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A REVIEW OF THE BLUEFIN TUNA (THUNNUS THYNNUS) FISHERIES OF THE ATLANTIC OCEAN[1]

GARY T. SAKAGAWA, WILLIAM H. LENARZ AND WILLIAM W. FOX, JR.

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Center
La Jolla, California 92037

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[1]This is a preliminary document that was prepared for the 1972 annual meeting of ICCAT, Madrid, Spain. Revisions are anticipated as better data on the fisheries are made available.

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Two species of bluefin tuna are found in the Atlantic Ocean. One is the bluefin tuna (Thunnus thynnus) that has a distribution range from about 40° S latitude to about 60° N latitude (Figure 1), and the other is the southern bluefin tuna (Thunnus maccoyii) which is found in the south Atlantic, south of about 30° S latitude. The former species is commonly referred to as bluefin tuna,or Atlantic bluefin tuna and is the species dealt with in this review.

The catch of Atlantic bluefin tuna has gradually declined from a peak of about 36,000 tons[2] in 1962 to 15,500 tons in 1971 (Table 1). This decline has been accompanied by the demise of several fisheries (e.g., the German and Danish handline fisheries) and the substantial reduction in catch and effort in some others (e.g., Portugese and Spanish trap fisheries). The small (40-120 cm) fish fisheries off New England (U.S.A.) and the Bay of Biscay and adjacent waters, on the other hand, developed during the 1950's and 1960's, and there is no marked trend in the catch of these fisheries.

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[2] Throughout this paper "tons" refer to metric tons.

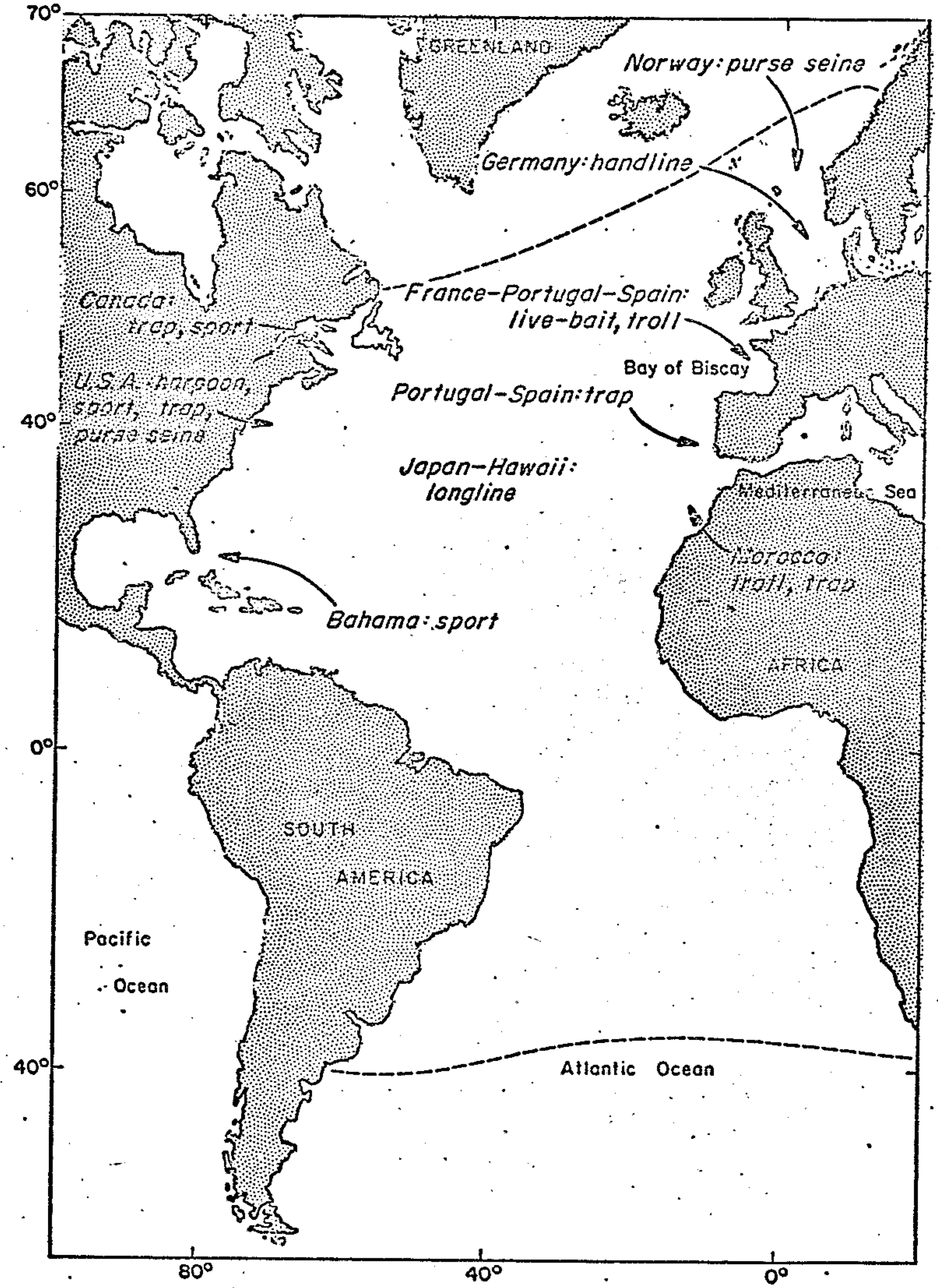

Figure 1. Locations of the different fisheries for bluefin tuna in the Atlantic Ocean. Dash lines delineate the distributional range of bluefin tuna.

Table 1. Catch (in thousands of metric tons) of bluefin tuna from the Atlantic Ocean and Mediterranean Sea. (Source of data ICCAT, 1971a; 1971b.)

	Year															
	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971[2]	1972
Northeast Atlantic																
Denmark	0.6	0.3	0.8	0	0.2	0.2	0	0.1	0	0	0	0	0	0		
Germany	1.3	0.5	1.0	0.4	0.3	0.2	0	0	0	0	0	0	0	0		
Norway	5.0	3.6	2.5	3.3	8.0	8.2	0.2	1.5	2.5	1.0	1.9	0.7	0.9	0.4	0.6	
Total northeast	6.9	4.4	4.3	3.7	8.5	8.6	0.2	1.6	2.5	1.0	1.9	0.7	0.9	0.4	0.6	
Southeast Atlantic																
France	1.8	1.8	2.0	0.4	1.4	1.5	0.9	1.1	1.0	2.4	1.6	1.4	1.1	1.4	0.7	
Morocco	4.5	10.5	5.0	6.0	2.3	1.6	3.9	4.4	2.9	3.6	3.4	1.3	0.8	0.7	0.2	
Portugal	0.8	0.7	0.9	0.9	1.6	0.8	0.4	0.4	0.1	0.2	0.2	0.1	0.4	0		
South Africa	-	-	-	-	-	-	0.4	0.2	-	-	-	-	-	-		
Spain	14.6	13.8	9.0	9.7	6.8	15.6	10.8	8.2	11.2	8.7	10.6	8.7	11.5	7.2	3.9	
Total southeast	21.7	26.8	16.9	17.0	12.1	19.5	16.4	14.3	15.2	14.9	15.8	11.5	13.8	9.3	4.8	
Northwest Atlantic																
Canada	0	0	0.1	0	0.1	0.2	0.7	1.0	0.7	0.3	0.4	0.4	0.6	1.6	1.1	
Cuba	-	-	-	-	-	-	-	-	0.1	0.5	2.4	1.4	0.5	0.2		
U.S.A.	0.5	1.1	1.3	0.6	1.1	4.0	5.7	4.9	3.2	1.2	2.3	0.6	1.2	6.3	3.7	1.9[1]
Total northeast	0.5	1.1	1.4	0.6	1.2	4.2	6.4	5.9	4.0	2.0	5.1	2.4	2.3	8.1	4.8	
Southwest Atlantic																
Argentina	-	0	-	-	0	0	0.3	0.2	0.1	0.1	0.1	0	0	-		
Longline Atlantic																
Japan	0.1	0	0.3	0.8	0.6	3.7	7.8	12.6	9.6	2.9	0.9	0.4	0.8	4.4	5.2	
Taiwan	0	0	0	0	0	0	0	0	0	0	0	0.1	0.2	0.1	0.1	
Total longline	0.1	0	0.3	0.8	0.6	3.7	7.8	12.6	9.6	2.9	0.9	0.5	1.0	4.5	5.3	
Total Atlantic	27.0	32.3	22.9	22.1	22.4	36.0	31.1	34.6	31.4	20.9	23.8	15.1	18.0	22.3	15.5	
Mediterranean																
Algeria	-	0.4	0.6	0.3	0	-	0	0	0	0.1	0.2	0.1	0.2	0.1	0.1	
France	0.6	0.2	0.4	0.4	0.6	0.2	0.3	0.6	0.4	0.4	0.4	0.4	0.4	0.4		
Greece	0.5	0.7	0.7	-	1.1	1.0	-	0.6	0.7	0.5	0.6	0.5	-	0.5		
Italy	-	3.7	2.1	1.4	2.0	2.0	2.4	2.5	2.1	1.7	4.0	3.4	5.5	3.4	4.5	
Libya	-	-	-	-	-	-	-	0.4	0.6	0.7	0.8	1.0	2.9	3.0	0.6	
Malta	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0		
Tunisia	-	-	-	-	-	-	-	0.5	0.8	0.6	-	-	-	0.7	0.5	
Turkey	0.8	0.4	0.5	0.3	0.3	0.2	0.1	0	0.1	0.1	1.5	0.3	-	0.4		
Yugoslavia	0.4	0.4	0.2	0.1	0.1	0.3	0.3	0.1	0.2	0.3	0.3	0.2	0.3	0	0.3	
Total Mediterranean	2.4	5.9	4.6	2.6	4.2	3.8	3.2	4.8	5.0	4.5	7.9	6.0	9.3	8.5	6.0	
Total Atlantic and Mediterranean	29.4	38.2	27.5	24.7	26.6	39.8	34.3	39.4	36.4	25.4	31.7	21.1	27.3	30.8	21.5	

[1] Includes catch by Canadian boats.
[2] Estimates from ICCAT (1972).

The United Nations, Food and Agriculture Organization (FAO) and the International Commission for the Conservation of Atlantic Tunas (ICCAT) have recognized this disturbing decline in total Atlantic catch and have urged that the capture of bluefin tuna less than 10 kg (78 cm) be discouraged (FAO, 1968; ICCAT, 1971a). ICCAT has also recognized that in order to rationally manage Atlantic bluefin tuna a thorough investigation on the dynamics of bluefin tuna is required. Thus, one of the five proposed research activities for 1972 made by the Standing Committee on Research and Statistics of ICCAT was research on the dynamics of bluefin tuna on an Atlantic-wide basis (ICCAT, 1971a).

In this paper, we report the results of a study on the dynamics of Atlantic bluefin tuna on an Atlantic-wide basis. The study had the objectives of compiling and analyzing all pertinent data on the dynamics of Atlantic bluefin tuna to provide answers to such questions as: What is the quality of available bluefin tuna statistics? What are the estimates of population parameters? What is the trend in production and is the trend the same in all fisheries? What is the "optimum" age at recruitment? What are the effects on yield per recruit if a minimum size limit of, say, 10 kg (78 cm) was imposed on the fisheries?

ANALYSIS OF BASIC DATA ON THE FISHERIES

Catch Statistics

Catch statistics on Atlantic bluefin tuna have been compiled and published by FAO (1968), by the International Council for the Exploration of the Sea, (ICES)

Bluefin Tuna Working Group (Hamre et al., 1966, 1971), and by ICCAT (1971b, 1972). These organizations use different methods of compiling statistics and in some cases the total catch by countries do not agree.

We compiled a table of Atlantic Ocean and Mediterranean Sea catches (Table 1), gleaned primarily from statistics published by ICCAT (1971a, 1971b).[3] In some cases where the ICCAT publications did not separate the country catch into Atlantic and Mediterranean Sea catches, we used unpublished data (Mather, personal communication) to divide the catch. We are cognizant that some of the reported catches are incomplete or even erroneous. For example, the U.S.A. catch does not include fish caught by the sport fishery; the Cuban catch probably is not all bluefin tuna, but includes other species as well; and the 1970-71 increase in catch for the Japanese longline fleet is too high because of inclusion of southern bluefin tuna in the statistics (see Table 6). However, we presume that Table 1 is reasonably accurate, and we have generally used the statistics in our analyses. We recommend that the statistics be further refined, especially to a point where the catches are accurate and broken down by gear, country, and ocean region of capture.

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[3] After we had compiled Table 1, ICCAT (1972) released still another version of catch statistics. The catches are reported by nation and a few by gear. ICCAT's new version is different from Table 1, especially for the Portuguese catch, which is several thousand tons more than that reported in Table 1. However, we point out that ICCAT's statistics apparently groups Atlantic and Mediterranean catches together and reports the total as Atlantic catch.

The time series for 1957-70 of bluefin tuna catches in the Atlantic Ocean is shown in Figure 2. There has been considerable fluctuation in the catch, but for recent years (1962-70) the trend is downward.

Small bluefin tuna (40-120 cm) are caught primarily off the U.S.A. (western Atlantic) and in the Bay of Biscay and adjacent waters (eastern Atlantic). In recent years, this size group has contributed substantially to the total catch from each region (about 50% for the western Atlantic and about 90% for the eastern Atlantic). The total catch of small bluefin caught commercially in the western Atlantic has been reported by Mather (Aloncle et al., 1971). Similar data on catch of small bluefin tuna caught in the eastern Atlantic are unavailable. However, since most small bluefin tuna are caught by fishing gears other than traps (Mather, personal communication), and the nontrap catch of bluefin tuna caught by countries that fish in the Bay of Biscay and adjacent waters are available, we estimated the catch of small bluefin tuna landed in the eastern Atlantic. Our procedure was to assume that all nontrap catches of France (Mather, personal communication), Morocco (ICCAT, 1971a) and Spain (ICCAT, 1971a) were composed of only small fish. Of course, it is possible that our assumption is not entirely correct, and some catches are not included in our estimate, e.g., small but unknown amounts are caught by the Portugese troll fleet, but we believe that our estimates are reasonable approximations. The catches are shown in Figure 3. They indicate that the catch of small bluefin tuna from the eastern Atlantic has been relatively stable, more so than the catch of small

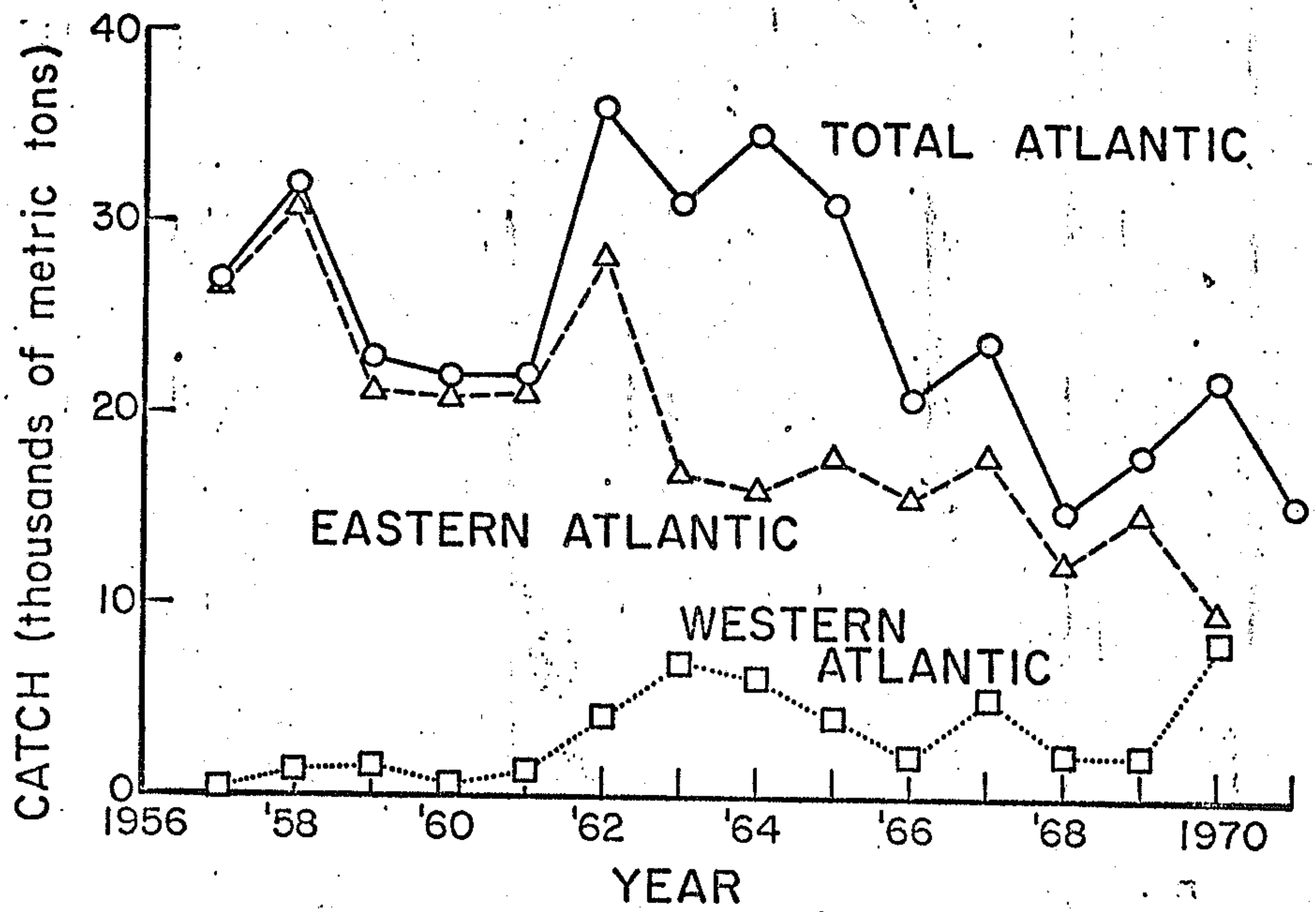

Figure 2. Catch of Atlantic bluefin tuna.

