SPATIAL AND TEMPORAL DISTRIBUTIONS OF JUVENILE TUNAS FROM STOMACHS OF TUNAS CAUGHT BY POLE-AND-LINE GEAR IN THE CENTRAL AND WESTERN PACIFIC OCEAN

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PREFACE

The Skipjack Survey and Assessment Programme was an externally funded part of the work programme of the South Pacific Commission. Governments which provided funding for the Programme were Australia, France, Japan, New Zealand, United Kingdom and the United States of America.

The Skipjack Programme has been succeeded by the Tuna and Billfish Programme which is receiving external funding from Australia, France, New Zealand and the United States of America. The Tuna Programme is designed to improve understanding of the status of the stocks of commercially important tuna and billfish species in the region. Publication of final results from the Skipjack Programme is continuing under the Tuna Programme.

The staff of the Programme at the time of preparation of this report comprised the Programme Co-ordinator, R.E. Kearney; Research Scientists, A.W. Argue, C.P. Ellway, R. Farman, R.D. Gillett, P. Kleiber, J.R. Sibert, W.A. Smith and M.J. Williams; Research Assistants, Susan Van Lopik and Veronica van Kouwen; and Programme Secretary, Carol Moulin.

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Tuna Programme
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ABSTRACT

New information on distribution and relative abundance of tuna juveniles in the central and western Pacific Ocean was obtained by examination of stomach contents from 12,135 tunas caught by pole-and-line gear between October 1977 and August 1980. Analyses focused on skipjack juveniles in adult skipjack stomachs, since skipjack accounted for over three-quarters of the samples of predators and prey. Two indices, percentage occurrence and number of juveniles per 100 predator stomachs, were assumed to measure relative abundance of juveniles. Three- and four-way G-tests of independence were used to examine variation in juvenile occurrence in predator stomachs with distance from land, time of day, season and geographical location from which predators were sampled.

Skipjack juveniles occurred in 4.5 per cent of stomachs of 8,175 adult skipjack from tropical waters, and in 2.0 per cent of 1,711 yellowfin stomachs from tropical waters. Other common species of juveniles were frigate tuna, albacore, and mackerel tuna; each occurred in less than one per cent of predator stomachs. Juvenile skipjack occurrence in adult skipjack stomachs was highest later in the day and further from land and there was evidence that skipjack juveniles form schools. Such distributions of juveniles were postulated to minimise mortality caused by surface-dwelling predators.

Skipjack juveniles were absent from samples of predator stomachs taken in subtropical waters, and were uncommon from samples of predator stomachs taken in the region of the north equatorial counter current and in the region of equatorial upwelling. Juvenile skipjack occurred most frequently in adult skipjack stomachs between October and March south of the Equator, and in two broad geographical areas, one including eastern French Polynesia and the other encompassing Papua New Guinea, Solomon Islands and Vanuatu. It was hypothesised that skipjack spawning activity in the study area was most intense in these months and areas.

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1.0 INTRODUCTION

Tuna juveniles and larvae are common in tropical surface waters of the Pacific Ocean, but for most tuna species they are uncommon polewards of the 24°C surface isotherm (Klawe 1963; Ueyanagi 1969; Yoshida 1971; Mori 1972). Knowledge of the general distribution of larval tuna in the Pacific, based on plankton net sampling, has been summarised by several authors (Matsumoto 1966; Nishikawa *et al.* 1978; Suzuki, Tomlinson and Honma 1978; Matsumoto and Skillman MS). There is, however, little published information on relative abundance of tuna early life-history stages, particularly in the central and western Pacific. For skipjack (*Katsuwonus pelamis*), this gap greatly limits the understanding of population structure and recruitment (Anon 1981; Skipjack Programme 1981).

Occurrence of juveniles in predator stomachs has been used in the past to infer distribution and relative abundance of juveniles within portions of the Skipjack Programme study area (Waldron and King 1963; Nakamura 1965a; Yoshida 1971; Mori 1972). The Skipjack Survey and Assessment Programme provided an opportunity to study distribution and relative abundance of juvenile tunas over a vast area of the central and western Pacific (Figure 1) through examination of juveniles found in stomach contents of tunas caught by pole-and-line gear.

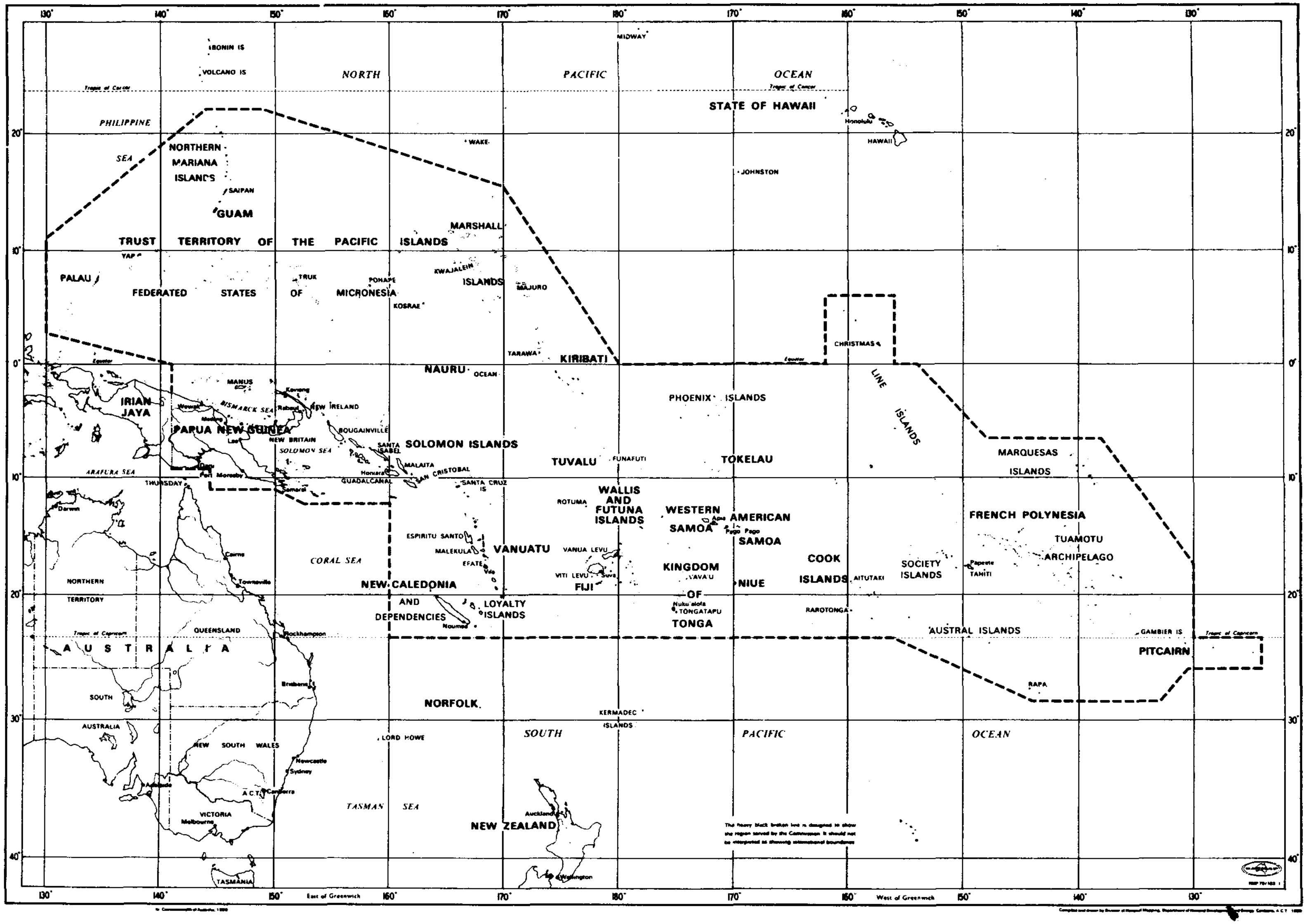
In this paper, general description of the total data set is followed by presentation of results from analyses of variation in the occurrence of tuna juveniles in predator stomachs with size of predators, distance from land, time of day, season and geographical location from which predators were sampled. These analyses concentrate on skipjack juveniles since this species accounted for over three-quarters of tuna juveniles found in the stomachs of predators. For the purpose of this study, predators are defined as those species caught by pole-and-line gear that were found to include tuna juveniles in their diet; and juveniles are defined as tuna from the post-larvae stage (10-12 mm total length) to 150 mm standard length (Matsumoto 1958; Mori 1972).

2.0 METHODS

2.1 Data Collection

Collection of juvenile tuna data was constrained by the objectives of the Skipjack Programme, particularly those pertaining to the distribution of tagging. Considerable effort was directed towards timing tagging activity and resource surveys within the waters of individual countries and territories to coincide with seasonal activity of locally based skipjack fisheries, or with any known or suspected period of higher skipjack abundance within countries and territories which did not have fisheries (Kearney 1982). The results presented in this report are from skipjack and other species, principally immature yellowfin tuna (*Thunnus albacares*), that were not tagged for various reasons such as hook injuries and excessive handling time.

FIGURE 1. THE AREA OF THE SOUTH PACIFIC COMMISSION. Sampling area of the Skipjack Programme included waters within the South Pacific Commission area, as well as waters within 200 miles of the coasts of the North Island of New Zealand, the east coast of Australia and the Bonin Islands of Japan.



Between October 1977 and August 1980 the Programme conducted three cruises, each of approximately 10 months' duration, using a live-bait pole-and-line vessel of Japanese registry. Appendix A gives the sequence of surveys to countries and territories for each cruise; Appendix B gives dates for each survey.

South of the Equator, samples were collected in every month except August and September; north of the Equator, samples were collected at the beginning (October, November) and end (July, August) of each cruise. Since the routes and timing of the three cruises were quite different, and there were only a few countries and territories that were surveyed during the same season on successive cruises, the juvenile tuna data were not examined for variability between years.

Argue (1982) detailed field methods used by the Skipjack Programme for collecting general biological data, for sampling of tuna juveniles, and for describing tuna schools. Stomachs from a maximum of twenty fish per species per school were examined for tuna juveniles. Other stomach contents from a maximum of five fish per species per school were classified, in the field, into broad, easily recognised taxonomic categories - generally to the family level for fish, and to the class or order level for invertebrates.

2.2 Identification of Tuna Juveniles

Tuna juvenile samples were accumulated on board the research vessel and were forwarded every two to three months to the Noumea laboratory of Office de la Recherche Scientifique et Technique Outre Mer (ORSTOM) where each specimen was measured (standard length) and identified to species, whenever possible. For damaged specimens, lengths were estimated to the nearest millimetre using one of the regression equations of Yoshida (1971), or in cases where this was impossible, a range in length was estimated from pieces of the vertebral column and skull.

Most of the characteristics used to identify tuna juveniles are based on the anatomy of the vertebral column as described by various authors, principally Nakamura (1965b), Gibbs and Collette (1967), Potthoff and Richards (1970), and Potthoff (1974). These features require careful use due to variation among individual specimens and due to the delicate nature of some body parts, particularly for specimens damaged by digestion. The use of alizarin dye, which stains bones red, was often helpful in exposing more obscure skeletal features (e.g. the haemal prezygapophysis). Whenever possible, several distinguishing characteristics were used in identification of juvenile specimens (Conand and Argue 1980).

Identification of tuna juveniles to the generic level is normally possible by following the above procedures (98 % of specimens identified to generic level); identification to the species level is also possible, but often difficult. For example, in the genus *Thunnus*, juvenile albacore (*T. alalunga*) can be readily distinguished from yellowfin (*T. albacares*) and bigeye (*T. obesus*), but separation of the latter two species of juveniles was not possible. Bigeye have been grouped with yellowfin in the present study, and all specimens of these species have been retained in the hope that separation will be possible at a later date. Identifications of several specimens of the major species were confirmed by Dr Shoji Ueyanagi, Far Seas Fisheries Research Laboratory, Japan Fisheries Agency.

2.3 Geographical Sample Grouping

During 30 months of field sampling there were 59 separate visits to countries, territories and subdivisions thereof. These are defined as "country visits" and number two or more for some countries and territories. Although samples were obtained from a broad expanse of the western and central Pacific Ocean, sample sizes were small within individual visits. Thus, to examine variation in the occurrence of tuna juveniles with respect to geographical location, season, time of day, and distance from land, it was necessary, for statistical purposes, to combine some individual country visits. Geographic and oceanographic criteria were the basis for combining country visits (Table 1) since such conditions might influence the occurrence of tuna juveniles.

2.4 Statistical Analyses

Two indices of juvenile occurrence in stomachs of predators, assumed to provide information on the relative abundance of tuna juveniles, were used in this study. The first index was the number of predators containing one or more identifiable tuna juvenile in their stomachs, expressed as a percentage of the number of predators whose stomachs were examined for tuna juveniles (percentage occurrence). The second index is based on the numbers of prey of a particular species that were found per 100 predator stomachs. Yoshida (1971) and Mori (1972) called this an index of "apparent abundance" of tuna juveniles in their analyses of skipjack from the stomachs of several tuna and billfish species. Both indices are conservative since an unknown, but presumably relatively constant proportion of tuna juveniles was overlooked due to the effects of digestion.

Statistical analyses of temporal and spatial variation in the occurrence of tuna juveniles were carried out on the presence-absence of juveniles (numbers of predator samples with or without juveniles), using three- and four-way G-tests of independence (Sokal and Rohlf 1969, p. 601). Predators with or without juveniles were classified according to the time of day, distance from land, season and geographical location (country group) of their capture. Chi-square tests were used for some comparisons among classifications.

Analyses of variance were used to compare the size of skipjack juveniles found in predator stomachs, among predator size groups, country groups, times of day and distances from land, and to compare variance in skipjack juvenile size among predators and within individual predators. Analyses excluded those juveniles for which only a range in length was available.

3.0 RESULTS AND DISCUSSION

3.1 The Total Data Set

During 30 months of fieldwork 12,135 stomachs from tunas and other predators were examined for tuna juveniles; 10,604 (87 %) of these samples were from fish taken in tropical waters (Table 2). For each country visit, sample sizes, by predator species, and numbers of tuna juveniles of each species that were found in the stomachs of predators are presented in Appendix B. Seventy-seven (77) per cent of the total of 1,346 juveniles

TABLE 1. GEOGRAPHICAL GROUPS OF COUNTRIES AND TERRITORIES IN TROPICAL WATERS

Group No.	Countries and Territories	Surface Oceanographic and Geographic Features*
1	Papua New Guinea Solomon Islands Vanuatu	Water temperature high; salinity low; large, high land masses; South Equatorial Current
2	American Samoa Western Samoa Fiji Niue Wallis and Futuna Islands Tonga	Water temperature high; salinity moderate; high islands; South Equatorial Current
3	Southern Cook Islands Society Islands Tuamotu Islands	Water temperature high; salinity high; mostly small islands and atolls; South Equatorial Current
4	Marquesas Islands	Water temperature high; salinity high; small islands (some high)
5	Federated States of Micronesia Marshall Islands Northern Mariana Islands Palau	Water temperature high; salinity low; mixture of small islands (some high) and atolls; North Equatorial Countercurrent
6	Kiribati Nauru Tokelau Tuvalu Northern Cook Islands	Water temperature moderate; salinity high; atolls; equatorial upwelling region
7	Queensland New Caledonia	Strong seasonal variation in water temperature; salinity high; large land mass; Coral Sea
8	Gambier Islands Pitcairn Islands	Strong seasonal variation in water temperature; salinity moderate; small islands

* Average annual water temperature high...........~28.0°C to 30.0°C
Average annual water temperature moderate.......~25.0°C to 27.9°C
Average annual surface salinity high............greater than ~35.5‰
Average annual surface salinity moderate........~34.5‰ to 35.5‰
Average annual surface salinity low.............less than ~34.5‰

TABLE 2. NUMBERS AND INCIDENCE OF TUNA JUVENILES IN THE STOMACHS OF ALL PREDATORS SAMPLED FROM TROPICAL WATERS

Predator	Predators Examined for Full Stomach Content	Predators Examined for Tuna Juveniles	Prey Species	No. of Juveniles	Predators with Juveniles	Juveniles per 100 Predators	Percentage of Predators with Juveniles
Skipjack *Katsuwonus pelamis*	3896	8175	Skipjack	884	364	10.81	4.45
			Yellowfin/ Bigeye	17	14	0.21	0.17
			Mackerel Tuna	31	19	0.38	0.23
			Frigate Tuna	148	60	1.81	0.73
			Albacore	52	38	0.64	0.46
			Dogtooth Tuna	2	2	0.02	0.02
			Thunnus sp.	1	1	0.01	0.01
			Unidentified Tuna Juvenile	1	1	0.01	0.01
Yellowfin *Thunnus albacares*	1018	1711	Skipjack	122	34	7.13	1.99
			Yellowfin/ Bigeye	2	1	0.12	0.06
			Mackerel Tuna	30	2	1.75	0.12
			Frigate Tuna	20	3	1.17	0.18
			Thunnus sp.	1	1	0.06	0.06
Mackerel Tuna *Euthynnus affinis*	145	233	Mackerel Tuna	2	1	0.90	0.45
Frigate Tuna *Auxis thazard*	90	146	Skipjack	23	3	15.75	2.05
Dolphin Fish *Coryphaena hippurus*	31	33	Yellowfin/ Bigeye	7	3	21.21	9.09
Wahoo *Acanthocybium solandri*	2	2	Skipjack	2	1	100.00	50.00
			Albacore	1	1	50.00	50.00
Rainbow Runner *Elagatis bipinnulatus*	197	273					
Bigeye Tuna *Thunnus obesus*	17	17					
Dogtooth Tuna *Gymnosarda unicolor*	9	9					
Double Lined Mackerel *Grammatocynus bicarinatus*	7	7					
Spanish Mackerel *Scomberomorus commerson*	3	3					
Layang Scad *Decapterus macrosoma*	2	2					
White-spotted Triggerfish *Canthidermis rotundatus*	1	1					
Shark *Carcharinus* sp.	1	1					
Barracuda *Sphyraena* sp.	1	1					
TOTALS	5416	10604		1346			

were skipjack and 86 per cent of skipjack juveniles were from adult skipjack stomachs. Numbers of skipjack juveniles per 100 skipjack predators for each country visit are presented in Appendix C.

