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Temporal-Spatial Relationships among Tunas and Billfishes Based on the Japanese Longline Fishery in the Atlantic Ocean, 1956 - 1965

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PREFACE

The Sea Grant Colleges Program was created in 1966 to stimulate research, instruction, and extension of knowledge of marine resources of the United States. In 1969 the Sea Grant Program was established at the University of Miami.

The outstanding success of the Land Grant Colleges Program, which in 100 years has brought the United States to its current superior position in agricultural production, was the basis for the Sea Grant concept. This concept has three objectives: to promote excellence in education and training, research, and information services in the University's disciplines that relate to the sea. The successful accomplishment of these objectives will result in material contributions to marine oriented industries and will, in addition, protect and preserve the environment for the enjoyment of all people.

With these objectives, this series of Sea Grant Technical Bulletins is intended to convey useful research information to the marine communities interested in resource development quickly, without the delay involved in formal publication.

While the responsibility for administration of the Sea Grant Program rests with the Department of Commerce, the responsibility for financing the program is shared equally by federal, industrial, and University of Miami contributions. This report, Temporal-Spatial Relationships among Tunas and Billfishes Based on the Japanese Longline Fishery in the Atlantic Ocean, 1956-1965, is published as a part of the Sea Grant Program. Graduate research work was done as an employee of the Bureau of Commercial Fisheries with considerable financial support in the form of computer time, drafting services, and guidance from Bureau of Commercial Fisheries employees.

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INTRODUCTION

The temporal-spatial relationships among tunas and billfishes caught by the Japanese Atlantic longline fishery were examined by use of statistical techniques of joint occurrences (presence-absence) and abundance correlation. Presence-absence techniques estimate the degree of distributional overlap between two species from the frequency which the two species occurred together relative to the total number of occurrences of each species among the sampling units. Abundance correlation techniques estimate the degree to which the abundances of a pair of species coincide in time and space. Both of these techniques were employed in this study to construct species groups of similar ecological preference and to assist future studies of proper management policies and optimum fishing strategy.

The distributions and abundances of some tunas are known to be influenced by environmental characteristics. The case for most species of tunas and billfishes, however, is unclear since definitive studies are few, particularly in the Atlantic Ocean. Blackburn (1965) discussed the known relationships between oceanography and the ecology of tunas. Recent studies of the relationships between longline catches of some tunas in the Atlantic and oceanographic features (e.g., temperature, thermal domes, nearness of land, productivity) were conducted by Squire (1963), Nakagome _et al_. (1965a, 1965b), and Beardsley (1969). The ecological knowledge of some species caught by longline in the Atlantic, especially the billfishes, may be enhanced by inferences from their temporal-spatial relationships with species whose ecological relationships are more fully understood.

Tunas and billfishes have been exploited by the Japanese longline fishery in the Atlantic Ocean since mid-1956. The catches per unit of fishing effort (defined by Marr, 1951, as relative apparent abundances) of some tunas and billfishes have declined through 1965, and there are indications that the fishing intensity has reached or exceeded that level which would produce a maximum sustainable annual yield (Le Guen and Wise, 1967; FAO, 1968; Wise, 1968; Wise and Fox, 1969; Fox, _in press_; Wise and Fox, _in press_). Therefore, the longline fishery would probably benefit from proper management and determination of an optimum fishing strategy. The longline fishery is a mixed-species fishery, however, so proper management and optimum fishing strategy are not easily determined (Paulik _et al._, 1967; Rothschild, 1967). One basis for such studies of mixed-species fisheries is an understanding of the temporal-spatial relationships among the exploited species.

DESCRIPTION OF THE FISHERY

The catch and fishing effort history of the Japanese Atlantic longline fishery through 1965 was published by Shiohama, Myojin, and Sakamoto (1965) and the Fisheries Agency of Japan (1966, 1967a, 1967b). The fishery has been fully reviewed by Wise (1968), Wise and Fox (1969), and Wise and Le Guen (*in press*). The Japanese reports listed ten species or species groups of scombroid fishes. Most of the fishes caught were tunas (family Scombridae). Ranked in descending order of the number caught they are yellowfin tuna, *Thunnus albacares* (Bonnaterre)[1]; albacore, *T. alalunga* (Bonnaterre); bigeye tuna, *T. obesus* Lowe; bluefin tuna, *T. thynnus* (Linnaeus); and skipjack tuna, *Katsuwonus pelamis* (Linnaeus). Billfishes (family Istiophoridae), ranked in similar order, include white marlin, *Tetrapturus albidus* Poey; blue marlin, *Makaira nigricans* Lacépède; a species group composed of sailfish, *Istiophorus platypterus* (Shaw and Nodder), and longbill spearfish, *Tetrapturus pfluegeri* Robins and de Sylva; and black marlin, *M. indica* (Cuvier). Finally, the broadbill swordfish (family Xiphiidae), *Xiphias gladius* Linnaeus, was caught in smaller numbers than scombrids or istiophorids. For the purposes of this study,

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[1] Only common names were listed in the Japanese reports which covered the fishery through 1965. Fisheries Agency of Japan (1969), however, listed the scientific names which were assumed in this study to apply to the common names given in the earlier reports.

the group listing of sailfish and spearfish was assumed to consist entirely of sailfish.

A pelagic longline was used by the Japanese to catch tunas and billfishes. The Japanese pelagic longline is 60-75 km long with about 2000 baited hooks and is divided into about 400 sections with 4 to 6 (usually 5) hooks per section. Setting the longline begins before daylight, taking about 5 hours; it is usually completed before sunrise. The longline is often set across currents or perpendicular to oceanic fronts, and is left to fish for 2-3 hours. Hauling the longline takes 12-16 hours depending mainly on the frequency of breaks in the line and the number of fish caught. Further discussion of the components of a pelagic longline and their various dimensions was presented by Okabe (1964) and Zharov et al. (1964).

Longline gear fishes from the surface (during setting and hauling) to depths of over 150 m (after settling) with the center hooks of a section fishing deeper than those near the ends. There is much uncertainty about the actual depth of capture, because the depth of fishing after the longline has settled depends on the current and wind conditions as well as the number and size of the fish already captured on the line. Conclusions by several investigators on the depth of capture of tunas and billfishes by longline, presented by Miyake (1968), are: bigeye tuna were caught on the deepest hooks, yellowfin and skipjack tunas were caught primarily when the longline was moving (during setting or hauling), and most billfishes were caught near the surface while the longline was moving.

Two major types of fishing vessels used by the Japanese in longlining for tunas and billfishes in the Atlantic Ocean were: (1) longliners of 50-1000 GT (gross tons) referred to hereafter as boats and (2) smaller longliners of about 19 GT, carried to the fishing grounds on the decks of "motherships," hereafter called skiffs (Zharov _et al_., 1964). Nearly all boat operations were conducted by longliners of 200-500 GT with an average crew of 30. The motherships of skiff operations were primarily over 500 GT with an average crew of 80 men (Federation of Japan Tuna Fisheries Co-operative Associations and Japan Tuna Fisheries Federation, 1968). The fishery in the Atlantic was instituted in 1956 by boat operations. Skiff operations entered the fishery in 1957 and by 1964 fished nearly half the total number of hooks (Fisheries Agency of Japan, 1967a). Prior to 1964, the Fisheries Agency of Japan did not distinguish between the two types of operations in reporting the catch and fishing effort statistics, but for 1964 and 1965 the data from boats and skiffs were published separately.

The temporal-spatial distribution of fishing was not the same in the years 1956-1965, mainly because the Japanese Atlantic longline fleet expanded its fishing both in time and space to a maximum coverage in 1965. The seasonal fishing pattern of the fleet remained generally the same through 1963, though increasing in intensity, and may be summarized as follows: (1) in the tropics, roughly 20°N to 10°S latitude, fishing was heaviest in the eastern Atlantic in January-March, it favored the western side in April-September, and was fairly evenly distributed in October-December; (2) outside of the tropics, fishing was most intense in the southwest during January-March, in April-June it was heaviest in the northwest, it favored the northwest and southeast in July-September, and was fairly evenly distributed in October-December (see Shiohama _et al_., 1965; Fisheries Agency of Japan, 1966). In 1964 and 1965 fishing extended over most of the tropical and temperate Atlantic Ocean year-round except in the southwest and northeast during April-June (see Fisheries Agency of Japan, 1967a, 1967b).

MATERIALS

The data used in this study, published by Shiohama _et al_. (1965) and by the Fisheries Agency of Japan (1966, 1967a, 1967b), were made available on punched cards by the Bureau of Commercial Fisheries Tropical Atlantic Biological Laboratory, Miami, Florida. Each data card included the number of hooks fished and the number of each species of fish caught by month and location expressed as an area of 5° longitude by 5° latitude (hereafter called a 5° square).

The temporal-spatial sampling unit, for the purpose of this study, was a month-5° square. The sampling unit is large, covering about 90,000 square miles at the equator and somewhat less at greater latitudes, but it was the smallest unit available at the time of this study.

Charts of monthly mean sea surface temperature isotherms for the tropical Atlantic Ocean were published by Mazeida (1968). The charts covered the Atlantic Ocean from 20°N to 20°S latitude and provided the data for comparing the relative ecologies of tunas and billfishes on the basis of temperature.

ANALYSES OF TEMPORAL-SPATIAL RELATIONSHIPS

Analyses of temporal-spatial relationships among organisms are used to estimate associations or abundance correlations resulting from commensalism, mutualism, parasitism, or symbiosis in the strictest sense, of similarity of ecological preference in a broader sense. Which type of relationship is estimated depends on (1) the size of the sampling unit and (2) the type of analysis. Because of the large sampling unit (5° square) used in this study and the known biology of tunas and billfishes, any relationships inferred by this study were considered to be a result of ecological similarity.

Fundamentally, there are only two approaches to estimating temporal-spatial relationships, one based on presence-absence (joint occurrences) and the other based on abundance. The main argument against use of presence-absence analyses is that much information about a relationship is lost by merely recording a presence rather than the "degree of presence" or abundance. The most common abundance analysis -- correlation -- was criticized by Hurlbert (1969) on the bases that (1) results are dependent on within-quadrat heterogeneity, (2) competition is difficult to differentiate from associations in the strictest sense, and (3) abundance data usually exhibit contagion and are therefore not amenable to statistical analysis.

There are basically two procedures used in presence-absence analyses. The most common procedure involves calculation of a measure of the degree to which two species occur jointly in the samples as compared to the degree of occurrence that would be expected due to chance alone. Those species pairs showing significant affinity are either grouped (Fager and Longhurst, 1968) or considered to be associated in some sense. Primary criticisms of this procedure are: (1) species with widely different frequencies in the samples are usually not treated, or if they are statistical probability may be distorted, (2) species not showing statistically significant affinity are not treated, and (3) statistical significance may be a function of the energy of the data-collector rather than a function of the relationship between two species (Mc Connaughey, 1964). The alternative procedure of Mc Connaughey (1964) involves calculation of a grouping coefficient which is not based on statistical significance, which regularly compensates for the relative frequencies of each species, and which is used to group those species with positive coefficients. Mc Connaughey's procedure was chosen for this study primarily for the reasons he outlined and secondarily because of its relative simplicity, since presence-absence procedures provide information on the degree of distributional overlap only.

There are two common procedures which use abundance data -- percentage species composition and correlation. The former procedure usually involves calculation of an index of similarity of species composition among samples and essentially provides information similar to that of a presence-absence analysis (see Day and Pearcy, 1968). The correlation procedure estimates relationships if the abundances (or measures of them) of two species being compared vary concomitantly (i.e., in the same direction to estimate a positive relationship or in opposite directions to estimate a negative relationship). There are several indices of correlation (see Hurlbert, 1969), but the one used in this study was the simple (or product-moment) correlation coefficient, _r_.

Hurlbert's (1969) objections to use of correlation analysis resulted from the type of information he desired. Hurlbert was interested in a procedure that would estimate associations in the strictest sense and would avoid estimating associations due to similar ecology or competition. The primary concern of this study is to estimate temporal-spatial relationships resulting from similar relative ecology between pairs of species, a function of within-quadrat heterogeneity. Competition should not influence estimation of broad ecological similarity because of the large sampling unit. Appropriate transformation makes the data amenable to statistical analysis.

Mc CONNAUGHEY'S PRESENCE-ABSENCE PROCEDURE

Methods

Mc Connaughey's grouping coefficient, I, was calculated by:

$$I = \frac{(A+B)C}{A \cdot B} - 1 \qquad \ldots .(1)$$

where A is the number of samples in which Species A occurred, B is the number of samples in which Species B occurred, and C is the number of samples in which both species occurred (number of joint occurrences). The statistic I theoretically ranges from +1 indicating that the two species are never found separate, to -1 indicating that the two species are never found together.

Results

Total occurrences of each species among all sampling units, 1956-65, and the joint occurrences and Mc Connaughey's grouping coefficients, I, among all species pairs are given in Table 1. Four species -- yellowfin tuna, bigeye tuna, albacore, and blue marlin -- occurred in more than 80% of the sampling units. The magnitude of the grouping coefficients for all pairs of these four species among themselves and among all other species paralleled the frequencies of occurrence of each species. It has already been shown that fishing effort of the Japanese longline fleet was correlated in time and space with the catch per unit effort of yellowfin tuna in most years (Wise, 1968; Wise and Fox, 1969; and

TABLE 1. -- Total occurrences (diagonally within boxes), joint occurrences (above boxes), and McConnaughey's (1964) grouping coefficients *I* (below boxes) for pairs of tunas and billfishes from all sampling units[a] in the Atlantic Ocean, 1956-65

	Yellowfin Tuna	Bigeye Tuna	Albacore	Blue Marlin	Swordfish	White Marlin	Sailfish	Bluefin Tuna	Skipjack Tuna	Black Marlin
Yellowfin Tuna	4570	4259	4141	3891	3698	3216	2954	1377	303	171
Bigeye Tuna	.887	4460	4065	3749	3670	3148	2902	1393	294	168
Albacore	.870	.857	4298	3612	3471	3055	2738	1400	292	169
Blue Marlin	.839	.792	.757	3941	3345	2995	2768	1249	294	166
Swordfish	.782	.788	.721	.729	3801	2867	2681	1293	284	155
White Marlin	.686	.667	.644	.675	.630	3274	2521	1195	278	145
Sailfish	.633	.620	.552	.645	.601	.612	2993	1033	282	128
Bluefin Tuna	.266	.288	.306	.192	.246	.202	.069	1428	146	85
Skipjack Tuna	.053	.024	.019	.032	-.000	-.010	.013	-.422	307	18
Black Marlin	.032	.014	.022	.007	-.058	-.113	-.213	-.446	-.837	172

[a] 4839 total sampling units

Wise and Le Guen, in press). This would account for the high degree of incidence of yellowfin tuna in the sampling units. The measure of the degree of distributional overlap of yellowfin tuna with other species was determined merely by the number of occurrences of the other species, which was also the case for bigeye tuna and blue marlin. One exception was that the distribution of albacore overlaped more with that of black marlin than that of skipjack tuna.