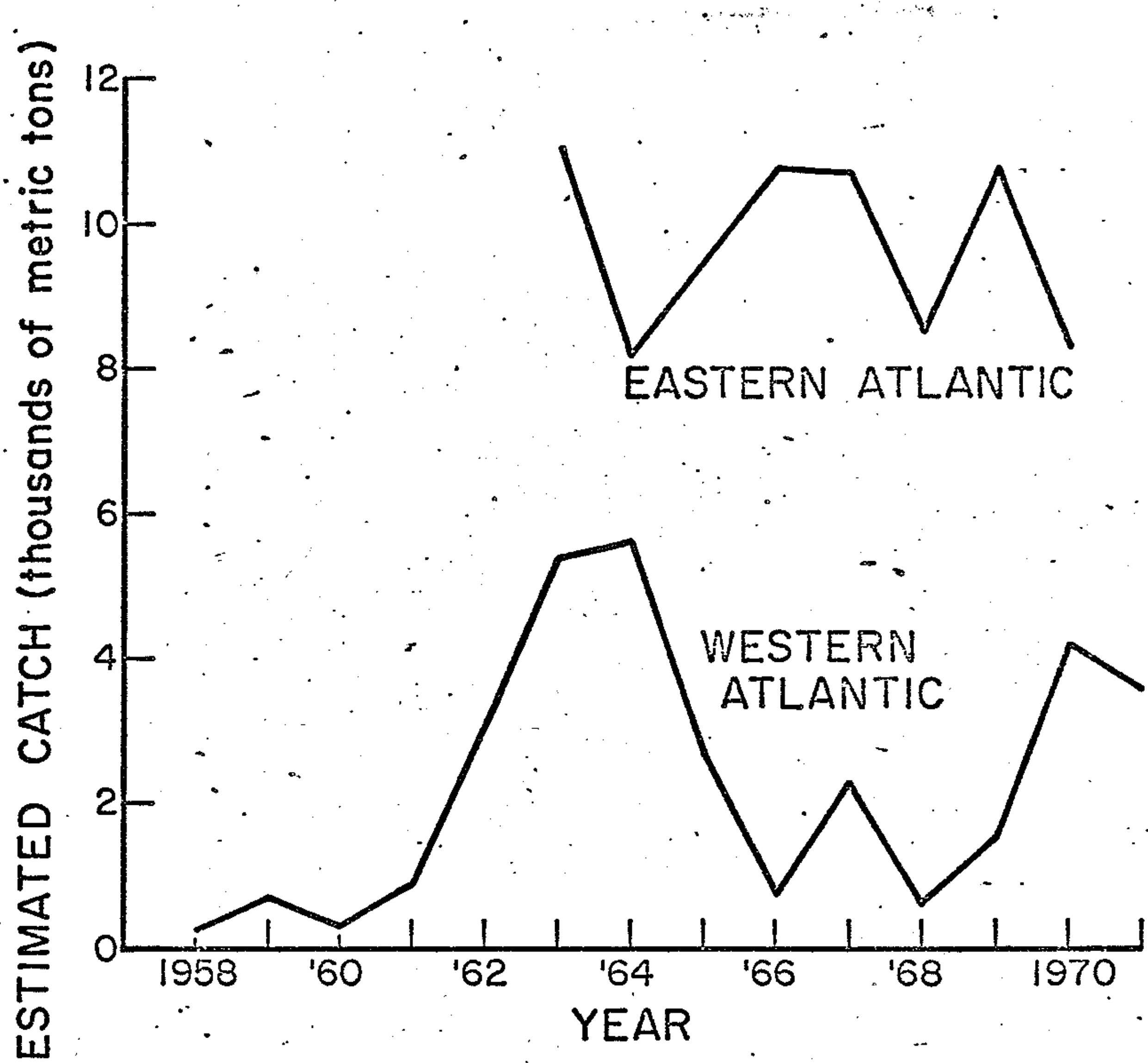

Figure 3. Estimated catch of small bluefin tuna (40–120 cm) from the Atlantic Ocean.

bluefin tuna from the western Atlantic. Also of significance is the substantially larger catch of small bluefin tuna from the eastern Atlantic than from the western Atlantic.

Mather et al. (MS, 1971) has shown from tagging that small bluefin tuna migrate between the U.S.A. east coast and the Bay of Biscay (Figure 4), suggesting that the fisheries in the eastern and western Atlantic are exploiting fish from identical stocks. The small fish catches from the eastern and western regions were examined to determine whether they are correlated (Figure 5). No correlation was found. Our result, however, is inconclusive because changes in fishing effort, for example, could account for the absence of a correlation. Unfortunately, data on fishing effort for the eastern Atlantic small bluefin tuna fishery are unavailable to correct this bias.

Catch-Effort Statistics

Atlantic bluefin tuna have been exploited by several fisheries for many years, but useful catch-effort statistics are available for only a few fisheries (Table 2). Most of the available statistics are inadequate for definitive analysis of changes in catch-per-unit-of-effort, or apparent abundance of the bluefin tuna population.

For the available catch-effort statistics, catch is reported in tons, or in numbers of fish caught. Effort is reported in numbers of traps (Morocco, Portugal, and Spain), numbers of boats (France and Norway), numbers of hooks (Japan), and

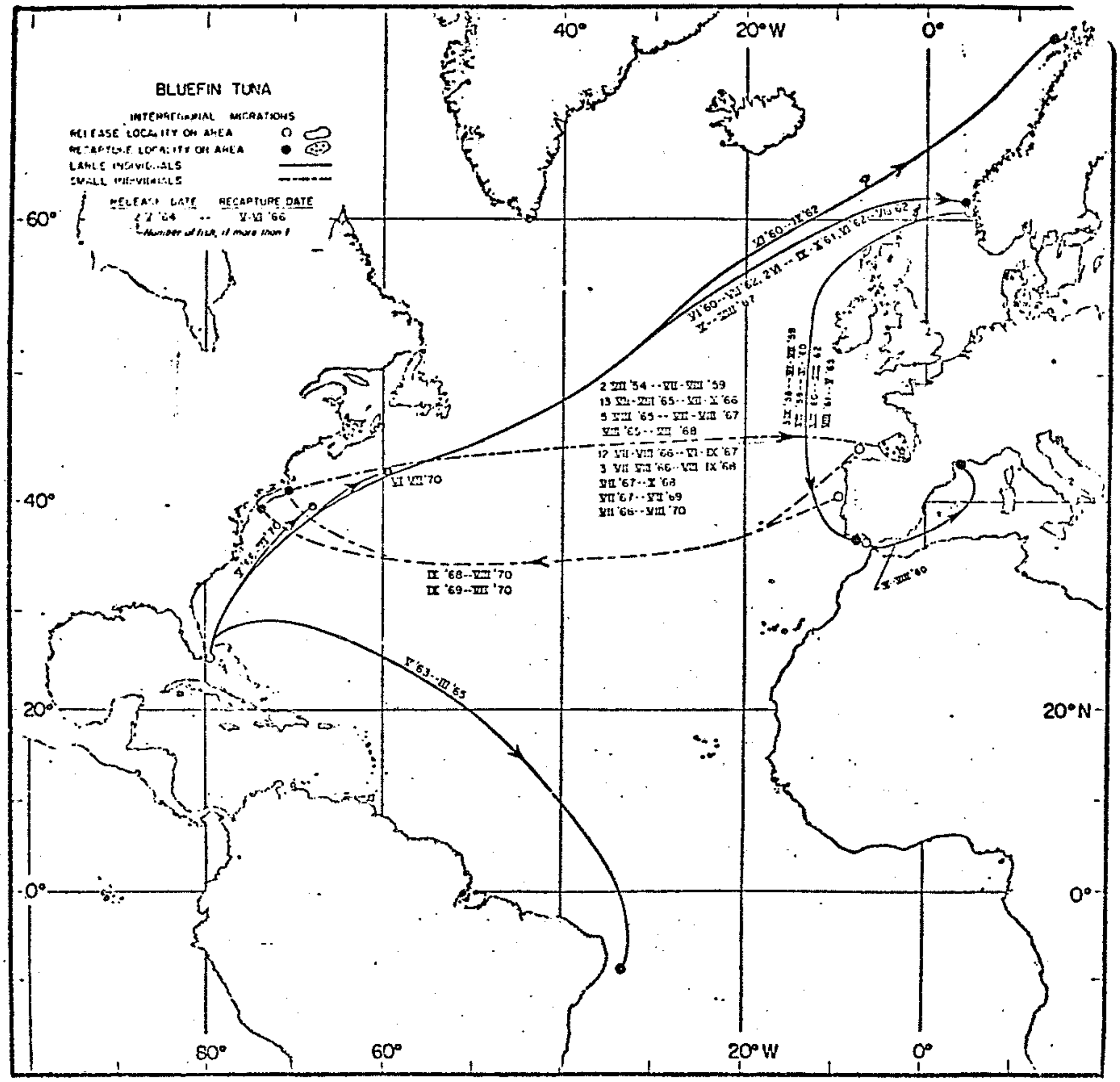

Figure 4. Migration routes as deduced from tag returns of Atlantic bluefin tuna (after Mather et al., MS, 1971).

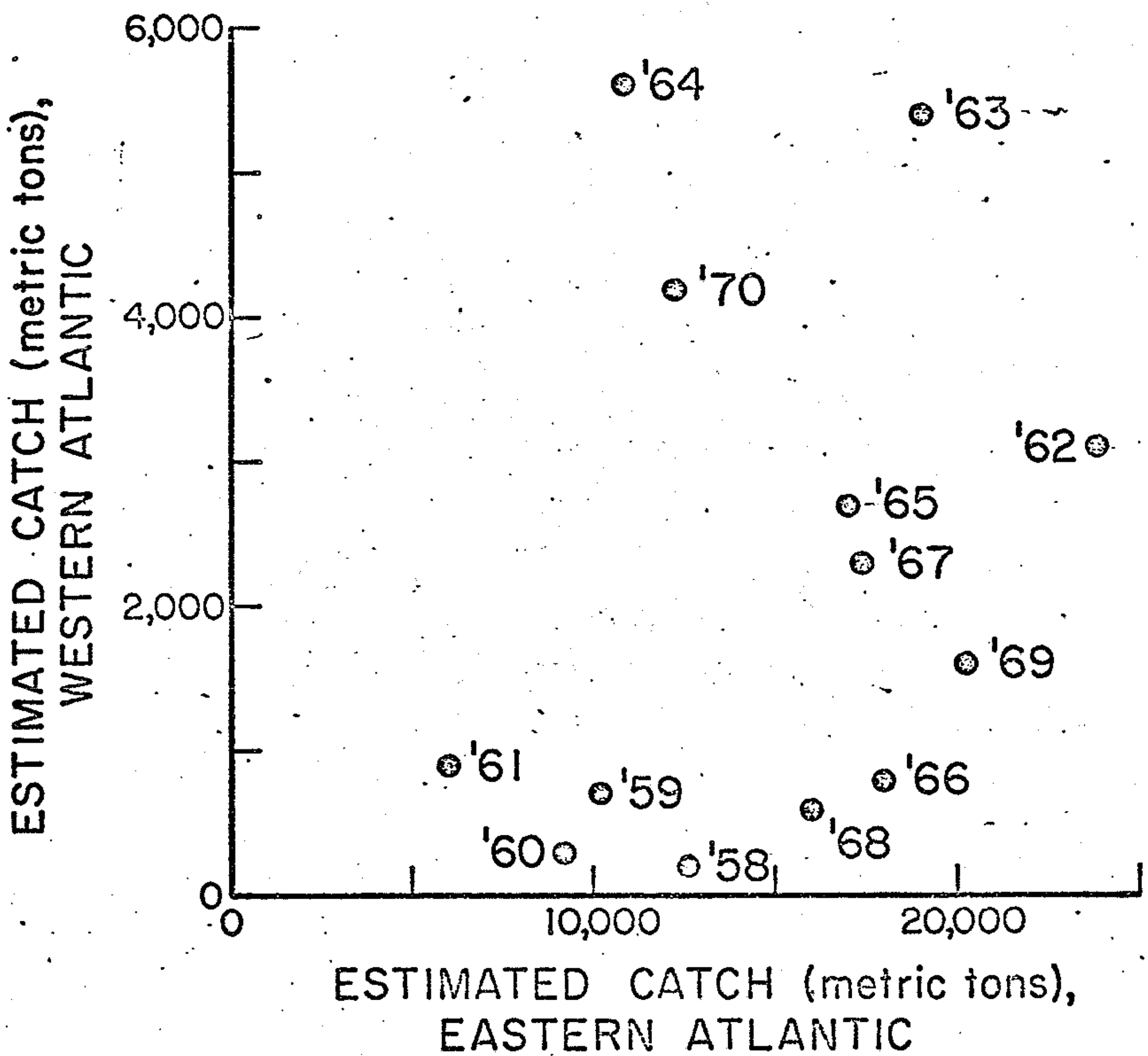

Figure 5. Relation between estimated catch of small (40-120 cm) bluefin tuna from the western and eastern Atlantic fisheries.

Table 2. Summary of available data on catch and effort for bluefin tuna from the Atlantic Ocean.

Nation	Type of gear	Catch		Effort		Comments
		Size of area	Years	Size of area	Years	
Argentina	Handline	none	none	none	none	Possibly southern bluefin.
Canada	Longline	none	none	none	none	Catch of longline is small, mostly discarded and not landed.
	Purse seine	1° x 1°	1963-71	1° x 1°	1963-71	
	Trap	District	1962-71	none	none	
	Sport	District	1962-71	none	none	
Cuba	Handline	none	none	none	none	Catch is small.
	Longline	none	none	none	none	
Denmark	Handline	none	none	none	none	Catch is small. Fishery collapsed in 1965.
France	Troll	none	none	none	none	
	Live bait	none	none	none	none	
Germany	Handline	North Atlantic	1952-63	North Atlantic	1952-63	Effort is in fishing trips. Fishery collapsed in 1963.
Japan	Longline	5° x 5°	1957-71	5° x 5°	1957-71	
Korea	Longline	none	none	none	none	
Morocco	Purse seine	none	none	none	none	
	Trap	Southeast Atlantic	1927-66	Southeast Atlantic	1927-66	
	Troll	none	none	none	none	
Norway	Purse seine	North Atlantic	1954-64	North Atlantic	1954-64	Effort is in number of boats. Catch is small.
Portugal	Trap	District	1950-62	District	1950-62	Data by individual traps.
	Troll	none	none	none	none	Catch is small.
Spain	Trap	District	1941-70	District	1941-70	Effort is in number of traps.
	Live bait	none	none	none	none	
Sweden	Handline	none	none	none	none	Catch is small.
Taiwan	Longline	5° x 5°	1967-69	5° x 5°	1967-69	Data may not be representative of the fleet's catch.
U.S.A.	Handline	State	1946-71	none	none	
	Harpoon	State	1930-71	none	none	
	Purse seine	1° x 1°	1962-71	1° x 1°	1962-71	
	Trap	State	1929-71	none	none	
	Sport	none	none	none	none	

numbers of day's fishing (Canada and the U.S.A.). The first two measures of effort, numbers of traps and boats, are imprecise because they do not account for the length of the fishing season, which can affect the catch. Also, if different sizes of traps and boats are employed during a season, the measure of effort do not account for differences in fishing power owing to size of gear.

Number of hooks is generally a reasonable measure of Japanese longline fishing effort. For the Atlantic bluefin tuna, however, the gear is generally not set for this species but for other tunas and for billfishes. The nominal effort is therefore a gross measure.

Canada and the U.S.A. have reported nominal fishing effort of purse seiners in day's fishing. This appears to be a reliable measure of effort, based on historic use of this measure in other tuna fisheries, e.g., the yellowfin-skipjack tuna fisheries of the eastern tropical Atlantic and the eastern tropical Pacific. However, different sizes (classes) of purse seiners with different fishing powers are employed by the Americans. An illustrated example is the small (<181 tons capacity) seiners, or local boats, that regularly operate out of New England ports and utilize airplanes for spotting schools of bluefin tuna. This technique has been successful and the local boats have produced 19-100% (1962-71) of the total western Atlantic purse seine landings of Atlantic bluefin tuna. The larger seiners (>181 tons capacity), on the other hand, generally are based in California, Puerto Rico, or New Brunswick and sporadically fish for bluefin tuna in the western Atlantic, usually before proceeding to the yellowfin-skipjack fishing grounds off west Africa or when fishing for bluefin or skipjack tuna is reportedly good in the western Atlantic. These large seiners do not use airplanes for spotting tuna schools, and their catch rate is considerably less than that for the local boats (Figure 6). The nominal effort of the different classes of seiners is therefore not comparable.

Keeping these inadequacies in the catch-effort statistics in mind, we analyzed the catch rates for the different fisheries. In the eastern Atlantic, the trend in catch rate has been downward in every fishery for which data are available (Figure 7). Fisheries such as the German handline and the Norwegian purse seine fisheries have collapsed and others have substantially reduced their fishing effort, e.g., Portugese and Spanish trap fisheries (Tables 3 and 4). The reduction in effort is apparently a response to the unavailability of large bluefin tuna (176-280 cm), sizes of fish that are primarily harvested by these fisheries.

Adequate data on fisheries (live bait and troll) that primarily exploit the smaller individuals in the eastern Atlantic are unavailable. It is well known, however, that in recent years the live bait and troll fleets that operate in the Bay of Biscay and adjacent waters have expanded, and they catch significant amounts of small bluefin tuna.

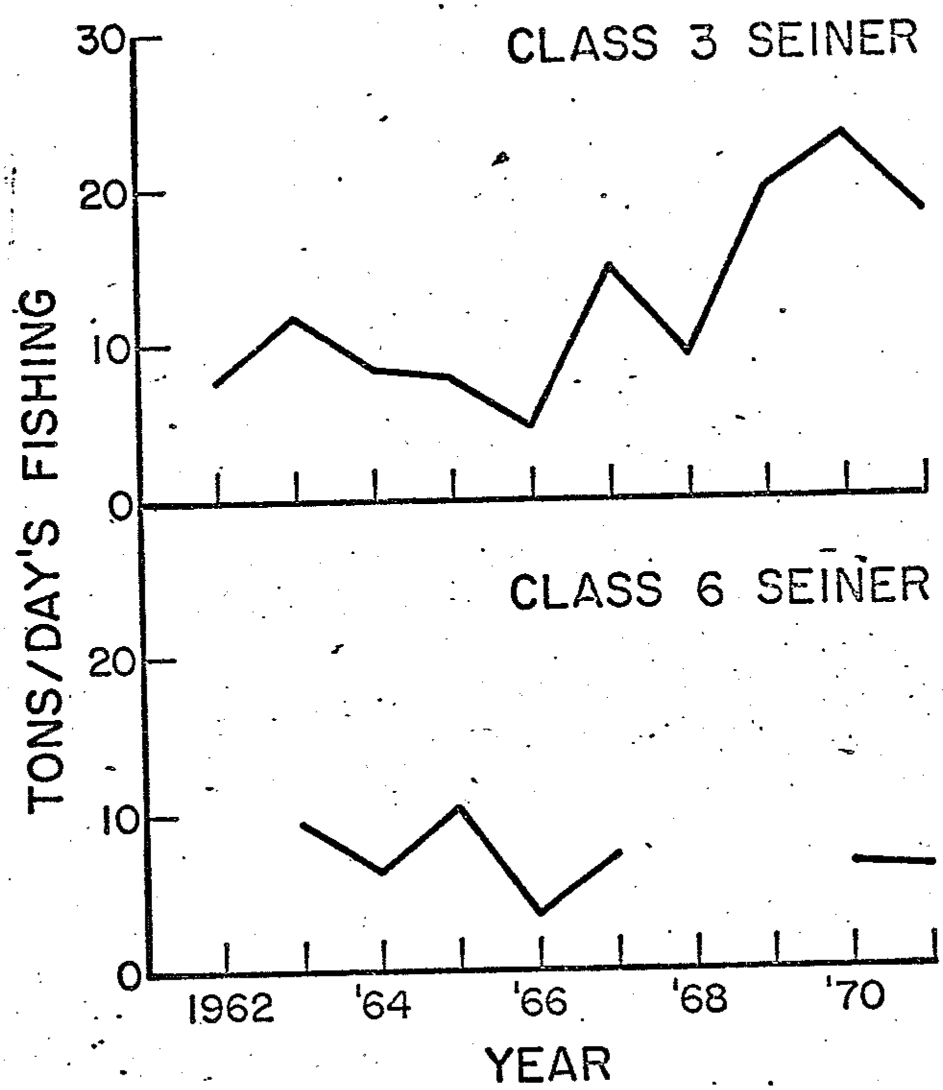

Figure 6. Catch per unit of effort for two classes of seiners in the Canadian-U.S.A. purse seine fishery for Atlantic bluefin tuna.