Tuna juveniles were absent from large samples of predator stomachs (1,511) taken in the subtropical waters of New Zealand, Norfolk Island, New South Wales and from a small sample (20) taken in waters near the Bonin Islands. In tropical waters, the number of skipjack juveniles per 100 skipjack predators ranged from high values of 25 to 50 in the Marquesas Islands, Vanuatu, and Wallis and Futuna, to values of zero to four in the region of the north equatorial counter current (Federated States of Micronesia, Marshall Islands, Northern Mariana Islands, Palau) and in the region of equatorial upwelling (Kiribati, Nauru, Tokelau, Tuvalu, northern Cook Islands) (see Appendix C).

Table 2 presents the numbers of tuna prey per 100 predators and the percentage occurrence of tuna prey for the total data set from tropical waters. Skipjack juveniles occurred more frequently than other species of juveniles in the stomachs of adult skipjack (4.5 % occurrence) and yellowfin (2.0 %). Frigate tuna (*Auxis thazard*) and albacore, the second and third most common species of tuna juvenile in skipjack, each occurred in less than one per cent of skipjack stomachs. Juvenile albacore were not widespread (Appendix B), occurring principally in two areas - Tuamotu Islands and near Wallis Island.

Tuna juveniles were absent from the stomachs of all 273 rainbow runners (*Elagatis bipinnulatus*) examined, most of which were sampled from locations where juveniles were common in the stomachs of other predators.

Except where noted, analyses that follow omit the subtropical predator samples.

3.1.1 Size of predators examined for tuna juveniles

Predator length frequency distributions in Figure 2 show the size range and average length for those fish from tropical waters that were examined for juveniles. Frigate tuna were the smallest of the predators examined, and as with skipjack, their size frequency distribution was quite narrow. Yellowfin, rainbow runners and dolphin fish (*Coryphaena hippurus*) were larger and were sampled over a greater range of lengths. The size distributions under-represent, to varying degrees, the small and large predators of each species due to size-selective properties of the pole-and-line fishing technique, and due to differing accessibility of predator size classes to pole-and-line gear.

3.1.2 Size of tuna juveniles

Tuna juveniles ranged in standard length from 15 to 240 mm and averaged 69 mm in length (Figure 3, lower right graph). Less than two per cent were greater than the arbitrary 150 mm upper size limit which Mori (1972) used to separate juvenile and young tuna. Size distributions for juveniles of each species had large variances, and were skewed to the right (Figure 3); generally the distributions were quite similar in shape. Modal lengths ranged from 35 mm for skipjack to 85 mm for albacore. During the two visits to French Polynesia, large numbers of small skipjack juveniles (20 to 40 mm) were found in predator stomachs. Exclusion of these samples shifted the modal length for skipjack juveniles from 35 to 75 mm. The sharp declines in numbers of juveniles to the left of the modal lengths for

FIGURE 2. SIZE FREQUENCY DISTRIBUTIONS OF TUNAS AND OTHER SPECIES THAT WERE EXAMINED FOR TUNA JUVENILES. Mean fork length, standard deviation of the mean (SD) and sample size (N) indicated on each graph.

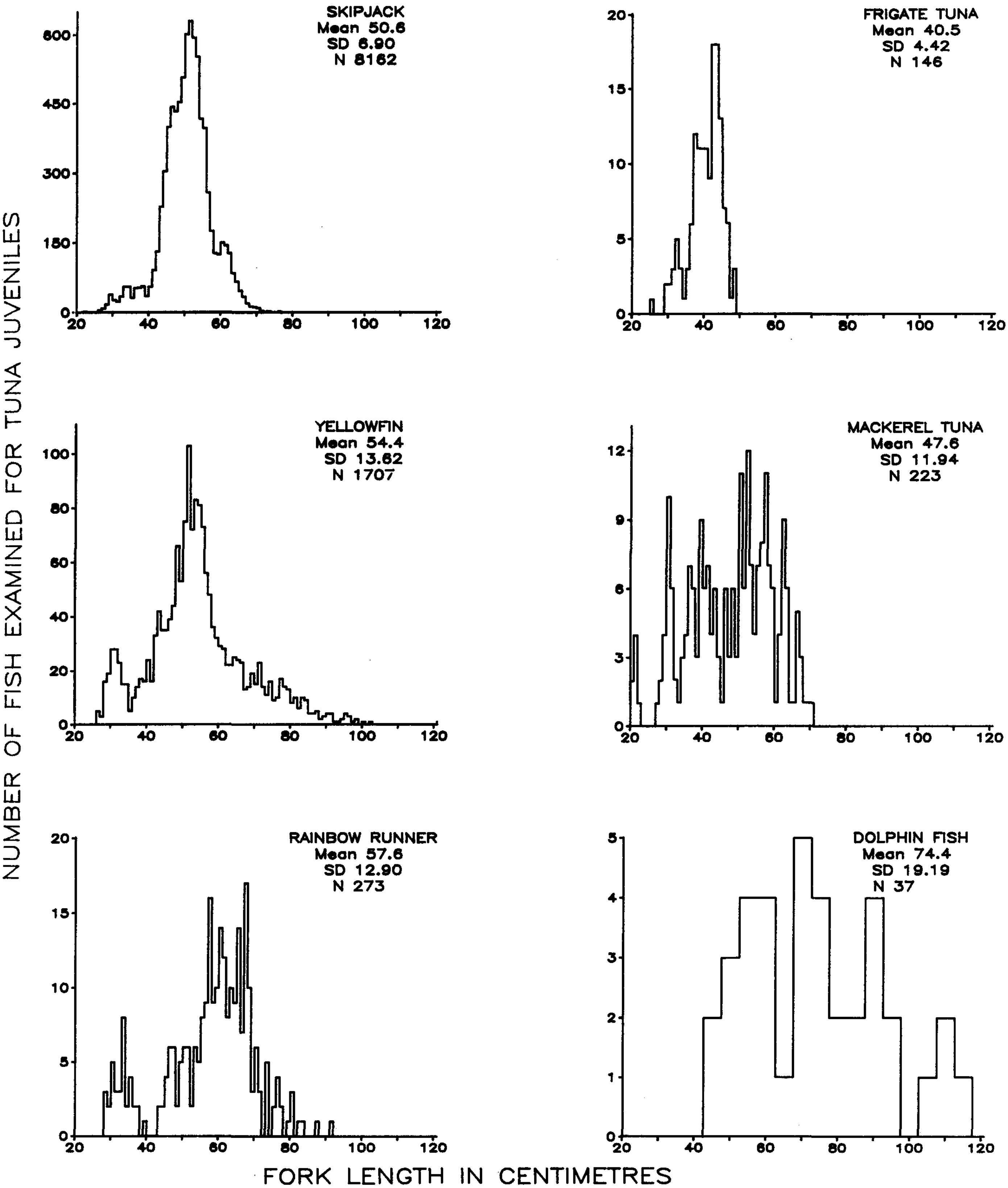
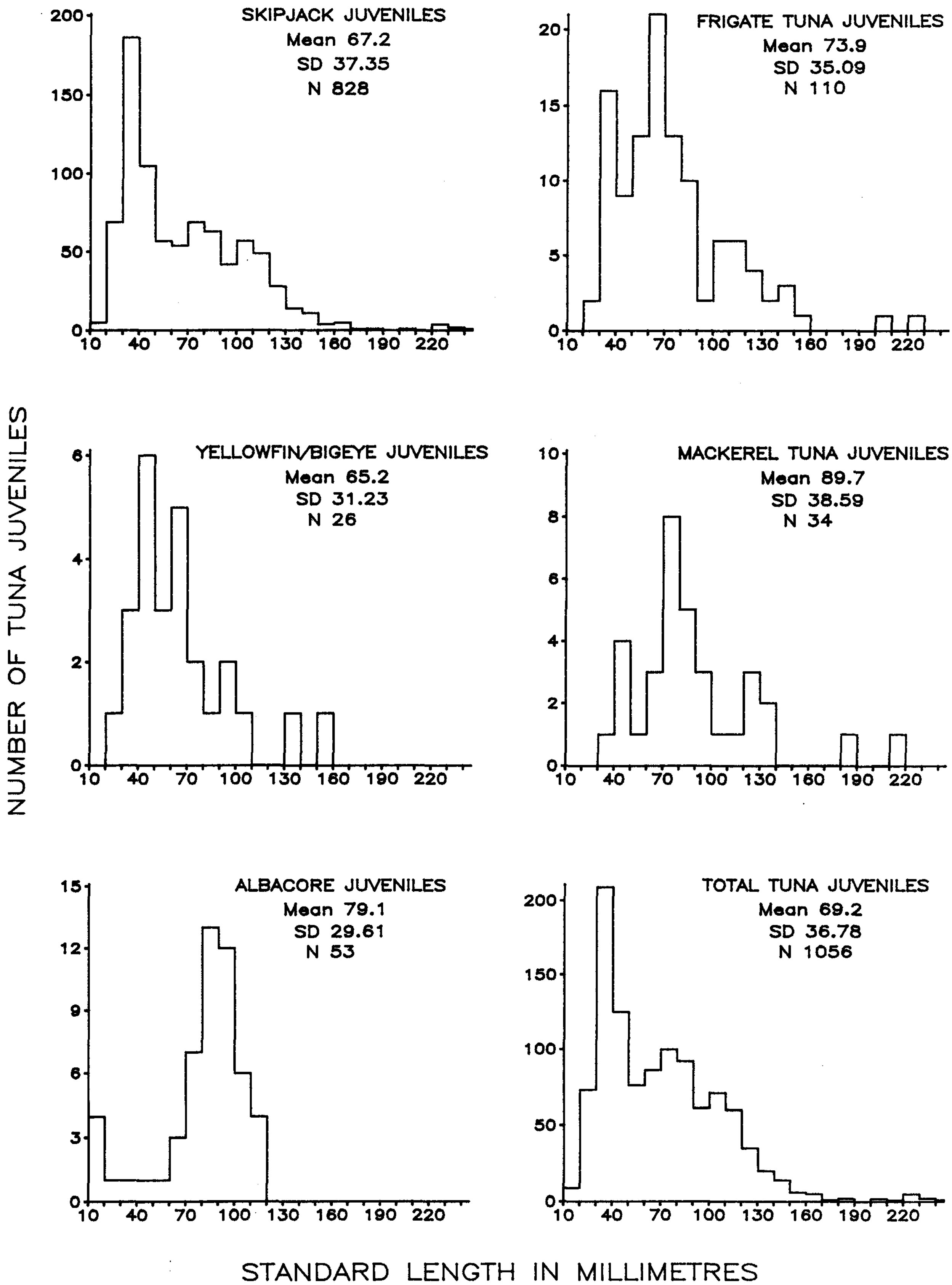


FIGURE 3. SIZE FREQUENCY DISTRIBUTIONS OF TUNA JUVENILES FROM THE STOMACHS OF ALL SPECIES THAT WERE EXAMINED FOR TUNA JUVENILES. Mean standard length, standard deviation of the mean (SD) and sample size (N) indicated on each graph.



each prey species were probably due to the combined effects of size-selective feeding by predators, and rapid digestion of small prey beyond recognition at time of sampling. The more gradual decrease in numbers of juveniles to the right of the modes was probably due to a combination of size-selective feeding by predators, increased capacity of larger prey to escape predators, and reduced abundance and availability of larger individuals.

3.1.3 Species composition of tuna juveniles

For skipjack predators, the overall ratio of skipjack juveniles to other species of juveniles was 3.5:1, and the ratio of skipjack juveniles to yellowfin/bigeye juveniles was 52:1 (Table 2). The latter ratio is much higher than the ratios of 4:1 or less reported by Matsumoto (1966) and Higgins (1970) for larvae and very small juveniles of these species sampled with plankton and midwater trawl gear from Hawaiian waters, and for larvae sampled with plankton gear from Marquesas Islands waters (Nakamura and Matsumoto 1967) and from the much larger Indo-Pacific region (Ueyanagi 1969). However, it is closer to the ratio of 24:1 reported by Waldron and King (1963) for juveniles from the stomachs of skipjack sampled from central Pacific waters. It is possible that skipjack exhibit a feeding preference for their own juveniles. It is also possible that between the larval and juvenile stages, availability or abundance of yellowfin/bigeye may decrease substantially compared to that for skipjack.

3.2 Size-Selective Predation

Previous investigations of skipjack diet in the waters of the Hawaiian islands (Yuen 1959; Waldron and King 1963) and Marquesas Islands (Nakamura 1965a) showed that the percentage occurrence and volume of fish in skipjack stomach contents increased with increased skipjack size. Figure 4 suggests a similar positive relationship between size of skipjack predators and both numbers of skipjack juveniles per 100 predators (upper graph) and percentage occurrence of skipjack juveniles (middle graph). Based on t-tests, slopes for linear regressions of these juvenile occurrence indices on predator length were all significantly greater than zero ($p<0.05$). Numbers of skipjack prey per predator with prey (lower graph) ranged between one and four over most of the predator size range. Yellowfin predators, covering a broader size range than skipjack, had similar relationships between juvenile skipjack occurrence indices and predator size (Figure 5).

Closer inspection of Figures 4 and 5 suggests that the two indices, prey per 100 predators and percentage occurrence, were relatively constant for predators in the size range of approximately 42 to 59 cm. Within this size range, slopes for linear regressions were not significantly different from zero ($p>0.10$). Therefore, to minimise variability in occurrence indices due to size-selective predation, predators outside the length range 42 to 58.9 cm were excluded, except where noted, from remaining analyses. This adjustment or filter for suspected size-selective predation was the simplest method to minimise a potential source of bias and still maintain sufficient samples (8,018 of 10,604 predators) for remaining analyses.

3.3 Temporal and Spatial Variation in Tuna Juvenile Abundance

3.3.1 Seasons

In a preliminary report, Conand and Argue (1980) suggested that

FIGURE 4. SKIPJACK JUVENILE PREY PER 100 PREDATOR STOMACHS (upper graph), PERCENTAGE OCCURRENCE (middle graph) AND AVERAGE NUMBERS OF SKIPJACK JUVENILES PER PREDATOR WITH SUCH JUVENILES (lower graph) FOR SKIPJACK PREDATORS IN ONE-CENTIMETRE LENGTH INTERVALS. Predator sample sizes ≥40 per size interval; points omitted for intervals with no samples.