The degree of distributional overlap between species pairs other than those already discussed did not parallel frequency of occurrence in many cases. Swordfish overlaped most with bigeye tuna and more with blue marlin than albacore. White marlin overlaped most with blue marlin aside from yellowfin tuna. Sailfish exhibited the highest overlap with blue marlin, more overlap with white marlin than with swordfish, and least overlap with albacore among the more frequent species. Bluefin tuna overlaped most with albacore and next with bigeye tuna. Skipjack tuna overlaped more with blue marlin than with either bigeye tuna or albacore. Finally, black marlin overlaped more with albacore than with bigeye tuna.

Segregation of species groups with similar relative ecology was not achieved with this procedure since all species pairs, except many of those with skipjack tuna and black marlin, received positive grouping coefficients among each other. Possibly, the sampling unit (1 month - 5° square) was too large for an analysis based on joint occurrences. The only conclusion that can be drawn, on the basis of joint occurrences, is that within the sampling unit most species of tunas and billfishes may be caught together.

ABUNDANCE CORRELATION PROCEDURE

Methods

The correlation coefficient, $\underline{r}$, used as a measure of the temporal-spatial relationship between the abundances (or measures of them) of two species theoretically ranges from +1, indicating that the abundances (or measures of them) of two species change in the same direction, to -1 indicating such change in opposite directions. Since it is seldom possible to measure true abundance (actual number of organisms per unit area or volume), a measure of relative abundance is often adopted which is assumed to be proportional to true abundance. Three assumptions which must be made in order for $\underline{r}$ to be a statistically valid measure of the relationship between two variables are: (1) the relationship must be linear, (2) the frequency distribution of each variable must be normal, and (3) the standard deviation of each variable must be independent of their means. The assumptions involved with statistical analyses and those with the measure of relative abundance were examined.

Measure of relative abundance. -- In using fishery data the measure of relative abundance most often chosen is catch, $\underline{C}$, per unit of fishing effort, $\underline{f}$, per unit time per unit area or simply catch per unit effort, denoted $\underline{U}$. Catch per unit effort used in this study is the number of fish caught per 100 hooks per month in a 5^{o} square. Since some 5^{o} squares are coastal and contain land areas, the catch per 100 hooks per month was weighted according to the number of 1^{o} squares (Appendix,

Table A-1) covering water, n, as follows:

$$U_{ijk} = (n_k/25)\ (C_{ijk}/f_{ijk}) \qquad \text{....(2)}$$

where i refers to the species, j refers to the month, and k refers to the particular 5^0 square.

Statistical assumptions. -- It has been shown that the distribution of U_{ijk} in space exhibits "contagion," therefore its frequency distribution is not normal and its standard deviation is dependent on the mean (Taylor, 1953; Murphy and Elliot, 1954; and Taylor, 1961). Two transformations, the arcsin and the logarithmic, frequently have been employed to make U_{ijk} amenable to statistical analysis.

In a study of the variability of trawl catch per unit effort, Taylor (1953) concluded that, while both transformations achieved satisfactory results, the arcsin transformation was more appropriate on theoretical bases. Murphy and Elliot (1954) studied both transformations in connection with longline catch per unit effort and concluded that the logarithmic transformation was as acceptable as the arcsin transformation and was considerably easier to apply. Therefore, the U_{ijk} were transformed to natural logarithms as follows:

$$U'_{ijk} = \log_e(U_{ijk}+1) \qquad \text{....(3)}$$

which was the statistic used in all subsequent analyses in this study.

Sources of variation in U_{ijk}. -- Catch per unit effort is proportional to true abundance if each unit of effort removes the same proportion of fish present in any constant temporal-spatial stratum. Variation in this proportionality may result from (1) changes in availability (i.e. the proportion of fish present which are available to the fishing effort), (2) low amounts of fishing effort in the temporal-spatial stratum, (3) competition for gear in a multiple species fishery, and (4) differences in the efficiency of fishing gear.

Availability was not measurable so was assumed to be a random variable with a mean deviation of 0.

The number of hooks fished in any 5° square during any month ranged from about 1000 to about 600,000. No major study has been conducted to determine the level of effort which would provide reliable catch per unit effort values for the Japanese Atlantic longline fishery. Griffiths and Nemoto (1967), in a study of a small amount of longline data from the Caribbean Sea and adjacent regions, concluded that deletion of observations represented by low fishing effort levels was not necessary. While most variation of this sort may result from fishing only a few days in a small part of the 5° square, subjectivity in estimation of effective fishing effort is another source of variation. This subjectivity is high in fisheries which use gear such as purse seines and which search for fish before setting the gear, but is probably relatively low in the longline fishery in which effort is measured by the number of hooks fished. Therefore, deletion of observations represented by low levels of fishing effort was considered unnecessary in this study.

A single longline set may catch several species of tunas and billfishes, inferring the possibility of competition among species for the gear (i.e. a hook which is occupied by a fish of one species is no longer available to capture a fish of any other species). Competition for the gear produces bias in the catch per unit effort estimate for individual species in a mixed catch. Rothschild (1967) developed a simple stochastic model for predicting the theoretical probability of capture for any single species from the probability of capture observed for the single species and from that observed for the total catch. The difference between the predicted and observed probabilities of capture for a single species depends primarily on the observed probability of capture for the total catch, approaching no difference asymptotically as the observed probability of capture for the total catch approaches 0. Generally, as Rothschild points out in his example, the observed probability of capture for the total catch in the Japanese longline tuna fishery is rarely greater than 0.1 (10 fish per 100 hooks) and the correction which would be applied to the data is quite small. In fact, for the data used here, the total fish per 100 hooks rarely exceeds 5.0, so no correction was applied to the data.

To use data from both boat and skiff operations, either it must be assumed that these operations capture tunas and billfishes with equal efficiency or their comparative efficiencies must be investigated. The latter alternative was chosen since differences in efficiency might seriously affect the results of subsequent analyses.

As mentioned previously, the data were published separately for boat and skiff operations only in 1964 and 1965. For comparison of efficiencies of boat and skiff operations, only those data representing sampling units (1 month - 5° square) in which both operations were conducted in 1964 and

1965 were used. The total catch (all species combined) per unit effort was considered to be a more reliable variable for a study of gear efficiency than the catch per unit effort for individual species. The slope, b, of the regression between boat and skiff catch per unit effort values was calculated as:

$$b = \frac{\Sigma X_1 X_2}{\Sigma X_1^2} \qquad \ldots.(4)$$

where X_1 represented the U'_{ijk} of skiff operations and X_2 represented the U'_{ijk} of boat operations, since the intercept of the regression was assumed to pass through the origin. In the analysis no attempt was made to distinguish temporal or spatial differences in boat and skiff efficiency. If there was no difference in efficiency between boats and skiff, the value or b would not be expected to deviate significantly from 1. Therefore, a t-test was used to compare b with 1 at $P<0.05$, the level of significance used throughout this study.

There were 315 paired boat and skiff operations in 1964 and 396 in 1965. The frequency distribution of the ratio of U'_{ijk} of boats to that of skiffs was significantly different between 1964 and 1965 (Table 2); therefore the comparison of boat and skiff efficiency was made separately for each year. The regression coefficient, b, was 1.007 for 1964 and 1.063 for 1965 (Table 3). For 1964, b was not significantly different from 1; i.e., boats and skiffs were apparently equally efficient. However, b for 1965 was significantly different from 1; boats were significantly more efficient than skiffs. Even though b was significantly different from 1 in 1965, the difference was very small (0.063). Since

TABLE 2. -- Frequency distribution of the ratio of $U'_{\underline{ijk}}$ for boats to $U'_{\underline{ijk}}$ for skiffs for 1964 and 1965, and chi-square test of homogeneity between distributions

Lower Limit of Class	1964	1965	Lower Limit of Class	1964	1965
.45	2	1	1.10	23	35
.50	1	0	1.15	19	34
.55	3	1	1.20	14	28
.60	1	0	1.25	10	16
.65	1	3	1.30	9	10
.70	4	4	1.35	5	14
.75	9	15	1.40	6	4
.80	20	11	1.45	1	2
.85	22	17	1.50	4	8
.90	27	28	1.55	2	4
.95	37	35	1.60	1	4
1.00	48	58	1.65	2	3
1.05	39	45	1.70	5	16

Chi-square = 74.54

TABLE 3. -- Regression coefficient b between boat U'_{ijk} and skiff U'_{ijk} and t-tests of significance from 1

Year	b	Mean Square Deviation from Regression	Variance of b	t	n
1964	1.007	8.189×10^{-2}	1.041×10^{-4}	0.727	315
1965	1.063	8.876×10^{-2}	1.186×10^{-4}	5.747*	396

*Indicates b is significantly different from 1 the total catch per 100 hooks rarely exceeds 5.0 any adjustment due to this slight difference of b from 1 would be minor for any individual species and therefore it was considered unnecessary.

Analytical procedure. -- There are three ways that the data may be treated in calculating the correlation coefficient, r: (1) by using all data from all sampling units, (2) by including only those data in which at least one species of the pair occurred, or (3) by using only the data in which both species of the pair occurred. The first treatment was used in this study since the degree of distribution overlap is taken into account by using all data. The premise made was that two species, whose abundances (or measures of them) vary directly when and where the species are together, are ecologically more similar if their distributions are alike.

There were two sources of bias which still existed in the data after logarithmic transformation: (1) the frequency of sampling and (2) the declines in catch per unit effort of some species in some areas of the Atlantic Ocean. Much bias was eliminated by omitting data before 1961, which included the largest expansion of the fishery (Table 4) and the greatest declines in catches per unit effort. Furthermore, r-values were calculated for all species pairs each year separately to minimize variation due to among year declines.

To examine possible effects of (1) bias introduced by temporal and spatial differences in sampling frequency and (2) fish stock differences in ecological preference, the 1961-65 data were analyzed by selecting 5° square subsamples which were sampled every month within one year, by including the sampling units of larger geographical areas

TABLE 4. -- Number of sampling units (n), 1956-65

Year	n	Year	n
1956	23	1963	586
1957	134	1964[a]	806
1958	132	Boats	(742)
1959	241	Skiffs	(379)
1960	307	1965[a]	1058
1961	401	Boats	(920)
1962	440	Skiffs	(534)

[a] Catch and effort data for jointly occurring boat and skiff operations were pooled. See text for explanation.

of high sampling intensity for 1961-65, and by grouping all sampling units into four quadrants of the Atlantic Ocean for 1961-65. In the year of most intense fishing, 1965, there were only four 5° squares which were fished every month, but two of them were adjacent squares. Therefore, only three of the squares were selected as the best representative subsample and were numbered 1, 2, and 3 for convenience (Figure 1). These three 5° squares represented three widely separate geographical regions and formed the nuclei for treating the data in larger geographical areas. Next the sampling units in larger areas, lettered A, B, and C (Figure 1), were analyzed for each year, 1961-65. Areas A, B, and C introduced some temporal-spatial bias (Table 5) into the results but included broader pictures of the apparent relationships among the species. Finally, all sampling units were treated on the basis of four quadrants of unequal size, NW, SW, NE, and SE (Figure 1), of the Atlantic Ocean for each year, 1961-65. The Quadrant SW represented a geographical region not treated at the two smaller scales because of its highly seasonal distribution of fishing effort. Presence of sampling units, denoted by an X (Table 6), indicates the high degree of possible bias in the results from the quadrant treatment. The divisioning of the quadrants was based on the author's personal belief of the approximate stock distribution of the more abundant species and on the consideration of areas used in other studies of the Japanese Atlantic longline fishery.

For each species pair there are 3 $\underline{r}$-values in the "Square" treatment (i.e. three 5° squares), 15 $\underline{r}$-values in the "Area" treatment (i.e. five yearly values for each of three areas), and 20 $\underline{r}$-values in the "Quadrant" treatment (i.e. five yearly values for each of four

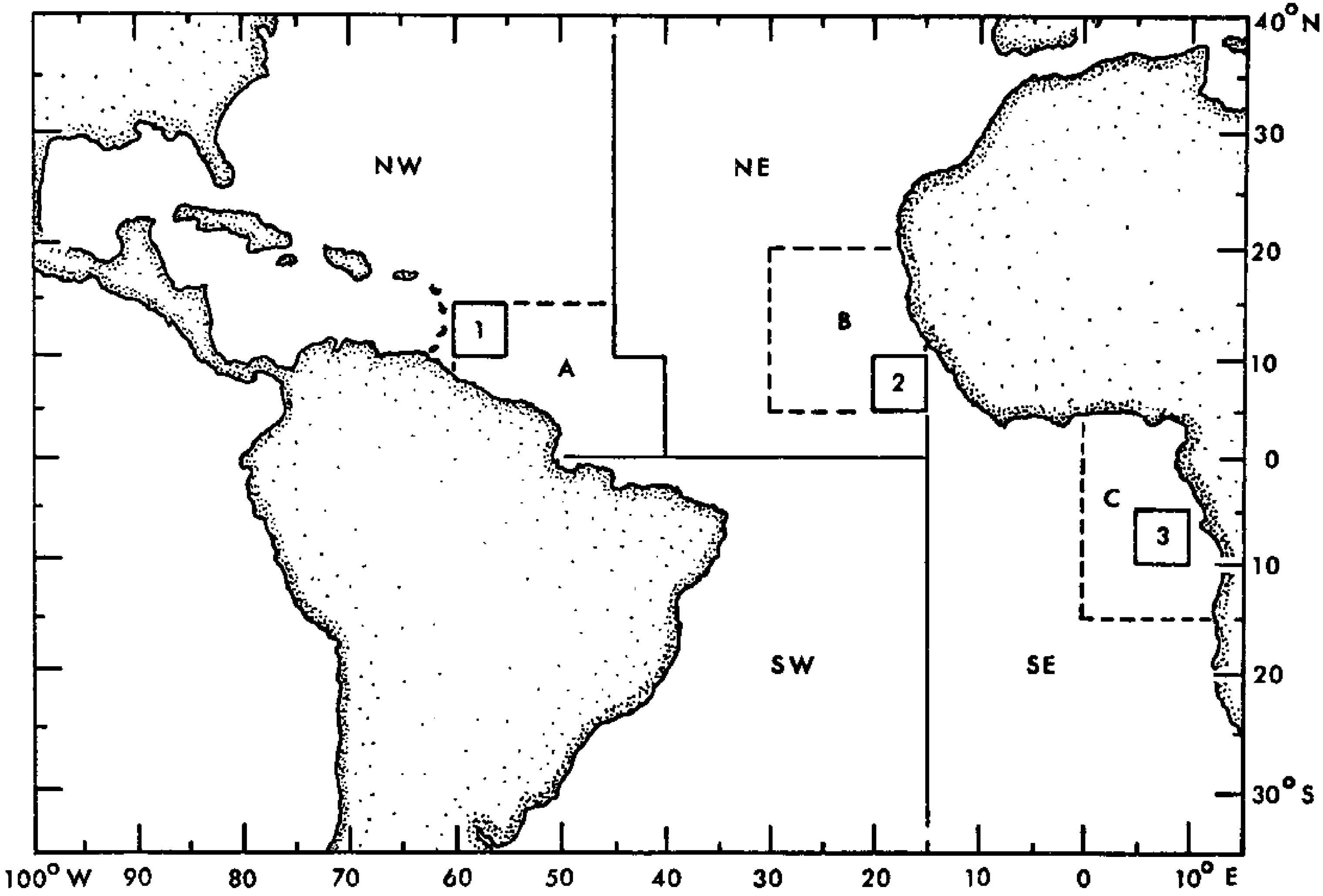

Figure 1. -- Subdivisions of the Atlantic Ocean used in this study: Squares 1, 2, and 3; Areas A, B, and C; and Quadrants NW, SW, NE, and SE.

