribution of Catch Per Unit Effort

To show the relative abundance of skipjack tuna taken by longlines, the catch per unit effort (CPUE), expressed here as number of skipjack tuna caught per 1,000 hooks per quarter in all 5° areas fished, was calculated and plotted for the 4 yr. Because of skewed distribution of the catches, the geometric mean was calculated for each quarter's catches and contour lines were drawn to emphasize high-CPUE areas (Figs. 4-7).

The distribution of CPUE (Figs. 4-7) indicates widespread occurrence of skipjack tuna in the Pacific Ocean. The north-south distribution is expanded latitudinally in the west due largely to the greater poleward dispersion there of warm water inhabited by the tunas. The distribution is generally narrow in the eastern Pacific where cooler waters flowing toward the equator tend to restrict the poleward dispersion of the skipjack tuna. The predominance of zero-catch areas (indicated by -'s) at both the northern and southern fringes during most quarters assured that fishing had occurred over the whole range of adult skipjack tuna distribution.

The contoured areas of above-average CPUE appear either singly or in clusters in various parts of the Pacific. To facilitate the discussion the Pacific Ocean was partitioned into western (A), central (B), and eastern (C) regions (Figs. 4-7). Boundary lines were drawn as close as possible along lines of apparent breaks in the distribution of above-average CPUE areas.

In region A, north of the equator, high catch rates occurred sporadically; in 1964, for example, they occurred in all four quarters, but in 1965-67 in only two quarters. The above-average CPUE cells there were small and seemed to be associated with seasons and areas: in the second and third quarters off Japan, and in the first, second, and fourth quarters east of the Philippine Islands. South of the equator high-CPUE cells generally occurred off northeastern Australia in the fourth and first quarters and off southeastern Australia in the second and third quarters. Cells of high CPUE, however, seemed less consistent from year to year off Australia than in the adjacent region B. In 1966, for example, high CPUE occurred only in the first quarter, and in both 1964 and 1965 they were not as extensive as in 1967. Here as in other regions interyear differences probably relate to changes in gross oceanographic conditions.

In region B, south of latitude approximately 10°N, the high-CPUE cells were most extensive and persistent throughout the year. In most quarters, these cells straddled the equator, but in some they were displaced slightly to the south. The cells also expanded and contracted, or were displaced to the east or west seasonally, but without any obvious regularity. The number and locations of these cells varied from quarter to quarter and from year to year. Of particular interest about the area is that it is also where skipjack tuna larvae have been found in abundance (see later discussion), and it may well be the main spawning grounds of skipjack tuna of the central and eastern Pacific.

North of lat. 10°N, the high-CPUE cells occurred in the Hawaiian to Leeward Islands area and in the Wake to Marcus Island area west of long. 180°. These high-CPUE cells generally occurred farther to the north in the fourth and first quarters than they did in the second and third quarters. The cells in the Wake-Marcus area were not consistent from year to year; the CPUEs were high in the fourth quarter in 1964 and first quarter in 1965, nil in 1966, and high in the first and second quarters of 1967. In the Hawaiian area, the high-CPUE cells were often contiguous with the large high-CPUE area straddling the equator. This occurred in the first quarter 1964, second, third, and fourth quarters 1965, and second and fourth quarters 1966. The contiguity of high-CPUE cells in Hawaiian waters with the large equatorial high-CPUE cell in the east-central Pacific seems to be associated with the annual surface catches of the Hawaiian pole-and-line fishery. In 1964, 1966, and 1967, when the high-CPUE cells in the two areas were contiguous in fewer than two quarters, the Hawaiian pole-and-line catches were below the 1952-70 long-term average catch of 4,311 metric tons, in 1965, however, when the high-CPUE cells were contiguous in three successive quarters, the Hawaiian pole-and-line catch was 7,329 metric tons, the highest in the history of the fishery and 70% above the long-term average catch.

In region C, south of the equator, the high-CPUE cells were not extensive, but were persistent throughout most of the year. During some quarters these cells were contiguous with those of region B; in others they were discrete and were found either further south or east. North of the equator high-CPUE cells generally occurred near the equator adjacent to and often as part of the central Pacific (region B) high-CPUE area. They appeared more consistently in the first and fourth quarters. In waters closer to Mexico and California, the cells of high CPUE occurred in all 4 yr but they were not all large or equally close to shore. Prominent high-CPUE cells nearshore occurred only in the fourth quarter of 1965 and in the third and fourth quarters of 1967. In both years, the skipjack tuna landings in the eastern Pacific surface fishery were high; in fact the 1967 catch was the highest ever recorded there.

In region C north of the equator, particularly around the southern half of Baja California in waters bounded by lat. 20° and 30°N and long. 110° and 120°W, the Japanese longliners also fish for swordfish, *Xiphias gladius*. This fishing is done at night, and both the gear change and the time of fishing adversely affect the capture of skipjack tuna. According to Kume and Joseph (1969, Fig. 4), night fishing in the area accounted for 21% of the longline effort (in sets) in 1964-66, mostly (about 75%) in the fourth quarter. If the night fishing effort is deducted from the total longline effort, the CPUE of skipjack tuna in this area will be higher. The resulting changes in CPUE, however, will not materially change the contours as shown in Figures 4-7.

Salient Features in the Distribution of Catches and Catches Per Unit Effort

Several features stand out in the distributions of catches and cells of high CPUE in the Pacific. The first is the irregular north-south displacement of boundaries of skipjack tuna catches (Fig. 8). The northern and southern boundaries do not move in unison with respect to seasons, nor uniformly across the ocean. In the western Pacific (west of long. 180°), the maximum northward displacement of the northern boundary occurs in the third quarter and maximum southward displacement in the second quarter. To the east of long. 180°, however, the maximum northward displacement of the northern boundary occurs in the fourth quarter and the maximum southward displacement occurs in the third and fourth quarters. Such differences also are evident in the shifting of the southern boundary in the eastern, central, and western Pacific.

Irregular north to south movement is indicated also in the high-CPUE cells. In the Hawaiian to Leeward Islands area, the high-CPUE cells occur throughout the year, with the maximum southward displacement occurring in the second quarter. In Philippine and Japanese waters, the northward displacement of high-CPUE cells occurs in the second and third quarters and the southward displacement in the fourth and first quarters.

The second feature is the apparent disparity between the high catch areas of the longline fishery and those of the surface fisheries. The bulk of the skipjack tuna production in the Pacific comes from the northwestern (Japanese pole and line) and the eastern (United States purse seine) surface fisheries, yet the high-CPUE areas in both places are not as extensive as one would expect. This is likely due 1) to gear selectivity, longlines fishing deeper and being more effective on large fish and 2) to the relative absence of large fish near the surface in these areas. The predominance of younger fish in the two surface fisheries has been shown by Kawasaki (1965) and Broadhead and Barrett (1964). In the Hawaiian Islands area, where large skipjack tuna are better represented in the surface fishery (Rothschild 1965), the disparity between the longline and surface fishery catches is less evident. In fact, as previously mentioned, there may be some association there between the longline and surface pole-and-line catches.

The third feature is the extent and persistence of high CPUE in the central equatorial area (region B, south of lat. 10°N), where presently there is only a small surface fishery in Tahiti (Brun and Klawe 1968). The high-CPUE areas there not only persist throughout the year, but are more extensive than all other high-CPUE areas combined during most quarters. The general location of this high-CPUE area is of particular

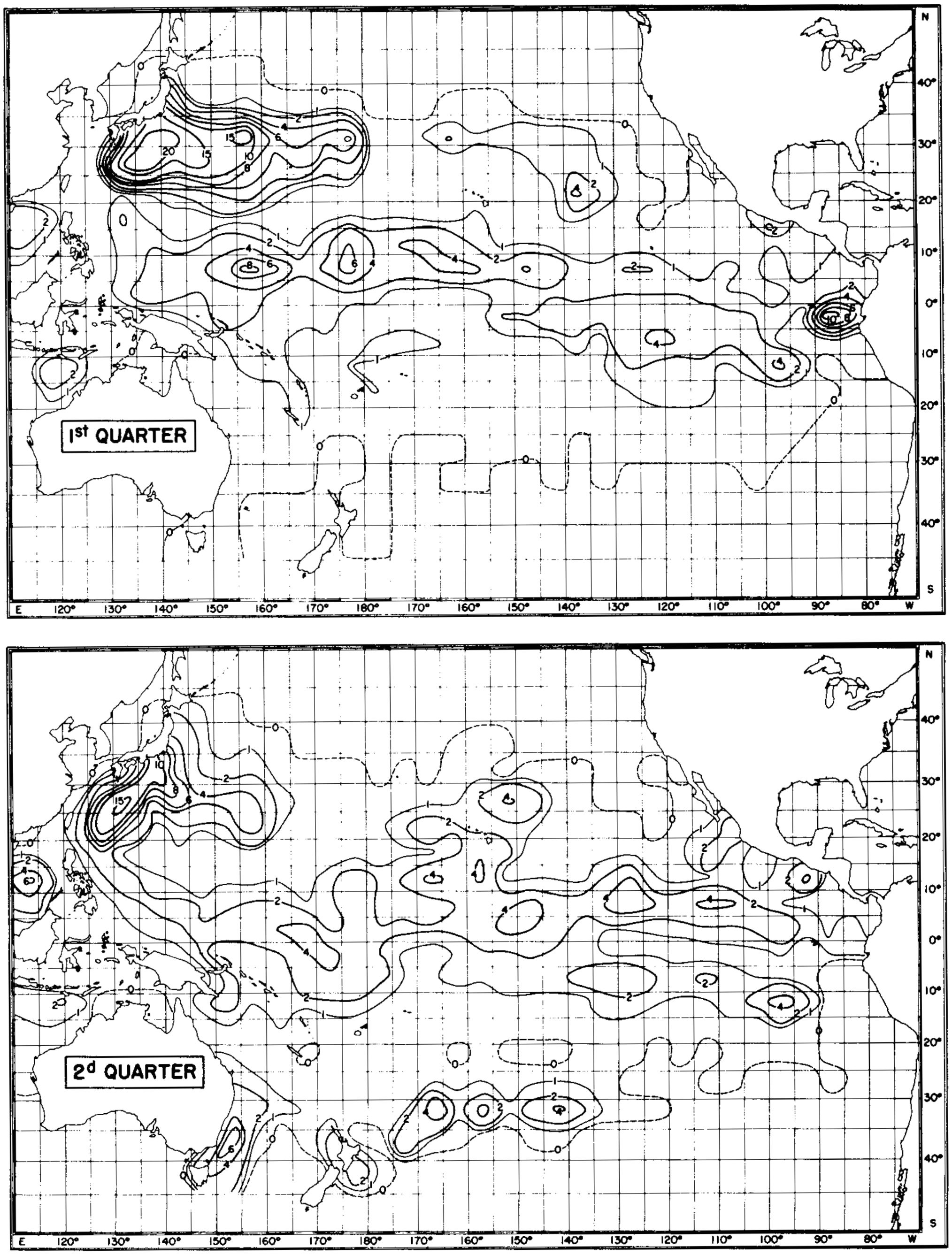
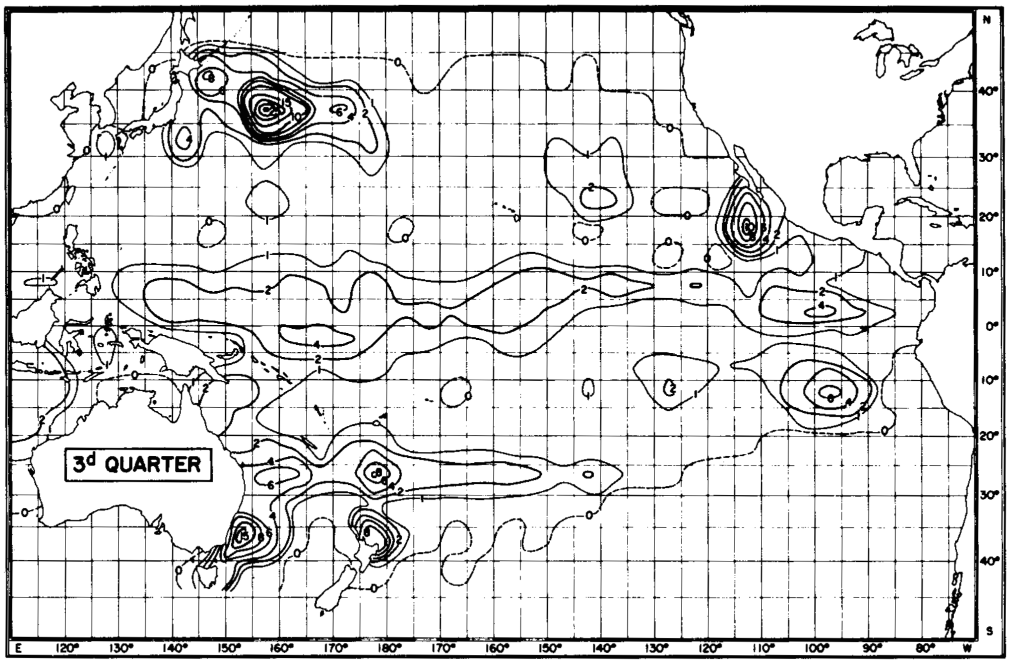
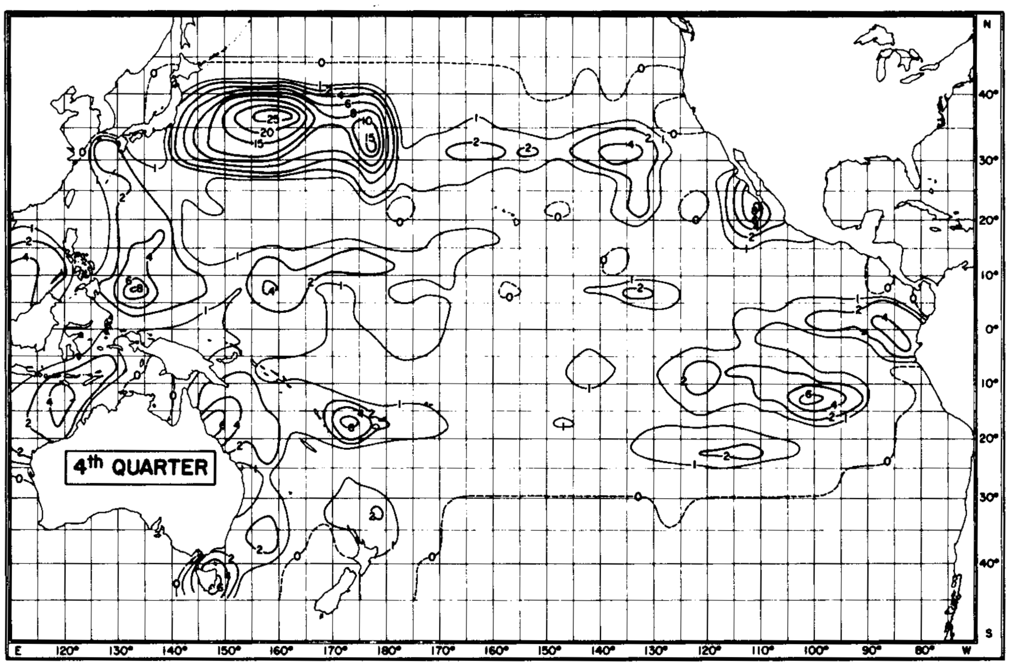


Figure 3.—Average quarterly effort expended by the Japanese tuna longline fishery, 1964-67.





