DISTRIBUTION AND ECOLOGY OF SKIPJACK TUNA, *KATSUWONUS PELAMIS*, IN AN OFFSHORE AREA OF THE EASTERN TROPICAL PACIFIC OCEAN

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ABSTRACT

Distributions of skipjack tuna, *Katsuwonus pelamis*, were studied in the offshore eastern tropical Pacific between lat. 15°N and 5°S, long. 115° and 125°W, during two cruises in 1970 and 1971. Another cruise was made there with different methods in 1969. All cruises were between October and April. Various environmental properties were measured.

Catches of skipjack included fish smaller and larger than those generally taken near the American coast. This is consistent with previous hypotheses that mature adults and their larvae generally occur far offshore, whereas adolescents are generally coastal, in the eastern Pacific. The juveniles arriving near the coast and the older fish leaving it evidently cross the studied area on migrations from and to the spawning regions.

In 1970 and 1971 skipjack > 45 cm were most abundant in the equatorial upwelling and at the northern boundary of the North Equatorial Countercurrent, and scarce in the Countercurrent. Correlation coefficients between skipjack > 45 cm and skipjack forage in 1970 were positive and significant by the usual criteria, but the significance may in part be disputable because many other correlations involving skipjack were nonsignificant. The apparent significance was lost when juvenile skipjack (< 45 cm) were included with the larger ones. Juveniles may have different relations to environment. The 1971 data were scanty and yielded no significant correlations between skipjack and forage.

On the 1969 cruise forage was not studied. Skipjack were abundant in the Countercurrent, but at a prespawning stage, whereas postspawners predominated on the other cruises. Other studies suggest that skipjack larvae require relatively high temperatures, which occurred only in the Countercurrent on the 1969 cruise. Skipjack may be distributed according to the environmental requirements of their larvae when spawning and according to their own feeding requirements when not spawning.

Williams (1971) described plans for a series of cruises in two offshore areas of the eastern tropical Pacific Ocean. This report deals with results of two cruises made in 1970 and 1971 in one of the areas, bounded by lat. 15°N-5°S and long. 115°-125°W (Figure 1). The cruises were initiated by the National Marine Fisheries Service, Southwest Fisheries Center, and the Scripps Tuna Oceanography Research (STOR) Program, Institute of Marine Resources, University of California. They were designed to investigate on a seasonal basis the occurrence and relative abundance of skipjack tuna, *Katsuwonus pelamis*, in relation to environmental conditions. Coverage of

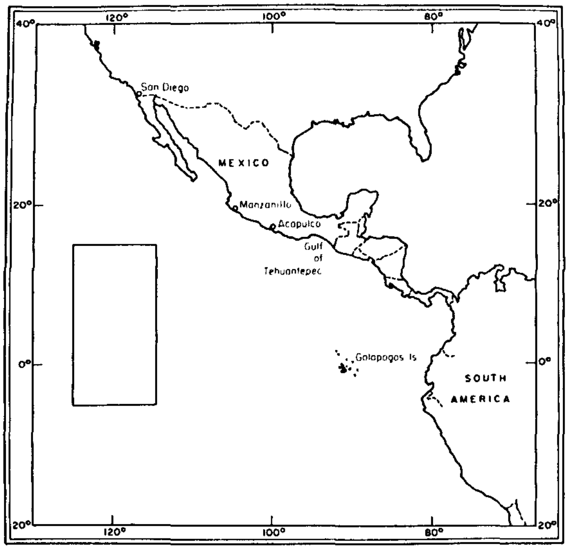

FIGURE 1.—Area of eastern tropical Pacific Ocean under investigation.

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offshore areas by the U.S. surface tuna fishery has been very limited, especially for skipjack. Coverage by the Japanese subsurface tuna fishery has been greater, but still poor for skipjack (Miyake 1968). The regulation of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific is expected to increase the need for information on skipjack in the offshore waters.

Work in coastal waters has shown that adult skipjack are most numerous when temperature is in the range 20° to 29°C (Williams 1970) and standing stock of skipjack forage is high (Blackburn 1965, 1969). Sea surface temperatures are in the suitable range for most of the year throughout the offshore eastern tropical Pacific (Wyrtki 1964; La Violette and Seim 1969; Love 1971b, 1972a, b, in prep.). Thus distribution of forage seemed likely to be a main factor in determining distribution of adult skipjack in offshore waters. The distribution of forage in that region was described from data of EASTROPAC Expedition (1967-68) by Blackburn and Laurs (1972), who expected that adult skipjack would prove to be distributed in the same way. One of the purposes of the present study was to test that expectation. The forage concentrations on EASTROPAC were characteristically high in certain zones of latitude and low in others, broadly corresponding to distributions of phytoplankton, zooplankton, and total micronekton (Love 1970, 1971a, in prep.; Blackburn et al. 1970; Owen and Zeitzschel 1970a).

Evidence, summarized by Williams (1972), indicates that most exploited skipjack in the eastern Pacific have a spawning origin in the central Pacific west of long. 130°W. It also suggests that the majority of the skipjack enter the present fishery, which is concentrated near tropical American coasts, during only 1 yr of their life history. They are then relatively small (average length about 50 to 55 cm, average weight 3 to 3.5 kg) and sexually immature. Thus it is probable that migration pathways exist for skipjack, both below and above these sizes, across the offshore eastern tropical Pacific.

Such pathways might occur at particular latitudes since forage concentrations and many other ocean conditions, including surface currents, are zonally oriented. On this basis Williams (1972) presented three qualitative models of the migration of young (recruit) skipjack from the central Pacific into the eastern Pacific fishing areas. The data from the present cruises may be useful for testing and modification of the models, and incorporation with other models of skipjack movement such as that of Seckel (1972).

PLAN OF THE INVESTIGATIONS

The inward skipjack migration models of Williams (1972) assumed that the routes were principally zonal across the offshore eastern Pacific. Mechanisms and timing of the migrations are probably dependent on oceanographic conditions and events in this region. The strategy for the present investigations was to have latitudinal sampling of fish and environmental parameters in meridional areas considered critical to the migrations. The area discussed in this paper includes the meridian of 119°W. It is important because the surface North Equatorial Countercurrent normally becomes intermittent or absent east of this meridian from January to May.

Each cruise had two parts (Williams 1971). Part I was a rapid meridional transect of the area along long. 119°W to monitor ocean conditions and compare them with previous data. These results showed the positions of zonal surface current boundaries and forage bands, and hence the latitudinal zones that were to be fished for skipjack.

In Part II detailed fisheries operations were carried out in the selected zones to a standardized plan based on a "unit area" of 2° latitude by 2° longitude, together with supporting environmental observations. Fishing was by multiple trolling during daylight. Figure 2 shows schematically the track and scheduled observations. The work time for each unit area, including entry and exit, was 96 h. Coverage in a zone of latitude could consist of any multiple of unit areas or fractions thereof (quadrants or 1° × 1° areas).

The first cruise in November-December 1970 utilized the vessels *Townsend Cromwell* (Cruise C 51) (R. Uchida, Chief Scientist) and *David Starr Jordan* (J 57) (F. Williams, Chief Scientist). The second cruise in March-April 1971, was made with only the *Jordan* (J 60) (M. Blackburn, Chief Scientist). The *Jordan* 60 cruise was severely curtailed due to illness of a crew member. On the first cruise the Part I transect was completed by the *Cromwell*; and data were sent by radio to the *Jordan*; subsequent Part II operations were carried out by both vessels.

This paper also discusses data from a cruise made by National Marine Fisheries Service, Hawaii, to the same area in October-November

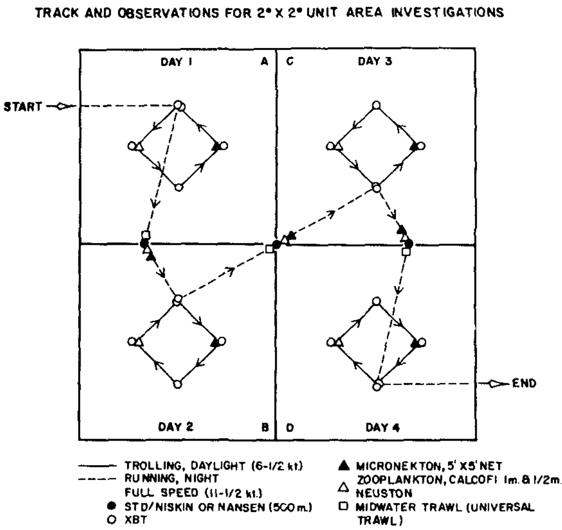

FIGURE 2.–Track and observations scheduled for each 2° × 2° unit area during Part II operations. [Dawn trawl haul was eliminated on cruise *Jordan* 60].

1969, in more detail than the previous cruise report by Hida (1970).

METHODS

This section deals with methods used on the 1970 and 1971 cruises. The Bissett-Berman[3] Salinity-Temperature-Depth probe (STD) and Sippican expendable bathythermograph (XBT) were used for measuring temperature and salinity. A Niskin 12-bottle rosette sampler coupled with the STD was used to collect water samples for salinity and oxygen. The STD system had digital (magnetic tape data logger) and analog chart outputs, as did the XBT system (punched paper tape and analog chart). STD/Niskin casts were normally made to 500 m and XBT drops to 450 m. Nansen bottle casts, for calibration of the STD system, were made at the start and finish of the Part I transect and at intervals during Part II fishing operations. On the Part I transect, STD/Niskin stations for temperature, salinity, and oxygen were made every 6 h, with one or more XBT drops between STD stations. In Part II operations, three STD stations were made at night in each 2° × 2° unit area, and five XBT drops between dawn and dusk on fishing tracks (Figure 2). Processing of the physical oceanographic data was as described by Taft and Miller (1970). Depth of the mixed layer was derived directly from analog charts of XBT and STD systems according to criteria of Owen (1970a).

Dissolved oxygen content of water samples from the Niskin sampler was determined, and data processed, as indicated by Owen (1970b). Discrete surface samples for chlorophyll *a* were taken at approximately noon and midnight and processed as described by Owen and Zeitzschel (1970b).

Zooplankton hauls were made and samples processed by the methods used on EASTROPAC Expedition (Laurs 1970). Oblique hauls from 200 m to surface were made with nets of 50 cm and 1 m mouth diameter in a paired frame. A wire angle of 45° was maintained during the haul at a speed about 1.5 to 2 knots. In Part II operations, one daylight haul was made during each of 4 days of fishing in a 2° × 2° unit area (see Figure 2), and three night hauls were made during the 4-day period. No hauls were made near dawn or dusk. Data were expressed in displacement volume in milliliters per 1,000 m^3.

Micronekton was sampled with a net 1.5 m square at the mouth, in oblique hauls from 200 m to surface at a ship speed of 5 knots (Blackburn 1968, 1970; Blackburn et al. 1970). During the Part I transect, micronekton hauls were made at approximately 12-h intervals following STD casts, one during daylight and one at night. In Part II operations, day and night hauls were made with the same frequency as for zooplankton (see Figure 2). Processing of the samples and estimation of volume of water strained was as discussed by the same authors, and total micronekton was expressed as displacement volume in milliliters per 1,000 m^3. A variable and generally large proportion of this micronekton consisted of organisms that skipjack are known or likely to eat (skipjack forage) in the eastern tropical Pacific. The micronekton catches were therefore sorted into forage and nonforage organisms (Blackburn and Laurs 1972). Forage organisms were all crustaceans, all cephalopods, all epipelagic fish and *Vinciguerria*. Nonforage organisms were all mesopelagic fish except *Vinciguerria* and all leptocephali.

The trolling gear used to catch skipjack and other fish was similar to that used in the albacore fishery off the U.S. west coast (Yoshida 1966). Feather jigs were fished with nylon traces and

[3]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

nylon parachute cord lines. The *Cromwell* could fish only 4 lines from the stern, compared with 11 fished by the *Jordan*, 8 from outriggers and 3 from the stern. On the *Jordan* the 4 lines on each outrigger were connected to a set of hydraulic power gurdies for rapid hauling.

Charts and sections were contoured by hand except those of dissolved oxygen content which were prepared by computer and Calcomp plotter. Gear and methods used for neuston and midwater trawl samples are not discussed because the results are not utilized in this report. The same applies to observations on birds, fish schools, and marine mammals.

RESULTS OF THE EXPERIMENTAL FISHING

Based on the position of the surface current boundaries and distributions of temperature and skipjack forage derived from Part I operations, the latitudinal zones investigated in Part II fishing operations were similar on the 1970 and 1971 cruises: 12°-14°N, 9°-11°N, 6°-8°N, 3°-5°N, 1°-3°N, and 2°-4°S. Figures 3 and 4 show the cruise tracks during Part II fishing operations in the above-mentioned zones. They also show approximate positions of surface current boundaries, which were obtained from data on thermocline topography.

TABLE 1.–Total fishing effort in the study area.

Period	Cruise no.		Line-hours fished in unit areas	Line-hours fished on passage
Nov.-Dec. 1970	*Jordan* 57	2,746 }	3,213	131
Nov.-Dec. 1970	*Cromwell* 51	467 }		
Mar.-Apr. 1971	*Jordan* 60		2,088	255

The total fishing effort (number of line-hours) in or immediately adjacent to the study area was very much higher on the November-December 1970 cruise than in March-April 1971, because of the curtailment of the latter cruise (Table 1). The catch by species on each cruise is given in Table 2, which shows the number boarded and kept, tagged and released, and lost but identified, and the overall size range of each species. Skipjack was obviously the dominant species on each cruise.

DISTRIBUTION AND RELATIVE ABUNDANCE OF SKIPJACK AND OTHER TUNA

This section deals with results from the 1970 and 1971 cruises. Relative abundance of skipjack was calculated in terms of catch per line-hour on track. Catch equals number boarded, tagged, and lost but identified. Fish taken when the vessel circled following an initial strike, or when chumming with live anchovy, are not included. Troll catches of skipjack made on track and separated, arbitrarily, by >10 min are considered to have come from separate schools or aggregations of fish, and an index of schools encountered per hour of trolling has been derived. There are highly significant positive correlations between catch/line-hour and schools/hour for each cruise ($r = +0.907$ for data of Table 3 and $+0.716$ for Table 4, both significant at the 1% level). Schools/hour is a more conservative indicator of relative abundance of skipjack than catch/line-hour because each

TABLE 2.–Summary of fish catch by species: Cruises *Jordan* 57-*Cromwell* 51, November-December 1970, and *Jordan* 60, March-April 1971.