TABLE 5. -- Monthly number of sampling units[a] in Areas A, B, and C, 1961-65

		Month											
Area	Year	J	F	M	A	M	J	J	A	S	O	N	D
A	1961					3	4	6	7		9	4	2
	1962					7	9	5	4	8	7	2	
	1963		1	4	5	9	3	4	7	6	8	8	5
	1964	4	7	7	9	6	4	6	7	8	7	8	3
	1965	6	4	8	8	8	5	7	8	9	7	4	6
B	1961				1	6	8	7	7	6	1	2	3
	1962	3			6	9	7	8	4	6	3	2	
	1963	1	4	1	6	9	9	5	7	6	4	7	4
	1964		2	4	6	9	4	4	6	9	8	7	1
	1965	5	3	8	9	8	7	7	9	9	9	5	8
C	1961	9	8	7	9	4	4	10	5	1	8	10	5
	1962	2	9	9	9		5	6	2	2	4	2	3
	1963	6	10	9	1	1	2	4	4	6	8	6	5
	1964	5	3	2					2	3	4	2	5
	1965	9	10	8	9	8	8	10	10	8	10	9	6

[a] 9 5-degree squares in Areas A and B, 10 5-degree squares in Area C.

TABLE 6. -- Presence of monthly sampling (X) in Quadrants NW, SW, NE, and SE, 1961-65b[a]

		Month											
Area	Year	J	F	M	A	M	J	J	A	S	O	N	D
NW	1961	X	X	X		X	X	X	X	X	X	X	X
	1962			X		X	X	X	X	X	X	X	
	1963		X	X	X	X	X	X	X	X	X	X	X
	1964	X	X	X	X	X	X	X	X	X	X	X	X
	1965b	X	X	X	X	X	X	X	X	X	X	X	X
SW	1961	X	X	X	X	X	X	X	X		X	X	X
	1962	X	X	X	X	X	X	X		X	X	X	X
	1963	X	X	X	X	X		X		X	X	X	X
	1964	X	X	X	X	X	X			X	X	X	X
	1965b	X	X	X	X	X			X	X	X	X	X
NE	1961			X	X	X	X	X	X	X	X	X	X
	1962				X	X	X	X	X	X	X	X	X
	1963	X	X	X	X	X	X	X	X	X	X	X	X
	1964		X	X	X	X	X	X	X	X	X	X	X
	1965b	X	X	X	X	X	X	X	X	X	X	X	X
SE	1961	X	X	X	X	X	X	X	X	X	X	X	X
	1962	X	X	X	X	X	X	X	X	X	X	X	X
	1963	X	X	X	X	X	X	X	X	X	X	X	X
	1964	X	X	X	X	X	X	X	X	X	X	X	X
	1965b	X	X	X	X	X	X	X	X	X	X	X	X

[a] See text for discussion of treatment of the data for 1965.

quadrants). To determine whether or not the _r_-values were homogeneous (i.e. all estimates of a common _r_-values, hence the common temporal-spatial relationship) within each treatment, the _r_-values were appropriately transformed, weighted, and tested with chi-square (Snedecor and Cochran, 1967: 185-188). An observed chi-square value, significantly different from the expected value, with unbiased sampling indicated the existence of a different relationship between the two species among geographic regions.

Within each geographical treatment of the data, ecological similarities among tunas and billfishes were summarized by a grouping procedure similar to those described by Mc Connaughey (1964) and Fager and Longhurst (1968) as follows:

1. Beginning with the dominant species, the species which shared the greatest positive _r_-value with the dominant species was grouped with it. All species sharing negative _r_-values with those two species were eliminated as possible members of the group.

2. A third species was selected from the remaining possible members which gave the highest possible sum of _r_-values with the first two members of the group. All species sharing negative _r_-values with the third member of the group were eliminated. This step was repeated for the fourth species, etc., until no more species could be added to the group.

3. All species sharing positive _r_-values with some members of the group but negative _r_-values with other members were listed as associates of the group.

4. The second most dominant species was selected and steps 1-3 were repeated.

5. Steps 1-4 were repeated for each species. All groups which had the same members were considered as one group and listed in the order determined by the group with the most dominant member at the head. Species which ended up in more than one group were placed in the group where they shared the greatest positive *r*-value with the dominant member and were listed as an associates of the other groups.

6. Inter-group relationships were expressed as fractions of possible connections indicated by the sharing of associates.

Results

Squares 1, 2, and 3. -- The correlation coefficients, *r*, between the U'_{ijk} of tunas and billfishes of Squares 1, 2, and 3 for 1965 are listed in the Appendix (Table A-2). Of the 100 possible *r*-values, 17 were significantly different from 0. In among-square comparisons of the *r*-values of each species pair, the chi-square test indicated significant heterogeneity in 7 of 36 possible comparisons (Appendix, Table A-2). The grouping procedure, therefore, was completed separately for each square (Figure 2). All species were grouped regardless of the magnitude of their species pair *r*-values. An asterisk after a species name in Figure 2, however, indicates that the U'_{ijk} of the species were significantly correlated with those of the dominant member (listed first in the box) of the particular group.

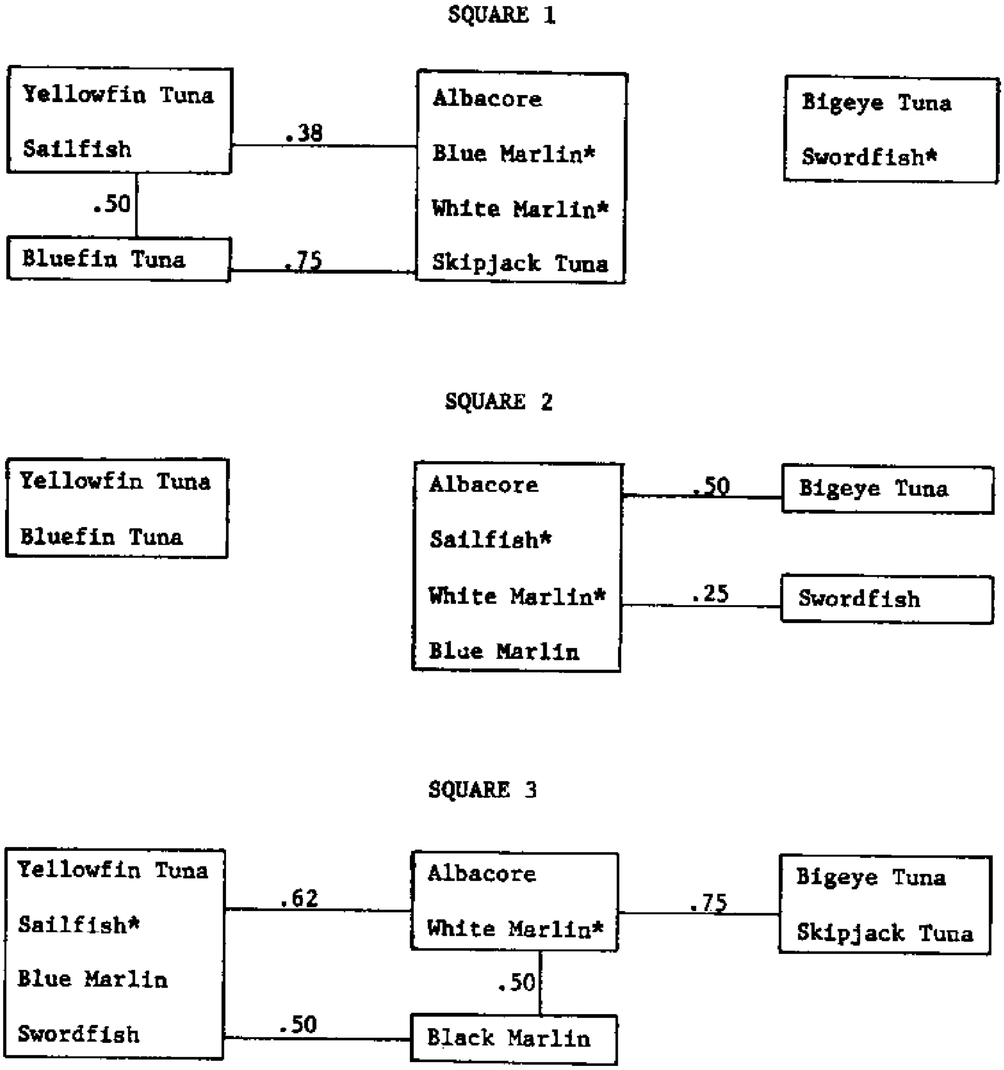

Figure 2. -- Diagram of species groups for Squares 1, 2, and 3. An asterisk (*) after a species name indicates that the species and the dominant member of the group are significantly correlated ($P < 0.05$). Interconnecting lines indicate related groups; the value is the fraction of total possible connections between groups (see text for explanation).

In all three squares, yellowfin tuna, albacore, and bigeye tuna formed separate, though somewhat inter-related, groups. The members of their groups varied with the square. The only consistently grouped species pair was albacore-white marlin, which also exhibited significant correlation in all three squares. Albacore and blue marlin were grouped together in Squares 1 and 2, but not in Square 3. Yellowfin and sailfish were grouped together in Squares 1 and 3, but not in Square 2. Of the remaining species pairs, none were grouped the same in any two squares.

Areas A, B, and C. — The correlation coefficients, r, between the U'_{ijk} of tunas and billfishes of Areas A, B, and C for 1961-65 are listed in the Appendix (Table A-3). Of 621 possible r-values, 132 were significantly different from 0. Those species pairs with two or more r-values significantly different from 0 (i.e. more than the 5% expected due to chance alone) were selected for further analysis. This editing essentially eliminated all species comparisons with bluefin tuna, skipjack tuna, and black marlin, evidently a result of these three species appearing so infrequently (Table 1) and sporadically in the longline catch.

Chi-square tests among the r-values (areas and years) for each species pair indicated significant heterogeneity in all comparisons except bigeye tuna-sailfish. The r-values of the selected species pairs were transformed, weighted, and averaged to obtain weighted mean $\bar{r}$-values by areas and by years (Snedecor and Cochran, 1967: 185) for each species pair (Appendix, Table A-4). It was evident by inspection that the greatest contribution to chi-square, in most cases, was due to among-area variation. Grouping of the species, therefore, was conducted for each area separately using the area means (Figure 3). Asterisks after a species name in Figure 3 indicate the number of years in which the r-values between that species and the dominant member of the group were significantly correlated -- 1 asterisk for 2 or 3 and 2 asterisks for 4 or 5 years.

The species groups obtained for Areas A, B, and C are remarkably similar to those obtained for Squares 1, 2, and 3 respectively. Except for swordfish in Areas B and C, and bigeye tuna in Area C, the species groups for Squares and Areas are identical -- in spite of the temporal and spatial sampling bias of the treatment by areas.