The contour lines are drawn at intervals of 100,000 hooks. The broken lines denote limits of fishing.

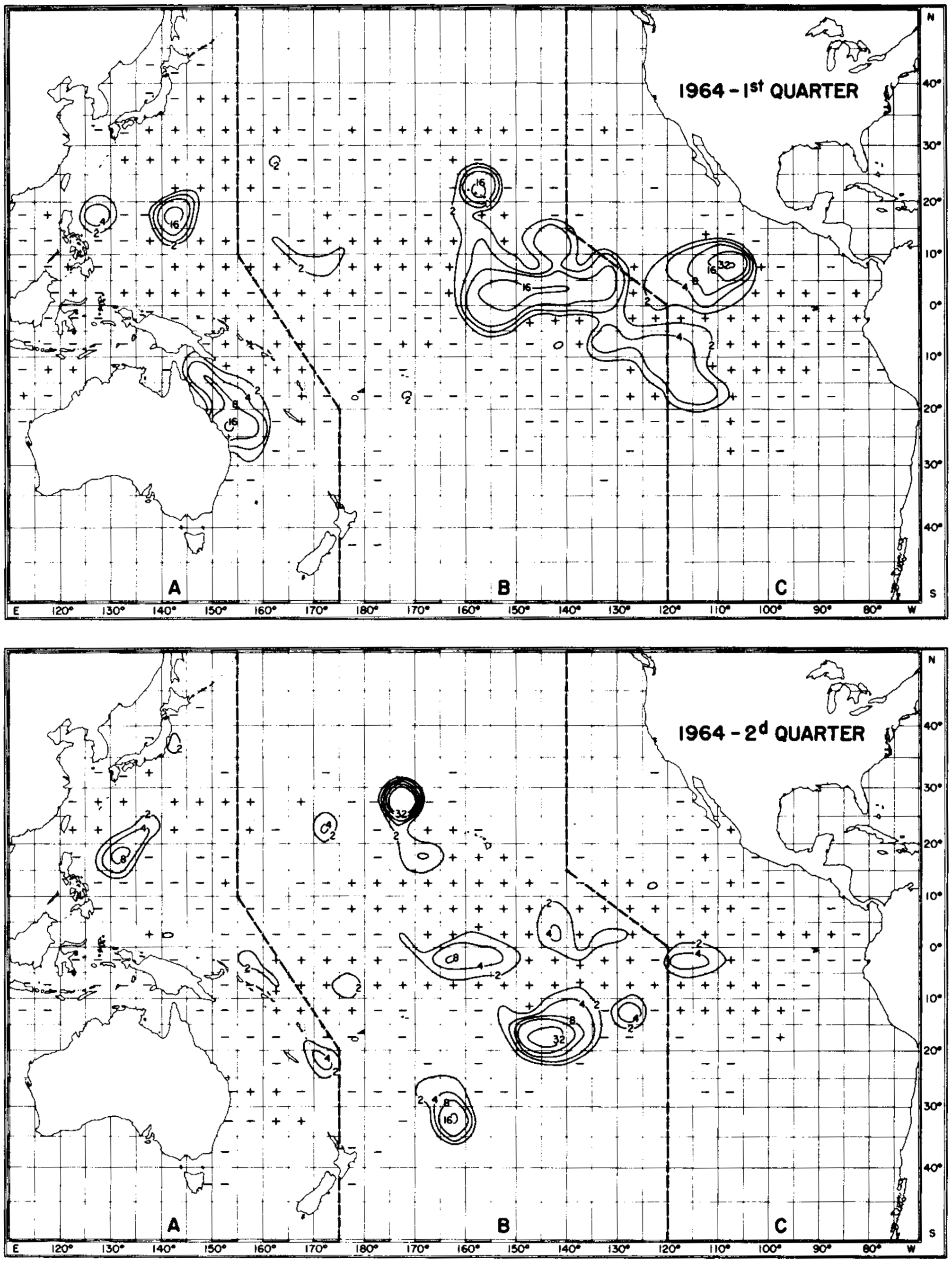
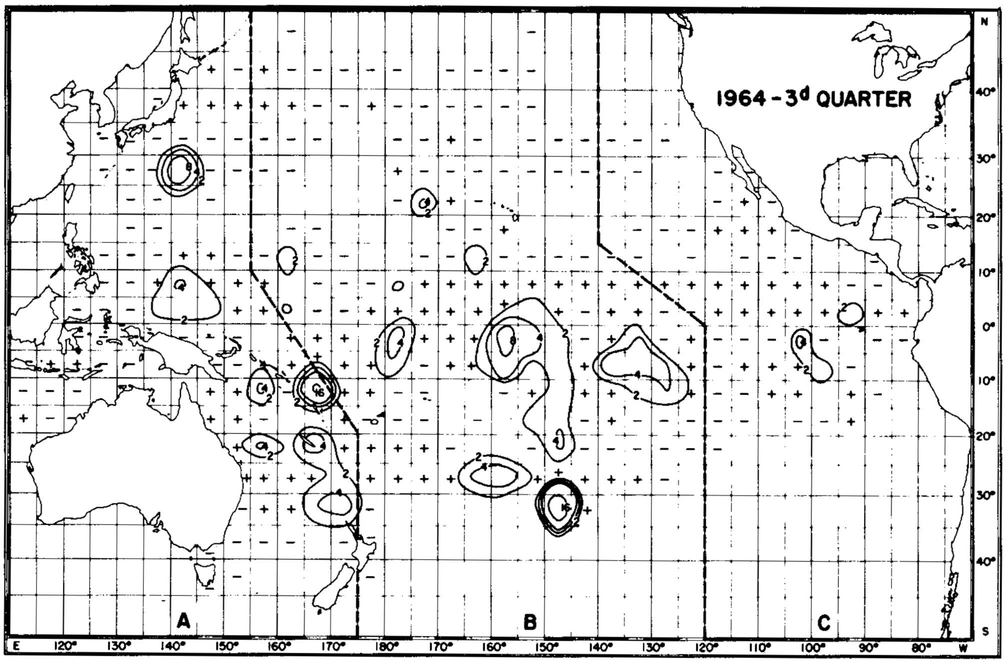
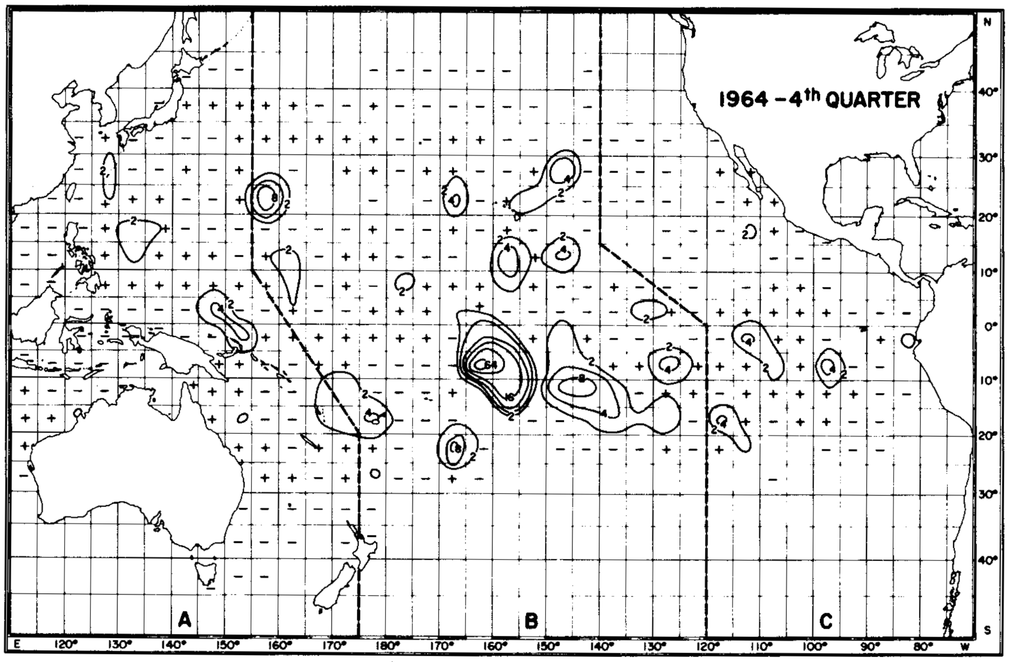


Figure 4.—Distribution of catch per unit effort of skipjack tuna taken by the Japanese tuna longline fishery, 1964. The contour lines are drawn at intervals of 2, 4, 8, 16, etc., times the mean catch per 1,000 hooks per quarter per 5° area fished. The symbols + and − represent CPUEs less than twice the mean and no skipjack tuna caught or recorded, respectively. (The small circles are contour lines, not





ciphers.). Mean CPUE for each 5° area fished; 1st quarter, 0.118; 2d quarter, 0.153; 3d quarter, 0.138; 4th quarter, 0.104. Regions A, B, and C are arbitrary partitions to facilitate the discussion.

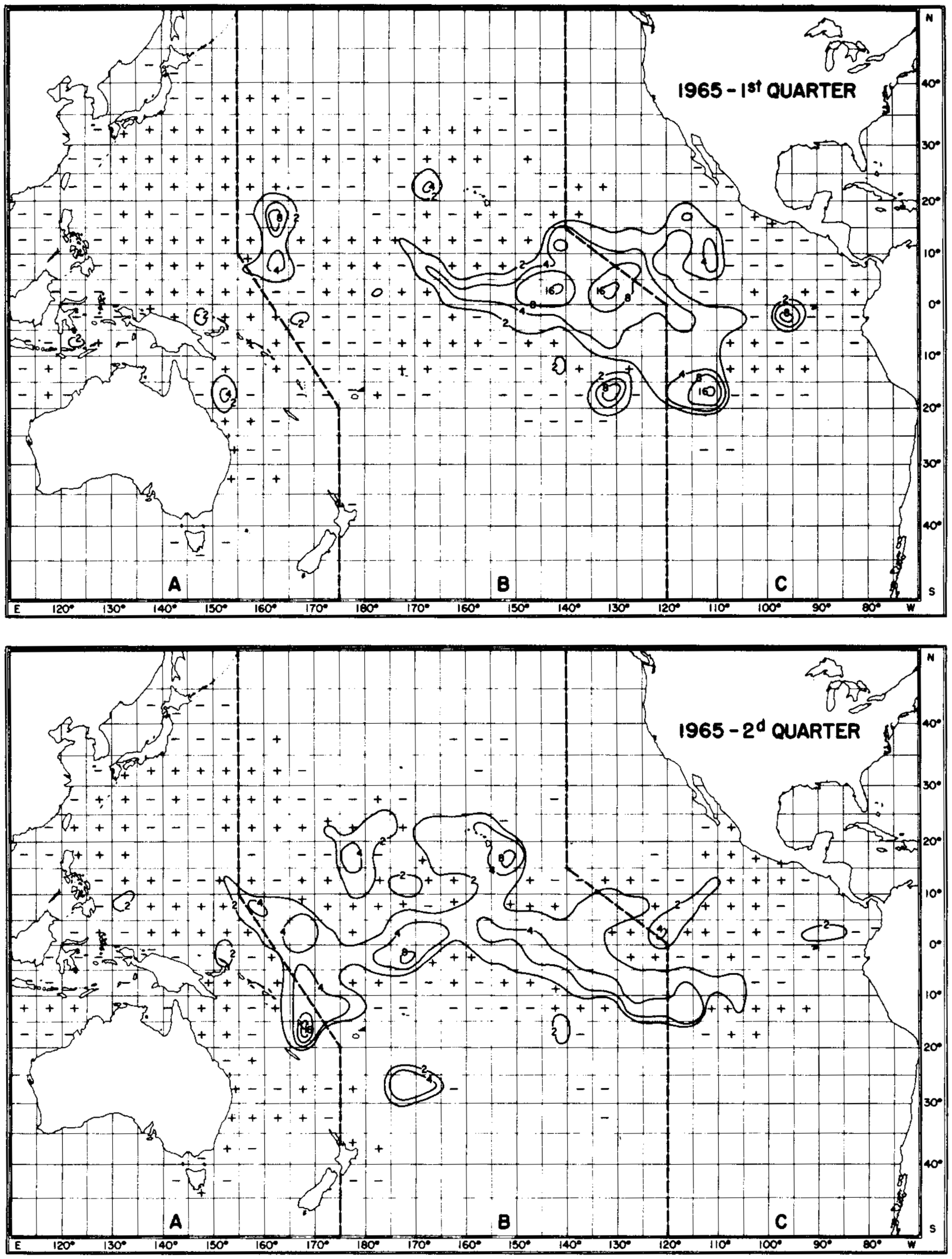
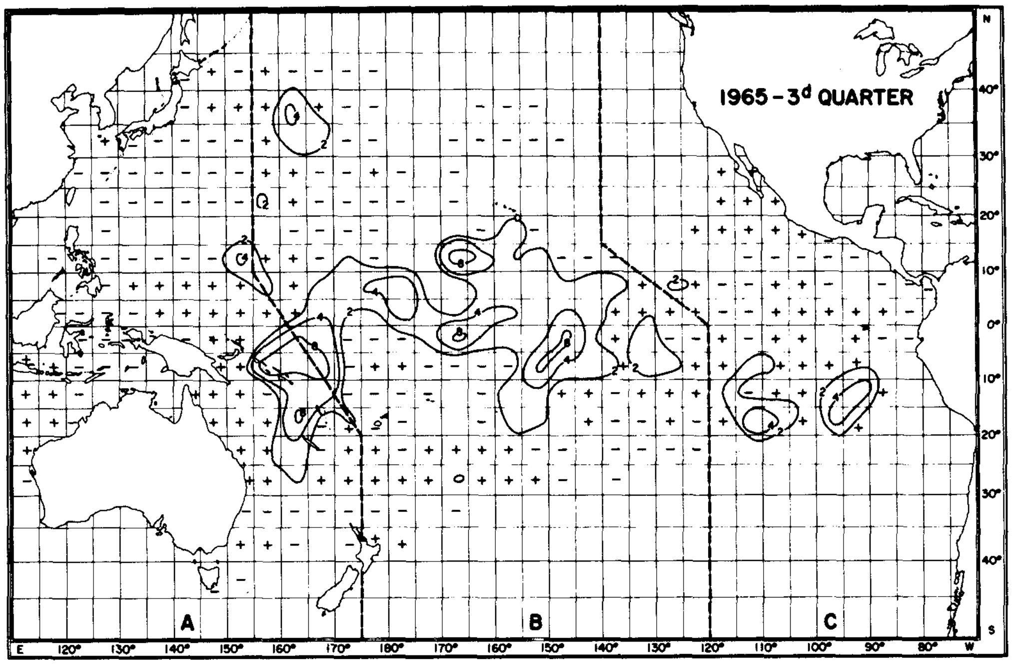
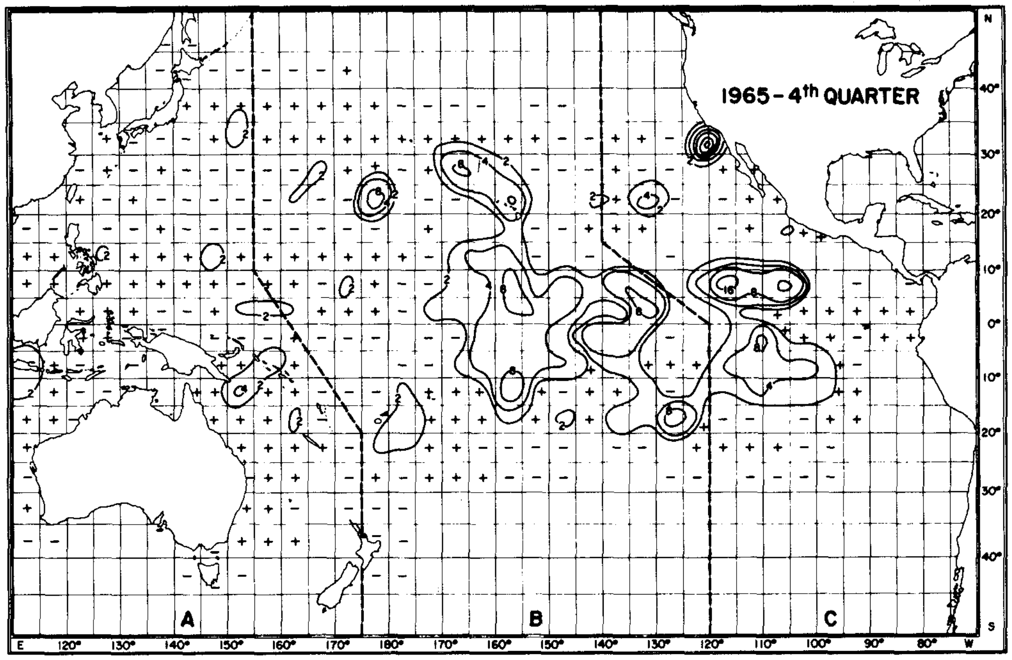


Figure 5.—Distribution of catch per unit effort of skipjack tuna taken by the Japanese tuna longline fishery, 1965. The contour lines are drawn at intervals of 2, 4, 8, 16, etc., times the mean catch per 1,000 hooks per quarter per 5° area fished. The symbols + and − represent CPUEs less than twice the mean and no skipjack tuna caught or recorded, respectively. (The small circles are contour lines, not





ciphers.) Mean CPUE for each 5° area fished; 1st quarter, 0.219; 2d quarter, 0.310; 3d quarter, 0.241; 4th quarter, 0.209. Regions A, B, and C are arbitrary partitions to facilitate the discussion.

