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ABUNDANCE OF BLUEFIN TUNA, *THUNNUS THYNNUS*, IN THE EASTERN PACIFIC OCEAN

by

William H. Bayliff

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PREFACE

The Internal Report series is produced primarily for the convenience of staff members of the Inter-American Tropical Tuna Commission. It contains reports of various types. Some will eventually be modified and published in the Commission's Bulletin series or in outside journals. Others are methodological reports of limited interest or reports of research which yielded negative or inconclusive results.

These reports are not to be considered as publications. Because they are in some cases preliminary, and because they are subjected to less intensive editorial scrutiny than contributions to the Commission's Bulletin series, it is requested that they not be cited without permission from the Inter-American Tropical Tuna Commission.

PREFACIO

Se ha producido una serie de Informe Internos con el fin de que sean útiles a los miembros del personal de la Comisión Interamericana del Atún Tropical. Esta serie incluye varias clases de informes. Algunos serán modificados eventualmente y publicados en la serie de Boletines de la Comisión o en revistas exteriores de prensa. Otros son informes metodológicos de un interés limitado o informes de investigación que han dado resultados negativos o inconclusos.

Estos informes no deben considerarse como publicaciones, debido a que en algunos casos son datos preliminares, y porque están sometidos a un escrutinio editorial menos intenso que las contribuciones hechas en la serie Boletinos de la Comisión; por lo tanto, se ruega que no sean citados sin permiso de la Comisión Interamericana del Atún Tropical.

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INTRODUCTION

Indices of abundance are of great importance in assessment of populations of fishes. Ahlstrom (1960: 1361) defined abundance as "the absolute number of individuals [post-recruits] in a population" and availability as "the portion (a percentage) of the recruited population that is physically within the geographical range of the fishery during the fishing season." For northern bluefin tuna, *Thunnus thynnus*, only the fish which migrate from the western Pacific Ocean (WPO) to the eastern Pacific Ocean (EPO) are available to the surface fisheries of the EPO. Although the population of northern bluefin includes individuals in coastal waters of the WPO and the EPO and in offshore waters of the Pacific Ocean, henceforth in this report the word abundance should be taken to mean abundance in coastal waters of the EPO.

The catches of bluefin in the EPO during the 1980s and early 1990s have been much less than they were during the 1960s and 1970s. The decreased catches during recent years are believed to be due, at least partly, to lesser availability of bluefin in the EPO (Bayliff *et al.*, 1991; Anonymous, 1992: 71-74). Bluefin are caught mostly by vessels with carrying capacities of 400 short tons or less (size classes 1-5), and the numbers of vessels in this size range have been decreasing, so it is possible that the declining catches are due to reduced fishing effort, rather than to reduced availability of fish.

INDICES OF ABUNDANCE

Catch

In general, the total catch during a year serves as an index of abundance, provided the following requirements are fulfilled:

1. the fishing effort remains constant, *i.e.* the numbers of vessels, the effectiveness of the gear, and the skill of the fishermen do not change from year to year;
2. the fishing effort is directed primarily at the species in question, *i.e.* the fishermen do not pass up opportunities to catch the species in question in order to try to catch other species;
3. the range of the species in question is the same each year;
4. the vulnerability to capture of the species in question is the same each year.

Requirements 3 and 4 are not often satisfied, but if a long series of data is available, the deviations from the means are not great, and there are no long-term trends in the deviations, they can be ignored.

Commercial catch

Calkins (1982) stated that, since the area where northern bluefin are caught is subjected to intensive searching for tunas and other pelagic fish throughout the year, the "total catch may be the best indicator of bluefin abundance." That statement could be correct, or nearly so, for the 1961-1980 period considered by Calkins, but it may not be true for subsequent years, due to decreased fishing effort. Commercial catch data for the EPO for 1959-1990 obtained from Bayliff (1991: Table 1) and for 1961-1991 obtained from Anonymous (1992: Table 1) are listed in Tables 1 and 3.

Sport catch

If commercial catch data provide a realistic index of abundance, then the same may be true of sport catch data. These vessels operate off California, off northern Baja California north of about 30°N, and in the vicinity of Guadalupe Island only, however, so they cannot provide realistic estimates of the abundance for the entire area where bluefin occur in the EPO unless the abundance off California and northern Baja California is proportional to that for the entire area. Data for the catches of bluefin aboard commercial passenger-carrying fishing vessels given by Leet *et al.* (1992: pages 247 and 255) are listed in Table 3. In general, bluefin are difficult to catch with sport gear, but their vulnerability to capture varies considerably from year to year. In 1956, the year in which the greatest catches of bluefin by sport gear were made, most of the fish were caught close to shore off Coronado, California. These fish did not form schools, so they could not be caught by purse-seine vessels. During the early 1980s sport-fishing vessels began fishing at Cortes Bank (32°20'N-119°12'W) for the first time, which increased the catches of bluefin by these vessels (Steven J. Crooke, California Department of Fish and Game, personal communication).

Catch per unit of effort

Catch per unit of fishing effort (CPUE) is the most widely-used index of the abundance of fish. It is superior to catch because it is not necessary that the numbers of fishing vessels be constant from year to year. It is still necessary that the effectiveness of the gear and the skill of the fishermen be constant from year to year unless information making it possible to adjust for annual changes in these is available. The other requirements listed above under **Catch** must still be satisfied. Bluefin are caught mostly by purse seines in the EPO, but the geographic range of the purse-seine fishery for tunas extends far beyond the geographic range in which bluefin occur in the EPO, so CPUE data for the EPO are unlikely to provide realistic estimates of the abundance of bluefin. The indices described below take that fact into account.

