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FISHERY BULLETIN 81

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ABSTRACT

The stomachs of 1,097 yellowfin tuna (*Neothunnus macropterus*) were collected in the central Pacific in 1950 and 1951, and their contents analyzed quantitatively. The tuna were captured by trolling, pole-and-line, and longline, came from different habitats—inshore and offshore, surface and subsurface—and were of different size groups. The results show that the yellowfin accepts a great variety of animal food, from plankton to large fish and squid. Of the total volume of food remains, 47 percent was fish, 26 percent squid, and 25 percent crustaceans. A total of 38 fish families and 11 major invertebrate groups was represented.

Composition of the food varied considerably with size of yellowfin and locale of capture, whether surface or subsurface, near shore or offshore. Comparison of the average volumes of stomach contents indicated that yellowfin from offshore areas contained as much food in their stomachs as those captured just off the reef; and those from subsurface levels as much as those from the surface. Feeding took place during daylight hours.

Yellowfin captured in the zone of high zooplankton abundance near the Equator contained greater amounts of food in their stomachs than those captured at more northerly or southerly latitudes. Since most elements of the pelagic fauna appear to be acceptable as food, distribution and abundance of the yellowfin is probably determined not by the occurrence of any specific food items but rather by the total amount of food organisms present in an area.

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By JOHN W. REINTJES and JOSEPH E. KING
Fishery Research Biologists

The Pacific Oceanic Fishery Investigations of the United States Fish and Wildlife Service is authorized [1] and directed to gather information to ensure maximum development and use of the high-seas fishery resources of the territories and island possessions of the United States in the tropical and subtropical Pacific. Since the tunas constitute the group of pelagic fishes having the largest and most immediate economic potential in this region, research has been concentrated on species of this group.

In view of the recognized importance of food as an environmental factor influencing the distribution of fish, a study was initiated to determine what tunas eat, and how the abundance and distribution of food organisms are related to the abundance and distribution of tunas. The first part of the study has been accomplished with a reasonable degree of completeness for the yellowfin tuna, *Neothunnus macropterus* (Temminck and Schlegel), and the results are presented in this report. Further study of the abundance and distribution of tuna is needed.

The yellowfin tuna occurs in all parts of the tropical Pacific. In recent years it has constituted 50 to 60 percent of the catch of the live-bait tuna fishery of the west coasts of the Americas. The longline fishery in the vicinity of the Hawaiian Islands depended on the yellowfin for more than 50 percent of its catch in the years 1945–48 (June 1950). The species also comprises about 50 percent of the catch of the Japanese longline fishery in the tropical western Pacific. It is taken by native peoples and sport fishermen throughout its range.

The literature contains many references to the food of yellowfin. Most of these, however, are based on casual observations made on small samples of fish, or refer to material regurgitated by the fish when it was landed. Observations by the following authors are worthy of mention.

Kishinouye (1917, 1923), reporting on the food of yellowfin captured by longline fishing in the Bonin Islands, stated that they feed on flyingfish, "coffer fish," "some deep-sea fish," "calamaries," pteropods, heteropods, hyperid amphipods, larval and immature *Squilla*, and the megalops of crabs. Okuma, Imaizumi, and Maki (1935) noted that large amounts of small skipjack, shrimp, small crabs, carangids, and balistids were found in yellowfin stomachs collected in Indo-Pacific waters. Nakamura (1936, 1943), from an examination of the stomach contents of yellowfin captured by longline gear in the Celebes Sea, reported clupeoid, scombroid, and plectognath fishes among the most common food items, followed by squid and palinurids, squillids, syllarids, and *Leander* among the crustaceans.

Walford (1937) reported that flyingfish, sauries, sardines, squid, and larval and adult planktonic crustaceans were found in the stomachs of yellowfin captured by surface fishing in the coastal waters of the eastern Pacific. Marukawa (1939) examined 12 longline-caught yellowfin from equatorial waters south of the Palaus, and briefly summarized the results in a checklist which includes fishes, squid, and crustaceans. Kanamura and Yazaki (1940a, 1940b) found squid, triggerfish, balloonfish, and shrimp in the stomachs of longline-caught yellowfin from the East Philippine Sea and the South China Sea. Ban (1941) reported the occurrence of planktonic animals, paper nautilus, trunkfish, juvenile carangids, mackerel, sphyraenids, and mature skipjack among the stomach contents of yellowfin. Ikebe (1942) stated that yellowfin captured in waters southwest of New Guinea were feeding mostly on squid. Suyehiro (1942) reported briefly on the stomach contents of a "sample" taken during one day's fishing off southern Japan. In addition to his own observation he reported that leatherfish, cuttlefish, and shrimp were found in the stomachs of yellowfin taken near Timor Island.

[1] Public Law 329, 80th Congress.

Tinker (1944), Chapman (1946), and Hildebrand (1946) briefly referred to the food of the yellowfin tuna as consisting of small shore and pelagic fishes, squid, and planktonic crustaceans. Herald (1949) found a 42-millimeter seahorse, juvenile surgeonfish, triggerfish, and other common forms in the stomach of a yellowfin taken near the Hawaiian Islands. Fitch (1950) found large numbers of postlarvae of the pointed-tailed ocean sunfish (*Masturus lanceolatus*) in yellowfin from Hawaiian waters.

All of these investigators listed the kinds and, in a few cases, the numbers of organisms that were found in the stomachs of yellowfin tuna, but they gave no quantitative analysis of the relative importance of the various food elements or their relation to locality, habitat, or body size of the tuna concerned. Welsh (1949), on the other hand, has made a quantitative study of the food of the yellowfin, but only 20 relatively small specimens, all captured within ½ mile or less of Oahu, Hawaiian Islands, were examined. Ronquillo (1950) examined the stomachs of 144 yellowfin from the waters of the southern Philippines and made a preliminary report and checklist of organisms found and their frequency of occurrence.

The authors are grateful to fellow staff members, ships' officers and crews of the *Hugh M. Smith*, *John R. Manning*, and the *Henry O'Malley*, for their assistance in handling these large fish at sea and in removing and preserving the stomach material.

SOURCE OF MATERIALS

Material collected in 1950 and 1951, during 12 cruises of Fish and Wildlife Service vessels [2] in waters surrounding the Line and Phoenix Islands, was available for this investigation (table 1). Of the 5,164 yellowfin captured on these cruises, the stomachs from 1,097 were preserved for subsequent analysis. Of the 1,097 fish sampled, 786 were taken at the surface by trolling or by live-bait pole-and-line fishing, and 311 were caught at depths of 100 to 500 feet with longline gear.[3] A total of 775 of the surface-caught fish and 70 of those taken on longlines were captured within 10 miles of land (table 2). The remaining 11 surface-caught fish and 241 subsurface-caught fish were taken in waters 10 miles or more from land.

The sampled yellowfin ranged widely in size, from approximately 500 to 1,700 millimeters (5 to 200 pounds). The length distribution of these fish is given in figure 1. For purposes of comparison the fish were classified in three size categories: (1) small, less than 1,000 mm. fork length, or approximately 43 lb.; (2) medium, 1,000 to 1,299 mm.

[2] The *Hugh M. Smith*, *John R. Manning*, and *Henry O'Malley*.

[3] The live-bait method of tuna fishing has been described by Godsil (1938), the longline method by Shapiro (1950) and June (1950), and surface trolling by Bates (1950).

TABLE 1.—*Distribution of the yellowfin tuna taken and stomachs collected in the central Pacific, by time of year, cruise, locality, and fishing method, 1950 and 1951*

Time of year	Vessel	Cruise	Locality	Fishing method	Number of yellowfin captured	Number of stomachs examined	Percent of catch sampled
1950							
February	Hugh M. Smith	2	Phoenix Islands	Trolling	10	9	90.0
				Pole-and-line	4	4	100.0
April–June	John R. Manning	2	Line Islands	Trolling	882	105	11.9
July	Hugh M. Smith	5	Phoenix Islands	Longline	53	52	98.1
				Trolling	2	2	100.0
July–August	Henry O'Malley	4	Phoenix Islands	Trolling	24	7	20.8
				Pole-and-line	271	24	15.4
August	Henry O'Malley	4	Line Islands	Trolling	4	2	50.0
				Pole-and-line	8	5	62.5
	John R. Manning	3	Phoenix Islands	Trolling	64	41	64.1
September	John R. Manning	3	Line Islands	do	109	21	19.3
November	Hugh M. Smith	7	do	Trolling	5	4	80.0
				Longline	132	106	80.3
	John R. Manning	4	do	Trolling	98	96	98.0
1951							
January–February	Hugh M. Smith	8	do	do	25	23	92.0
	John R. Manning	5	Phoenix Islands	do	27	23	85.2
February	John R. Manning	5	Line Islands	do	43	27	62.8
April–May	do	6	do	do	110	100	90.9
June	Hugh M. Smith	9	Line Islands	Trolling	29	19	65.5
				Pole-and-line	2,628	209	8.0
			Phoenix Islands	Trolling	2	2	100.0
				Pole-and-line	177	63	35.6
August–September	do	11	Line Islands	Longline	457	153	33.5
Percent of total sampled							21.2