Quadrants NW, SW, NE, and SE. -- When the correlation coefficients among all species pairs had been calculated for the quadrants shown in Figure 1, it was noted that significant correlations between bigeye tuna and other species from 1961-64 were not significant in 1965. Examination of the data revealed that fishing had expanded north and south in 1965 and fishing above 30° North and below 25° South had become more intense. Groups of bigeye tuna exist in these regions (see Fisheries Agency of Japan, 1967b) and apparently exhibit opposite temporal-spatial relations relative to other species than do bigeye tuna which are nearer the equator. The result was a cancelling out of the r-values, which indicates the importance of stock distribution in creating statistical areas for this analysis. Therefore, all data above 30° North and below 25° South were separated into two new regions, N and S respectively, and the r-values were recalculated for 1965. The r-values calculated from all 1965 data in Quadrants NW, SW, NE, and SE

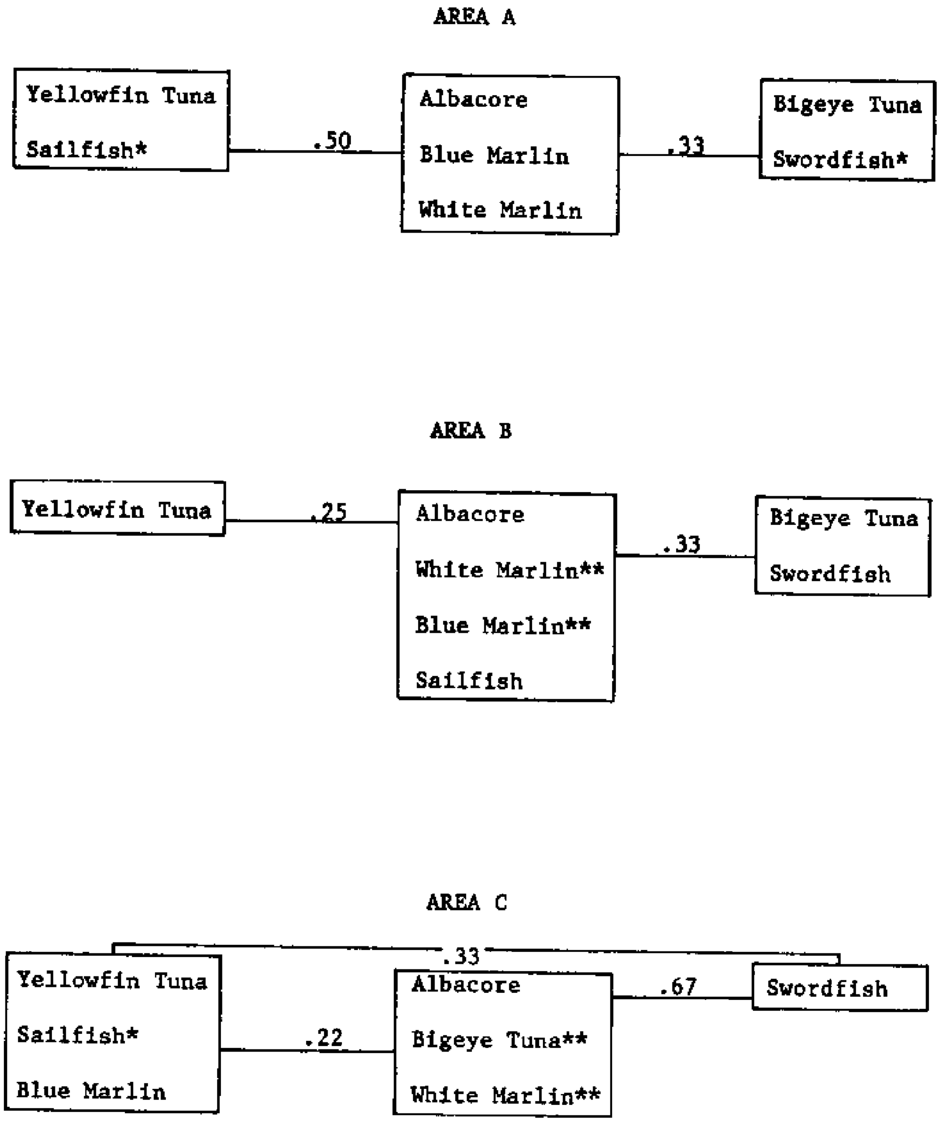

Figure 3. -- Diagram of species groups for Areas A, B, and C. The number of asterisks after a species name indicates the level of confidence between the species and the dominant member of the group (see text). Interconnecting lines indicate related groups; the value is the fraction of total possible connections between groups (see text).

were designated 1965a and those calculated from the edited 1965 data were designated 1965b (Appendix, Table A-5). The 1965b data were used in the following analysis since for species other than bigeye tuna the r-values did not differ appreciably between sets a or b.

Of 837 possible r-values, 257 were significantly different from 0. Those species pairs with three or more r-values significantly different from 0 with the same sign (+ or -) within a quadrant (i.e. more than the 5% expected due to chance alone), were selected for further analysis. As in the analysis by areas, this editing effectively removed comparisons of species pairs with bluefin tuna, skipjack tuna, and black marlin. One exception worth mentioning is that the $\underline{U'_{ijk}}$ of albacore and bluefin tuna were significantly negatively correlated in Quadrant SW for 4 of the 5 years treated (1961-65).

Chi-square tests among the r-values (quadrants and years) for each of the selected species pairs indicated significant heterogeneity in all comparisons. Weighted mean $\bar{r}$-values were calculated as in the area section by quadrants and years (Appendix, Table A-6). It was evident by inspection that the greatest contribution to chi-square, in most cases, was due to among-quadrant variation. Grouping of the species, therefore, was conducted for each quadrant separately using the quadrant means (Figure 4). Asterisks after species names in Figure 4 indicate the same level of confidence in the relationship as in the area relationships (Figure 3).

Except for bigeye tuna and swordfish in some quadrants, the species groups of Quadrants NW, NE, and SE are identical with those of Areas A, B, and C and those of Squares 1, 2 and 3 respectively. They are:

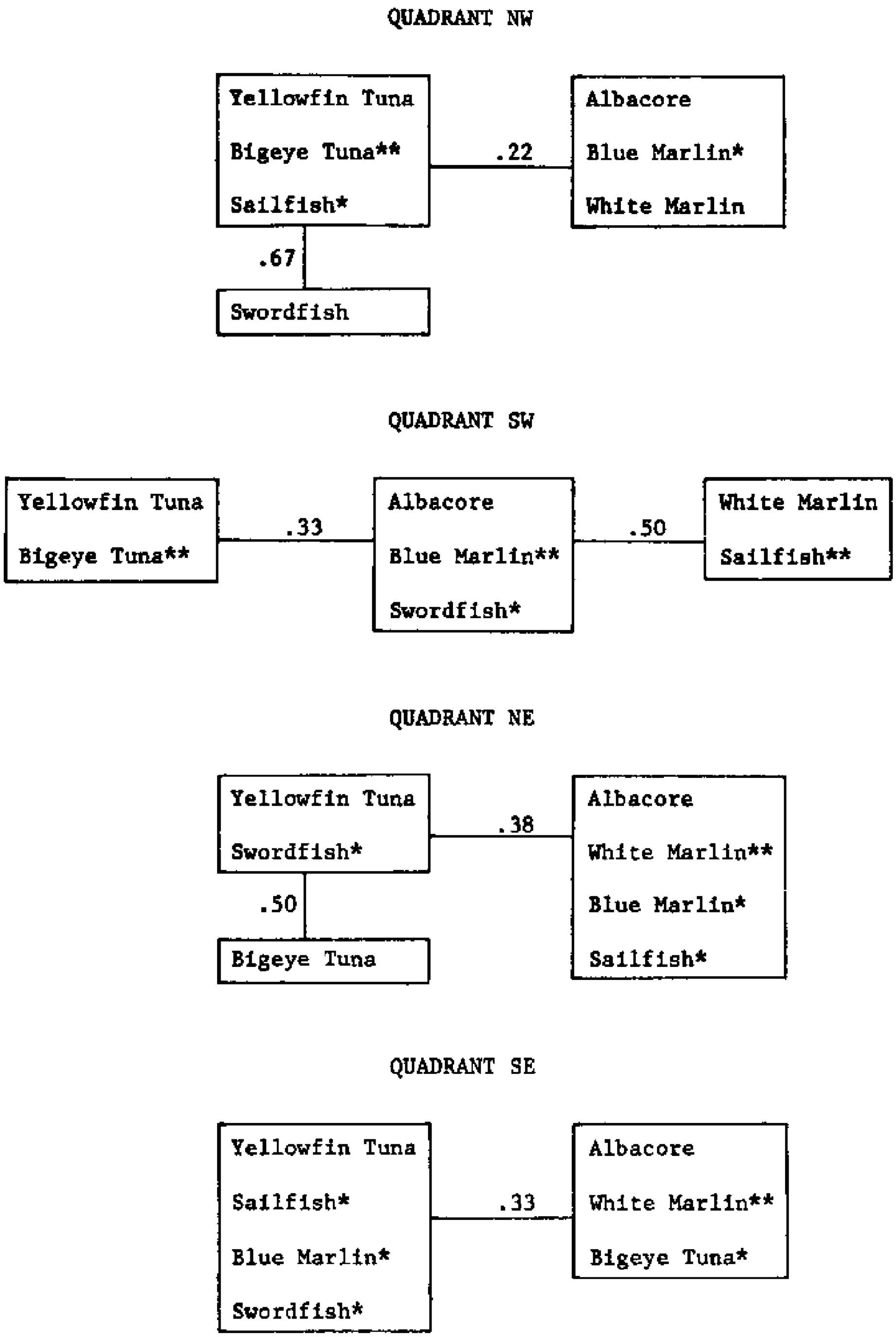

Figure 4. -- Diagram of species groups for Quadrants NW, SW, NE, and SE. The number of asterisks after a species name indicates the level of confidence between the species and the dominant member of the group (see text). Interconnecting lines indicate related groups; the value is the fraction of total possible connections between groups (see text).

Region I (Square 1, Area A, Quadrant NW)

a. Yellowfin tuna - sailfish

b. Albacore - blue marlin - white marlin

Region II (Square 2, Area B, Quadrant NE)

a. Yellowfin tuna (alone)

b. Albacore - white marlin - blue marlin - sailfish

Region III (Square 3, Area C, Quadrant SE)

a. Yellowfin tuna - sailfish - blue marlin

b. Albacore - white marlin

Quadrant SW was similar to the others in that yellowfin tuna and albacore are separate, but was closer to NW and NE, though, in that blue marlin was grouped with albacore and bigeye tuna was closely allied with yellowfin tuna.

CORRELATION OF SEA TEMPERATURE AND SPECIES ABUNDANCE

According to Blackburn (1965) the primary oceanic property which may determine seasonal distribution of tunas is temperature. Therefore, some insight can be gained concerning the ecological significance of the species groups obtained with abundance correlation, by examining the relationships of these groups to sea temperature. No sea temperature data collected synoptically with the species catch and effort data were available. In addition, the only sea temperature data available were surface temperatures from Mazeika (1968). Temperature at the average depth of capture, say 75 m, would probably be more directly related to the abundance of longline-caught tunas and billfishes. Sea surface temperature, however, may reflect the same trend as deeper water. Significant time-lag between surface and deep water trends may result in failure to detect real temperature correlations unless there is a similar time-lag in the trend of fish abundance.

Methods

Weighted monthly mean sea surface temperatures were obtained from Mazeika (1968) for Squares 1, 2, and 3, and Areas A, B, and C. This was not done for the quadrants since Mazeika's charts did not extend as far as the fishing. The weighted monthly mean sea surface temperatures, $\bar{T}_{ig}$ were calculated by:

$$\bar{T}_{jg} = \frac{\Sigma a_{m,m+1}\left(\frac{T_m + T_{m+1}}{2}\right)}{N} \qquad \ldots .(5)$$

where j refers to the month, g refers to the particular geographic configuration (square or area), m refers to the particular temperature contour, $a_{m,m+1}$ refers to the number of 1° squares within contours m and $m+1$, and N refers to the number of 1° squares in geographic configuration g ($N = 25$ in Squares 1, 2, and 3, and $N = 214$ in Area A, 212 in Area B, and 224 in Area C).

Monthly mean sea surface temperatures (°C) obtained for Squares 1, 2, and 3, and Areas A, B, and C are depicted in Figures 5 and 6 respectively. The $\bar{T}_j$ of Squares 1 and 3 are highly correlated with those of Areas A and C respectively. The $\bar{T}_j$ of Square 2, however, bear little relation to those of Area B. This is a result of the oceanographic regime of Square 2 (Figure 1). During the first half of the year, warm water (as isotherms) originates from the north and during the latter half of the year warm water originates from the south yielding an apparent random fluctuation of about 2° C. In Area B, though, a cold oceanic front enters from the north during the first half of the year and receeds during the latter half producing a sinusoidal annual fluctuation.

If temperature were to be a factor influencing the distribution of tunas and billfishes, then the abundances (or measures of them) of fish within a geographic configuration would be expected to change in response to sea temperature changes. Since isotherms move across Squares 1, 2, and 3 and Areas A, B, and C, the response of fish to sea temperature was

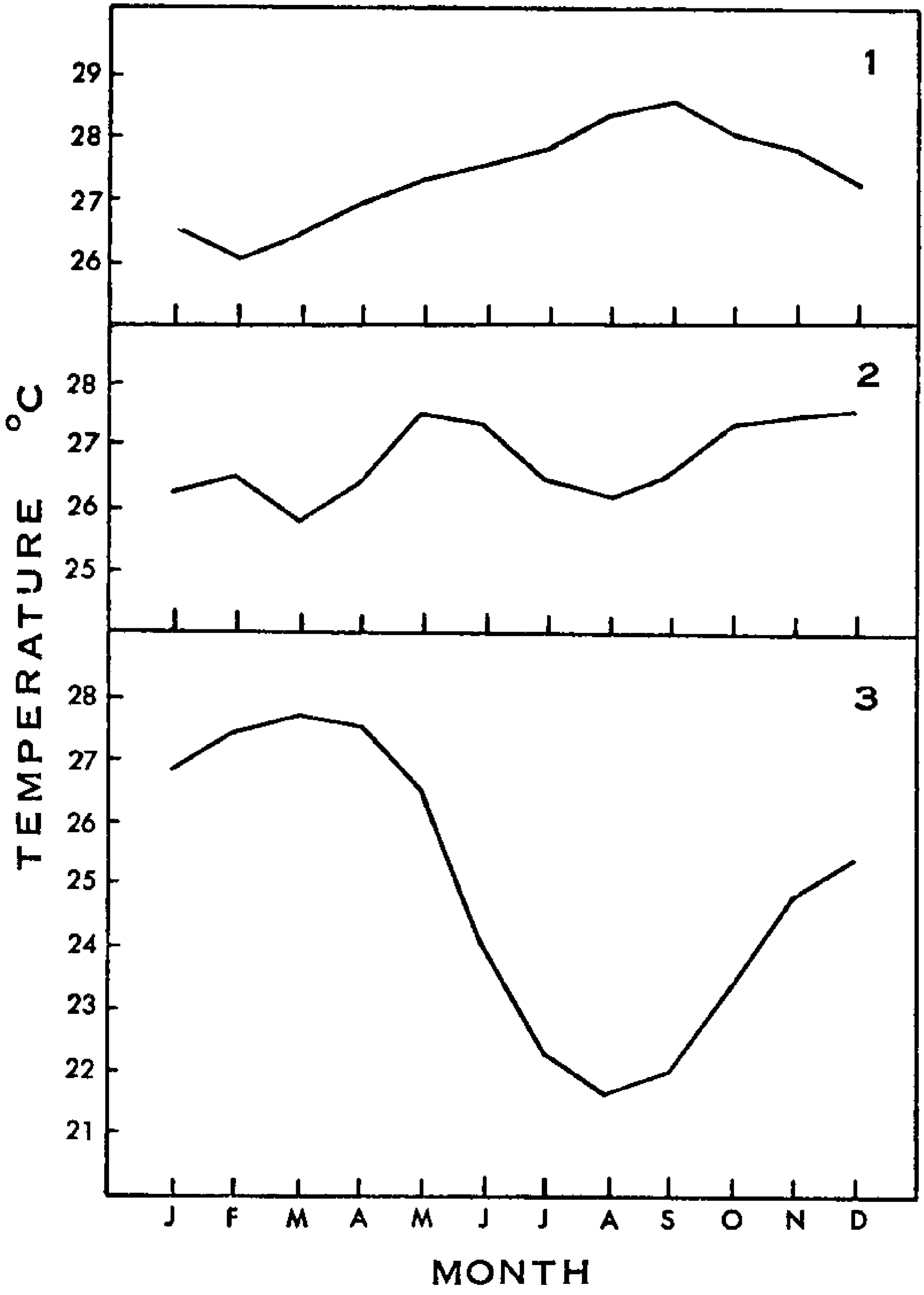

Figure 5. -- Monthly mean surface temperatures (°C) in Squares 1, 2, and 3, from Mazeika (1968).