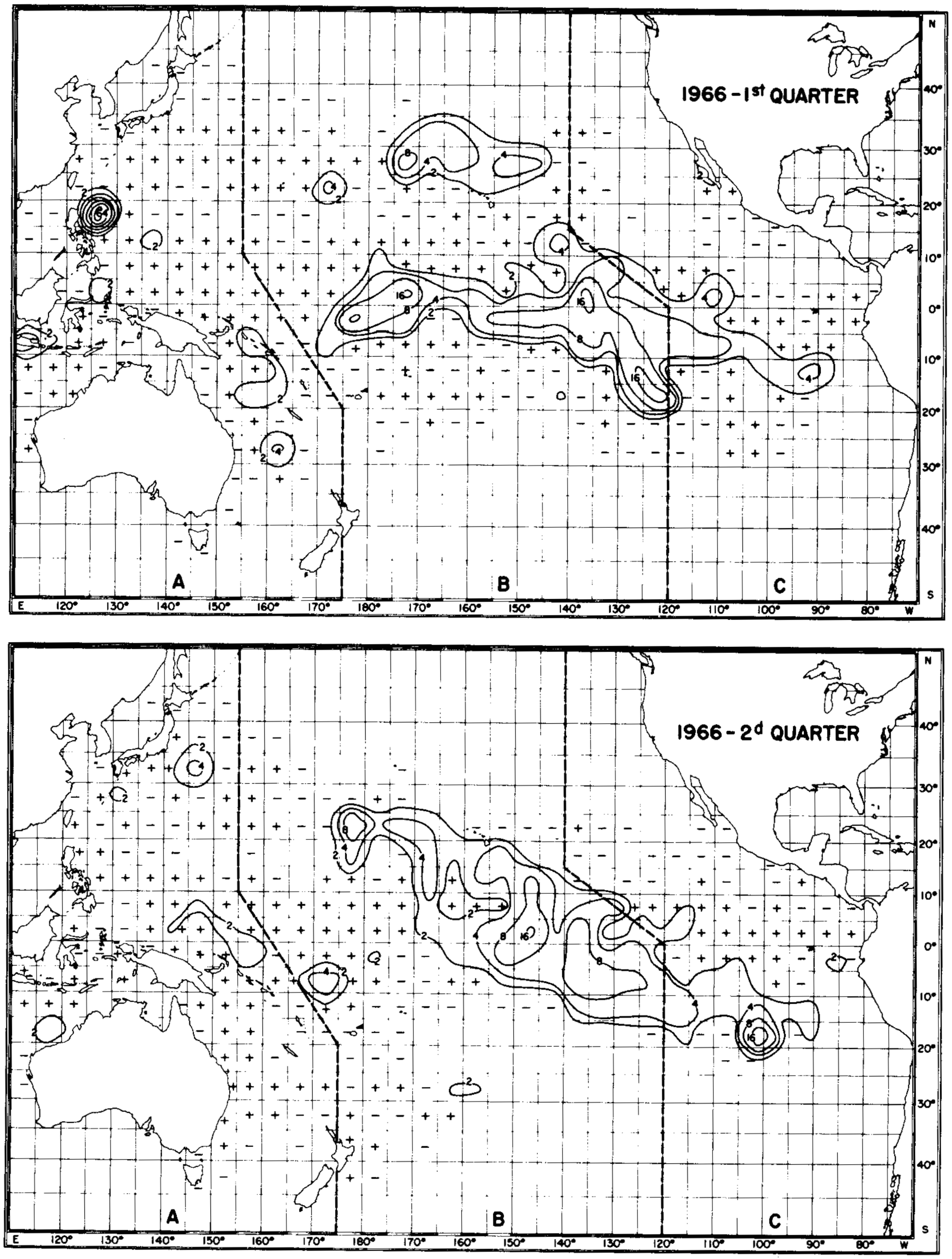
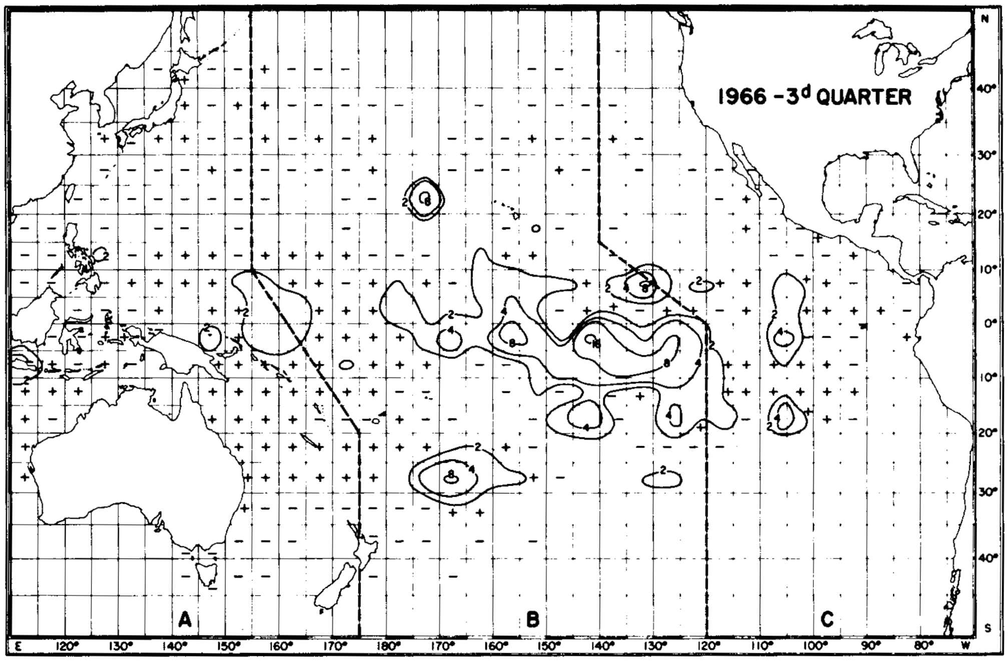
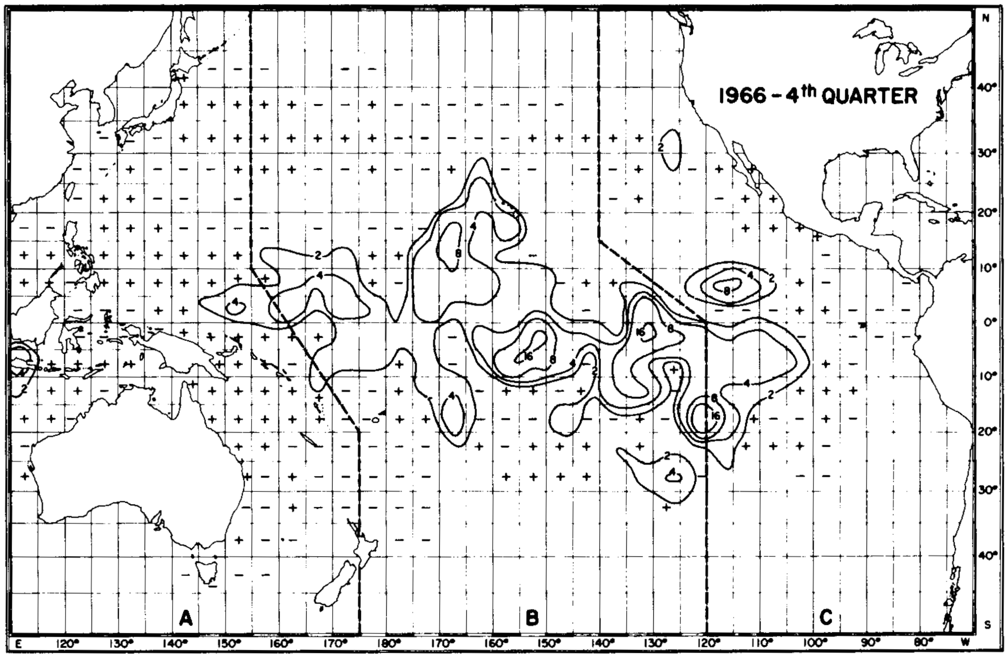


Figure 6.—Distribution of catch per unit effort of skipjack tuna taken by the Japanese tuna longline fishery, 1966. The contour lines are drawn at intervals of 2, 4, 8, 16, etc., times the mean catch per 1,000 hooks per quarter per 5° area fished. The symbols + and — represent CPUEs less than twice the mean and no skipjack tuna caught or recorded, respectively. (The small circles are contour lines, not





ciphers.) Mean CPUE for each 5° area fished: 1st quarter, 0.241; 2d quarter, 0.206; 3d quarter, 0.208; 4th quarter, 0.237. Regions A, B, and C are arbitrary partitions to facilitate the discussion.

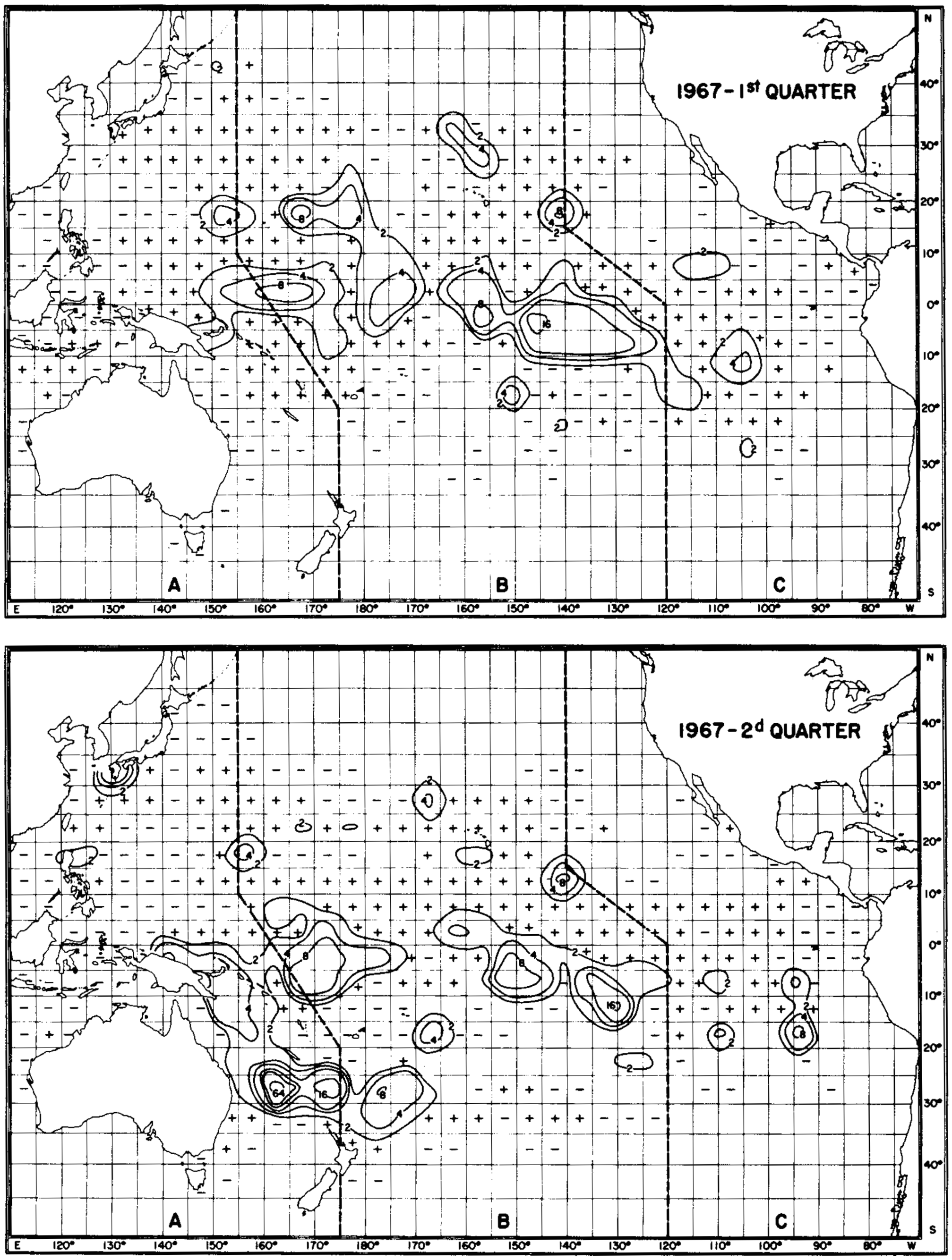
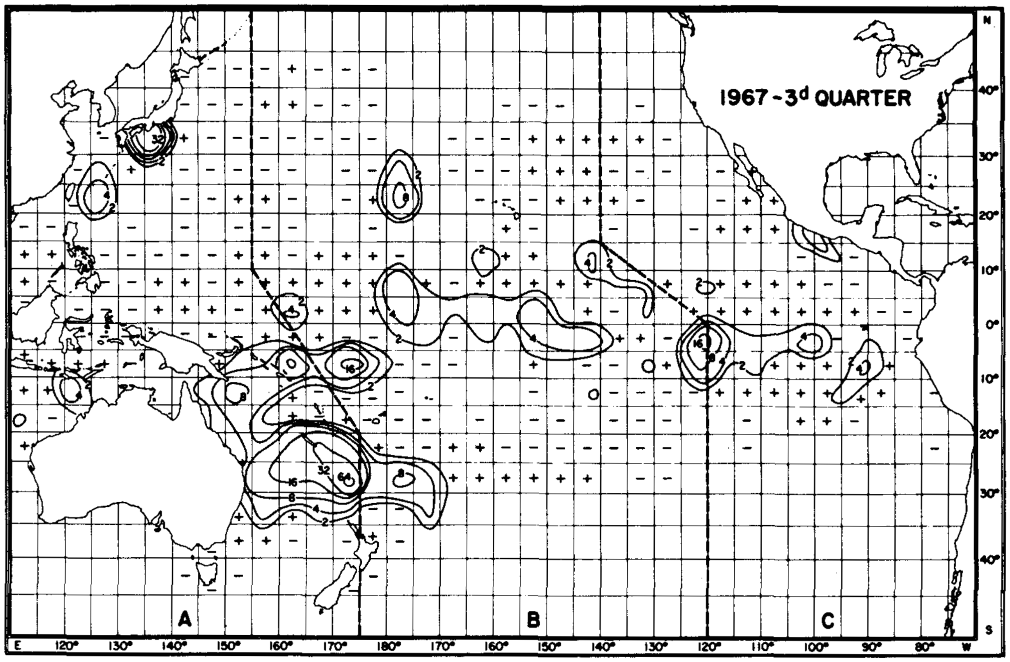
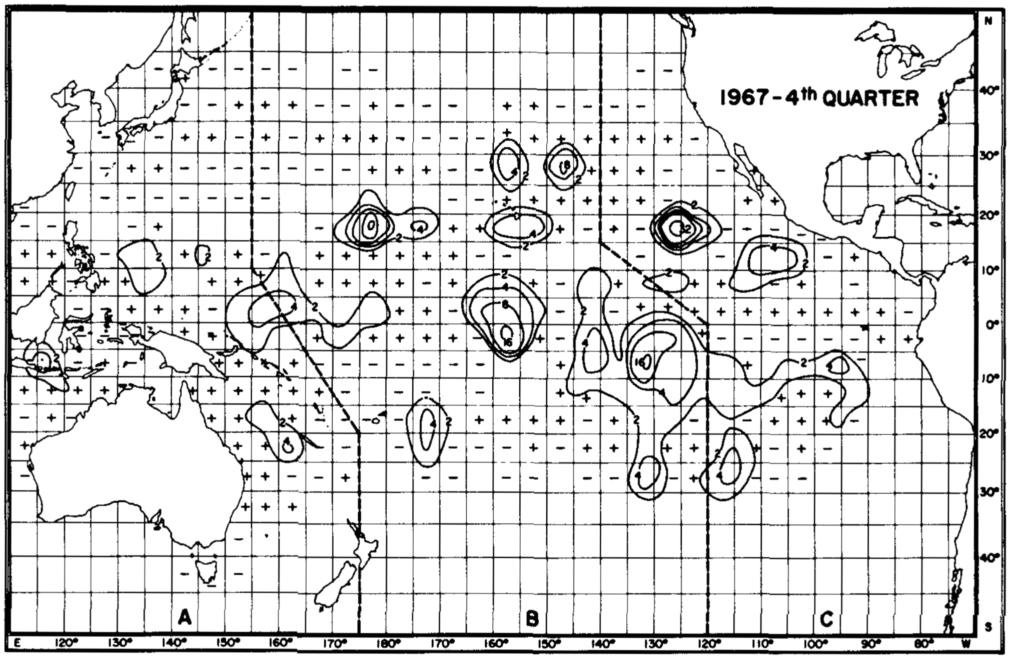