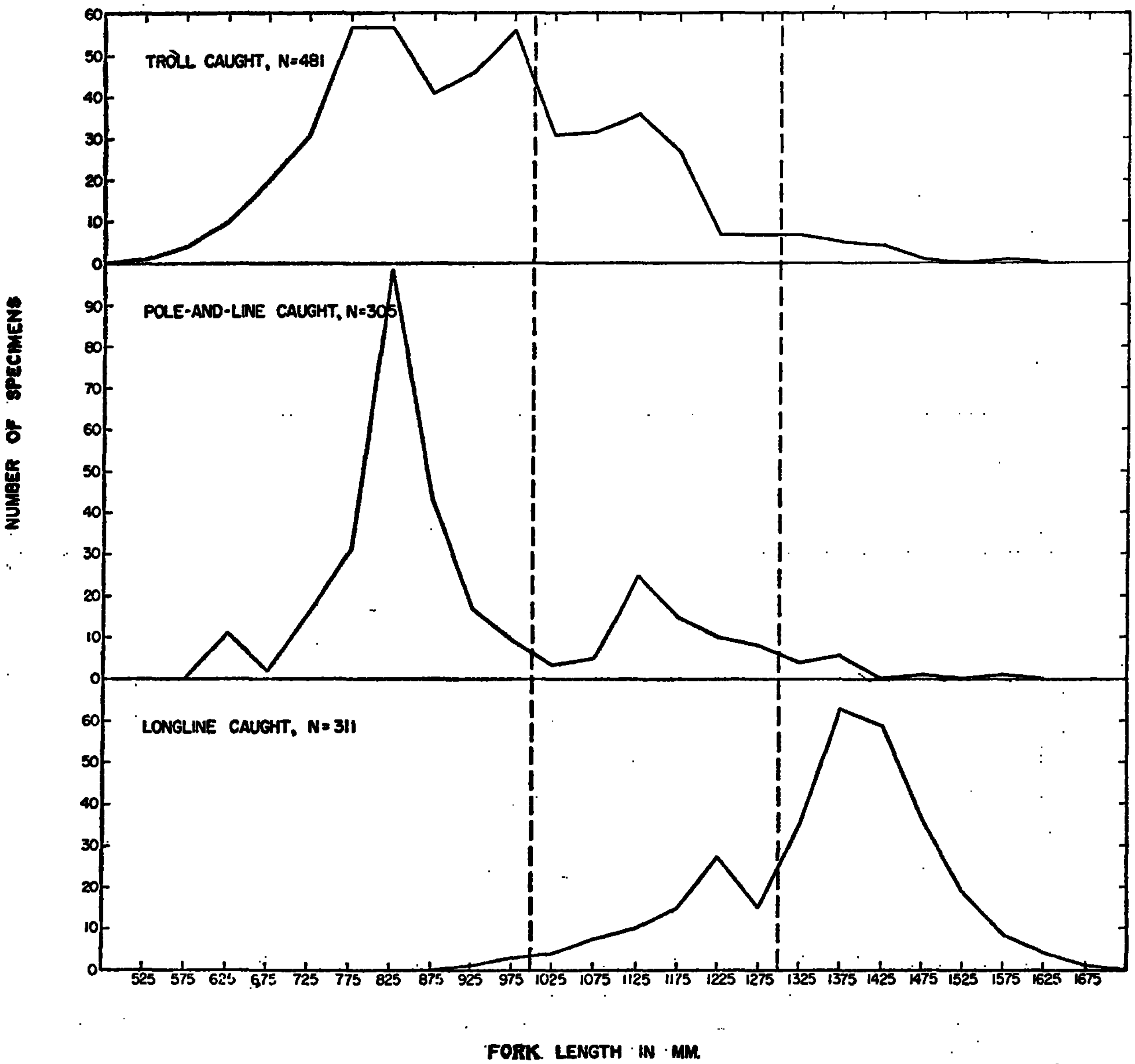

FIGURE 1.—Length distribution of sampled yellowfin according to method of capture. N=number of fish.

TABLE 2.—*Distribution of 1,097 yellowfin-tuna samples, by distance of capture from land and fishing method*

Distance from land	Trolling	Pole-and-line	Longline
0 to 9 miles	470	305	70
10 to 24 miles	5	----------	27
25 to 49 miles	1	----------	12
50 to 99 miles	----------	----------	27
100 to 199 miles	1	----------	37
200 to 499 miles	4	----------	124
500 miles and more	----------	----------	14
Total	481	305	311

fork length; and (3) large, 1,300 mm. and over, fork length, or about 94 lb. or more. These size classes were established to provide an intermediate size range which would include comparable numbers of fish captured by all three fishing methods.

The collections were made chiefly in three general localities: the Phoenix Islands, the Line Islands, and the open ocean to the east and west of the Line Island group. Although the sampling was fairly well distributed over the 2-year period,

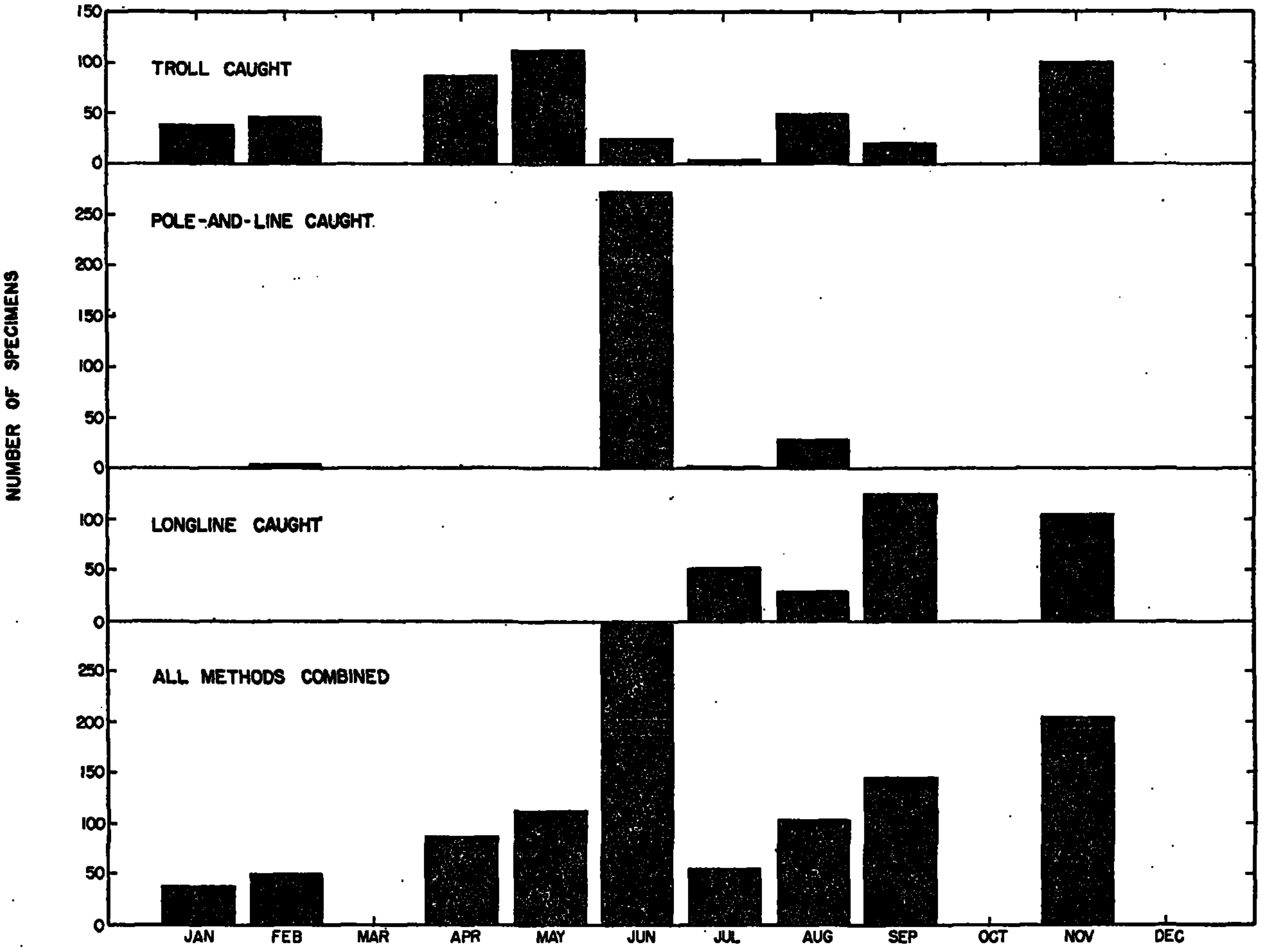

FIGURE 2.—Distribution of yellowfin stomach collections, by month and by method of capture, February 1950 to September 1951.

it was not distributed over the months of the year for each fishing method as well as desired. Figure 2 indicates, for each method of capture and for all methods combined, the number of stomachs obtained during each month, the years 1950 and 1951 combined.

METHODS

COLLECTION OF MATERIALS

In the field, the stomach was removed as soon as possible after the fish was captured, placed with any regurgitated material in an unbleached muslin bag, and preserved in 10-percent formalin. A label bearing the date, the locality, the method, depth, and time of capture, the species, fork length, bait used, name of observer, and vessel, was placed with each stomach.

The stomach was removed by one of the following methods:

(1) The abdominal cavity was opened by a longitudinal midventral incision, the small intestine severed posterior to the pyloric valve, and the stomach freed by cutting through the muscular esophagus.

(2) The gill membrane was slit along the line of attachment with the cleithrum, posterior to the fourth gill arch, the viscera pulled out, and the stomach removed by cutting through the small intestine and esophagus.

IDENTIFICATION OF STOMACH CONTENTS

In the laboratory, the stomachs were leached in fresh water for a period of 12 to 24 hours to remove excess formalin. All of the contents were carefully removed and separated into groups.

Each organism was identified as completely as was practicable and the number of each species or group of organisms was recorded. Each subdivision or kind of food was then measured volumetrically by the displacement of water in a graduated cylinder of appropriate size. Bait used to capture the yellowfin was not considered in this analysis.

The methods used to identify food organisms and organic remains varied to a great extent, and depended on the group of animals under consideration. The arthropods were identified to taxonomic order from general exoskeletal characteristics. Although Euphausiacea, Mysidacea, and Decapoda were difficult to separate, the scarcity of the first two orders made the problem of secondary importance. Amphipoda, Isopoda, Stomatopoda, and most Decapoda were easy to distinguish to taxonomic order even with partial remains. Some members of the amphipod families of Calliopiidae, Hyperiidae, Oxycephalidae, and Gammaridae found in this region were recognized by certain cephalic characteristics and body shape. The species of Stomatopoda, which even when badly damaged were readily distinguished by certain exoskeletal features, have been described by Brooks (1886), Kemp (1913), Edmondson (1921), Bigelow (1931), and Townsley (1950), who reported on Pacific forms and constructed keys for their separation. Such decapod crustaceans as the postlarval Palinuridae and Nephropsidae were readily identified because each possesses unique familial traits. Identification of the latter family was aided by the work of Holthius (1946).

The shelled molluscs found in the stomachs of tuna were readily identified as heteropods, pteropods, and nautiloid cephalopods from distinguishable shell remains. The cephalopods were separable to squid and octopods on the basis of general body shape, number of arms, presence or absence of a gladius (pen), and modification of suckers into hooks. The presence of tentacles (fifth pair of arms) was used as a distinguishing trait in all squid except in the aberrant family of eight-armed squid, Octopodoteuthidae, where the modification of suckers into hooks indicated a decapod mollusc. Berry (1914) used the perforation of the eyelid, arrangement of the suckers, and the hectocotylus (modification of one tentacle into an accessory sex character in the male) to distinguish genera and species of cephalopods; however, all of these structures are susceptible to the destructive action of the digestive juices so that in most instances organisms were identifiable only as squid or octopods.

Pelagic tunicates were seldom identifiable to family because the soft body readily disintegrated into gelatinous fragments in the tuna stomach. These remains retained certain characteristics, however, that distinguished them from the coelenterates and pelagic molluscs with similar gelatinous structure.

The teleost fishes were readily recognized by their skeletal remains. Further identification, even to taxonomic order, was dependent on certain traits, many of which were readily lost. Engulfment often separated the head from the body, mutilated the fins, skin, and lateral line, and removed scales, making identification difficult. Fishes with bony protuberances, carapace-like integument, and other distinguishable hard parts were the most easily identified. Familial identification was often dependent upon singular characteristics, such as bony scutes in the Carangidae and teeth and mandibles in the Tetrodontidae, Diodontidae, Alepisauridae, Aulostomidae, Belonidae, and Hemirhamphidae. In more generalized groups possessing neither unique nor resistant parts, identification could not be easily made. Juvenile fishes often lack traits characteristic of the adults; for these, identification to the family frequently was impossible. It is estimated that 80 percent of the fish specimens could be identified to family.