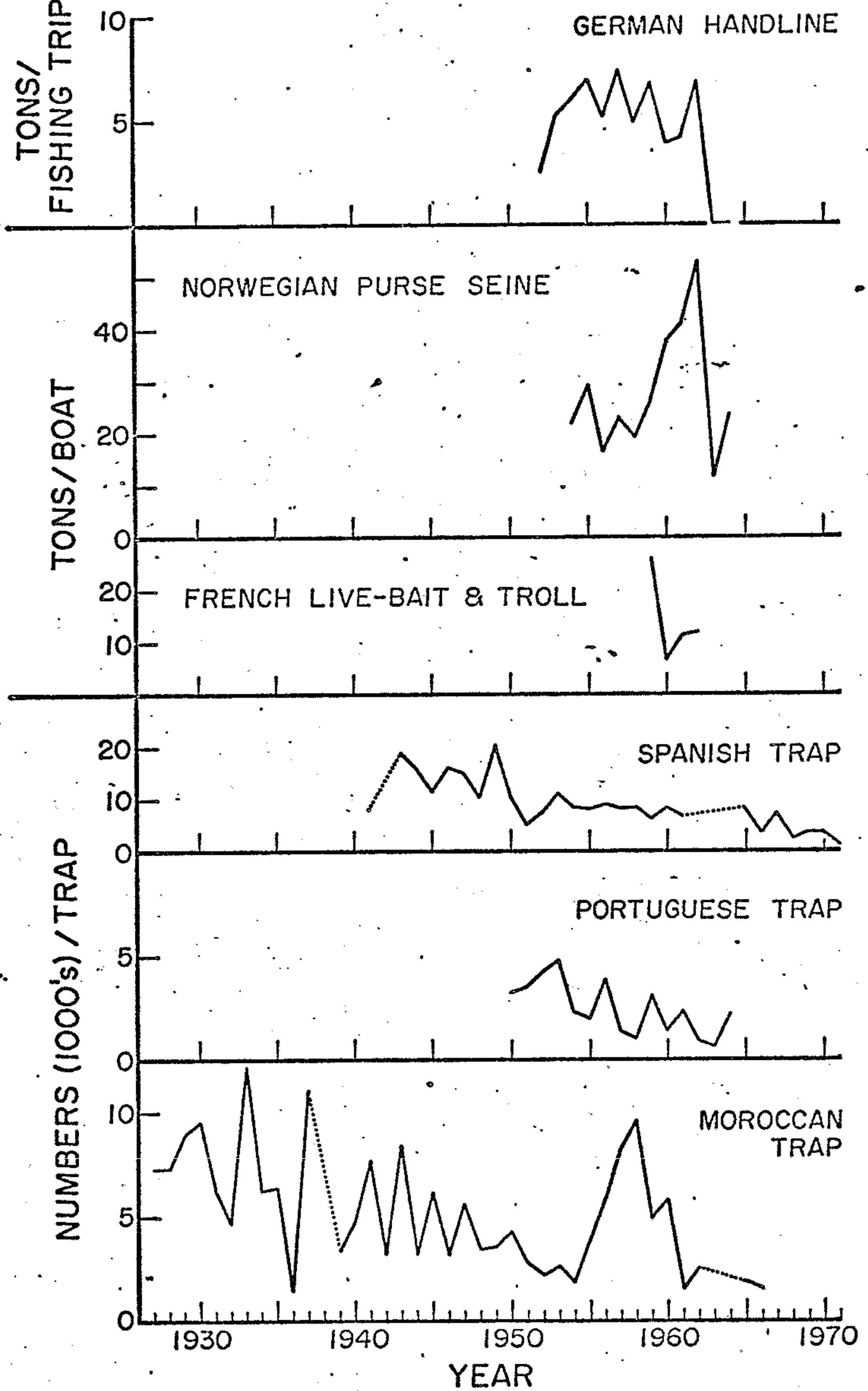

Figure 7. Catch per unit of effort for six eastern Atlantic fisheries for bluefin tuna.

Table 3. Catch and effort for three eastern Atlantic bluefin tuna fisheries. Data are from Hamre et al. (1966).

Year	French live bait and troll fishery			German handline fishery			Norwegian purse seine fishery		
	Catch (metric tons)	Effort (boats)	Catch rate	Catch (metric tons)	Effort (fishing trips)	Catch rate	Catch (metric tons)	Effort (boats)	Catch rate
1952				147	56	2.6			
1953				128	24	5.3			
1954				552	90	6.1	9,451	433	21.8
1955				970	141	6.9	10,423	352	29.6
1956				549	106	5.2	4,135	244	16.9
1957				1,264	173	7.3	5,009	218	23.0
1958				329	67	4.9	3,004	157	19.1
1959	2,031	79	25.7	938	141	6.7	2,522	97	26.0
1960	553	80	6.9	418	106	3.9	3,280	86	38.1
1961	907	79	11.5	283	68	4.2	6,656	161	41.3
1962	965	81	11.9	191	28	6.8	6,794	129	52.7
1963				0	0	0	129	11	11.7
1964				0	0	0	1,041	43	24.2

Table 4. Catch and effort of bluefin tuna caught in three trap fisheries of the eastern Atlantic. Data are from Aloncle et al. (1971, 1972) and Hamre et al. (1966, 1968, 1971).

Year	Morocco			Portugal			Spain		
	Catch (numbers)	Effort (traps)	Catch rate	Catch (numbers)	Effort (traps)	Catch rate	Catch (numbers)	Effort (traps)	Catch rate
1927	7,297	1	7,297						
1928	7,218	1	7,218						
1929	8,959	1	8,959						
1930	9,533	1	9,533						
1931	6,368	1	6,368						
1932	4,755	1	4,755						
1933	12,236	1	12,236						
1934	6,287	1	6,287						
1935	12,769	2	6,384						
1936	3,214	2	1,607						
1937	11,036	1	11,036						
1938	-	0	-						
1939	3,407	1	3,407						
1940	14,636	3	4,879						
1941	15,353	2	7,676				42,064	5	8,413
1942	9,963	3	3,321				-	-	-
1943	16,589	2	8,294				76,236	4	19,059
1944	6,459	2	3,229				63,503	4	15,876
1945	12,354	2	6,177				46,607	4	11,652
1946	9,590	3	3,197				63,131	4	15,783
1947	22,480	4	5,620				59,976	4	14,994
1948	17,493	5	3,499				43,520	4	10,880
1949	17,675	5	3,535				80,451	4	20,113
1950	21,604	5	4,321	16,879	5	3,376	52,018	5	10,404
1951	14,132	5	2,826	17,549	5	3,510	30,057	6	5,009
1952	11,180	5	2,236	21,481	5	4,296	44,791	6	7,465
1953	13,369	5	2,674	24,934	5	4,987	65,197	6	10,866
1954	9,428	5	1,886	12,031	5	2,406	51,000	6	8,500
1955	11,839	3	3,946	10,270	5	2,054	58,114	7	8,302
1956	17,576	3	5,859	19,260	5	3,852	62,540	7	8,934
1957	25,125	3	8,375	7,434	5	1,487	58,515	7	8,359
1958	29,038	3	9,679	5,753	5	1,151	51,885	6	8,647
1959	15,142	3	5,047	15,844	5	3,169	32,538	5	6,508
1960	17,572	3	5,857	7,702	5	1,540	41,492	5	8,298
1961	5,054	3	1,685	11,514	5	2,303	33,948	5	6,790
1962	12,713	5	3,543	5,165	5	1,033	-	-	-
1963	-	-	-	3,316	5	663	-	-	-
1964	-	-	-	11,246	5	2,249	-	-	-
1965	11,530	6	1,922				8,286	1	8,286
1966	9,630	6	1,605				7,784	2	3,892
1967							14,048	2	7,024
1968							5,360	2	2,680
1969							7,570	2	3,785
1970							7,119	2	3,559
1971							2,522	2	1,261

In the western Atlantic we find a different situation. Data are available for small bluefin tuna that are caught primarily by the purse seine fishery, but adequate data for other fisheries, e.g., trap, harpoon, and sport, that catch large bluefin tuna are lacking. For the purse seine fishery, the catch rates of Class 3 seiners (92-181 tons capacity), which are all local boats and which account for most of the catch from the western Atlantic, show an upward trend (Figure 6). In the early 1960's the catch rate was relatively low and the catch was high, but in the late 1960's the reverse occurred; the catch rate was relatively high and the catch was relatively low (Table 5). Since the fishery first began in the early 1960's by local boats (Wilson, 1965), this suggests that the local boats with their airplane spotters have become more efficient in their operations. In fact, the upward trend occurred soon after the local fleet was controlled by one operator, who began coordinating the operations of the boats and airplane spotters. A similar trend in catch rate is not evident for Class 6 seiners (>363 tons capacity) that do not use airplanes for spotting schools (Figure 6 and Table 5). Their catch rate has fluctuated but remained relatively low and substantially lower than the catch rates for local boats, in spite of the fact that the Class 6 seiners use a larger net and have a larger holding capacity than the Class 3 seiners.

It is obvious from these results that the nominal effort of the western Atlantic purse seine fishery is imprecise, especially for the local boats. Perhaps the fishing effort of the local boats should be measured as number of airplane spotting hours. In any event, the nominal effort should be adjusted for the different fishing powers of the different classes of seiners.

Table 5. Catch rate (tons/day's fishing) caught by Class 3 (92-181 tons capacity) and Class 6 (>363 tons capacity) U.S.A. purse seiners in the western Atlantic.

Year	Class 3	Class 6
	Catch rate	Catch rate
1962	7.7	-
1963	12.0	9.6
1964	8.5	6.3
1965	8.0	10.4
1966	4.8	3.4
1967	14.9	7.3
1968	9.0	-
1969	19.6	-
1970	23.3	6.7
1971	18.4	6.3

The Japanese longline fleet operates throughout the Atlantic, although fishing effort is concentrated in certain regions during particular months. We have divided the Atlantic Ocean into seven regions (Figure 8) for the purpose of analyzing the longline data (Table 6). Catch rates were computed for each region by averaging monthly catch rates for 5° x 5° areas. The time series of catch rates (Figure 9) indicate that in recent years the rates have generally been low and constant, except in regions II (off the U.S.A. and Canada) and V (off Brazil) where a peak in catch rate occurred in the mid-1960's. The highest catch in any one year occurred in region II. It is possible that the catch of region VI includes some southern bluefin tuna; this species was reported together with the catch of Atlantic bluefin tuna in the Japanese statistics up to 1966.

Size-Frequency Statistics

The ICES Bluefin Tuna Working Group has regularly published size-frequency statistics for various Atlantic bluefin tuna fisheries (Hamre and Tiews, 1964; Hamre et al., 1966, 1968, 1971; Aloncle et al., 1971, 1972). The statistics are reported in one of two forms: (1) smoothed percent frequencies by 5-cm or 5-kg groupings, or (2) numbers of fish by broad weight groupings that include several age groups. For most of the major fisheries the statistics are in Form 1, but for the small fish fisheries of the Bay of Biscay and adjacent waters the statistics are in Form 2. Because Form 2 groups fish of several year class together, it is inadequate for detailed analysis of the catch. We recommend that size-frequency statistics be compiled by 10-cm or less groupings, month, and 5° x 5° area of capture.

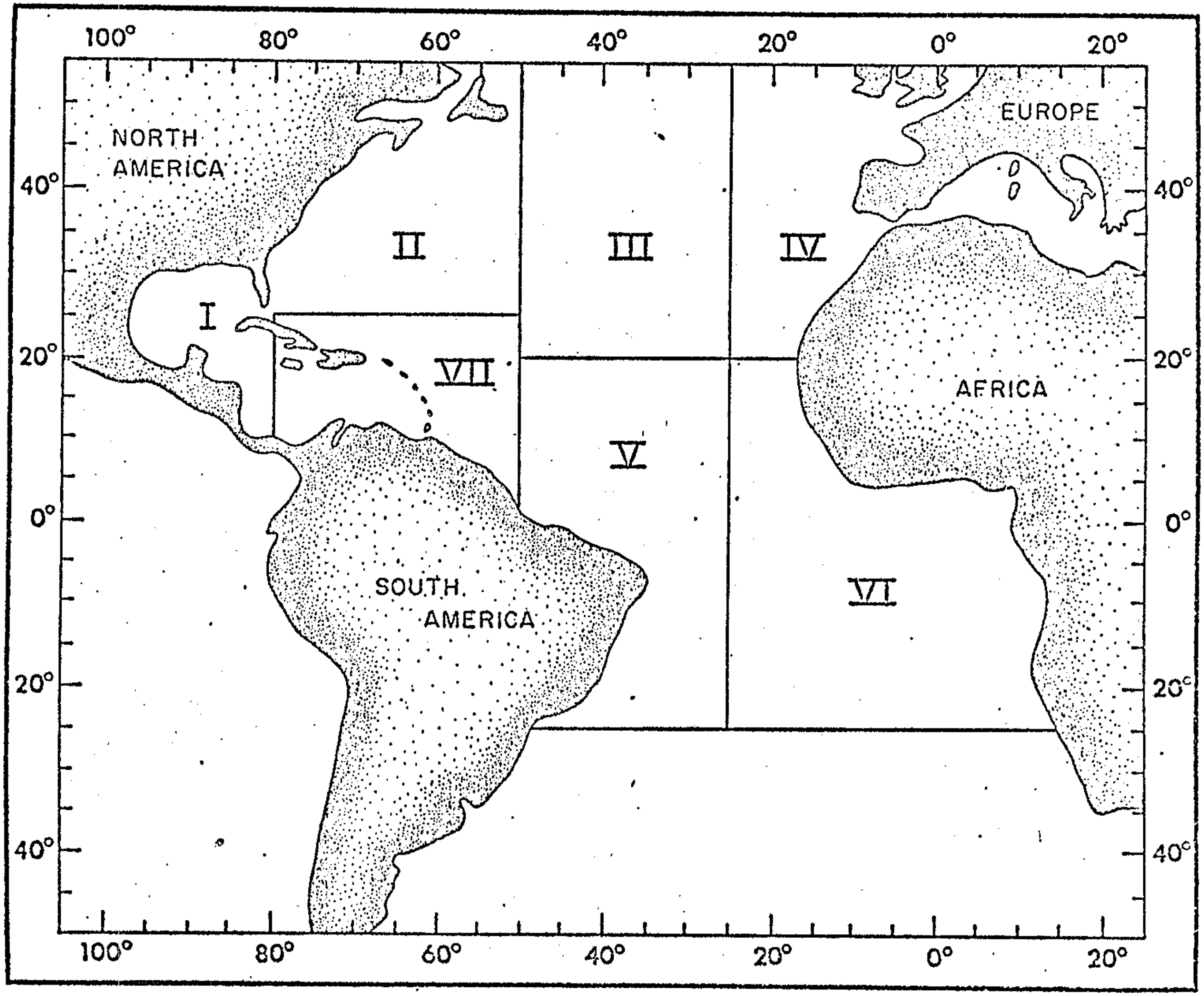

Figure 8. Map showing regions in the Atlantic Ocean. The regions were used to compile Japanese longline data on catch and effort of bluefin tuna.

Table 6. Catch (numbers) and effort (thousands of hooks) of bluefin tuna for the Japanese longline fleet.