Calkins index

Calkins (1982) attempted to ascertain the fishing effort directed toward bluefin during 1961-1980. He adopted the following rules: (1) no effort made south of 23°N was considered to be bluefin effort; (2) no effort during the November-April period was considered to be bluefin effort; (3) no effort in 1-degree area-month strata in which no sets were made on bluefin was considered to be bluefin effort. The annual sums of the effort for 1959-1991 obtained by this method are listed in Table 2. (The values in this table differ slightly from those in Calkins' Table 6 because the IATTC's files have been updated and corrected, as necessary, since 1982.) Calkins calculated the CPUEs for 1961-1980 by dividing the sums of the catches of bluefin in the area-time strata in which bluefin effort was assumed to occur by the sums of the effort in those strata. The trends for this index of abundance were similar to those for the catches. When similar calculations were made for 1981-1989 (Bayliff, 1992:

Figure 7), very high CPUEs were obtained for 1985, 1986, 1987, and 1989, even though the catches were about average during 1985 and 1986 and very low during 1987 and 1989. This was apparently due to violation of Requirement 3 above, as during the years with high CPUEs the fish tended to occur in only a few area-time strata, with high CPUEs in them. In 1989, for example, no bluefin were caught south of 30°N, and 70 percent of the catch was made during August. The Calkins indices for 1959-1991 are listed in Table 3.

Bluefin vessel index

For this method, it is assumed that the fishing effort directed toward bluefin is proportional to the numbers of vessels which direct substantial portions of their effort to fishing for bluefin. Accordingly, each vessel of the purse-seine fleet was classified each year as a "bluefin vessel" or a "non-bluefin vessel." If a vessel caught bluefin in a given year and in two or more of the four closest adjacent years (two years before and two years after the year in question), it was classified as bluefin vessel for that year. Otherwise it was classified as a non-bluefin vessel. The criteria were relaxed for vessels which entered the EPO tuna fishery less than two years before the year in question or left the fishery less than two years after the year in question. For example, if a vessel entered the EPO tuna fishery in 1971, it was classified as a bluefin vessel for that year if it caught bluefin in 1971 and in either 1972 or 1973. This system of classification is arbitrary, and perhaps some other system would be better. However, it seems to be adequate to give some insight into the value of fleet size as a measure of the effort directed toward bluefin and total catch divided by fleet size as an index of the abundance of bluefin. Data are given in Table 1 on the commercial catches of bluefin, the numbers of bluefin vessels in the fleet, and the numbers of purse-seine vessels in the fleet. There are almost no data for Class-1 and Class-2 vessels prior to 1971 because these vessels rarely catch yellowfin or skipjack in the area where bluefin occur, and the IATTC staff did not begin to collect data on bluefin until 1971.

The coefficient of correlation between the catches and the numbers of bluefin vessels is 0.849 (d.f. = 27, $P<0.01$). This does not necessarily mean that the amounts of fish caught are determined mostly by the size of the bluefin fleet (or that the size of the fleet is determined mostly by the abundance of bluefin), however. For example, it can be seen that the catches during the 1961-1968 period varied by a factor of 2.7 (17,523/6,491), while the number of bluefin vessels varied by a factor of only 1.2 (70/60), and that the catches during the 1981-1989 period varied by a factor of 6.0 (5,604/940), while the number of bluefin vessels varied by a factor of only 1.6 (22/14). Accordingly, it appears that the fluctuations in the catches are not due primarily to fluctuations in the numbers of bluefin vessels in the fleet. There is no evidence from these data that indicates that the hypothesis of Bayliff *et al.* (1991) that decreased availability of fish is an important contributor to the reduced catches of bluefin in the EPO should be rejected.

Data on the numbers of purse-seine vessels in the fleet are also shown in Table 1 to satisfy the curiosity of readers who might think that the comparison might be made between bluefin catches and number of vessels in the purse-seine fleet. It can be seen that number of purse-seine vessels increased from 1961 to 1979 and then decreased from 1979 to 1989. There appears to be no relationship between bluefin catches and fleet size.

The bluefin vessel index is the total commercial catch for each year divided by the number of bluefin vessels in the fleet during that year. Indices for 1961-1989 are shown in Table 3.

Bluefin habitat index

Bluefin are most often caught in the EPO when the sea-surface temperatures (SSTs) are between 17° and 23°C (62.6° and 73.4°F) (Bell, 1963). Accordingly, it was assumed that EPO waters north of 23°N and west of Baja California and California with SSTs in that range are suitable habitat for bluefin during the period of May through October. (The decision to use only data for the area north of 23°N and only the data for May-October follow the rules of Calkins (1982).) Data were assembled on logged purse-seine catch and effort and SSTs in the 1-degree area-month strata fitting the above criteria. The logged catch and effort data were taken from computer files of the IATTC and the SST data were taken from Anonymous (1960-1980 and 1981-1991). The monthly and annual sums of the logged catches of bluefin in the EPO were divided by the monthly and annual sums of the effort in the 1-degree areas which were suitable bluefin habitat (Table 2) to get monthly and annual CPUEs of bluefin. These data appear in Table 3 and Appendix Table 1.

Squire's indices

If indices of abundance based upon visual surveys are to be valid the following requirements must be satisfied:

1. the effectiveness of the equipment and the skill of the searchers do not change from year to year;
2. the range of the species in question is the same each year;
3. the visibility of the species in question is the same each year.