The most useful references for the identification of fishes were Fowler (1928, 1931, 1934, 1949), Jordan and Evermann (1905), Gilbert (1905), Weber and De Beaufort (1913–1936), De Beaufort (1940), Schultz (1943), Brock (1950), and De Beaufort and Chapman (1951). Berg's (1947) modification of Regan's system of classification was used for the forage fishes. A reference collection of invertebrates and fishes maintained at our laboratory in Honolulu was used intensively during the study.

EVALUATING FOOD COMPONENTS

Three general systems of analysis and methods of expressing results have evolved from the many investigations of the stomach contents of fish, birds, mammals, and other animals. These systems might be termed the "numerical," the "frequency of occurrence," and the "volumetric." Each has its shortcomings, some of which are inherent in the nature of the problem, and at best it can afford only a rough indication of the food habits of the animal.

The numerical system is based solely on a count of organisms present, with each food element evaluated as a percent of the total number of all elements. This method tends to place undue emphasis on food organisms with very resistant parts. In summing up the food of a number of individuals, instead of getting a cross section of the most recently obtained food, a record is obtained of the more durable elements of past and recent food and a false idea of the food may result. Furthermore, the numerical system does not take into account the size of objects, and hence conveys little of the relative importance of the separate components in terms of bulk since the numerical majority may form but a small proportion of the food. Foods that have become finely broken up can be only roughly estimated by number. Also, the time required for the investigator to make an accurate count, as for example, of the thousands of crab larvae in the stomach of a tuna which has gorged itself on this food, may be prohibitive, necessitating the use of an estimation based on a subsample.

In frequency-of-occurrence analysis, each food element is expressed as a percentage computed by dividing the number of stomachs containing the food, regardless of amount, by the total number of stomachs examined. This provides a rough but useful index to the overall availability, and perhaps the palatability, of the food element.

The volumetric system is based on percentage by bulk. Its use reduces the overevaluation of food organisms with more durable parts to a minimum. A large series of stomachs yields reliable information on recent food, with old food represented by traces. The size of individual items is taken into account only by this system. As with the other two methods of analysis, some soft-bodied organisms may leave no appreciable trace in the stomach and thus may be underrated in importance. Other errors may result from different digestion rates. Hess and Rainwater (1939), for example, demonstrated that of the different kinds of immature insects fed to brook trout, small soft-bodied forms were digested more rapidly than large thick-skinned types. Karpevich (1941) found that Gammaridae were digested more rapidly by three marine fishes than were larger crustaceans and small fish. Despite its defects, we believe this system to be the best of the three, if conclusions are to be based on but one method of analysis.

The volumetric system can be used in several ways to evaluate the amount of each kind of food present. Martin, Gensch, and Brown (1946), for example, describe the following two ways:

Aggregate-total-volume method: The percentage for each kind of food is obtained by dividing the total volume of all food of each kind by the total volume of the stomach contents of all the fish. The variation in the total volume of food from each stomach influences the final result in direct proportion to that volume.

Average-percentage method: Percentage equivalents are calculated for each food item with each stomach evaluated 100 percent regardless of the volume of its contents. Variation in the total volume of food present, therefore, does not influence the results. Stomachs containing very little food exert the same influence on results as do well-filled stomachs.

The aggregate-total-volume method has the definite merit of reflecting truly the volumetric importance of a particular food organism regardless of whether much or little of other foods is present.

Various combinations of the three basic systems of analysis have been devised to present a more complete picture of the food habits of the animal being studied. Tester (1932) combined the volumetric and the frequency-of-occurrence methods for a graphic representation of the food of the smallmouth black bass, *Micropterus dolomieu.* The relative importance of each kind of food was demonstrated graphically by a rectangle in which the percentage volume of a kind of food was the horizontal line and the percentage frequency-of-occurrence was the vertical. The vertical scale was arbitrarily fixed at 40 percent of the horizontal to give the volume of food more weight. In a different method devised by Welsh (1949), each kind of food was evaluated by a percentage rating which was "an average of the percent of the total bulk of the individual food used (indicating food value), the total number of individual food-animals used (indicating abundance), and the total number of stomachs in which the individual food were found indicating availability." Although this final averaged-percentage figure appears to be a combination of dissimilar terms, it perhaps serves as a simplified and useful index.

Throughout this investigation, as complete records as possible were kept on the contents of each stomach so that all necessary information would be available for whatever method or methods of analysis were finally decided on. In reviewing the results of the study, it appeared that all three of the basic methods were necessary for proper evaluation of the food of the yellowfin. Therefore, in table 3, which gives the detailed results of the study, there is shown for each food element the total number of such organisms in all stomachs, the number of stomachs in which it occurred, the percent frequency of occurrence, the aggregate total volume of such organisms in all stomachs, and the percent aggregate total volume.

Regardless of the method of analysis used, there are many uncontrollable variables inherent in food studies which detract from the precision of the results. One may safely conclude, however, that those food items that rank large in number, large in volume, and high in frequency of occurrence are important foods—at the time and in the area sampled.

TABLE 3.—*Checklist of food organisms found in the stomachs of 1,097 yellowfin tuna captured in the central Pacific, 1950 and 1951*

Food organisms	Number of organisms	Stomachs in which occurred		Aggregate total volume	
		Number	Percent	Cc.	Percent [1]
ARTHROPODA					
Crustacea	[85, 140]	[734]	[66. 9]	[12, 991. 1]	[24. 8]
Mysidacea					
Oplophoridae:					
Oplophorus foliaceus	20	1	.1	105. 0	.2
Unidentified mysids	4	2	.2	.6	-------
Amphipoda					
Hyperiidae	251	80	7. 3	78. 0	.2
Oxycephalidae	11	4	.4	2. 3	-------
Gammaridae	1	1	.1	.2	-------
Calliopiidae	2	1	.1	.5	-------
Unidentified amphipods	202	50	4. 6	58. 3	.1
Isopoda	7	3	.3	1. 2	-------
Stomatopoda					
Squillidae:					
Squilla sp. alima	46	7	.6	10. 5	-------
Pseudosquilla ciliata monodactylus stage	3, 574	290	26. 4	1, 186. 5	2. 3
Pseudosquilla oculata erichthus	631	112	10. 2	215. 3	.4
Lysiosquilla sp. erichthus	315	114	10. 4	152. 4	.3
Lysiosquilla n. sp. erichthus and postlarvae	81	34	3. 1	62. 3	.1
Gonodactylus guereni postlarvae	902	148	13. 5	233. 6	.4

[1] Given only when 0.1 percent or greater.

TABLE 3.—*Checklist of food organisms found in the stomachs of 1,097 yellowfin tuna captured in the central Pacific, 1950 and 1951*—Continued

Food organisms	Number of organisms	Stomachs in which occurred		Aggregate total volume	
		Number	Percent	Cc.	Percent [1]
Crustacea—Continued					
Stomatopoda—Continued					
Squillidae—Continued					
Odontodactylus hanseni postlarvae	1, 046	142	12. 9	446. 6	0. 8
Unidentified stomatopods	164	61	5. 3	105. 5	.2
Euphausiacea					
Euphausiidae:					
Euphausia sp	35	5	.5	6. 4	-------
Unidentified euphausiids	6	2	.2	2. 0	-------
Decapoda					
Penaeidae:					
Metapenaeus sp	38	4	.4	70. 0	.1
Unidentified shrimp	999	81	7. 4	288. 8	.6
Nephropsidae:					
Enoplometopus sp. postlarvae	905	95	8. 7	295. 0	.6
Palinuridae:					
Panulirus sp.					
phyllosoma (larvae)	7	5	.5	2. 8	-------
puerulus (postlarvae)	18	12	1. 1	16. 0	-------
Unidentified crab larvae					
zoeae	2	2	.2	1. 0	-------
megalops	75, 875	529	48. 2	9, 363. 0	17. 9
Paguridae	1	1	.1	.3	-------
Unidentified crustaceans	-------	39	3. 6	287. 0	.5
MOLLUSCA					
Pteropoda					
Cavolinidae:					
Cavolinia sp	10	1	.1	5. 0	-------
Unidentified pteropods	1	1	.1	1. 0	-------
Pectinibranchiata (Heteropoda)					
Atlantidae	4	2	.2	1. 0	-------
Unidentified heteropods	99	51	4. 6	169. 2	.3
Decapoda (squid)	[3, 642]	[608]	[55. 4]	[13, 722. 2]	[26. 2]
Onychoteuthidae:					
Onychoteuthis banksi	17	3	.3	66. 0	.1
Ommastrephidae:					
Symplectoteuthis oualaniensis	43	7	.6	309. 0	.6
Octopodoteuthidae	1	1	.1	700. 0	1. 3
Unidentified squid	3, 581	603	55. 0	12, 647. 2	24. 2
Octopoda					
Argonautidae:					
Argonauta hians	3	3	.3	12. 5	-------
Unidentified argonauts	184	41	3. 7	456. 5	.9
Bolitaenidae:					
Eledonella sp	2	2	.2	45. 0	.1
Unidentified octopods	80	26	2. 4	176. 0	.3
CHORDATA					
Tunicata	[240]	[69]	[6. 3]	[300. 0]	[. 6]
Salpidae:					
Pyrosoma sp	27	8	.7	76. 0	.1
Unidentified salps	128	43	3. 9	137. 2	.3
Unidentified tunicates	85	16	1. 5	86. 8	.2
Vertebrata (Pisces)	[5, 333]	[772]	[70. 4]	[24, 456. 6]	[46. 7]
Sternoptychidae (hatchetfishes):					
Sternoptyx diaphana	2	1	.1	1. 0	-------
Synodidae (lizardfishes)	2	2	.2	3. 0	-------
Sudidae	3	1	.1	20. 0	-------
Alepisauridae (lancetfishes)	5	4	.4	32. 0	-------
Leptocephalus (larvae)	12	5	.5	7. 2	-------
Myctophidae (lanternfishes)	35	17	1. 5	79. 0	.2
Belonidae (needlefishes)	3	2	.2	52. 0	.1
Hemirhamphidae (halfbeaks)	1	1	.1	30. 0	-------
Exocoetidae (flyingfishes)	23	21	1. 9	1, 740. 0	3. 3
Macruridae (grenadiers)	1	1	.1	2. 0	-------
Aulostomidae (trumpetfishes):					
Aulostomus chinensis	4	3	.3	7. 0	-------
Syngnathidae (pipefishes and seahorses):					
Hippocampus kudo	1	1	.1	1. 0	-------
Unidentified pipefishes	4	2	.2	1. 5	-------
Lophotidae (oarfishes):					
Lophotes capellei	2	1	.1	15. 0	-------
Holocentridae (squirrelfishes)	2	1	.1	6. 0	-------