Figure 7. — Distribution of catch per unit effort of skipjack tuna taken by the Japanese tuna longline fishery, 1967. The contour lines are drawn at intervals of 2, 4, 8, 16, etc., times the mean catch per 1,000 hooks per quarter per 5° area fished. The symbols + and – represent CPUEs less than twice the mean and no skipjack tuna caught or recorded, respectively. (The small circles are contour lines, not





ciphers.) Mean CPUE for each 5° area fished; 1st quarter, 0.233; 2d quarter, 0.190; 3d quarter, 0.169; 4th quarter, 0.205. Regions A, B, and C are arbitrary partitions to facilitate the discussion.

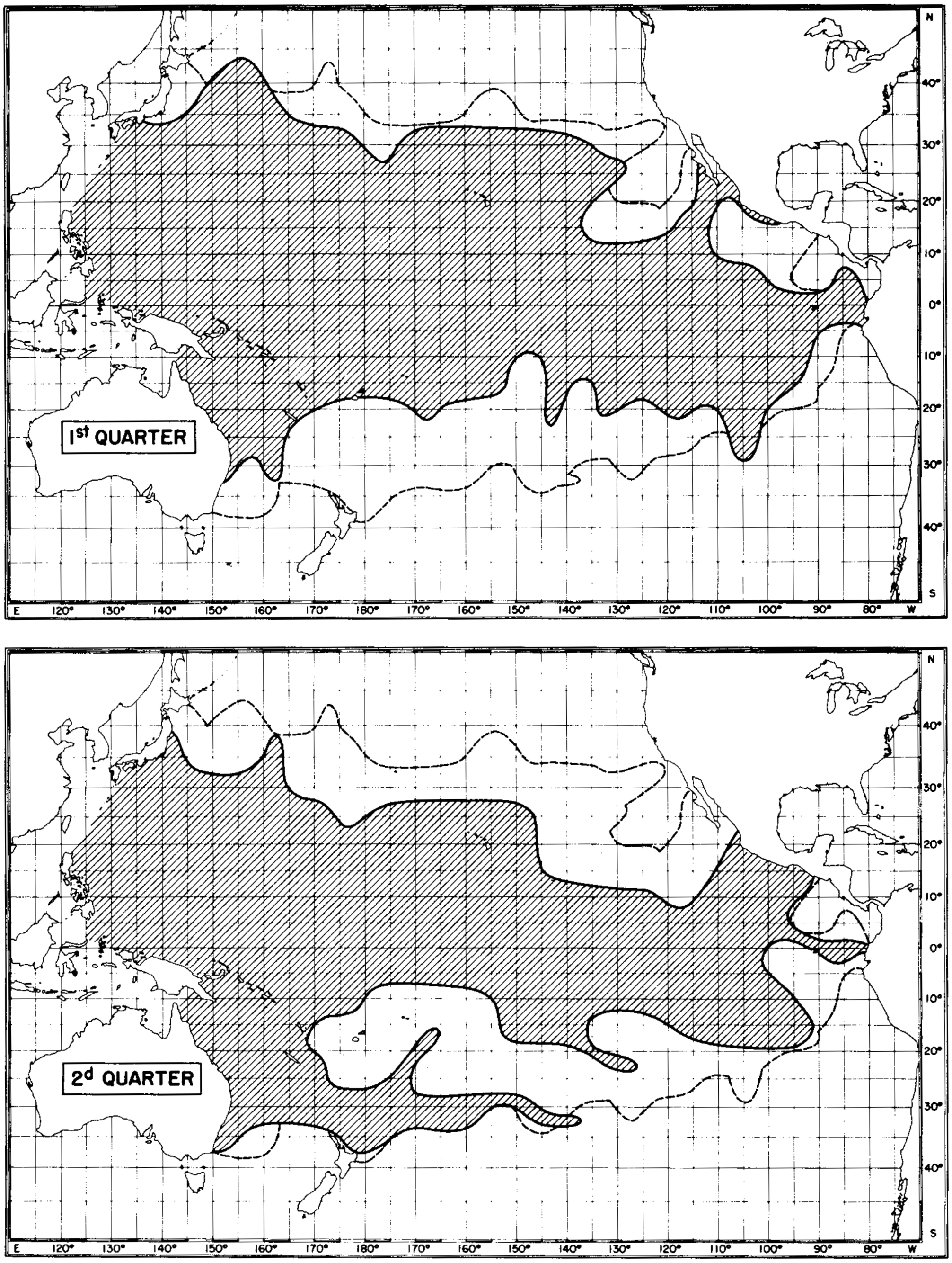
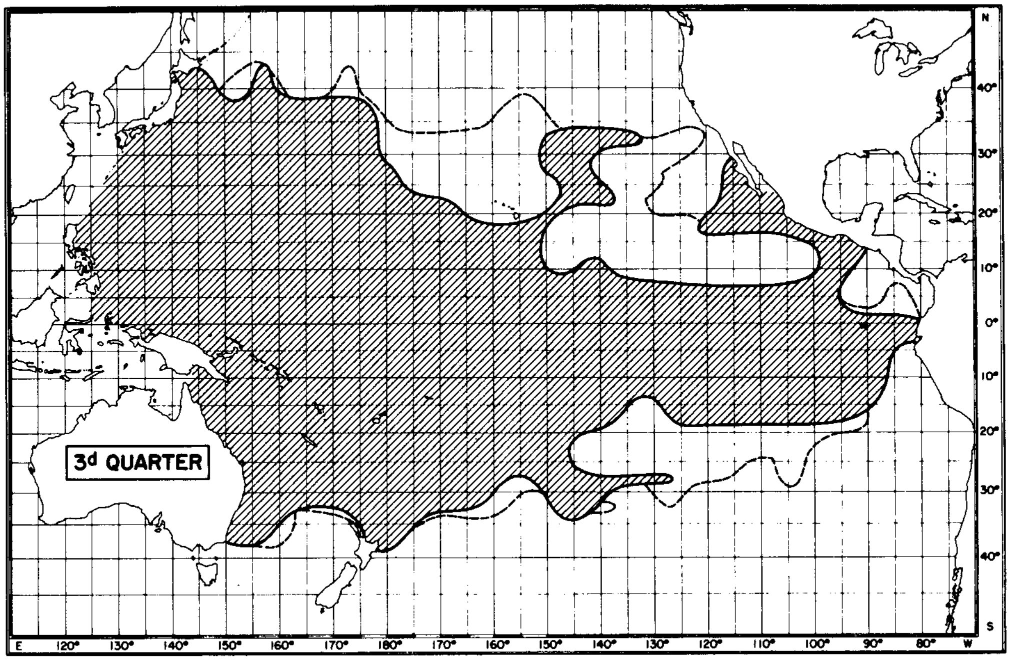
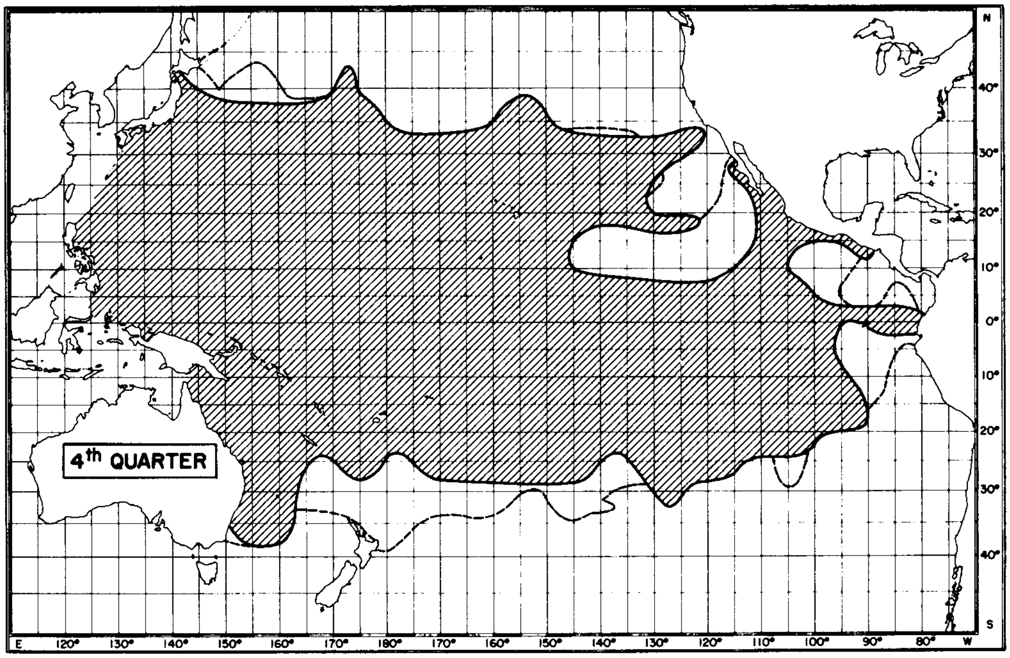


Figure 8.—Outlines of the northern and southern boundaries of skipjack tuna caught in the Japanese tuna longline





fishery, 1964-67, by quarters (shaded area). The broken lines denote the maximum range in the four quarters.

interest since it corresponds with the central equatorial spawning grounds from which the skipjack tuna taken in the eastern Pacific fishery is assumed to originate (Kawasaki 1965; Rothschild 1965; Williams 1972).

Adult-Larvae Relationship in the Equatorial Pacific

As discussed previously, the tuna longline tends to catch the larger tunas, and so a major portion of the skipjack tuna taken by this gear consists of the larger, more mature fish. Consequently, in areas where the longline CPUE is high, especially in waters suitable for spawning, the concentrations of larvae also should be high. To confirm this probable relationship and to delineate the spawning area, the relative abundance of adults in 20° sectors along the equator was compared with that of the larvae.

Numerous larval net tows have been made in the Pacific over the past 25-30 yr, but this coverage of the ocean with respect to time and space has not been as intensive as that by the longline. Moreover, larval net tows made in all sections of the Pacific were not uniform with respect to towing methods and net sizes. In the eastern Pacific, where net tows were made principally by the Inter-American Tropical Tuna Commission, the Scripps Institution of Oceanography, and the National Marine Fisheries Service, La Jolla Laboratory, 30-min surface tows and oblique tows to 140, 300, and 400 m were made with a 1-m net equipped with a flowmeter (Klawe 1963); in the central Pacific, where net tows were made by the National Marine Fisheries Service, Honolulu Laboratory, 30-min surface tows and oblique tows to 60, 140, and 200 m were made with a similar net (Matsumoto 1958; Strasburg 1960); and in the western Pacific, where net tows were made by the Far Seas Fisheries Research Laboratory, a 2-m net without flowmeter was towed horizontally for 20 min at the surface and at depths of 20-30 and 50 m at vessel speeds of 1.03 m/s or 2 knots (Ueyanagi 1969).

Of all the tows made, only the surface tow was commonly used in all three areas. Consequently, abundance of skipjack tuna larvae across the Pacific was determined only from catches in surface tows after the following adjustments had been made:

1. To eliminate variability resulting from diel vertical migration, a prominent characteristic of the skipjack tuna larvae (Matsumoto 1958; Ueyangi 1969), only surface night tows were used.
2. To obtain comparable coverage across the ocean, the areas from which tows were compared were limited to 20° longitudinal sectors along the equator between lat. 00° and 20°N in the western; between lat. 10°S and 20°N in the central; between lat. 07°S and 15°N in the east-central; and between lat. 04° and 15°N in the eastern Pacific.
3. To reduce seasonal variability in the catches, only tows made in spawning months were considered. These included April through September in areas between lat. 10° and 20°N and all months of the year in areas between lat. 10°N and 10°S (Matsumoto 1958; Strasburg 1960; Klawe 1963; Ueyanagi 1969).
4. To compensate for differences in net size and duration of tow, the catches in all areas were adjusted to a standard tow that strained 1,454 m^3 of water, a volume equivalent to that strained by a 1-m net towed at 1.03 m/s for 30 min. The adjustment was made by applying a conversion factor (i.e., the ratio of standard volume to average volume of water strained in the central Pacific do not constitute a single, homogeneous volume to estimated volume of water strained in the western Pacific) to the catches in the three areas. Although the adjustment is rough, the adjusted catch values for all quarters for the years 1950-67 (Table 3) appear reasonable.