	1965		1966		1967		1968		1969		1970	
	Catch	Effort	Catch	Effort	Catch	Effort	Catch	Effort	Catch	Effort	Catch	Effort
Western Atlantic												
I	2	1,055	27	424	0	345	205	682	1	492	7	1,803
II	41,417	6,241	19,858	3,329	3,148	2,425	993	1,483	621	1,209	190	3,868
III	1,247	6,089	379	2,073	64	1,271	133	1,147	0	866	156	2,881
V	15,340	26,490	1,381	10,155	678	7,559	76	6,592	99	6,164	83	6,382
VII	426	7,618	306	7,108	12	1,529	45	2,193	1	2,096	1	3,212
Total	58,432	47,493	21,951	23,089	3,902	13,129	1,452	12,097	722	10,827	437	18,146
Eastern Atlantic												
IV	107	717	10	107	3	22	10	130	0	20	86	60
VI	730	41,981	46	18,723	39	14,231	8	9,763	112	11,314	1	6,076
Total	837	42,698	56	18,830	42	14,253	18	9,893	112	11,334	87	6,136
Entire Atlantic												
Total	59,269	90,191	22,007	41,919	3,944	27,382	1,470	21,990	834	22,161	524	24,282

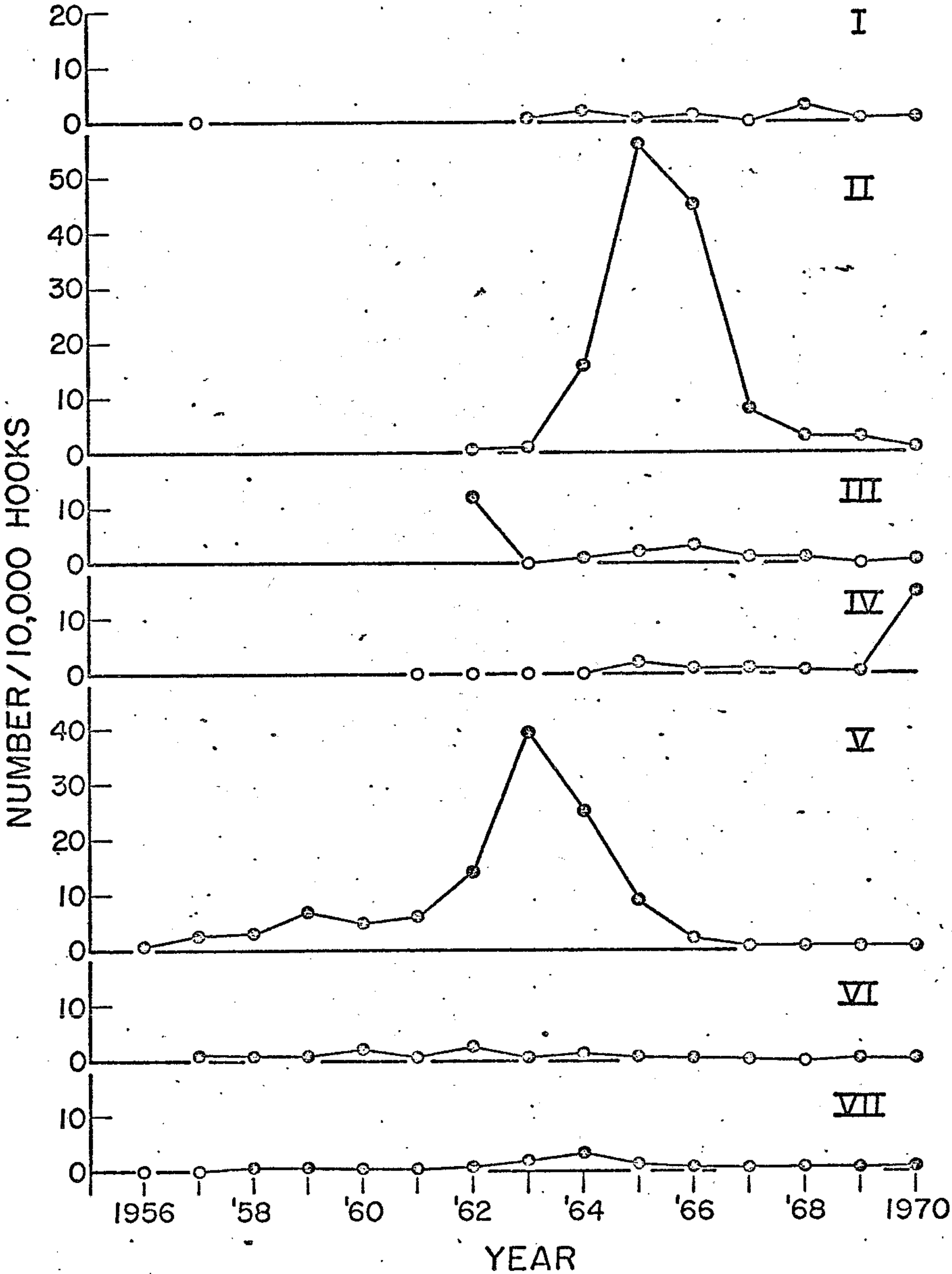

Figure 9. Catch per unit of effort of bluefin tuna caught by the Japanese longline fleet by regions in the Atlantic Ocean.

Data for the longline fishery has been published by Hayasi and Shingu (MS). Unfortunately, the sample sizes are small (Table 7).

Recently, Mather and Jones (MS, 1972) have compiled all the available statistics on size-frequencies of fish that are caught in the various fisheries. This is a good source of available data. Their results show that in fisheries for large bluefin tuna, such as the Spanish trap, Norwegian purse seine, and U.S.A. fisheries north of Cape Cod the trend has been for larger fish in the catch. This trend is shown in the time series of average size of bluefin tuna caught by various fisheries (Figure 10).

In Table 8 we have listed the available data on size-frequency of bluefin tuna by fleets. Fleets for which there are inadequate data are identified. Greater effort should be made to collect better data for those fleets.

Size Composition of Catch

Data on catch and size-frequency were used to estimate the size composition of the catch, 1965-70, of various fleets. Since most of the fleets fish close inshore, we divided the Atlantic Ocean into western and eastern regions. Our estimates of the size composition of the catch are grouped according to these regions.

Table 7. Length-frequency samples of bluefin tuna caught by the Japanese longline fleet in the Atlantic Ocean. Data are from Hayasi and Shingu (MS, Table 2).

Length group	1965	1966	1968	1969
110-119				
120-129		1		
130-139	1	-		
140-149	1	-		
150-159	1	1		
160-169	-	-		1
170-179	-	1		-
180-189	-	2		-
190-199	-	7		-
200-209	1	19	2	-
210-219	2	14	2	-
220-229	4	10	-	1
230-239	1	11	-	
240-249		-	-	
250-259		2	-	
260-269			-	
270-279			-	
280-289			-	
290-299			2	
Total	11	68	6	2

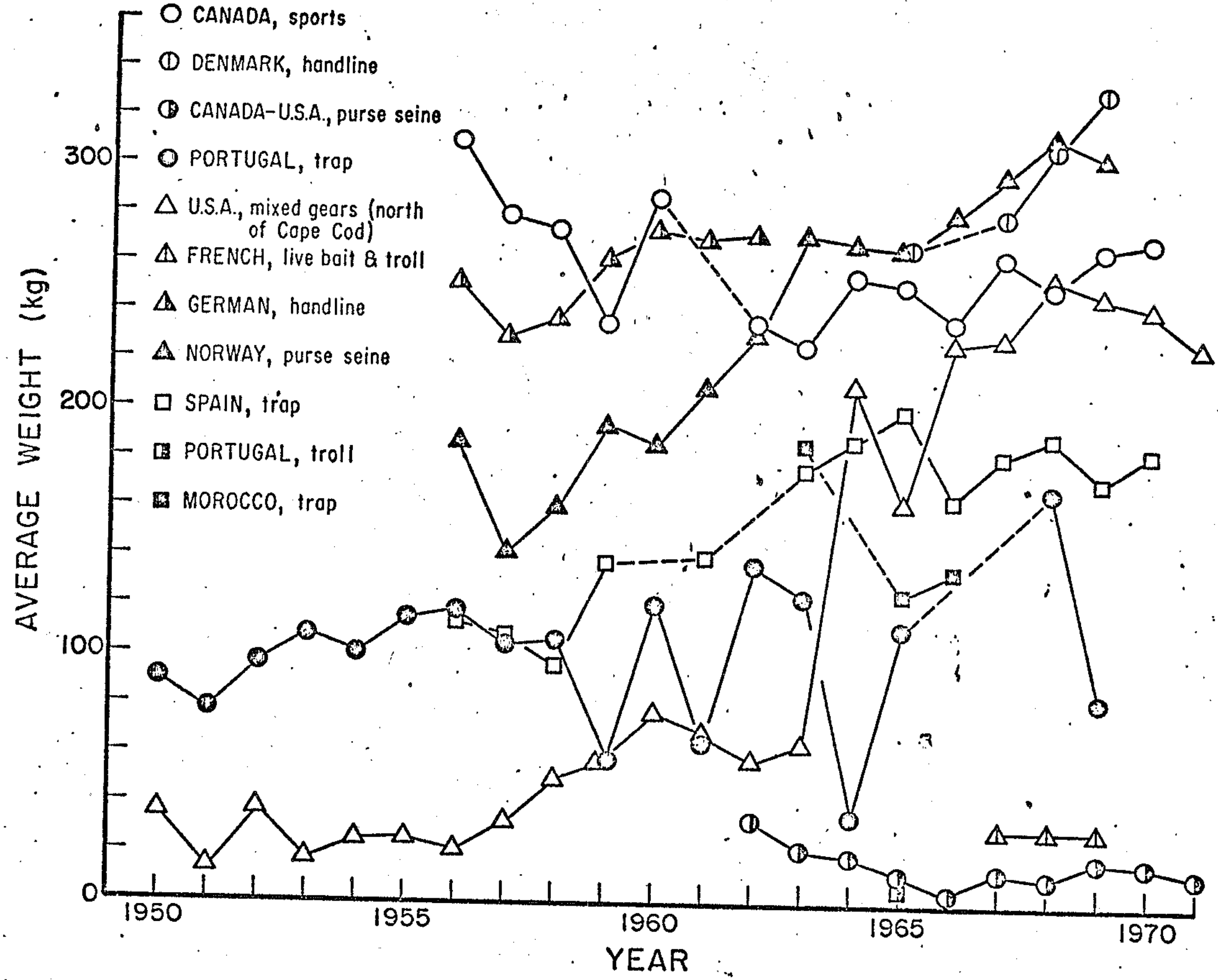

Figure 10. Average weight of bluefin tuna caught in various Atlantic fisheries.

Table 8. Available data on length-frequency distributions of bluefin tuna from the Atlantic Ocean.

Nation	Type of gear	Size frequency: Size of area	Size frequency: Years	Comments
Argentina	Handline	none	none	Possibly southern bluefin.
Canada	Longline	none	none	
	Purse seine	1° x 1°	1963-71	
	Trap	none	none	
	Sport	District	1946-71	
Cuba	Handline	none	none	
	Longline	none	none	
Denmark	Handline	North Atlantic	1962-71	
France	Troll	none	none	Some data available for broad size groups.
	Live bait	none	none	Some data available for broad size groups.
Germany	Handline	North Atlantic	1951-62	
Japan	Longline	5° x 5°	1965-69	Samples are small and for scattered years.
Korea	Longline	none	none	
Morocco	Purse seine	none	none	
	Trap	none	none	Some data available for broad size groups.
	Troll	District		
Norway	Purse seine	North Atlantic	1956-70	
Portugal	Trap	none	none	Some data available for broad size groups.
	Troll	none	none	Some data for 1961 are available.
Spain	Trap	Districts	1956-70	Mostly from one trap.
	Troll	none	none	
	Live bait	none	none	
Sweden	Handline	none	none	
Taiwan	Longline	none	none	Average dressed weights per 5° x 5° areas are available for 1967-69.
U.S.A.	Handline	District	1962-71	Samples for some years are small; not a complete series.
	Harpoon	District	1958-71	Not a complete series
	Purse seine	1° x 1°	1962-71	
	Trap	District	1947-71	Samples for some years are small; not a complete series.
	Sport	District	1956-71	Samples for some years are small.

A summary of the data set is shown in Tables 9 and 10, and the 1965-70 average size composition of the catch by fleets is shown in Tables 11 and 12. Since several assumptions were used in our estimation procedure, a few comments about the assumptions are appropriate:

Western Atlantic

Canada-U.S.A., purse seine.--In 1965, 1966, and 1968, large bluefin tuna were caught by purse seiners that usually fish for only small and medium size bluefin tuna. Length-frequency samples were obtained for the catch in those years, but the large fish were not samples. To convert the tonnage of large fish caught to numbers caught we therefore assumed that the distribution of large fish in the purse seine catch was identical to that for the U.S.A. trap fishery.

U.S.A., sport.--Total catch of Atlantic bluefin tuna caught by the U.S.A. sport fishery is not compiled by any agency. Some data on large (176-280 cm) bluefin tuna are available from tournament records, but for the bulk of the catch, which is small (40-120 cm) bluefin tuna, no data are available. Mather (personal communication) have guessed that in some years the sport catch of small fish equals or exceeds the commercial catch of small fish.

We therefore had to estimate the sport catch of small fish. To do this, we used tag recoveries by the sport and purse seine fisheries in 1964-69 and 1971 (Table 13). No recoveries were made in 1970. The estimation procedure was by

Table 9. Summary of data on bluefin tuna that were used to estimate the size composition of the catch from the western Atlantic Ocean.

Type of gear	Type of measurement	Catch 1965	1966	1967	1968	1969	1970	Length-frequency sample	Source of data
Canada-U.S.A.									
Purse seine	tons, small fish	2,700	800	2,300	600	1,600	4,200	U.S.A., purse seine	Mather (personal communication)
	tons, large fish	440	120	-	70	-	-	U.S.A., trap	
U.S.A.									
Sport	estimated tons, small fish	160	200	90	100	410	-	U.S.A., purse seine	Mather (personal communication)
	numbers, large fish	32	37	82	50	225	-	U.S.A., rod and reel	
Canada-U.S.A.									
Trap	tons (Canada)	180	240	300	250	-	280	U.S.A., trap	Aloncle et al. (1972, Table 1); Mather (personal communication)
	tons (U.S.A.)	160	130	140	20	-	-		
	numbers (U.S.A.)	-	-	-	-	-	240		
Canada									
Sport	tons	90	100	60	180	170	150	Canada, rod and reel	Aloncle et al. (1972, Table 1); Beckett (personal communication)
U.S.A.									
Harpoon	tons	50	40	50	60	-	-	U.S.A., harpoon	BCF (1967, 1968, 1969); NMFS (1971); Mather (personal communication)
	numbers	-	-	-	-	60	100	U.S.A., harpoon	
Bahamas									
Sport	numbers	10	116	14	-	-	11	Bahamas, rod and reel	Mather (personal communication)
Argentina-Cuba									
Handline	tons (Argentina)	100	100	100	-	-	-	Bahamas, rod and reel	ICCAT (1971b); Mather (personal communication)
	tons (Cuba)	100	500	2,400	1,400	500	200		
Japan-Taiwan									
Longline	numbers	58,432	2,195	3,901	1,982	1,652	883	Japan, longline, 1966	Fisheries Agency of Japan (1966-71); ICCAT (1971a); Hayasi and Shingu (MS)

Table 10. Summary of data on bluefin tuna that were used to estimate the size composition of the catch from the eastern Atlantic Ocean.

Type of gear	Type of measurement	Catch 1965	Catch 1966	Catch 1967	Catch 1968	Catch 1969	Catch 1970	Length-frequency sample	Source of data
France-Morocco-Spain									
Live bait and troll[1]	tons (France)	700	1,800	800	400	400	400	U.S.A., purse seine	ICCAT (1971b); Mather (personal communication)
	tons (Morocco)	1,000	1,800	2,000	500	700	400		
	tons (Spain)	7,900	7,300	7,600	7,600	9,700	5,400		
Portugal									
Trap	tons	100	200	200	100	400	-	Spain, trap	Aloncle et al. (1971); ICCAT (1971b); Hamre et al. (1968, 1971)
	numbers	-	-	-	-	-	492[2]		
Morocco									
Trap	tons	1,900	1,800	1,400	800	100	300	Spain, trap	Aloncle et al. (1971); ICCAT (1971b); Hamre et al. (1968, 1971)
Spain									
Trap[3]	numbers	8,340	7,780	14,060	5,380	7,570	7,170	Spain, trap	Aloncle et al. (1971); Hamre et al. (1968, 1971)
Norway									
Purse seine	tons	-	1,000	1,900	700	900	400	Norway, purse seine	Aloncle et al. (1971); ICCAT (1971b); Hamre et al. (1968, 1971)
	numbers	8,382	-	-	-	-	-		
Japan-Taiwan									
Longline	numbers	837	56	42	23	251	176	Japan, longline, 1966	Fisheries Agency of Japan (1966-71); ICCAT (1971a); Hayasi and Shingu (MS)

[1] Catches are estimates.

[2] Catch was reported by Aloncle et al. (1971), but ICCAT (1971b) reported no catch.

[3] Catches are from the Barbate, Conil and Sancti-Petri traps.

Table 11. Average size composition of the Atlantic bluefin tuna catch from the western Atlantic.

Length group (cm)	1 Argentina-Cuba handline	2 Bahama sport	3 Canada-U.S.A. Purse seine	4 Canada-U.S.A. trap	5 Canada sport	6 U.S.A. harpoon	7 U.S.A. sport	8 Japan-Taiwan longline	Total	Total w/o (1)
40- 49			481				114		595	595
50- 59			30,503				7,933		38,436	38,436
60- 69			8,167				2,050		10,217	10,217
70- 79			48,567				6,344		54,911	54,911
80- 89			22,806	1			1,773		24,580	24,580
90- 99			24,781	-			1,360		26,141	26,141
100-109			13,593	-			2,545		16,138	16,138
110-119			2,608	2			399		3,009	3,009
120-129			3,753	7			267	207	4,234	4,234
130-139			1,598	16			153	-	1,767	1,767
140-149			1,918	14			198	-	2,130	2,130
150-159			866	37			58	207	1,168	1,168
160-169			325	52		1	18	-	396	396
170-179			161	70		-	8	207	446	446
180-189			189	54		2	21	400	666	666
190-199	4		43	48	1	-	6	1,421	1,523	1,519
200-209	30	1	53	87	1	12	5	3,848	4,037	4,007
210-219	258	7	58	139	11	3	8	2,842	3,326	3,068
220-229	650	12	64	199	73	20	13	3,034	4,065	3,415
230-239	1,073	10	64	266	131	27	17	2,235	3,823	2,750
240-249	645	6	48	245	153	25	19	-	1,141	496
250-259	118	1	43	167	60	36	15	400	840	722
260-269	335	1	23	100	25	17	5		506	171
270-279	309	1	6	29	11	10	1		367	58
280-289			1	7	5				13	13
Total	3,422	39	160,719	1,540	471	153	23,330	14,801	204,475	201,053

Table 12. Average size composition of the Atlantic bluefin tuna catch from the eastern Atlantic.

Length group (cm)	1 Bay of Biscay live bait and troll	2 Moracco trap	3 Norway purse seine	4 Portugal trap	5 Spain trap	6 Japan-Taiwan longline	Total
40- 49	3,310			1	3		3,314
50- 59	220,225	1		5	18		220,249
60- 69	62,102	1		4	15		62,122
70- 79	243,479	5		20	68		243,572
80- 89	95,078	1		4	13		95,096
90- 99	89,355	-		-	-		89,355
100-109	72,007	6		-	5		72,018
110-119	11,412	10		1	8		11,431
120-129	11,328	19		2	18	3	11,370
130-139	4,967	37		4	38	-	5,046
140-149	6,112	98		11	99	-	6,320
150-159	2,274	152		19	193	3	2,641
160-169	719	233		30	299	-	1,281
170-179	290	269		41	335	3	938
180-189	574	311		67	509	6	1,467
190-199	189	445		98	807	22	1,561
200-209	25	558	1	109	1,034	60	1,787
210-219		688	27	123	1,082	44	1,964
220-229		904	176	142	1,216	47	2,485
230-239		953	725	145	1,300	35	3,158
240-249		587	1,242	96	870	-	2,795
250-259		207	1,236	43	359	6	1,851
260-269		34	561	13	86		694
270-279		3	137	1	9		150
280-289			19				19
Total	823,446	5,522	4,124	979	8,384	229	842,684

Table 13. Estimated U.S.A. sport catch of small Atlantic bluefin tuna from tag returns.