TABLE 3.—*Checklist of food organisms found in the stomachs of 1,097 yellowfin tuna captured in the central Pacific, 1950 and 1951*—Continued

Food organisms	Number of organisms	Stomachs in which occurred		Aggregate total volume	
		Number	Percent	Cc.	Percent [1]
Vertebrata (Pisces)—Con.					
Sphyraenidae (barracudas)	1	1	0.1	5.0	-------
Polynemidae (threadfins)	1	1	.1	2.0	-------
Priacanthidae (big-eyes)	6	5	.5	9.0	-------
Carangidae (jacks):					
Decapterus sp.	46	24	2.2	4,395.0	8.4
Naucrates ductor	3	1	.1	960.0	1.8
Unidentified jacks	4	4	.4	445.0	.9
Bramidae (pomfrets):					
Taractes sp.	28	16	1.5	194.5	.4
Collybus drachme	449	150	13.8	1,756.6	3.4
Unidentified pomfrets	101	21	1.9	171.0	.3
Coryphaenidae (dolphins)	1	1	.1	205.0	.4
Lutianidae (snappers)	48	15	1.4	46.0	.1
Chaetodontidae (butterflyfishes)	24	13	1.2	50.5	.1
Pomacentridae (demoiselles)	14	8	.7	8.5	-------
Labridae (wrasses)	8	3	.3	5.0	-------
Champsodontidae	2	2	.2	6.0	-------
Bleniidae (blennies):					
Petroscirtes sp.	29	10	.9	29.5	-------
Unidentified blennies	21	3	.3	12.0	-------
Acanthuridae (surgeonfishes)	1,067	184	16.8	1,007.2	1.9
Gempylidae (snake mackerels):					
Gempylus serpens	1	1	.1	9.0	-------
Unidentified snake mackerels	84	49	4.5	534.0	1.0
Scombridae (tunas and mackerels):					
Katsuwonus pelamis (skipjack)	19	16	1.5	2,668.0	5.1
Neothunnus macropterus (yellowfin)	1	1	.1	820.0	1.6
Parathunnus sibi (big-eyed tuna)	2	2	.2	270.0	.5
Unidentified tunas	34	24	2.2	1,093.5	2.0
Nomeidae (rudderfishes)	1	1	.1	2.0	-------
Bothidae (flatfishes)	1	1	.1	1.0	-------
Echeneidae (remoras):					
Remora remora	16	15	1.4	123.0	.2
Unidentified remoras	5	4	.4	31.0	-------
Balistidae (triggerfishes):					
Balistes ringens	45	24	2.2	570.5	1.1
Unidentified triggerfishes	322	91	8.3	698.0	1.3
Monacanthidae (filefishes)	24	16	1.5	49.0	.1
Ostraciidae (trunkfishes):					
Ostracion diaphana	137	75	6.8	349.5	.7
O. lentiginosus	1	1	.1	4.0	-------
Unidentified trunkfishes	215	84	7.7	223.5	.4
Tetrodontidae (puffers):					
Sphaeroides lagocephalus	14	11	1.0	768.0	1.5
Unidentified puffers	10	12	1.1	133.0	.3
Diodontidae (porcupinefishes)	8	8	.7	81.0	.2
Molidae (headfishes):					
Ranzania truncata	1	1	.1	520.0	1.0
Unidentified fish and fish remains	2,439	529	48.2	4,204.1	8.0
Total	-------	-------	-------	52,336.1	-------

[1] Given only when 0.1 percent or greater.

RESULTS

FOOD HABITS OF THE YELLOWFIN TUNA

Detailed data obtained during this study are presented in table 3. This table incorporates the combined data for all stomachs examined and serves as a checklist of the food organisms identified. It is apparent from table 3 and figure 3 that the food of the 1,097 yellowfins sampled was composed by volume almost entirely of fish (46.7 percent), squid (26.2 percent), and crustaceans (24.8 percent). The small remainder consisted of pelagic tunicates (0.6 percent) and molluscs other than squid (1.7 percent). Representatives of 38 fish families and 11 major invertebrate groups were found in the stomach contents. Despite the great variety of organisms only a few items were of primary importance in the diet of the yellowfin. Those food elements ranking large in number, volume, and frequency of occurrence were crab larvae, stomatopod larvae, squid, pomfrets (Bramidae), and surgeonfish (Acanthuridae). Fishes such as flyingfish (Exocoetidae), mackerel scad (*Decapturus* sp.), and skipjack (*Katsuwonus pelamis*) were relatively important in volume because of their large individual size, but ranked low in number and frequency of occurrence, indicating that they were only occasionally utilized.

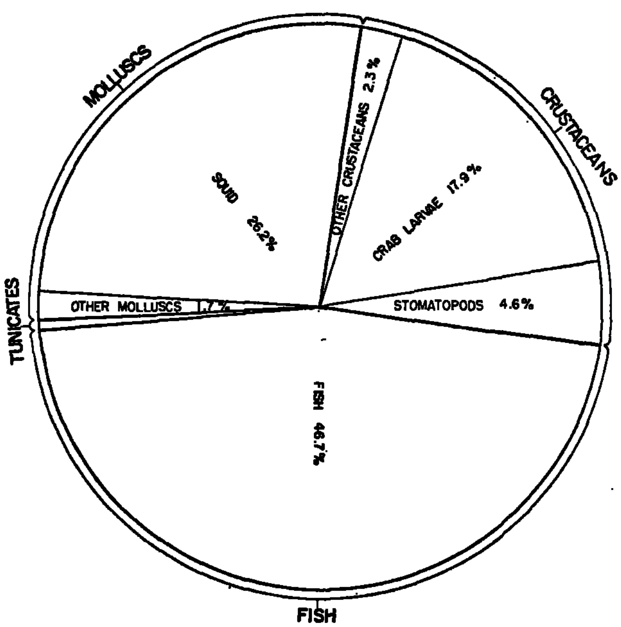

FIGURE 3.—The comparative importance of the major food categories for the 1,097 sampled yellowfin (as percent of total volume).

Size of organisms taken

More than 75 percent of the stomachs examined contained organisms individually displacing less than 0.5 cc. The regular occurrence of larval and postlarval crustaceans, and the occasional record of small heteropods and pteropods indicate a consistent tendency for the tuna to take organisms of very small size.

The maximum size of organisms used for food is dependent on the size of the tuna. Some stomachs were distended by large carangid and scombroid fishes. Certain elongate fishes such as the alepisaurids and snake mackerels were folded two or three times in the stomach. One stomach from a yellowfin (1,358 mm. fork length) contained a skipjack, *Katsuwonus pelamis*, exceeding 400 mm. in length, and vertebral remains found during the study suggest that prey of this size is not uncommon. The maximum size of food organisms, estimated from these data, is approximately one-third the length of the yellowfin.

Gorging

Observers aboard the *John R. Manning* reported an aggregation of crab megalops in the vicinity of Christmas Island (Line Island Group) on May 12 and 13, 1950. The larvae were so numerous that the screened intake of the heat exchanger for the vessel's engines became clogged and had to be cleaned on several occasions. Stomachs were preserved from 21 yellowfin, ranging from 879 to 1,365 mm. fork length, captured in the vicinity at this time. All contained crab larvae as the principal food component, averaging 1,500 larvae (180 cc.) per stomach. Many fish were gorged and regurgitated large amounts of the larvae when they were landed.

Diurnal variation

The time of capture is known for 660 yellowfin caught at the surface. Of these, 398 yellowfin landed between 6 a. m. and 12 m. had an average stomach-content volume of 22.1 cubic centimeters; 74 of the 398 fish had empty stomachs. The average volume of stomach contents of 258 yellowfin landed between 12 m. and 6 p. m. was 49.7 cubic centimeters; of this number, 14 had empty stomachs. These results indicate that the yellowfin sampled were not necessarily night feeders, as sometimes reported (Ban 1941), but that they had definitely been feeding during the day and probably right up to the time of capture. These data are based primarily on small and medium-sized yellowfin, all surface-caught fish; consequently, the implications may possibly not apply to yellowfin in general.

Variation in volume of stomach contents

Table 4 shows the distribution of stomach-content volumes according to an arbitrary scale devised by the authors. The large percentage of empty or almost empty stomachs is surprising, but may be related to the rate of digestion or feeding habit. It is difficult to believe that the food volumes of less than 25 cc. which were found in 58 percent of the yellowfin examined represent an average daily ration for these large, fast-moving fish. We conclude that the rate of digestion is very rapid or that the fish must depend largely on occasional opportunities to gorge.

The frequency of empty stomachs and of volumes less than 3 cc. appears to vary considerably among the catches obtained by the three fishing methods. The high percentage of empty stomachs among the pole-and-line-caught yellowfin may be the result of these fish coming from surface schools, whereas there are indications that the catch for the other two fishing methods was not from well-defined schools but rather was composed of individual fish or of fish from small congregations. Also, the different fishing methods, by taking fish

TABLE 4.—*Distribution of the volume of stomach contents from 1,097 yellowfin tuna, for each fishing method and for all methods combined*

Volume of stomach contents	Troll caught			Pole-and-line caught			Longline caught			Total		
	Number	Percent	Accumulated percent	Number	Percent	Accumulated percent	Number	Percent	Accumulated percent	Number	Percent	Accumulated percent
Empty [1]	35	7.3	7.3	61	20.0	20.0	5	1.6	1.6	101	9.2	9.2
0.1 to 2.9 cc	118	24.6	31.9	33	10.8	30.8	9	2.9	4.5	160	14.6	23.8
3.0 to 9.9 cc	125	25.9	57.8	46	15.1	45.9	28	9.1	13.6	199	18.1	41.9
10.0 to 24.9 cc	80	16.6	74.4	39	12.8	58.7	61	19.6	33.2	180	16.4	58.3
25.0 to 49.9 cc	37	7.7	82.1	33	10.8	69.5	74	23.8	57.0	144	13.1	71.4
50.0 to 99.9 cc	28	5.8	87.9	62	20.3	89.8	61	19.6	76.6	151	13.8	85.2
100.0 to 199.9 cc	34	7.1	95.0	27	8.9	98.7	47	15.1	91.7	108	9.8	95.0
200.0 to 499.9 cc	21	4.4	99.4	4	1.3	100.0	22	7.1	98.8	47	4.3	99.3
500.0 to 999.9 cc	2	0.4	99.8	----------	----------	----------	4	1.3	100.0	6	0.5	99.8
1,000 cc and more	1	0.2	100.0	----------	----------	----------	----------	----------	----------	1	0.1	99.9
Total	481	100.0	----------	305	100.0	----------	311	100.0	----------	1,097	99.9	----------

[1] Less than 0.1 cc.

of somewhat different size groups and from different habitats, may influence the average volume of stomach contents.

In general, there was an increase in the mean food volume with an increase in the fork length of the fish (table 5, fig. 4). The average stomach content per unit of body weight (cc./lb.) was found to decrease, however, as the weight of the fish increased (fig. 5). Except for possible aberrancies at the extreme ends of the polygons and in the 1,250-mm., approximately 84-lb., group, which may be due to quirks of sampling, there appears to be a rectilinear relation between the volume of stomach contents and size of the fish.