Species	*Jordan 57-Cromwell 51* Boarded	Tagged	Lost but identified	Size range (cm)	*Jordan 60* Boarded	Tagged	Lost but identified	Size range (cm)
Skipjack (*Katsuwonus pelamis*)	114	67	~118	32.5- 71.0	61	8	49	41.8-70.0
Yellowfin tuna (*Thunnus albacares*)	30	4	5	26.2-111.5	2	–	–	33.5-44.7
Frigate mackerel (*Auxis thazard*)	2	–	–	30.2- 31.0	1	–	–	34.6
Unidentified tuna	–	–	12	–	–	–	–	–
Wahoo (*Acanthocybium solandri*)	4	–	1	52.0-110.0	–	–	–	–
Shortbill spearfish (*Tetrapturus angustirostris*)	–	–	1	–	–	–	–	–
Dolphin (*Coryphaena hippurus*)	8	–	–	20.5-114.5	6	–	~5	34.0-46.3
Pompano dolphin (*C. equiselis*)	4	–	2	26.5-~50.0	–	–	–	–
Rainbow runner (*Elagatis bipinnulatus*)	–	–	–	–	1	–	–	81.5
Unidentified fish (lost)	–	–	10	–	–	–	10	–

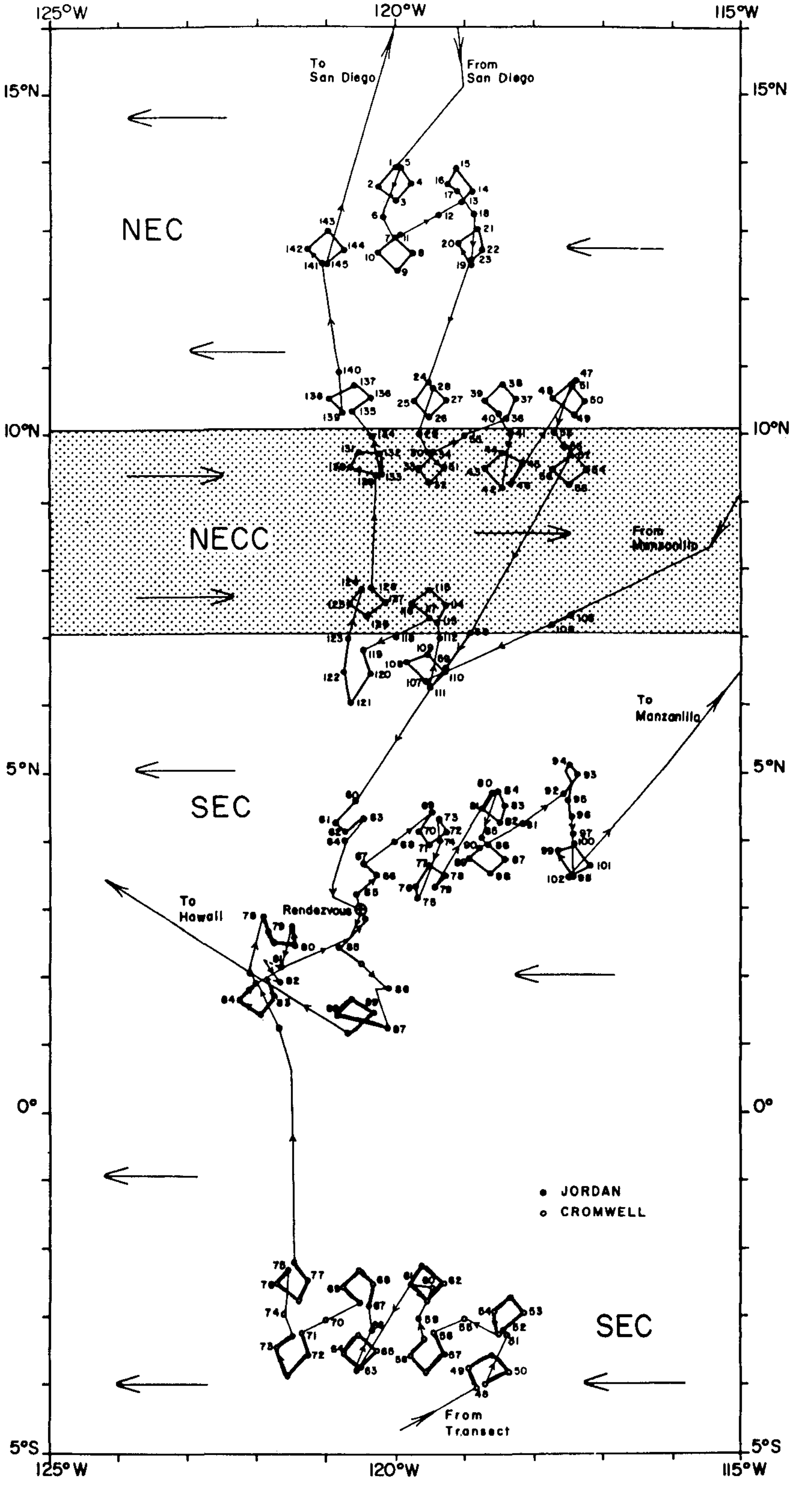

FIGURE 3.–Cruise tracks, Part II operations, *Jordan* 57-*Cromwell* 51, November-December 1970. Thickened lines indicate daylight fishing tracks. Approximate boundaries of surface currents are indicated.

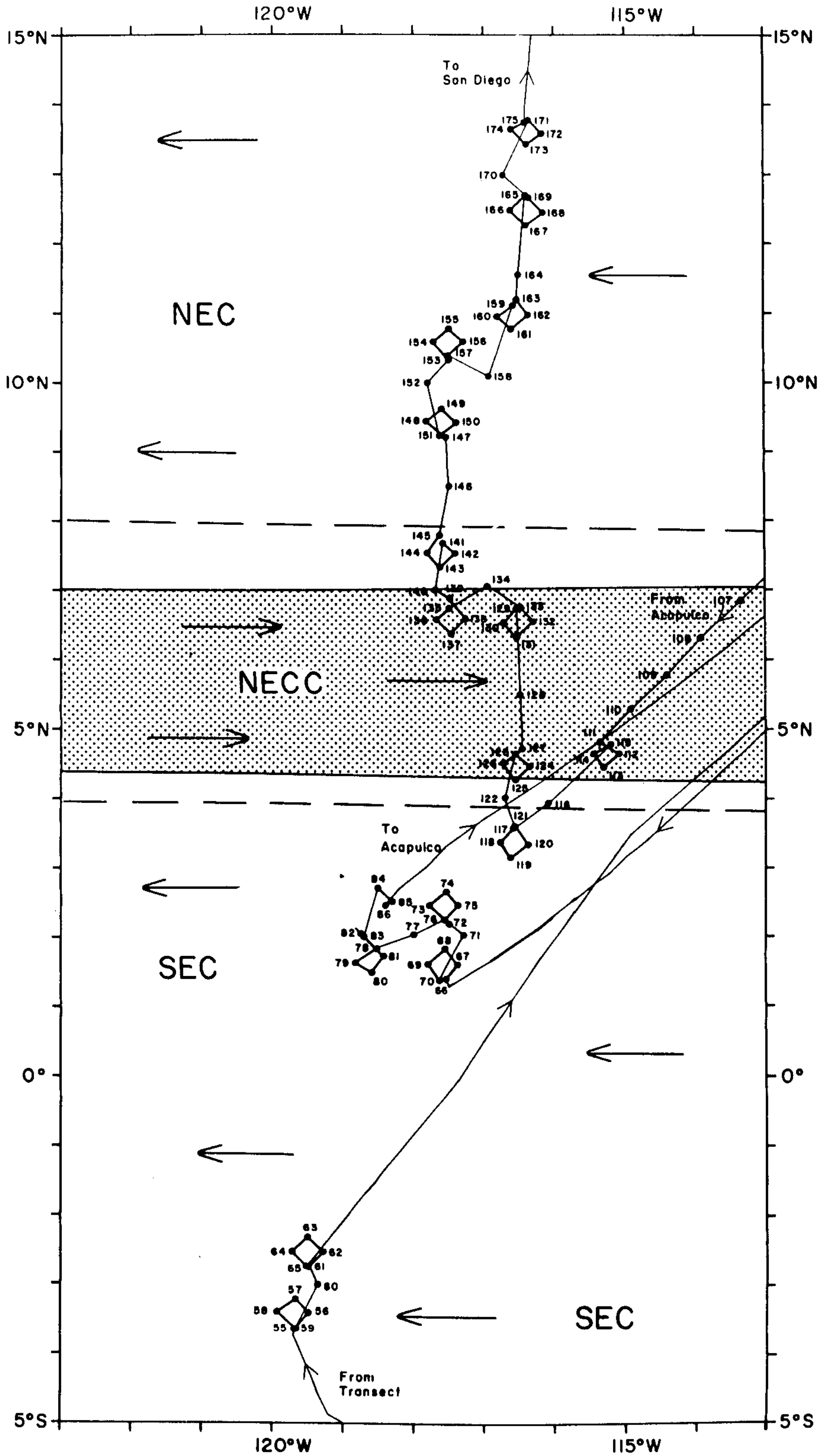

FIGURE 4.—Cruise tracks, Part II operations, *Jordan* 60, March-April 1971. Thickened lines indicate daylight fishing tracks. Approximate boundaries of surface currents are indicated.

TABLE 3.—Relative abundance of troll-caught skipjack and other tuna, Cruises *Jordan* 57-*Cromwell* 51, November-December 1970.

Zone latitude	Current system	Catch/line-hour			Schools/hour skipjack
		Skipjack	Yellowfin	All tuna	
13°-14°N	NEC	0.072	0	0.072	0.10
12°-13°N	NEC	0.038	0.057	0.101	0.17
10°-11°N	NEC	0.064	0.022	0.099	0.17
9°-10°N	NECC	0.014	0	0.014	0.08
7°-8°N	NECC	0.075	0.004	0.079	0.10
6°-7°N	SEC	0.009	0	0.037	0.05
4°-5°N	SEC	0.100	0	0.100	0.10
3°-4°N	SEC	0.130	0.016	0.146	0.25
2°-3°N	SEC	0.015	0	0.015	0.06
1°-2°N	SEC	0.354	0	0.354	0.40
0°40′-1°N[1]	SEC	0.208	0	0.208	0.48
2°-3°S	SEC	0.096	0	0.096	0.13
3°-4°S	SEC	0.028	0	0.028	0.10

[1]Data on this line are from fishing on passage, <50 line-h.

TABLE 4.—Relative abundance of troll-caught skipjack and other tuna, Cruise *Jordan* 60, March-April 1971. Data in square brackets are from fishing on passage and are included in totals to the left.

Zone latitude	Current system	Catch/line-hour			Schools/hour skipjack
		Skipjack	Yellowfin	All tuna	
[16°-17°N	NEC	0.064	0	0.064	0.32]
13°-14°N	NEC	0.008	0.008	0.016	0.09
12°-13°N	NEC	0.054	0	0.054	0.08
10°-11°N	NEC	0.107	0	0.107	0.46
9°-10°N	NEC	0.134	0	0.134	0.17
7°-8°N	NEC	0	0	0	0
6°-7°N	NECC	0.031	0	0.031	0.09
4°-5°N	NECC/SEC	0.042	0.004	0.046	0.08
3°-4°N	SEC	0	0	0	0
2°-3°N	SEC	0.023 [0.019]	0	0.023 [0.019]	0.12 [0.10]
1°-2°N	SEC	0.067 [0.064]	0	0.067 [0.064]	0.17 [0.17]
2°-3°S	SEC	0.062	0	0.063	0.25
3°-4°S	SEC	0.039	0	0.029	0.16

aggregation is given equal weighting irrespective of the number of fish caught. The index does not reflect the size of the aggregations, which on both cruises were considered to be relatively small. No large surface schools of skipjack or other tuna were seen in the study area.

Tables 3 and 4 show the relative abundance of skipjack, yellowfin tuna and total tuna as catch/line-hour and skipjack as schools/hour for 1° latitudinal zones fished in Part II operations. Approximate boundaries of surface current systems are also indicated: NEC, NECC, and SEC mean North Equatorial Current, North Equatorial Countercurrent, and South Equatorial Current. In November-December 1970 the highest level of relative abundance of skipjack was between lat. 0°40′ and 2°N, with a secondary maximum at lat 3° to 5°N and other high levels north of the NECC and south of the Equator. Within the NECC at lat. 7° to 10°N, relative abundance in terms of catch rate was variable, but generally low in terms of schools encountered. With the added contribution of yellowfin and other tuna, there was a marked maximum north of the NECC. In March-April 1971, overall relative abundance was much lower, and the principal maximum was situated north of the NECC, between lat. 9° and 11°N. Secondary maxima occurred at lat. 1° to 3°N and south of the Equator. The relative abundance of skipjack in the NECC was again low.

In Figures 5, 6, 7, and 8, daily values of relative abundance (catch rates and schools) are plotted and contoured. The results are more difficult to interpret in this form, but there are some general agreements with the zonally averaged data.

Off-track Catches of Skipjack

Off-track troll catches of skipjack were made with the use of anchovy, *Engraulis mordax*, live bait on *Jordan* 57. On five occasions schools of skipjack were chummed with live bait, following initial jig strikes (4) or fish sighting (1). On two of these occasions the chumming and circling of the vessel produced a substantial additional catch. Use of live bait on cruises of this type is advantageous in order to increase sample size of fish.

Distribution of Skipjack by Time of Day

Percentages of the total numbers of skipjack schools encountered on track in each 1-h period have been calculated and are given in Table 5. Schools are defined as above. Some 60-min periods included station time (i.e., not fishing), and the numbers of schools per unit time have been adjusted. Variability in occurrence is considerable between cruises for 1-h periods. However, when presented by 2-h periods, the temporal occurrence of skipjack shows remarkable similarity on the two cruises. Surprisingly, fewest aggregations were encountered before 1000 h. Aggregations were encountered most frequently between 1200 and 1500 h, and again, as expected, in the predusk period, 1700 to 1759 h.

Biological Characteristics of Skipjack and Other Tuna

Size of Skipjack

Measurements of fish length (tip of snout to tip of median caudal fin rays) were made to the nearest millimeter on all fish. Table 6 shows the

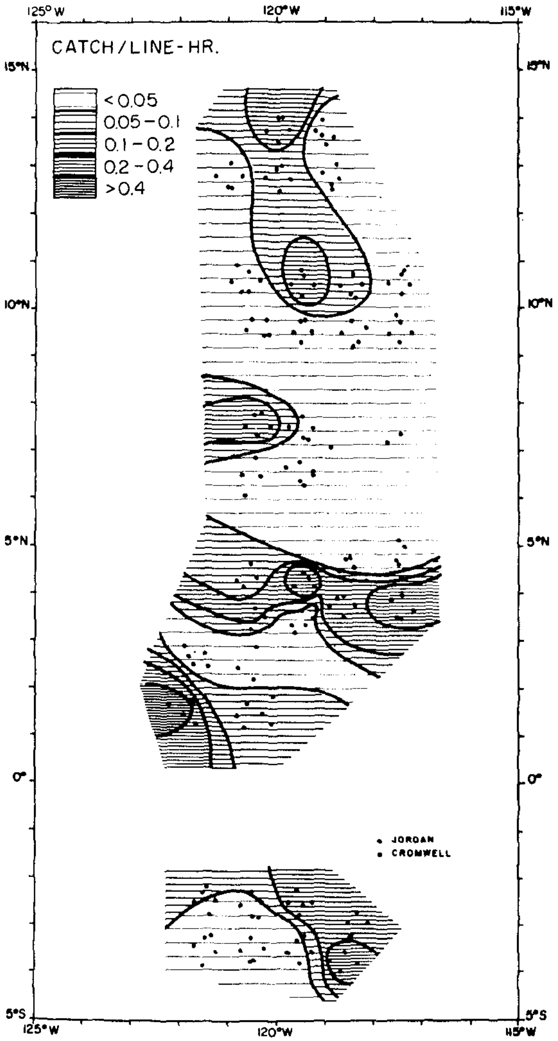

FIGURE 5.—Relative abundance of skipjack in catch/line-hour, cruises *Jordan* 57-*Cromwell* 51, November-December 1970.

percent of skipjack in three broad size categories for the two cruises. The most significant feature is that 13.3% of skipjack were <45 cm in November-December 1970, as against 2.9% on the next cruise.