Requirements 2 and 3 are not often satisfied, but if a long series of data is available, the deviations from the means are not great, and there are no long-term trends in the deviations, they can be ignored. There is no need to satisfy the second requirement if the surveys cover the entire range of the species in all years.

Squire (1972, 1983, and 1992) calculated indices of abundance for bluefin tuna from data obtained from airplane pilots who were searching for tunas and other pelagic fishes off Southern California and northern Baja California for fishing vessels. He calculated two indices for each year, one for "core areas" (areas in which bluefin most commonly occur) and the other for "total areas" (between 27°50'N and 38°10'N). His indices for 1962-1990 are listed in Table 3.

Indices for areas north of 28°N

Because Squire's indices apply only to the area north of 27°50'N, and because the California-based sport fishery takes place mostly north of 30°N, logged effort in bluefin habitat north of 28°N are listed in Table 2 and data on the logged catches and effort north of 28°N and habitat indices for this area are listed in Table 3 and Appendix Table 2.

COMPARISON OF MEASURES OF EFFORT AND INDICES OF ABUNDANCE

Measures of effort

Five measures of effort are listed in Table 2. No adjustments have been made for differences in efficiencies of vessels of different sizes because sufficient data to perform the necessary calculations are not available. In general, for at least two reasons, larger vessels are more efficient than smaller ones. First, larger vessels are faster, so they can search for fish in greater areas per unit of time than can smaller ones. Second, larger vessels have greater carrying capacities for fish, so when they find an area where fishing is good they can usually remain there for extended periods, whereas smaller vessels often have to return to port to unload their catches while fishing is still good. On the other hand, bluefin are caught mostly by smaller vessels, which may indicate that their captains direct their effort more toward bluefin and are more skillful at catching bluefin than are the captains of larger vessels.

Four of the five measures indicate that the fishing effort for bluefin has been less during the 1980s and early 1990s than during the 1960-1979 period. The exception, total number of vessels, is not a meaningful measure of effort directed toward bluefin, as most of these vessels seldom fish in the area where bluefin occur. The decline in the measure of effort used for calculating the Calkins index is greater than those for the habitat indices. This is because the Calkins index is calculated only with effort in area-time strata where sets on bluefin were made, whereas the habitat indices are calculated with effort in area-time strata where bluefin are likely to be found (assuming that sea-surface temperature is the only factor influencing their distribution). It is the belief of the author of this report that the effort used in calculating the habitat index for the entire area is more realistic than that used in calculating the Calkins index.

Indices of abundance

The top panel of Table 4 lists coefficients of correlation for indices of abundance involving the entire area in which bluefin are caught. All but two of these are significant at the 1-percent level, the exceptions being total catch *versus* the Calkins index (Test 2) and logged catch during May-October *versus* the Calkins index (Test 7). It was pointed out above that high values of the Calkins index were obtained for 1985, 1986, 1987, and 1989, and that this was probably due to concentration of the fish in a few small areas. When the data for 1981-1991 were omitted high coefficients of correlation (Tests 3 and 8) were obtained, confirming Calkins' observation that the total catch and his index for years prior to 1981 are highly correlated. A scatter plot of the data used for Test 13 showed the point for 1989 to be an outlier, so the coefficient of correlation was recalculated without the data for 1989 (Test 14), producing a higher coefficient of correlation.

The middle panel of Table 4 lists coefficients of correlation for indices of abundance involving the area north of 28°N. Only the r values for logged catch *versus* habitat index (Tests 19 and 20) and Squire's core index *versus* Squire's total index (Test 24) are significant. A scatter plot of the data used for Test 19 showed the point for 1986 to be an outlier, so the coefficient of correlation was recalculated without the data for 1986 (Test 20), producing a higher coefficient of correlation. It is noteworthy that the two Squire indices are correlated significantly only to each other and the sport catch index is not correlated significantly with any other index.

The bottom panel of Table 4 lists coefficients of correlation for indices of abundance for the entire area in which bluefin are caught and the area north of 28°N.

Tests 27 and 28 were performed first to see if indices which were identical except for the areas included were correlated. Both of these tests produced high values of *r*, which indicates that the sport catch indices and Squire's indices can be considered to be indices for the entire area of the fishery, rather than just the area north of 28°N or 30°N.

None of the original five tests involving sport catches (Tests 30, 37, 46, 53, and 60 produced significant results. When a single outlier (1986) was removed, a significant relationship was found for the Calkins index-sport catch comparison (Test 47).

Only one (Test 31) of the original ten tests (Tests 31, 33, 38, 40, 48, 49, 54, 55, 61, and 63) involving Squire's indices produced significant results. When single outliers (1978) were removed, the significance of one relationship increased from 5 percent to 1 percent (Test 32), three relationships which were previously insignificant became significant (Tests 34, 39, and 41), and two relationships remained insignificant (Tests 62 and 64).

Only one (Test 44) of the remaining eight original tests involving catch and/or effort data (Tests 29, 35, 42, 44, 50, 52, 56, and 58), produced insignificant results. When a single outlier (1986) was removed the relationship remained insignificant (Test 45).

For the most part, the indices of abundance derived from catch and effort data are related only to each other, as are the two indices derived from aerial observations. The sport catch data are not related to any of the other indices. The sport catches are probably not realistic indices of abundance, for reasons stated above, so they are not considered further. The following possibilities remain: the catch and effort data provide realistic indices of abundance; the aerial observations provide realistic indices of abundance; neither of these provides realistic indices of abundance.