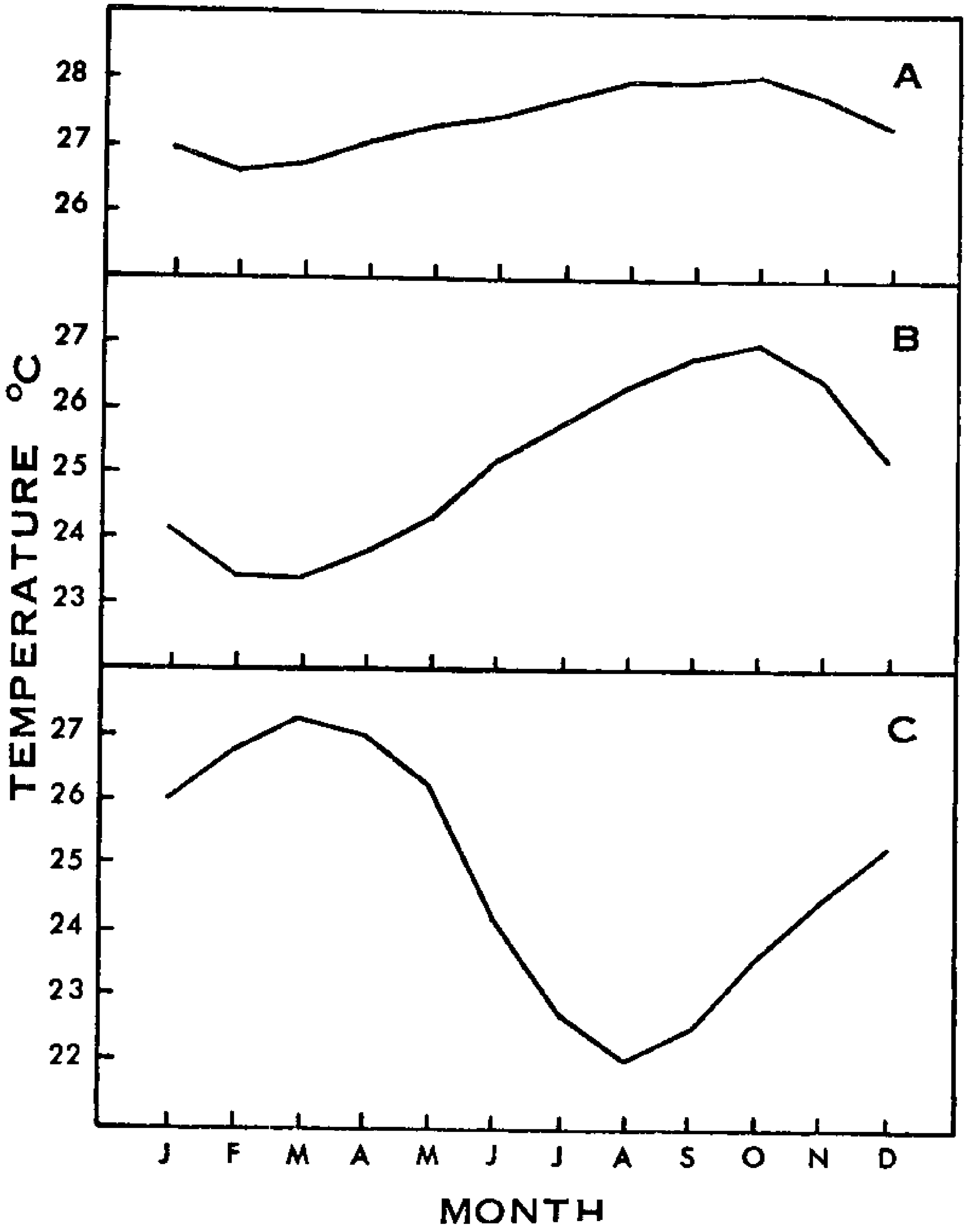

Figure 6. -- Monthly mean surface temperatures (^{o}C) in Areas A, B, and C, from Mazeika (1968).

expected to be migration, with a gain or loss of fish to the geographic configuration as the monthly mean sea surface temperature changed. The transformed measure of relative abundance of tunas and billfishes within Squares 1, 2, and 3 were the U'_{ijk} (Equation 3). Within Areas A, B, and C, however, the measure of abundance must be calculated in a different manner due to possible bias created by seasonal variation in the distribution of fishing effort. Within each area, the monthly mean catch per unit effort was calculated as the weighted mean of all 5° square catches per unit effort, U_{ijk} (Equation 2), thereby avoiding bias due to seasonal fishing distribution (Gulland, 1966). It was calculated and transformed as follows:

$$\bar{U}'_{ijg} = \log_e \left(\frac{\Sigma U_{ijk}}{\sum \frac{n_k}{25}} + 1 \right) \qquad \ldots.(6)$$

For Squares, the $\bar{T}_{jg}$ and U'_{ijk} were correlated and for Areas, the $\bar{T}_{jg}$ and $\bar{U}'_{ijg}$ were correlated.

Results

Squares 1, 2, and 3. -- The correlation coefficients, *r*, between the temperature, $\bar{T}_{jg}$, and U'_{ijk} of tunas and billfishes in Squares 1, 2, and 3 for 1965 are presented in Table 7. Of the 26 possible *r*-values, 7 were significantly different from 0. For species which occurred in all three squares, except swordfish, their *r*-values were significantly heterogeneous among squares. There was only one comparison, bigeye tuna, which was significantly positively correlated in one square and significantly negatively correlated in another square. No significant correlations

TABLE 7. -- Correlation coefficients (r) between monthly mean sea surface temperature and the $U'_{\underline{ijk}}$ of tunas and billfishes, chi-square tests of homogeneity among r-values, and weighted mean correlation coefficients ($\bar{r}$) among three selected 5° squares in the Atlantic Ocean, 1965

Species	Selected 5° Squares[a] 1	2	3	Chi-square	Weighted Mean ($\bar{r}$)
Yellowfin Tuna	-.220	-.424	.872*	17.18*	--
Albacore	-.808*	.345	-.124	10.26*	--
Bigeye Tuna	.688*	.276	-.576*	10.34*	--
Bluefin Tuna	-.149	-.517	--	0.80	-.346
Skipjack Tuna	-.286	--	-.464	0.19	-.379
White Marlin	-.818*	.082	-.442	6.86*	--
Blue Marlin	-.781*	.120	.184	8.68*	--
Black Marlin	--	--	-.206	--	-.206
Sailfish	-.229	.422	.744*	6.44*	--
Swordfish	.460	-.068	.068	1.56	.164

*$P < 0.05$

[a] Squares 1, 2, and 3 refer to quadrants 0422, 0024, and 3354 respectively of the Marsden latitude-longitude coding system.

were obtained in Square 2.

Areas A, B, and C. -- The correlation coefficients, *r*, between the temperature, $\bar{T}_{ig}$, and the $\bar{U}'_{ijg}$ of tunas and billfishes in Areas A, B, and C for 1961-65 are listed in the Appendix (Table A-7). Of the 144 possible *r*-values, 25 were significantly different from 0 -- none for bluefin tuna, skipjack tuna, or black marlin, only one for blue marlin and two for swordfish. Eliminating those five species, there were 22 *r*-values significantly different from 0 out of 75 possible. Weighted mean correlation coefficients, $\bar{r}$, were calculated as before by area and year for yellowfin tuna, albacore, bigeye tuna, white marlin, and sailfish (Table 8). By inspection it is apparent that most variation in *r*-values was among areas.

Agreement in signs (+ or -) was good between the *r*-values of Squares 1 and 3, and Areas A and C respectively, with only one difference -- sailfish which was negative, though not significantly so, in Square 1 was positive in Area A. Three of five *r*-values of Area B were of a different sign than the *r*-values in Square 2 which may be due to the differences in temperature trends between Square 2 and Area B. Except for white marlin there were no consistent (for more than 2 years) significant correlations in Areas A or B. In Area C, however, consistent significant correlations were obtained for yellowfin tuna, albacore, bigeye tuna, white marlin, and sailfish.

Comparison of temperature-species relationships and species groups. -- Since the temperature and fishery data were not synoptic, probably the results for Areas A, B, and C (average relationships over 5 years) were

TABLE 8. — Weighted mean correlation coefficients ($\bar{r}$) between monthly mean sea surface temperature and the $\bar{U}'_{ijg}$ of selected tunas and billfishes among Areas A, B, and C in the Atlantic Ocean, 1961-65

Species	Area Means A	Area Means B	Area Means C	Year Means 1961	Year Means 1962	Year Means 1963	Year Means 1964	Year Means 1965
Yellowfin Tuna	-.101	-.014	.898	.725	.604	.583	-.218	.415
Albacore	-.224	-.106	-.639	-.126	-.481	-.228	-.302	-.567
Bigeye Tuna	.163	-.282	-.920	-.776	-.657	-.330	-.372	-.574
White Marlin	-.541	.096	-.734	-.153	-.147	-.607	-.533	-.570
Sailfish	.315	-.026	.599	.322	.026	.192	.538	.436

best for comparing the temperature-species relationships and species groups. The only valid comparison was in Area C where consistent significant correlations were obtained. Yellowfin tuna and sailfish were positively correlated between their $\underline{U'_{ijk}}$ and monthly mean sea surface temperature. Albacore, bigeye tuna, and white marlin formed a species group and all are negatively correlated with temperature. This may be expanded to include discussion of Area A with some reservation. Albacore, white marlin, and blue marlin which formed a species group in Area A were each negatively correlated (significantly in 4 of 6 cases) with temperature in 1964 and 1965, the years most frequently sampled.

DISCUSSION AND CONCLUSIONS

It is generally known that pelagic longline fishing captures older and larger members of tuna populations than do surface fishing methods, i.e. bait boat or pole-and-line, purse seine, and trolling (Alverson and Peterson, 1963; Clemens, 1963; Schaefer, Broadhead, and Orange, 1963; Waldron, 1963). Average weights in kilograms for all species of tunas and billfishes except black marling caught by Japanese longline boat operations in 1964 and 1965 are given in Table 9. Results of this study, therefore, do not necessarily reflect temporal-spatial relationships commonly observed from data collected by surface fishing methods. In addition, the ecological relationships inferred by the results of this study are very broad due to the large size of the sampling unit. The implications of the results of this study, however, are pertinent to an analysis of optimum fishing strategy and proper management policies for this mixed-species fishery.

Distributional overlap as determined from data from the Japanese Atlantic longline fishery was very high among yellowfin tuna, bigeye tuna, albacore, blue marlin, swordfish, white marlin and sailfish as indicated by Mc Connaughey's grouping coefficients (Table 1). This reflected the degree of similarity of their ecology on the broadest scale, at least between 20° N and 20° S latitude where most of the sampling occurred. Skipjack tuna and black marlin exhibited little distributional overlap with swordfish, white marlin, sailfish and bluefin tuna, resulting in negative _I_-values except for the skipjack tuna - sailfish pair.

TABLE 9. — Average weight (kg) of tunas and billfishes caught by boats, 1964-1965[a]

Species	Weight (kg)
Yellowfin Tuna	40.3
Albacore	20.1
Bigeye Tuna	49.0
Bluefin Tuna	163.8
Skipjack Tuna	16.5
White Marlin	26.0
Blue Marlin	101.2
Sailfish	21.9
Swordfish	67.5

[a] Data from Federation of Japan Tuna Fisheries Co-operative Associations and Japan Tuna Fisheries Federation (1968) and Fisheries Agency of Japan (1967a, 1967b)

Laevastu and Rosa (1963) published surface temperature modes and ranges for tunas on a world-wide basis (Table 10). Squire (1963) related the catch of tunas from exploratory longline fishing in the Northwest Atlantic 1957-60 to temperature means and ranges taken at the surface and estimated depth of fishing (Table 11). The two studies are in general agreement except for the order of albacore (comparing modes and means). Also, Squire reported albacore and bluefin tuna from both cooler and warmer waters than did Laevastu and Rosa.

Relationships of distributional overlap, as indicated by Mc Connaughey's grouping coefficients (Table 1), agree broadly with those implied by the temperature studies of Laevastu and Rosa (1963) and Squire (1963). Bigeye and skipjack tuna, and bluefin tuna overlaped more with albacore than the others. Black, blue, and white marlins were most similar with yellowfin tuna in distributional overlap, sailfish with blue marlin, and swordfish with bigeye tuna, which may be interpreted as marlins and sailfish favoring warmer and swordfish favoring more temperate waters.

There was a phenomenon of the abundance correlation procedure which needs clarification before discussion of the relative ecologies of the species. There was an increase in the proportion of r-values which were significantly different from 0 as the geographical treatment of the data expanded (i.e. as the analyses progressed from Squares to Areas to Quadrants). From 17% at the Square level, the proportion of significant correlations increased to 21% at the Area level to 31% at the Quadrant level, a larger increase than would be expected due to chance alone. This phenomenon may reflect that some species relationships were due more to the spatial than the temporal component.

TABLE 10. -- World sea surface temperature (°C) modes and ranges for tunas from Laevastu and Rosa (1963)

Species	Temperature °C Mode	Range
Yellowfin Tuna	23	18 - 31
Skipjack Tuna	21	17 - 28
Bigeye Tuna	20	11 - 28
Bluefin Tuna	19	14 - 21
Albacore	18	14 - 23

TABLE 11. -- Northwest Atlantic Ocean surface and deep[a] temperature (°C) means and ranges for tunas from Squire (1963)

	Temperature °C			
	Means		Ranges	
Species	Surface	Depth[a]	Surface	Depth[a]
Yellowfin Tuna	25.2	22.2	18.4 - 28.8	10.0 - 26.9
Skipjack Tuna	25.3	23.6	21.5 - 26.7	19.4 - 26.4
Bigeye Tuna	18.7	13.3	13.5 - 27.3	8.7 - 26.9
Bluefin Tuna	16.2	15.5	6.4 - 28.8	6.5 - 26.9
Albacore	20.8	17.5	11.5 - 28.3	8.7 - 26.7

[a] Estimated depth of fishing is 52.7 m.