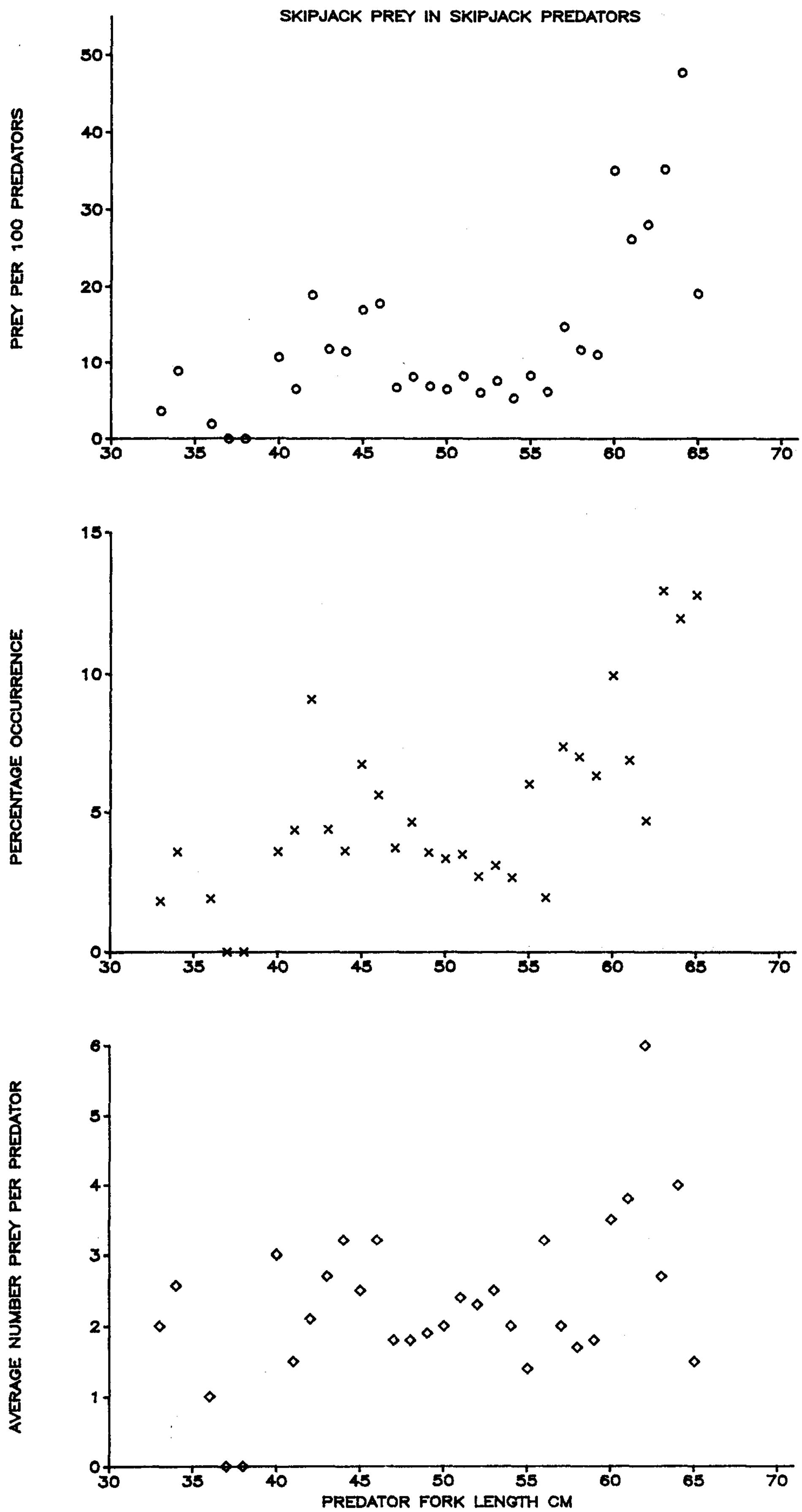


FIGURE 5. SKIPJACK JUVENILE PREY PER 100 PREDATOR STOMACHS (upper graph), PERCENTAGE OCCURRENCE (middle graph) AND AVERAGE NUMBERS OF SKIPJACK JUVENILES PER PREDATOR WITH SUCH JUVENILES (lower graph) FOR YELLOWFIN PREDATORS IN FIVE-CENTIMETRE LENGTH INTERVALS. Predator sample sizes ≥ 10 per size interval.

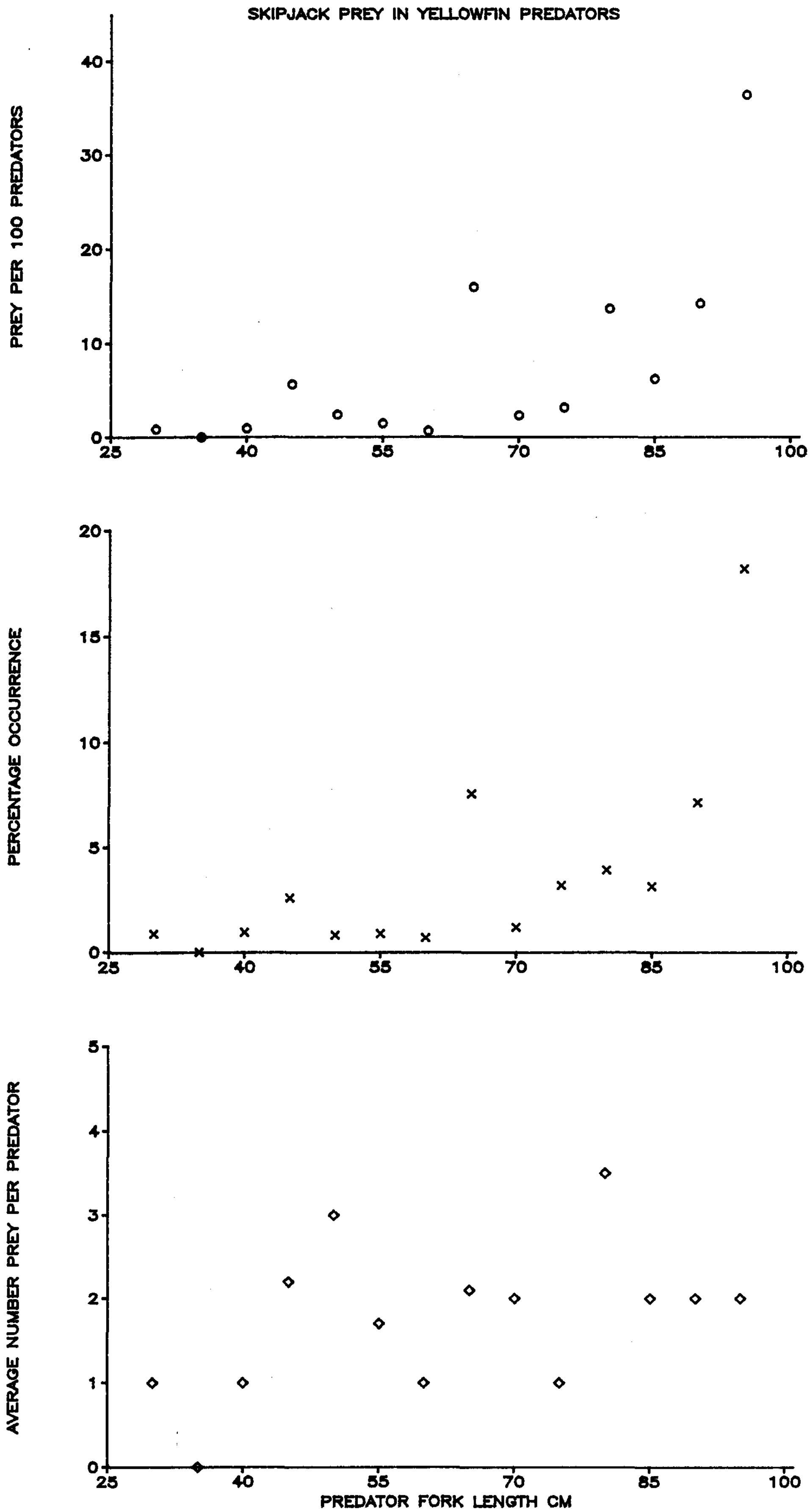


TABLE 3. PREY PER 100 PREDATOR STOMACHS AND PERCENTAGE OCCURRENCE OF SKIPJACK JUVENILES IN SKIPJACK PREDATORS FOR THREE-MONTH PERIODS AND INTERVALS OF 12° OF LATITUDE. Skipjack less than 42 cm and greater than 58.9 cm excluded. N is the number of skipjack predators; % Occur. is the percentage of skipjack predators with skipjack prey.

Latitude	January/March			April/June			July/August*			October/December		
	N	Prey per 100 Predators	% Occur.	N	Prey per 100 Predators	% Occur.	N	Prey per 100 Predators	% Occur.	N	Prey per 100 Predators	% Occur.
24°00-35°59'N	0	-	-	0	-	-	0	-	-	20	-	-
12°00-23°59'N	34	-	-	0	-	-	0	-	-	0	-	-
00°00-11°59'N	0	-	-	0	-	-	297	0.67	0.34	198	1.52	1.01
00°00-11°59'S	856	7.24	5.25	1091	3.21	2.93	136	2.21	1.47	1132	24.21	7.86
12°00-23°59'S	1040	9.14	4.23	1219	5.33	2.38	0	-	-	644	10.40	5.12
24°00-35°59'S	462	0	0	448	0	0	0	-	-	0	-	-
36°00-44°59'S	247	0	0	98	0	0	0	-	-	0	-	-

* No samples taken during September.

seasonal differences in occurrence of skipjack juveniles in adult skipjack were not great between the Equator and 25°S. Data from November 1979 to the end of fieldwork in August 1980 are now included with those from the preliminary report, and are presented by three-month intervals and 12 degrees of latitude in Table 3. Samples were insufficient north of the Equator to examine seasonality in juvenile occurrence. Between the Equator and 24°S, skipjack juveniles were most common in adult diets between October and March. However, south of the Equator the survey vessels obtained samples from a large, diverse area, from Manus Island, Papua New Guinea in the west to Pitcairn Island in the east. Over this area there is geographical variation in surface water temperature and salinity, and timing of peak precipitation (Donguy and Henin 1976). Such environmental variability, coupled with unequal temporal distribution of samples (samples east of 150°W longitude all collected between December and February), could have given rise to the seasonal differences in juvenile occurrence observed in the total data set.

Surveys in the waters of Papua New Guinea, Solomon Islands, Queensland, New Caledonia, Vanuatu and Fiji took place during both October to March and April to August time periods, providing three data sets for smaller geographical areas with which to examine seasonal differences in the occurrence of juveniles (Table 4). For each data set, the incidence of skipjack juveniles in the October to March period was approximately double the incidence for the April to September period, although none of the individual differences was statistically significant based on chi-square tests. Results from a more powerful three-way G-test of independence (two time periods, three country groups and occurrence) showed that, collectively, the occurrence of skipjack juveniles was highest between October and March ($p<0.001$). The test for interaction was not significant. A similar period of peak occurrence for larger skipjack juveniles from the stomachs of billfishes, captured in southern tropical waters between 180° and 137°W, is suggested by data presented by Yoshida (1971). Nakamura and Matsumoto (1967) found in the Marquesas Islands that skipjack larvae were most abundant between January and April.

TABLE 4. SEASONAL VARIATION IN THE PERCENTAGE OCCURRENCE OF SKIPJACK JUVENILES FROM THE STOMACHS OF 42 TO 58.9 CM SKIPJACK PREDATORS FOR SELECTED COUNTRIES. N is the number of predators examined.

		October-March	April-August	Total	Chi-square	Probability
Papua New Guinea	%	5.33	3.47	3.96	2.14	0.144
Solomon Islands	N	319	894	1213		
Queensland	%	6.05	2.42	5.39	2.62	0.106
New Caledonia	N	562	124	686		
Vanuatu						
Fiji	%	3.68	1.87	2.21	2.02	0.155
	N	163	697	860		
TOTALS	Predators with prey	57	47	104	12.78*	<0.001
	N	1044	1715	2759		

* G-statistic, 1 df.

Based on female gonad indices shown in Figure 6, there is also seasonality in the state of gonad development. Gonad indices were highest (45-60) from November through February, or, roughly, the southern hemisphere summer. Index values over 50 are associated with female skipjack whose gonads have a high percentage of eggs that are ready to be spawned (Raju 1964). Results in Figure 6 are similar to those presented by Lewis (1981) and Wilson (1982) for female skipjack sampled from pole-and-line catches in Papua New Guinea, to those presented by Naganuma (1979) for a large, widely distributed sample of female skipjack from south of the Equator, and to those presented by Yoshida (1966) for female skipjack from the Marquesas and Tuamotu Islands of French Polynesia.

Argue and Kearney (1983) contrasted female skipjack maturity indices between tropical and subtropical waters for skipjack samples taken from south of the Equator between December and April. None of the skipjack examined from subtropical waters showed evidence of spawning, which is consistent with the absence of juvenile skipjack in stomach samples of predators taken from these waters at that time.

3.3.2 Time of day and distance from land

The data set from tropical waters for juvenile skipjack, frigate tuna and mackerel tuna from skipjack and yellowfin stomachs was used to examine whether occurrence of juveniles varied with time of day and distance from land. This data set does not include some samples from the first cruise (October 1977 to August 1978) for which distance from land was not recorded.

The upper graph in Figure 7 shows that the percentage occurrence of skipjack and frigate tuna juveniles in the diets of skipjack increased substantially after 1700 hours. The same data were then arrayed into eight intervals of distance from land. Results presented in the lower graph of Figure 7 show that skipjack juvenile occurrence increased with increasing distance from land. Occurrence of juvenile frigate tuna was relatively constant with respect to distance from land.

A simple presentation such as the above might suffice if it could be assumed that time of day and distance from land effects were independent. To adjust for confounding effects of time of day and distance from land, a four-way classification of the data was constructed. It was necessary to choose time of day and distance from land intervals that resulted in usable numbers of samples within each of the four classifications. The classes selected were distance from land ($\leq$10.0 miles, >10.0 miles), time of day (<1500 hours, $\geq$1500 hours), country groups (1, 2, 3, 4, 5 and 6 combined, see Table 1), and presence/absence of tuna juveniles. Since groups 5 and 6 are contiguous and both consist mainly of atolls, they were combined to increase sample size. There were sufficient numbers of samples for skipjack juveniles in skipjack predators for each stratum. For skipjack juveniles in yellowfin predators, frigate tuna juveniles in skipjack predators, and mackerel tuna juveniles in skipjack predators, data were only sufficient for three-way categorisations (summed over country groups). Table 5 presents percentage occurrence and sample sizes for this analysis.

A four-way G-test of independence was used to test the hypothesis that occurrence of skipjack juveniles in skipjack was independent of time of day, distance from land, and country group. It is assumed here that time of day, distance from land, and country effects are independent of the season in which the data were collected. Table 6 presents the resulting

FIGURE 6. AVERAGE GONAD INDICES (circles) AND TWO STANDARD ERRORS ON EITHER SIDE OF THE AVERAGES (vertical lines), BY MONTH, FOR SKIPJACK FEMALES SAMPLED FROM TROPICAL WATERS SOUTH OF THE EQUATOR. Standard errors omitted for one small (<5) sample (top graph, March); other sample sizes were at least eight and most exceeded 100. No samples for August and September. Gonad Index = 10^7 (gonad weight gm/(fish length mm)^3), from Schaefer and Orange (1956).