The great variation in volume of stomach contents is illustrated in table 5. For the various size groups represented, the standard deviation (s) is roughly proportional to the mean volume ($\bar{x}$), indicating a great increase in variance, or variation about the mean, of volume of stomach contents with increase in fork length. This variation is related to the fact that large yellowfin eat organisms of greater dimension than those consumed by small yellowfin, but that both groups feed on the same minute organisms, such as crab and stomatopod larvae. Therefore, the larger the yellowfin the greater the size range of the individual food elements and the greater the range in volume of stomach contents that may be expected.

Variation in food of yellowfin related to locality, habitat, and body size

As indicated in tables 1 and 2 and figure 1, yellowfin were captured by three methods, came from different depths and localities, and covered a wide size range. It was difficult, therefore, to find within this heterogeneous lot of fish, groups that might be compared to show differences resulting from the action of a single variable.

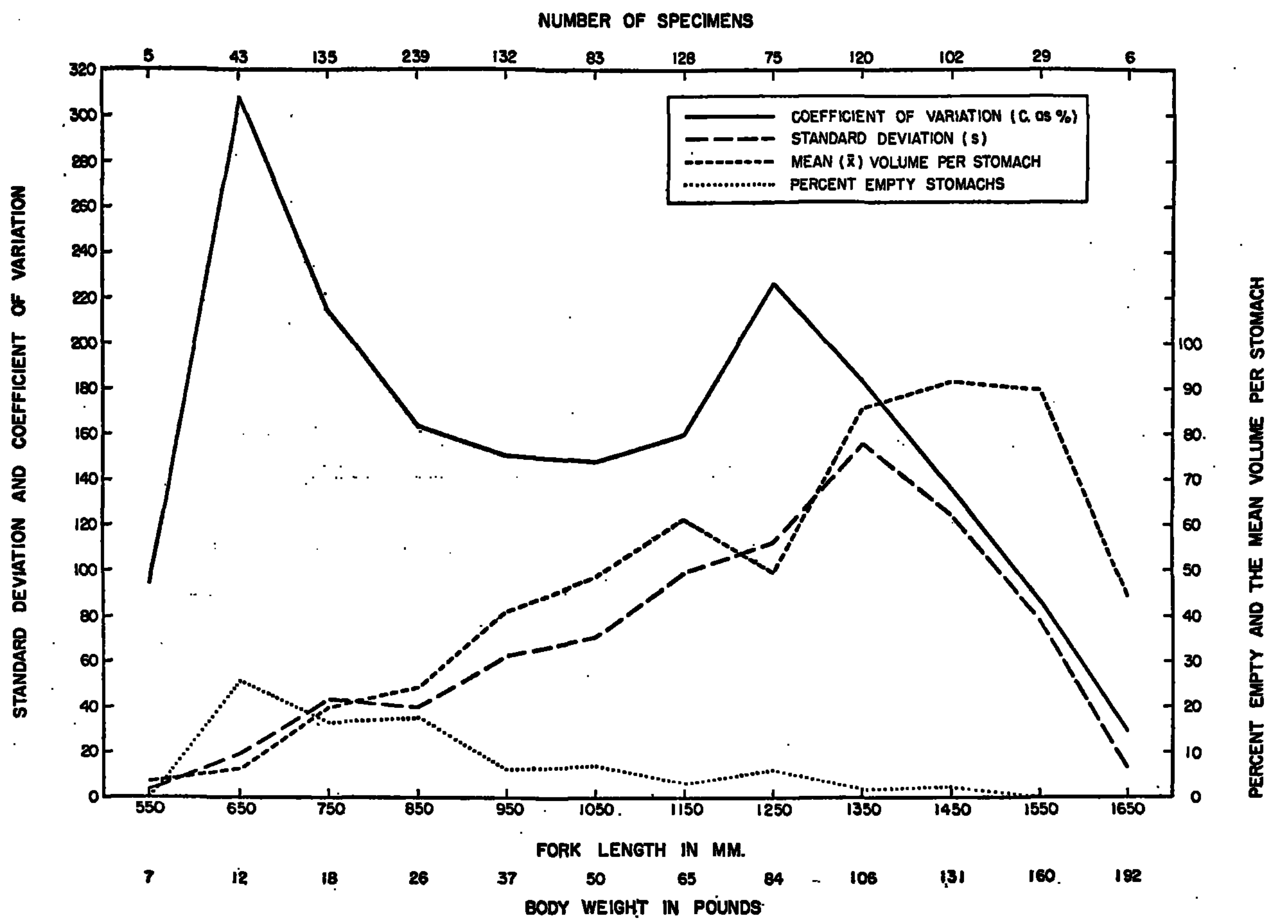

FIGURE 4.—Relation of percent of empty stomachs, mean volume of food per stomach, standard deviation, and coefficient of variation for volumes of stomach contents to body size of 1,097 yellowfin tuna.

Table 5.—*Relation between size and volume of stomach contents of yellowfin tuna*

N = total number of sampled fish for each size group
Empty = number of empty stomachs
x̄ = mean, or average food volume per stomach
s = standard deviation, indicating variation in food volume for each size class
C = the coefficient of variation, an index to variability

Variation in volume of stomach contents	For size class (fork length in millimeters) of—												Total
	500–599	600–699	700–799	800–899	900–999	1000–1099	1100–1199	1200–1299	1300–1399	1400–1499	1500–1599	1600 1699	
Troll caught:													
N	5	30	88	98	102	63	63	14	12	5	1		481
Empty	0	2	11	7	7	5	1	1	0	1	0		35
Percent empty	0	6.7	12.5	7.1	6.9	7.9	1.6	7.1	0	20	0		
x̄	3.7	8.6	12.0	15.9	37.0	50.8	77.1	19.4	199.1	86.3			
s	3.5	24.2	30.6	30.7	62.4	77.9	126.0	19.9	376.3	114.6			
C (percent)	94.1	281.4	255.0	193.1	168.6	153.3	163.4	102.6	189.0	132.8			
Pole-and-line caught:													
N		13	47	141	26	8	40	18	10	1	1		305
Empty		9	11	35	1	1	1	1	1	1	0		61
Percent empty		79.2	23.4	24.8	3.8	12.5	2.5	5.6	10.0	100.0	0		
x̄		0.8	35.0	30.3	60.9	51.6	35.5	42.7	76.3				
s		1.5	57.2	44.2	62.3	47.1	30.4	32.8	77.8				
C (percent)		187.5	163.4	145.9	102.3	91.3	85.6	76.8	102.0				
Longline caught:													
N					4	12	25	43	98	96	27	6	311
Empty					0	0	2	2	1	0	0	0	5
Percent empty					0	0	8.0	4.7	1.0	0	0	0	
x̄					12.9	29.2	61.7	62.2	72.5	92.7	85.8	44.2	
s					4.7	35.2	79.9	145.5	108.3	125.5	75.2	12.8	
C (percent)					36.4	120.5	129.5	233.9	149.4	135.4	87.6	29.0	
All methods combined:													
N	5	43	135	239	132	83	128	75	120	1u2	29	6	1,097
Empty	0	11	22	42	8	6	4	4	2	2	0	0	101
Percent empty	0	25.6	16.3	17.6	6.1	7.2	3.1	5.7	1.7	2.0	0	0	
x̄	3.7	6.2	20.0	24.4	41.0	47.7	61.1	49.5	85.5	91.5	89.9	44.2	
s	3.5	19.1	43.1	39.8	62.1	70.7	97.8	112.3	156.7	124.2	78.3	12.8	
C (percent)	94.1	308.1	215.5	163.1	151.5	148.2	160.1	226.9	183.3	135.7	87.1	29.0	

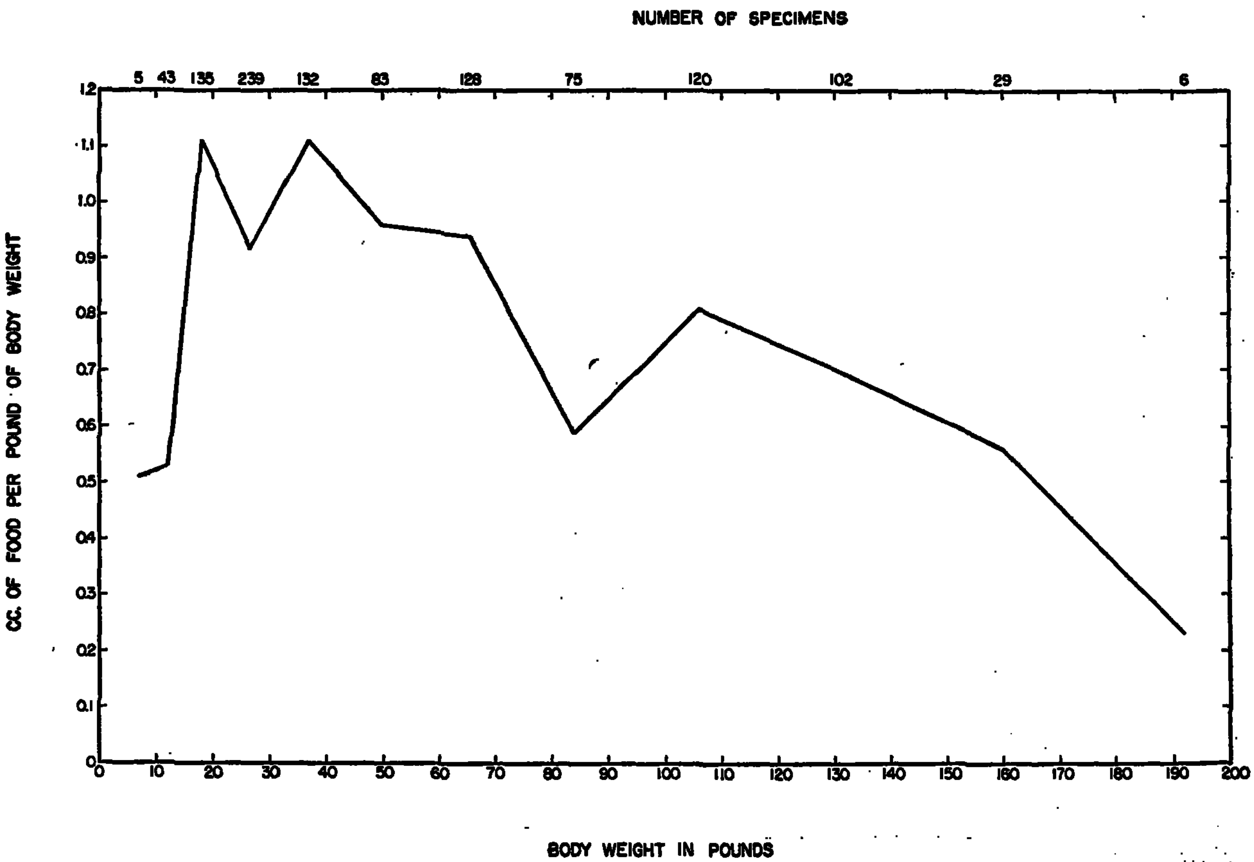

Figure 5.—Relation of stomach contents per unit body weight (cc./lb.) to body weight of 1,097 yellowfin tuna.