A plot of adjusted catch rates (Fig. 9) indicates that between lat. 20°N and 10°S, skipjack tuna larvae were most abundant in the central Pacific between long. 140°W and 160°E, with the peak in the sector between long. 160°W and 180°. Larvae were less abundant in the areas east of long. 140°W and west of long. 160°E. The

Table 3.—Catch rates of larval skipjack tuna in night surface tows across the Pacific Ocean.

Longitude	Latitude	Quarter sampled	Net diameter	Duration of tow	Number of tows	Total larvae	Conversion factor	Adjusted catch	Adjusted larvae per tow
			Meter	*Minutes*		*Number*			
80°-100°W	4°-15°N	I, II	1	30	33	7	[2]1.836	12.85	0.39
100°-120°W	10°-15°N	II	1	30	10	11	[2]1.836	20.20	1.63
100°-120°W	0°-7°S	I	1	30	12	19	[3]0.827	15.71	
120°-140°W	10°S-10°N	I, IV	1	30	21	42	[3]0.827	34.73	1.65
140°-160°W	10°S-20°N	I, III	1	30	32	239	[3]0.827	195.18	6.10
160°W-180°	10°S-20°N	I, II, III	1	30	45	389	[3]0.827	321.70	7.15
160°E-180°	10°S-20°N	I, III	1	30	6	45	[3]0.827	37.22	4.94
160°E-180°	10°S-20°N	II, IV	2	20	44	560	[4]0.375	210.00	
140°-160°E	10°S-20°N	II, III, IV	2	20	112	562	[4]0.375	210.75	1.88
120°-140°E	0°-20°N	II, IV	2	20	141	581	[4]0.375	217.88	1.54

[1]Conversion factor is the ratio of standard to average volume of water strained. Standard volume used was 1,454 m^3.

[2]Computed from average volume of 792 m^3 from 62 tows in the eastern Pacific. (Data from Klawe 1963.)

[3]Computed from average volume of 1,759 m^3 from 289 tows in the central Pacific. (Data from BCF Biological Laboratory, Honolulu files and Strasburg 1960.)

[4]Computed from estimated volume of 3,878 m^3, the volume strained at a given towing speed of 1.03 m/s (2 knots) in the western Pacific. (Catch data from Ueyanagi 1969.)

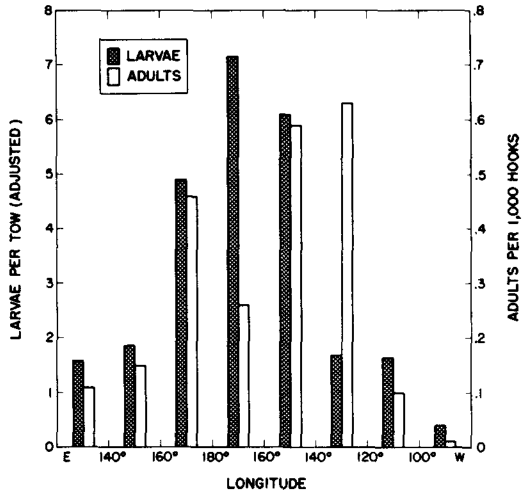


Figure 9.—Catch rates of skipjack tuna larvae and adults across the Pacific Ocean between lat. 10°S and 20°N.

extremely low catch rate in the eastern Pacific may be due partly to incomplete sampling coverage near the equator and to the lack of sampling south of the equator. Even with comparable sampling in these areas, however, it seems unlikely that the catch rate would have been as high as in the central Pacific.

The catch rates (catch per 1,000 hooks fished) of adult skipjack tuna taken by the longline in areas and quarters similar to those of the larvae showed a comparable trend (Fig. 9). The catch rates were low in the eastern and western Pacific and high in the central Pacific. The only apparent difference between the two plots was the slight dislocation of the peaks. The lack of larval net tows for the years 1964-67 across the Pacific, however, does not permit statistical testing of the catch trends. Nevertheless, the similarity between the high CPUE of adult skipjack tuna and the high larval density in the central equatorial Pacific, seems to support the assumptions by Kawaski (1965), Rothschild (1965), and Williams (1972) that the central equatorial spawning ground is the source of the skipjack tuna taken in the eastern Pacific fishery.

MOVEMENT OF SKIPJACK TUNA IN THE PACIFIC

Past Studies on Movemnt of Skipjack Tuna

A number of studies have been made on the population structure and movement of skipjack tuna in various sections of the Pacific. Fujino (1970a, 1970b) has proposed the existence of two genetically distinct subpopulations of skipjack tuna in the western North Pacific, separated by a line passing through the Caroline-Mariana-Bonin archipelagoes. In a more recent study, Fujino (1972) has extended this boundary line southward along long. 170°E from the Equatorial Countercurrent to the area east of New Caledonia and through the Tasman Sea and has proposed a model of population structure and migration for the entire area (Fig. 10). He proposed 1) that fish of the western Pacific subpopulation in the northern hemisphere remain within the Philippine Sea and areas of the Caroline Islands in the northern winter and range eastward to about long. 165°E in the northern summer; 2) that in both northern and southern hemispheres there are two spawning groups (summer, A; winter, B) which behave differently from each other without diversification in genetic composition; and 3) that the two groups (A and B) migrate in different proportions by age and area, with intermingling taking place between northern and southern A groups and between northern and southern B groups at the time of spawning and during the larval stages.

Kawasaki (1965) proposed that the skipjack tuna in the eastern and western North Pacific fishery originated from fish spawned in the central equatorial region between long. 160°E and 140°W. He (1972) subsequently modified this view by extending the principal spawning area westward to long. 120°E and, as a result of Fujino's work, recognized the possibility of a separate western Pacific subpopulation.

Rothschild (1965) suggested that skipjack tuna in the central Pacific do not constitute a single, homogeneous population unit; that they originate in three possible zones—Hawaiian, equatorial, and Marquesan; that the Marquesan zone does not contribute significant numbers to the skipjack tuna taken in the eastern Pacific; and that the eastern Pacific skipjack tuna originate either in the Hawaiian or equatorial zone. He further proposed that the potential recruits to the eastern Pacific are "split" into a northern group that enters the Mexican fishery and a southern group that enters the South American fishery, citing as a possible splitting mechanism the warm-water cell (surface temperature >28°C) in the vicinity of lat. 15°N off the central American coast.

Fink and Bayliff (1970) discussed the migration of skipjack tuna in the eastern Pacific based on tagging results. Their findings indicated that fish in the northern group (north of lat. 15°N) entered the fishery in April through the Revilla Gigedo Islands and moved inshore and northward along the coast of Baja California generally to lat. 30°N in the third quarter. The fish then moved southward, most of them likely returning to the central Pacific and some to the fishery the following year (see their figure 89). The migrations of fish in the southern group appeared more complex, and the inshore-offshore movements were not well defined owing to inadequate data in the offshore areas. Nevertheless, from the large number of skipjack tuna tagged in the Gulf of Panama in 1959 and 1961, many went north and west to Central America and many went south to Ecuador-Peru. At least one tagged fish moved from Ecuador and one from the Galapagos Islands to Peru.

Seckel (1972) proposed a drift model showing how ocean currents could contribute to the travel of skipjack tuna from the eastern North Pacific to Hawaii. From an earlier study (Seckel 1968) he noted that a pronounced salinity gradient, which implied a strong convergence, existed at the boundary of the North Pacific Central Water. Using the geostrophic and wind-driven current speeds he calculated the monthly drift displacement of 11 objects hypothetically placed between lat. 10° and 20°N along long. 120°W at monthly intervals. The results of his calculations show that objects initially locat-

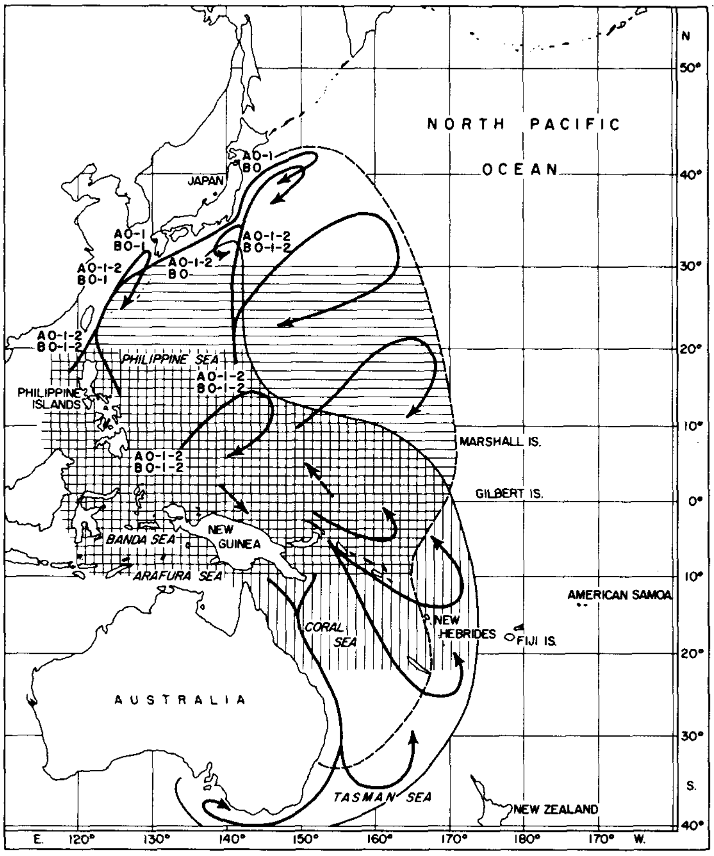


Figure 10.—Range and migration routes of skipjack tuna of the western subpopulation. The eastern limit of distribution is indicated by thin solid line (northern winter) and broken line (northern summer). Migration routes are shown by arrows. The numerals with A or B represent age classes of fish from summer or winter spawning, respectively. Intensive spawning grounds in the northern summer and northern winter are shown by horizontal and vertical hatching, respectively. [Reproduced from Fujino (1972).]

ed south of lat. 15°N rapidly drifted northward and all were north of lat. 15°N by the time they had crossed long. 128°W; that the objects appeared to concentrate on the northern and southern edges of their distribution and to merge west of long. 150°W in a relatively narrow band between lat. 18° and 22°N, so that the initially meridional distribution of objects along long. 120°W became oriented along the northern edge of the equatorial current west of long. 160°W after 24 mo. The minimum duration of drift of objects from long. 120° to 155°W ranged from 21 to 23 mo, which is of the same order of magnitude as the duration of freedom of four of the seven skipjack tuna tagged in the eastern Pacific and recovered in Hawaii. As a result of this model Seckel (1972) postulated that a possible, and the simplest, mode by which skipjack tuna travel from the eastern Pacific to Hawaii, is by swimming randomly and drifting with the current.

Williams' (1972) proposal included three migration models of young skipjack tuna that enter the eastern Pacific fishery areas on the basis of oceanographic conditions and events in the central-east Pacific. In the first model (active migration), he proposed that skipjack tuna larvae and early juveniles in the equatorial area west of long. 130°W are located principally in the westward flowing North Equatorial Current (NEC) and South Equatorial Current (SEC); that the juveniles orient themselves eastward and migrate in that direction along the zonal "productivity" bands at the northern and southern boundaries of the North Equatorial Countercurrent (NECC) and enter the offshore areas of the southern fishery; that the cessation of the surface NECC east of long. 120°W from January through May disrupts the orientation and movement of skipjack tuna juveniles through significant changes in the position and continuity of the "productivity" bands, at which time the skipjack tuna are reoriented to the northeast and enter the northern fishery following a "food bridge" (i.e., pelagic stages of the red crab, *Pleuroncodes planipes*), linking that area with the Revilla Gigedo Islands and

Baja California. In the second model (passive migration), he proposed that larval and juvenile skipjack tuna are passively carried eastward in equatorial countercurrent(s), but he admits to problems in recruitment of fish to the northern fishery from the terminus of the countercurrent. In the third model (gyral migration), developed after personal communication with me when this report was in the early stages of preparation, he proposed that fish in the northeastern Pacific fishery move around a zonally narrow counterclockwise equatorial gyre consisting of the NECC and the NEC. In this model, he considered that skipjack tuna spawn in northern spring and summer in equatorial waters west of long. 130°W; the larvae and early juveniles are carried eastward in the NECC to the area south of the Revilla Gigedo Islands where the juveniles, now of near recruitment size, actively migrate out of the gyre into the Revilla Gigedo waters and subsequently into the feeding grounds off Baja California; and with the advance of cold water in late fall the skipjack tuna leave the area via the California Current Extension (CCE) to return to the equatorial spawning grounds. He also proposed that skipjack tuna forming the southern group spawn in the southern spring and summer in the central equatorial Pacific; that the larvae and juveniles north of the equator enter the NECC and are carried eastward were, on reaching the terminus of the NECC, the juveniles actively migrate into the feeding areas off Central and South America, leaving there via the SEC; and that larvae and juveniles south of the equator are carried eastward in the South Equatorial Countercurrent (SECC) and return to the central Pacific as adults in the SEC.

Kasahara (1968) cited the hypothetical movements of skipjack tuna on a Pacific-wide basis developed by Naganuma (Unpubl. manuscr., see footnote 2). The movements are based on catch as well as monthly variations in length frequencies of skipjack tuna taken in the Japanese longline fishery in 1965 (Fig. 11).

Of the seven hypotheses above, only that by Naganuma (in Kasahara 1968) shows the migration of skipjack tuna on an oceanwide basis; others deal with more restricted areas in the Pacific which contain today's major fisheries or discuss movement in general without indicating actual migratory routes. For the most part, however, the routes proposed by Nagnuma in the western and central North Pacific and eastern South Pacific are incomplete, due to his reliance upon only one year's data, and his proposed route in the central South Pacific could be opposite to the direction indicated (see following discussion).

Movement of Skipjack Tuna Inferred from Present Study

To detect movement, the positions of high (>4× mean) CPUE were noted and connected by arrows in quarterly sequence beginning with the earliest year (Fig. 12), on the assumption that the quarterly changes in the high-CPUE postions reflected actual movement of fish. In some areas lacking in high-CPUE cells, above-average (2×-4× mean) CPUEs were followed to complete the movement pattern. In the figure, areas of above-average CPUE in the first quarter of two or more years were shaded to show that high-CPUE cells are not

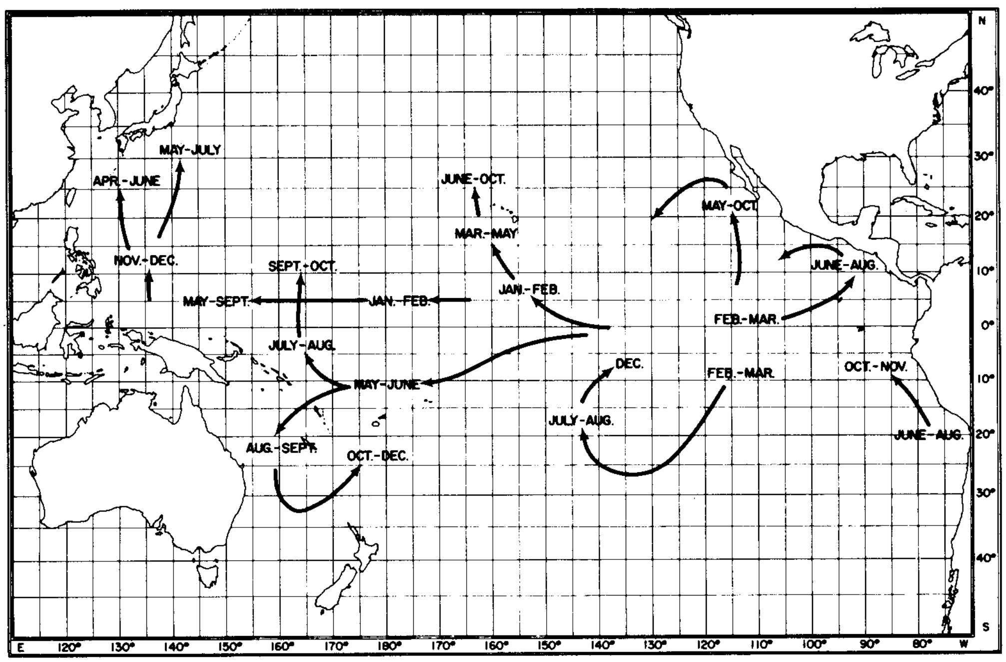


Figure 11.—Migration routes of skipjack tuna proposed by Naganuma (unpublished manuscript, see text footnote 2) based on tuna longline data. [Reproduced from Kasahara (1968).]

always discrete or isolated units. Other quarters also show large areas of above-average CPUEs within which high-CPUE cells are grouped.