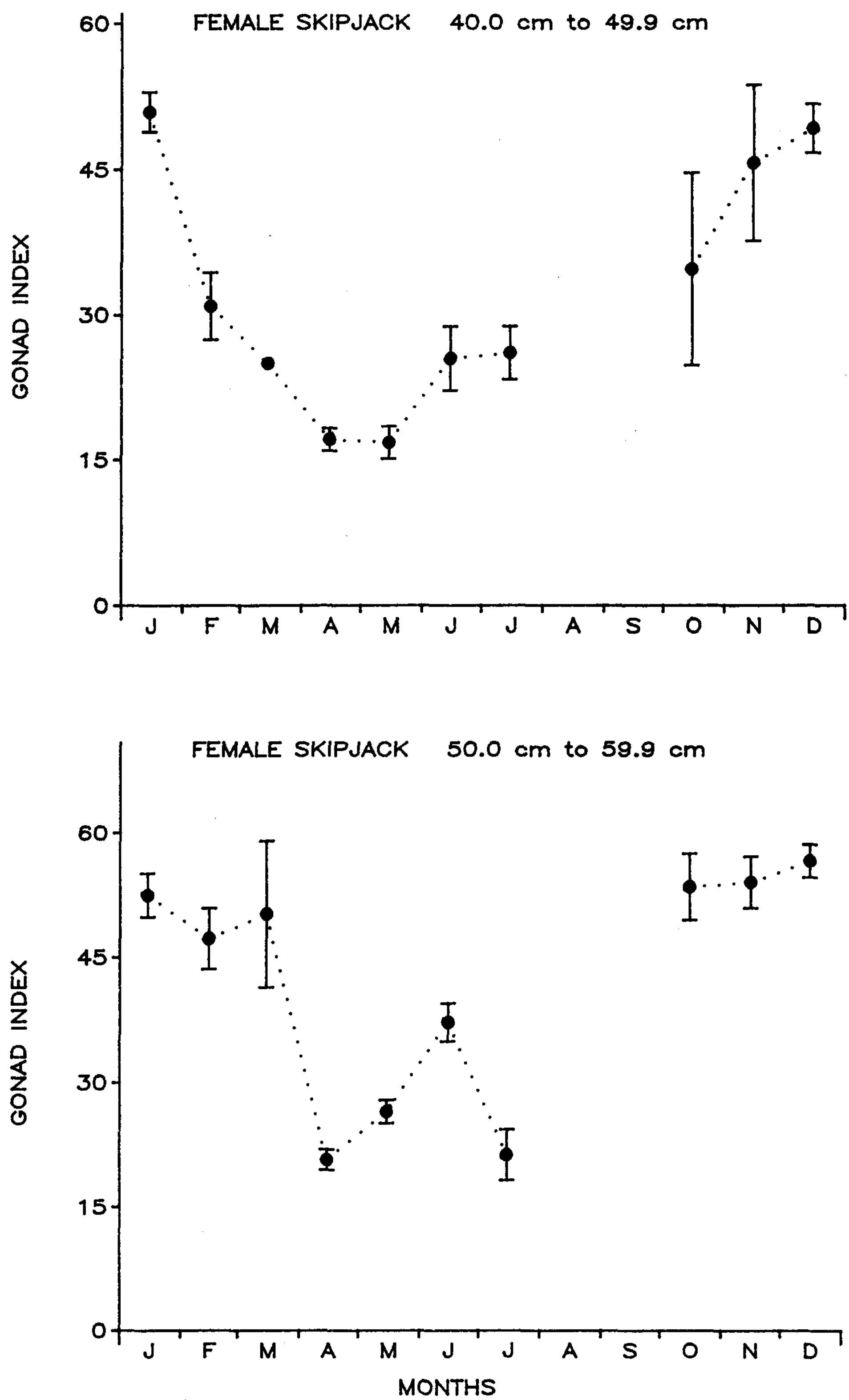
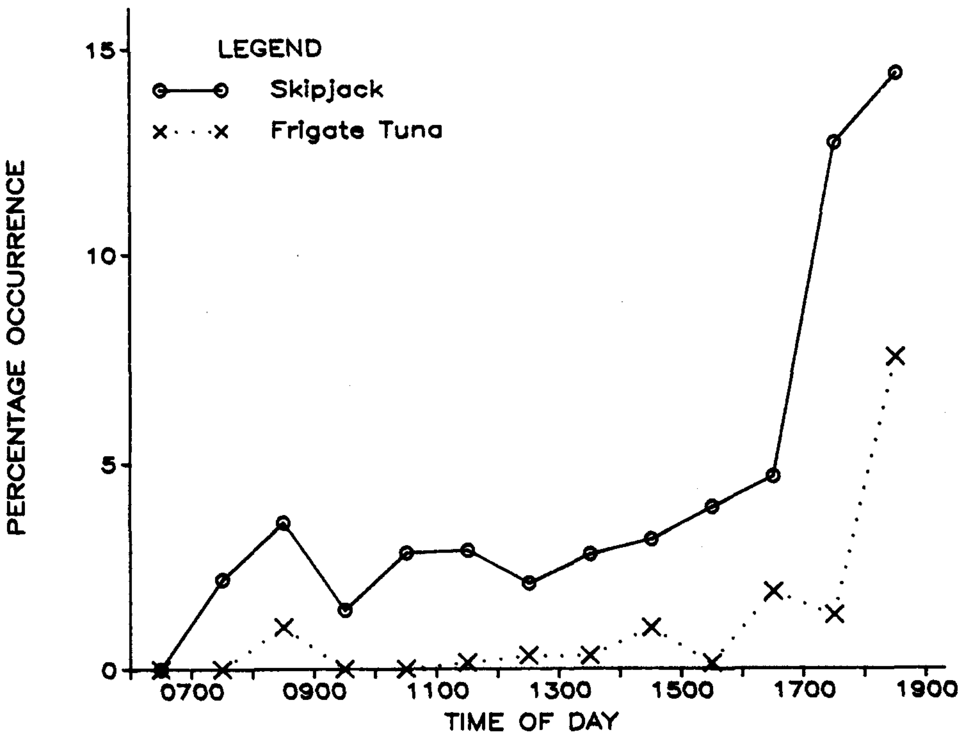


FIGURE 7. PERCENTAGE OCCURRENCE OF SKIPJACK AND FRIGATE TUNA JUVENILES IN THE STOMACHS OF 42-58.9 CM SKIPJACK PREDATORS VERSUS THE TIME OF DAY (upper graph) AND DISTANCE FROM LAND (lower graph) AT WHICH PREDATORS WERE CAPTURED. Predator sample sizes for all time and distance intervals exceeded 75, and most exceeded 500.



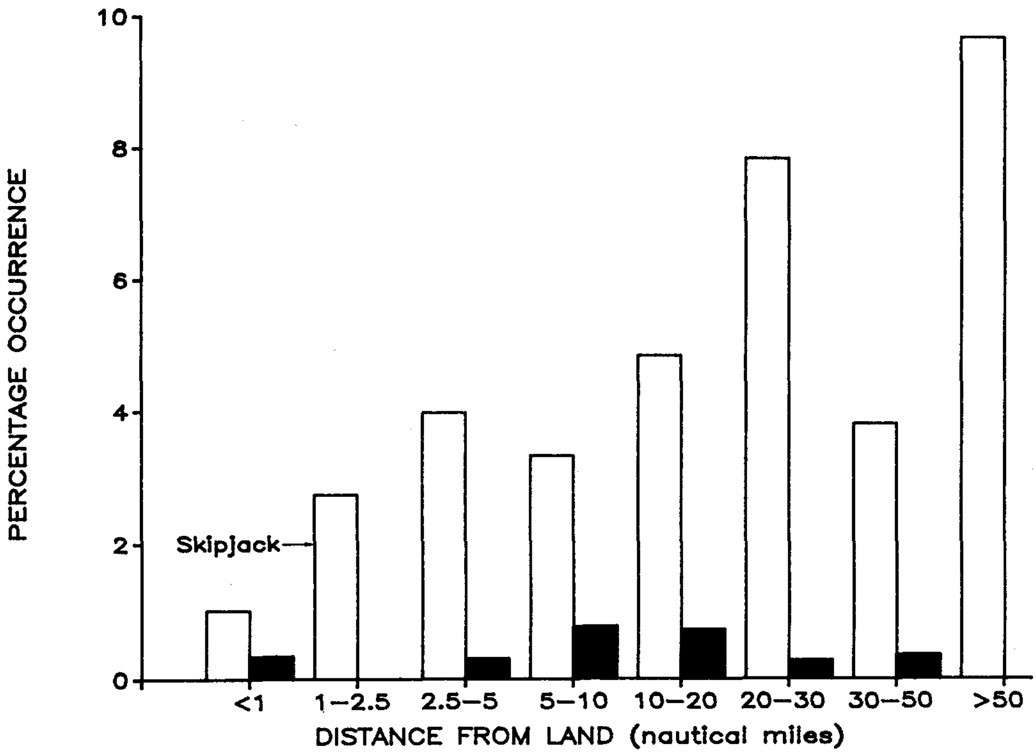


TABLE 5. PERCENTAGE OCCURRENCE OF TUNA JUVENILES FOR TWO DISTANCE FROM LAND INTERVALS, TWO TIME OF DAY INTERVALS AND FIVE COUNTRY GROUPS (SKIPJACK ONLY). Skipjack predators less than 42 cm and greater than 58.9 cm excluded. N is the number of predators examined.

			0-10.0 miles			>10.0 miles			Total		
Prey Species/ Predator Species	Country Group		<1500 hours	≥1500 hours	Total	<1500 hours	≥1500 hours	Total	<1500 hours	≥1500 hours	Total
Skipjack/ Skipjack	1	%	1.38	2.61	1.73	2.32	8.95	4.88	1.86	6.56	3.46
		N	290	115	405	302	190	492	592	305	897
Skipjack/ Skipjack	2	%	.76	1.36	.92	2.55	5.13	2.77	1.70	2.15	1.78
		N	395	147	542	431	39	470	826	186	1012
Skipjack/ Skipjack	3	%	0.85	5.35	2.68	6.98	7.69	7.20	2.85	5.92	4.01
		N	354	243	597	172	78	250	526	321	847
Skipjack/ Skipjack	4	%	3.70	10.82	6.39	3.59	16.88	11.39	3.68	13.15	7.83
		N	622	379	1001	167	237	404	789	616	1405
Skipjack/ Skipjack	5 & 6	%	1.73	-	1.46	-	4.05	2.94	1.63	1.89	1.70
		N	462	85	547	28	74	102	490	159	649
Skipjack/ Skipjack	TOTALS	%	1.93	6.09	3.23	3.27	11.00	6.05	2.39	8.00	4.24
		N	2123	969	3092	1100	618	1718	3223	1587	4810
Skipjack/ Yellowfin	TOTALS	%	.35	1.35	.55	.30	13.70	2.74	.33	7.48	1.71
		N	287	74	361	328	73	401	615	147	762
Frigate Tuna/ Skipjack	TOTALS	%	.18	1.08	.47	.27	.78	.46	.21	.96	.46
		N	2206	1018	3224	1104	641	1745	3310	1659	4969
Mackerel Tuna/ Skipjack	TOTALS	%	.09	.59	.25	.09	.31	.17	.09	.48	.22
		N	2206	1018	3224	1104	641	1745	3310	1659	4969

G-statistics. The test for interaction, that is, whether the degree of association between one pair of factors differs over the levels of the others, was significant ($p=0.043$). Three-way G-tests of independence were all significant (Table 6), as were main effect G-statistics for skipjack juvenile occurrence in skipjack versus distance from land, time of day and country groups ($p<0.001$). Inspection of the first five rows of data in Table 5 shows that within each of the country groups, percentage occurrence of skipjack juveniles was highest after 1500 hours and further than 10 miles from land (8 of 10 comparisons). From these results it is concluded that skipjack juveniles were more common in the diet of adult skipjack both later in the afternoon and further from land.

TABLE 6. G-STATISTICS FOR TESTS OF INDEPENDENCE FOR THE FOUR-WAY CLASSIFICATION OF SKIPJACK JUVENILE OCCURRENCE. C is country group, D is distance from land, T is time of day and O is occurrence.

Hypotheses Tested		Degrees of Freedom	G-statistics
CxDxTxO	interaction	4	9.88*
CxDxO	independence	13	459.94***
CxTxO	independence	13	342.42***
DxTxO	independence	4	104.48***
CxDxT	independence	13	831.84***
DxO	independence	1	20.72***
TxO	independence	1	76.40***
CxO	independence	4	70.02***

* $p<0.05$.
*** $p<0.001$.

Summed over country groups (6th row, Table 5), skipjack juveniles occurred in 3.4 times (8.00/2.39) as many stomachs after 1500 hours, as compared to earlier in the day; and occurred 1.9 times (6.05/3.23) as frequently at distances greater than 10 miles from land, compared to 0-10.0 miles from land. These results show that for the time and distance intervals chosen, time of day influences occurrence of skipjack juveniles in predator stomachs more so than distance from land.

Three-way tests of independence (time, distance, occurrence) were carried out for skipjack juveniles in yellowfin, frigate tuna juveniles in skipjack, and mackerel tuna juveniles in skipjack. The last three rows in Table 5 present percentage occurrence and sample sizes for these tests. Tests for interaction were not significant. The occurrence of skipjack, frigate tuna and mackerel tuna juveniles were all significantly higher ($p<0.01$) later in the day. The occurrence of frigate tuna juveniles and mackerel tuna juveniles did not differ with respect to distance from land. Skipjack juveniles were more common in yellowfin stomachs further from land ($p<0.05$).

3.3.3 Geographical variation

Although in the previous test, country groups differed significantly with respect to juvenile skipjack occurrence, implying that apparent abundance of juvenile skipjack varies over the study area, this difference may have been confounded by the season in which the samples were obtained for each country group. There were sufficient samples for the October to March period to examine whether, within this period, occurrence of juvenile skipjack differed among country groups. Table 7 presents data that were used for this comparison. The distance from land strata, which showed less variability than the time of day strata, had to be aggregated in order to obtain sufficient sample sizes for the country group comparisons. G-statistics from a three-way test of independence between country groups, time of day and juvenile occurrence confirmed that occurrence of skipjack juveniles differed significantly amongst country groups ($p<0.001$), and as in the previous section, skipjack juveniles were most common in predator stomachs later in the day ($p<0.001$). The test for interaction was not significant. Selected comparisons showed that group 4 (Marquesas Islands) and group 1 (Papua New Guinea, Solomon Islands, Vanuatu), both had significantly higher occurrence levels ($p<0.001$) than groups 5 and 6 (atolls and small islands in the north equatorial counter current-equatorial upwelling region). Figure 8 is a more detailed geographical presentation of prey per 100 predators (apparent abundance) for April to August and October to March samples within 12°x10° latitude-longitude cells. Apparent abundance indices were averaged over the before-1500-hour and after-1500-hour periods in order to give equal weight to the indices for each time period, regardless of numbers of samples. Isopleths on the figure indicate two centres of higher juvenile skipjack abundance roughly 3,500 nautical miles apart, one amongst the Marquesas and Tuamotu Islands in the east and the second near the large land masses of Papua New Guinea, Solomon Islands and Vanuatu in the west. Within the north equatorial counter current-equatorial upwelling region, and in the waters between the Samoan Islands and Society Islands, skipjack juveniles were occasionally present in adult skipjack stomachs, but at much lower levels.

TABLE 7. OCTOBER TO MARCH PERCENTAGE OCCURRENCE OF SKIPJACK TUNA JUVENILES IN SKIPJACK PREDATORS FOR TWO TIME OF DAY INTERVALS AND FIVE COUNTRY GROUPS. Skipjack predators less than 42 cm and greater than 58.9 cm excluded. N is the number of predators examined, including predators from schools for which distance from land was not recorded.

Country Group		<1500 hours	≥1500 hours	Total
1	%	3.08	10.84	6.10
	N	260	166	426
2	%	3.51	3.53	3.52
	N	171	85	256
3	%	2.85	5.92	4.01
	N	526	321	847
4	%	3.68	13.15	7.83
	N	789	616	1405
5 & 6	%	0.36	1.34	0.70
	N	550	302	852
TOTALS	%	2.68	8.39	4.89
	N	2296	1490	3786

FIGURE 8. APPARENT ABUNDANCE OF JUVENILE SKIPJACK (NUMBER OF JUVENILES PER 100 SKIPJACK PREDATOR STOMACHS) FROM 42-58.9 CM ADULT SKIPJACK SAMPLED WITHIN 12° LATITUDE BY 10° LONGITUDE CELLS. Upper values of each pair are for April to August, lower values for October to March. Apparent abundance indices have been averaged over two daily time periods (<1500 hours, ≥1500 hours) except where indicated by stars (single star <1500 sample, double star ≥1500 sample). All predator sample sizes ≥10 per season per cell; most >75. NS or blank denotes no sample. Isopleths of apparent abundance were drawn by hand.