To investigate differences between localities, we may compare the food of yellowfin of 1,000 to 1,299 mm. fork length (approximately 43 to 92 lb.), captured in the Line Islands, with the food of a group of the same size range from the Phoenix Islands. In figure 6, we used average volume per stomach for each of the major food groups as an index to the availability of those organisms in each locality. As shown in figure 6, the most apparent locality differences lay in the proportionately greater average volume of crab larvae (megalops) found in the Line Island yellowfin, at least in respect to the surface-caught fish, and the greater average volume of fish in the Phoenix Island yellowfin. During the 2-year period covered by this study, we failed to encounter in the Phoenix Islands any swarms of crab larvae such as occurred in the Line Islands during May and June, 1950 and 1951. The data indicate that locality differences may be of considerable importance and should be considered in an evaluation of the food of the yellowfin.

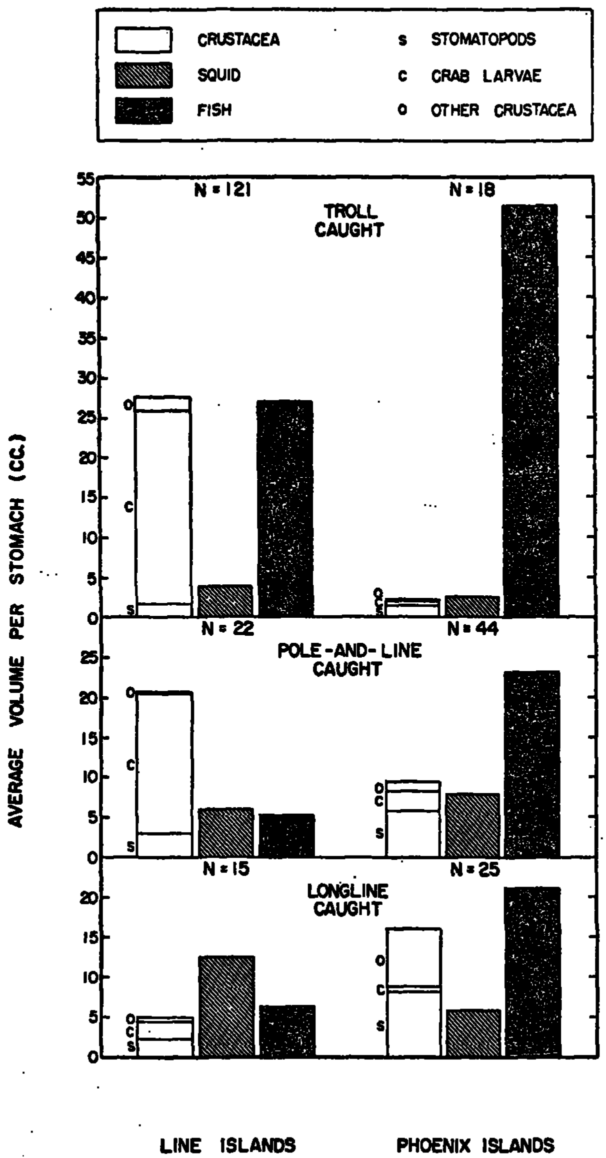

FIGURE 6.—Differences in availability of the major food categories between the Line and Phoenix Islands, as indicated by average volume per stomach, for yellowfin 1,000 to 1,299 mm. fork length. The troll- and pole-and-line-caught fish were captured within 10 miles of land; the longline fish within 25 miles of land. N = number of stomachs.

Not only are differences in the availability of food organisms between localities evident (fig. 6), but also between lots of fish taken by different fishing methods, i. e., fish from different habitats or depths within an area. To examine the influence of habitat on the composition of the food, we may compare the same six lots of fish, using the percentage of total volume as a measure of importance for each food group (fig. 7). The localities were treated separately, since we had found that locality differences did exist. Figure 7 indicates that there was great variation in food composition between similar habitats from different localities, and also for different habitats within localities. The only apparent consistent relationship is that the proportion of stomatopods was higher in the subsurface-caught (longline) fish than in the surface-caught (troll and pole-and-line) fish.

Figure 8 demonstrates the variation in availability of the major food groups in relation to distance the tuna was captured from land. Since fish taken at the surface came almost entirely from inshore regions, the major data available for this comparison are those from the longline-caught fish. For both size groups of yellowfin, 1,299 mm. or less and 1,300 mm. or more, the average volume of crustacea per stomach was much greater for the fish taken near land (0 to 24 miles from shore) than for those from offshore areas. The crustacean fraction changed not only in its average volume, but also in its composition; i. e., for the near-shore region it was composed predominantly of crab and stomatopod larvae, whereas for the offshore region it consisted of pelagic amphipods and shrimps. Squid and fish were staple foods in all environments, although the former was consistently higher in average volume in the larger yellowfin.

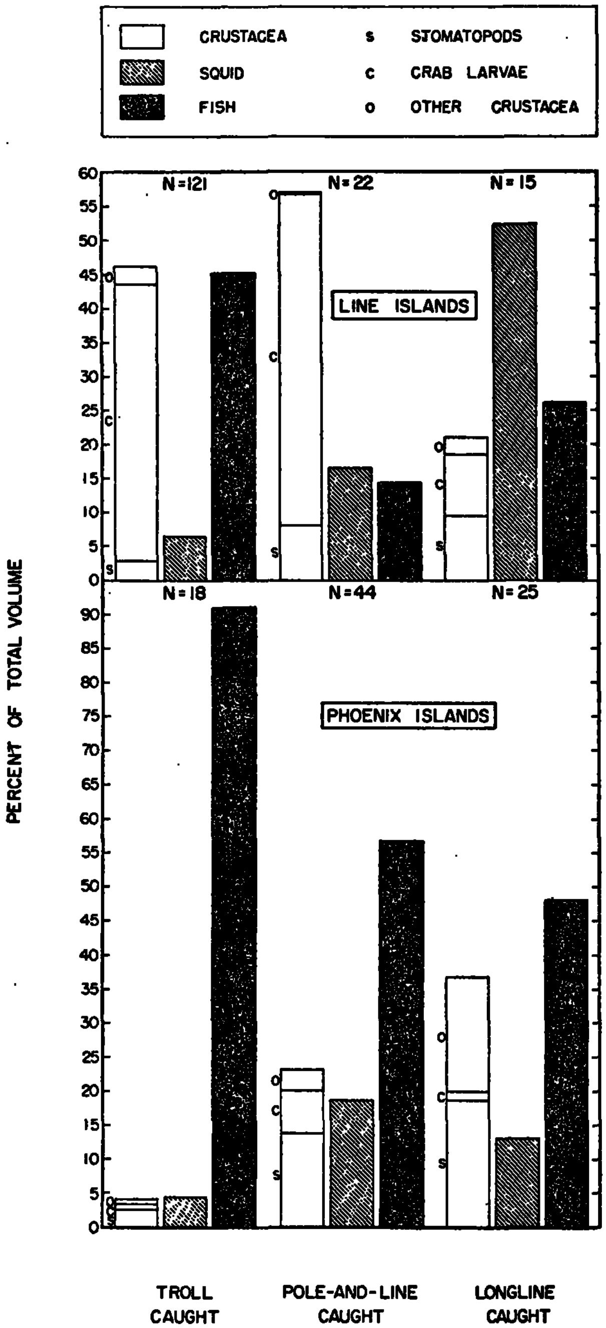

FIGURE 7.—Differences in the composition of the food of yellowfin (1,000–1,299 mm. fork length) with method of capture, for two general localities. The troll- and pole-and-line-caught fish were captured within 10 miles of land, the longline-caught fish within 25 miles of land. N=number of stomachs.

As in the crustacea, there were differences in the kinds of fish found in the food of yellowfin from different environments. Fish families commonly occurring in stomachs of the near-shore yellowfin were Balistidae, Acanthuridae, and Carangidae. For the offshore yellowfin, representatives of Bramidae, Exocoetidae, and Gempylidae were more prevalent in the food. The food of 11 troll-caught yellowfin captured more than 10 miles from land consisted of 57 percent fish, 42 percent squid, and about 1 percent crustacea, the average volumes per stomach being, respectively, 32.3, 23.8, and 0.6 cc.

From the beginning of the study it was obvious that not only the volume of stomach contents but also the composition of the food varied with the size of the yellowfin. While the same foods were eaten by both large and small tuna, they were not consumed in the same proportions. Since large, medium, and small yellowfin were taken by surface fishing from the same coastal areas, we assume that they had equal opportunity to feed on a common source of food organisms. The differences in stomach contents may be due either to a change in food preference or to the ability to catch and swallow certain organisms as the tuna increases in size. Figure 9 shows the variation in the three major food categories with increase in size of yellowfin. The most marked differences are the low percentage of crustacea and the high percentage of fish in the large surface-caught yellowfin, and the apparently greater importance of squid in the food of small and medium-sized yellowfin. As all but 2 percent of the surface-caught fish were taken less than 10 miles from land, the variation in the size of the yellowfin tuna captured appears to be the greatest variable. Table 6 summarizes the stomach contents of 775 of the 781 fish taken by surface fishing. The data arranged in arbitrary size categories show that the stomachs of the smaller fish contained more crustacean elements and fewer fish than did those of the larger specimens. Squid are a relatively unimportant fraction in all sizes of fish caught near land at the surface. On the other hand, longline-caught (subsurface) yellowfin tuna were mostly larger fish and showed little variation in size; however, the locality of capture, in reference to distance from land, did vary greatly. Table 7 summarizes the stomach contents of 311 fish taken well below the surface by longline fishing.