The fish <45 cm were not distributed over a large part of the area, as fish >45 cm were, in November-December 1970. Of the small fish, 16 (85%) were from areas north of the NECC, lat. 10° to 14°N, and the remaining 3 (15%) from south of the NECC, lat. 0°30′ to 4°N; none were found in the NECC or south of the equator. Table 7 shows small skipjack (<45 cm) as percent of total in the latitudinal zones north of 10°N. It appears that the

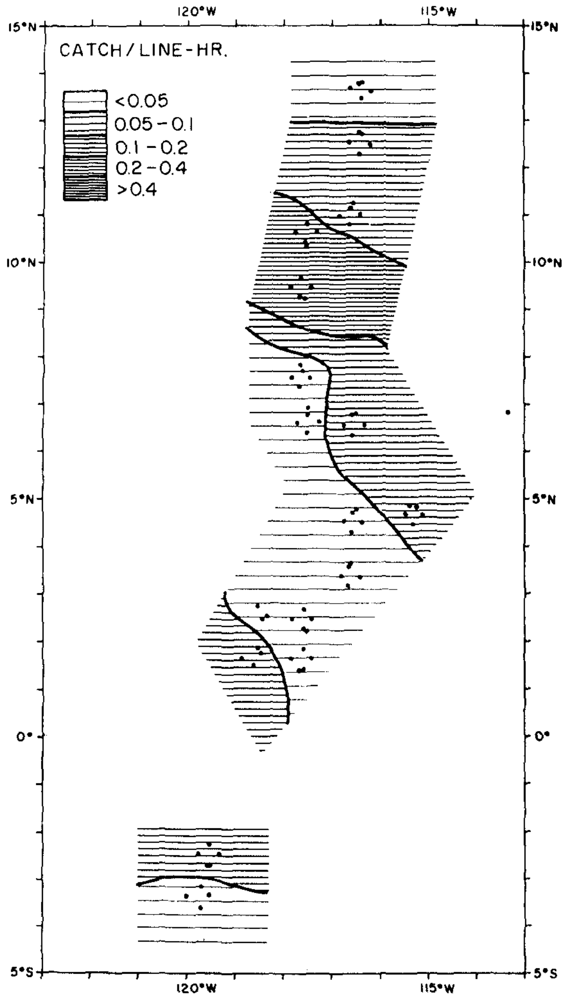

FIGURE 6.—Relative abundance of skipjack in catch/line-hour, cruise *Jordan* 60, March-April 1971.

TABLE 5.—Percent[1] of total number of skipjack schools encountered on track, by 1-h periods (all fishing days combined): Cruises *Jordan* 57-*Cromwell* 51, November-December 1970, and *Jordan* 60, March-April 1971.

Time period	*Jordan* 57-*Cromwell* 51		*Jordan* 60	
Start[2]-0659	3.7%	12.3%	12.2%	12.2%
0700-0759	8.6		0	
0800-0859	2.5	9.4	3.6	9.4
0900-0959	6.9		5.8	
1000-1059	8.8	16.0	10.6	16.2
1100-1159	7.2		5.6	
1200-1259	14.9	21.2	2.9	20.2
1300-1359	6.3		17.9	
1400-1459	7.5	14.8	15.8	21.6
1500-1559	7.3		5.8	
1600-1659	7.3	26.3	5.4	19.8
1700-1759	19.0		14.4	
Total fishing days	28		21	

[1]Adjusted data, see text p. 388.
[2]Mean start 0556 h and 0539 h on *Jordan* 57-*Cromwell* 51 and *Jordan* 60 respectively.

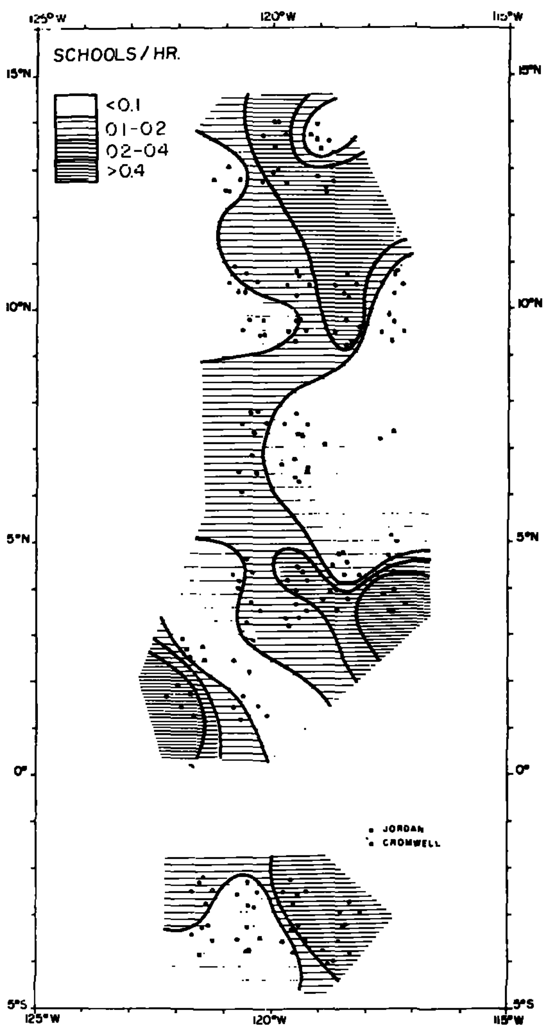

FIGURE 7.—Relative abundance of skipjack in schools/hour, cruises *Jordan* 57-*Cromwell* 51, November-December 1970.

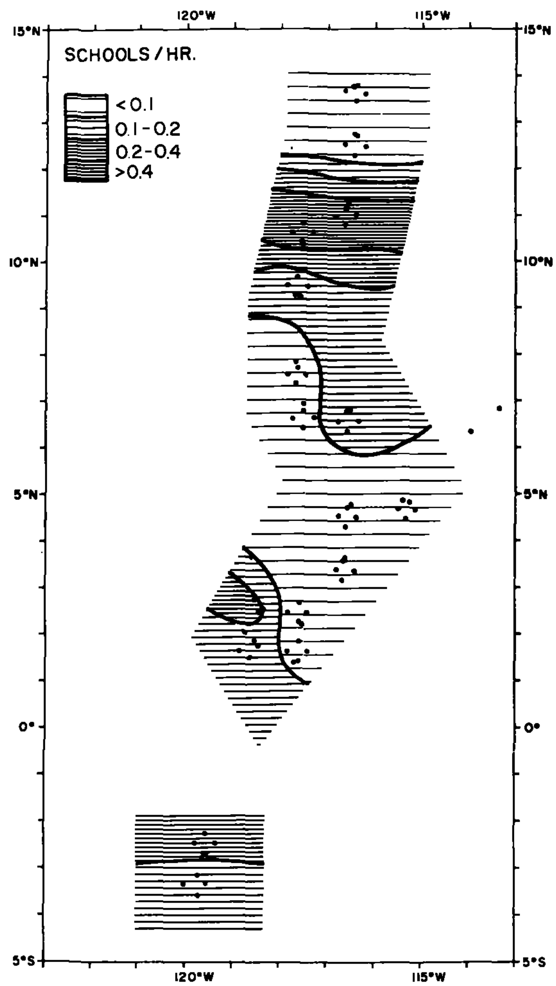

FIGURE 8.—Relative abundance of skipjack in schools/hour, cruise *Jordan* 60, March-April 1971.

fish <45 cm were largely segregated geographically from the medium and large ones. Figure 9 indicates a distinct separation in age as well. Small skipjack were very scarce in March-April 1971.

Figure 9 shows the percent length-frequency distributions of skipjack by 2-cm classes. In November-December 1970, the principal mode was at 58 cm, with a minor mode at 36 cm and perhaps another at 48 cm. The fish of modal size 36 cm could be about 14 to 15 mo old, if one accepts the growth rates for juveniles indicated by Yoshida (1971) and Joseph and Calkins (1969: from tagging data, averaged). This would suggest a spawning origin in the northern summer. Because no definite information is available on skipjack growth rates beyond this size, the age represented by the 58-cm mode is uncertain, but probably it is 2 to 3 yr. Whether the possible mode at 48 cm represents fish 1 yr or 6 mo between the other two modes is not known. If there were 6-mo difference, it would signify a spawning origin in the southern summer.

In March-April 1971, there is a single wide mode composed of fish >48 cm (peak 56 to 60 cm). The fish had about the same size distribution in all areas.

Skipjack in the eastern Pacific coastal fishery ranged from about 3 to 3.5 kg, with mean and modal lengths 50 to 55 cm, in the years 1955-71 (Miyake 1968; Inter-American Tropical Tuna

TABLE 6.–Skipjack in size categories as percent of total, Cruises *Jordan* 57-*Cromwell* 51, November-December 1970 and *Jordan* 60, March-April 1971.

Size (cm)	Percent of total: *Jordan 57-Cromwell* 51	Percent of total: *Jordan* 60
<45	13.3	2.9
45-60	62.2	55.1
>60	24.5	42.0
Total skipjack	143	70

TABLE 7.–Small skipjack (<45 cm) as percent of total in latitudinal zones north of 10°N, Cruises *Jordan* 57-*Cromwell* 51, November-December 1970.

Zone latitude	Size (cm) Category	Range	Mean	No. of fish	Percent
12°-14°N	<45	32.5-39.8	35.5	13	76.5
	>45	48.8-56.5	54.2	4	23.5
10°-11°N	<45	33.4-34.7	34.2	3	13.6
	>45	45.0-65.0	58.0	19	86.4

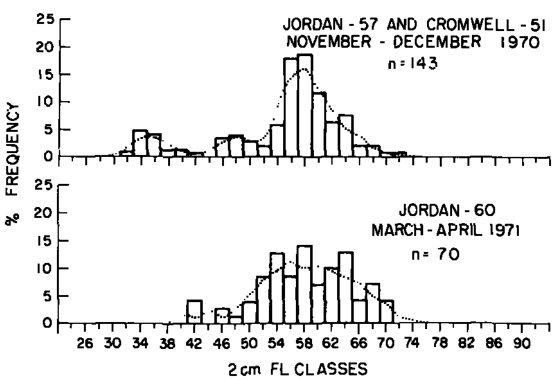

FIGURE 9.–Skipjack percent-length-frequency distribution in the study area. Smoothed curves are from 3-figure moving averages. Stated length indicates midpoint of class.

Commission 1966, 1972). The principal component of the Hawaiian catch usually consists of fish of modal sizes >60 cm (U.S. Bureau of Commercial Fisheries 1963; Rothschild 1965; Higgins 1966). The principal modes of skipjack caught in the study area, 56 to 60 cm on the two cruises, are intermediate between those in the eastern Pacific coastal fishery and the Hawaiian fishery. Purse seine samples of skipjack obtained in and near the study area in 1970 and 1971, which are mentioned later, had mean sizes from 58 to 61 cm.

Size of Other Tuna

Only 34 yellowfin tuna were boarded (39 caught) on the November-December 1970 cruise, and 2 in March-April 1971. None were taken south of lat. 3°N. Yellowfin ranged from 26 to 112 cm, with mean lengths for different aggregations ranging from 28.5 to 42.3 cm. The majority (68%) were <45 cm. These small yellowfin were mainly (83%) from the same latitudinal zone (10°-14°N) as the small skipjack. On three occasions schools of mixed small tunas–skipjack, yellowfin, and frigate mackerel (*Auxis*: 30 to 31 cm)–were sampled north of lat. 10°N. Small tuna of different species may occur together because of similar environmental and food requirements, and behavior.

Sex and Maturity of Skipjack

Sex ratios of skipjack for the two cruises were as follows:

November-December 1970:		Total 143, Sexed 72
		Males 24; females 33; indeterminate 15
	Ratio:	Males to females, 1:1.4
March-April 1971:		Total 72, sexed 59
		Males 24; females 35
	Ratio:	Males to females, 1:1.5

Gonad maturity was determined macroscopically in the field, and stages were classified as follows:

Immature, virgin	Roughly	1-S
Immature, resting	equivalent	1
Maturing	to indicated	2
Spent	stages in	5-A
Spent-recovering	Orange (1961)	5-B

The number of gonads in each stage by size of fish are given in Tables 8 and 9.

In November-December the smallest spent or spent recovering female skipjack was 46.5 cm. In March-April the corresponding size for females was 49.8 cm, and for males 48.3 cm. These data support other evidence that first maturity in female skipjack in the Pacific is reached between 40 and 45 cm (Orange 1961; Waldron 1963; Kawasaki 1965).

A relatively large number of recently spawned fish, i.e., with spent and spent-recovering gonads, was taken on each cruise: 30% of the females and 7% of the males in November-December 1970, and

TABLE 8.—Number of skipjack gonads in each maturity stage by size of fish, Cruises *Jordan* 57-*Cromwell* 51, November-December 1970.

Size class (cm)	Immature: Virgin M	Virgin F	Resting M	Resting F	Maturing M	Maturing F	Spent M	Spent F	Spent recovering M	Spent recovering F
<40	? 15 ?									
40-49.9		1	5	1						1
50-59.9			5	12	1			1	2	6
60-69.9			11	2		2				
≥70								2		

Totals: males (M) 24; females (F) 28; indeterminate (<40 cm) 15.

TABLE 9.—Number of skipjack gonads in each maturity stage by size of fish, Cruise *Jordan* 60, March-April 1971.

Size class (cm)	Immature: Virgin M	Virgin F	Resting M	Resting F	Maturing M	Maturing F	Spent M	Spent F	Spent recovering M	Spent recovering F
<40										
40-49.9				2					1	1
50-59.9			5	1	1				10	13
60-69.9					2	8			5	8
≥70						1				

Totals: males (M) 24; females (F) 34.

63% and 67%, respectively, in March-April 1971 (Tables 8, 9). Most others were at the immature resting stage. The spent-recovering fish appeared to be at a more advanced stage of recovery in March-April than in November-December 1970.

Data on other skipjack ovaries taken from or near the study area in 1970-71 are available from samples of purse seine-caught fish examined by the Inter-American Tropical Tuna Commission (C. L. Petersen, pers. commun.). Gonad indices were calculated by them according to Orange (1961), and data are given in Table 10.

The principal interest lies in the samples (mean lengths >57 cm) from long. 110°W westwards. It is assumed that gonad indices < 15.1 indicate immature (virgin or resting) or spent-recovering ovaries, 15.1 to 45 indicate maturing ovaries, and > 45 indicate mature or ripe ovaries. The occurrence of 35% of skipjack ovaries with indices > 45 in the middle of the study area in September 1970 may correspond to the 36% of ovaries in spent condition in fish >50 cm in the same area in November-December 1970 (Table 8). The sample from lat. 5°N, long. 110°W in April 1971 (Table 10) showed similar ovarian states to those in skipjack > 50 cm caught in March-April 1971 (Table 9): about 75% immature or spent-recovering, and 25% maturing, in each case.

Sex and Maturity of Yellowfin

In November-December 1970, 24 specimens of yellowfin under 50 cm were classified as immature, sex indeterminate; of 5 yellowfin from 50 to 60 cm, 3 were immature female, 1 was immature male, and 1 was indeterminate.

OBSERVATIONS ON THE ENVIRONMENT IN RELATION TO SKIPJACK

Temperature

The data from Part I operations on the 1970 and 1971 cruises were used to construct temperature

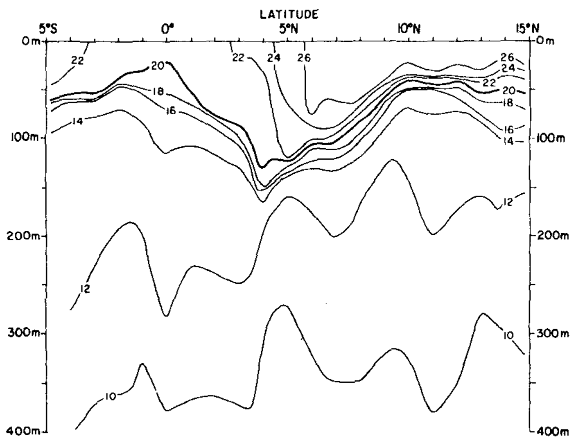

FIGURE 10.—Temperature (°C) section from lat. 15°N to 5°S along long. 119°W, cruise *Cromwell* 51, 1-7 November 1970.