The first possibility appears to be the most likely, for two reasons. First, the catches and CPUEs are highly correlated, as indicated especially by Tests 3, 4, 5, and 19. Second, most of the indices are based upon data for the entire area in which bluefin are caught, rather than only the northern part of that area. (Admittedly, however, the indices of abundance for the entire area and for its northern part are highly correlated (Tests 27 and 28).)

There are seven indices of abundance based on catch and effort data. The three based on catches can be disregarded, as these give biased results when the effort is not constant from year to year. The habitat index for the area north of 28°N can also be disregarded, as it is presumably inferior to the habitat index for the entire area in which bluefin are caught. This leaves the Calkins index, the vessel index, and the habitat index for the entire area in which bluefin are caught. The Calkins index is biased when the range of bluefin contracts, as apparently was the case during 1985-1987 and 1989-1991. The measure of effort from which the vessel index is calculated is based upon arbitrary classification of vessels as bluefin and non-bluefin vessels, whereas the measure of effort from which the habitat index is calculated is based upon actual effort in area-time strata which are judged to be suitable habitat for bluefin. Accordingly, the habitat index is considered to be the best index of abundance of bluefin in the EPO.

CONCLUDING REMARKS

The habitat indices indicate that the abundance of bluefin in the EPO has been low during the 1977-1991 period, except for 1985 and 1986. These were apparently years of high abundance of bluefin, but the catches were only average because the fishing effort was so low. Unless the fishing effort increases, it appears unlikely that catches greater than those of 1985 and 1986 will be taken in the future.

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TABLE 1. Commercial catches (in short tons) of bluefin in the eastern Pacific Ocean, numbers of bluefin vessels (defined in the text) in the fleet, and numbers of purse-seine vessels in the fleet. The numbers 1 through 6 refer to the size classes, based on carrying capacities of the vessels in tons (1 = 50 or less; 2 = 51-100; 3 = 101-200; 4 = 201-300; 5 = 301-400; 6 = greater than 400).

Year	Catch	Bluefin vessels							Total purse-seine vessels						
		1	2	3	4	5	6	Total	1	2	3	4	5	6	Total
1961	8,968	0	1	38	16	7	0	62	0	3	52	40	20	9	124
1962	12,421	0	0	34	22	9	0	65	0	2	46	41	29	12	130
1963	13,527	0	0	26	27	15	0	68	1	7	43	41	31	18	141
1964	10,161	0	0	27	30	13	0	70	0	1	39	45	29	20	134
1965	7,592	0	0	27	23	12	0	62	1	12	39	43	29	22	146
1966	17,523	0	0	23	27	14	0	64	0	0	34	39	32	21	126
1967	6,491	0	0	21	24	16	0	61	0	2	29	37	30	24	122
1968	6,587	0	0	21	25	12	2	60	1	11	26	34	30	37	139
1969	7,635	0	0	18	20	7	1	46	0	7	29	35	29	49	149
1970	4,372	0	0	15	17	12	3	47	0	13	24	33	27	65	162
1971	9,215	0	9	17	17	13	5	61	0	16	26	32	27	84	185
1972	14,714	0	10	16	13	12	10	61	1	22	22	34	25	102	206
1973	11,845	0	10	16	18	8	11	63	1	16	24	39	16	120	216
1974	6,192	0	14	12	15	5	7	53	0	19	27	37	15	132	230
1975	10,563	0	14	14	13	9	9	59	4	24	33	25	17	146	249
1976	11,735	0	15	11	11	11	12	60	0	24	27	25	16	158	250
1977	6,033	0	5	10	8	12	15	50	0	20	32	19	18	161	250
1978	5,948	0	9	6	6	9	16	46	0	24	37	25	20	156	262
1979	6,744	0	9	6	4	9	14	42	2	27	34	25	22	158	268
1980	3,239	0	9	4	4	7	11	35	0	17	32	25	20	164	258
1981	1,201	0	9	3	3	2	3	20	1	20	25	20	16	166	248
1982	3,472	0	10	2	2	2	4	20	1	22	16	16	13	153	221
1983	940	0	9	3	0	1	2	15	7	28	21	14	10	123	203
1984	972	0	11	1	2	0	3	17	3	27	16	9	6	105	166
1985	4,469	0	11	3	2	1	3	20	4	22	18	10	6	117	177
1986	5,604	2	14	4	0	1	1	22	5	19	19	9	5	109	166
1987	1,097	0	9	4	0	0	2	15	2	16	18	8	5	128	177
1988	1,569	0	10	4	0	0	0	14	2	23	17	7	6	132	187
1989	1,282	0	10	4	0	0	2	16	5	19	17	7	6	122	176

TABLE 2. Measures of fishing effort for bluefin in the eastern Pacific Ocean.