Recovery year	Numbers recovered			(1)/(2)	Catch (1,000's metric tons)		
	Sport fishery (1)	Purse seine fishery (2)	Total		Purse seine fishery	Sport fishery (estimated)	Total
1964	3	60	63	0.050	5.6	0.28	5.88
1965	8	125	133	0.060	2.7	0.16	2.86
1966	80	320	400	0.250	0.8	0.20	1.00
1967	17	460	477	0.037	2.3	0.09	2.39
1968	26	161	187	0.161	0.6	0.10	0.70
1969	7	27	34	0.259	1.6	0.40	2.01
1971	1	78	79	0.013	3.6	0.05	3.65

proportion, based on the ratio of tag recoveries by the two fisheries and the purse seine catch. This procedure assumes that the small fish are equally available to both fisheries and that the tags are returned in proportion to the total number recovered. This latter assumption may not hold because sportsmen and commercial fishermen do not return many tags they recover (Mather, personal communication), and it is uncertain whether this behavior is proportionately identical for both types of fishermen.

To obtain the size composition of the estimated small bluefin tuna catch by sportsmen, we used length-frequency samples of the purse seine catch. This is reasonable because the sport fishery usually operates in the same area as the purse seine fishery.

Canada-U.S.A., trap.--Canadian catches are reported for combined trap and longline (Aloncle et al., 1972). The longline fraction of the combined catch is presumably small (Mather, personal communication). We used the combined catch in our calculations.

Canada, sport.--Weight-frequency samples of bluefin tuna caught by the Canadian sport fishery have been published by ICES (Aloncle et al., 1971). In our calculations, however, we used size-frequency data that were supplied by Beckett (personal communication). The data are not too different from those published by ICES.

U.S.A., harpoon.--Length-frequency samples were small and from fish caught off Massachusetts. However, we assumed that the total Massachusetts-Maine catch had identical size distribution.

Bahama, sport.--The total catch is not complete but we have estimated the size composition of the catch.

Argentina-Cuba, handline.--The total catch of this fishery is questionable, but estimates of the size composition of the catch were made, based on length-frequency samples from the Bahama sport fishery. No length-frequency samples are available for this fishery.

Japan-Taiwan, longline.--The size composition of the catch was estimated on the basis of the total catch for regions shown in Table 6, and length-frequency sample for 1966. It was assumed that the length-frequency of the catch was constant during 1965-70.

Eastern Atlantic

France-Morocco-Spain, live bait and troll.--Size-frequency samples are unavailable for this fishery. The fishery exploits small bluefin tuna, and we assumed that the size distribution of the catch was the same as that for the Canadian-U.S.A. purse seine fishery.

Portugal, trap.--We assumed that the size-frequency samples for the Spanish trap fishery is applicable to this fishery.

<u>Morocco, trap.</u>--We assumed that the size-frequency samples for the Spanish trap fishery is applicable to this fishery.

<u>Spain, trap.</u>--Size-frequency samples are from catches made by primarily one trap, Barbate. We assumed that the samples were applicable to all Spanish traps.

<u>Norway, purse seine.</u>--Complete data on the size composition of the catch are available for this fishery.

<u>Japan-Taiwan, longline.</u>--Estimates were based on the same assumptions as used in the western Atlantic.

In Figures 11, 12, and 13, the average size distribution of the catch for the Atlantic bluefin tuna fisheries are shown. It is evident from the figures that there are two prominent sizes of fish that are caught, small (40-120 cm) and large (176-280 cm) fish, and each fishery exploits primarily only one size group. This phenomenon is evident in both the western and eastern regions.

It has been suggested (Mather and Jones, MS, 1972) that the lack of medium size fish (121-175 cm) in the catch is the result of a recent heavy exploitation on the small fish which decreased recruitment to the medium- and large-size groups, and that the large catch of large fish is composed of old fish, year classes that were not exposed to the recent heavy exploitation. It is also possible that the medium size fish are less vulnerable to the gears, or even the possibility that the present fisheries are not fishing in areas where the medium size fish are available. Mather (personal

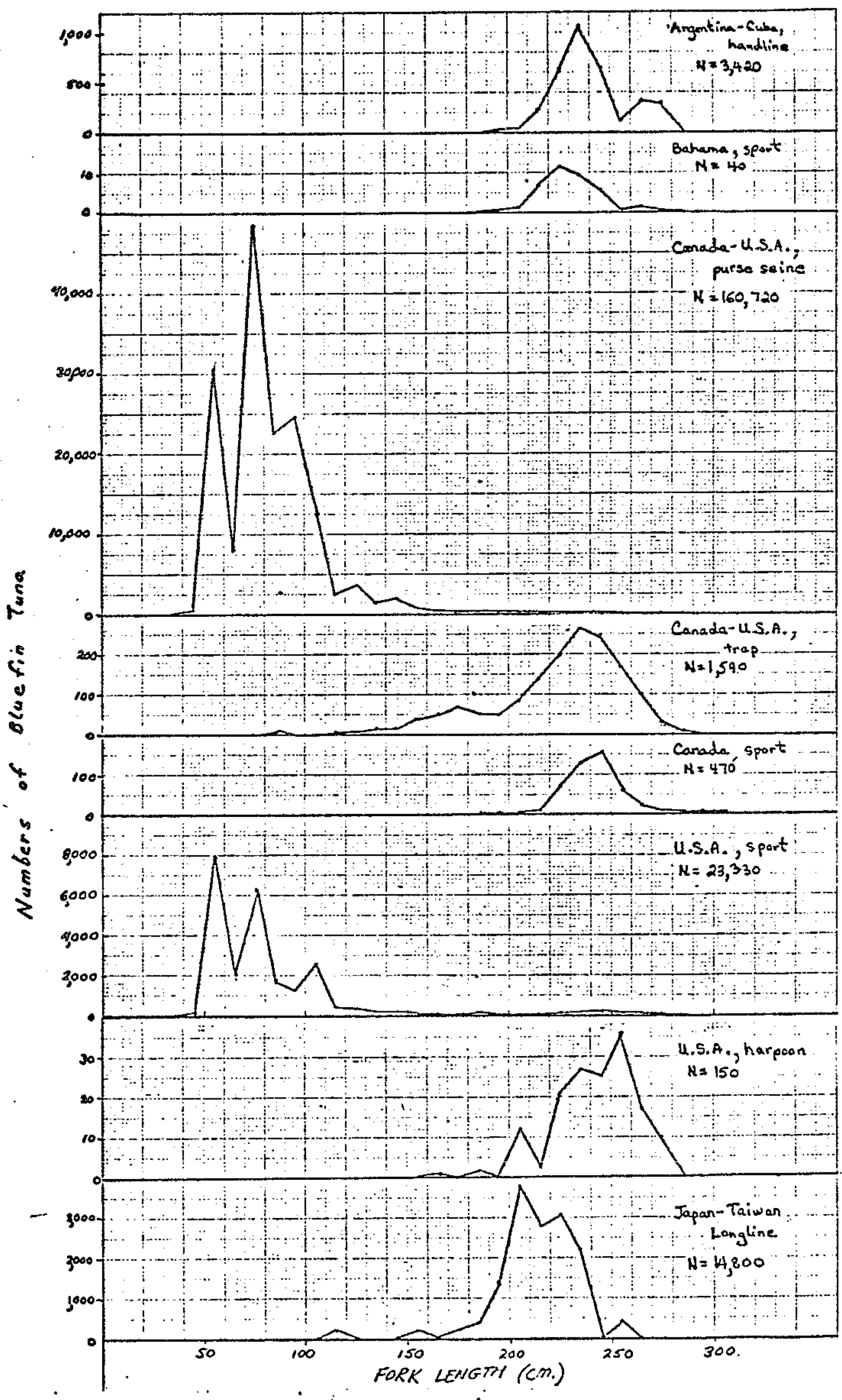

Figure 11. Average, 1965-70, size composition of the catch of bluefin tuna from eight western Atlantic fisheries.

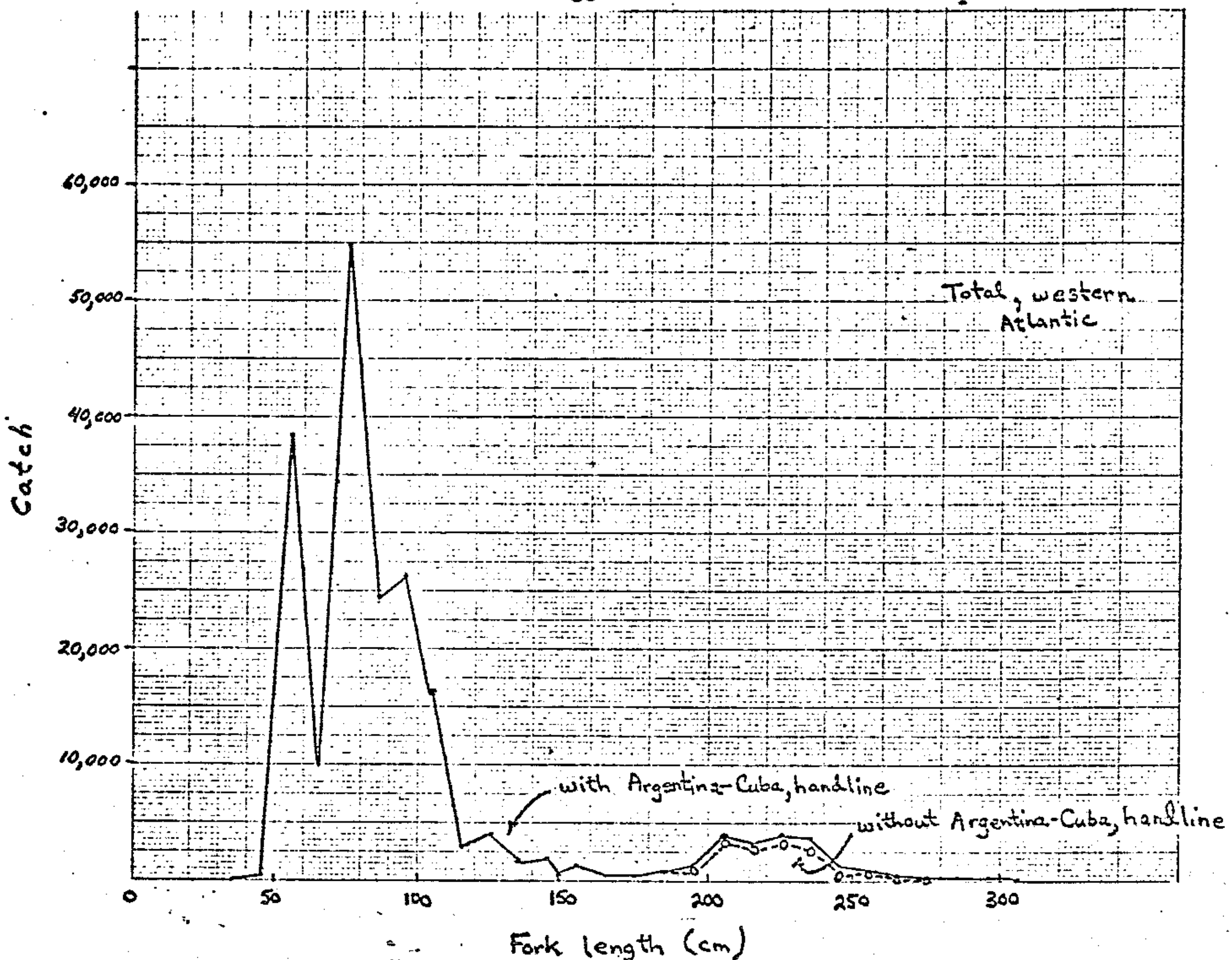

Figure 12. Average, 1965-70, size composition of the catch of bluefin tuna from the western Atlantic.

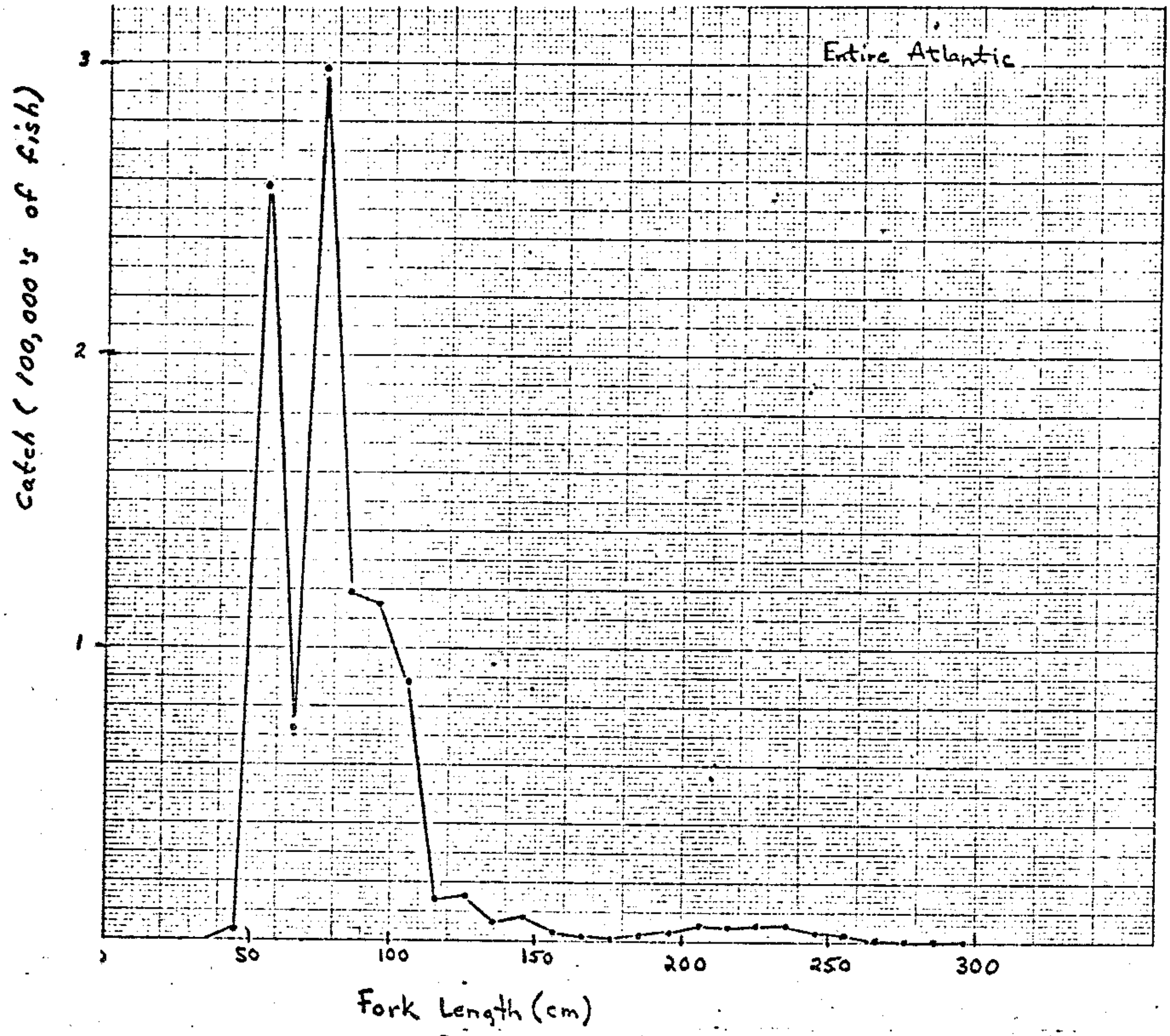

Figure 13. Average, 1965-70, size composition of the catch of bluefin tuna from the entire Atlantic.

communication) believes that these possibilities are remote, since medium size fish were caught in fair numbers in early years. However, it is possible that the medium size fish have become less available if their distribution range has constricted, and their center of abundance is out of the range where the present gears operate.

Age Composition of Catch

The age composition of the Canadian-U.S.A. catch was estimated based on modal progression for ages 1-3 years and the length-age key (Mather and Jones, MS, 1972) for older ages. A significant feature of the results (Table 14 and Figure 14) is the fluctuation in the dominate age group. From the relative numbers of fish caught in each age group, it is not possible to conclude that the fluctuation is caused by variation in year-class strength. However, it is possible that there is enough transatlantic migration (Mather et al., MS, 1971) in the bluefin population(s) to obscure the actual picture. Another significant feature of the results is that not all year classes are represented in the catch in all years, a feature caused by the selection of small fish by the purse seine fleet.

We estimated the age composition of the catch for the entire Atlantic (Table 15) to more closely trace the progression of a year class through the fisheries. The results (Figure 15) show that in 1966 a strong (1965) year class was recruited to the fishery as 1-year-olds and that this year class can be traces as it progressed through the years. After 4 years in the fishery, it appears that the 1966 year class was reduced substantially.

Table 14. Age composition of the catch of Atlantic bluefin tuna caught by Canadian-U.S.A. purse seiners in the western Atlantic.