TABLE 10.—Gonad indices of female skipjack caught by purse seine in northeastern tropical Pacific, 1970-71.

Date of capture	Approximate position: Lat. °N	Long. °W	Gonad indices: % <15.1	%15.1-45	% >45	Sample no.	Size (cm): Range	Mean
23 August 1970	5	135	48.9	46.8	4.3	50	53.5-63.8	59.9
8 September 1970	5	120	2.5	62.5	35.0	40	55.0-62.3	57.8
April 1971	5	110	76.0	24.0	0	50	54.3-67.6	60.5
30 April 1971	5	90	57.1	42.9	0	49	53.3-68.7	62.3
May 1971	5	90	32.0	60.0	8.0	59	57.8-70.0	64.5

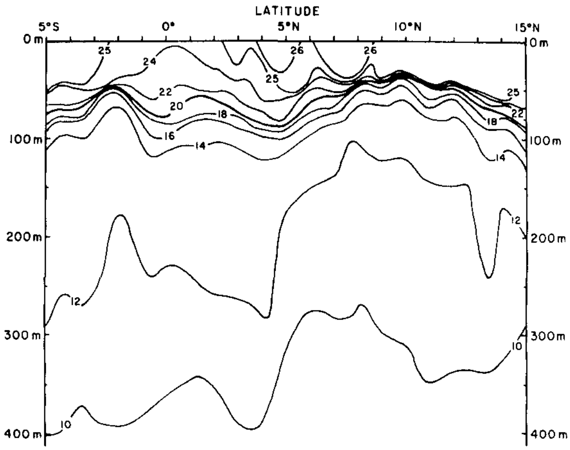

FIGURE 11.—Temperature (°C) section from lat. 15°N to 5°S along long. 119°W, cruise *Jordan* 60, 5-11 March 1971.

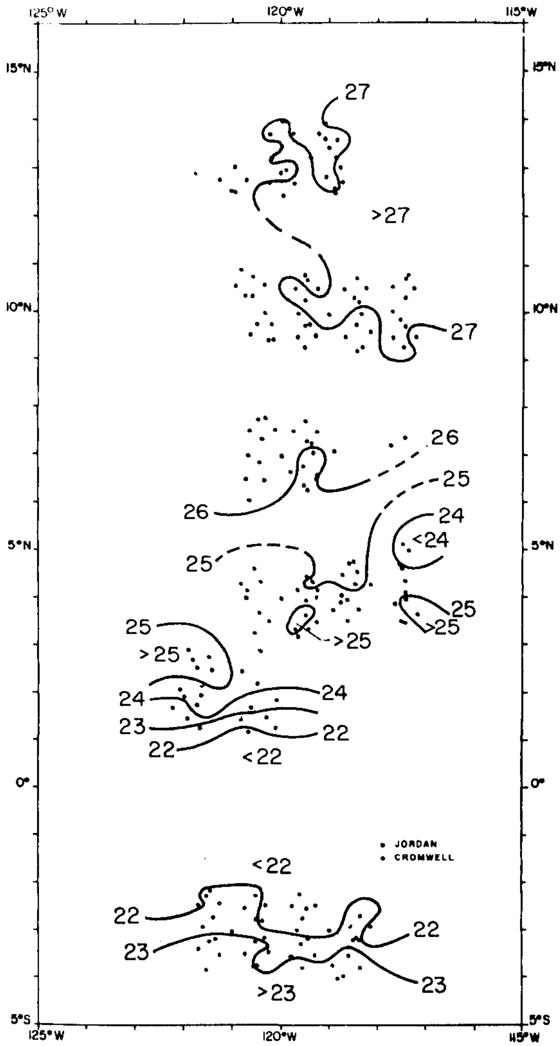

FIGURE 12.—Surface temperature (°C) during Part II operations, cruises *Jordan* 57-*Cromwell* 51, November-December 1970.

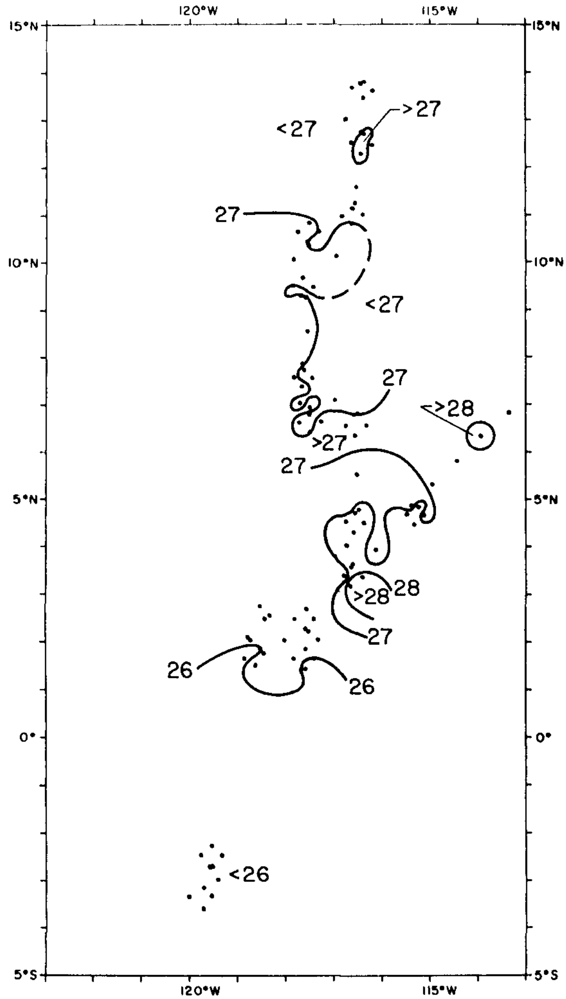

FIGURE 13.—Surface temperature (°C) during Part II operations, cruise *Jordan* 60, March-April 1971.

sections (Figures 10, 11). The temperature distributions were generally similar to those observed on the same meridian at the same time of year during EASTROPAC Expedition (M. Tsuchiya, pers. commun.). Surface temperatures suitable for skipjack, i.e., between 20° and 29°C, occurred at all latitudes on both cruises.

The distribution of surface isotherms (assumed synopticity) during Part II (fishing) operations on both cruises is shown in Figures 12 and 13. These figures have been compared, using overlays, with all charts of relative abundance of skipjack

(Figures 5, 6, 7, 8). The only apparent relationship between surface temperature and skipjack abundance appears to be the high abundance in the western part of the area of strong temperature gradient at lat. 1° to 3°N in November-December 1970.

Mixed Layer Depth

The depths (meters) of the bottom of the mixed layer are contoured at 20-m intervals in Figures 14 and 15 for Part II of the cruises. Figures 10 and 11 show the depths on Part I. Even though data are zonally discontinuous in parts of Figures 14 and 15, they are generally consistent with those of Cromwell (1958), Wyrtki (1964), and Love (1971b, 1972a, b, in prep.: EASTROPAC data).

In November-December 1970, the mixed layer depth was shallow (< 40 m) north of lat. 9°N, but south of there increased rapidly to > 100 m in the region of lat. 5°N. This ridge and trough are to be expected at the approximate northern and southern boundaries of the surface NECC. The gradient of change from this trough southwards to another ridge was particularly intense in the eastern edge of the area around lat. 4°N. In March-April 1971, the mixed layer was very shallow over most of the area surveyed south of lat. 10°N, becoming < 10 m in the region lat. 3° to 4°N. The even depth of the mixed layer from lat. 4° to 10°N

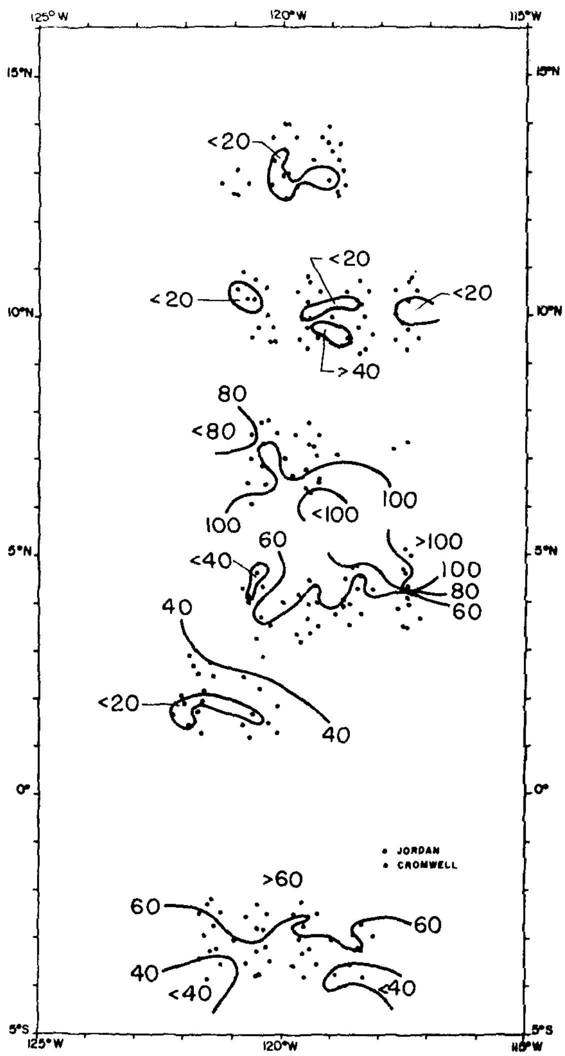

FIGURE 14.—Depth (m) of upper mixed layer, Part II operations, cruises *Jordan* 57-*Cromwell* 51, November-December 1970.

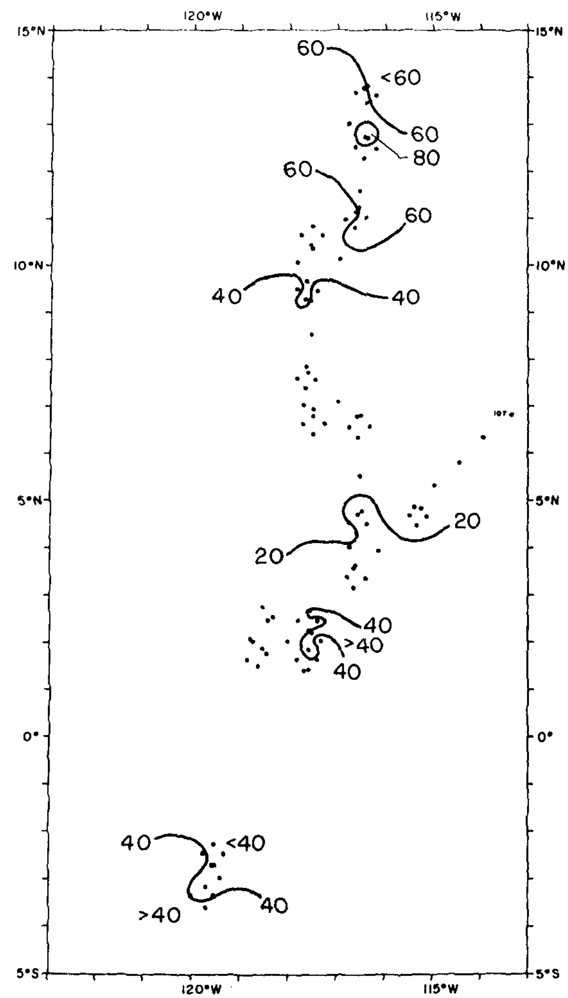

FIGURE 15.—Depth (m) of upper mixed layer, Part II operations, cruise *Jordan* 60, March-April 1971.

indicates the extreme weakness of the surface NECC at this time.

The charts of mixed layer depth have been compared by overlay with those of relative abundance of skipjack (Figures 5, 6, 7, 8). Areas of high relative abundance in November-December were generally close to ridges (< 40 m) in the mixed layer depth. There were exceptions, some of which are less obvious when utilizing schools/hour. There is no such trend in the March-April data.

Oxygen

Oxygen content (milliliters/liter) was measured to 500 m, and sections showing oxygen distributions along the Part I transects of both cruises are presented in Figures 16 and 17. Sampling was also carried out in Part II fishing operations but for various reasons was more restricted than planned.

Figure 16 shows a strong oxycline (2 to 4 ml/liter) throughout the section of November 1971 parallel to the thermocline (Figure 10). In view of the probability of the lethal level of oxygen for skipjack being about 2.4 to 2.8 ml/liter (Anonymous 1973; R. Lasker pers. commun.), the depth of the 2.5-ml/liter isopleth may delimit the region of the water column suitable for skipjack. Its shallowest level in November-December 1970 (Figure 16) was about 50 m. In March-April 1971, (Figure 17) the oxycline was weaker and much reduced just north of the equator. The 2.5-ml/liter isopleth was on the average a little shallower than in November-December. The strong thermo-oxycline over most of the area on both cruises probably represented a bottom limit to vertical movement of skipjack, but even so at least the top 50 m of water were available to the fish.

The ridge in the oxycline at about lat. 10°N appears to be the western extension of the upper edge of the low oxygen-content water mass stretching out from the coast of Central America. (Tsuchiya 1968, Figure 7a, oxygen on the δ_T = 400 cl/T surface, which there is at < 100 m).

Currents

The positions of the boundaries between the North Equatorial Current (NEC), the surface North Equatorial Countercurrent (NECC), and the South Equatorial Current (SEC) have been indicated schematically in Figures 3 and 4. They were based on the slope of the thermocline during Part I and II operations. In November-December 1970 the surface NECC was confined to a narrow band between lat. 7° and 10°N, with a geostrophic flow of < 1 knot (44 cm/s). On the second cruise in March-April 1971 the surface NECC was located between lat. 4° and 8°N during Part I operations, but a short time later in Part II it had narrowed to between lat. 4°30′ and 7°N. The geostrophic flow was lower than on the previous cruise, < 0.5 knot (< 25 cm/s), except at the southern boundary, where the subsurface NECC may have surfaced and geostrophic flow was about 1.25 knots (65 cm/s). Average current charts for the area (Wyrtki 1965) show the surface NECC absent east of long. 120°W at this time of year. EASTROPAC data (Love 1971b, 1972a; M. Tsuchiya, pers. commun.) show the surface current absent at this meridian and time in 1967, but present in 1968.

Data from XBT records of the return passage of the *Cromwell* from the study area to Hawaii in November 1970 have been used to construct a diagonal temperature section from lat. 3°N, long. 124°20′W to lat. 16°30′N, long. 146°06′W (Figure 18). From the slope of the thermocline, the approximate boundaries of the surface NECC along the transect are defined as lat. 6° to 8°N (southern boundary) and lat. 10° to 11°N (northern boundary).

Chlorophyll

In November-December 1970, the range of surface chlorophyll *a* values was 0.03 to 0.22 mg/m^3, with a maximum (> 0.20) between lat. 0°30′ and 2°00′S. A small area with chlorophyll values > 0.20 also existed at about lat. 2°30′N, long. 119°W. An area of low chlorophyll (< 0.05) was located at lat. 9° to 10°N, long. 117° to 119°W. During March-April 1971, surface chlorophyll ranged from 0.03 to at least 0.25 and probably to about 0.40 mg/m^3. Maxima (> 0.20) occurred from lat. 9° to 11°N and lat. 13° to 14°N, and a minimum (< 0.05) occurred from lat. 5° to 7°30′N, all east of long. 118°W.