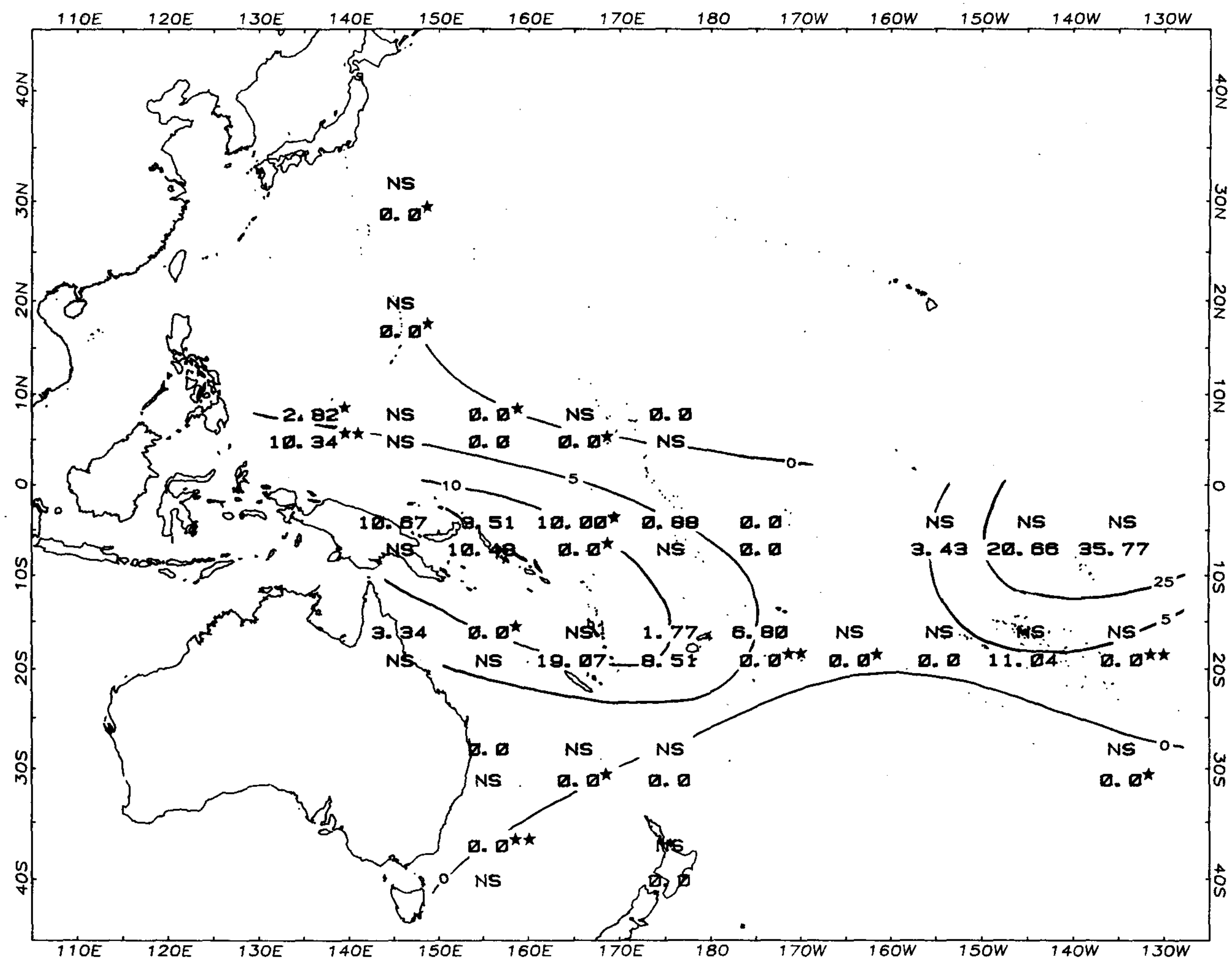


FIGURE 9. GONAD INDICES FOR 42-58.9 CM FEMALE SKIPJACK SAMPLED WITHIN 12° LATITUDE BY 10° LONGITUDE CELLS. Upper values of each pair are for April to August, lower values for October to March. All sample sizes ≥ 5 per season per cell; most >75. NS or blank denotes no sample.

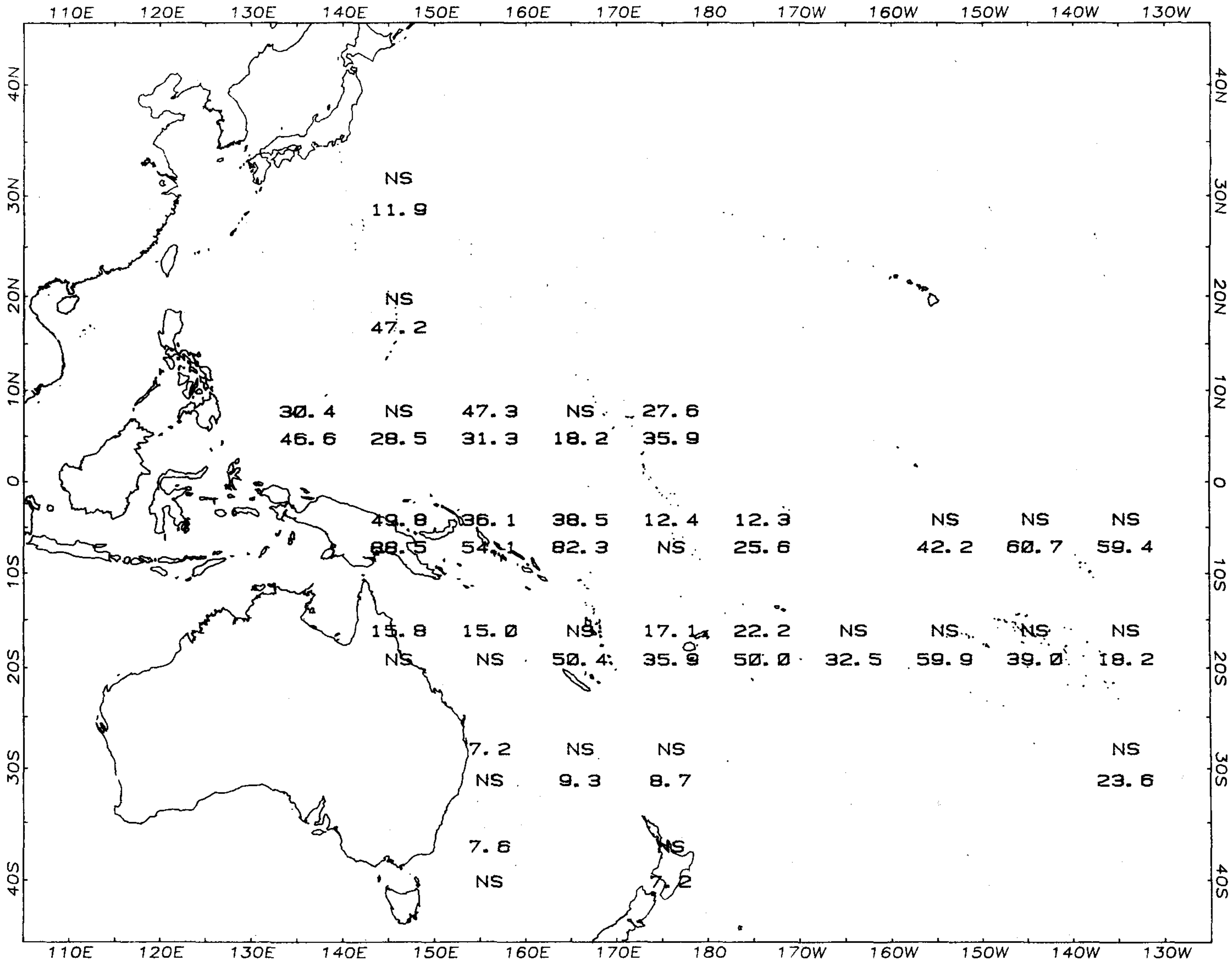
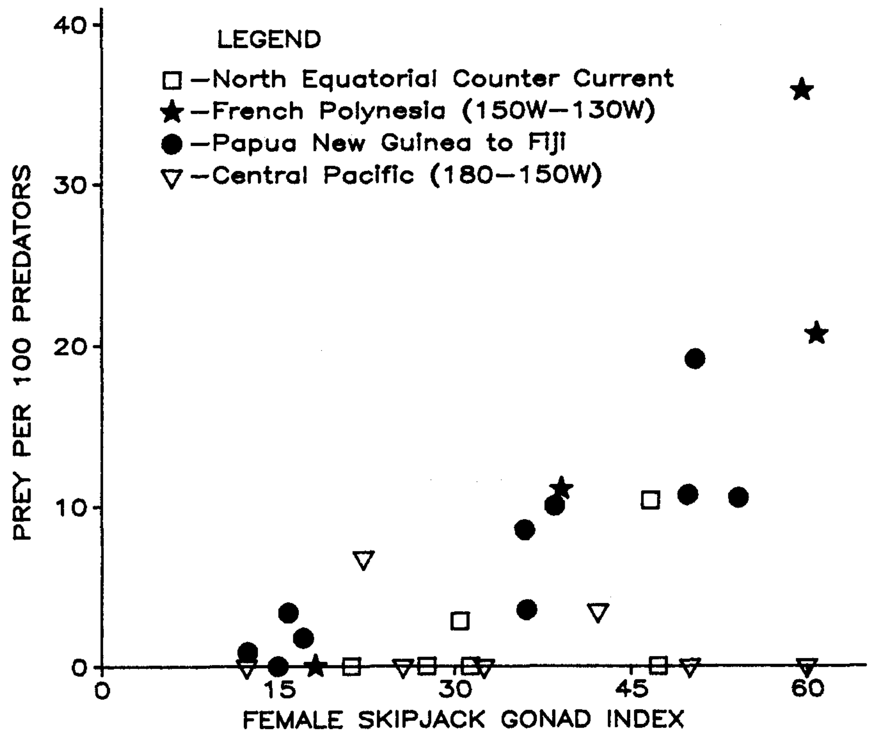


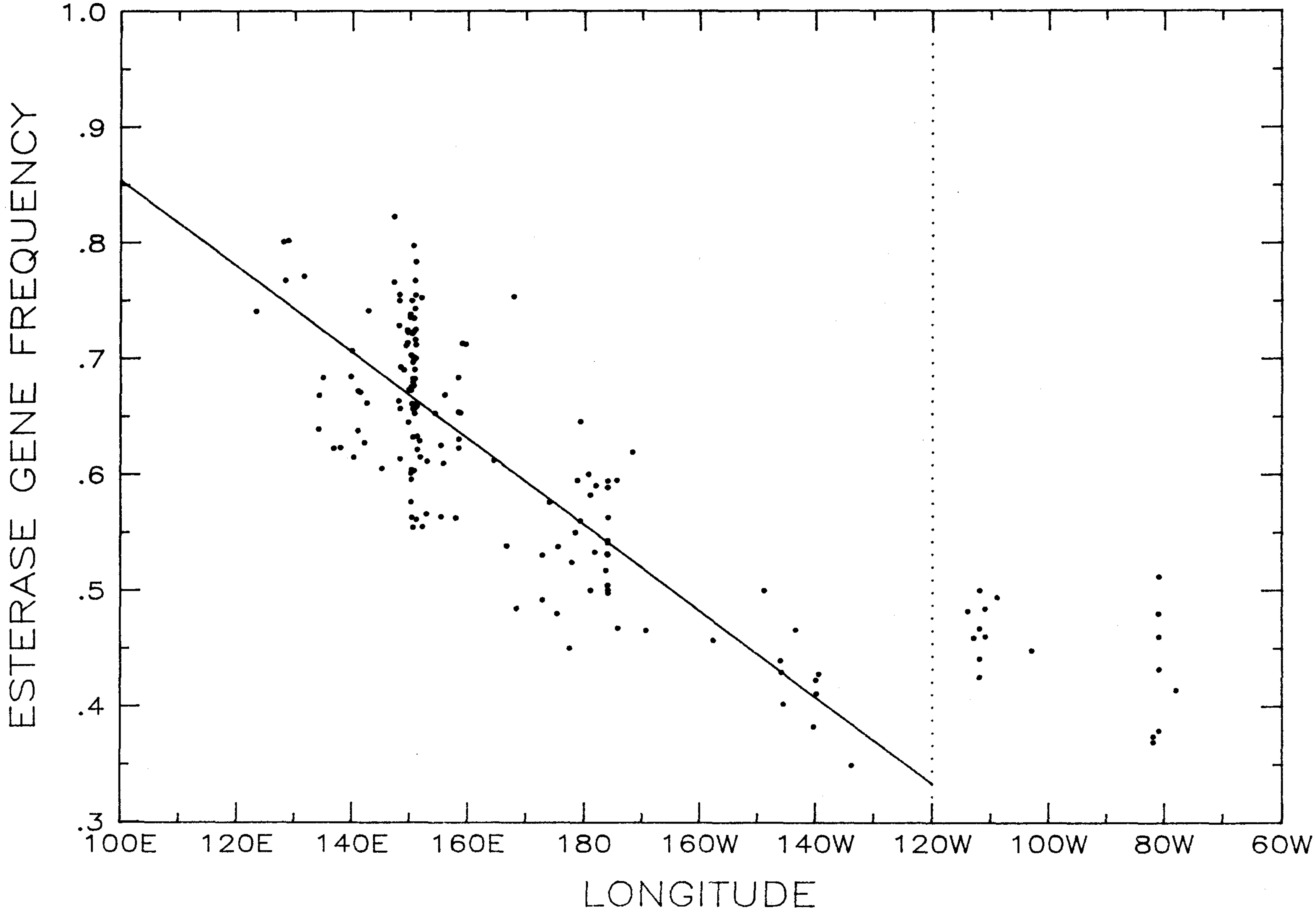
Figure 9 is a similar geographical presentation of female skipjack gonad index. Figure 10 shows the relationship between apparent abundance and female skipjack gonad index for samples from the same 12°x10° latitude-longitude cells and seasons. It is assumed that juveniles grow fast enough so that any lag between high gonad indices and occurrence of juveniles is captured within the six-month time periods. Estimates of daily growth for juvenile skipjack (Uchiyama and Struhsaker 1981) and yellowfin (Harada, Murata and Oda 1980) of over one millimetre per day support this assumption. There was a significant positive correlation between apparent abundance of juvenile skipjack and skipjack maturity, primarily due to the strong relationship between juvenile occurrence and maturity for samples from the two regions of higher juvenile occurrence (solid symbols in Figure 10). Skipjack juveniles and skipjack spawning would thus appear to be similarly distributed over the study area.

FIGURE 10. RELATIONSHIP BETWEEN SKIPJACK JUVENILES PER 100 SKIPJACK PREDATOR STOMACHS AND FEMALE SKIPJACK GONAD INDEX, FOR SAMPLES OF 42-58.9 CM ADULT SKIPJACK FROM 12° LATITUDE BY 10° LONGITUDE CELLS. The correlation coefficient for the total data set was 0.60 ($p<0.01$), and for the French Polynesia-Papua New Guinea to Fiji subsets it was 0.84 ($p<0.01$).



One must be cautious in interpreting these results since it is always possible that cyclic fluctuations in oceanographic parameters (Wyrtki 1975; Donguy and Henin 1981; Schreiber and Schreiber 1983) might alter the distribution and relative abundance of skipjack juveniles. Nevertheless, these results complement the Programme's analyses of blood genetics data (Anon 1981). A gradient in esterase gene frequency, a genetic marker used to infer population structure, was evident from west to east across the tropical Pacific between approximately 120°E and 120°W (Figure 11). The gradient is consistent with a relatively even distribution of skipjack spawning in tropical waters across the study area. It was also postulated

FIGURE 11. SKIPJACK SERUM ESTERASE GENE FREQUENCY FOR 163 SAMPLES FROM INDIVIDUAL SKIPJACK SCHOOLS, VERSUS LONGITUDE OF THE SAMPLE LOCATION. The regression line on the left of the dotted line includes 145 samples collected between Indonesia and Pitcairn Island (correlation coefficient -0.81). Esterase gene frequencies for 18 eastern Pacific samples are shown to the right of the dotted line. Redrawn from Anon (1981).



(Anon 1981) that the gradient could represent a region of "overlap" of skipjack from two or more centres of higher spawner density at the approximate extremes of the study area or beyond. The similarity between eastern Pacific esterase gene frequencies and those from French Polynesia suggests that eastern Pacific skipjack and skipjack in French Polynesia have a similar genetic origin, and could collectively represent the spawning group at one extreme. Evidence that there is minimal skipjack spawning in the eastern Pacific (Klawe 1963) supports this hypothesis. Previous results for juvenile skipjack apparent abundance and skipjack maturity support the supposition of two or more centres of heavier or more "successful" skipjack spawning in the study area.