Year	Calkins index	Bluefin vessels	Total vessels	Habitat index	Habitat north of 28°N index
1959	824.0		87		
1960	1453.0		112	1889.5	932.0
1961	2051.0	62	124	2721.5	1265.5
1962	2886.5	65	130	2890.5	1572.0
1963	2677.0	68	141	3131.5	1957.5
1964	2941.0	70	134	3240.0	1182.0
1965	2370.0	62	146	2569.5	861.0
1966	2422.5	64	126	2727.0	1102.5
1967	2812.0	61	122	3483.0	998.0
1968	1968.0	60	139	2336.0	1279.5
1969	2258.0	46	149	2801.0	1092.0
1970	1682.5	47	162	2658.5	916.0
1971	2595.5	61	185	2944.5	1196.0
1972	3220.0	61	206	3613.0	1727.5
1973	2664.5	63	216	3271.0	1461.0
1974	1974.0	53	230	2105.5	699.5
1975	1673.0	59	249	1811.0	484.5
1976	2322.0	60	250	2524.5	1685.5
1977	1948.0	50	250	2723.0	1251.0
1978	1841.0	46	262	2356.5	1211.5
1979	1771.0	42	268	3284.0	1010.0
1980	1329.5	35	258	2481.0	600.0
1981	664.5	20	248	1515.5	673.5
1982	1060.0	20	221	2845.5	1260.5
1983	651.0	15	203	2430.0	1215.0
1984	1022.0	17	166	2159.5	1463.5
1985	566.0	20	177	916.5	587.5
1986	384.0	22	166	522.0	370.0
1987	174.5	15	177	500.0	242.5
1988	755.5	14	187	1705.5	493.0
1989	140.0	16	176	808.0	292.5
1990	234.0			764.5	375.0
1991	75.0			335.0	150.5

TABLE 3. Indices of abundance for bluefin tuna. The units are as follows: commercial catch, short tons; sport catch, numbers of fish; Calkins index, short tons per day; Squire indices, short tons per block-area flight; vessel, short tons per year; habitat, short tons per day.

Year	Catch				Calkins index	Squire indices		Present study		
	Commercial			Sport		Core	Total	Vessel index	Habitat indices	
	Jan.-Dec.	May-Oct.	May-Oct. N of 28°N						Total	N of 28°N
1959	7,621	3,407	1,169	1,330	4.04					
1960	5,977	4,923	3,475	97	3.34				2.61	3.73
1961	8,968	8,746	7,452	2,268	4.20			145	3.21	5.89
1962	12,421	10,970	8,630	2,453	3.82	6.57	4.40	191	3.80	5.49
1963	13,527	13,355	9,563	737	4.96	6.97	6.81	199	4.26	4.89
1964	10,161	8,725	5,242	693	2.93	6.97	6.81	145	2.69	4.43
1965	7,592	6,495	4,091	92	2.62	1.28	0.90	122	2.53	4.75
1966	17,523	16,032	3,974	1,998	6.46	13.03	9.46	274	5.88	3.60
1967	6,491	5,904	616	3,166	2.07	4.51	3.42	106	1.70	0.62
1968	6,587	5,517	4,649	1,231	2.78	9.45	6.03	110	2.36	3.63
1969	7,635	6,433	2,886	1,470	2.83	0.59	0.39	166	2.30	2.64
1970	4,372	4,400	730	1,833	2.48	<0.01	0.02	93	1.66	0.80
1971	9,215	8,243	2,823	749	3.16	0.87	0.42	151	2.80	2.36
1972	14,714	13,203	8,056	1,470	4.08	6.94	2.75	241	3.65	4.66
1973	11,845	9,925	5,846	5,347	3.67	17.38	16.45	188	3.03	4.00
1974	6,192	4,472	1,613	5,765	2.17	18.32	17.28	117	2.12	2.31
1975	10,563	7,252	2,553	3,348	4.27	2.60	2.54	179	4.00	5.27
1976	11,735	9,873	7,720	2,040	4.19	13.73	13.20	196	3.91	4.58
1977	6,033	5,261	2,945	1,838	2.65	8.71	7.12	121	1.93	2.35
1978	5,948	4,323	3,651	479	2.32	34.52	30.07	129	1.83	3.02
1979	6,744	5,212	3,154	1,087	2.92	12.87	12.32	161	1.59	3.12
1980	3,239	2,660	831	729	1.97	0.89	0.69	93	1.07	1.38
1981	1,201	774	693	542	1.14	0.95	0.80	60	0.51	1.03
1982	3,472	2,672	1,862	665	2.42	1.37	1.27	174	0.94	1.48
1983	940	605	589	1,912	0.83	0.05	0.20	63	0.25	0.48
1984	972	800	800	2,834	0.77	0.62	0.66	57	0.37	0.55
1985	4,469	3,702	2,085	4,980	6.60	2.32	2.57	223	4.04	3.55
1986	5,604	4,715	4,490	693	12.07	1.98	3.03	255	9.03	12.14
1987	1,097	851	802	1,859	4.45	0.77	0.55	73	1.70	3.31
1988	1,569	1,369	653	321	1.69	1.23	0.56	112	0.80	1.32
1989	1,289	1,087	1,087	6,519	7.77	1.02	0.48	80	1.35	3.72
1990	1,682	1,514	1,514	3,756	6.09	0.73	0.35		1.98	4.04
1991	462	458	341		5.92				1.37	2.27

TABLE 4. Correlations between different indices of availability of bluefin tuna in the eastern Pacific Ocean.