Given the set of numerals denoting high-CPUE positions by quarters, one could show arrows pointing in directions other than those shown, but such a change in direction would be contrary to the seasonal movements of the surface fishery (and also tag return data) in areas where this is known. In Japanese waters, for example, the skipjack tuna are known to enter the fishery from the south and southwest, continue northeastward along the southern coast of Japan and then move offshore in an easterly direction with the progression of the seasons from spring through late fall (Kimura 1949; Kasahara 1971; Kasahara et al. 1971); in the eastern Pacific, the skipjack tuna are known to enter the northern fishery off central Mexico in about the second quarter, move northward in succeeding quarters, and presumably move offshore and back to the central equatorial areas in late fall (Fink and Bayliff 1970; Williams 1972). Although the direction of seasonal movement of fish in the eastern Pacific is opposite to that in the western Pacific, certain factors that could determine the movement pattern are common to both areas. First,. the east-west component of the movement of high-CPUE cells generally follows that of the prevailing surface currents. Second, there is a poleward shifting of the high-CPUE cells corresponding to a similar shifting of the warm isotherms during late spring to fall, and an equatorward shifting during winter and early spring. The net effect of surface current flow and poleward shifting of skipjack tuna in response to seasonal warming of the water thus would result in roughly circular paths.

On the basis of these observations, roughly circular paths were drawn (Fig. 12) in the direction of the prevailing currents (Fig. 13) to indicate the probable movement of skipjack tuna in all regions of the Pacific. Thus, in the southern hemisphere, where the major ocean currents flow counterclockwise around the South Pacific Central Water mass, the movement of skipjack tuna are shown in counterclockwise paths. In the northern hemisphere, where the major currents flow clockwise, the paths of skipjack tuna movement are also clockwise, except in the eastern Pacific, where current flow around the North Pacific Equatorial Water mass is counterclockwise. The correspondence of skipjack tuna movement to current flow is believed to be more than incidental, as hypothesized for albacore in the waters off Japan and yellowfin tuna off eastern Australia by Nakamura (1969).

The several paths depicted in the figure suggest that skipjack tuna in the Pacific Ocean may be composed of different groups (not necessarily separate subpopulations), possibly seven in the northern and seven in the southern hemispheres. For ease of discussion, these will be referred to as environmentally defined "groups" of skipjack tuna. A schematic diagram of the group movements is presented in Figure 14.

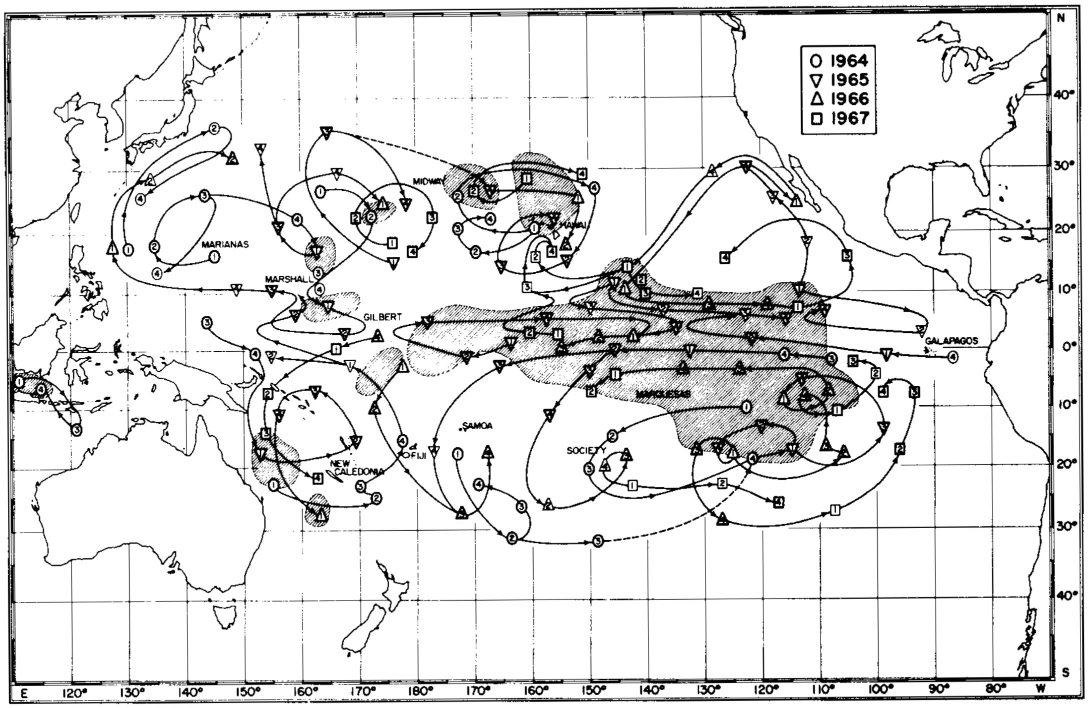


Figure 12.—Quarterly changes in position of high-CPUE areas in the Japanese tuna longline fishery, 1964-67. The shaded areas denote above-average CPUE areas in the first quarter of 2 or more years.

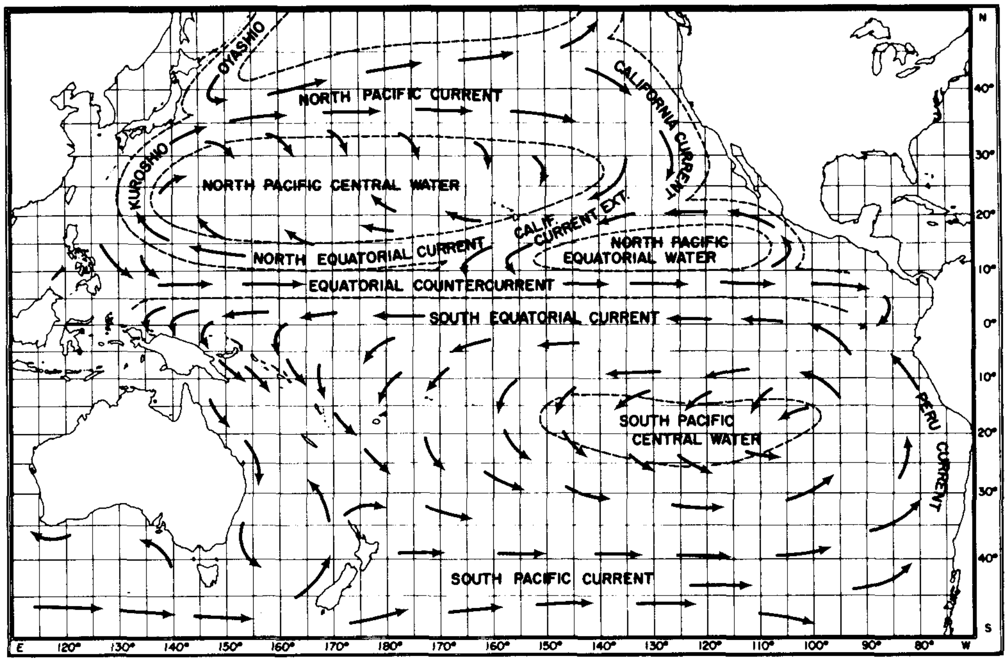


Figure 13.—Major circulation features of the Pacific Ocean. [Based on Sverdrup, Johnson, and Fleming (1946) and [U.S.] Bureau of Commercial Fisheries (1963).]

Western Pacific.—At least three groups, perhaps more, may be present in the northwestern Pacific (north of the equator and west of long. 180°). The westernmost groups, originating off the Philippine (NW1) and the Mariana-Marshall islands (NW2) in the first quarter, apparently move northward through Japanese waters in the second and third quarters and return south in the fourth quarter (Fig. 14). The third group (NW3), originating east of the Marshall Islands, moves northwestward into the Japanese offshore waters in the second and third quarters and returns southeastward in the fourth quarter to the area southwest of Midway Island. Part of this group could move farther downstream of the Kuroshio to the area east of Midway Island.

In the area south of the equator and west of long. 180°, two major movement patterns are suggested. The group (SW1) off northeastern Australia moves southward along the continent in the first quarter, then eastward south of New Caledonia in the second and third quarters, and returns northward either through or slightly west of the Fiji Islands in the fourth quarter. At or near the equator, part of this group may continue northward and subsequently mix with the western groups in the northern hemisphere, while the other part continues westward, returning south in the following season. The second major movement pattern is seen in the group (SW2) originating near the Gilbert Islands in the fourth quarter. This group follows a path southwestward into waters east of New Guinea in the second quarter of the following year and into waters off New Caledonia in the fourth quarter.

Eastern Pacific.—The group (NE1) in the eastern Pacific north of the equator (east of long. 130°W) likely originates in equatorial waters, mainly in the NEC. Its movement is toward the Mexican coast in the second quarter, north along the coast in the third quarter, and subsequently back to equatorial waters in the fourth quarter (Fig. 14). Part of this group (NE2) branches eastward toward Cocos Island (perhaps fish that form part of the southern fishery) and returns westward in the SEC. The proposed movements of these fish generally agree with the movements of fish in the surface fishery as determined from tagging results by Fink and Bayliff (1970), and are similar to those proposed by Rothschild (1965) and Williams (1972) for this area. Although Fink and Bayliff (1970) do not show any tagging effort in the Clipperton Island area, a recovery at Cocos Island of a skipjack tuna tagged in the Revilla Gigedo Islands (Inter-American Tropical Tuna Commission 1966) suggests that the route of group NE2 (Fig. 14) is not improbable.

In the area south of the equator (east of long. 130°W), the movement suggested by the longline catches is generally southward in the first and second quarters and northward in the third and fourth quarters. The area seems to contain several groups (SE1, 2, 3), which revolve about an area midway between the Society Islands and the South American coast. The movement patterns of these groups correspond with the circulation gyre formed by the South Pacific, Peru, and South Equatorial Currents. The data suggest that these groups may require more than a year to complete the circuit.

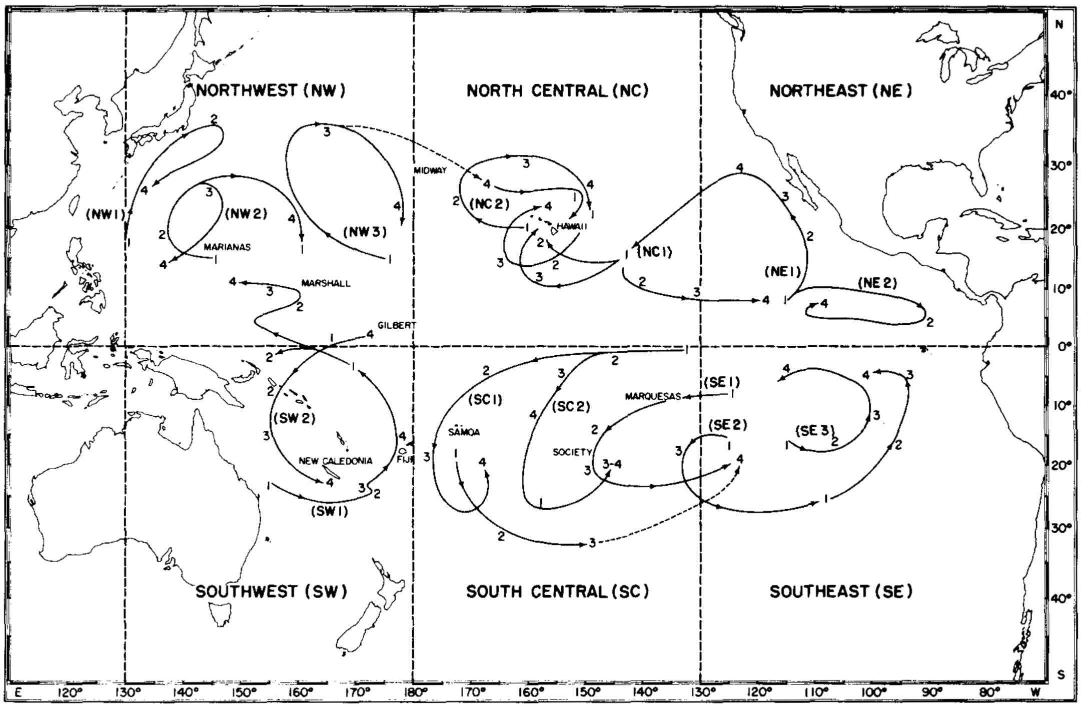


Figure 14.—Assumed movement of the various stocks of skipjack tuna in the Pacific Ocean. The numerals along the migratory routes represent quarters and locations of high-CPUE cells of skipjack tuna taken by the Japanese tuna longline fishery, 1964-67. Stock designations are shown in parentheses.

Central Pacific.—In the central (long. 130°W to 180°) North Pacific, particularly the area between Hawaii and Midway, two or possibly more groups may be present. One group (NC1), originating in the NEC to the southeast of Hawaii, could move directly into the Hawaiian fishery in the second quarter. A portion of this group could move farther downstream in the CCE taking a longer route before entering the Hawaiian fishery in the third or fourth quarter. At least part of this group consists of fish that have migrated from the eastern Pacific northern fishery area. A second group (NC2), originating west of Hawaii, could move into the Midway Islands area in the second quarter, then continue to an area northeast of Hawaii in the third or fourth quarter, winter there, and move into Hawaiian waters in the second or third quarter of the following year. This could be a purely local group, from offspring originating in Hawaiian waters. Fish from a third group of the northwestern Pacific (NW3) could move into the Midway Islands area via the Kuroshio extension and arrive in the Hawaiian fishery 1 or 2 yr later.

In the central South Pacific at least two major routes, possibly representing the same group of skipjack tuna, are indicated. The first group (SC1), originating at the equator near long. 130°W, moves westward in the first and second quarters, southward in the third quarter, passing near the Fiji Islands, and northward in the fourth quarter, into the Samoa area. The second group (SC2), having the same origin as the first, moves at a slower pace, turning southward in the second quarter and passing between Samoa and the Society Islands between the fourth quarter and first quarter of the following year. It turns northeastward in the second quarter and arrives in the Society Islands area in the third or fourth quarter. Both groups could conceivably swing southward and eastward during the following year and end up in the southeastern sector of the Pacific 15° to 20° latitude south of the equator.