3.3.4 Random versus clumped distribution of skipjack juveniles

Table 8 presents the observed numbers of predators with zero, one, two, etc. juvenile skipjack in their stomachs. Predators include all species sampled from tropical waters, regardless of their size. The long tail to the distribution suggests that it is a contagious or clumped distribution. To test this hypothesis the observed predator numbers were compared with the expected numbers calculated from the formula for the negative binomial frequency distribution. Based on a test of goodness of

TABLE 8. NUMBERS OF SKIPJACK PREDATORS (ALL LENGTHS) ON JUVENILE SKIPJACK FOR CLASSES OF OBSERVED PREY PER PREDATOR

Number of Prey per Predator	Observed Number of Predators	Observed Percentage of Predators	Expected Number of Predators*
0	7811	95.55	7811.5
1	189	2.31	190.0
2	76	0.93	74.3
3	39	0.48	38.1
4	16	0.20	21.9
5	6	0.07	13.4
6	15	0.18	8.5
7	5	0.06	5.5
8	8	0.10	3.7
9	1	0.01	2.5
11	2	0.03	1.2
13	3	0.04	0.6
15	1	0.01	0.3
17	1	0.01	0.2
19	1	0.01	0.1
22	1	0.01	<0.1
TOTALS	8175	100.00	
MEAN PREY/PREDATOR	0.108		
VARIANCE:MEAN RATIO	5.25		

* From formula for negative binomial distribution.

fit using chi-square, the observed frequencies were not significantly different from the expected frequencies ($p>0.05$), and this result was consistent within each country group. One interpretation of these results is that the spatial distribution of skipjack juveniles was clumped, assuming that predators encountering skipjack prey had similar feeding intensities and that each predator ingested juveniles over a relatively short time period. The contagion parameter for the negative binomial did not increase or decrease systematically for different times of day, implying that the degree of clumping of juveniles in predator stomachs was approximately the same between 0600 and 1900 hours.

Clumping of skipjack juveniles could represent some form of schooling response. If so, groups of prey might be expected to be associated on the basis of size, much as adults are, and individual predators might therefore be expected to have, on average, similar sized prey in their stomachs. Under these conditions the variance in size of skipjack juveniles found within individual skipjack predators should be less than the variance in mean juvenile size amongst skipjack predators. As a test, predators of similar size and containing three or more juvenile skipjack, were selected for ten one-way analyses of variance. The tests were carried out for predators from the same school (Table 9). The hypothesis of less variance in size amongst juveniles within predators was accepted in six of the ten tests. Probabilities from each of the analyses of variance were then pooled using the method of Sokal and Rohlf (1969, p. 621) and the hypothesis of less variance in size amongst juveniles within predators was accepted ($p<0.001$) for the combined data in Table 9. These results suggest that juvenile skipjack may form size-specific schools or aggregations.

3.4 Size of Skipjack Juveniles

Conand and Argue (1980) noted that skipjack predators between 40 and 70 cm in length ate skipjack juveniles over a broad size range, but with a tendency for larger predators to contain larger prey. This relationship was further examined in a two-way analysis of variance, using lengths of skipjack prey for three size groups of skipjack predators and for six country groups.

There was a significant predator size class effect ($p<0.01$). Small skipjack (40-49.9 cm) ate juveniles averaging 57 mm standard length, 50-59.9 cm skipjack ate juveniles averaging 78 mm in length, and large skipjack (60-69.9 cm) ate juveniles averaging 87 mm in length (Table 10). These results support previous observations that larger skipjack predators tend to contain larger juvenile prey in their stomachs, although there was considerable variability in the size of prey eaten by predators of a particular size. Average prey size also differed significantly among country groups ($p<0.001$). This might reflect geographical variation in timing of spawning, in growth, or in food preferences, none of which could be adequately tested with the available data.

To examine whether juvenile skipjack size differed with respect to time of day at which predators were captured, lengths of juvenile skipjack were used in a two-way analysis of variance (two time periods, before and after 1500 hours; six country groups). The test was restricted to juveniles from skipjack predators of 50 to 59 cm in length. The length of juveniles did not differ significantly between time periods.

Size of juvenile skipjack may also vary with distance from land. Such differences were not obvious for juvenile skipjack captured by pelagic

TABLE 9. DATA AND RESULTS FROM ONE-WAY ANALYSES OF VARIANCE FOR VARIATION IN LENGTH OF SKIPJACK PREY WITHIN AND BETWEEN INDIVIDUAL SKIPJACK PREDATORS

School Number	Country/ Visit*	Yr/Mo/Day/Time	Latitude/Longitude	Length of Predator	Prey Average Length	Number of Prey	F Ratio	Degrees of Freedom	Probability
1	TUA1	78 12 15 1750	14°53'S 147°35'W	552	66.0	4			
	TUA1	78 12 15 1750	14°53'S 147°35'W	522	84.0	5			
	TUA1	78 12 15 1750	14°53'S 147°35'W	534	75.3	3			
	TUA1	78 12 15 1750	14°53'S 147°35'W	522	88.0	3	3.67	3,11	0.048
2	MAQ2	79 12 22 1710	10°29'S 141°11'W	458	35.2	6			
	MAQ2	79 12 22 1710	10°29'S 141°11'W	460	47.7	6			
	MAQ2	79 12 22 1710	10°29'S 141°11'W	473	38.0	3			
	MAQ2	79 12 22 1710	10°29'S 141°11'W	460	39.8	8			
	MAQ2	79 12 22 1710	10°29'S 141°11'W	545	40.7	3			
	MAQ2	79 12 22 1710	10°29'S 141°11'W	469	37.0	3			
	MAQ2	79 12 22 1710	10°29'S 141°11'W	466	36.3	4			
	MAQ2	79 12 22 1710	10°29'S 141°11'W	480	38.4	7			
	MAQ2	79 12 22 1710	10°29'S 141°11'W	520	50.1	7			
	MAQ2	79 12 22 1710	10°29'S 141°11'W	468	35.0	6			
	MAQ2	79 12 22 1710	10°29'S 141°11'W	457	29.7	15			
	MAQ2	79 12 22 1710	10°29'S 141°11'W	460	36.7	19	3.19	11,75	0.001
3	MAQ2	79 12 23 1740	10°00'S 139°33'W	403	32.0	3			
	MAQ2	79 12 23 1740	10°00'S 139°33'W	424	36.7	3			
	MAQ2	79 12 23 1740	10°00'S 139°33'W	396	33.5	13			
	MAQ2	79 12 23 1740	10°00'S 139°33'W	430	31.0	3			
	MAQ2	79 12 23 1740	10°00'S 139°33'W	446	33.0	3	1.10	4,20	0.384
4	MAQ2	79 12 23 1810	10°02'S 139°30'W	528	35.0	3			
	MAQ2	79 12 23 1810	10°02'S 139°30'W	538	36.3	17			
	MAQ2	79 12 23 1810	10°02'S 139°30'W	545	41.0	6			
	MAQ2	79 12 23 1810	10°02'S 139°30'W	480	33.6	8	3.36	3,30	0.032
5	MAQ2	79 12 24 1700	09°02'S 140°11'W	508	34.0	9			
	MAQ2	79 12 24 1700	09°02'S 140°11'W	500	28.0	3	9.00	1,10	0.013
6	MAQ2	79 12 25 1130	09°14'S 139°59'W	464	39.3	3			
	MAQ2	79 12 25 1130	09°14'S 139°59'W	470	35.0	7	3.82	1,8	0.086
7	MAQ2	79 12 26 1730	09°01'S 140°08'W	414	62.7	3			
	MAQ2	79 12 26 1730	09°01'S 140°08'W	408	44.3	3			
	MAQ2	79 12 26 1730	09°01'S 140°08'W	432	73.3	3	8.35	2,6	0.019
8	MAQ2	80 01 21 1700	10°22'S 141°18'W	462	71.4	5			
	MAQ2	80 01 21 1700	10°22'S 141°18'W	454	58.7	6	4.93	1,9	0.054
9	SOL2	80 06 20 1335	08°09'S 160°16'E	587	46.7	3			
	SOL2	80 06 20 1335	08°09'S 160°16'E	637	49.2	6			
	SOL2	80 06 20 1335	08°09'S 160°16'E	613	54.0	6	1.10	2,12	0.354
10	SOL2	80 06 21 1040	08°28'S 160°20'E	430**	30.8	4			
	SOL2	80 06 21 1040	08°28'S 160°20'E	424**	24.4	17	5.96	1,19	0.025

* TUA - Tuamotu Islands; MAQ - Marquesas Islands; SOL - Solomon Islands.

** Frigate tuna predator.

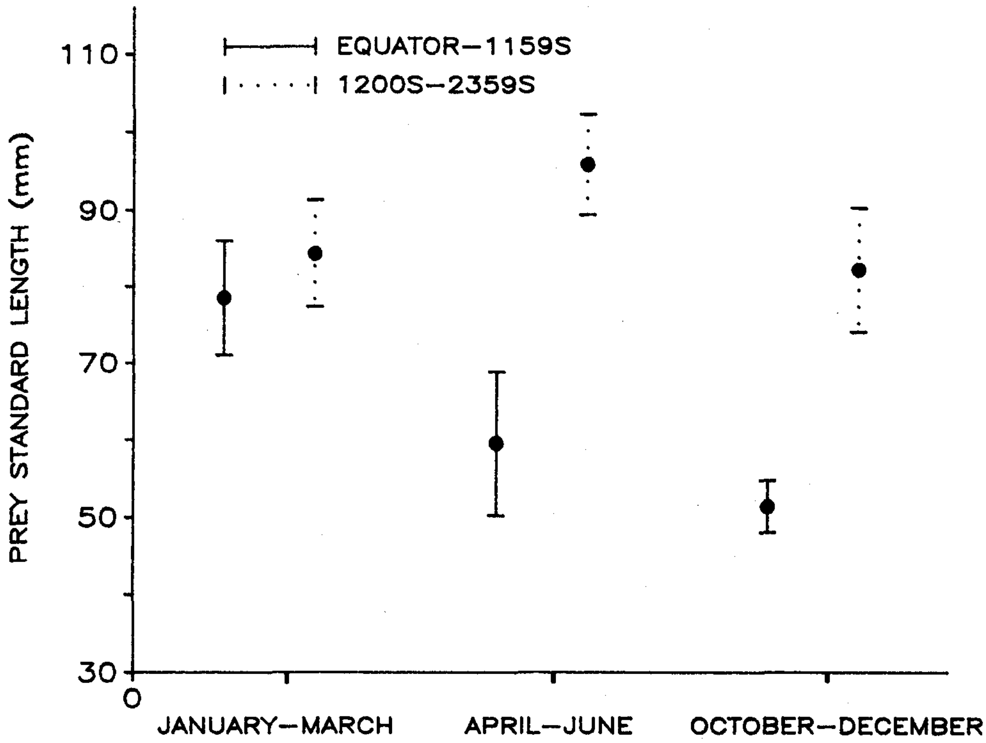
trawl gear at stations between 7 and 57 km from shore in Hawaiian waters (Higgins 1970); and were not significant for our data set for juveniles from 50 to 59 cm skipjack predators based on a two-way analysis of variance ($\leq$10 miles from land and >10 miles from land; six country groups).

TABLE 10. MEAN STANDARD LENGTH (MM) OF SKIPJACK JUVENILES FOUND IN THREE SIZE CLASSES OF SKIPJACK PREDATORS. SD is the standard deviation and N is the number of skipjack juveniles, with the number of predators that were examined for juveniles shown in brackets.

		PREDATOR SIZE INTERVAL (FORK LENGTH)			
Country Group		40-49.9 cm	50-59.9 cm	60-69.9 cm	Totals
1	Mean	53.2	78.6	67.3	70.6
	SD	26.32	36.32	28.08	33.49
	N	21(14)	61(41)	36(13)	118(68)
2	Mean	79.1	99.7	102.5	95.6
	SD	25.12	22.62	25.70	26.23
	N	29(16)	38(20)	46(22)	113(58)
3	Mean	99.6	94.0	105.5	95.2
	SD	20.58	21.91	-	21.49
	N	11(8)	51(27)	1(1)	63(36)
4	Mean	50.5	52.9	80.5	51.8
	SD	24.95	32.50	17.70	27.00
	N	236(90)	69(25)	8(4)	313(119)
7	Mean	83.8	79.0	85.7	81.0
	SD	17.87	38.86	7.33	32.17
	N	13(10)	33(14)	6(3)	52(27)
5 & 6	Mean	54.0	80.9	89.2	79.8
	SD	28.41	24.59	41.99	31.99
	N	4(3)	17(10)	9(7)	30(20)
Totals	Mean	56.5	78.1	86.8	69.6
	SD	27.80	34.91	30.98	33.50
	N	314(141)	269(137)	106(50)	689(328)

It has been suggested that juvenile skipjack in the central and western Pacific tend to migrate polewards as they grow to the size of first recruitment to pole-and-line gear (Kearney 1978). Average lengths of skipjack juveniles in this study are presented in Figure 12 for three three-month time periods and two 12° latitude zones south of the Equator. Skipjack juveniles from south of 12°S had average lengths consistently greater than those of juveniles recovered closer to the Equator. For two of the three time periods, April to June and October to December, skipjack juveniles in the southern most zone were almost twice as large on average as those from the more equatorial zone. These results offer some support to the hypothesis of poleward movement by skipjack juveniles as they increase in size.

FIGURE 12. SEASONAL COMPARISON OF JUVENILE SKIPJACK AVERAGE STANDARD LENGTHS FOR 12° LATITUDE INTERVALS SOUTH OF THE EQUATOR. 95 per cent confidence limits are indicated above and below each average. Juveniles are from skipjack predators that were between 42 and 58.9 cm fork length.



3.5 Tuna Juvenile Occurrence Contrasted with Occurrence of Other Diet Items

To place the occurrence of tuna juveniles in stomach contents of skipjack and yellowfin in some perspective, it is useful to consider all diet items that were found in the stomachs of these species in tropical waters. Complete lists of diet items and percentage occurrence levels for all skipjack and yellowfin that were sampled for diet content from tropical waters are presented in Appendix D. Percentage occurrence levels for tuna juveniles in this section differ slightly from those in previous sections since these estimates are only for predators that were given a full stomach examination.

There were 113 diet items in the stomachs of 3,888 skipjack and 95 diet items in the stomachs of 988 yellowfin, not including chum and various miscellaneous items from the research vessel. Both species had representatives of over 50 fish families in their diets. Tuna juveniles were the seventh most common item (6.6 % occurrence) in skipjack stomachs, and the twenty-third most common item (2.7 %) in yellowfin stomachs. Skipjack juveniles, a subset of the tuna juvenile category, occurred in 5.2 per cent of skipjack stomachs (ninth most common item) and in 2.3 per cent of yellowfin stomachs (twenty-eighth most common item). Based on percentage occurrence, tuna juveniles collectively, and skipjack juveniles in particular, do not appear to be dominant food items for skipjack and yellowfin over the tropical western and central Pacific study area. This contrasts with recent findings of Olson (1981) that frigate tuna juveniles were the dominant food item in the diet of yellowfin caught with purse-seine gear over a large portion of the eastern tropical Pacific (east of 150°W).

Stomach content of skipjack containing skipjack juveniles was compared with stomach content of skipjack that did not contain skipjack juveniles. Comparisons were made using equal numbers of skipjack with and without skipjack prey, from each school in which there was at least one skipjack with and one skipjack without a skipjack juvenile in its stomach. Comparisons were restricted to chum, fish remains (not chum), squid, alima stage of stomatopods, acanthurids, holocentrids, gempylids and synodontids (Table 11), since there were at least five skipjack, per category, containing these particular items in their stomachs. This is an advisable minimum sample size for chi-square tests. Contingency chi-square statistics were used to test whether percentage occurrence for individual diet items differed between skipjack containing skipjack juveniles and skipjack without skipjack juveniles. The only diet item for which there was a significant difference was gempylids; in this case, skipjack with skipjack juveniles had more than double ($p<0.05$) the incidence of gempylids (15.6 %) compared to skipjack without skipjack juveniles (7.4 %). This implies a degree of spatial association between skipjack juveniles and gempylids. The gempylids from skipjack stomachs were generally somewhat larger than juvenile skipjack. They are thought to prey on other small fishes (Monroe 1967; Grandperrin 1975), and this may explain their apparent association with skipjack juveniles in this study.

TABLE 11. COMPARISON OF STOMACH CONTENTS BETWEEN SKIPJACK PREDATORS CONTAINING SKIPJACK JUVENILES AND SKIPJACK PREDATORS WITHOUT SKIPJACK JUVENILES FOR EQUAL REPLICATES OF SKIPJACK PREDATORS FROM INDIVIDUAL SCHOOLS

	Skipjack with Skipjack Juveniles (%)	Skipjack without Skipjack Juveniles (%)	Chi-square
Chum	68.03	74.59	1.28
Fish remains	53.28	58.20	0.60
Squid (Cephalopoda)	45.90	39.34	1.07
Alima (Stomatopoda)	18.03	18.85	0.03
Acanthuridae	30.33	26.23	0.51
Holocentridae	17.21	14.75	0.28
Gempylidae	15.57	7.38	4.03*
Synodontidae	6.56	6.56	0.00
TOTAL STOMACHS EXAMINED	122	122	

* $p<0.05$.