The prime example was the temporal-spatial relationship between yellowfin tuna and albacore. At the Square level there were negative, though non-significant, correlations between yellowfin tuna and albacore in two of three squares. Inclusion of more sampling units, at the Area level, 9 of 15 r-values were significantly different from 0 and negative -- all in Areas B and C. At the Quadrant level, which included all the data except those in regions N and S for 1965, 19 of 20 r-values were significant and negative. Although the distributions of yellowfin tuna and albacore overlaped broadly (Table 1) their centers of abundance were diametric. The centers of yellowfin abundance in 1965 were geographically situated within Squares 1, 2, and 3 and the only albacore entering these squares were few and sporadic in occurrence. Areas B and C, however, included sampling units (5^{o} squares) in which albacore were in high abundance at certain times of the year, thereby producing the expected significant negative correlations. Each quadrant, therefore, included sampling units containing high abundance of both species, pointing out the utility of the different geographic configurations in discussing the temporal-spatial relationships of species pairs in relation to their stock structure.

Since it is generally accepted that yellowfin tuna and albacore form large coherent distributions which perform large-scale migrations (Clemens, 1963; Wise and Le Guen, in press), these two species are convenient bases for comparisons of the relative ecologies of other species based on the results of the abundance correlation procedure. First, yellowfin tuna and albacore were negatively correlated in time and space which indicates that they differ in their relative ecologies.

From the standpoint of temperature regimes, of course, yellowfin tuna and albacore are quite different (Tables 10 and 11).

Bigeye tuna was inconsistent in its temporal-spatial relationships with other species among geographic regions. Bigeye was significantly positively correlated with yellowfin tuna in the western Quadrants (NW and SW), which is probably due to the spatial component since such was not the case for Area A or Square 1. In the eastern Quadrants (NE and SE) and the N region for 1965, bigeye tuna were, however, significantly negatively correlated with yellowfin tuna, which were also the cases for Areas B and C, and Square 3. Between bigeye tuna and albacore the converse relationships were obtained. They were significantly positively correlated in Quadrants SE (also Area C) yet were significantly negatively correlated in Quadrants NW, SW, and NE (also Square 1, and Area B). This reversal of significant relationships in bigeye tuna may be due to (1) stock differences in ecological preference or (2) ecological parameters which strongly affect the temporal-spatial distribution of bigeye tuna being present in only some of the geographical regions.

White marlin, like bigeye tuna, exhibited temporal-spatial relationships which differed among geographic regions. Significant negative correlations were obtained between white marlin and yellowfin tuna in the South Atlantic Ocean (Quadrants SW and SE, and Area C). Suda and Schaefer (1965) and Kume and Schaefer (1966) reported an apparent negative correlation between yellowfin tuna and striped marlin, Tetrapturus audax (Phillipi), the Pacific counterpart of white marlin, in some areas of the eastern tropical Pacific Ocean. In the North Atlantic Ocean the *r*-values between white marlin and yellowfin tuna were generally negative, though not significant, but significant positive correlations were obtained for 2 years. White marlin and albacore were significantly correlated in Quadrants SW, NE, and SE, Areas B and C, and Squares 1, 2, and 3. White marlin are highly abundant in the Gulf of Mexico, as are yellowfin tuna, yet are highly abundant off Brazil, as are albacore (Grant L. Beardsley, personal communication). Therefore, when and where white marlin and albacore occur together, which must be often to result in such high r-values, their abundances are positively correlated. Similarly, Howard and Ueyanagi (1965) mentioned that striped marlin and albacore were distributed alike in the Pacific Ocean.

Blue marlin was significantly negatively correlated with yellowfin tuna in the western Atlantic (Quadrants NW and SW, and Area B), but significantly positively correlated with yellowfin tuna in Quadrant SE. Blue marlin was significantly positively correlated with albacore in all Quadrants (and Area B and Square 1) except SE where they were significantly negatively correlated.

Sailfish was significantly positively correlated with yellowfin tuna in Quadrants NW and SE (also Areas A and C, and Square 3). In Quadrant NE, Area B and Square 2, however, sailfish was significantly positively correlated with albacore.

Swordfish was significantly positively correlated more often with yellowfin tuna than with albacore, but most consistently with bigeye tuna. This was also apparent from the presence-absence analysis (Table 1).

The problems associated with determining optimum fishing strategy and proper management policies for a mixed-species and multiple-stock fishery have been examined by Ricker (1958), Paulik and Greenough (1966) and Paulik, Hourston, and Larkin (1967). The Japanese Atlantic longline fishery is such a mixed-species and multiple-stock fishery. Paulik _et al._ (1967) stated "If the stocks (or species) are harvested separately, the total maximum sustained yield is the sum of the individual (each stock or species) maximum sustained yields". Since yellowfin tuna and albacore are so strongly negatively correlated, fishing pressure can be applied to each species nearly separately and a total maximum sustained yield from these two species is nearly the sum of their individual maximum sustained yields. This is apparently what is happening in the Japanese Atlantic longline fishery. Up to 1962 fishing effort was correlated with the abundance of yellowfin tuna; then there was a transition through 1963 as the fishing effort was correlated with the abundance of yellowfin tuna plus albacore (Wise and Le Guen, _in press_). In 1964 fishing effort was correlated with albacore abundance (Wise, 1968). Then in 1965 fishing effort was again correlated with both the abundances of yellowfin tuna plus albacore (Wise and Fox, 1969).

The other major species caught by the Japanese Atlantic longline fishery, bigeye tuna, white marlin, blue marlin, and sailfish, however, are harvested jointly with yellowfin tuna or albacore to different degrees depending on the geographic location. Therefore, the individual maximum sustained yields of yellowfin tuna and albacore are influenced by the mixture of species in the joint harvest (see Paulik _et al._, 1967: Table I). The results of this study indicate the relative degree to which each species must be considered in planning optimum fishing strategy and proper management policies by each geographic location.

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APPENDIX

TABLE A-1. -- Relative area, number of 1° squares (n), of coastal 5° squares[a] in the Atlantic Ocean[b]

Square	n	Square	n	Square	n	Square	n
0824	7	1164	2	3042	3	1094	10
0822	11	1162	21	3762	1	1092	6
0464	1	0444	24	3764	16	0014	1
0823	21	0084	3	3041	12	0012	23
0821	24	0443	17	3761	13	0013	1
0463	5	0441	15	3032	21	0364	1
1172	1	0434	22	3034	1	0363	6
0814	23	0432	20	3392	15	0362	20
0812	20	0433	24	3394	21	3352	23
0454	15	0431	21	0742	19	3341	2
1171	2	0073	1	0384	18	3343	15
0813	12	0064	16	0382	19	3701	16
0811	19	0063	23	0743	11	3703	10
0453	23	0061	3	0381	1	4061	20
0451	16	4131	8	0023	15	4064	3
0093	2					4422	15

[a] Marsden latitude-longitude coding system designates the 5° squares.

[b] Table is constructed to read north to south, west to east.

TABLE A-2. -- Correlation coefficients (r) between the $U'_{\underline{ijk}}$ of tunas and billfishes, chi-square tests of homogeneity among r-values, and weighted mean correlation coefficients ($\bar{r}$) among three selected 5° squares in the Atlantic Ocean, 1965

Species Pair	Selected 5° Squares[a] 1	2	3	Chi-square	Weighted Mean ($\bar{r}$)
Yellowfin Tuna and					
Albacore	-.197	-.413	.057	1.11	-.191
Bigeye Tuna	-.258	-.198	-.693*	2.33	-.414
Bluefin Tuna	.120	.402	--	0.42	.268
Skipjack Tuna	-.439	--	-.344	0.06	-.392
White Marlin	-.012	-.305	-.331	0.61	-.220
Blue Marlin	.012	-.464	.429	4.16	-.010
Black Marlin	--	--	-.319	--	-.319
Sailfish	.429	-.247	.850*	10.24*	--
Swordfish	-.060	-.069	.194	0.41	.022
Albacore and					
Bigeye Tuna	-.746*	-.165	.223	6.63*	--
Bluefin Tuna	.066	-.101	--	0.13	-.018
Skipjack Tuna	.378	--	-.059	0.94	.168
White Marlin	.657*	.602*	.683*	0.09	.649
Blue Marlin	.684*	.464	.417	0.81	.533
Black Marlin	--	--	-.150	--	-.150
Sailfish	.313	.612*	-.010	2.35	.329
Swordfish	-.656*	-.150	.128	3.96	-.263
Bigeye Tuna and					
Bluefin Tuna	-.198	-.102	--	0.04	-.151
Skipjack Tuna	-.138	--	.398	1.42	.141
White Marlin	-.485	-.086	.336	3.48	-.088
Blue Marlin	-.604*	.240	-.503	4.65	-.324
Black Marlin	--	--	-.077	--	-.077
Sailfish	-.635*	.451	-.732*	10.72*	--
Swordfish	.837*	-.081	-.461	14.29*	--
White Marlin and					
Bluefin Tuna	.397	-.094	--	1.19	.162
Skipjack Tuna	.586*	--	.102	1.46	.369
Blue Marlin	.842*	.402	.043	6.57*	--
Black Marlin	--	--	.195	--	.195
Sailfish	-.009	.366	-.197	1.60	.058
Swordfish	-.258	-.314	.417	3.29	-.048

TABLE A-2 (Continued)

Species Pair	Selected 5° Squares[a] 1	2	3	Chi-square	Weighted Mean ($\bar{r}$)
Blue Marlin and					
Bluefin Tuna	.564	-.306	--	4.14*	--
Skipjack Tuna	.360	--	.039	0.51	.205
Black Marlin	--	--	.133	--	.133
Sailfish	.203	.405	.446	0.38	.356
Swordfish	-.491	.406	.405	5.62	.108
Sailfish and					
Bluefin Tuna	-.024	-.197	--	0.14	-.112
Skipjack Tuna	-.007	--	-.272	0.33	-.142
Black Marlin	--	--	-.195	--	-.195
Swordfish	-.683*	-.126	.365	6.73*	--
Swordfish and					
Bluefin Tuna	-.054	-.119	--	0.02	-.087
Skipjack Tuna	-.210	--	-.351	0.11	-.282
Black Marlin	--	--	.619*	--	.619
Skipjack Tuna and					
Bluefin Tuna	-.182	--	--	--	-.182
Black Marlin	--	--	-.154	--	-.154

*$P < 0.05$

[a] Squares 1, 2, and 3 refer to quadrants 0422, 0024, and 3354 respectively of the Marsden latitude-longitude coding system.

TABLE A-3. -- Correlation coefficients (r) between the $U'_{\underline{ijk}}$ of tunas and billfishes among Areas A, B, and C in the Atlantic Ocean, 1961-65

Species Pair	Area			Year		
		1961	1962	1963	1964	1965
Yellowfin Tuna	A	.118	-.131	-.089	-.067	-.108
and	B	-.328*	-.398*	-.342*	-.244	-.223*
Albacore	C	-.458*	-.454*	-.560*	-.590*	-.244*
Yellowfin Tuna	A	-.177	-.264	-.057	-.086	-.130
and	B	.212	-.258	-.054	-.500*	-.249*
Bigeye Tuna	C	-.728*	-.706*	-.698*	-.400*	-.711*
Yellowfin Tuna	A	.262	-.152	-.149	-.228*	.025
and	B	.057	-.217	-.050	.015	.046
Bluefin Tuna	C	-.189	.129	.244	-.368	-.126
Yellowfin Tuna	A	--	--	-.011	.047	-.142
and	B	--	--	.169	-.238	-.209
Skipjack Tuna	C	.169	--	-.121	.233	-.015
Yellowfin Tuna	A	.057	-.238	.223	.132	.136
and	B	-.010	-.231	.106	-.288*	-.119
White Marlin	C	-.560*	-.656*	-.530*	-.586*	-.330*
Yellowfin Tuna	A	.134	-.236	.138	.287*	-.144
and	B	.006	-.312*	-.368*	.140	.028
Blue Marlin	C	-.127	-.164	.028	.159	.279*
Yellowfin Tuna	A	-.084	.106	.145	-.231*	.334*
and	B	.157	-.013	-.001	--	-.113
Black Marlin	C	.086	.086	.088	.298	.007
Yellowfin Tuna	A	.162	.308*	.097	.002	.395*
and	B	-.124	-.128	.063	.122	.062
Sailfish	C	.058	.446*	.018	.126	.331*
Yellowfin Tuna	A	-.004	-.251	-.061	.097	-.030
and	B	.170	.074	-.060	.151	-.104
Swordfish	C	-.259*	-.055	-.004	-.143	-.085
Albacore	A	-.323	.110	-.244	-.162	-.099
and	B	-.277	-.418*	-.401*	-.067	-.023
Bigeye Tuna	C	.390*	.611*	.663*	.388*	.323*
Albacore	A	-.176	.075	-.130	.177	.156
and	B	.224	.348*	.137	.018	.038
Bluefin Tuna	C	.068	-.079	-.088	.496*	-.062

TABLE A-3 (Continued)

Species Pair	Area			Year		
		1961	1962	1963	1964	1965
Albacore	A	--	--	-.132	.068	.056
and	B	--	--	-.080	.672*	.047
Skipjack Tuna	C	.053	--	-.052	-.103	-.001
Albacore	A	.111	-.208	-.056	.085	.421*
and	B	.611*	.578*	.364*	.522*	.495*
White Marlin	C	.346*	.276*	.312*	.859*	.398*
Albacore	A	.222	-.072	.215	.192	.320*
and	B	.492*	.716*	.644*	.160	.344*
Blue Marlin	C	.201	-.091	.034	-.093	-.013
Albacore	A	-.178	-.082	.018	.116	-.136
and	B	-.114	.141	-.085	--	-.034
Black Marlin	C	-.099	.062	-.071	-.144	.004
Albacore	A	-.086	-.233	-.091	-.076	.059
and	B	.065	.673*	.321*	.427*	.458*
Sailfish	C	.013	-.219	-.007	-.217	-.014
Albacore	A	-.055	-.079	-.123	.230*	.136
and	B	-.012	.195	-.114	.266*	.125
Swordfish	C	.088	.078	-.041	-.167	-.028
Bigeye Tuna	A	.159	.129	.152	.105	.091
and	B	-.157	-.190	.018	-.089	.008
Bluefin Tuna	C	.226*	.061	-.147	.331	.173
Bigeye Tuna	A	--	--	.049	-.036	-.041
and	B	--	--	.041	.062	.362*
Skipjack Tuna	C	-.156	--	-.064	-.116	.012
Bigeye Tuna	A	.032	-.034	-.370*	-.236*	-.218
and	B	-.138	-.181	-.165	.042	-.095
White Marlin	C	.614*	.589*	.657*	.556*	.357*
Bigeye Tuna	A	.111	.092	-.319*	.198	-.062
and	B	-.186	-.336*	-.454*	-.131	-.314*
Blue Marlin	C	.105	.206	.099	-.382	-.311*
Bigeye Tuna	A	-.117	-.158	-.161	-.115	-.086
and	B	.116	-.136	.063	--	.041
Black Marlin	C	-.054	-.220	-.072	-.193	-.009