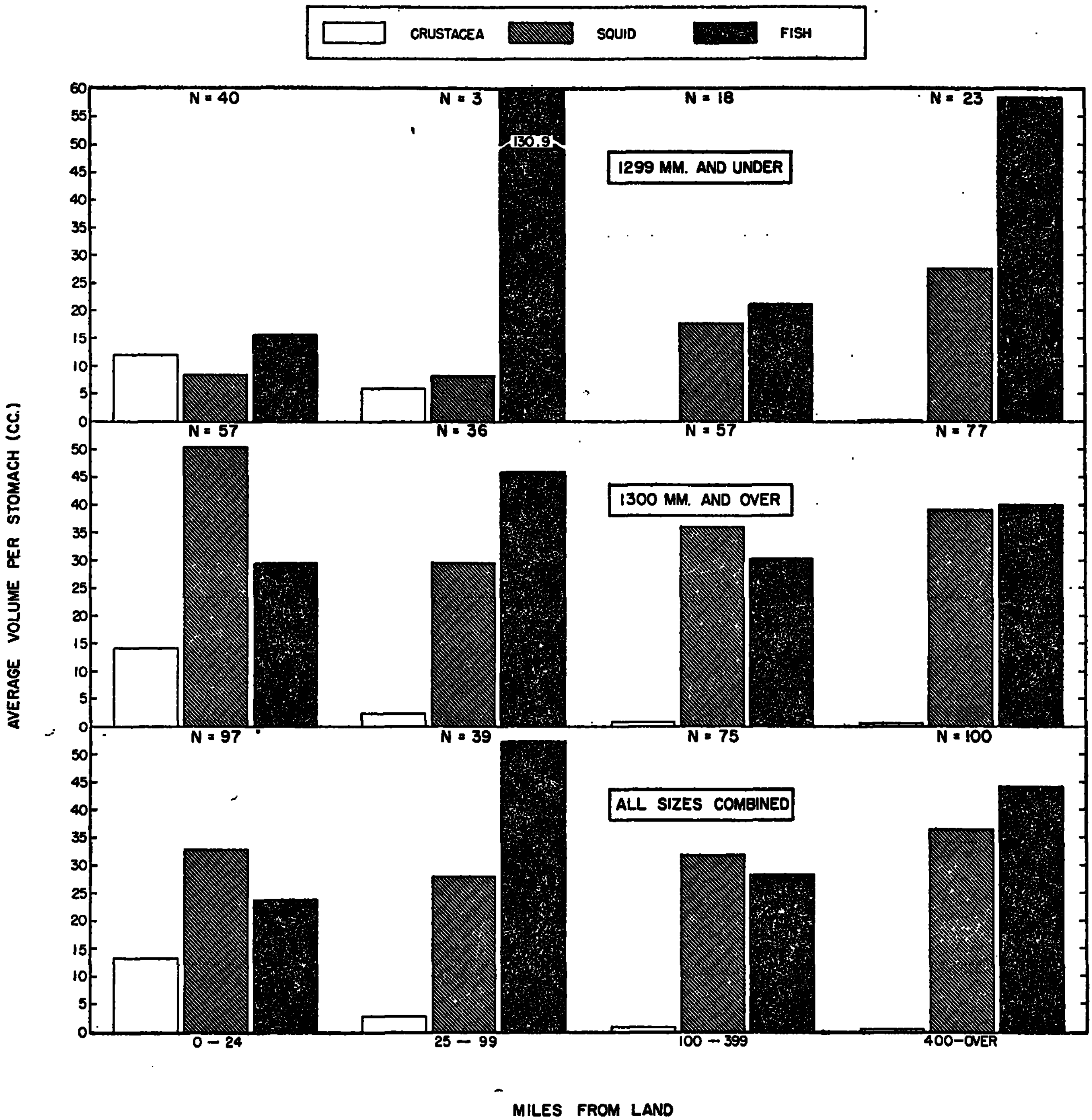

FIGURE 8.—Variation in availability of the major food categories with distance from land, for longline-caught yellowfin, as indicated by average volume per stomach. N=number of stomachs.

Relation of volume of stomach contents to oceanographic conditions

On cruise 11 of the *Hugh M. Smith,* longline fishing was conducted at a series of stations along 150° W. longitude, ranging from about 15° N. to 5° S. latitude. A single oblique plankton haul to a depth of 200 meters was made daily at each station. The volume of zooplankton at each station, expressed in cubic centimeters for each cubic meter of water strained, and the catch of yellowfin per 100 hooks fished at each station are given in figure 10. For purposes of comparison the cruise area may be divided into (1) An area of poor tuna catch, north of 6° N. latitude; (2) an area of good tuna catch at 6° to 4° N. latitude; (3) another area of good catch at 3° to

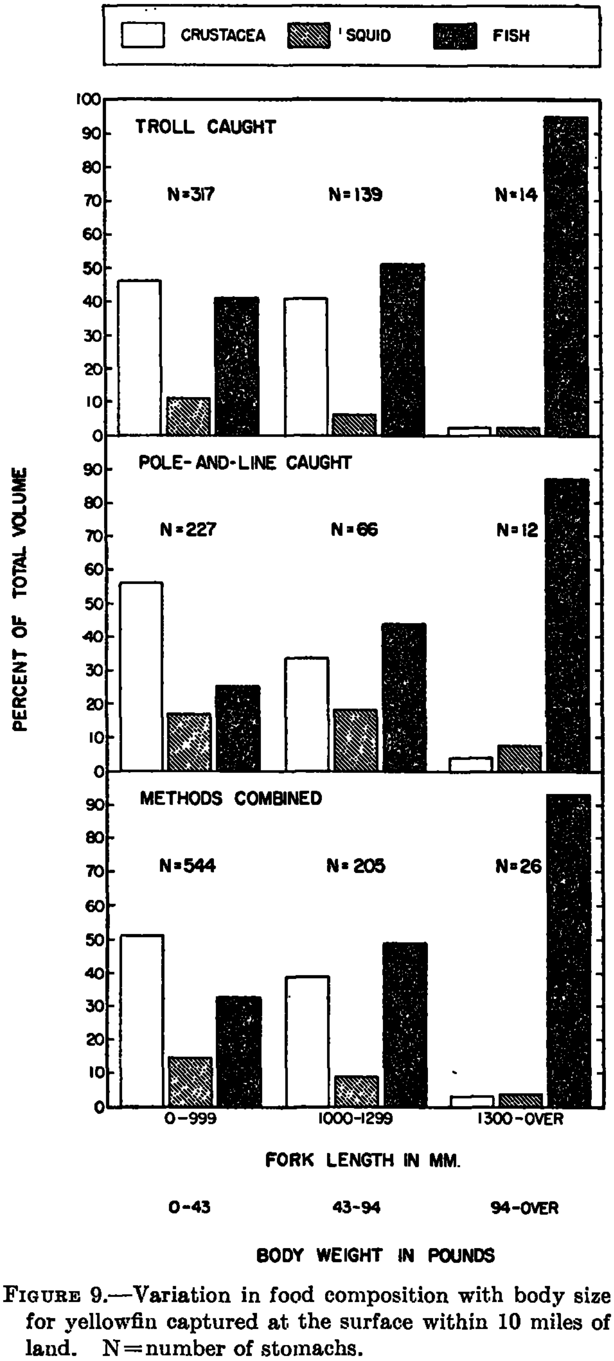

FIGURE 9.—Variation in food composition with body size for yellowfin captured at the surface within 10 miles of land. N=number of stomachs.

1° N. latitude; and (4) an area of poor catch, from the Equator to 5° S. latitude. Fishing was done at stations 1 and 3, but no yellowfin were captured. The number of yellowfin captured in each of these areas, the number of stomachs examined, and the average volume of food in each stomach are shown in figure 10.

North of the Equator the yellowfin catch varied generally with zooplankton volumes, but south of the Equator the catch dropped off markedly while the zooplankton population persisted at a relatively high level. The few yellowfin captured south of the Equator were well fed, however, as indicated by the relatively high volume of food found in their stomachs.

Previous cruises of the *Hugh M. Smith* have demonstrated the existence of a "rich zone" in the region of the Equator that has been considerably higher in chemical nutrients and zooplankton than waters to the north or south (Cromwell 1951, King and Demond 1953). On most crossings of the equatorial region, the rich zone was found between the Equator and 4° to 5° N. latitude. On occasion, however, perhaps because of certain peculiar conditions of winds and currents, the rich zone was found to be displaced three or four degrees to the southward with the general pattern of relative zooplankton distribution remaining as in figure 10. It may be that for the greater part of the year the region of greatest productivity conforms more nearly to the distribution of the yellowfin catch of cruise 11 than to the distribution of zooplankton abundance. The latter may be more transitory in position than the fish population.

DISCUSSION

The 1,097 yellowfin upon which this study is based represent slightly more than 20 percent of all yellowfin captured during experimental and exploratory fishing in 1950 and 1951 by vessels of the Pacific Oceanic Fishery Investigations. The fish were captured by three standard commercial fishing methods: longline or flagline fishing, pole-and-line fishing with live bait, and surface trolling with artificial lures. The yellowfin caught on longlines averaged approximately 125 pounds in weight and were captured well below the surface both near and away from land; the fish caught by pole-and-line were taken near shore at the surface and averaged less than 30 pounds; and the fish caught by trolling were all taken at the surface, most of them near shore (less than 2 percent were taken more than 10 miles from land), and averaged approximately 30 pounds.

There are two possible explanations for this marked variation in results obtained by the different fishing methods. First, the fishing methods

TABLE 6.—*Surface-caught yellowfin tuna, localities combined: stomach-content analysis of 775 fish*

Fork length and method of capture	Number of stomachs	Stomatopods		Crab larvae		Other crustaceans		Squid		Other molluscs		Tunicates		Fish	
		Average volume (cc.)	Percent of total volume	Average volume (cc.)	Percent of total volume	Average volume (cc.)	Percent of total volume	Average volume (cc.)	Percent of total volume	Average volume (cc.)	Percent of total volume	Average volume (cc.)	Percent of total volume	Average volume (cc.)	Percent of total volume
Less than 1,000 mm.:															
Trolling	317	2.2	11.1	6.0	29.7	1.0	5.2	2.3	11.2	0.1	0.7	0.2	0.9	8.3	41.2
Pole-and-line	227	2.1	6.4	16.0	48.5	.3	.1	5.6	17.1	.5	1.5	.1	.2	8.3	25.3
Combined	544	2.2	2.2	8.6	39.8	.7	2.9	3.7	14.4	.3	1.1	.1	.2	8.3	32.6
1,000 to 1,299 mm.:															
Trolling	139	1.6	2.7	21.2	35.7	1.5	2.5	3.7	6.3	.2	.4	.8	1.4	30.2	50.9
Pole-and-line	66	4.8	12.2	7.5	19.1	.9	2.3	7.1	18.1	1.5	3.9	.3	.7	17.2	43.7
Combined	205	2.6	5.0	16.8	31.7	1.3	2.5	4.8	9.1	.7	1.3	.6	1.2	26.0	49.2
Over 1,300 mm.:															
Trolling	14	.6	.3	4.1	2.1	---	---	4.9	2.5	---	---	.7	.4	187.4	94.8
Pole-and-line	12	1.4	2.1	.5	.8	.9	1.4	5.2	7.6	.4	.6	.1	.2	59.2	87.3
Combined	26	1.0	.7	2.4	1.8	.4	.3	5.0	3.6	.2	.1	.4	.3	128.2	93.1

TABLE 7.—*Subsurface-caught yellowfin tuna, size groups combined: stomach-content analysis of 311 fish*

Distance from land	Number of stomachs	Stomatopods		Crab larvae		Other crustaceans		Squid		Other molluscs		Tunicates		Fish	
		Average volume (cc.)	Percent of total volume	Average volume (cc.)	Percent of total volume	Average volume (cc.)	Percent of total volume	Average volume (cc.)	Percent of total volume	Average volume (cc.)	Percent of total volume	Average volume (cc.)	Percent of total volume	Average volume (cc.)	Percent of total volume
0 to 24 miles	97	6.5	9.1	2.9	4.1	3.9	5.5	33.1	46.1	0.8	1.2	0.6	0.8	23.8	33.3
25 to 99 miles	39	.2	.2	---	---	2.5	3.0	28.1	33.4	.4	.5	.3	.4	52.4	62.4
100 to 399 miles	75	.1	.2	.1	.1	.5	.8	31.9	51.2	1.2	1.9	.1	.2	28.3	45.5
400 miles and over	100	---	---	.3	.4	.2	.2	36.5	42.9	3.8	4.4	.1	.1	44.2	52.0

as employed by our vessels may be selective. Surface trolling and live-bait fishing appear to be more effective near land than away from land, and in the central Pacific they take small and medium-sized fish. Longline fishing, in contrast, is effective both near and away from land, but the catch is composed almost exclusively of medium-sized and large fish. On the other hand, the distribution of the fish may actually be in accordance with the catch; i. e., large fish scarce in surface waters both offshore and near shore but more abundant at subsurface levels; small fish occurring most abundantly in surface waters near shore, uncommonly in surface waters offshore, and rarely in subsurface waters, whether offshore or near shore; and medium-sized fish existing throughout the ranges of both the smaller and the larger fish.