Age (years)	Approximate length (cm)	Year								
		1962	1963	1964	1965	1966	1967	1968	1969	1970
1	48- 67	362	83,831	48,568	35,346	125,062	8,715	3,939	891	27,027
2	68- 84	1,401	49,664	65,729	133,000	29,151	118,689	32,556	27,445	92,292
3	85-105	20,710	40,692	103,261	37,442	6,434	49,334	14,342	46,643	113,097
4	106-127	23,323	10,532	29,742	872	2	4,645	214	5,736	18,592
5	128-145	42,779	48,752	32,078	7,093	7	385	86	2,937	4,917
6	146-159	1,099	19,446	16,618	8,407	29		-	956	1,556
7	160-168	556	1,521	1,492	1,672	12		-	-	267
8	169-180	2,243	1,479	187	883	25		-	-	57
9	181-195	1,227	704	257	961	30		20	213	41
10	196-214	434	245		525	51		34		13
11	215-229	10	66		465	47		47		
12	230-239		44		307	51		27		
13	240-246				90	38		17		
14+	247+				246	213		125		
Total		94,144	256,976	298,032	227,309	161,153	181,768	51,407	84,821	257,859
Estimated effort (day's fishing)					392	192	156	75	80	180

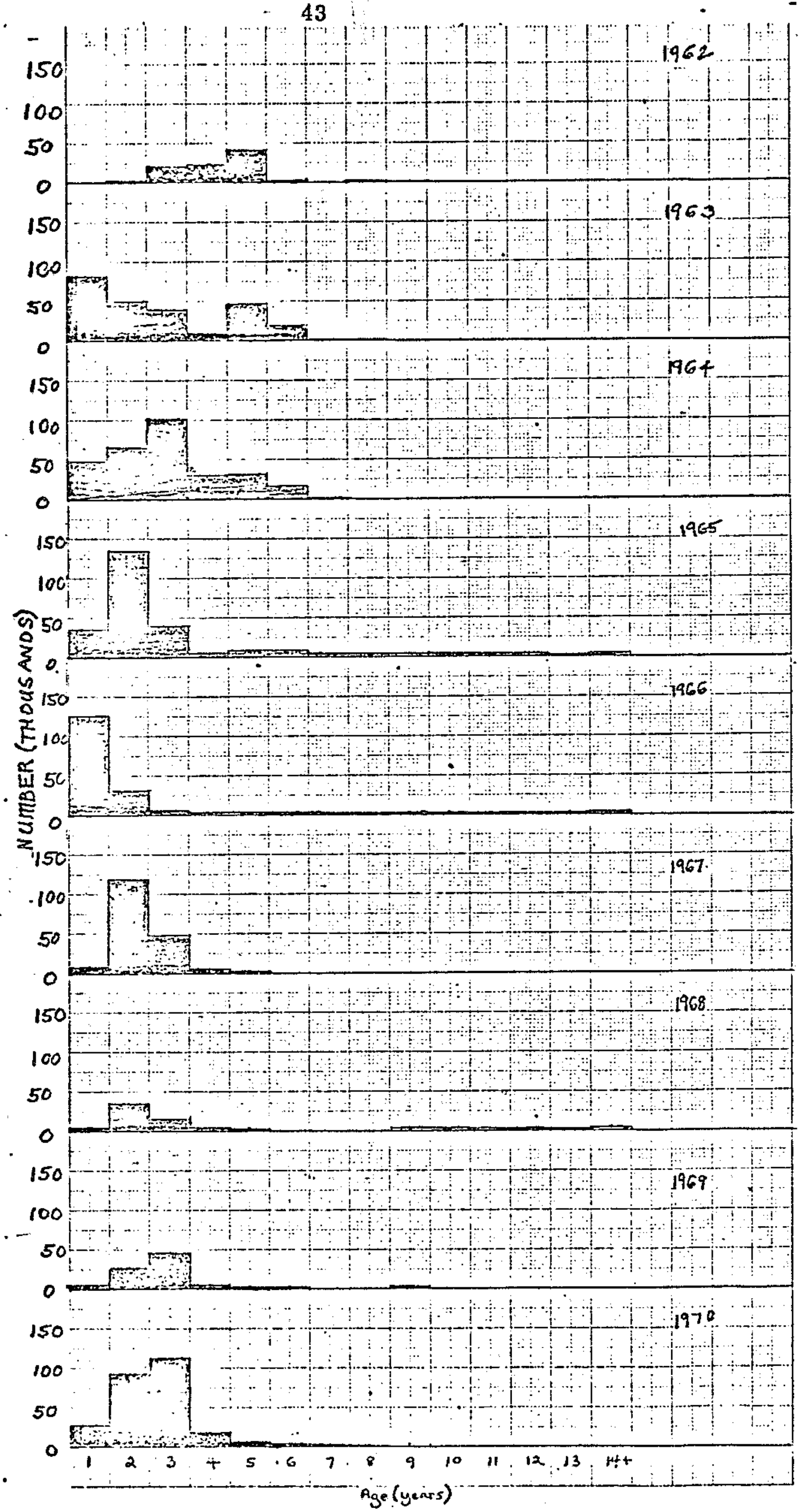

Figure 14. Age composition of the catch of Atlantic bluefin tuna caught by the Canadian-U.S.A. purse seine fishery.

Table 15. Estimated age composition of the catch of Atlantic bluefin tuna from all fisheries in the Atlantic Ocean, 1965-70.

Age (years)	Approximate length (cm)	Year					
		1965	1966	1967	1968	1969	1970
1	48- 67	188,557	1,552,884	71,605	32,413	20,722	99,393
2	68- 84	427,958	422,560	488,840	422,508	231,224	222,908
3	85-105	150,527	110,550	313,841	268,468	187,965	291,005
4	106-127	38,993	17,944	81,696	25,033	181,234	49,004
5	128-145	27,550	612	2,229	115	22,536	12,996
6	146-159	33,841	1,333	982	227	7,382	4,234
7	160-168	6,568	1,035	1,145	299	113	832
8	169-180	4,239	2,023	811	387	338	432
9	181-195	8,744	4,385	2,927	1,132	3,100	1,646
10	196-214	27,752	12,572	7,649	3,849	2,941	4,146
11	215-229	24,872	11,120	5,174	3,820	2,836	2,366
12	230-239	16,678	7,366	5,205	2,118	2,160	1,620
13	240-246	2,866	1,659	2,687	877	1,040	610
14+	247+	7,799	4,888	8,201	3,798	4,037	2,753
Total		966,944	2,150,931	992,992	765,044	667,628	693,945

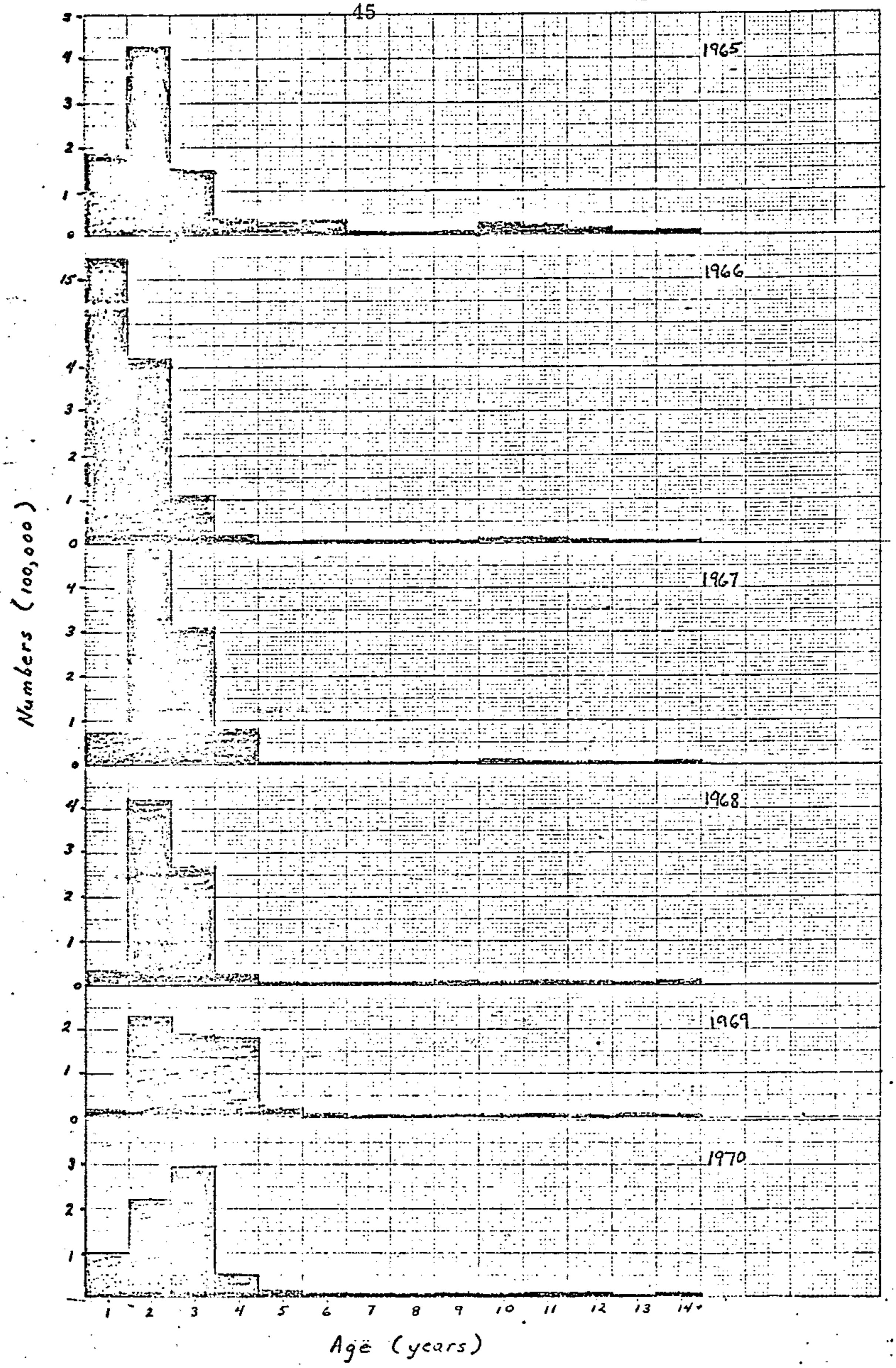

Figure 15. Estimated age composition of the catch of bluefin tuna from the entire Atlantic.

Words of caution about our results, the results for the Canadian-U.S.A. purse seine fishery and the western Atlantic fisheries are reasonably accurate, because they were based on a fair volume of data. On the other hand, the results for the entire Atlantic may be questionable because the age composition for the bulk of the catch, small bluefin tuna, was estimated from size-frequency samples from the Canadian-U.S.A. purse seine fishery. In essence, this procedure assumes that a homogeneous population of bluefin tuna is exploited throughout the Atlantic. Such an assumption, although has not been demonstrated to be correct, seems possible on the basis of (1) transatlantic migrations of small and large bluefin tuna (Mather et al., MS, 1971), and (2) the increase in average size in different fisheries on both sides of the Atlantic (Figure 10; Mather and Jones, MS, 1972). Another assumption is that the total catch of the Atlantic fisheries is reasonably accurate.

ESTIMATES OF SOME POPULATION PARAMETERS

Growth

Several studies have dealt with growth of bluefin tuna (see Tiews, 1962). Mather and Schuck (1960) described growth of bluefin tuna from the western Atlantic and formulated a length-age key (Table 16). Recently, Mather and Jones (MS, 1972) gave a slightly different version of the key (Table 16). We used both sets of data to estimate parameters of the von Bertalanffy growth equation. The results are:

Table 16. Fork length (cm) at age for bluefin tuna from the western Atlantic.

Age (years)	Source of data	
	Mather and Schuck (1960)	Mather and Jones (MS, 1972)
0	31	38
1	60	56
2	78	77
3	94	91
4	110	119
5	135	135
6	155	155
7	161	162
8	175	174
9	185	186
10	203	203
11	222	224
12	232	234
13	243	243
14	248	248

	Source of data	
	Mather and Schuck (1960)	Mather and Jones (MS, 1972)
K (yearly)	0.055	0.053
L_∞ (cm)	437.46	447.88
t_o (years)	-1.489	-1.592

Rodriguez-Roda (1971) has studied growth of bluefin tuna caught in traps off southern Spain. He gave the following growth estimates:

$$K = 0.09$$
$$L_\infty = 355.84 \text{ cm}$$
$$t_o = 0.89 \text{ years}$$

His estimates were based on primarily large fish.

A comparison of these three growth curves (Figure 16) shows that they are not too different. The little difference that does exist could easily be attributed to differences in the samples of fish used. Thus, it appears that growth of bluefin tuna from the eastern and western Atlantic is similar. For our purpose, we have used the parameters from the Mather-Jones curve.

Several weight-length relations are available for Atlantic bluefin tuna (e.g., Mather and Jones, MS, 1972; Rodriguez-Roda, 1971). From data on fish from the western Atlantic, Mather (personal communication) calculated the following relation:

$$W = 0.0000317L^{2.90444}$$

where W = weight in kilograms and L = fork length in centimeters. We used this relation throughout our report.

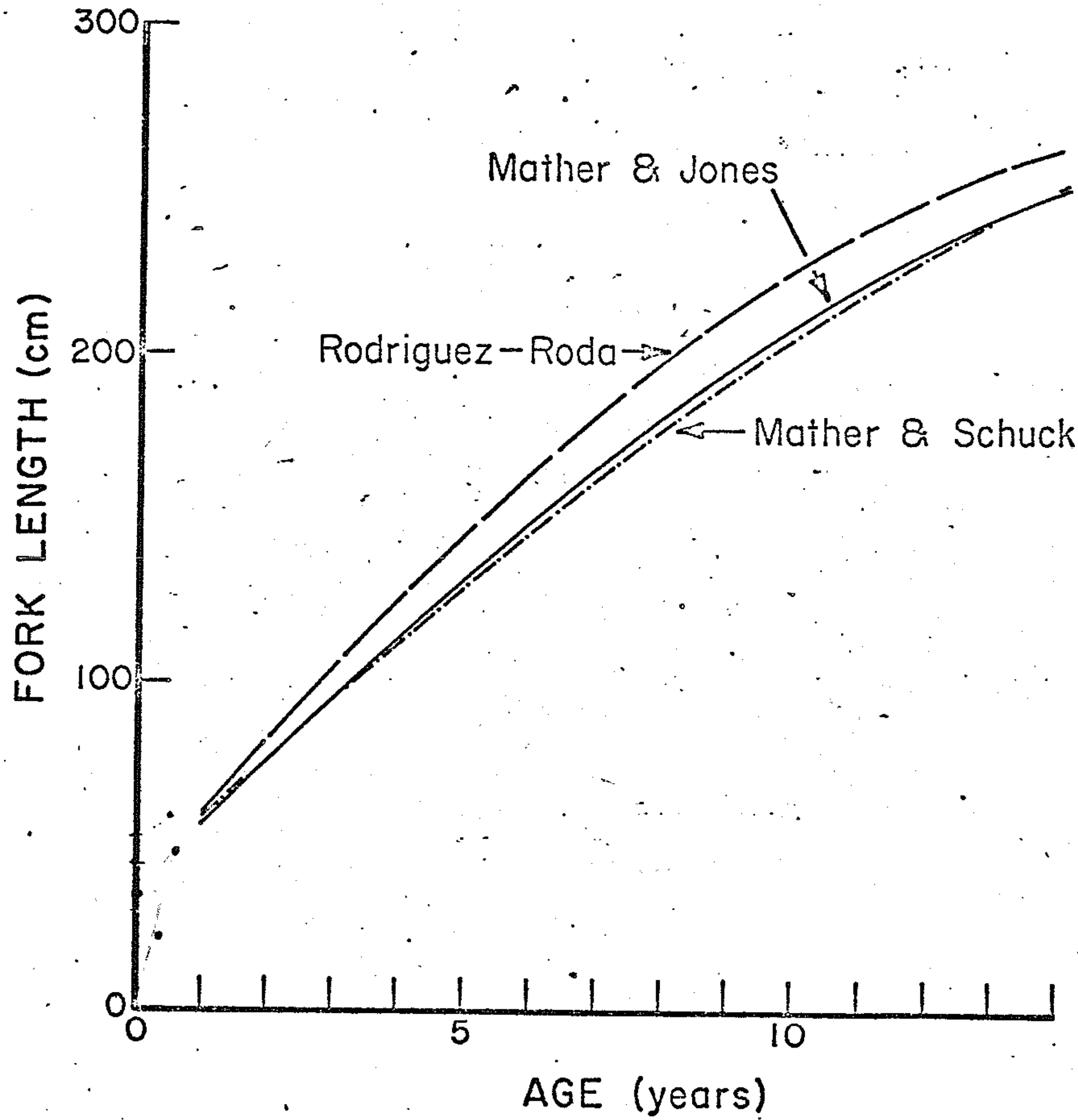

Figure 16. Estimated growth of Atlantic bluefin tuna. Curves are fitted to the von Bertalanffy growth equation.

Instantaneous Coefficient of Total Mortality (Z)

A procedure of estimating Z is by regression of catch per unit of effort (CPUE) of a year class on age. This procedure assumes that CPUE is a reasonable estimate of apparent abundance and that the exponential mortality model applies. We used this procedure to estimate Z for bluefin tuna caught in the Canadian-U.S.A. purse seine fishery. Apparent abundance was measured as numbers of fish caught per day's fishing (Table 17), fishing effort based on Class 3 seiners.

The age at full recruitment ranged from age 1-3 years: age 1 for the 1962 year class; age 2 for the 1963 and 1965 year classes; and age 3 for the 1961, 1964, and 1966 year classes (Figure 17). An interesting feature of the CPUE's is the unrepresentative catches of 4- and 5-year old fish. These age groups are not as fully available to the purse seine fishery as the younger and older fish. In our estimates of Z, we did not use data on 4- and 5-year-old fish whenever it appeared that they were under represented in the catch.

Estimates of Z range from 0.88-1.18, averaging 1.01 (Table 18). These estimates are quite close to the refined Z's of Lenarz et al. (MS, 1972b), which averaged 1.28 (Table 19).

It is important to note that our estimates are approximations because of deficiencies in the data from which they were derived. One significant deficiency is in the measure of fishing effort, which was discussed in an earlier section. A bias in this measure would affect the CPUE and the estimate of Z. Of course, our ageing technique is also another source of deficiency, although it probably is insignificant for the smaller sizes below 120 cm long; distinct modes are usually present in length-frequency distributions within 20-120 cm.

Table 17. Apparent abundance of year classes of bluefin tuna exploited by the Canadian-U.S.A. purse seine fishery in 1965-70.