Comparison	Coefficient of correlation	Degrees of freedom	Probability
Entire area			
1. Total catch versus Logged catch, May-October	0.981	31	**
2. Total catch versus Calkins index	0.151	31	n.s.
3. same with 1981-1991 data omitted	0.867	20	**
4. Total catch versus Vessel index	0.767	27	**
5. Total catch versus Habitat index	0.616	30	**
6. same with 1986 data omitted	0.872	29	**
7. Logged catch, May-October, versus Calkins index	0.163	31	n.s.
8. same with 1981-1991 data omitted	0.812	20	**
9. Logged catch, May-October, versus Vessel index	0.751	27	**
10. Logged catch, May-October, versus Habitat index	0.611	30	**
11. same with 1986 data omitted	0.867	29	**
12. Calkins index versus Vessel index	0.624	27	**
13. Calkins index versus Habitat index	0.763	30	**
14. same with 1989 data omitted	0.854	29	**
15. Vessel index versus Habitat index	0.836	27	**
North of 28°N			
16. Logged catch, May-October, versus Sport catch	-0.132	30	n.s.
17. Logged catch, May-October, versus Squire's core index	0.363	27	n.s.
18. Logged catch, May-October, versus Squire's total index	0.333	27	n.s.
19. Logged catch, May-October, versus Habitat index	0.594	30	**
20. same with 1986 data omitted	0.773	29	**
21. Sport catch versus Squire's core index	0.078	27	n.s.
22. Sport catch versus Squire's total index	0.102	27	n.s.
23. Sport catch versus Habitat index	-0.032	29	n.s.
24. Squire's core index versus Squire's total index	0.988	27	**
25. Squire's core index versus Habitat index	0.090	27	n.s.
26. Squire's total index versus Habitat index	0.106	27	n.s.
Total area versus North of 28°N			
27. Logged catch, May-October, versus Logged catch north of 28°N	0.818	31	**
28. Habitat index versus Habitat index north of 28°N	0.866	31	**
29. Total catch versus Logged catch north of 28°N	0.787	31	**
30. Total catch versus sport catch	-0.058	30	n.s.
31. Total catch versus Squire's core index	0.391	27	*
32. same with 1978 data omitted	0.586	26	**
33. Total catch versus Squire's total index	0.345	27	n.s.
34. same with 1978 data omitted	0.508	26	**
35. Total catch versus Habitat index north of 28°N	0.410	30	*
36. same with 1986 data omitted	0.631	29	**
37. Logged catch, May-October, versus Sport catch	-0.071	30	n.s.
38. Logged catch, May-October, versus Squire's core index	0.342	27	n.s.
39. same with 1978 data omitted	0.550	26	**
40. Logged catch, May-October, versus Squire's total index	0.292	27	n.s.
41. same with 1978 data omitted	0.466	26	*
42. Logged catch, May-October, versus Habitat index north of 28°N	0.396	30	*
43. same with 1986 data omitted	0.613	29	**
44. Calkins index versus Logged catch north of 28°N	0.211	31	n.s.
45. same with 1986 data omitted	0.236	30	n.s.

46.	Calkins index versus Sport catch	0.245	30	n.s.
47.	same with 1986 data omitted	0.470	29	**
48.	Calkins index versus Squire's core index	-0.071	27	n.s.
49.	Calkins index versus Squire's total index	-0.056	27	n.s.
50.	Calkins index versus Habitat index north of 28°N	0.777	30	**
51.	same with 1986 data omitted	0.575	29	**
52.	Vessel index versus Logged catch north of 28°N	0.628	27	**
53.	Vessel index versus Sport catch	-0.013	27	n.s.
54.	Vessel index versus Squire's core index	0.231	26	n.s.
55.	Vessel index versus Squire's total index	0.213	26	n.s.
56.	Vessel index versus Habitat index north of 28°N	0.640	27	**
57.	same with 1986 data omitted	0.596	26	**
58.	Habitat index versus Logged catch north of 28°N	0.566	30	**
59.	same with 1986 data omitted	0.696	29	**
60.	Habitat index versus Sport catch	-0.012	29	n.s.
61.	Habitat index versus Squire's core index	0.129	27	n.s.
62.	same with 1978 data omitted	0.260	28	n.s.
63.	Habitat index versus Squire's total index	0.132	27	n.s.
64.	same with 1978 data omitted	0.256	26	n.s.

** significant at the 1-percent level
* significant at the 5-percent level
n.s. not significant at the 5-percent level

APPENDIX TABLE 1. Catches (C), in short tons, effort (f), in days of fishing by purse-seine vessels in "bluefin habitat," and catch per unit of effort (C/f) for bluefin tuna in the eastern Pacific Ocean.