DISCUSSION

The movement of skipjack tuna interpreted from longline catches generally agrees with that hypothesized by Fujino (1972) for the western Pacific and by Rothschild (1965) and Williams (1972) for the eastern Pacific. In the western Pacific, movement patterns not only bear out the demarcation of the two subpopulations reported by Fujino (1970a), but show that the demarcation line and area of intermingling between the two subpopulations agree quite well with those described for the surface fishery. The movement patterns of the groups of skipjack tuna in the western Pacific subpopulation (NW1 and NW2) are of particular interest since they permit the qualification of Kawasaki's (1965) suggestion that there is an exchange of skipjack tuna populations between Japanese and Hawaiian waters. The possibility of such an exchange is indicated in Figure 14 (dashed line from Japanese offshore waters to area east of Midway).

Continued movement eastward in subsequent quarters could find these fish in Hawaiian waters. Any such move, however, can be made only by fish of the central-eastern Pacific subpopulation (NW3), since Fujino (Kitasato University, Iwate Prefecture 022-1, Japan, pers. commn.) has indicated that no fish of the western Pacific subpopulation have been sampled in the Hawaiian fishery.

The migration paths of deep-swimming skipjack tuna of the western subpopulation in the southern hemisphere (SW1 and SW2) closely resemble those of the surface fishery postulated by Fujino (1972), even to the possibility of the southern groups moving across the equatorial current system, which could result in the mixing of fish of both hemispheres. The area west of Fiji seems to be the dividing line between the western and central-eastern skipjack tuna subpopulations in the South Pacific.

In the eastern Pacific, the migration of skipjack tuna (NE1) into the northern fishery, based on longline catches, is similar to that of the surface fishery as postulated by Rothschild (1965) and Williams (1972). Even the latter's "food bridge" theory linking the area of the NECC east of long. 120°W to the Revilla Gigedo Islands and Baja California is suggested in the progression of longline catches (indicated by +'s) from the second through the third quarters (Fig. 4). Williams also hypothesized the possibility of a surface SECC as an additional mechanism of eastward transport of juvenile skipjack tuna into the eastern Pacific southern fishery. Although a surface SECC has been identified as extending from the Solomon Islands to the coast of South America along lat. 10°S (Reid 1961), its occurrence at the surface in the area east of long. 120°-140°W has not been clearly defined. Wyrtki (1965) suggested that the SECC exists there only in subsurface layers, whereas Tsuchiya (1970, 1972) doubted the existence of zonal continuity all the way across the ocean. Recently, Tsuchiya (1974) recognized an eastward surface current (average speed of 7 cm/s) along lat. 10°S between long. 112° and 90°W in the southern summer. It should be noted, however, that the current may be too weak and too short to play a major role in supplying recruits into the eastern Pacific southern fishery.

The longline data discussed herein not only demonstrate a possible avenue of southern hemisphere skipjack tuna migration into the southern fishery, but show this to be possible without the presence of a SECC. According to the longline data, adult skipjack tuna are present as far south as lat. 20°S and as far east as long. 90°-95°W in the second and third quarters. The offspring of these fish could easily enter the wake system of the Galapoagos islands by simply moving along with the current (Fig. 13). Once there the move into the South American coastal waters can be made actively, as demonstrated by tagging results (Fink and Bayliff 1970, fig. 90).

The return route of skipjack tuna from the eastern Pacific northern fishery to the equatorial central Pacific spawning grounds is seen more clearly in the longline data than in the schematic presentation by Williams (1972). It seems that the westward movement of fish extends farther west, past long. 140°W, and this is corroborated by the recovery near Christmas Island and Hawaii of seven fish tagged in the eastern Pacific fishery (Table 4). These recaptures indicate that at least part of the fish returning to equatorial waters from the eastern Pacific migrate to Hawaii and the Line Islands, while the remainder could return eastward in the NECC.

Table 4.—Skipjack tuna tagged in the eastern Pacific and recaptured in the central Pacific (Seckel 1972).

Tagged fish	Release		Recapture		Months free
	Date	Area	Date	Area	
A	5 Sept. 1960	Baja California	12 June 1962	Hawaii	21
B	17 Apr. 1960	Revilla Gigedo Is.	22 Aug. 1962	Hawaii	28
C	22 Sept. 1961	Baja California	5 Apr. 1963	Christmas Is.	18
D	5 June 1965	Revilla Gigedo Is	27 June 1967	Hawaii	24
E	6 Nov. 1969	Clipperton Is.	21 July 1970	Hawaii	9
F	6 Nov. 1969	Clipperton Is	8 Aug. 1970	Hawaii	10
G	26 Oct. 1969	Lat. 4°11'N, long. 119°02'W	14 July 1971	Hawaii	21

Much of the westward migration of skipjack tuna from the eastern Pacific to Hawaii probably occurs in the area covered by Seckel's (1972) drift hypothesis, i.e., lat. 10°-20°N, long. 120°-160°W. Seckel gave 21-23 mo as the average minimum duration of westward drift through this area, and cited the possibility of even shorter drift periods if the skipjack tuna were caught in cells of high westerly flow of more than 25 cm/s (Seckel, 1972, fig. 17). Such a flow could take the skipjack tuna well over 3,900 km (2,100 nautical miles) in 6 mo. Both the average minimum drift period and the accelerated drift period are reflected in the recoveries in Hawaii of fish tagged in the eastern Pacific. Of six such recoveries, four were of 21-28-mo duration and two were of 9-mo duration (Table 4). The duration of skipjack tuna migration from northern Baja California to Hawaii suggested by the tuna longline data is 6 mo, similar to that attainable by fish in the cells of high westerly flow.

That the movement of the skipjack tuna in the above area involves more than just being transported by the surface currents is evident from the seasonal shifting of the northern boundary of distribution of the adults. The boundary shifts northward in the third and fourth quarters and southward in the first and second quarters (Fig. 8). More likely than not, the skipjack tuna in this region move southward actively in response to the southward advance of cool water from late fall to early spring, the fish seeking an environment more in accord with spawning than with feeding requirement (Blackburn and Williams 1975). Support for this view is seen in the northern limit of larval skipjack tuna occurrence within this region. The distribution of skipjack tuna larvae terminates sharply at lat. 10°-12°N between long 110° and 150°W (Matsumoto 1966).

Utilizing information gained from tagging by Fink and Bayliff (1970), the drift model by Seckel (1972), and the longline catch data, one could postulate the routes followed by the tagged fish from the eastern to the central Pacific (Fig. 15). Fish A, tagged off Baja California in September 1960 and recaptured in Hawaii in June 1962, had been at liberty for 21 mo. Fish B, tagged off the Revilla Gigedo Islands in April 1960 and recaptured in Hawaii in August 1962, had been at liberty for 28 mo. Considering that fish B had been tagged 5 mo earlier than fish A, that the general movement of fish in the eastern Pacific is northward in the third quarter, and that both fish had been recaptured in the same season (only 2 mo apart) in Hawaii, it is not unreasonable to assume that fish B had been tagged from the same group of fish (either school or schools) as fish A and that both fish, having left the eastern Pacific fishery in the fourth quarter, had a) entered the Hawaiian fishery in the following spring, remaining in the area a full season before being recaptured (routes A1, B1), or b) followed the longer routes A2, A3, B2, or B3.

Fish C, tagged off Baja California in September 1961 and recaptured east of Christmas Island in April 1963, was at liberty for 18 mo. The elasped time from release to recovery and the movement across the NECC suggest that the fish followed route C1 or C2, or some route between the two. The recovery of this fish in the SEC shows that the movement involved active migration as well as drifting with the current.

Fish D, tagged off Revilla Gigedo Islands in June 1965 and recaptured in Hawaii in June 1967, had been at liberty for 24 mo. This fish probably followed a path similar to that taken by fish B.

Fish E and F, tagged in November 1969 off Clipperton Island and recovered in Hawaii 9 and 10 mo later, respectively, lighely followed a shorter, more direct route, migrating nearly due west into the Hawaiian area and being caught soon after arrival. Such a movement is possible simply by drifting with the current, as indicated by Seckel (1972), with a minimum of active migration by the fish. Current trajectories drawn from monthly sea surface current charts also indicate a current path similar to that shown in Figure 15, with a time requirement of 11 mo between the two islands (Barkley, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, pers. commn.).

Fish G was tagged by the Honolulu Laboratory at lat. 4°11′N, long. 119°02′W on 26 October 1969 and recaptured in Hawaii 21 mo later on 14 July 1971. Based on the length of time at liberty, this fish likely had passed through the eastern Pacific fishery during the first year and had entered the Hawaiian fishery in the second or third quarter of the following year. A path that coincides with the assumed paths of fishes A, B, and D, and with the quarterly movement of high-CPUE cells of the longline fishery can be projected without exaggeration. The importance of this recovery, as well as the one east of Christmas Island, is that it showed the ability of the skipjack tuna to migrate across the NECC at a time when the current was well developed.

An alternate route that these fish could have taken in moving from the eastern Pacific to Hawaii is directly across the California Current (Fig. 14, route A4, B4, C3, D4, and G2). It seems unlikely that they did this, however, because 1) if this was the normal migratory route, the longline catches of skipjack tuna there should have been much higher than those recorded, yet the CPUE in each 5° area was not only low, but inconsistent from year to year; and 2) fish C would have had to move counter to the seasonal trend between Hawaii and the equatorial region without dallying in Hawaiian waters. It would seem more likely that once fish C had entered the Hawaiian fishery it would have stayed there for the remainder of the season and perhaps into the next as well.

In the central Pacific, the movements of skipjack tuna derived from longline catch data largely represent new information. In the area north of the equator, between Midway and Hawaii, the movement patterns indicate entry of fish into the Hawaiian fishery from 1) the eastern Pacific (corroborated by tag recoveries), 2) equatorial waters to the south, and possibly 3) the Japanese offshore fishery. Additionally, there could be a strictly local stock within the area. Captures of larval skipjack tuna (Matsumoto 1958) around Hawaii indicate that the species spawns there from spring through early fall. Some of the larvae remain in the vicinity of the islands and develop through the early juvenile stages, but many are undoubtedly carried downstream in the prevailing westerly current. Some of these probably get caught in the North Pacific gyre and return the following year or the year after as either 1- or 2-yr-old fish. An indication of the presence of fish from these several sources in the Hawaiian fishery was hinted at by Rothschild (1965). From length-frequency distributions of fish taken by the fishery, he recognized typical modal lengths of 35, 50, and 70 cm in winter and 45 and 75 cm in summer. Because the positions of the modes did not necessarily increase with time, Rothschild reasoned that the data suggested passage of successive groups of skipjack tuna through the fishery and that this passage was not uniform with respect to time.

In the South Pacific, at least two types of migratory routes are indicated: a short route that takes fish from an area east of the Marquesas through the Society Islands and back to an area southeast of the Marquesas Islands within 1 yr, and a longer route that takes fish from the equator northeast of the Marquesas to as far west as the Samoa-Fiji area and back east to an area southeast of the Marquesas Islands in 2, or possibly 3, yr.

The image one gets from these projected routes of migration of the central-eastern Pacific subpopulation is that the skipjack tuna or their progeny can wend their way in due time from the eastern Pacific to the boundary of the western Pacific subpopulation in both hemispheres.

How well this model of stock identification and migration reflects the actual conditions in the Pacific Ocean can be tested by the more positive means of tag

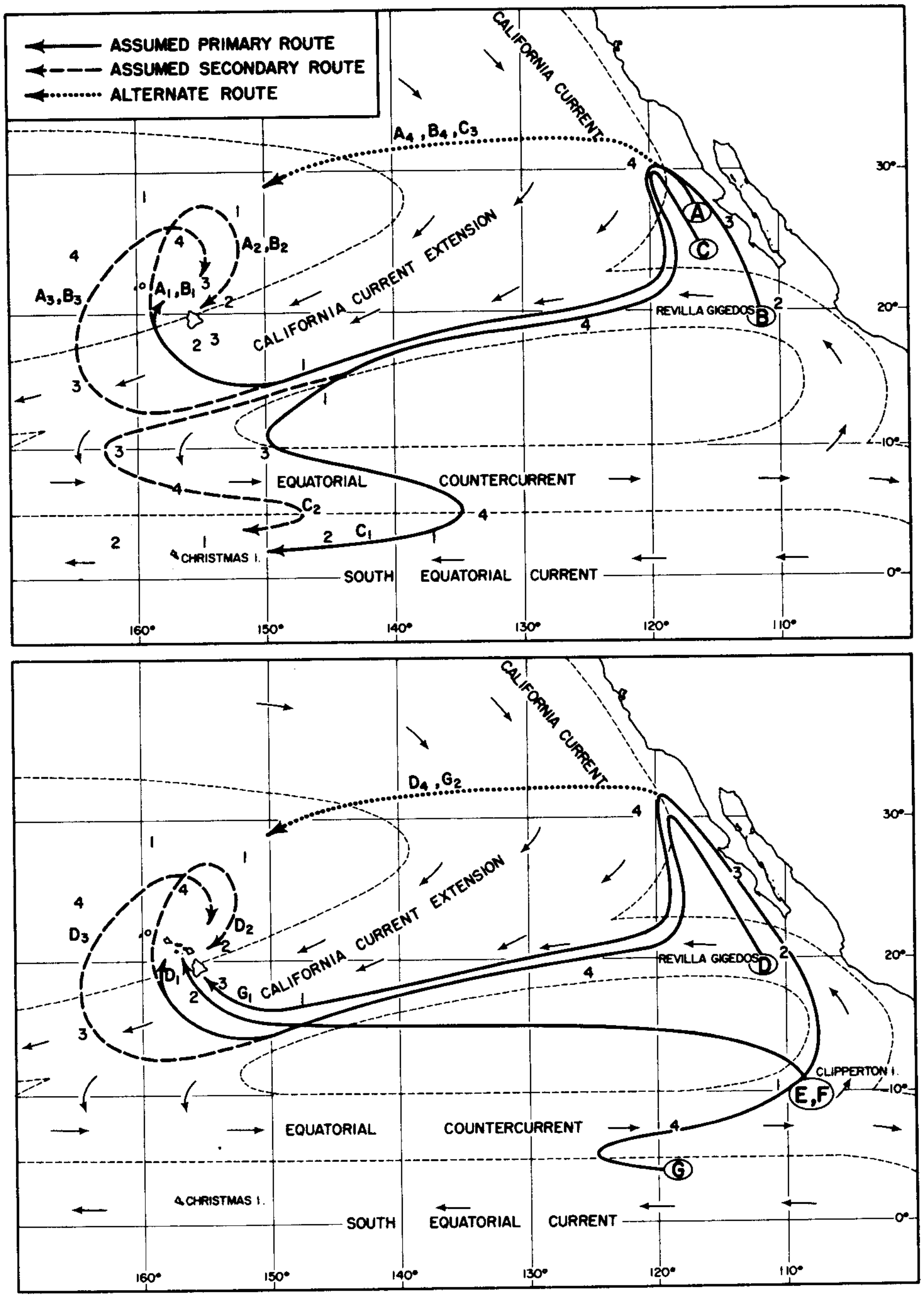


Figure 15.—Assumed routes followed by tagged skipjack tuna from the eastern to the central Pacific. The letters represent tagged fish and the numerals along the routes represent quarters of high catch rates of skipjack tuna taken by the Japanese tuna longline fishery, 1964-67.

returns. Unfortunately tagging of skipjack tuna in the past has not been as widespread nor as consistent and intensive as desirable. In the few areas where tagging has been done on a moderate scale, i.e., in the eastern and northwestern Pacific, the few tag recoveries have aided in developing parts of this model. Much more tagging effort is needed in these and other areas, however, if we are to gain a better knowledge of skipjack tuna migration in the Pacific Ocean. A model such as this could be the basis upon which a Pacific-wide tagging experiment could be developed.