Age (years)	Year class											
	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
1							0.91	187.12	73.80	90.17	651.37	55.87
2						3.52	110.86	99.89	339.29	151.83	760.82	434.08
3					52.04	90.83	156.93	95.52	33.51	316.24	191.23	583.04
4				58.60	23.51	45.20	2.23	0.02	29.77	2.85	71.70	103.29
5			107.48	108.82	48.75	18.09	0.03	2.47	1.14	36.71	27.32	
6		2.76	43.41	25.26	21.45	0.15	-	-	11.95	8.64		
7	1.40	3.40	2.42	4.27	0.06	-	-	-	1.48			
8	3.30	0.39	2.25	0.13	-	-	-	0.32				
9	0.39	2.45	0.16		0.27	2.66	0.23					

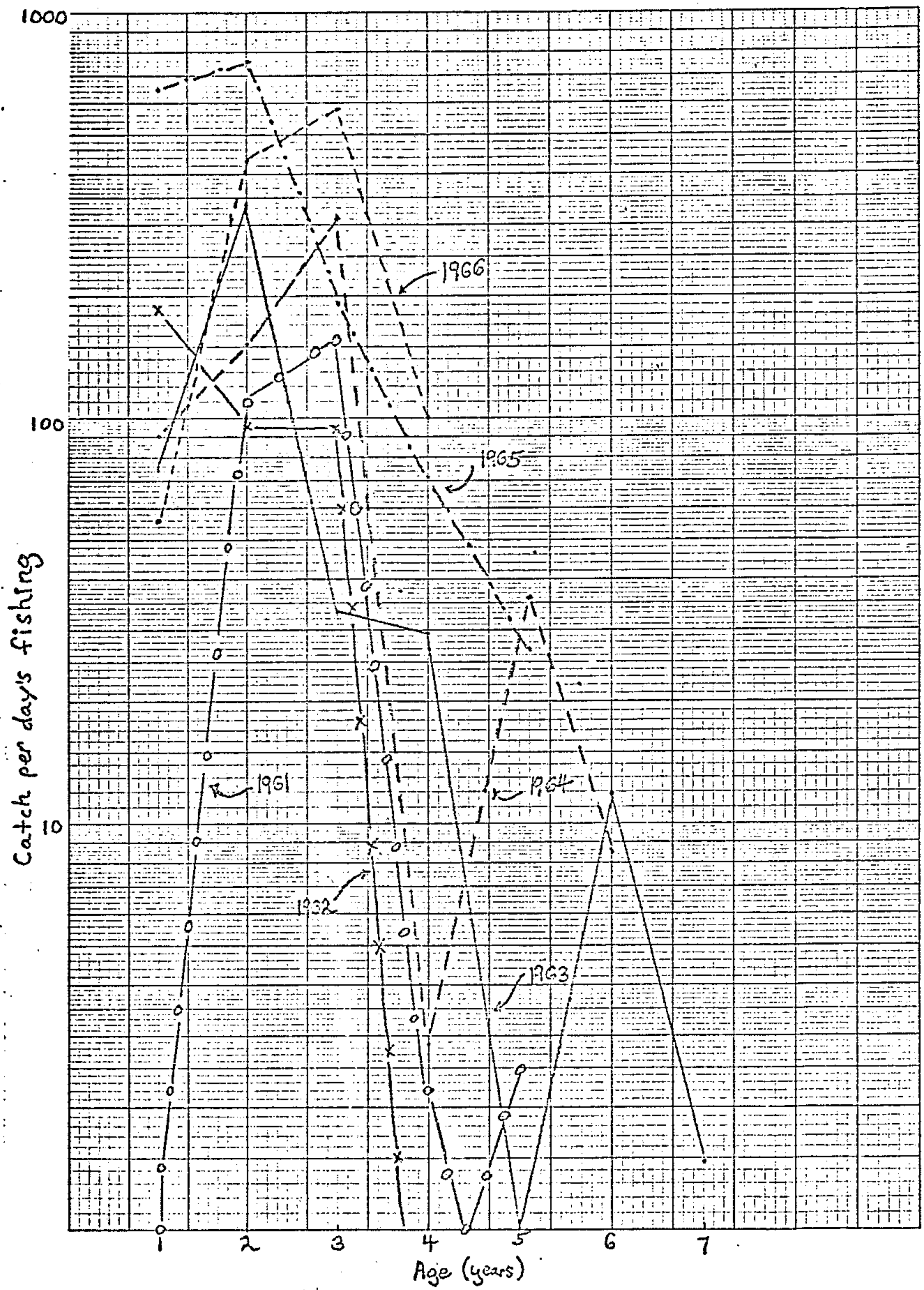

Figure 17. Catch curves for the 1961-66 year class that were exploited by the Canadian-U.S.A. purse seine fishery.

Table 18. Estimates of instantaneous coefficient of total mortality (Z), and instantaneous coefficient of fishing mortality (F), assuming natural mortality, M = 0.1. Estimates of Z are based on data from the Canadian-U.S.A. purse seine fishery.

Year class	Range of ages (years)	Z	F (M = 0.1)
1961	3-9	0.88	0.78
1962	1-8	0.98	0.88
1963	2-7	0.89	0.79
1964	3-6	1.18	1.08
1965	2-5	1.10	1.00
Average		1.01	0.91

Table 19. Estimates of instantaneous coefficient of fishing mortality (F) and of total "other-loss" (X) for the Canadian-U.S.A. purse seine fisheries.

	1964	1965	1966	1967	1968	1964-68 Average
Mather et al. (MS, 1972)						
F	0.497	0.326	0.202	0.412	0.767	0.441
X	1.558	1.506	0.697	0.999	0.838	1.120
F + X	2.056	1.833	0.899	1.411	1.604	1.561
Lenarz et al. (MS, 1972b)						
F	0.512	0.336	0.223	0.431	0.795	0.459
X	1.264	1.217	0.396	0.700	0.529	0.821
F + X	1.776	1.553	0.619	1.131	1.324	1.280

Mortality Coefficients for Fish Caught by the Canadian-U.S.A. Purse Seine Fishery

Mather et al. (MS, 1972) analyzed bluefin tuna tagging data and estimated the instantaneous coefficient of fishing mortality (F) and the instantaneous coefficient of total "other-loss" rate (X) for 1964-68. The total "other-loss" coefficient includes natural mortality, tag loss, tagging mortality, and emigration.

In 1971 a double tagging experiment was conducted by Canada and the U.S.A. to evaluate two types of tags. The data were used by Lenarz et al. (MS, 1972b) to estimate rates of tag loss. Lenarz et al. then used the loss rates to refine the estimates of F and X of Mather et al. The refined and unrefined estimates are shown in Table 19. It is important to mention that Lenarz et al. felt that the estimates of F's are probably biased downwards because of tagging mortality.

The average X of Lenarz et al. (MS, 1972b) is 0.8 which is extremely high for a longlived fish. However, this high value, as explained in Lenarz et al. (MS, 1972b), may be an overestimate. It also includes losses owing to emigration. If emigration from the western Atlantic fisheries accounts for most of X and the stock is not exploited after it passes through the New England fisheries (trap, purse seine, sport, et., of Canada and U.S.A), then X is an appropriate estimate of an effective natural mortality rate, "M", for analysis of management strategies in the New England fisheries.

Effective Size at Recruitment

A method of estimating the effective size at recruitment was first described by Lenarz and Sakagawa (MS, 1972) and later developed in detail by Lenarz et al. (MS, 1972a). The method is based on an equation, similar to that given by Beverton and Holt (1956):

$$l_r = \bar{l} - \left[\frac{K(L_\infty - \bar{l})}{Z}\right]$$

where K and L_∞ are parameters of the von Bertalanffy growth equation, $\bar{l}$ is the average length of fish in the catch, Z is the instantaneous coefficient of total mortality, and l_r is the effective length at recruitment. From a weight-length relation, l_r can be converted to w_r, effective weight at recruitment.

For Atlantic bluefin tuna we used our best estimates of K = 0.053, L_∞ = 447.88 cm (Mather-Jones growth curve) and Z = 1.0 (Table 18) and estimated l_r for three different fisheries (Table 20). The range of l_r for 1965-70 is: 42.63-65.93 cm for the Canadian-U.S.A. purse seine fishery, 58.05-91.24 cm for the western Atlantic fishery, and 45.86-79.95 cm for the entire Atlantic fishery. From 1965-70, there is no discernible trend in the size at recruitment. The average l_r is 58.73 cm, 70.13 cm and 60.09 cm for the respective fisheries.

The possible effects of a minimum size regulation can be examined. For example, if Z = 1.0 and an effective minimum size of 10 kg was instituted, the average size of bluefin tuna in the catch must at least be 98 cm long (Figure 18).

Table 20. Estimates of L_r and w_r for the bluefin tuna fisheries of the Atlantic Ocean.

	1965	1966	1967	1968	1969	1970	1965-70 Weighted Average
Canadian and U.S.A. Purse Seine							
Z	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$\bar{l}$ (cm)	83.14	63.03	74.79	73.48	85.15	84.85	78.32
l_r (cm)	63.81	42.63	55.02	53.64	65.93	65.61	58.73
w_r (kg)	5.54	1.72	3.60	3.34	6.09	6.00	4.35
Western Atlantic Fishery							
Z	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$\bar{l}$ (cm)	109.19	77.67	79.10	82.18	88.09	86.45	89.14
l_r (cm)	91.24	58.05	59.55	62.80	69.02	67.29	70.13
w_r (kg)	15.64	4.21	4.53	5.29	6.95	6.46	7.28
Entire Atlantic Fishery							
Z	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$\bar{l}$ (cm)	97.98	66.09	80.67	75.87	98.47	89.05	79.61
l_r (cm)	79.44	45.86	61.21	56.15	79.95	70.03	60.09
w_r (kg)	10.46	2.12	4.91	3.82	10.66	7.25	4.65

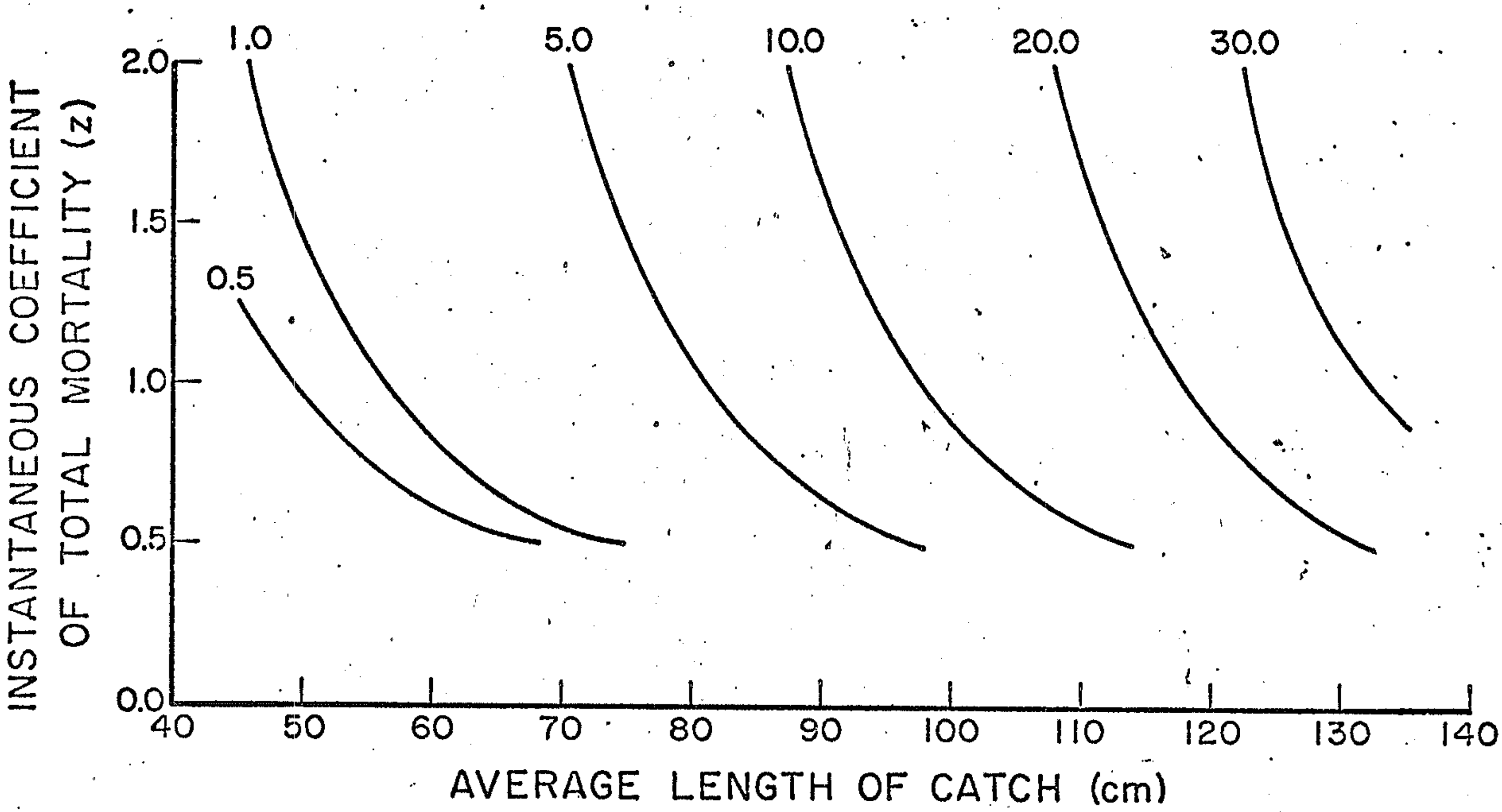

Figure 18. Estimated weight at recruitment (w_r in kg) isopleths for Atlantic bluefin tuna. See text for details of the estimation procedure

The average size of bluefin in the catch has so far been well below this size for the Canadian-U.S.A. purse seine fishery (Table 20). Only in 1965 did the average length of the catch exceed this value for the western Atlantic fisheries, and only in 1969 for the entire Atlantic fisheries (Table 20).

ANALYSIS OF YIELD

Yield of Atlantic bluefin tuna was examined with two objectives in mind: (1) analysis of past performance of the fisheries in order to determine the probable trend in future production and (2) to determine the "optimum" age at recruitment in regard to maximizing yield per recruit and the possible imposition of a minimum size regulation. A minimum size limit of 10 kg (78 cm) was considered in our analyses because it is the size that has been suggested by FAO (1968).

There is uncertainty as to how many stocks of bluefin are present in the Atlantic. Mather and Jones (MS, 1972) felt that there are essentially two stocks for management purposes. They based their hypothesis primarily on reported occurrence of spawning in the Caribbean (western Atlantic) and off northwest Africa (eastern Atlantic), and on the locations where small bluefin tuna are caught in large numbers, so far only off the New England coast and in the Bay of Biscay and adjacent waters. On the other hand, there is some evidence that suggests there is only one exploited stock in the Atlantic. For example, the pronounced increase in average size of large fish in the catch of fisheries on both sides of the Atlantic (Figure 10), the decrease in catch of large fish on both sides of the Atlantic (Table 1), the occurrence of transatlantic migration of small and large bluefin tuna (Figure 4), and the greater propensity of young fish to migrate across the Atlantic (Mather, et al., MS, 1971) suggest there may be only one exploited stock in the Atlantic. This hypothesis, however, recognizes the fact that spawning does occur on both sides of the Atlantic and perhaps by genetically distinct subpopulations (Marr, 1957) but mixing occurs before the fish are recruited to the fisheries. Thus, under this hypothesis from the management point of view there is essentially one exploited stock in the Atlantic. Our analyses of yield per recruit were performed with consideration of these two hypotheses; (1) two stocks, with bluefin tuna in the western Atlantic a homogeneous but separate stock from that in the eastern Atlantic, and (2) one stock in the entire Atlantic.

Production and Total Fishing Effort

Our previous review of catch and effort statistics for Atlantic bluefin tuna identified the available statistics and the fisheries for which statistics are deficient. We have graphed catch against fishing effort for fisheries with adequate statistics: German handline, Norwegian purse seine, and Spanish trap fisheries (Figure 19), Japanese longline fishery (Figure 20), and Canadian-U.S.A. purse seine fishery (Figure 21). Total fishing effort for the Canadian-U.S.A. purse seine fishery was estimated on the basis of (1) the CPUE of Class 3 seiners, and (2) the CPUE of Class 6 seiners.

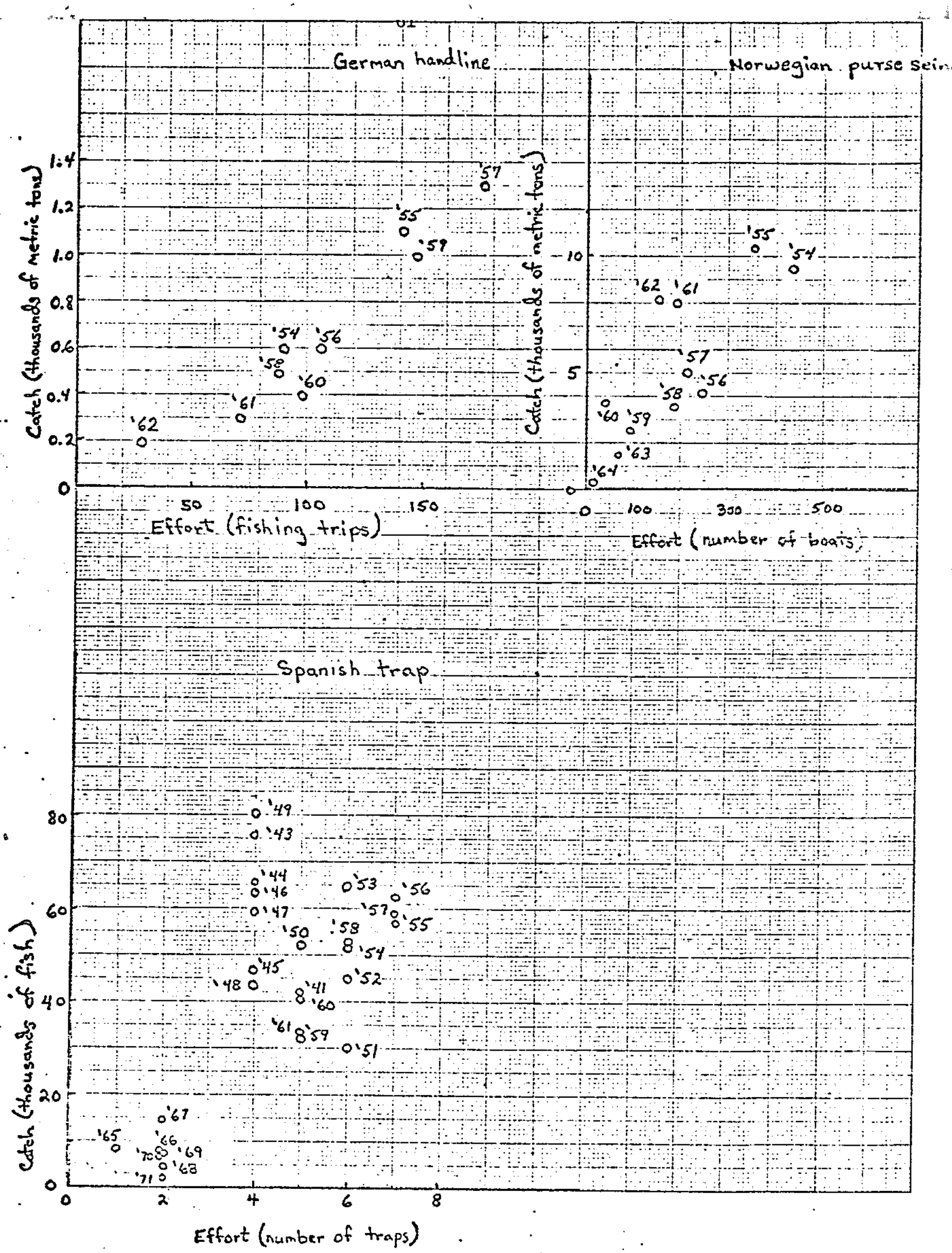

Figure 19. Catch of bluefin tuna as a function of fishing effort for three fisheries of the eastern Atlantic. The fisheries catch primarily large (176–280 cm) bluefin tuna.