Year	May			June			July			August			September			October			Total		
	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f
1960	0	5.0	0.0	1777	366.0	4.9	1971	997.0	2.0	967	499.5	1.9	208	18.0	11.6	0	4.0	0.0	4923	1889.5	2.61
1961	33	104.0	0.3	1255	564.5	2.2	1188	726.0	1.6	4833	806.5	6.0	1285	434.0	3.0	152	86.5	1.8	8746	2721.5	3.21
1962	339	253.5	1.3	2080	556.0	3.7	3436	945.5	3.6	4711	954.0	4.9	404	160.5	2.5	0	21.0	0.0	10970	2890.5	3.80
1963	98	88.0	1.1	2389	356.0	6.7	1954	568.0	3.4	5192	1065.5	4.9	3714	921.5	4.0	8	132.5	0.1	13355	3131.5	4.26
1964	20	18.0	1.1	1610	552.5	2.9	2322	1215.0	1.9	3916	1009.5	3.9	852	430.0	2.0	5	15.0	0.3	8725	3240.0	2.69
1965	3	77.0	0.0	580	452.0	1.3	900	754.5	1.2	2515	373.5	6.7	1524	474.0	3.2	973	438.5	2.2	6495	2569.5	2.53
1966	231	136.5	1.7	5057	496.0	10.2	7068	1051.0	6.7	3512	782.5	4.5	164	236.5	0.7	0	24.5	0.0	16032	2727.0	5.88
1967	52	448.5	0.1	3093	636.0	4.9	2405	1161.0	2.1	91	425.0	0.2	245	537.0	0.5	18	275.5	0.1	5904	3483.0	1.70
1968	0	58.5	0.0	813	475.5	1.7	2251	761.5	3.0	1487	704.0	2.1	803	272.0	3.0	163	64.5	2.5	5517	2336.0	2.36
1969	557	309.0	1.8	760	489.5	1.6	2494	878.0	2.8	1922	554.5	3.5	700	352.0	2.0	0	218.0	0.0	6433	2801.0	2.30
1970	0	264.5	0.0	1611	478.5	3.4	2388	980.5	2.4	330	671.5	0.5	71	208.5	0.3	0	55.0	0.0	4400	2658.5	1.66
1971	2135	456.0	4.7	1925	304.5	6.3	1425	944.0	1.5	780	441.5	1.8	1101	341.5	3.2	877	457.0	1.9	8243	2944.5	2.80
1972	376	201.0	1.9	2465	627.0	3.9	2609	1033.5	2.5	5362	896.5	6.0	766	566.0	1.4	1625	289.0	5.6	13203	3613.0	3.65
1973	18	107.5	0.2	1923	559.0	3.4	5219	1153.0	4.5	2528	961.0	2.6	237	324.0	0.7	0	166.5	0.0	9925	3271.0	3.03
1974	0	35.5	0.0	1316	413.0	3.2	1565	709.5	2.2	691	377.5	1.8	833	394.5	2.1	67	175.5	0.4	4472	2105.5	2.12
1975	58	5.0	11.6	2744	177.0	15.5	1678	630.5	2.7	401	463.0	0.9	1743	288.0	6.1	628	247.5	2.5	7252	1811.0	4.00
1976	266	64.0	4.2	1819	551.5	3.3	308	327.5	0.9	3738	500.0	7.5	3399	937.0	3.6	343	144.5	2.4	9873	2524.5	3.91
1977	1525	355.0	4.3	431	607.5	0.7	68	559.5	0.1	2156	605.0	3.6	715	512.5	1.4	366	83.5	4.4	5261	2723.0	1.93
1978	0	172.0	0.0	648	609.5	1.1	1478	601.0	2.5	2185	752.0	2.9	0	155.0	0.0	12	67.0	0.2	4323	2356.5	1.83
1979	1654	383.5	4.3	394	986.5	0.4	765	794.0	1.0	2040	660.5	3.1	236	339.5	0.7	123	120.0	1.0	5212	3284.0	1.59
1980	335	350.0	1.0	1213	825.5	1.5	263	466.0	0.6	552	282.5	2.0	297	303.5	1.0	0	253.5	0.0	2660	2481.0	1.07
1981	0	222.5	0.0	289	283.0	1.0	88	223.5	0.4	281	282.0	1.0	116	199.0	0.6	0	305.5	0.0	774	1515.5	0.51
1982	0	328.5	0.0	0	380.0	0.0	939	526.5	1.8	726	609.5	1.2	640	500.0	1.3	367	501.0	0.7	2672	2845.5	0.94
1983	0	235.0	0.0	0	646.0	0.0	276	478.5	0.6	180	606.0	0.3	108	247.5	0.4	41	217.0	0.2	605	2430.0	0.25
1984	25	256.0	0.1	89	446.5	0.2	348	910.5	0.4	138	336.5	0.4	135	60.0	2.2	65	150.0	0.4	800	2159.5	0.37
1985	30	23.0	1.3	1706	161.0	10.6	355	292.5	1.2	840	170.0	4.9	143	145.0	1.0	628	125.0	5.0	3702	916.5	4.04
1986	16	13.0	1.2	338	49.5	6.8	1710	181.0	9.4	1720	130.5	13.2	400	57.0	7.0	531	91.0	5.8	4715	522.0	9.03
1987	0	13.5	0.0	36	38.0	0.9	288	132.5	2.2	270	154.5	1.7	207	89.5	2.3	50	72.0	0.7	851	500.0	1.70
1988	0	5.0	0.0	237	167.0	1.4	939	660.0	1.4	109	504.0	0.2	18	172.0	0.1	66	197.5	0.3	1369	1705.5	0.80
1989	0	15.0	0.0	0	83.0	0.0	7	127.0	0.1	807	221.0	3.7	234	254.5	0.9	39	107.5	0.4	1087	808.0	1.35
1990	0	100.5	0.0	0	202.5	0.0	518	141.0	3.7	318	178.0	1.8	591	79.0	7.5	87	63.5	1.4	1514	764.5	1.98
1991	0	1.0	0.0	108	6.0	18.0	18	55.0	0.3	332	160.5	2.1	0	75.5	0.0	0	37.0	0.0	458	335.0	1.37

APPENDIX TABLE 2. Catches (C), in short tons, effort (f), in days of fishing by purse-seine vessels in "bluefin habitat" north of 28°N, and catch per unit of effort (C/f) for bluefin tuna in the eastern Pacific Ocean.