Zooplankton

All four sets of zooplankton data (1-m and 0.5-m nets, day and night) from Part II operations show broadly similar distributions for the same cruise on contour charts, and it is unnecessary to show them for both nets. The 0.5-m net catches probably give a better representation of the standing stock of small herbivores than the 1-m net catches, and

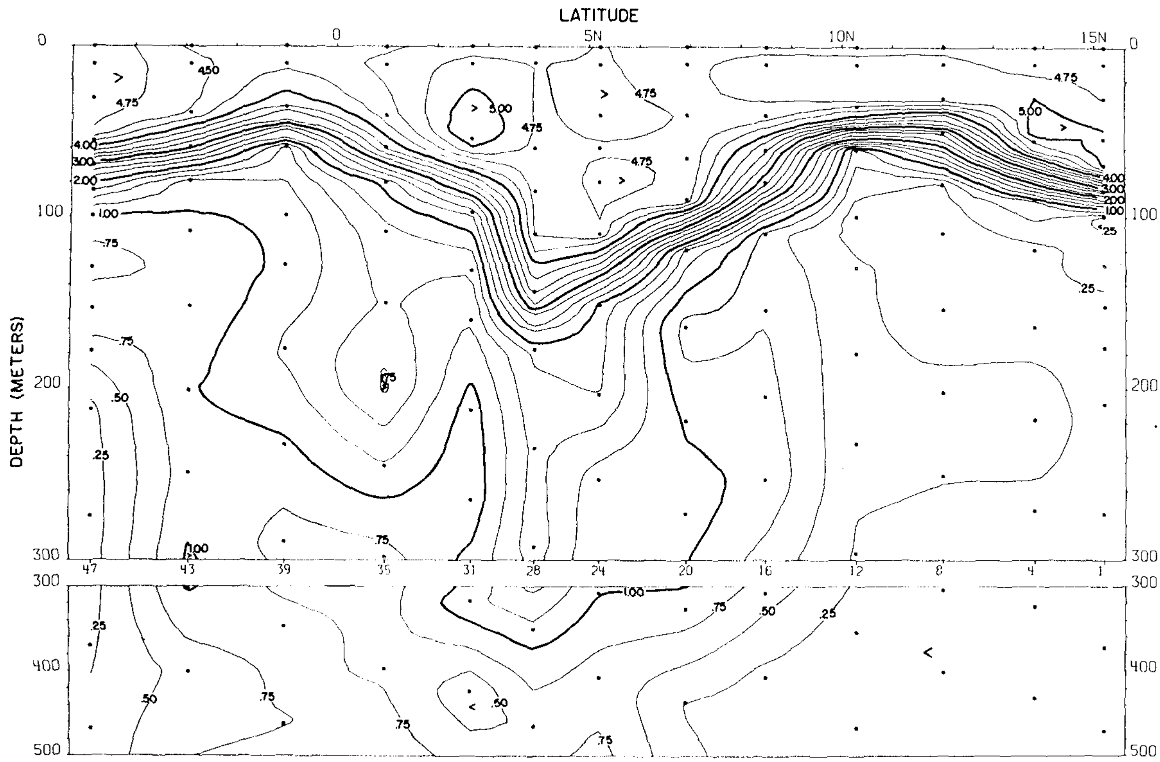

FIGURE 16.—Dissolved oxygen content (ml/liter), Part I transect, cruise *Cromwell* 51, 1-7 November 1970.

their distributions are charted here (Figures 19 to 22). Catches by the 1-m net are more likely to be related to skipjack tuna than those by the 0.5-m net, because more skipjack forage organisms occur in them. These relationships are investigated statistically in the next section.

The main features of the day and night zooplankton distributions in November-December 1970 are a maximum at about lat. 1° to 2°N, a minimum in the extreme north of the area, and a secondary minimum at about lat. 3° to 5°N. Maxima occurred in March-April 1971 at about lat. 3° to 6°N and 9° to 10°N; elsewhere at that period the catches were moderate with no conspicuous spatial minima except in the extreme north. Comparisons between Figures 19 to 22, and Figures 5 to 8, made by overlay, show no obvious relation between distributions of zooplankton and skipjack.

Skipjack Forage (and Zooplankton in Part)

One of the objectives of the cruises was to see if availability of offshore skipjack varied with the forage, as presumed by Blackburn (1965, 1969) and Blackburn and Laurs (1972); or with zooplankton, as suggested by Schaefer (1961); or with the arithmetic product of forage and zooplankton, as suggested by Riley (1963).

Charts of skipjack forage (in milliters/1,000 m³), both day and night data, are shown in Figures 23 and 24 for both parts of the November-December 1970 cruise, and similarly in Figures 25 and 26 for the March-April 1971 cruise. Corresponding charts of total micronekton were very similar and are not given here. Data are available at Southwest Fisheries Center, National Marine Fisheries Service, La Jolla, Calif.

Measurements of day concentration of forage were more numerous than those of night concentration. Thus Figures 23 and 25 show more detail than Figures 24 and 26. Blackburn and Laurs (1972) showed that day and night distributions of forage were broadly similar in the area on a given cruise as far as locations of maxima and minima were concerned, although the night concentrations were about 10 times higher than day concentrations. Contours for day and night distributions were therefore drawn to agree with each other as

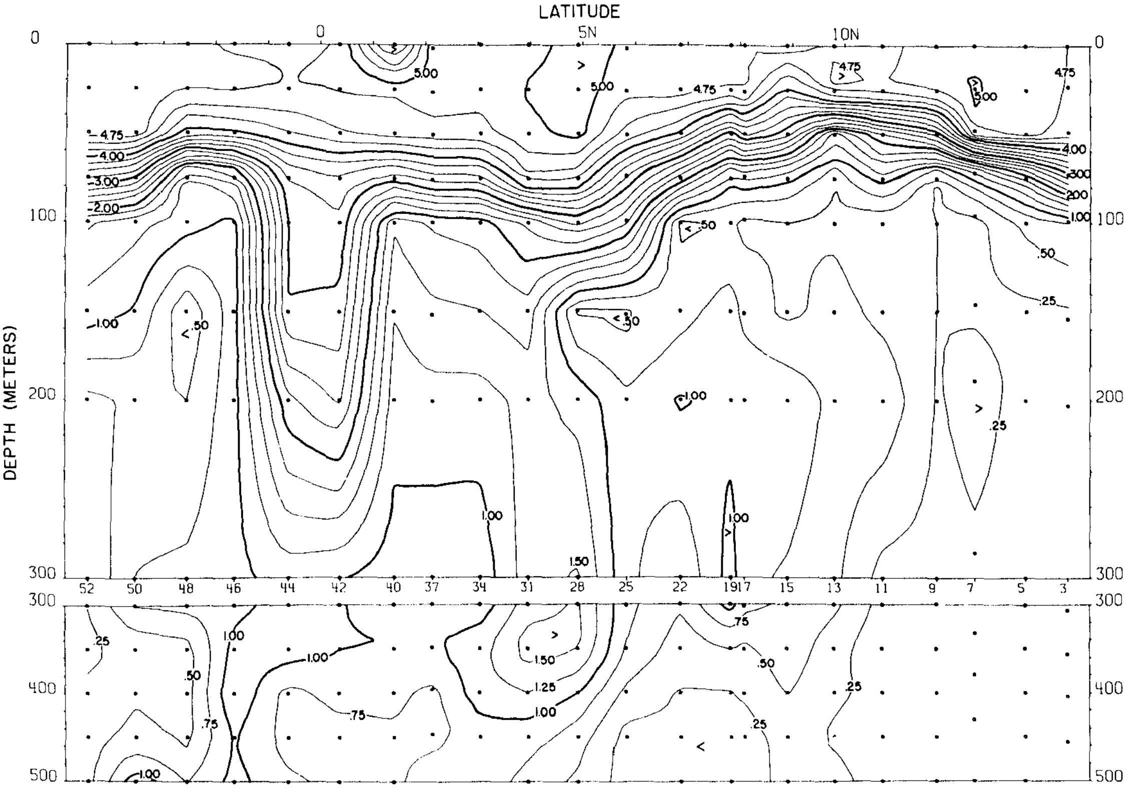

FIGURE 17.–Dissolved oxygen content (ml/liter), Part I transect, cruise *Jordan* 60, 5-11 March 1971.

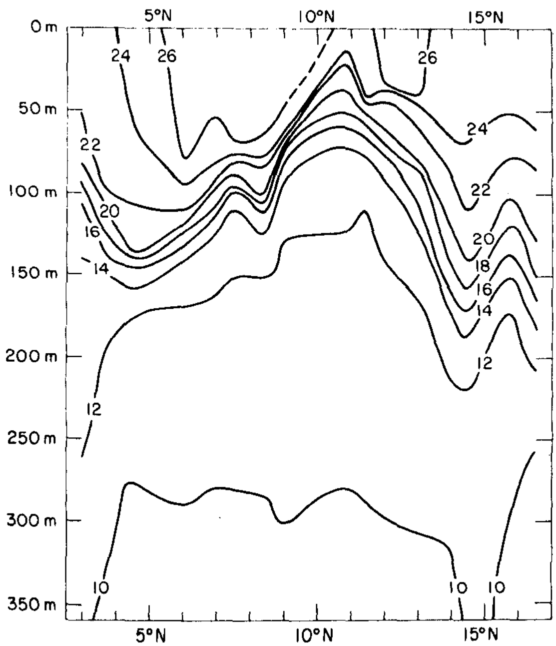

FIGURE 18.–Temperature (°C) section from lat. 3°N, long. 124°20′W, to lat. 16°30′N, long. 146°06′W, cruise *Cromwell* 51, November 21-26, 1970.

much as possible without violating the data. Fewer data were available for the March-April cruise than for the November-December one, for reasons given elsewhere.

According to Blackburn and Laurs (1972), the most conspicuous and consistent feature of day and night forage distributions in the study area is a zonally oriented maximum between lat. 0° and 5°N, which is probably associated with the equatorial upwelling as explained by King (1958). Figures 23 and 24 show this feature, and Figures 25 and 26 show one which is probably the same although it does not appear to be zonally oriented. Stations at the eastern end of the maximum in Figures 25 and 26 were occupied 13 days after the last stations at the western end were occupied, and the maximum could have moved north in the interval. Other maxima and minima in Figures 23 to 26 are smaller and less consistent in location between cruises.

The data from these micronekton net hauls, especially those for the March-April cruise which are very sparse, may not give a complete picture of the distribution of skipjack forage. On the March-

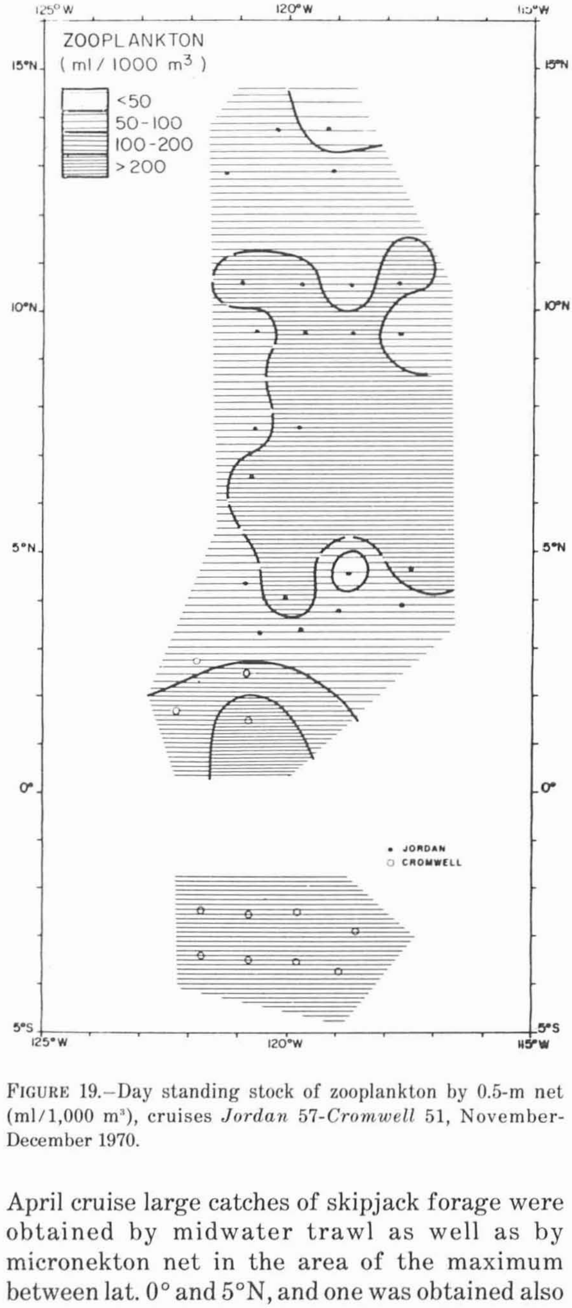

FIGURE 19.—Day standing stock of zooplankton by 0.5-m net (ml/1,000 m³), cruises *Jordan* 57-*Cromwell* 51, November-December 1970.

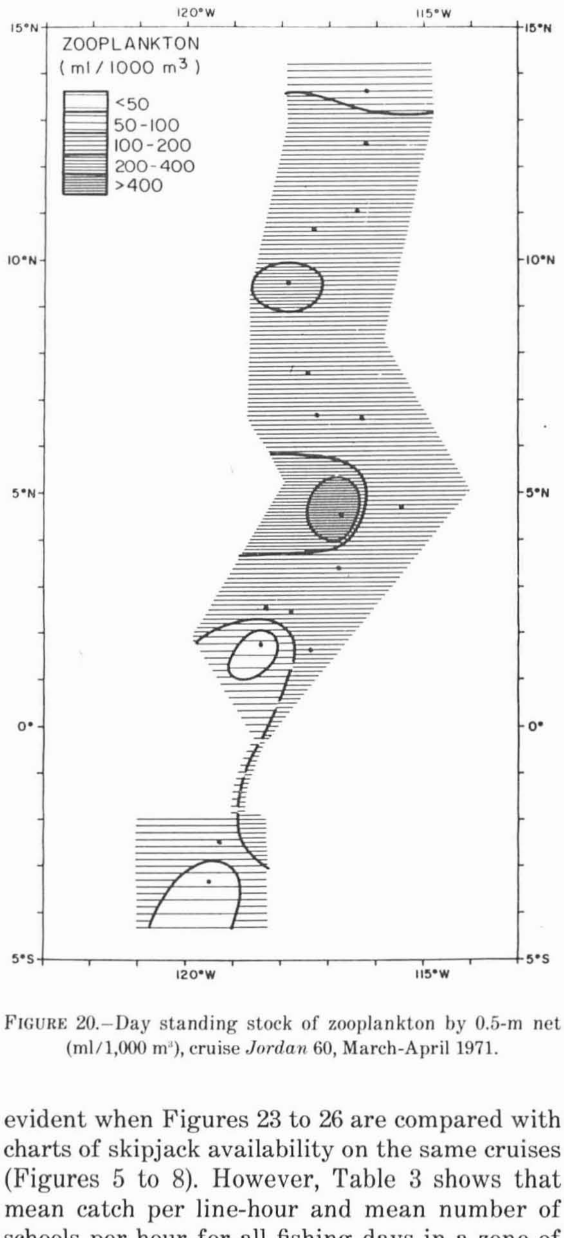

FIGURE 20.—Day standing stock of zooplankton by 0.5-m net (ml/1,000 m³), cruise *Jordan* 60, March-April 1971.

April cruise large catches of skipjack forage were obtained by midwater trawl as well as by micronekton net in the area of the maximum between lat. 0° and 5°N, and one was obtained also at about lat. 10°N where the micronekton net indicated a rather low concentration. This result from a single trawl haul thus indicates an area of rich forage of unknown extent at about lat. 10°N, which the sparse data from the micronekton net hauls do not show. The forage may have been patchy in this area.