As the collection of stomach material was just one of several objectives of each fishing cruise, it was not possible to schedule the trips so as to yield samples evenly distributed in time for each major area and habitat. For example, pole-and-line fishing was conducted only during January and July 1950 and June 1951. Longline fishing was done near Canton Island (Phoenix Group) in July 1950, and in the general area of the Line Islands in November 1950 and September 1951. Surface trolling was done on all cruises but, as previously stated, yielded few fish from waters 10 miles or more from land. It is apparent, therefore, that while our samples were rather homogeneous within themselves, they differed in time and area of capture, habitat, average size, and in other ways. Consequently any comparisons between different lots of fish must be qualified with respect to these different factors.

According to Ricker (1946), fish are usually classified as bottom feeders, plankton eaters, or fish eaters. From the results of this study it is apparent that maturing and adult yellowfin of the central Pacific feed on macrozooplankton, fish, and also pelagic cephalopods. In addition to the great variety in the food, it is surprising to discover that small organisms of 0.2 to 0.5 cc. in volume are regular prey of these large, fast-moving fish.

Since crustacean larvae were so prominent in the food of those small yellowfin sampled, the question arises as to whether the apparent greater

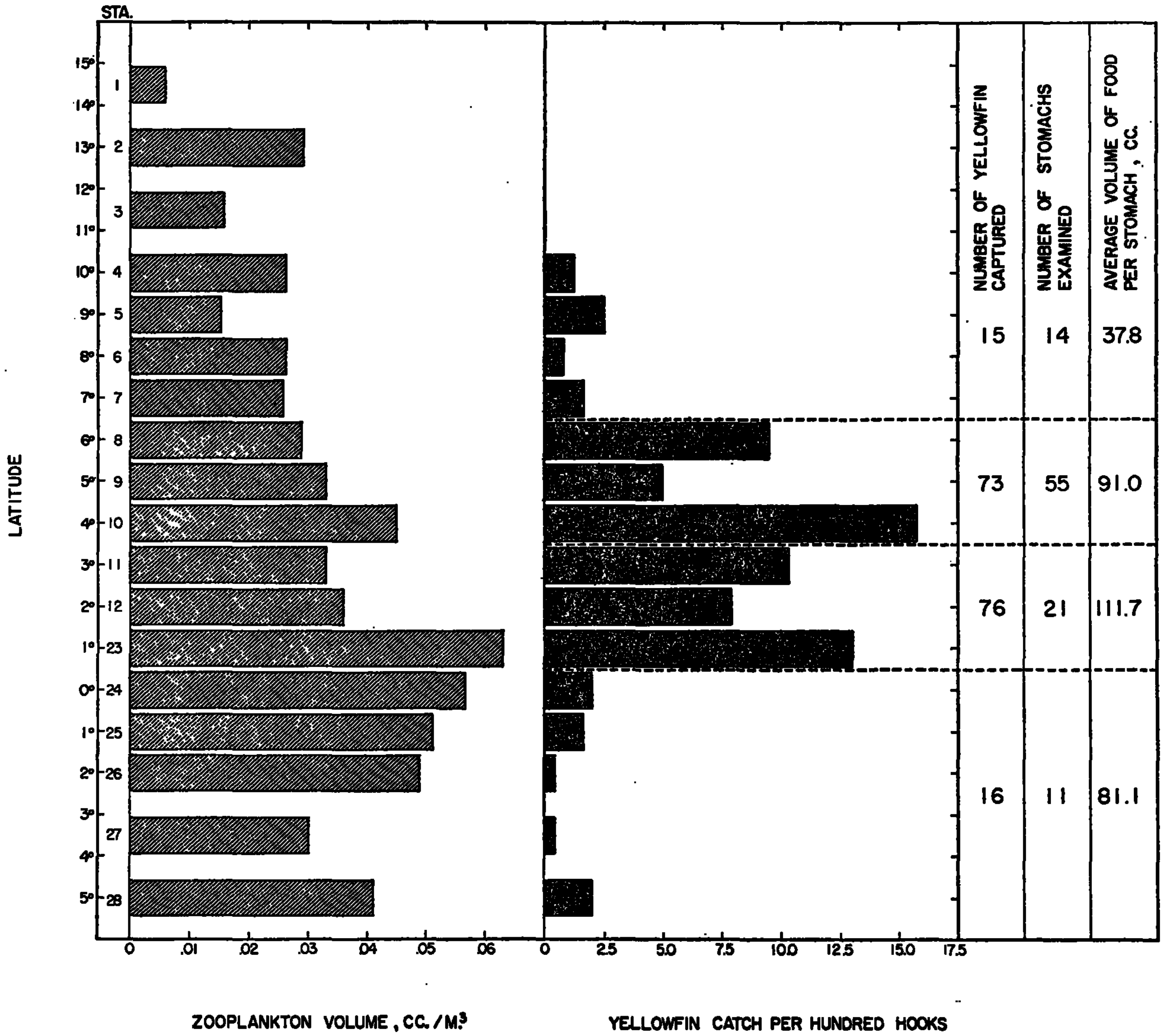

FIGURE 10.—Relation of zooplankton abundance, yellowfin catch per hundred hooks, and average volume of food per stomach as found on cruise 11 of the *Hugh M. Smith* along 150° W. longitude for the range of latitudes indicated.

abundance of these fish near land is related to the greater abundance of crustacean larvae in such areas. Is the distribution of the fish dependent upon the availability of these food elements? These questions cannot be answered from the results of this study, but they will be the objectives of future research.

Ricker (1946) states that with few exceptions large fish more often have empty stomachs than do smaller ones of the same species. Our observations (table 5) indicate that just the reverse may be true for the yellowfin. Ricker states also that the average stomach content per unit of body weight is less among large fish, which is in general agreement with the results of this investigation (fig. 5).

There is some evidence that the rate of feeding in fishes is directly proportional to the availability of food. Therefore, in view of the average fisherman's belief that more tuna "feed" is found near the reefs than offshore in the open ocean, it was surprising to find that for comparable size groups the fish taken offshore contained on the average the same quantity of food in their stomachs as the fish taken near land (table 7). Also, fish from the subsurface contained as much food as those from the surface.

Although we believe this report provides the most complete information available on the food of the yellowfin, the more important observations in other areas (Kishinouye (1917, 1923) for the Bonin Islands and general western Pacific; Nakamura (1936) for the Celebes Sea; Marukawa (1939) and Ban (1941) for the equatorial western Pacific; Kanamura and Yazaki (1940a, 1940b) and Ronquillo (1950) for the Philippines; Herald (1949) and Welsh (1949) for the eastern Pacific and Hawaiian Islands) and those reported here are in general agreement on the chief constituents of the food of the yellowfin. The number and kind of individual species listed may vary with the locality and the extensiveness of the work done. A summary of the species taken shows that yellowfin have an extremely varied diet and feed to a large extent not only on reef fauna but also on organisms of the open ocean, both plankton and nekton. Since most pelagic crustaceans, molluscs, and fish, within rather broad size limits, appear to be acceptable as food, the distribution and abundance of maturing and adult yellowfin are most probably not determined by the occurrence of specific food items, but rather are influenced by the total amount of food present in an area.

The food of juvenile yellowfin is yet to be investigated. Whereas the adults accept a wide variety of food, the juveniles may be more specific in their feeding habits. In such a case, the abundance of a particular food or foods could have an important influence on the survival and growth of the young. Few yellowfin less than 400 mm. (about 2.8 lb.) are taken by present fishing methods.

Also there remains the problem of evaluating the abundance of tuna food organisms in different areas and at different depths to determine which regions of the Pacific may potentially support the greatest populations of tuna. This phase of the problem, however, awaits the development of effective gear for quantitative sampling.

SUMMARY

1. This study is based on the quantitative analysis of the stomach contents of 1,097 yellowfin tuna (*Neothunnus macropterus*) taken in the central Pacific.
2. The fish were captured by three fishing methods, trolling, pole-and-line, and long-line, came from varying habitats, onshore and offshore, surface and subsurface, and were of different size groups.
3. The 1,097 stomachs contained a total volume of 52,336.1 cc. of food, of which 47 percent by volume was fish, 26 percent squid, and 25 percent crustaceans.
4. Yellowfin appear to accept a great variety of animal food, and take advantage of whatever is most plentiful in the area at the time.
5. They feed on very small plankton organisms as well as large squid and fish one-third the length of the tuna.
6. Yellowfin captured in the afternoon by trolling and live-bait fishing had more food in their stomachs and fewer empty stomachs than those captured in the morning; therefore, feeding must take place during daylight hours.
7. The yellowfin taken at the surface had been feeding primarily on crustacean larvae and fish, the fish taken beneath the surface on fish and squid.
8. The yellowfin taken near land had fed on fish, crustacean larvae, and squid; those caught away from land on fish and squid.
9. Small yellowfin fed preponderantly on crustacean larvae; medium-sized yellowfin fed on fish, crustacean larvae, and squid; while the large yellowfin fed mainly on fish and squid.
10. Yellowfin from offshore areas contained as much food in their stomachs as those captured just off the reef, and they fed at subsurface levels as well as at the surface.
11. The average volume of stomach contents was (cruise 11, *Hugh M. Smith*) roughly proportional to the concentration of zooplankton in the area in which the fish were captured, i. e., the yellowfin tuna captured in the rich zone near the Equator contained greater amounts of food—zooplankton, forage fish, and squid—than those captured at more northerly or southerly latitudes.
12. Further research is needed on the food of juvenile yellowfin; on the abundance of food organisms in different areas of the Pacific and at different seasons to determine

which areas may potentially be the most productive of tuna; and on the manner of distribution of tuna in relation to the distribution of available food.

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