Year	May			June			July			August			September			October			Total		
	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f
1960	0	0.0	0.0	604	118.0	5.1	1696	353.0	4.8	967	440.0	2.2	208	18.0	11.6	0	3.0	0.0	3475	932.0	3.73
1961	33	0.0	-	169	33.0	5.1	980	232.5	4.2	4833	707.0	6.8	1285	274.5	4.7	152	18.5	8.2	7452	1265.5	5.89
1962	29	5.0	5.8	225	0.0	-	3261	667.0	4.9	4711	771.0	6.1	404	124.0	3.3	0	5.0	0.0	8630	1572.0	5.49
1963	98	19.0	5.2	27	4.0	6.8	590	50.5	11.7	5126	870.5	5.9	3714	906.0	4.1	8	107.5	0.1	9563	1957.5	4.89
1964	20	0.0	-	60	1.0	60.0	485	111.0	4.4	3916	887.5	4.4	756	174.5	4.3	5	8.0	0.6	5242	1182.0	4.43
1965	3	0.0	-	0	6.0	0.0	3	22.5	0.1	1679	291.5	5.8	1518	369.0	4.1	888	172.0	5.2	4091	861.0	4.75
1966	8	1.0	8.0	0	11.5	0.0	313	100.0	3.0	3512	764.5	4.6	111	201.0	0.5	0	24.5	0.0	3974	1102.5	3.60
1967	0	0.0	0.0	100	12.0	8.3	233	180.0	1.3	20	144.0	0.1	245	537.0	0.5	18	125.0	0.1	616	998.0	0.62
1968	0	0.0	0.0	3	12.0	0.2	2193	383.5	5.7	1487	601.5	2.5	803	245.5	3.3	163	37.0	4.4	4649	1279.5	3.63
1969	40	0.0	-	51	41.5	1.3	188	294.0	0.6	1908	532.5	3.6	699	188.0	3.7	0	36.0	0.0	2886	1092.0	2.64
1970	0	0.0	0.0	0	21.5	0.0	329	286.5	1.1	330	507.5	0.7	71	89.5	0.8	0	11.0	0.0	730	916.0	0.80
1971	2	9.0	0.2	0	0.0	0.0	63	84.0	0.8	780	402.0	1.9	1101	341.5	3.2	877	359.5	2.4	2823	1196.0	2.36
1972	0	0.0	0.0	9	12.0	0.8	555	121.0	4.6	5133	774.5	6.6	739	531.0	1.4	1620	289.0	5.6	8056	1727.5	4.66
1973	18	1.0	18.0	0	7.0	0.0	3135	526.5	6.0	2456	746.5	3.3	237	157.0	1.5	0	23.0	0.0	5846	1461.0	4.00
1974	0	0.0	0.0	0	6.0	0.0	256	105.5	2.4	559	265.0	2.1	773	295.0	2.6	25	28.0	0.9	1613	699.5	2.31
1975	0	0.0	0.0	7	0.0	-	303	98.5	3.1	337	107.0	3.1	1403	177.0	7.9	503	102.0	4.9	2553	484.5	5.27
1976	0	0.0	0.0	4	18.5	0.2	308	154.5	2.0	3677	438.5	8.4	3394	932.0	3.6	337	142.0	2.4	7720	1685.5	4.58
1977	0	0.0	0.0	15	53.0	0.3	68	170.5	0.4	2147	551.0	3.9	715	423.5	1.7	0	53.0	0.0	2945	1251.0	2.35
1978	0	2.0	0.0	100	24.0	4.2	1394	372.5	3.7	2145	661.0	3.2	0	134.0	0.0	12	18.0	0.7	3651	1211.5	3.02
1979	0	0.0	0.0	0	10.0	0.0	755	145.5	5.2	2040	479.5	4.3	236	304.0	0.8	123	71.0	1.7	3154	1010.0	3.12
1980	0	3.5	0.0	0	12.0	0.0	15	35.0	0.4	519	226.0	2.3	297	275.5	1.1	0	48.0	0.0	831	600.0	1.38
1981	0	5.0	0.0	289	50.0	5.8	77	163.0	0.5	231	254.5	0.9	96	178.5	0.5	0	22.5	0.0	693	673.5	1.03
1982	0	0.0	0.0	0	8.0	0.0	129	64.5	2.0	726	403.0	1.8	640	453.0	1.4	367	332.0	1.1	1862	1260.5	1.48
1983	0	4.0	0.0	0	5.0	0.0	276	196.5	1.4	164	545.0	0.3	108	247.5	0.4	41	217.0	0.2	589	1215.0	0.48
1984	25	4.0	6.2	89	155.5	0.6	348	828.5	0.4	138	304.0	0.5	135	60.0	2.2	65	111.5	0.6	800	1463.5	0.55
1985	0	0.0	0.0	295	18.5	15.9	227	144.0	1.6	792	161.0	4.9	143	141.0	1.0	628	123.0	5.1	2085	587.5	3.55
1986	16	1.0	16.0	238	16.5	14.4	1585	138.5	11.4	1720	121.0	14.2	400	52.0	7.7	531	41.0	13.0	4490	370.0	12.14
1987	0	2.0	0.0	9	5.0	1.8	266	46.0	5.8	270	72.0	3.8	207	57.5	3.6	50	60.0	0.8	802	242.5	3.31
1988	0	1.0	0.0	1	12.0	0.8	459	185.5	2.5	109	184.0	0.6	18	55.5	0.3	66	55.0	1.2	653	493.0	1.32
1989	0	0.0	0.0	0	3.0	0.0	7	7.5	0.9	807	117.0	6.9	234	145.5	1.6	39	19.5	2.0	1087	292.5	3.72
1990	0	2.5	0.0	0	3.0	0.0	518	123.0	4.2	318	105.0	3.0	591	79.0	7.5	87	62.5	1.4	1514	375.0	4.04
1991	0	0.0	0.0	0	0.0	0.0	11	10.0	1.1	330	80.0	4.1	0	55.5	0.0	0	5.0	0.0	341	150.5	2.27