The expected resemblance between the spatial distributions of forage and skipjack is not strongly evident when Figures 23 to 26 are compared with charts of skipjack availability on the same cruises (Figures 5 to 8). However, Table 3 shows that mean catch per line-hour and mean number of schools per hour for all fishing days in a zone of latitude was highest in November-December from lat. 1° to 5°N, where the principal forage maximum was located (Figures 23 and 24). Table 4 shows that the same indices were highest in March-April from lat. 9° to 11°N, where Figures 25 and 26 show no forage maximum, although one may have existed there as explained above. A secondary skipjack maximum occurred in March-April in the equatorial region, south of lat. 3°N, where a forage maximum was present.

Attempts were made to correlate forage con-

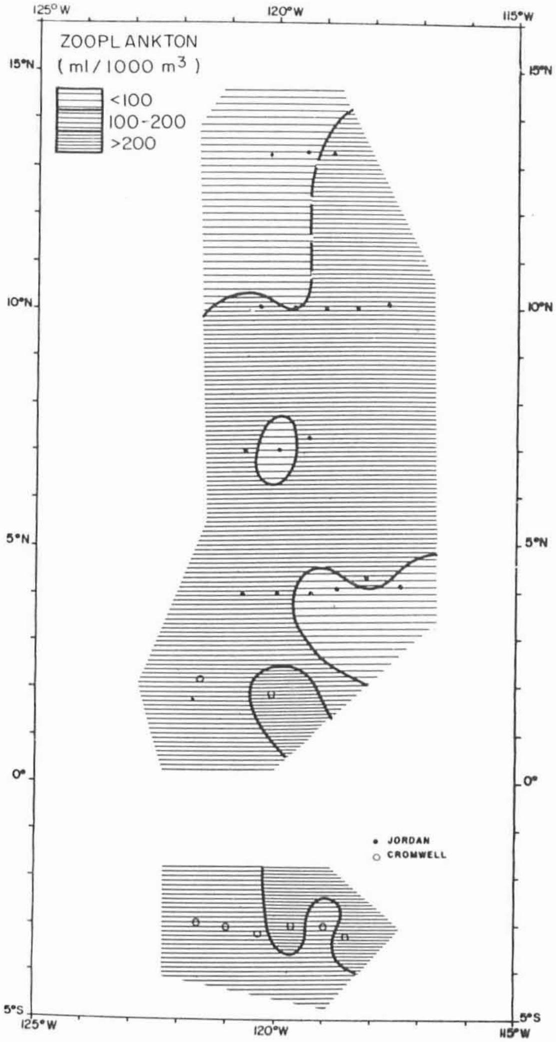

FIGURE 21.—Night standing stock of zooplankton by 0.5-m net (ml/1,000 m³), cruises *Jordan* 57-*Cromwell* 51, November-December 1970.

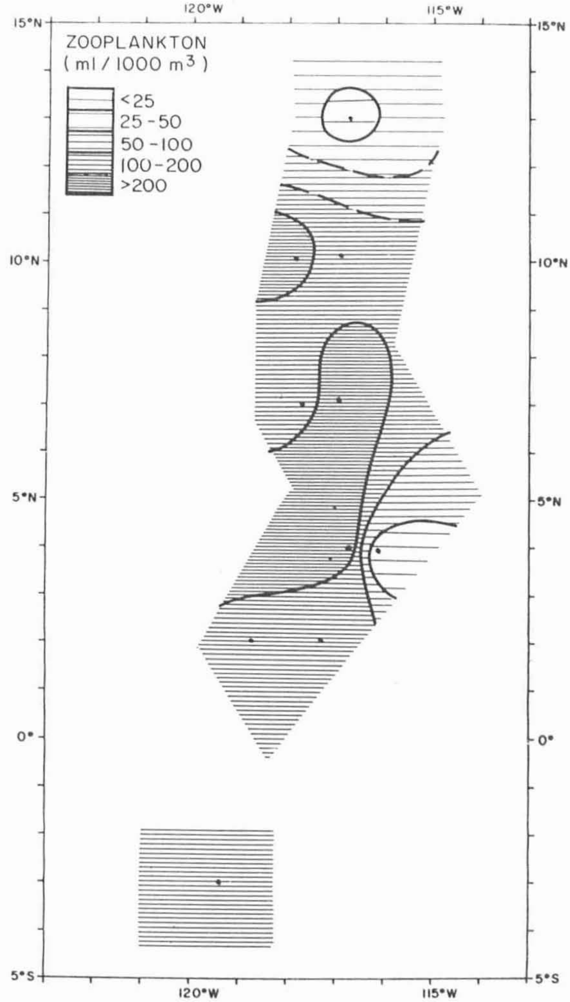

FIGURE 22.—Night standing stock of zooplankton by 0.5-m net (ml/1,000 m³), cruise *Jordan* 60, March-April 1971.

centration and related measurements with skipjack availability for all data from the study area. Table 11 gives the results of the tests using concentrations of day forage, day zooplankton, and their arithmetic product. Table 12 gives similar results using night concentrations. All variables were transformed to logarithms in order to bring distributions closer to normal, before correlation coefficients were calculated. A distinction is made between all skipjack and large skipjack; the latter excludes skipjack < 45 cm, which seem to be a separate age-group and exhibited some segregation from the other skipjack in space and time. Zooplankton data are from hauls of the 1-m net only, as explained above.

None of the 72 correlations in Table 11, involving day concentrations of forage and zooplankton with skipjack, are significant. On the other hand 4 of the 48 correlations in Table 12, involving night concentrations of forage and zooplankton with skipjack, are significant by the usual criteria and positive: two coefficients are above the 5% level of probability and two are above the 1% level. They refer only to availability of large November-December skipjack measured as catch per line-hour or schools per hour, in relation to night forage and to the product of night forage and night zooplankton, with both variables averaged over

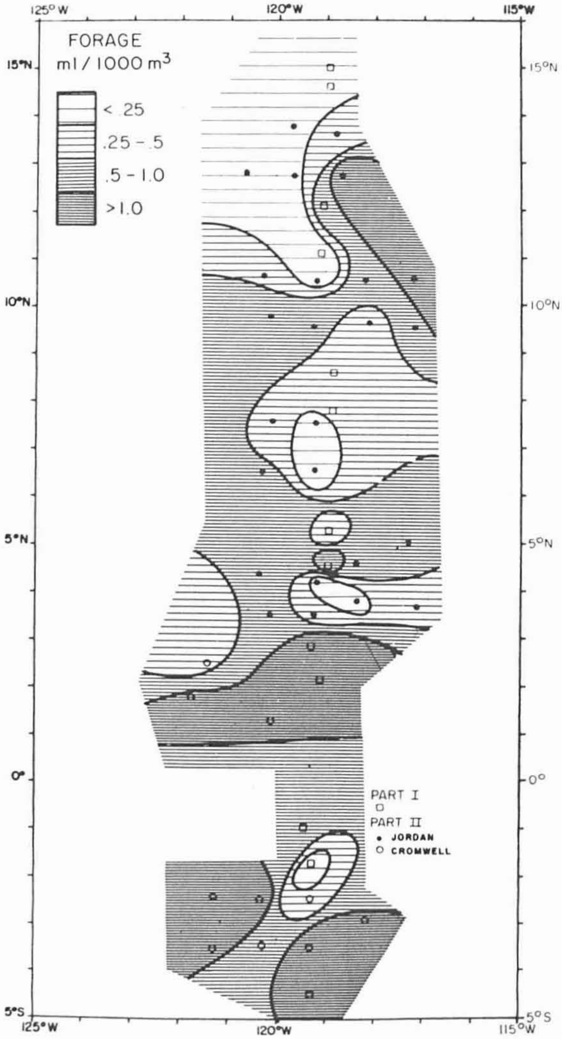

FIGURE 23.—Day standing stock of skipjack forage (ml/1,000 m³) (combined Part I and II data), cruises *Jordan* 57-*Cromwell* 51, November-December 1970.

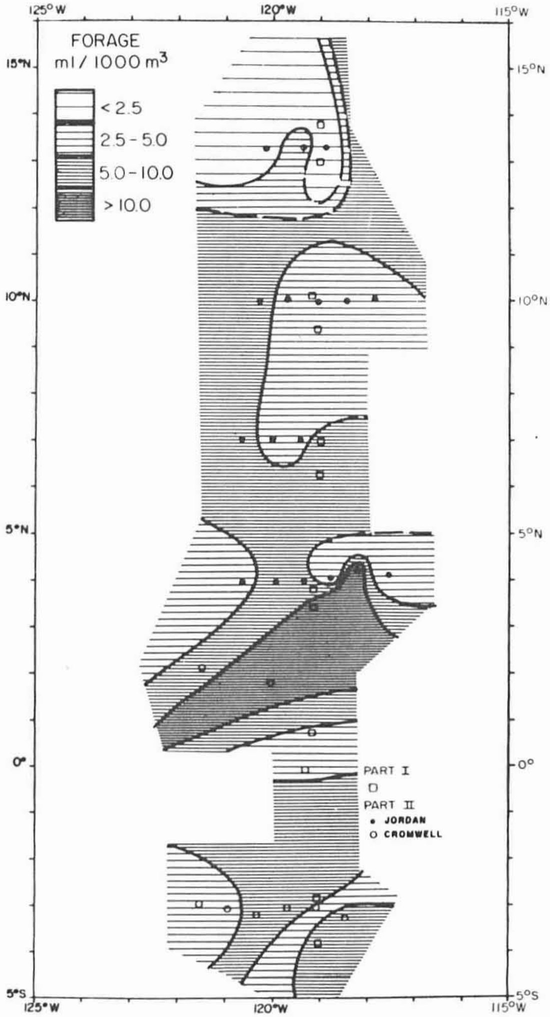

FIGURE 24.—Night standing stock of skipjack forage (ml/1,000 m³) (combined Part I and II data), cruises *Jordan* 57-*Cromwell* 51, November-December 1970.

zones about 2° of latitude wide. There is no difference in the significance of coefficients depending on whether forage or forage × zooplankton was the variable, and no significant coefficients are obtained with zooplankton alone.

Table 13 gives the data that yielded the significant correlations between large skipjack and forage. The correlation coefficients are +0.947 with catch per line-hour and +0.886 with number of schools per hour, significant at the 0.5 and 2.0% probability levels respectively. The corresponding Spearman rank correlation coefficients are +0.952 and +0.905, both significant at the 5% level. No other grouping of 2°-latitude zones would have given so many zones with so much data in each (see Figure 3).

The significance of the four correlation coefficients in Table 12 has been disputed because of the much larger number of nonsignificant correlations in Tables 11 and 12 combined. It has also been pointed out that the two coefficients involving forage × zooplankton are not independent of the two coefficients involving forage alone. In our following comments we ignore all coefficients with forage × zooplankton, whether apparently significant or otherwise. We then have two possibly significant coefficients in a total of 80 for Tables 11 and 12, i.e., one in 40. From the previous paragraph, there is a chance of about one in 50 that

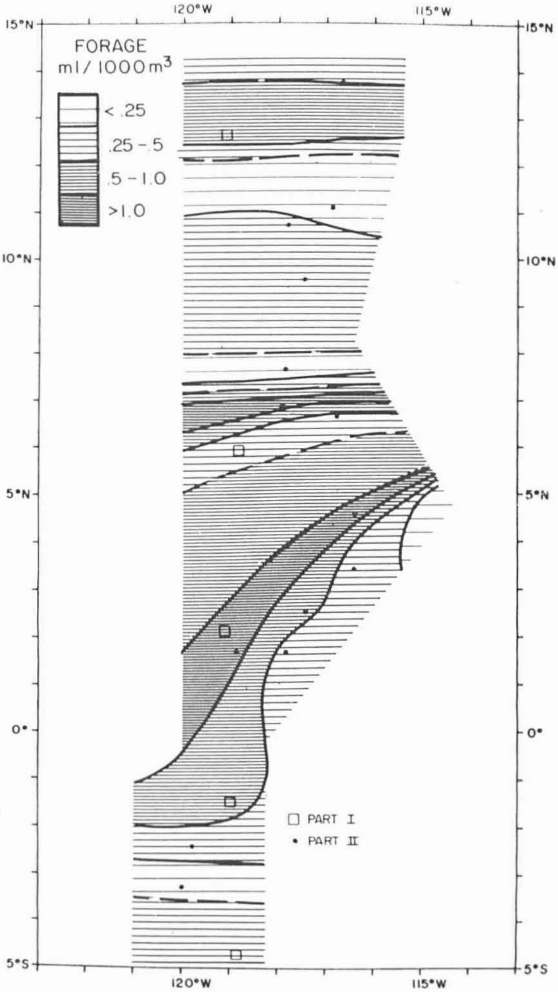

FIGURE 25.—Day standing stock of skipjack forage (ml/1,000 m³) (combined Part I and II data), cruise *Jordan* 60, March-April 1971.

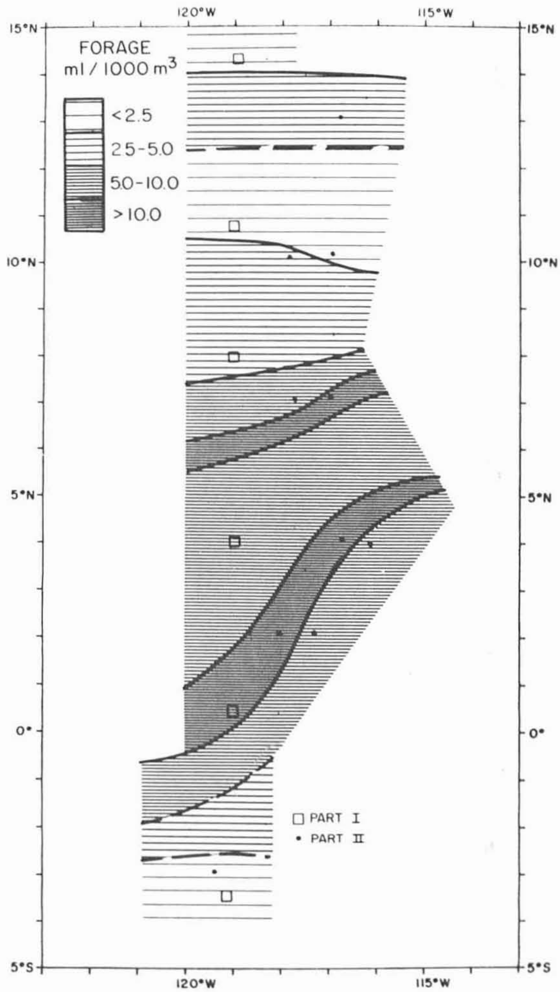

FIGURE 26.—Night standing stock of skipjack forage (ml/1,000 m³) (combined Part I and II data), cruise *Jordan* 60, March-April 1971.

the lower coefficient could have been so high with no correlation, and a corresponding chance of only about one in 200 for the higher coefficient. There seems no reason to presume nonsignificance, at least for the higher coefficient.

Significant correlations were not obtained for any data from the March-April cruise. Only two degrees of freedom are available to test the significance of correlations corresponding to the significant correlations in the November-December data. In any case the meager forage data for March-April seem not to have adequately depicted the actual conditions, as noted above. Relations of skipjack to forage are discussed later.

CRUISE 116 OF RV *CHARLES H. GILBERT*, OCTOBER-NOVEMBER 1969

In October-November 1969, the RV *Charles H. Gilbert* of the Honolulu Laboratory of the National Marine Fisheries Service made a cruise to collect samples of skipjack and other tunas for a subpopulation study. The main fishing operations were located in the same area as the combined cruise *Jordan* 57-*Cromwell* 51, though approximately 1 yr earlier. The fishing and environmental data are analyzed here in more detail than by Hida (1970). Figure 27 shows the cruise track of

TABLE 11.—Measures of daytime availability of skipjack correlated with day concentrations (ml/1,000 m^3) of skipjack forage, zooplankton, and their arithmetic product. All tests were made with the variables transformed to logarithms. Numbers are pairs of observations from which correlation coefficients were calculated. No coefficients were significant. "All" means all skipjack; "large" means skipjack ≥45 cm.