4.0 DISCUSSION OF TUNA JUVENILE OCCURRENCE

Skipjack juveniles, frigate tuna juveniles and mackerel tuna juveniles were found to occur most frequently in predator stomachs during the later daylight hours, that is between 1500 and 1900 hours; and skipjack juveniles occurred most frequently in the stomachs of predators that were sampled further than ten miles from land. Other investigators have postulated that such results reflect predator feeding intensity. Magnuson (1969) showed experimentally that skipjack in confinement fed most intensively between 0630 and 0830 hours, but not to full stomach capacity, and continued to feed at lower intensity throughout the day. Waldron and King (1963) suggested that high stomach volumes observed in skipjack sampled early in the morning and late in the afternoon from pole-and-line catches in Hawaiian waters were due to increased skipjack feeding intensity at these times.

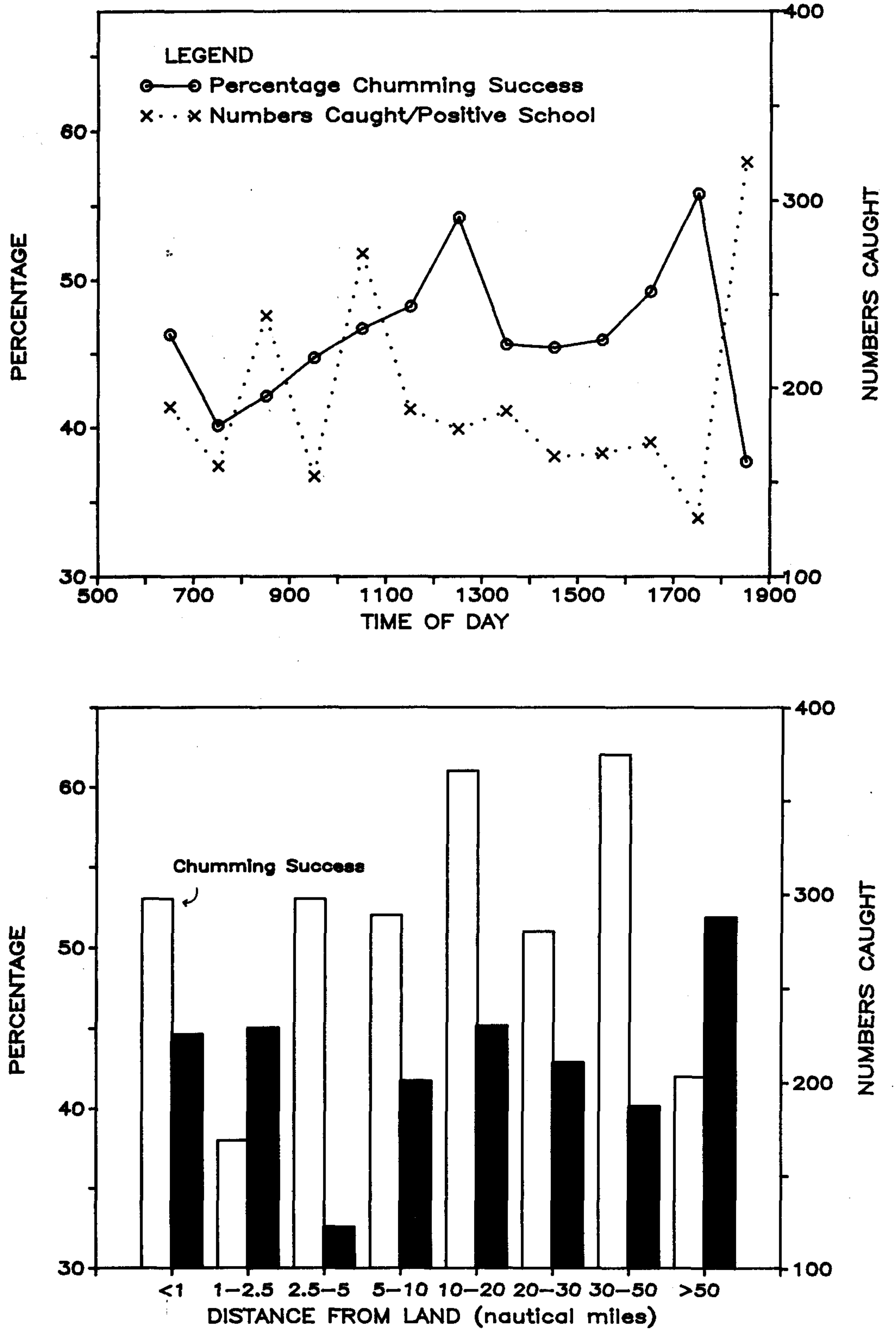
Alternatively, it could be argued that higher levels of juvenile occurrence in predator stomachs late in the day and further from land (skipjack juveniles only) in this study were primarily the result of increased availability of juveniles to predators. Predator response to live bait used by the Skipjack Programme (Figure 13) suggested that predators, predominantly skipjack, maintained a relatively constant feeding response to bait and tuna lures between approximately 0600 and 1800 hours, and with respect to distance from land. Previously, Nakamura (1965a) implied that in French Polynesia late afternoon and early morning peaks in skipjack stomach volumes were associated with availability of food. Several studies, using plankton and midwater trawl gear, provide evidence of upward vertical migrations by both larval skipjack (Strasburg 1960; Ueyanagi 1969; Nishikawa et al. 1978) and juvenile skipjack (Higgins 1970) towards dusk and during the night. Higgins also found that skipjack juveniles, somewhat smaller (7-47 mm) than those in this study, were more common in surface trawl catches at a station 57 km from land as compared to a station only 7 km from land. These observations support the alternative hypothesis.

By staying below the daytime feeding range of surface tunas, skipjack juveniles may avoid considerable daytime predation (Kearney 1978), particularly in the early morning period that Magnuson observed to be the period of most intense feeding by adult skipjack. Movement of juvenile skipjack to the surface at dusk could mark the beginning of their period of intense feeding as they follow upward movement of zooplankton in the deep scattering layer. Juvenile skipjack found furthest from land might also avoid some predation since surface tunas and other predators often appear less abundant further from land, which Lewis (1981) suggests is a response by surface tunas to the island mass effect (Gilmartin and Revelante 1974) that concentrates many prey organisms near islands (Murphy and Shomura 1972).

Analyses of size and spatial distributions of juveniles in Section 3.3.4 indicated that skipjack juveniles may form schools. This is also a mechanism that is believed to reduce predation by greatly reducing the risk that an individual prey will be eaten (Brock and Riffenburgh 1960), since in the open ocean predators have only a slightly greater chance of finding a school of prey than of finding an individual prey (Partridge 1982).

Although skipjack may be "...their own greatest predators...", as Kearney (1978) suggested, skipjack juveniles were not a dominant item in skipjack stomachs over the total western and central Pacific area from

FIGURE 13. CHUMMING SUCCESS AND NUMBERS OF FISH (PREDOMINANTLY SKIPJACK) CAUGHT PER POSITIVE SCHOOL VERSUS TIME OF DAY (upper graph) AND DISTANCE FROM LAND (lower graph). A positive school is a school from which at least one fish was landed on board the research vessel. Chumming success is the percentage that positive schools are of the total schools that were chummed with live bait. The number of schools chummed (and positive schools) exceeded 100(50) for all distance and time intervals except the first and last time intervals when schools chummed (positive schools) exceeded 40(18).



which Skipjack Programme samples were obtained. Over 100 diet items were identified from skipjack adults, and skipjack juveniles were only the ninth most common item in terms of percentage occurrence. This suggests that skipjack juveniles are not a major source of food for skipjack adults.

On the other hand, it is tempting to speculate on the amount of mortality due to cannibalism. Given an estimate of three million tonnes for the standing stock of skipjack vulnerable to surface fishing gear in an area approximately the size of the South Pacific Commission area (Kleiber, Argue and Kearney 1983), and an average weight of 2.5 kg per adult skipjack based on skipjack caught by the Skipjack Programme (Tuna Programme, unpublished data), then there are roughly 1.2×10^9 skipjack predators in the size range captured by surface fishing gears. Daily consumption of skipjack juveniles by adult skipjack predators in this size range, **D** , was estimated using the equation of Bajkov (1935) and Darnell and Meierotto (1962), as modified by Eggers (1979):

$$D = 24\ AR$$

where **A** is the average amount of a food species in the predator's stomach over a 24-hour period and **R** is the instantaneous gastric evacuation rate ($hours^{-1}$) for that food species. **A** was calculated for skipjack juveniles, substituting numbers of juveniles for weight of juveniles, under the assumption that average size of juveniles in adult stomachs did not vary systematically over the daily sampling period. The estimate of **A** was 0.112 skipjack juveniles per skipjack predator and was calculated from the average of hourly (0600 to 1900 hours) measures of prey per predator presented in Figure 4 (middle graph). The instantaneous gastric evacuation rate, estimated to be 0.105 per hour from results in Magnuson (1969) for captive skipjack that were fed small (10.2 gm average weight) whitebait (Osmeridae), is assumed to be representative for skipjack juveniles in skipjack adults. The estimate of daily consumption of skipjack juveniles by skipjack predators was 0.282 (24 x 0.112 x 0.105) juveniles per adult. The product of this value and the estimate of the number of skipjack predators gives a value of 3.4×10^8 skipjack juveniles eaten by adult skipjack per day. At this rate skipjack predators of a size vulnerable to surface fishing gear would consume, in just over three days, a number of juveniles equal to their own number.

There is no doubt that the number of skipjack juveniles eaten by skipjack adults is large; however, this information is of limited value without, at least, an estimate of the standing stock of juveniles within the predators' preferred size range, and some knowledge of the period of time juveniles are vulnerable to adult predators. The latter may be quite short, perhaps a few months or less, if one accepts the average growth rate of 1.6 mm per day estimated from daily otolith increments for small skipjack by Uchiyama and Struhsaker (1981), and the size distribution for skipjack juveniles given in this paper. There is also the unknown impact of other predator species on abundance of skipjack of all sizes, but most particularly on juvenile and larval stages. For example, squid are thought to prey heavily on larval and juvenile fishes in tropical waters (Arnold 1979), and the close spatial association between gempylids and skipjack juveniles (Section 3.5) is also suggestive of predation. In brief, cannibalism may play an important role in regulating skipjack abundance; however, there is little objective basis for concluding so at present, although this is certainly an important area for further investigation.

5.0 SUMMARY AND CONCLUSIONS

Stomachs from 12,135 tunas and other predator species caught by pole-and-line gear between October 1977 and August 1980 in the western and central Pacific Ocean were examined for tuna juveniles. In subtropical waters, tuna juveniles were absent from the diet of tunas, principally skipjack. In tropical waters, nearly five per cent of 10,604 predators contained at least one tuna juvenile. Seventy-seven (77) per cent of the total of 1,346 tuna juveniles identified from these stomachs were skipjack; the remaining 23 per cent were predominantly frigate tuna, albacore, and mackerel tuna juveniles, but included a few yellowfin/bigeye and dogtooth tuna juveniles. Skipjack juveniles occurred in 4.5 per cent of adult skipjack stomachs from tropical waters in the study area; other species of tuna juveniles each occurred in less than one per cent of skipjack stomachs. Skipjack juveniles were found in just under two per cent of yellowfin stomachs. The size frequency distributions for each species of juvenile were skewed towards the larger specimens; the modal lengths fell between 35 mm standard length (skipjack) and 85 mm (albacore); and the overall range in standard length was 15 to 240 mm.

The indices prey per 100 predator stomachs and percentage occurrence of prey in predator stomachs were assumed to represent relative abundance of skipjack juveniles. Skipjack juveniles appeared most abundant in surface waters later in the afternoon (after 1700 hours) and further than ten miles from land. Evidence was presented that skipjack juveniles formed size-specific schools or aggregations. These temporal and spatial distributions of skipjack juveniles were postulated to represent adaptations on the part of skipjack to minimise predation by surface-dwelling predators.

Selective predation by predators of different sizes and the time of day and distance from land that predators were sampled were taken into account in an analysis of seasonal and geographical occurrence of skipjack juveniles in predator stomachs. Results for tropical waters south of the Equator suggested that skipjack juveniles were in highest abundance during spring-summer months (October to March), which coincided with a period of much higher female skipjack gonad indices. Skipjack juveniles also appeared most abundant in two geographical centres roughly 3,500 miles apart in the Programme study area - one including the waters surrounding the Marquesas and Tuamotu Islands, and the other encompassing the waters of Papua New Guinea, Solomon Islands and Vanuatu. Juveniles were in very low abundance in large samples taken from waters in the region of the north equatorial counter current and the region of equatorial upwelling. These observations support the hypothesis that skipjack spawning is heaviest in two or more centres at the approximate longitudinal extremes of the central and western Pacific study area.

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APPENDIX A. SEQUENCE OF SURVEYS FOR CRUISES BY THE SKIPJACK PROGRAMME RESEARCH VESSELS. The Hatsutori Maru No.1 was chartered for cruises one and two and the Hatsutori Maru No.5 was chartered for cruise three.

Cruise One	Cruise Two	Cruise Three
October 1977-August 1978	October 1978-July 1979	November 1979-August 1980
Papua New Guinea	Bonin Islands	Bonin Islands
Solomon Islands	Northern Mariana Islands	Northern Mariana Islands
Vanuatu	Guam	Truk
New Caledonia	Yap	Ponape
Fiji	Palau	Kosrae
Tonga	Truk	Marshall Islands
Wallis and Futuna	Ponape	Kiribati
American Samoa	Kosrae	Northern Cook Islands
Western Samoa	Marshall Islands	Society Islands
Tuvalu	Kiribati	Marquesas Islands
Kiribati	Tokelau	Tuamotu Islands
Marshall Islands	Northern Cook Islands	Pitcairn Islands
Kosrae	Society Islands	Gambier Islands
Ponape	Tuamotu Islands	Tuamotu Islands
Truk	Marquesas Islands	Society Islands
Guam	Tuamotu Islands	Southern Cook Islands
Northern Mariana Islands	Society Islands	American Samoa
	Southern Cook Islands	Western Samoa
	New Zealand	Niue
	New South Wales	Tonga
	Queensland	New Zealand
	Papua New Guinea	Norfolk Island
		New Caledonia
		Fiji
		Wallis and Futuna
		Solomon Islands
		Tuvalu
		Kiribati
		Nauru
		Kosrae
		Ponape
		Truk
		Yap
		Palau

APPENDIX B. NUMBERS OF PREDATORS SAMPLED FOR PRESENCE OF TUNA JUVENILES AND NUMBERS OF TUNA JUVENILES OBSERVED IN PREDATOR STOMACHS FOR EACH COUNTRY VISIT