TABLE A-3 (Continued)

Species Pair	Area			Year		
		1961	1962	1963	1964	1965
Bigeye Tuna and Sailfish	A	.022	-.380*	-.182	-.156	-.445*
	B	-.032	-.325*	-.282*	-.394*	-.212*
	C	-.182	-.394*	-.139	-.422*	-.451*
Bigeye Tuna and Swordfish	A	.261	.398*	.423*	.042	.440*
	B	.068	-.242	.276*	-.060	.057
	C	.085	.070	-.105	.116	.145
Bluefin Tuna and Skipjack Tuna	A	--	--	.001	-.059	-.004
	B	--	--	-.018	-.031	.050
	C	-.032	--	-.027	-.058	-.018
Bluefin Tuna and White Marlin	A	.100	.004	.006	.017	-.047
	B	-.050	.037	.088	-.048	.259*
	C	.035	-.102	-.111	.332	-.037
Bluefin Tuna and Blue Marlin	A	.131	.268	.130	-.036	.062
	B	.247	.415*	-.071	.466*	-.002
	C	-.072	-.148	-.026	-.230	.118
Bluefin Tuna and Black Marlin	A	-.050	-.052	-.059	-.043	-.043
	B	-.046	-.072	.004	--	-.061
	C	-.034	-.048	-.008	-.081	-.023
Bluefin Tuna and Sailfish	A	.135	-.146	-.049	.044	-.086
	B	.056	.221	-.076	-.062	-.020
	C	-.075	-.075	.208	-.136	-.062
Bluefin Tuna and Swordfish	A	.047	.264	.451*	.093	.124
	B	.002	.063	.033	.393*	.290*
	C	-.085	-.248	-.016	-.007	-.160
Skipjack Tuna and White Marlin	A	--	--	-.139	-.104	.003
	B	--	--	-.109	.552*	-.053
	C	-.069	--	-.066	-.095	.093
Skipjack Tuna and Blue Marlin	A	--	--	-.098	-.000	.005
	B	--	--	-.082	.031	-.151
	C	-.101	--	-.057	-.113	-.003
Skipjack Tuna and Black Marlin	A	--	--	-.053	-.024	-.047
	B	--	--	.007	--	-.034
	C	-.029	--	.055	.852*	-.038

TABLE A-3 (Continued)

Species Pair	Area	Year				
		1961	1962	1963	1964	1965
Skipjack Tuna and Sailfish	A	--	--	-.053	-.068	-.047
	B	--	--	.180	.149	-.034
	C	.028	--	-.000	-.086	.084
Skipjack Tuna and Swordfish	A	--	--	.173	-.011	-.057
	B	--	--	-.086	.046	-.128
	C	-.041	--	-.074	-.043	-.004
White Marlin and Blue Marlin	A	.146	.431*	.413*	-.015	.449*
	B	.806*	.133	.323*	.245	.467*
	C	.473*	.262	.153	-.125	-.127
White Marlin and Black Marlin	A	-.081	-.128	.094	-.024	-.103
	B	-.058	-.138	.035	--	-.034
	C	-.071	-.125	.024	-.124	-.047
White Marlin and Sailfish	A	.191	.384*	-.079	.431*	.007
	B	.243	.165	.169	.340*	.314*
	C	.016	-.203	-.130	-.301	-.160
White Marlin and Swordfish	A	-.132	.270	-.165	-.206	-.068
	B	.075	.267	-.142	-.023	.189
	C	.217	.135	-.038	-.001	.202*
Blue Marlin and Black Marlin	A	-.086	-.027	.291*	-.128	-.117
	B	-.149	.061	.068	--	.023
	C	-.016	.046	.010	-.009	.048
Blue Marlin and Sailfish	A	.346*	-.076	.097	-.178	-.080
	B	.581*	.838*	.078	.175	.462*
	C	.267*	-.020	.093	.860*	.210*
Blue Marlin and Swordfish	A	.146	.627*	.086	.495*	.224*
	B	-.028	.216	.017	.504*	.191
	C	.223*	.296*	.153	-.518*	-.027
Black Marlin and Sailfish	A	-.115	.107	.202	-.024	.256*
	B	-.068	-.028	-.103	--	-.107
	C	.106	-.104	.211	.103	.001
Black Marlin and Swordfish	A	-.081	-.143	-.015	-.109	-.074
	B	.903*	-.003	-.024	--	-.042
	C	.002	.002	-.088	-.052	.124

TABLE A-3 (Continued)

Species Pair	Area	1961	1962	Year 1963	1964	1965
Sailfish	A	.191	-.254	-.022	-.286*	-.154
and	B	-.050	.228	-.140	-.048	-.022
Swordfish	C	.214	.142	-.233	-.489*	-.104

*Significant from 0 at $P \leq 0.05$, with the following respective degrees of freedom:

A	33	40	59	74	78
B	39	46	64	58	85
C	78	52	60	24	103

TABLE A-4. -- Weighted mean correlation coefficients ($\bar{r}$) between the $\underline{U'_{ijk}}$ of selected tunas and billfishes among Areas A, B, and C in the Atlantic Ocean, 1961-65

Species	Area Means			Year Means				
Pair	A	B	C	1961	1962	1963	1964	1965
Yellowfin Tuna and								
Albacore	-.071	-.296	-.424	-.302	-.349	-.346	-.223	-.198
Bigeye Tuna	-.127	-.205	-.695	-.436	-.460	-.310	-.299	-.433
White Marlin	.092	-.109	-.506	-.311	-.418	-.083	-.147	-.130
Blue Marlin	.048	-.098	.052	-.036	-.236	-.081	-.213	.078
Sailfish	.196	.020	.214	.034	.226	.059	.066	.269
Swordfish	-.032	.021	-.114	-.096	-.070	-.042	.081	-.075
Albacore and								
Bigeye Tuna	-.144	-.217	.468	.069	.151	.033	-.041	.094
White Marlin	.117	.504	.404	.377	.260	.217	.422	.436
Blue Marlin	.201	.476	.031	.286	.240	.335	.138	.204
Sailfish	-.066	.418	-.055	.049	.118	.085	.101	.168
Swordfish	.056	.095	-.003	.031	.072	-.093	.170	.069
Bigeye Tuna and								
White Marlin	-.203	-.103	.540	.332	.182	.075	-.005	.049
Blue Marlin	-.077	-.299	-.056	.031	-.011	-.241	-.014	-.242
Sailfish	-.259	-.260	-.321	-.100	-.367	-.204	-.289	-.377
Swordfish	.314	.037	.069	.119	.066	.207	.015	.210
White Marlin and								
Blue Marlin	.293	.414	.148	.530	.272	.299	.067	.248
Sailfish	.182	.256	-.129	.114	.095	-.009	.296	.043
Swordfish	-.085	.073	.136	.106	.223	-.116	-.108	.120
Blue Marlin and								
Sailfish	-.018	.444	.242	.375	.359	.089	.172	.215
Swordfish	.330	.198	.084	.143	.381	.084	.363	.117
Sailfish and								
Swordfish	-.138	-.017	-.052	.142	.056	-.133	-.254	-.093

TABLE A-5. -- Correlation coefficients (r) between the U'_{ijk} of tunas and billfishes among Quadrants in the Atlantic Ocean, 1961-65

Species Pair	Area	Year					
		1961	1962	1963	1964	1965a	1965b
Yellowfin Tuna	NW	-.062	-.638*	-.526*	-.298*	-.430*	-.454*
and	SW	-.424*	-.736*	-.614*	-.654*	-.554*	-.491*
Albacore	NE	-.224*	-.210*	-.236*	-.505*	-.497*	-.454*
	SE	-.209*	-.568*	-.583*	-.676*	-.547*	-.494*
	N						.123
	S						-.190
Yellowfin Tuna	NW	.035	.572*	.193*	.371*	.113*	.387*
and	SW	.091	.300*	.529*	.413*	.053	.372*
Bigeye Tuna	NE	.152	-.050	-.110	-.002	-.197*	-.075
	SE	-.461*	-.538*	-.467*	-.225*	-.307*	-.400*
	N						-.291*
	S						.150
Yellowfin Tuna	NW	.260	.065	.018	-.051	-.192*	-.205*
and	SW	-.039	.120	-.084	.278*	.364*	.366*
Bluefin Tuna	NE	-.029	-.257*	-.153	.109	.139*	.179*
	SE	.107	.086	.235*	-.199*	-.117*	-.143*
	N						.020
	S						.123
Yellowfin Tuna	NW	--	--	-.124	-.084	-.085	-.109
and	SW	--	--	-.080	-.155	.129	.071
Skipjack Tuna	NE	--	--	.167*	-.121	.001	-.032
	SE	.133	--	-.137	-.077	.077	.066
	N						-.017
	S						-.049
Yellowfin Tuna	NW	-.038	-.018	.164*	-.014	.171*	.092
and	SW	.004	-.206*	-.040	-.184*	-.081	-.264*
White Marlin	NE	.003	-.185	-.008	-.138	.021	-.123
	SE	-.422*	-.474*	-.453*	-.187*	-.174*	-.238*
	N						.152
	S						.184
Yellowfin Tuna	NW	-.030	-.691*	-.269*	-.117*	-.163*	-.245*
and	SW	-.221*	-.347*	-.412*	-.158	-.035	-.228*
Blue Marlin	NE	.176	-.152	-.236*	.136	.311*	.163*
	SE	-.065	-.051	.182*	.472*	.397*	.336*
	N						.140
	S						.026

TABLE A-5 (Continued)

Species Pair	Area	Year					
		1961	1962	1963	1964	1965a	1965b
Yellowfin Tuna and Black Marlin	NW	-.036	-.025	.090	-.005	-.060	-.077
	SW	-.125	-.126	.126	.159*	.027	.008
	NE	-.019	-.011	-.030	.009	-.020	-.046
	SE	-.024	.078	.002	.100	-.066	-.052
	N						-.006
	S						-.049
Yellowfin Tuna and Sailfish	NW	.149	.293*	.100	.079	.511*	.480*
	SW	-.111	-.152	-.098	-.218*	.013	-.227*
	NE	.027	.037	.063	-.070	.138*	.044
	SE	.014	.314*	.056	.289*	.357*	.313*
	N						.033
	S						.214*
Yellowfin Tuna and Swordfish	NW	.018	.058	.141	.102	-.159*	-.073
	SW	-.135	.098	.100	.178*	.210*	.108
	NE	.050	.258*	-.013	.141	.152*	.118
	SE	.056	.257*	.161*	.337*	.230*	.138
	N						-.111
	S						.428
Albacore and Bigeye Tuna	NW	-.276	-.408*	-.354*	-.194*	-.085	-.211*
	SW	-.298*	-.334*	-.250*	-.374*	.035	-.181*
	NE	-.393*	-.361*	-.442*	-.224*	-.025	-.216*
	SE	.139	.476*	.294*	.197*	-.056	-.002
	N						.006
	S						-.167
Albacore and Bluefin Tuna	NW	-.157	-.063	.020	.006	.075	.082
	SW	.123	-.280*	-.326*	-.386*	-.240*	-.236*
	NE	.190	.142	.031	-.085	.011	.004
	SE	.022	-.058	-.054	.183*	.162*	.177*
	N						-.020
	S						-.135
Albacore and Skipjack Tuna	NW	--	--	.030	-.087	.011	.021
	SW	--	--	.106	.269*	-.081	-.006
	NE	--	--	.031	.168*	-.073	-.063
	SE	.002	--	.182*	.066	-.085	-.075
	N						.016
	S						.161
Albacore and	NW	-.026	-.091	.222*	.062	-.117*	-.092
	SW	.262*	.335*	.191	.189*	-.135	.074

TABLE A-5 (Continued)

Species Pair	Area	Year 1961	1962	1963	1964	1965a	1965b
White Marlin	NE	.508*	.368*	.418*	.047	.127*	.322*
	SE	.415*	.294*	.352*	.123	.076	.198*
	N						.098
	S						-.383*
Albacore and Blue Marlin	NW	.240	.497*	.646*	-.071	-.107	-.081
	SW	.262*	.250*	.499*	.253*	.159*	.487*
	NE	.421*	.531*	.459*	.066	-.073	.088
	SE	.301*	-.115	.066	-.367*	-.319*	-.188*
	N						-.030
	S						-.188
Albacore and Black Marlin	NW	-.151	.113	-.039	.015	.078	.092
	SW	.186	.204*	-.119	-.096	.040	.079
	NE	-.085	.044	-.062	-.046	-.029	-.028
	SE	.039	-.083	.007	-.034	.120	.101
	N						.082
	S						.149
Albacore and Sailfish	NW	-.132	-.227*	-.161*	-.250*	-.261*	-.256*
	SW	.376*	.145	.021	.221*	-.233*	-.010
	NE	.253*	.405*	.191*	.063	-.053	.039
	SE	.107	-.250*	.057	-.315*	-.210*	-.095
	N						.088
	S						-.312*
Albacore and Swordfish	NW	-.125	-.178	-.177*	.045	-.177*	.264*
	SW	.255*	-.124	.017	.107	-.128	.238*
	NE	-.087	-.044	.150	.219*	.016	.139*
	SE	-.003	-.291*	-.146	-.355*	-.319*	.200*
	N						-.151
	S						.096
Bigeye Tuna and Bluefin Tuna	NW	.198	.184	.181*	-.056	-.078	-.106
	SW	-.100	.249*	-.152	-.039	.034	.046
	NE	-.120	-.186	-.138	-.083	.011	.016
	SE	-.019	.031	-.069	.190*	.025	.117
	N						-.148
	S						.061
Bigeye Tuna and Skipjack Tuna	NW	--	--	-.100	-.084	-.086	-.089
	SW	--	--	-.010	-.131	-.095	-.065
	NE	--	--	.032	.083	.163*	.229*
	SE	-.095	--	.047	.013	.012	.013