Skipjack availability		Period	Data grouping[1]	Forage (F)	Zooplankton (Z)	F × Z
Catch/line-hour	All	Nov.-Dec.	A	35	33	33
			B	11	10	10
			C	6	6	6
		Mar.-Apr.	A	16	16	16
			B	4	4	4
			C	6	6	6
	Large	Nov.-Dec.	A	35	33	33
			B	11	10	10
			C	6	6	6
		Mar.-Apr.	A	16	16	16
			B	4	4	4
			C	6	6	6
Schools/hour	All	Nov.-Dec.	A	35	33	33
			B	11	10	10
			C	6	6	6
		Mar.-Apr.	A	16	16	16
			B	4	4	4
			C	6	6	6
	Large	Nov.-Dec.	A	35	33	33
			B	11	10	10
			C	6	6	6
		Mar.-Apr.	A	16	16	16
			B	4	4	4
			C	6	6	6

[1]A. Numbers to the right of this letter are numbers of 1° × 1° quadrants. For each quadrant skipjack availability is based on all observations for the day, and F and Z are each based on a single observation made in the quadrant during the day.
B. Numbers to the right of this letter are numbers of 1° zonal rows of quadrants with ≥2 quadrants per row. For each row skipjack availability, F and Z are means of the data for the individual quadrants.
C. Numbers to the right of this letter are numbers of 2° zonal rows of quadrants. For each row skipjack availability, F and Z are means of the data for the individual quadrants.

TABLE 12.—Measures of daytime availability of skipjack correlated with night concentrations (ml/1,000 m^3) of skipjack forage, zooplankton, and their arithmetic product. All tests were made with the variables transformed to logarithms. Numbers are pairs of observations from which correlation coefficients were calculated. Significant correlations occurred as shown by * (5% level of probability) or ** (1% level) and were positive. "All" means all skipjack; "large" means skipjack ≥45 cm.

Skipjack availability		Period	Data grouping[1]	Forage (F)	Zooplankton (Z)	F × Z
Catch/line-hour	All	Nov.-Dec.	A	25	25	25
			B	6	6	6
		Mar.-Apr.	A	11	11	11
			B	4	4	4
	Large	Nov.-Dec.	A	25	25	25
			B	6**	6	6**
		Mar.-Apr.	A	11	11	11
			B	4	4	4
Schools/hour	All	Nov.-Dec.	A	25	25	25
			B	6	6	6
		Mar.-Apr.	A	11	11	11
			B	4	4	4
	Large	Nov.-Dec.	A	25	25	25
			B	6*	6	6*
		Mar.-Apr.	A	11	11	11
			B	4	4	4

[1]A. Numbers to the right of this letter are numbers of night stations, one station per night, at which observations of F and Z were made. F, Z, and F × Z for a night station were paired for correlation purposes with the mean of skipjack availability for the daytime periods immediately before and after the night on which the station was occupied, in closely adjacent 1° × 1° quadrants.
B. Numbers to the right of this letter are numbers of 2° zonal rows of quadrants and night stations. For each row skipjack availability is the mean of the data for the individual quadrants, and F and Z are the means of the data for the individual night stations.

TABLE 13.—Means of night skipjack forage and availability of large skipjack for 2° zonal rows of quadrants and night stations in November-December 1970, on which significant correlations in Table 12 are based.

Zone latitude	A Forage (ml/1,000 m³)	B Skipjack (catch/ line-hour)	C Skipjack (schools/hour)
12°-14°N	1.54	0.020	0.060
9°-11°N	3.62	0.036	0.111
6°-8°N	3.98	0.044	0.070
3°-5°N	12.07	0.118	0.161
1°-3°N	10.23	0.189	0.235
2°-4°S	4.89	0.080	0.112

the *Gilbert* in relation to the area of the present investigations. Observations on tuna forage were not made.

Temperature and Surface Currents

Data from bathythermograph (BT) records have been used to make the two temperature sections shown in Figures 28 and 29. Surface temperatures everywhere were optimal for skipjack. The lowest temperatures on both sections occurred at lat. 0°30′S in the equatorial upwelling, namely < 24°C at long. 118°W and < 26°C at long. 137°W.

The approximate boundaries of the surface NECC during the cruise have been determined from the slope of the thermocline in Figures 28 and 29. On the outward track from Honolulu, the northern boundary of the NECC was lat. 10°N at long. 147°30′W, and the southern boundary, lat. 5°N at long. 142°15′W. On the south-north transect of the survey area, the southern boundary of the NECC was about lat. 6°N at about long. 120°45′W, and the northern boundary, lat. 9°N at about long. 129°30′W. The location of the surface NECC is shown in Figure 27.

Distribution and Relative Abundance of Troll-caught Tuna

Relative abundance of troll-caught tuna has been calculated as previously. The data are considered for: the area equivalent to the present study area plus the area fished by *Gilbert* south of lat. 5°S within long. 115°-125°W; the outward track from Honolulu to the area; and the inward track from the area to Honolulu. Total fishing effort in line-hours is given in Table 14.

The relative abundance of troll-caught skipjack and other tuna as catch/line-hour in the study area is shown in Table 15 by 1° latitudinal zones and

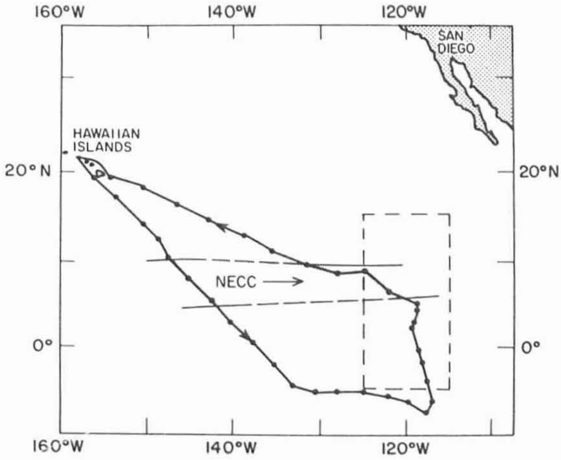

FIGURE 27.—Track of cruise *Charles H. Gilbert* 116, October-November 1969. Noon positions are indicated. Area of present investigations is outlined by dashed lines. NECC is surface North Equatorial Countercurrent.

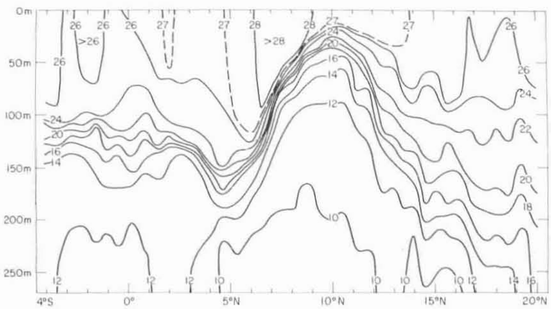

FIGURE 28.—Temperature (°C) section from lat. 19°55′N, long. 156°36′W to lat. 4°08′S, long. 133°40′W, cruise *Gilbert* 116, 3-13 October 1969.

surface currents. There was relatively little fishing effort (< 50 line-hours) in some latitudinal zones, which makes it difficult to define limits of maxima of skipjack abundance. However, the area from lat. 6° to 8°10′N is a maximum, with indices comparable with the highest ones in Table 3. Moderately high indices are seen at lat. 5° to 6°S and in the area lat. 0°-6°N, alternating with areas fished for less than 50 line-hours. Catch indices of other tunas were moderately high in the two zones where they occurred.

Relative abundance of skipjack as schools/hour in the area is given in Table 16 in two ways: firstly, as in previous sections of this report based on troll catches, and secondly, based on schools encountered during trolling and pole-and-line fishing. Usually, pole-and-line fishing was carried out subsequent to a jig strike, but occasionally not. The

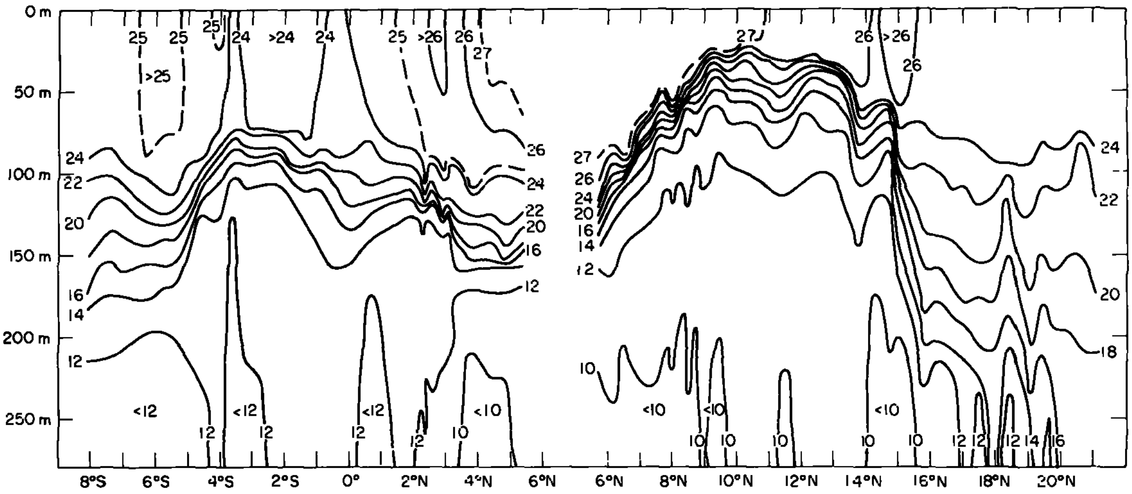

FIGURE 29.—Temperature (°C) sections from lat. 8°05'S to 5°21'N along long. 117° to 120°W, and from lat. 5°45'N, long. 120°14'W to lat. 21°03'N, long. 157°14'W, cruise *Gilbert* 116, 19 October-7 November 1969.

TABLE 14.—Total fishing effort Cruise *Gilbert* 116, October 1969.

Locality		Line-hours fished
Study area		963
Outward track	382	788
Inward track	406	
Total		1,851

TABLE 15.—Relative abundance (catch/line-hour) of troll-caught skipjack and other tuna in the study area, Cruise *Gilbert* 116, October 1969. YF and BE mean yellowfin and bigeye. * means <50 line-h.

Zone latitude	Current system	Skipjack catch/ line-hour	Other tuna catch/line-hour
7°-8°10'N	NECC	0.240	0
6°-7°	NECC	0.342	0
5°-6°	SEC	0*	0
4°-5°	SEC	0.065	0
3°-4°	SEC	0*	0
2°-3°	SEC	0.087	0.138 (YF)
1°-2°	SEC	0*	0
0°-1°N	SEC	0.095	0
0°-1°S	SEC	0*	0
1°-2°	SEC	0*	0
2°-3°	SEC	0*	0
3°-4°	SEC	0*	0
4°-5°	SEC	0	0.093 (YF or BE)
5°-6°	SEC	0.097	0
6°-7°	SEC	0.017	0
7°-8°S	SEC	0.017	0

correlation between catch/line-hour and schools/hour was significant at the 1% level (r = 0.908, data of Tables 15 and 16), as on the cruises made in 1970 and 1971. The covariance analysis in Table 17 shows that the regressions of schools/hour on catch/line-hour for the three cruises did not differ significantly in slope, but differed in elevation.

TABLE 16.—Relative abundance (schools/hour) of skipjack in the study area, Cruise *Gilbert* 116, October 1969. *means < 9 h of observations

Zone latitude	Current system	Schools/hour Based on troll catch	Based on total catch (troll plus pole-and-line)
7°-8°10'N	NECC	0.42	0.42
6°-7°	NECC	0.50	0.50
5°-6°	SEC	0*	0*
4°-5°	SEC	0.31	0.39
3°-4°	SEC	0*	0*
2°-3°	SEC	0.21	0.26
1°-2°	SEC	0*	0*
0°-1°N	SEC	0.34	0.34
0°-1°S	SEC	0*	0
1°-2°	SEC	0*	0*
2°-3°	SEC	0*	0*
3°-4°	SEC	0*	0*
4°-5°	SEC	0	0.22
5°-6°	SEC	0.15	0.15
6°-7°	SEC	0.05	0.05
7°-8°S	SEC	0.08	0.08

Table 16 shows the maximum at lat. 6° to 8°10'N, as in Table 15. Inclusion of the pole-and-line data increases the indices in other zones, i.e. lat. 4° to 5°N, 2° to 3°N, and 4° to 5°S. The range of the indices for schools/hour is about the same as for the other cruises.

Considerable catches of skipjack and other tuna were made on passage to and from the area. Data on relative abundance (catch/line-hour) are given in Table 18. Results should be used with care as fishing effort never exceeded 50 line-hours per day. There were moderate to high catch rates between lat. 4°45' and 8°30'N (long. 148° to 138°W), with indices at about the same level as at lat. 6° to 8°10'N in the study area (Table 15). Catch indices for other tuna were low.

TABLE 17.—Analysis of covariance: schools/hour (Y) on catch/line-hour (X) for the 1969, 1970, and 1971 cruises, data of Tables 3, 4, 15, and 16.

Year	df	Σx^2	Σxy	Σy^2	b	df	Σd^2	M.S.
1969	7	0.0905	0.1144	0.1754	1.264	6	0.0308	0.0051
1970	11	0.0936	0.0904	0.1060	0.965	10	0.0187	0.0019
1971	11	0.0187	0.0402	0.1684	2.147	10	0.0822	0.0082
Within						26	0.1317	0.0051
Reg. Coef.						2	0.0223	0.0112
Common	29	0.2028	0.2450	0.4498		28	0.1540	0.0055
Adj. Means						2	0.0410	0.0205
Total	31	0.2286	0.2807	0.5394		30	0.1950	

F (slope) = 2.196, nonsignificant.
F (elevation) = 3.727, significant at 5%.

TABLE 18.—Relative abundance (catch/line-hour) of troll-caught skipjack and other tuna, on track to and from the study area, Cruise *Gilbert* 116, October-November 1969. YF and BE mean yellowfin and bigeye.

Date	Approximate position (start and finish of day's trolling) Latitude	Longitude	Current system	Fishing effort (line-hour)	Catch/line-hour Skipjack	Other tuna
Outward track:						
4 Oct.	16°15′ -17°30′N	153° -154°15′W	NEC	24	0	0
5	14° -15°15′N	150°30′-151°45′W	NEC	24	0.043	0.043 (YF)
6	12° -13°15′N	148°30′-149°30′W	NEC	23	0	0
7	9°30′ -10°45′N	147° -147°45′W	NEC/NECC	23	0.088	0
8	7°15′ - 8°30′N	144°30′-145°45′W	NECC	23	0.216	0
9	4°45′ - 6°15′N	142°15′-143°30′W	NECC/SEC	24	0.336	0
10	2°15′ - 3°30′N	139°45′-141°W	SEC	24	0.083	0.042 (YF)
11	1°15′N- 0°15′S	137°15′-138°15′W	SEC	24	0.083	0
12	1°30′ - 2°30′S	134°45′-136°W	SEC	24	0	0
13	3°45′ - 5°S	133° -133°45′W	SEC	48	0.042	0
14	5°S	130°15′-131°45′W	SEC	50	0.040	0
15	5°S	127°15′-128°45′W	SEC	48	0.063	0
Inward track:						
30 Oct.	8° - 9°N	127°15′-129°W	NECC	48	0	0
31	9° -10°N	130°45′-132°45′W	NEC	48	0	0
1 Nov.	10°45′ -11°45′N	134°30′-136°30′W	NEC	48	0.021	0
2	12°30′ -13°30′N	138°15′-140°15′W	NEC	48	0.042	0.063 (BE)
3	14°30′ -15°15′N	142° -144°W	NEC	48	0	0
4	16° -17°N	145°45′-147°45′W	NEC	48	0	0
5	17°30′ -18°30′N	149°30′-151°30′W	NEC	48	0	0

Pole-and-Line Fishing

Hida (1970) recorded 109 schools of fish sighted during cruise *Gilbert* 116: 27 skipjack, 1 bigeye tuna, 1 yellowfin tuna, 2 mixed tunas (skipjack-bigeye-yellowfin), 13 of nontuna species, and 65 unidentified. On the outward track and in the southern part of the study area (from lat. 4°27′S, long. 133°22′W, to lat. 6°25′S, long. 117°47′W: 13 to 20 October 1969), at least 13 tuna schools were sighted or discovered by jig strikes. They were chummed, but did not respond to live bait. From 21 to 27 October in the study area (between lat. 4°09′S, long. 117°47′W and lat. 5°04′N, long. 118°50′W), at least 11 schools of tuna were chummed with live bait and of these 6 were successfully fished by pole-and-line (these schools were sighted and pursued, not discovered by jig strikes). Details are given in Table 19. All schools fished successfully by pole-and-line were located in the South Equatorial Current. These results are of special interest because they were obtained by a commercial fishing method. Trolling is not a commercial fishing method for skipjack in U.S. fisheries.