SUMMARY

1. Skipjack tuna are taken mainly in surface fisheries that are restricted to coastal waters. Consequently, our knowledge about the distribution of these fish is equally limited. To get a better idea of the distribution, abundance, and movement of skipjack tuna in noncoastal waters, data of the Japanese tuna longline fishery from 1964 through 1967 were analyzed by determining the catch-per-unit effort (CPUE) for each 5° area of latitude and longitude by quarters for each of the years. Contours were drawn of the CPUE values to determine high-CPUE areas or cells and their movements from quarter to quarter.

2. The concentrations of zero catches at the northern and southern boundaries of the fishery indicated that fishing had occurred throughout the distributional range of the skipjack tuna.

3. Large skipjack tuna were found to be concentrated a) east central equatorial Pacific; b) eastern Pacific south of lat. 10°S; c) central North Pacific, north and northwest of Hawaii, and in Hawaiian waters; d) western North Pacific, south and east of Japan; and e) western South Pacific, northeast and east of Australia. The distribution of CPUE was characterized by a) the absence of uniformity in the northward and southward shifts of the northern and southern boundaries and along the boundaries across the Pacific; b) the persistence of a very large area of better-than-average CPUE in the east central equatorial Pacific (between long. 130°W and 180°, and between lat. 10°N and 15°S); and c) the disparity between high catch areas of the longline and the surface fisheries.

4. The relative abundance of adult skipjack tuna was suggested in the relative abundance of larvae in tropical and subtropical waters. The abundance was low in the eastern Pacific east of long. 120°W, high in the central Pacific between long. 120°W and 160°E, and low in the western Pacific between long. 120° and 160°E. A similar trend also was noted in the longline catches of skipjack tuna.

5. The apparent movement of groups of skipjack tuna in the Pacific appeared to coincide with the circulation of the major ocean currents. The movement was counterclockwise in the southern hemisphere and clockwise in the northern hemisphere, except in the eastern Pacific where the movement appeared counterclockwise, corresponding with the flow in the north equatorial water mass.

The movement patterns of high CPUE suggested the occurrence of a number of groups of skipjack tuna, possibly 14 or more, in the Pacific. The movement of the four westernmost groups, two each in the northern and southern hemispheres, generally agreed with those of the two western Pacific subpopulations of skipjack tuna proposed by Fujino (1972). Each group of the central-eastern Pacific subpopulation of (Fujino 1970a) seemed to follow its own seasonal migratory pattern that permitted movement of adults or their progeny from one area to the next, e.g., 1) skipjack tuna in the eastern Pacific northern fishery apparently originated in and returned to central equatorial waters, with part of the group moving into Hawaiian waters in subsequent seasons and part to the Line Islands area south of the equatorial countercurrent; 2) skipjack tuna in the Midway-Hawaii area were apparently composed of groups from the eastern and equatorial Pacific, from waters farther west between Midway and Wake Island, and possibly from the Marshall Islands and Japanese offshore surface fishery; and 3) part of the skipjack tuna in the eastern Pacific southern fishery apparently originated in the South Pacific to the east and south of the Marquesas Islands.

6. The migration of skipjack tuna from the eastern Pacific to Hawaii had been established by recoveries there of five fish tagged in the eastern North Pacific and one fish tagged in the eastern Pacific near the southern edge of the Equatorial Countercurrent (lat. 4°11'N, long. 119°W). The migratory routes of these fish as well as a seventh fish tagged in the eastern Pacific northern fishery and recovered near Christmas Island were postulated. The five fish recovered in Hawaii presumably departed the eastern Pacific fishery area in late fall and arrived in Hawaiian waters via the California Current Extension in the following spring or summer. The fish tagged near the southern edge of the Equatorial Countercurrent moved through the eastern Pacific fishery and then to Hawaiian waters via the California Current Extension where it was recaptured soon upon arrival. The fish tagged off Baja California and recaptured east of Christmas Island left the tagging area in late fall, arrived in equatorial waters via the California Current Extension and remained there a full year before being recaptured. The latter two recoveries were especially noteworthy since they demonstrated that skipjack tuna can move across the Equatorial Countercurrent.

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LITERATURE CITED

BROADHEAD, G. C., and I. BARRETT.
1964. Some factors affecting the distribution and apparent abundance of yellowfin and skipjack tuna in the Eastern Pacific Ocean. Inter-Am. Trop. Tuna Comm. Bull. 8:417-473.

BLACKBURN, M., and F. WILLIAMS.
1975. Distribution and ecology of skipjack tuna, *Katsuwonus pelamis*, in an offshore area of the eastern tropical Pacific Ocean. Fish. Bull., U.S. 73:382-411.

BRUN, M., and W. L. KLAWE.
1968. Landings of skipjack and yellowfin tuna at Papeete market (Tahiti). Commer. Fish. Rev. 30(4):62-63.
FINK, B. D., and W. H. BAYLIFF.
1970. Migrations of yellowfin and skipjack tuna in the eastern Pacific Ocean as determined by tagging experiments, 1952-64. Inter-Am. Trop. Tuna Comm. Bull. 15:1-227.
FUJINO, K.
1970a. Immunological and biochemical genetics of tunas. Trans. Am. Fish. Soc. 99:152-178.
1970b. Skipjack tuna subpopulation identified by genetic characteristics in the western Pacific. *In* J. C. Marr (editor), The Kuroshio. A symposium on the Japan Current, p. 385-393. East-West Center Press, Honolulu.
1972. Range of the skipjack tuna subpopulation in the western Pacific Ocean. *In* K. Sugawara (editor), The Kuroshio II. Proceedings of the Second Symposium on the Results of the Cooperative Study of the Kuroshio and Adjacent Regions, p. 373-384. Saikon Publ. Co., Ltd., Tokyo.
INTER-AMERICAN TROPICAL TUNA COMMISSION.
1966. Annual report of the Inter-American Tropical Tuna Commission 1965. Inter-Am. Trop. Tuna Comm., 106 p.
JAPAN, FISHERIES AGENCY OF, RESEARCH DIVISION.
1965. Annual report of effort and catch statistics by area on Japanese tuna long line fishery, 1962. Fish. Agency Jap., Res. Div., 183 p.
1966. Annual report of effort and catch statistics by area on Japanese tuna long line fishery, 1963. Fish. Agency Jap., Res. Div., 322 p.
1967a. Annual report of effort and catch statistics by area on Japanese tuna long line fishery, 1964. Fish. Agency Jap., Res. Div., 379 p.
1967b. Annual report of effort and catch statistics by area on Japanese tuna long line fishery, 1965. Fish. Agency Jap., Res. Div., 375 p.
1968. Annual report of effort and catch statistics by area on Japanese tuna long line fishery, 1966. Fish. Agency Jap., Res. Div., 299 p.
1969. Annual report of effort and catch statistics by area on Japanese tuna long line fishery, 1967. Fish. Agency Jap., Res. Div., 293 p.
JAPAN, MINISTRY OF AGRICULTURE and FORESTRY, STATISTICS and SURVEY DIVISION.
1963. Annual report of catch statistics on fishery and aquaculture. 1962. Jap., Minist. Agric. For., Stat. Surv. Div., 353 p.
1964. Annual report of catch statistics on fishery and aquaculture. 1963. [In Jap.] Jap., Minist. Agric. For., Stat. Surv. Div., 311 p.
1966. Annual report of catch statistics on fishery and aquaculture. 1964. [In Jap.] Jap., Minist. Agric. For., Stat. Surv. Div., 311 p.
1967. Annual report of catch statistics on fishery and aquaculture. 1965. [In Jap.] Jap., Minist. Agric. For., Stat. Surv. Div., 354 p.
1968. Annual report of catch statistics on fishery and aquaculture. 1966. [In Jap.] Jap., Minist. Agric. For., Stat. Surv. Div., 197 p.
1969. Annual report of catch statistics on fishery and aquaculture. 1967. [In Jap.] Jap., Minist. Agric. For., Stat. Surv. Div., 395 p.
KASAHARA, K.
1968. A look at the skipjack fishery and its future. [In Jap.] Bull. Jap. Soc. Fish. Oceanogr. 13:127-132. (Translated 1969, 9 p.; available Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.)
1971. Skipjack tuna resource and fishing grounds. Suisan Sekai 20(10):30-37. (Translated 1972, 20 p.; available Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.)
KASAHARA, K., M. YAO, A. NAGANUMA, M. ANRAKU, and M. ASANO.
1971. Studies on the movement of the skipjack in the Japanese waters by tagging experiments. I. [In Jap., Engl. abstr.] Bull. Tohoku Reg. Fish. Res. Lab., Shiogama 31:141-152. (Translated 1971, 20 p.; available Division of Foreign Fisheries [Translations], National Marine Fisheries Service, NOAA, Wash., D.C.)
KAWASAKI, T.
1965. Ecology and dynamics of the skipjack population (II). Resources and fishing conditions. [In Jap.] Nihon Suisan Shigen Hogo Kyokai, Suisan Kenkyu Sosho (Jap. Fish. Resour. Conserv. Assoc. Stud. Ser.) 8(2):49-108. (Translated 1967, 79 p.; by U.S. Joint Publications Research Service for Inter-Am. Trop. Tuna Comm. and U.S. Bur. Commer. Fish., La Jolla, CA 92037.)
1972. The skipjack tuna resource. [In Jap.] The Fishing and Food Industry Weekly 660:32-38, July 15, 1972. (Translated 1972, 15 p.; available Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.) (Also Mar. Fish. Rev. 35(5-6):1-7.)
KIMURA, K.
1949. Atlas of skipjack fishing grounds [In Jap.] Kuroshio Shobō, Tokyo, 1 p., 43 charts.
KLAWE, W. L.
1963. Observations on the spawning of four species of tuna (*Neothunnus macropterus, Katsuwonus pelamis, Auxis thazard* and *Euthynnus lineatus*) in the Eastern Pacific Ocean, based on the distribution of their larvae and juveniles. Inter-Am. Trop. Tuna Comm. Bull. 6:449-540.
KUME, S., and J. JOSEPH.
1969. The Japanese longline fishery for tunas and billfishes in in the eastern Pacific Ocean east of 130°W, 1964-1966. Inter-Am. Trop. Tuna Comm. Bull. 13:277-418.
MATSUMOTO, W. M.
1958. Description and distribution of larvae of four species of tuna in central Pacific waters. U.S. Fish Wild. Serv., Fish. Bull. 58:31-72.
1966. Distribution and abundance of tuna larvae in the Pacific Ocean. *In* T. A. Manar (editor), Proceedings, Governor's Conference on Central Pacific Fishery Resources, State of Hawaii, p. 221-230.
MIYAKE, M. P.
1968. Distribution of skipjack in the Pacific Ocean, based on records of incidental catches of the Japanese longline tuna fishery. Inter-Am. Trop. Tuna Comm. Bull. 12:509-608.
MURPHY, G. I., and T. OTSU.
1954. Analysis of catches of nine Japanese tuna longline expeditions to the western Pacific. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish. 128, 46 p.
MURPHY, G. I., and R. S. SHOMURA.
1953. Longline fishing for deep-swimming tunas in the central Pacific, January-June 1952. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish. 108, 32 p.
1955. Longline fishing for deep-swimming tunas in the central Pacific, August-November 1952. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish. 137, 42 p.
NAKAMURA, H.
1969. Tuna distribution and migration. Fishing News (Books), Ltd., Long., 76 p.
REID, J. L., Jr.
1961. On the geostrophic flow at the surface of the Pacific Ocean with respect to the 1,000-decibar surface. Tellus 13:489-502.
ROTHSCHILD, B. J.
1965. Hypotheses on the origin of exploited skipjack tuna (*Katsuwonus pelamis*) in the eastern and central Pacific Ocean. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 512, 20 p.
1966. Major changes in the temporal-spatial distribution of catch and effort in the Japanese longline fleet. *In* T. A. Manar (editor), Proceedings, Governor's Conference on Central Pacific Fishery Resources, State of Hawaii, p. 91-126.
SECKEL, G. R.
1968. A time-sequence oceanographic investigation in the North

Pacific trade-wind zone. Trans. Am. Geophys. Union 49:377-387.

1972. Hawaiian-caught skipjack tuna and their physical environment. Fish. Bull., U.S. 70:763-787.

SHOMURA, R. S., and G. I. MURPHY.

1955. Longline fishing for deep-swimming tunas in the central Pacific, 1953. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 157, 70 p.

SIEGEL, S.

1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill, N.Y., 312 p.

STRASBURG, D. W.

1960. Estimates of larval tuna abundance in the central Pacific. U.S. Fish Wildl. Serv., Fish. Bull. 60:231-255.

SVERDRUP, H. U., M. W. JOHNSON, and R. H. FLEMING.

1946. The oceans, their physics, chemistry, and general biology. Prentice-Hall, Inc., N.Y., 1087 p.

TOHOKU REGIONAL FISHERIES RESEARCH LABORATORY.

n.d. Atlas of skipjack tuna fishing grounds in southern waters, 1966 and 1967. [In Jap.] (Translated 1969, 28 p.; available Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.)

TSUCHIYA, M.

1970. Equatorial circulation of the South Pacific. *In* W. S. Wooster (editor), Scientific exploration of the South Pacific. Proceedings of a symposium held during the Ninth General Meeting of the Scientific Committee on Oceanic Research, June 18-20, 1968, at the Scripps Institution of Oceanography, La Jolla, Calif., p. 69-74. Natl. Acad. Sci., Wash., D.C.

1972. A subsurface North Equatorial Countercurrent in the eastern Pacific Ocean. J. Geophys. Res. 77:5986. (Also eastern Pacific Ocean. J. Geophys. Res. 77:5981-5986. (Also Contrib. Scripps Inst. Oceanogr. 42:1378-1383.)

1974. Variation of the surface geostrophic flow in the eastern intertropical Pacific Ocean. Fish. Bull., U.S. 72:1075-1086.

UEYANAGI, S.

1969. Observations on the distribution of tuna larvae in the Indo-Pacific Ocean with emphasis on the delineation of the spawning areas of albacore, *Thunnus alalunga.* Bull. Far Seas Fish. Res. Lab. (Shimizu) 2:177-256.

[U.S.] BUREAU OF COMMERCIAL FISHERIES.

1963. Skipjack—A world resource. U.S. Fish Wild. Serv., Circ. 165, 28 p.

VAN CAMPEN, W. G.

1960. Japanese summer fishery for albacore (*Germo alalunga*). U.S. Fish Wildl. Serv., Res. Rep. 52, 29 p.

VAN CAMPEN, W. G. (editor).

1963. Progress in 1961-62. U.S. Fish Wildl. Serv., Circ. 163, 35 p.

WILLIAMS, F.

1972. Consideration of three proposed models of the migration of young skipjack tuna (*Katsuwonus pelamis*) into the eastern Pacific Ocean. Fish. Bull., U.S. 70:741-762.

WILSON, R. C., E. L. NAKAMURA, and H. O. YOSHIDA.

1958. Marquesas area fishery and environmental data, October 1957-June 1958. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 283, 105 p.

WYRTKI, K.

1965. Surface currents of the Eastern Tropical Pacific Ocean. Inter-Am. Trop. Tuna Comm. Bull. 9:269-304.

YOSHIHARA, T.

1954. On the distribution of catches by tuna long-line. J. Tokyo Univ. Fish. 41:1-26.