Country Visit		PREDATORS				TUNA JUVENILES						
		Skipjack	Yellowfin	Other	Totals	Skipjack	Yellowfin/ Bigeye	Albacore	Mackerel Tuna	Frigate Tuna	Other	Totals
American Samoa	June 1978	28	5	14	47	5						5
American Samoa	February 1980	31			31							-
New Caledonia	Dec. 1977-Jan. 1978	473	22	18	513	48			4	5		57
New Caledonia	March 1980	4	4		8							-
Fiji	Jan.-Feb. 1978	167	70	8	245	16						16
Fiji	March-April 1978	88	24	1	113	10						10
Fiji	April 1980	673	173	2	848	23	3				1	27
Gambier Islands	February 1980	19	20	10	49							-
Bonin Islands	October 1978	20			20							-
Kiribati	July 1978	179	14	25	218	1						1
Kiribati	November 1978	5			5							-
Kiribati	November 1979	27	5	1	33							-
Kiribati	July 1980	1			1							-
Kosrae	November 1978	17	3		20							-
Kosrae	November 1979	47	46	7	100							-
Line Islands	December 1978	1			1							-
Marquesas Islands	January 1979	240	2		242	14			43	53		110
Marquesas Islands	Dec. 1979-Jan. 1980	1236	55	1	1292	368	5	1	4	8	1	387
Northern Mariana Islands	October 1978	7			7	1						1
Northern Mariana Islands	November 1979	33		1	34	2		1				3
Marshall Islands	July 1978	6	4		10							-
Marshall Islands	November 1978	21	3	1	25							-
Marshall Islands	November 1979	18	22		40							-
Nauru	July 1980	1			1	2						2
Northern Cook Islands	Nov.-Dec. 1978	199	7		206	16			1			17
Northern Cook Islands	December 1979	33			33							-
Niue	February 1980	6	4		10	6						6
Norfolk Island	March 1980	84	43		127							-
New South Wales	April 1979	595	3	49	647							-
Palau	October 1978	40			40							-
Palau	August 1980	225	173	19	417	6						6
Phoenix Islands	December 1979	55	9		64						1	1
Pitcairn Island	February 1980	11	77	10	98	1						1
Papua New Guinea	October 1977	139	29	34	202	49	1			1		51
Papua New Guinea	May-June 1979	765	219	92	1076	54			4	2		60
Ponape	August 1978	15		6	21							-
Ponape	Oct.-Nov. 1978	65	39	2	106	1						1
Ponape	November 1979	135	43	24	202	3					1	4
Ponape	July 1980	207	27		234							-
Queensland	May 1979	270	35	2	307	11		1		1		13
Southern Cook Islands	February 1979	6			6							-
Southern Cook Islands	February 1980	18			18			1				1
Society Islands	Dec. 1978-Jan. 1979	181	5		186	1						1
Society Islands	February 1980		8		8							-
Solomon Islands	Oct.-Dec. 1977	214	37	23	274	15	2		3	15		35
Solomon Islands	June 1980	278	127	302	707	55	10			2		67
Tokelau	November 1978	24	2		26							-
Tonga	April 1978	104	68	22	194	7				3		10
Tonga	March 1980	94	1	5	100	21		1		9	1	32
Truk	August 1978	5			5							-
Truk	November 1979	22			22							-
Tuamotu Islands	Dec. 1978-Jan. 1979	554	35	1	590	59		28				87
Tuamotu Islands	February 1980	129	95		224	9						9
Tuvalu	June-July 1978	348	71	28	447	5						5
Tuvalu	July 1980	31		11	42							-
Vanuatu	Dec. 1977-Jan. 1978	130	13	11	154	40	3	1	4	69		117
Wallis and Futuna	May 1978	324	20	9	353	169	1	15				185
Wallis and Futuna	May 1980	121	72	2	195	1						1
Western Samoa	June 1978	35	18	17	70	3						3
Western Samoa	February 1980	31	2	9	42			4				4
Yap	October 1978	39	3		42	9	1					10
New Zealand	Feb.-March 1979	652		37	689							-
New Zealand	March 1980	48			48							-
TOTALS		9574	1757	804	12135	1031	26	53	63	168	5	1346

APPENDIX C. NUMBERS OF SKIPJACK JUVENILES PER 100 SKIPJACK PREDATOR STOMACHS FOR EACH COUNTRY VISIT

Country Visit		Skipjack Juveniles per 100 Skipjack Predators	Country Visit		Skipjack Juveniles per 100 Skipjack Predators
American Samoa	June 1978	14.29*	Pitcairn Island	February 1980	0*
American Samoa	February 1980	0*	Papua New Guinea	October 1977	11.51
New Caledonia	Dec. 1977-Jan. 1978	10.15	Papua New Guinea	May-June 1979	6.14
New Caledonia	March 1980	0*	Ponape	August 1978	0*
Fiji	Jan.-Feb. 1978	8.38	Ponape	Oct.-Nov. 1978	1.54
Fiji	March-April 1978	11.36	Ponape	November 1979	2.22
Fiji	April 1980	2.82	Ponape	July 1980	0
Gambier Islands	February 1980	0*	Queensland	May 1979	3.70
Bonin Islands	October 1978	0*	Southern Cook Islands	February 1979	0*
Kiribati	July 1978	0.56	Southern Cook Islands	February 1980	0*
Kiribati	November 1978	0*	Society Islands	Dec. 1978-Jan. 1979	0.55
Kiribati	November 1979	0*	Society Islands	February 1980	0*
Kosrae	November 1978	0*	Solomon Islands	Oct.-Dec. 1977	7.41
Kosrae	November 1979	0	Solomon Islands	June 1980	11.51
Line Islands	December 1978	0*	Tokelau	November 1978	0*
Marquesas Islands	January 1979	3.75	Tonga	April 1978	1.92
Marquesas Islands	Dec. 1979-Jan. 1980	25.72	Tonga	March 1980	22.34
Northern Mariana Islands	October 1978	14.29*	Truk	August 1978	0*
Northern Mariana Islands	November 1979	200.00*	Truk	November 1979	0*
Marshall Islands	July 1978	0*	Tuamotu Islands	Dec. 1978-Jan. 1979	9.93
Marshall Islands	November 1978	0*	Tuamotu Islands	February 1980	5.43
Marshall Islands	November 1979	0*	Tuvalu	June-July 1978	1.44
Nauru	July 1980	200.00*	Tuvalu	July 1980	0*
Northern Cook Islands	Nov.-Dec. 1978	9.30*	Vanuatu	Dec. 1977-Jan. 1978	30.77
Northern Cook Islands	December 1979	0*	Wallis and Futuna	May 1978	50.16
Niue	February 1980	100.0*	Wallis and Futuna	May 1980	1.39
Norfolk Island	March 1980	0	Western Samoa	June 1978	8.57*
New South Wales	April 1979	0	Western Samoa	February 1980	0*
Palau	October 1978	0	Yap	October 1978	20.51*
Palau	August 1980	2.22	New Zealand	Feb.-March 1979	0
Phoenix Islands	December 1979	0	New Zealand	March 1980	0

* Less than 40 predators sampled.

APPENDIX D. STOMACH CONTENTS OF ALL SKIPJACK AND YELLOWFIN SAMPLED BY THE SKIPJACK PROGRAMME FROM TROPICAL WATERS BETWEEN OCTOBER 1977 AND AUGUST 1980. All sizes of skipjack and yellowfin are included.

SKIPJACK

Item No.	Diet Item	Number of Stomachs	Percentage Occurrence
	Fish and Invertebrates		
1	Chum from *Hatsutori Maru*	2667	68.60
2	Fish remains (not chum)	1669	42.93
3	Squid (Cephalopoda)	907	23.33
4	Alima stage (Stomatopoda)	576	14.81
5	Acanthuridae	552	14.20
6	Holocentridae	387	9.95
7	Shrimp (Decapoda)	295	7.59
8	Tuna juvenile (Scombridae)	256	6.58
9	Blue goatfish (Mullidae)	213	5.48
10	Balistidae	210	5.40
11	Gempylidae	185	4.76
12	Megalopa stage (Decapoda)	180	4.63
13	Unidentified fish	172	4.42
14	*Stolephorus buccaneeri* (Engraulidae)	169	4.35
15	Chaetodontidae	163	4.19
16	Juvenile fish	154	3.96
17	Synodontidae	152	3.91
18	Stomatopoda	133	3.42
19	Aluteridae	123	3.16
20	Exocoetidae	117	3.01
21	Siganidae	116	2.98
22	Anchovy juvenile (Engraulidae)	94	2.42
23	*Decapterus* sp. (Carangidae)	82	2.11
24	Euphausiid (Euphausiacea)	70	1.80
25	Carangidae	67	1.72
26	Gastropoda	67	1.72
27	Phyllosoma stage (Decapoda)	54	1.39
28	Carid shrimp (Decapoda)	42	1.08
29	*Dactylopterus orientalis* (Dacylopteridae)	40	1.03
30	Amphipoda	35	0.90
31	Fistulariidae	34	0.87
32	Priacanthidae	30	0.77
33	Bramidae	30	0.77
34	Ostraciidae	30	0.77
35	Coryphaena hippurus (Coryphaenidae)	28	0.72
36	Paralepidae	25	0.64
37	Crustacean remains	21	0.54
38	Pteropoda (Gasteropoda)	21	0.54
39	Argonauta (Cephalopoda)	19	0.49
40	Tetrodontidae	18	0.46
41	Copepoda	18	0.46
42	Oxystoma crab larva (Decapoda)	16	0.41
43	Lutjanidae	16	0.41
44	Nomeidae	15	0.39
45	Heteropoda (Gastropoda)	15	0.39
46	*Xiphasia* sp. (Xiphasiidae)	15	0.39
47	Scaridae	14	0.36
48	*Selar* sp. (Carangidae)	14	0.36
49	Leptocephalus (Anguilliformes)	13	0.33
50	Octopus (Cephalopoda)	13	0.33
51	Blenniidae	13	0.33
52	Clupeidae	12	0.31
53	Mollusca	11	0.28
54	Unidentified invertebrate	11	0.28
55	Tunicate (Urochordata)	11	0.28
56	Syngnathidae	11	0.28
57	Crustacea	10	0.26
58	Diodontidae	10	0.26

YELLOWFIN

Item No.	Diet Item	Number of Stomachs	Percentage Occurrence
	Fish and Invertebrates		
1	Chum from *Hatsutori Maru*	577	58.40
2	Fish remains (not chum)	490	49.60
3	Alima stage (Stomatopoda)	390	39.47
4	Squid (Cephalopoda)	303	30.67
5	Acanthuridae	254	25.71
6	Megalopa stage (Decapoda)	195	19.74
7	Stomatopoda	170	17.21
8	Shrimp (Decapoda)	160	16.19
9	Balistidae	141	14.27
10	Chaetodontidae	96	9.72
11	Aluteridae	87	8.81
12	Holocentridae	80	8.10
13	*Stolephorus buccaneeri* (Engraulidae)	75	7.59
14	Ostraciidae	63	6.38
15	Phyllosoma stage (Decapoda)	53	5.36
16	Unidentified fish	50	5.06
17	Amphipoda	40	4.05
18	Bramidae	39	3.95
19	Tetrodontidae	36	3.64
20	*Dactylopterus orientalis* (Dacylopteridae)	34	3.44
21	Crustacean remains	33	3.34
22	Argonauta (Cephalopoda)	27	2.73
23	Synodontidae	27	2.73
24	Tuna juvenile (Scombridae)	27	2.73
25	Juvenile fish	27	2.73
26	Gempylidae	26	2.63
27	Oxystoma crab larva (Decapoda)	26	2.63
28	Blue goatfish (Mullidae)	23	2.33
29	*Decapterus* sp. (Carangidae)	23	2.33
30	Heteropoda (Gastropoda)	22	2.23
31	Fistulariidae	22	2.23
32	Siganidae	21	2.13
33	Octopus (Cephalopoda)	21	2.13
34	Carangidae	20	2.02
35	Carid shrimp (Decapoda)	18	1.82
36	Tunicate (Urochordata)	15	1.52
37	Penaeid shrimp (Decapoda)	15	1.52
38	Euphausiid (Euphausiacea)	14	1.42
39	Exocoetidae	13	1.32
40	Gastropoda	13	1.32
41	Diodontidae	13	1.32
42	Priacanthidae	10	1.01
43	*Xiphasia* sp. (Xiphasiidae)	8	0.81
44	Leiognathidae	8	0.81
45	Nomeidae	8	0.81
46	Trash material	7	0.71
47	Syngnathidae	7	0.71
48	Engraulidae	7	0.71
49	Crustacea	7	0.71
50	Sphyraenidae	6	0.61
51	Pteropoda (Gasteropoda)	6	0.61
52	Blenniidae	5	0.51
53	Scaridae	5	0.51
54	Trichiuridae	5	0.51
55	Zoaea stage (Crustacea)	5	0.51
56	Paralepidae	5	0.51
57	Anchovy juvenile (Engraulidae)	4	0.40
58	Lutjanidae	4	0.40

59	Caesiodidae	8	0.21
60	Serranidae	8	0.21
61	Sternoptychidae	8	0.21
62	Sphyraenidae	8	0.21
63	Leiognathidae	7	0.18
64	Billfish juvenile (Istiophoridae)	7	0.18
65	Myctophidae	7	0.18
66	Decapoda	5	0.13
67	Anthias sp. (Scolopsidae)	5	0.13
68	Mullidae	5	0.13
69	Pterycombus peterii (Bramidae)	5	0.13
70	Hemirhamphidae	5	0.13
71	Trichiuridae	5	0.13
72	Penaeid shrimp (Decapoda)	4	0.10
73	Trash material	4	0.10
74	Apogonidae	4	0.10
75	Stomiatidae	4	0.10
76	Engraulidae	4	0.10
77	Anthiidae	4	0.10
78	Ranzania sp. (Molidae)	3	0.08
79	Chiasmodon sp. (Chiasmodontidae)	3	0.08
80	Invertebrate remains	3	0.08
81	Polychaeta (Annelida)	3	0.08
82	Coelenterata	3	0.08
83	Hyperiidae (Amphipoda)	3	0.08
84	Scombrid juvenile (Scombridae)	3	0.08
85	Plant material	3	0.08
86	Mola mola (Molidae)	2	0.05
87	Rastrelliger sp. (Scombridae)	2	0.05
88	Plastic material	2	0.05
89	Gonostomidae	2	0.05
90	Platycephalidae	2	0.05
91	Cigarette material	2	0.05
92	Gastrophysus sp. (Lagocephalidae)	2	0.05
93	Gobiidae	2	0.05
94	Cirrhitidae	2	0.05
95	Prawn (Decapoda)	2	0.05
96	Callionymidae	1	0.03
97	Skipjack dart tag	1	0.03
98	Megalaspis sp. (Carangidae)	1	0.03
99	Theraponidae	1	0.03
100	Paint material	1	0.03
101	Feather tuna jig	1	0.03
102	Mulloidichthys samoensis (Mullidae)	1	0.03
103	Scomberoides sp. (Carangidae)	1	0.03
104	Menidae	1	0.03
105	Bothidae	1	0.03
106	Eleotridae	1	0.03
107	Caranx sp. (Carangidae)	1	0.03
108	Fish eggs	1	0.03
109	Mollusc larvae	1	0.03
110	Cypselurus sp. (Exocoetidae)	1	0.03
111	Mollusc egg case	1	0.03
112	Bark (wood) material	1	0.03
113	Scorpaenidae	1	0.03
114	Percoidei	1	0.03
115	Isopoda	1	0.03
116	Stolephorus indicus (Engraulidae)	1	0.03
117	Shark egg case (Elasmobranchii)	1	0.03
118	Echeneidae	1	0.03
119	Zoaea stage (Crustacea)	1	0.03
120	Scombridae	1	0.03

Total Stomachs Examined 3888

Percentage Empty Stomachs 6.43

59	Echeneidae	4	0.40
60	Plant material	4	0.40
61	Anthias sp. (Scolopsidae)	4	0.40
62	Sternoptychidae	3	0.30
63	Anthiidae	3	0.30
64	Mullidae	3	0.30
65	Billfish juvenile (Istiophoridae)	2	0.20
66	Gobiidae	2	0.20
67	Fish viscera	2	0.20
68	Stomiatidae	2	0.20
69	Leptocephalus (Anguilliformes)	2	0.20
70	Coryphaenidae	2	0.20
71	Gastrophysus sp. (Lagocephalidae)	2	0.20
72	Caesiodidae	2	0.20
73	Megalops sp. (Megalopidae)	2	0.20
74	Selar sp. (Carangidae)	1	0.10
75	Copepoda	1	0.10
76	Coelenterata	1	0.10
77	Unidentified invertebrate	1	0.10
78	Rastrelliger sp. (Scombridae)	1	0.10
79	Hemirhamphidae	1	0.10
80	Bregmacerotidae	1	0.10
81	Hemirhamphidae	1	0.10
82	Taracles sp. (Bramidae)	1	0.10
83	Myctophidae	1	0.10
84	Shark egg case (Elasmobranchii)	1	0.10
85	Scomberoides sp. (Carangidae)	1	0.10
86	Ammodytidae	1	0.10
87	Menidae	1	0.10
88	Caranx sp. (Carangidae)	1	0.10
89	Clupeidae	1	0.10
90	Decapoda	1	0.10
91	Eleotridae	1	0.10
92	Scombrid juvenile (Scombridae)	1	0.10
93	Labridae	1	0.10
94	Mola mola (Molidae)	1	0.10
95	Megalaspis sp. (Carangidae)	1	0.10
96	Feather tuna jig	1	0.10
97	Stolephorus indicus (Engraulidae)	1	0.10
98	Invertebrate remains	1	0.10
99	Apogonidae	1	0.10

Total Stomachs Examined 988

Percentage Empty Stomachs 2.33