Size of Skipjack and Other Tuna

Table 20 shows the percent of skipjack in three broad size categories by fishing method and area. Only one skipjack (45 cm) was taken on the inward track to Honolulu. In the study area the percentages in size groups are similar for the two fishing methods. The percentage of fish < 45 cm, namely 8 to 11%, is much the same as that in the area in November-December 1970. The smallest skipjack measured 34 cm. The largest skipjack (mean lengths > 75 cm) were taken in the extreme south of the area. Elsewhere mean sizes of skipjack ranged from 46 to 67 cm, with two exceptions: 34 cm (trolling) and 40 cm (pole-and-line). On the outward track to the area, troll-caught skipjack

TABLE 19.—Details of successful live-bait pole-and-line fishing of tuna schools in the study area, Cruise *Gilbert* 116, October 1969. SJ, YF, and BE mean skipjack, yellowfin, and bigeye.

Date	School data[1]	No. birds	Approximate position Lat.	Long.	Time successful fishing commenced	Species	No. taken	Size (cm) Range	Mean	No. measured	Approximate weight (lb) Range	(Mean)
Oct.												
21	—	15 birds	4°S,	118°W	0710[2]	SJ	13	37-52	40	13	—	(3)
						YF	8	37-43	39	8	—	(3)
						BE	7	37-43	41	7	—	(3)
24	—	Flock, 50	2°N,	119°W	1220[3]	SJ	213	64-70	68	50	15-18	(17)
26	Breezer	Flock, 150	4°N,	119°W	1125[4]	SJ	519	41-56	47	60	3-8	(5)
						YF	28	40-58	47	28	4-8	(4)
						BE	13	41-46	43	13	3-4	(4)
	Boiler	Flock, 500	4°N,	119°W	1707[3]	BE	97	50-81	69	33	10-20	(—)
27	Boiler	Flock, 300	4°50′N,	118°25′W	0650[2,3]	SJ	49	47-67	59	49	—	(10)
	Breezer	Flock, 250	5°N,	118°49′W	1031[3]	SJ	110	48-61	52	54	—	(—)

[1] After Scott (1969).
[2] Poor biting school.
[3] School abandoned when sample complete.
[4] Very large school still around ship at 1500 h.

TABLE 20.—Skipjack by size categories as percent of total, and by fishing method and area, Cruise *Gilbert* 116, October 1969.

Size (cm)	Study area Troll	Pole-and-line	Outward track to study area Troll
<45	8.0	11.2	80.0
45-59.9	52.0	57.0	15.0
≥60	40.0	31.8	5.0
Total skipjack	25	223	20

ranged from 29 to 78 cm, mean 41 cm. Although very few were caught, the high percentage of fish < 45 cm is of interest.

In the study area all small fish (< 45 cm) were from areas of the South Equatorial Current. In the area west of long. 125°W, small fish were found in all three current systems (NEC, NECC and SEC), approximately from lat. 15°15′N, long. 151°45′W to lat. 0°25′S, long. 137°15′W.

Skipjack percent length frequency distribution by 2-cm classes is given in Figure 30 for the study area in October 1969. There appear to be three

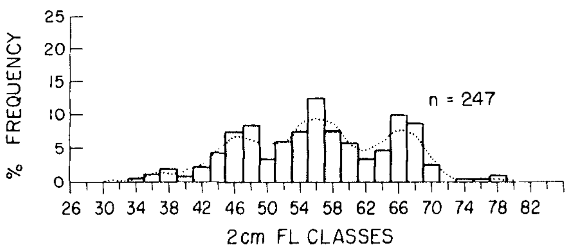

FIGURE 30.—Skipjack percent length frequency distribution (study area only), cruise *Gilbert* 116, October 1969. Smoothed curves are from 3-figure moving average. Stated length indicates midpoint of class.

modes at 46, 56, and 66 cm. Inclusion of data from the outward track would increase the probability of another mode at 36 to 38 cm. The November-December 1970 length data for the study area were similar and showed modes at 36, 48, and 58 cm; only the 66-cm mode was absent (Figure 9). The similarity suggests that the modes of 1969 (October-November) and 1970 (November-December) represent age-classes.

On the outward track yellowfin were small, mean lengths 37 and 32 cm, and on the return track bigeye had a mean length of 57 cm (Table 18). In the study area mean lengths of yellowfin ranged from 39 to 47 cm and those of bigeye from 41 to 69 cm (Table 19).

Sex and Maturity of Skipjack and Other Tuna

The sex ratio of skipjack in the study area was males to females 1:0.89 (n = 249), and on the outward track 1:1 (n = 20).

Tuna gonads taken on cruise *Gilbert* 116 were recorded as immature, maturing, mature, or spent and can be roughly compared with those for the other two cruises. The number of skipjack gonads in each maturity stage by size of fish is given in Tables 21 and 22 for the study area and outward track.

Apart from three females, all immature fish (19% of total in the study area and 80% of total on outward track) were <50 cm. The principal difference between fish caught on this cruise and the other two is the virtual absence of spent fish. Most fish (> 74%) were classed as maturing, and this could indicate that they were southern spawners. All troll-caught yellowfin tuna were immature, sex indeterminate, as were the bigeye except for one immature male of 59 cm.

DISCUSSION AND CONCLUSIONS

Gulland (1971) reviewed research findings which indicate that skipjack is the most abundant tuna in the Pacific, except possibly for frigate mackerel which is a small and presently valueless species. Our results and those of Hida (1970) show that each of the three cruises yielded many more skipjack than all other species of fish combined, including nontunas and unidentified fish (Tables 2, 15, 18, 19). On each cruise some skipjack were obtained in almost every part of the area in which fishing was done. Occurrences of other tunas (yellowfin, bigeye, and frigate mackerel) were much fewer and more localized (Tables 2, 3, 4, 15, 18, 19).

Our results also support the general hypothesis of Rothschild (1965), Williams (1972), and others that skipjack migrate as juveniles from central Pacific spawning areas towards the American coast, spend part of their adolescent life near the coast, and then return to the central Pacific. The present study area lies between the spawning areas and the coast. Thus one would expect the skipjack in that area to include, at times, individuals both smaller and larger than those typical of coastal waters. We have demonstrated their occurrence (Tables 6, 7, 20; Figures 9, 30).

Matsumoto (1966), Ueyanagi (1969), and Love (1970, 1971a, in prep.: EASTROPAC data) indicate that skipjack larvae are rare east of long. 130°W in the tropical Pacific, but increase rapidly west of that meridian. Thus our study area is close to a spawning region. One would then expect some of the large skipjack in the study area to have maturing, spent, or spent-recovering gonads at times, and this condition was found (Tables 8, 9, 10, 21, 22). The occurrence of spent-recovering and resting gonads in November-December suggest principally northern summer spawning, especially since no spawned-out fish were taken south of lat. 3°N. The presence of spent-recovering fish in March-April perhaps indicates southern summer spawners (northern winter); however, the occurrence of skipjack with maturing gonads at this time may also signify northern summer spawners. Fish taken on the two cruises may be of two spawning groups, northern and southern (see Williams 1972).

The juvenile skipjack (< 45 cm) constituted a small proportion, 13% or less on each cruise, of the total skipjack caught in the study area. Their distribution varied spatially and temporally (Tables 6, 7, 20; text p. 389). On the cruise of October-November 1969 they were found only in the South Equatorial Current, but the North Equatorial Current was not sampled. In November-December 1970 they were found principally in the North Equatorial Current and sparsely in the South Equatorial Current. In March-April 1971 they were very scarce or absent in all parts of the study area. West of long. 125°W in October-November 1969, some juveniles were taken in the North Equatorial Countercurrent as well as in the other two currents. It does not seem possible from these data to make a choice among any of the three models of coastward migration of juveniles proposed by Williams (1972), or to eliminate any of them from consideration. Data from other periods of the year are desirable.

From previous studies by Williams (1970), adult skipjack (> 45 cm) were expected to occur in waters of surface temperature 20° to 29°C, but not preferentially at particular temperatures within that range. All waters of the study area had such temperatures on all cruises (Figures 10, 11, 12, 13, 28, 29). Thus they were all suitable for skipjack as far as temperature was concerned, and skipjack occurred to some extent in most of them (Figures

TABLE 21.—Number of skipjack gonads in each maturity stage by size of fish, study area, Cruise *Gilbert* 116, October-November 1969.

Size class (cm)	Immature M	Immature F	Maturing M	Maturing F	Mature M	Mature F
30-39.9	2	6	1			
40-49.9	16	21	21	4		
50-59.9		3	48	38	3	6
60-69.9			38	34	1	2
70-79.9				1	2	2

Totals: males (M) 132, females (F) 117.

TABLE 22.—Number of skipjack gonads in each maturity stage by size of fish, outward track, Cruise *Gilbert* 116, October 1969.

Size class (cm)	Immature M	Immature F	Maturing M	Maturing F	Mature M	Mature F	Spent M	Spent F
20-29.9	2							
30-39.9	3	4						
40-49.9	4	3						
50-59.9			1			1		1
60-69.9								
70-79.9						1		

Totals: males (M) 10; females (F) 10.

5, 6, 7, 8; Tables 15, 16, 19). No relation appears between skipjack distribution and particular temperatures within the 20° to 29°C range.

Blackburn and Laurs (1972) expected adult skipjack to be distributed like their forage in offshore areas where all surface temperatures are suitable. This was because Blackburn (1969) found such a relation for skipjack in waters of suitable temperature near the coast, and Magnuson (1969) found that skipjack eat the equivalent of 15% of their body weight per day when fed to saturation. Thus adult skipjack would probably be most numerous in the latitudinally oriented zones of abundant forage which occur offshore, with forage concentrations comparable to those in coastal waters, during their westward movement from the coast to the spawning areas (Blackburn and Laurs 1972). They would probably migrate slowly through forage-rich zones or areas and quickly through those poor in forage, and thus be more abundant per unit area in the forage-rich situations.

Blackburn and Laurs (1972) showed from EASTROPAC data that the richest and most persistent zones of skipjack forage in our study area occurred a few degrees north and sometimes south of the equatorial upwelling. They also recognized a less conspicuous zonal forage maximum near the northern boundary of the North Equatorial Countercurrent, probably associated with high biological production over the shoal pycnocline. Data from the November-December cruise show the expected maxima of forage and skipjack near the Equator, but do not clearly show a maximum of either on the north side of the Countercurrent (Figures 23, 24; Table 3). Tables 12 and 13 show two statistically significant positive correlations between availability of large skipjack and their forage on the same cruise, although only for night concentrations of forage and for data averaged over a 2° zone of latitude. As mentioned earlier the actual significance may be disputable for the lower of these correlation coefficients, but not for the higher one, taking the total number of correlations in Tables 11 and 12 into account. Correlations between skipjack and day forage were not significant (Table 11).

Skipjack probably do much of their feeding in the daytime (Nakamura 1962) although forage is much scarcer in the upper water layers by day than by night. Thus the lack of relation between skipjack and day forage may seem surprising. One could however interpret these results as follows. Spatial distributions of day and night forage broadly coincide (Blackburn and Laurs 1972) because they are determined by the same physicochemical and basic biological features of the environment. Skipjack tend to occur in broad zones where both kinds of forage are initially abundant, for reasons suggested above. Within these zones they aggregate in the richer patches of day forage and eat them down, whereby their relation with the day forage will be sometimes direct and sometimes inverse. If they eat the much more abundant night forage they probably do not so frequently reduce it to a point at which the relation becomes inverse.

The significant November-December correlations become nonsignificant when data for skipjack < 45 cm are included (Table 12). Thus juvenile skipjack may be distributed in relation to a different kind of forage, or possibly to other environmental properties excluding forage. Blackburn and Laurs (1972) made no statement about ecology of juveniles.

The relatively sparse data for the March-April cruise of 1971 show a forage maximum near the Equator but not clearly elsewhere (Figures 25 and 26), although one may nevertheless have been present near the northern edge of the Countercurrent, as mentioned previously. The principal maximum of skipjack in March-April 1971 was located slightly north of the North Equatorial Countercurrent, and there was a secondary maximum near the Equator (Table 4). Data on skipjack and forage yielded no significant correlations. They were probably too sparse to do so (Table 12).

Tables 3 and 4 show that skipjack were less abundant in the North Equatorial Countercurrent than in either of the adjacent currents, on both the 1970 and 1971 cruises. This was expected because neither Blackburn and Laurs (1972) nor we found much forage in the Countercurrent. However skipjack availability was much higher in the Countercurrent (lat. 6° to 8°N) than in the South Equatorial Current on the 1969 cruise (Tables 15, 16). Forage data are lacking for the cruise, but it is not likely that forage was highly abundant in the North Equatorial Countercurrent. We note that the large skipjack taken in October-November 1969 had sexually maturing or mature gonads (Table 21), whereas most of those taken on the other cruises had spent, spent-recovering, or resting gonads (Tables 8, 9). Possibly the October-November fish were close to spawning, and thus becoming distributed in accordance with the requirements of their larvae. There is evidence that skipjack larvae occur only at sea temperatures from 23° to 31°C and are most common at about 29° to 30°C (Inter-American Tropical Tuna Commission 1971). Maximum surface temperatures in the study area in October-November 1969 were between 27° and 28°C and occurred from about lat. 4° to 11°N (Figure 29). Thus the Countercurrent waters at lat. 6° to 8°N could have been particularly suitable for the survival of skipjack larvae, and the parent fish may have been becoming distributed accordingly.

We found no direct relations between skipjack and mixed layer depth, dissolved oxygen, surface currents, chlorophyll, or zooplankton although some of these properties and features should have indirect effects on skipjack through their effects on temperature and forage. Some of them could also have direct effects upon larval or juvenile skipjack. Significant correlations between skipjack and zooplankton were not found (Tables 11, 12). Significant correlations between large skipjack and forage are also significant between skipjack and the arithmetic product of forage and zooplankton, but not between skipjack and zooplankton alone.

Although this paper has contributed to our knowledge of the distribution and relative abundance of skipjack in the offshore eastern tropical Pacific, where little information was previously available, the prospects for commercial fishing remain unknown. Our simple experimental fishing procedures served to identify zones of maximum occurrence of skipjack, but commercial trials will be needed to show if those zones can be exploited profitably. Ideally there should be trials by live-bait boats as well as purse seiners, in view of the fact that live-bait fishing gave good results on an experimental scale during the 1969 cruise. Our data and interpretations should be useful as a guide to those who make these tests.

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