TABLE A-5 (Continued)

Species Pair	Area	Year 1961	 1962	 1963	 1964	 1965a	 1965b
	N						-.047
	S						-.094
Bigeye Tuna and White Marlin	NW	-.085	-.212*	-.166*	-.014	-.209*	-.135*
	SW	-.176	.133	.148	-.288*	-.267*	-.145
	NE	-.015	-.190*	-.233*	-.193*	-.235*	-.194*
	SE	.333*	.189*	.211*	.007	.081	.103
	N						-.129
	S						-.354*
Bigeye Tuna and Blue Marlin	NW	.053	-.496*	-.334*	-.116*	-.244*	-.231*
	SW	-.308*	-.402*	-.284*	-.360*	-.303*	-.260*
	NE	-.047	-.318*	-.305*	-.206*	-.362*	-.299*
	SE	.115	-.091	-.122	-.291*	-.247*	-.291*
	N						-.194
	S						-.233*
Bigeye Tuna and Black Marlin	NW	-.074	-.078	.006	-.005	-.067	-.072
	SW	-.104	-.106	-.052	.084	-.014	.003
	NE	-.030	-.078	-.033	.021	.007	.016
	SE	-.022	-.170*	-.098	-.081	-.060	-.036
	N						.060
	S						-.100
Bigeye Tuna and Sailfish	NW	.059	.020	.085	.079	-.031	.093
	SW	-.066	-.252*	-.125	-.308*	-.357*	-.342*
	NE	-.101	-.279	-.109	-.192*	-.110	-.043
	SE	-.106	-.305*	-.196*	-.192*	-.331*	-.371*
	N						-.091
	S						-.185
Bigeye Tuna and Swordfish	NW	-.089	.343*	.265*	.102	.188*	.264*
	SW	.206*	.549*	.234*	-.045	.052	.238*
	NE	-.000	-.000	.120	.016	.053	.139*
	SE	.242*	-.084	-.055	.023	.202*	.200*
	N						-.151
	S						.096
Bluefin Tuna and Skipjack Tuna	NW	--	--	-.025	-.032	.433*	.441*
	SW	--	--	-.074	-.120	-.047	-.066
	NE	--	--	-.048	-.046	-.017	-.017
	SE	-.015	--	-.028	-.041	-.024	-.023
	N						-.024
	S						-.010

TABLE A-5 (Continued)

Species Pair	Area	Year 1961	1962	1963	1964	1965a	1965b
Bluefin Tuna and White Marlin	NW	.027	-.048	.216*	.137*	.048	.053
	SW	.005	.050	-.058	-.173*	-.058	-.090
	NE	.340*	.041	.212*	-.075	.023	.034
	SE	-.043	-.017	-.086	-.102	-.073	-.063
	N						-.073
	S						-.103
Bluefin Tuna and Blue Marlin	NW	.114	-.042	.122	-.060	-.101	-.104
	SW	.097	.054	-.076	.007	-.022	-.066
	NE	.213*	.225*	-.078	.106	-.068	-.062
	SE	-.005	-.091	.088	-.202*	-.131*	-.096
	N						.034
	S						-.080
Bluefin Tuna and Black Marlin	NW	-.037	-.031	-.023	-.023	-.032	-.032
	SW	-.048	-.055	-.045	-.001	-.021	-.026
	NE	-.024	-.086	.292*	.098	-.034	-.032
	SE	-.010	-.029	-.012	-.028	-.023	-.021
	N						-.041
	S						-.042
Bluefin Tuna and Sailfish	NW	.141	-.073	.019	-.066	-.149*	-.154*
	SW	.195	-.006	.213*	-.054	-.008	-.064
	NE	.033	.009	-.041	-.020	-.049	-.041
	SE	-.050	-.059	.091	-.141	-.112	-.100
	N						-.096
	S						-.073
Bluefin Tuna and Swordfish	NW	-.047	.205	.186*	.061	.081	.061
	SW	-.096	.378*	.060	.035	.116	.090
	NE	.008	-.055	.090	.100	.329*	.376*
	SE	-.019	-.142	.100	-.123	.076	-.033
	N						.388*
	S						.285*
Skipjack Tuna and White Marlin	NW	--	--	-.107	.120*	.171*	.162
	SW	--	--	.064	-.004	-.018	-.072
	NE	--	--	-.052	.074	-.004	-.020
	SE	-.053	--	-.010	.284*	.032	.027
	N						-.039
	S						-.048
Skipjack Tuna and	NW	--	--	.068	-.008	-.031	-.044
	SW	--	--	.002	.004	.135	.077

TABLE A-5 (Continued)

Species Pair	Area	Year 1961	1962	1963	1964	1965a	1965b
Blue Marlin	NE	--	--	-.043	-.104	-.052	-.082
	SE	-.077	--	-.100	.030	.022	.005
	N						-.032
	S						.031
Skipjack Tuna and Black Marlin	NW	--	--	-.035	-.013	-.015	-.018
	SW	--	--	-.019	-.029	-.023	-.032
	NE	--	--	-.024	-.015	-.017	-.020
	SE	-.010	--	-.022	-.021	-.020	-.018
	N						-.010
	S						-.040
Skipjack Tuna and Sailfish	NW	--	--	-.082	.026	-.035	-.049
	SW	--	--	-.032	.104	.327*	.294*
	NE	--	--	-.025	-.015	-.070	-.088
	SE	.013	--	.199*	.055	.065	.055
	N						-.024
	S						.022
Skipjack Tuna and Swordfish	NW	--	--	-.084	.006	-.054	-.067
	SW	--	--	-.036	-.137	-.093	-.172
	NE	--	--	.079	.036	-.016	-.021
	SE	-.008	--	-.119	-.020	.047	.039
	N						-.041
	S						.024
White Marlin and Blue Marlin	NW	.201	.018	.424*	.210*	.162*	.114
	SW	-.027	-.086	-.045	-.020	.058	-.108
	NE	.517*	.158	.268*	.527*	.329*	.266*
	SE	.404*	.293*	.082	.260*	.099	.065
	N						.086
	S						.663*
White Marlin and Black Marlin	NW	-.077	-.071	.008	-.015	-.050	-.064
	SW	-.044	-.045	.182	-.101	.026	.014
	NE	-.040	-.100	.067	-.015	-.030	-.042
	SE	-.030	-.102	.031	-.036	.108	.137*
	N						-.039
	S						-.066
White Marlin and Sailfish	NW	.018	-.033	.144	.162*	.156*	.103
	SW	.407*	.018	.262*	.594*	.355*	.265*
	NE	.255*	.137	.235*	.151*	.286*	.203*
	SE	.054	.024	-.010	.072	.170*	.150*

TABLE A-5 (Continued)

Species Pair	Area	Year					
		1961	1962	1963	1964	1965a	1965b
	N						.795*
	S						.369*
White Marlin and Swordfish	NW	.694*	.219*	-.057	.026	-.129*	-.068
	SW	-.130	.181	-.149	-.041	.004	-.147
	NE	.024	.117	.060	-.042	.122*	.078
	SE	.058	.003	-.070	-.035	.091	.055
	N						-.032
	S						.221*
Blue Marlin and Black Marlin	NW	-.069	-.060	-.002	-.050	-.032	-.042
	SW	-.004	.026	-.086	.002	-.019	-.042
	NE	-.012	.052	.033	-.012	.076	.070
	SE	-.067	.085	.026	.001	.011	.028
	N						-.032
	S						-.024
Blue Marlin and Sailfish	NW	.221	-.245*	-.096	.136*	-.006	-.053
	SW	.184	.476*	-.089	.066	.249*	.099
	NE	.418*	.705*	.089	.089	.274*	.214*
	SE	.097	.152	.114	.446*	.350*	.298*
	N						.049
	S						.094
Blue Marlin and Swordfish	NW	.032	-.058	-.127	-.028	-.101	-.064
	SW	.255*	-.071	.260*	.398*	.474*	.474*
	NE	.065	.133	-.016	.172*	.083	.011
	SE	.208*	.169*	.141	.202*	.113	.054
	N						.052
	S						-.077
Black Marlin and Sailfish	NW	-.089	.027	.179*	-.005	-.033	-.043
	SW	.083	.109	.055	-.054	.113	.105
	NE	-.004	.007	-.087	.019	-.030	-.040
	SE	-.044	-.073	.030	.033	-.050	-.039
	N						-.041
	S						-.067
Black Marlin and Swordfish	NW	-.053	-.104	-.012	-.037	-.026	-.024
	SW	-.119	-.024	-.090	-.004	.005	-.012
	NE	.857*	-.027	-.007	.024	-.001	-.025
	SE	.009	-.019	.340*	.018	-.016	.025
	N						.020
	S						-.110

TABLE A-5 (Continued)

Species Pair	Area	Year 1961	1962	1963	1964	1965a	1965b
Sailfish and Swordfish	NW	-.099	-.140	-.014	-.019	-.098	-.047
	SW	.015	-.082	-.075	-.086	.009	-.170
	NE	-.001	.216*	-.113	-.017	.006	-.053
	SE	.088	.298*	-.054	.054	.069	.020
	N						-.005
	S						.050

*Significant from 0 at $P \leq 0.05$ with the following respective degrees of freedom:

	1961	1962	1963	1964	1965a	1965b
NW	45	86	183	311	305	264
SW	94	91	98	150	170	120
NE	90	106	138	181	277	219
SE	164	149	159	156	298	255
N						97
S						91

TABLE A-6. -- Weighted mean correlation coefficients ($\bar{r}$) between the U'_{ijk} of selected tunas and billfishes among Quadrants NW, SW, NE, and SE of the Atlantic Ocean, 1961-65b[a]

Species Pair	Quadrant Means				Year Means				
	NW	SW	NE	SE	1961	1962	1963	1964	1965b
Yellowfin Tuna and									
Albacore	-.422	-.596	-.369	-.515	-.250	-.553	-.498	-.502	-.472
Bigeye Tuna	.348	.358	-.032	-.420	-.147	-.026	-.004	.176	.035
White Marlin	.053	-.149	-.099	-.347	-.188	-.265	-.091	-.109	-.113
Blue Marlin	-.250	-.261	.037	.201	-.044	-.291	-.166	.055	.037
Sailfish	.236	-.169	.016	.211	.025	.148	.046	.031	.232
Swordfish	.050	.083	.112	.183	.004	.185	.103	.172	.064
Albacore and									
Bigeye Tuna	-.258	-.292	-.306	.200	-.140	-.073	-.187	-.162	-.147
White Marlin	.031	.202	.309	.272	.358	.249	.302	.095	.126
Blue Marlin	.172	.354	.269	-.073	.314	.261	.440	-.039	.015
Sailfish	-.226	.153	.156	-.098	.181	.002	.014	-.107	-.100
Swordfish	-.079	.084	-.007	-.215	.027	-.175	-.129	.016	-.110
Bigeye Tuna and									
White Marlin	-.105	-.094	-.179	.164	.089	.004	-.026	-.104	-.082
Blue Marlin	-.228	-.324	-.250	-.155	-.032	-.300	-.262	-.218	-.271
Sailfish	.078	-.236	-.134	-.250	-.077	-.226	-.075	-.111	-.147
Swordfish	.199	.215	.069	.084	.142	.170	.139	.039	.209
White Marlin and									
Blue Marlin	.211	-.056	.355	.208	.316	.128	.220	.258	.109
Sailfish	.115	.353	.193	.069	.185	.039	.145	.237	.165
Swordfish	.052	-.062	.044	.008	.095	.113	-.048	-.014	-.005
Blue Marlin and									
Sailfish	-.000	.139	.277	.234	.209	.316	.007	.178	.143
Swordfish	-.059	.296	.070	.144	.167	.066	.040	.147	.071
Sailfish and									
Swordfish	-.042	-.085	-.010	.074	.029	.115	-.059	-.017	-.046

[a] See text for discussion of treatment of the data for 1965.

TABLE A-7. -- Correlation coefficients (r) between monthly mean sea surface temperature and the $\bar{U}'_{\underline{ijg}}$ of tunas and billfishes among Areas A, B, and C in the Atlantic Ocean, 1961-65

Species	Area	Year 1961	1962	1963	1964	1965
Yellowfin Tuna	A	.676	-.660	.074	-.311	-.136
	B	.345	.278	.374	-.551	-.320
	C	.870*	.942*	.893*	.533	.946*
Albacore	A	.087	.032	.507	-.501	-.697*
	B	.522	-.306	-.531	.435	-.419
	C	-.599*	-.743*	-.520	-.810*	-.552
Bigeye Tuna	A	-.357	.067	.360	.133	.281
	B	-.506	-.407	.347	-.299	-.572
	C	-.929*	-.902*	-.934*	-.893*	-.921*
Bluefin Tuna	A	.245	-.560	-.566	-.290	-.367
	B	.172	-.114	.516	-.350	-.183
	C	-.183	.440	.443	-.669	-.401
Skipjack Tuna	A	--	--	.345	.469	-.148
	B	--	--	-.391	.185	-.489
	C	.318	--	.318	.139	-.541
White Marlin	A	.278	.501	-.721*	-.706*	-.750*
	B	.551	.235	-.053	.268	-.344
	C	-.699*	-.657*	-.825*	-.900*	-.544
Blue Marlin	A	.481	.397	-.373	-.566	-.658*
	B	.165	-.558	-.481	-.394	.108
	C	-.015	-.041	-.315	.706	.495
Black Marlin	A	.059	-.651	.156	.184	.510
	B	.219	-.447	-.046	--	.425
	C	.112	.438	.079	.279	-.173
Sailfish	A	.909*	-.279	.383	.137	.181
	B	-.519	-.656	-.164	.694*	.197
	C	.389	.659*	.353	.773*	.769*
Swordfish	A	.103	.174	.096	-.444	-.074
	B	.535	.305	.652*	-.528	-.062
	C	-.107	-.172	-.026	-.766*	-.142

TABLE A-7 (Continued)

*Significant from 0 at $P < 0.05$ with the following respective degrees of freedom:

A	5	5	9	10	10
B	7	7	10	9	10
C	10	9	10	6	10