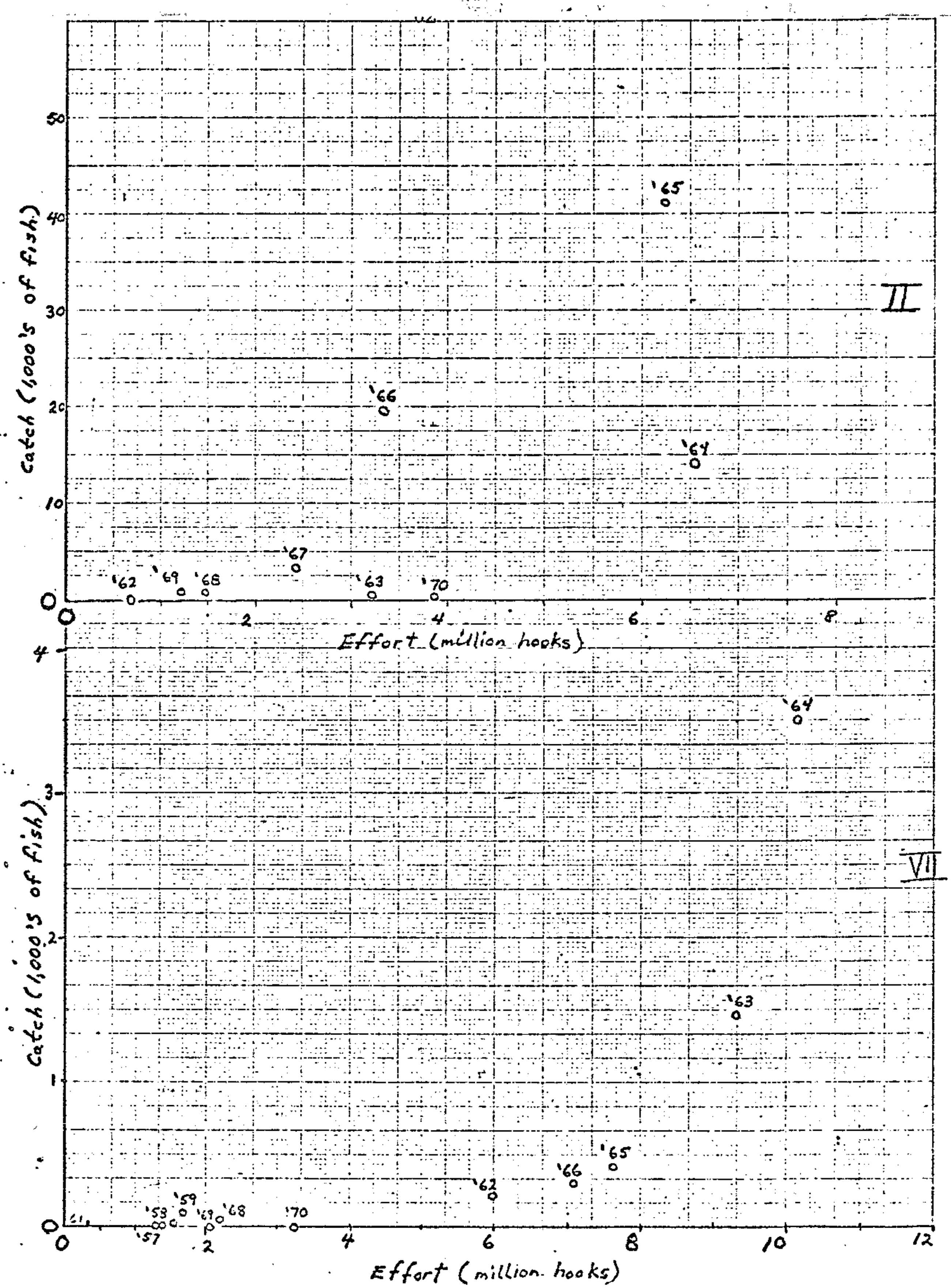

Figure 20. Catch of bluefin tuna as a function of fishing effort in two regions in the western Atlantic. Data are for the Japanese longline fleet, 1957-70. (Region II = off Canada and the U.S.A., Region VII = off Brazil)

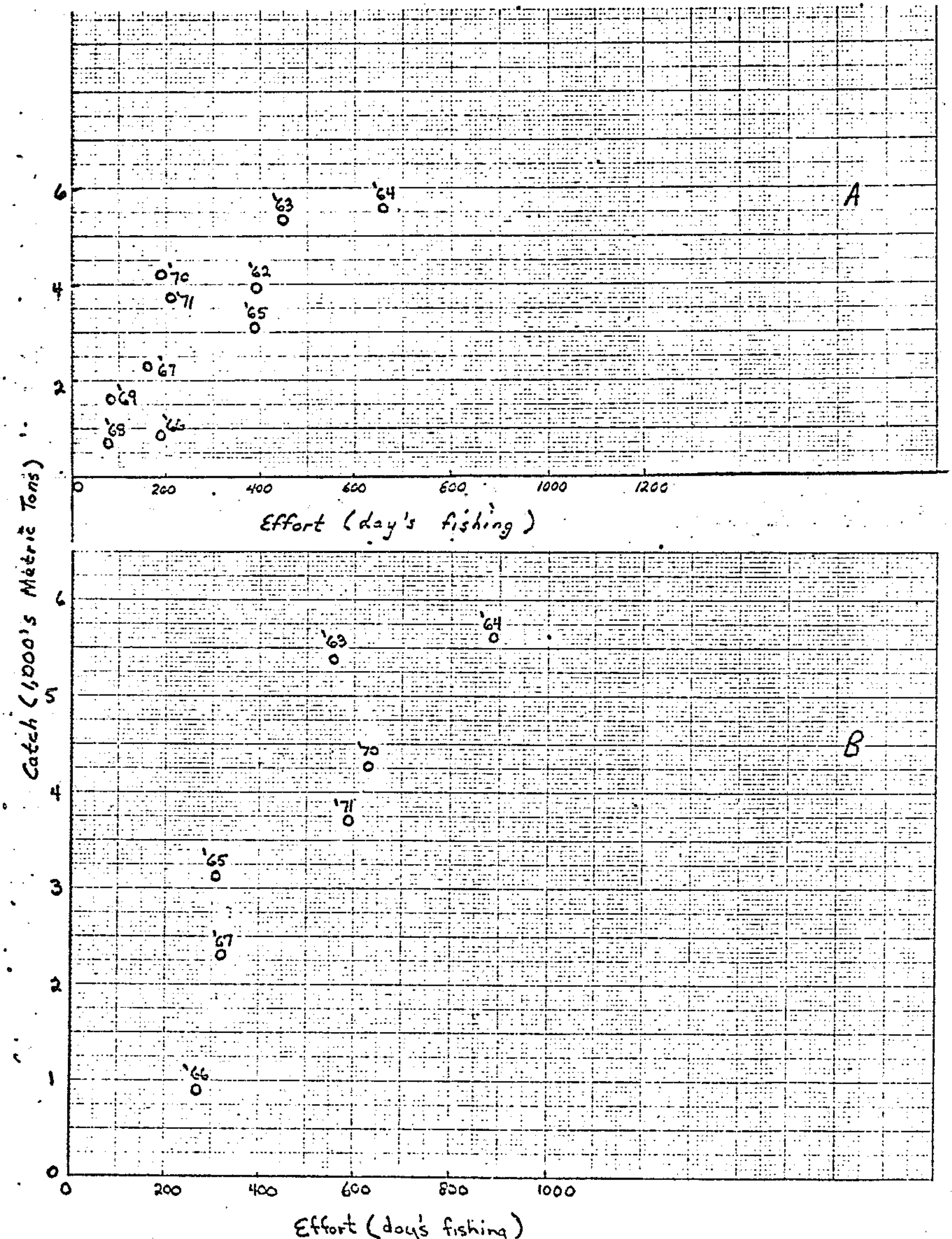

Figure 21. Catch of bluefin tuna as a function of fishing effort for the Canadian-U.S.A. purse seine fishery. Estimated fishing effort based on Class 3 seiners (Panel A) and on Class 6 seiners (Panel B) is used.

The German handline, Norwegian purse seine, and Spanish trap fisheries catch primarily large (176-280 cm) bluefin tuna. In each fishery, catch is a linear, increasing function of fishing effort (Figure 19). In recent years, the catch and effort of the German handline fishery has decreased to a negligible level. For the other two fisheries, catch and effort have also decreased to a low level. Apparently, these fisheries have responded to the low availability of large fish by decreasing their fishing effort proportionately to the catch.

Since 1956, the Japanese longline fleet has operated in the Atlantic. The trend of Japanese longline catch and effort for two regions in the western Atlantic is somewhat a curvilinear, increasing function (Figure 20). In recent years, 1968-70, the catch has been only a few hundred fish per region although effort per region has been a few thousand-11 million hooks (Table 6).

The Canadian-U.S.A. purse seine fishery began in 1962. Figure 21 shows that the catch is a linear, increasing function of fishing effort. The fishery has apparently adjusted its effort proportionately to variation in catch. Not accounted for in this analysis, however, is the fact that the local boats have become more efficient in their operations in recent years, as was discussed in an earlier section. The center of the fishing area has also shifted from Cape Cod Bay in 1962 to an area south of Cape Cod, Cape May-Montauk Point (Figure 22), where small bluefin tuna are now caught. In recent years, beginning in 1964, very few schools of small bluefin tuna have been sighted north of Cape Cod (Mather, personal communication). This was not the case in early years, when small bluefin tuna were frequently caught in Cape Cod Bay and off Maine (Wilson, 1965).

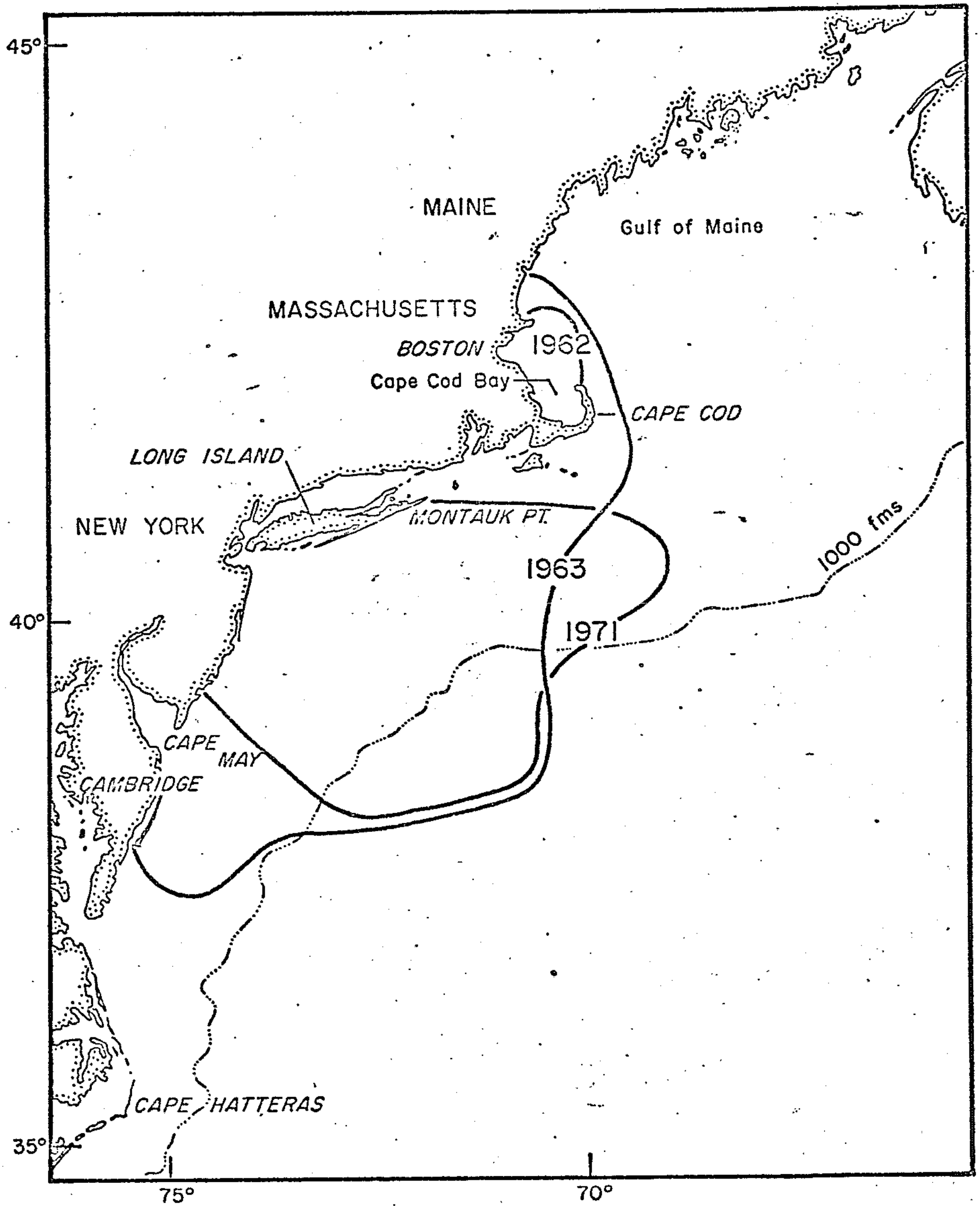

Figure 22. Fishing area of the Canadian-U.S.A. purse seine fishery for Atlantic bluefin tuna. The fishery began in 1962 in Cape Cod Bay and has shifted south to an area off Cape May to Montauk Point.

Simplified Beverton and Holt Model of Yield Per Recruit

The Beverton and Holt yield-per-recruit model may be simplified such that it is a function of three ratios:

$$C = l_r / L_\infty$$

$$E = F/(F + M) \text{ or } F/(F + X)$$

and

$$Q = M/K \text{ or } X/K$$

where W_∞, L_∞, and K are parameters of the von Bertalanffy growth equation and l_r is the length at first capture (effective minimum size). Y', relative yield per recruit, is tabulated extensively by Beverton and Holt (1966) for combinations of C, E, and Q. Their range of values, however, is not sufficient for this study so that a computer program, YPER, was written to compute Y' for values of C, E, and Q. With this approach, the effects of wide ranges in the parameter estimates can be examined. Two hypotheses were examined: (1) the bluefin tuna of the western north Atlantic were assumed to be a single stock and that F, X, and Z estimates (Table 19) of Lenarz et al. (MS, 1972b) are reasonably accurate; and (2) the bluefin tuna of the Atlantic were assumed to be a single stock.

The range of estimated values for the various parameters under hypothesis 1 are as follows: F = 0.223-0.795, X = 0.396-1.264, and Z = 0.619-1.776 (Table 19), K = 0.05-0.09 and L_∞ = 355.8-540.0 from Mather and Schuck (1960), Mather and Jones (MS, 1972), and Rodriguez-Roda (1971). Using our most reasonable parameter estimates of K = 0.05, X = 0.821, and Z = 1.280 (average of Lenarz et al's. estimates), a reasonable range for E and Q was established by allowing either the numerator or denominator of the ratio to be one of our most reasonable estimates. Therefore,

$E = 0.17\text{-}0.74$ and $Q = 7.92\text{-}25.28$ are the ranges, and $E = 0.36$ and $Q = 16.42$ are the point estimates. Table 21 contains optimal values of l_r for the ranges in E, Q, and L_∞; the underlined value in the center of Table 21 is the most likely value of the optimal length at first capture, about 46 cm (2.1 kg), for the mortality rates estimated for 1964-68. Using the widest range in our parameter estimates, the range for l_r is about 17 cm ($E = 0.15$, $M/K = 26.0$, $L_\infty = 355.8$) to 133 cm ($E = 0.75$, $M/K = 8.0$, $L_\infty = 540.0$). If, for the moment, we assume that recruitment is knife-edged at 40 cm (1.4 kg) which is the current absolute minimum size at recruitment, and that the fishery could be regulated such to obtain knife-edged recruitment at any desired size, then by decreasing l_r from 40 to 17 cm (0.1 kg), on one hand, we estimate a 39% increase in the yield per recruit, but, on the other hand, if we increase l_r from 40 to 133 cm (46.7 kg) we estimate a 208% increase in yield per recruit. Taking our most reasonable estimate of 46 cm, raising l_r from 40 cm would provide only about a 1% increase in yield per recruit. With the apparent paradox emanating from the range in our parameter estimates, we can offer no general solution as to which way the size at recruitment should be shifted under hypothesis 1 to obtain the best yield per recruit.

The effective minimum length at recruitment is currently about 70 cm (7.2 kg; average for 1965-70, Table 20) for the western Atlantic fisheries. To obtain an optimum yield per recruit with our most reasonable estimates of K, L_∞, Z and X, a reduction in the effective minimum size to 46 cm would be required. The increase in yield per recruit is about 18%. If a minimum length of 78 cm (10 kg) is imposed on the fisheries, the yield per recruit would decrease about 6%.

Table 21. Optimum lengths at recruitment as a function of the exploitation rate and M/K for three values of L_{∞}

TABLE OF OPTIMUM LENGTHS AT FIRST CAPTURE -- L(INFINITY) = 0.355800E 02

	EXPLOITATION RATE									
M/K	0.15	0.20	0.25	0.30	0.35	0.40	0.50	0.60	0.70	0.75
8.000	45.14	51.88	55.95	60.40	64.11	67.96	74.72	80.41	85.30	87.53
10.000	35.07	41.05	47.32	50.18	55.15	57.64	62.92	67.96	72.23	74.01
12.000	33.04	37.90	40.22	44.12	47.69	49.81	54.44	58.71	62.62	64.04
14.000	29.82	32.73	35.34	38.75	41.53	43.76	48.03	51.95	55.15	56.57
16.420	25.26	28.46	31.31	34.14	35.65	38.43	41.38	45.54	48.39	49.46
18.000	23.42	26.33	29.14	31.31	33.40	35.58	39.14	41.98	44.49	45.90
20.000	21.15	24.14	25.60	28.92	30.95	32.34	35.57	38.43	40.92	41.98
22.000	19.57	22.06	24.55	26.33	28.45	29.85	32.73	35.22	37.36	38.43
24.000	18.15	20.64	22.42	24.55	26.33	27.75	30.24	32.73	34.87	35.58
26.000	16.72	18.21	20.30	22.77	24.65	25.62	28.11	30.24	32.39	33.09

TABLE OF OPTIMUM LENGTHS AT FIRST CAPTURE -- L(INFINITY) = 0.447900E 02

	EXPLOITATION RATE									
M/K	0.15	0.20	0.25	0.30	0.35	0.40	0.50	0.60	0.70	0.75
8.000	56.28	64.65	70.32	75.14	81.07	85.55	94.06	101.23	107.50	110.18
10.000	47.41	54.20	59.57	64.05	68.42	72.56	79.28	85.55	90.62	93.16
12.000	41.65	46.58	51.51	56.54	60.22	62.71	68.51	73.90	78.83	80.62
14.000	36.38	41.21	45.24	48.82	52.25	55.09	60.47	65.39	69.42	71.22
16.420	31.10	35.23	39.47	43.05	46.13	48.37	52.55	57.33	60.91	62.26
18.000	29.56	33.14	36.71	39.42	42.55	44.79	49.27	52.85	55.59	57.78
20.000	26.67	30.46	33.58	36.24	38.97	40.76	44.70	48.37	51.51	52.85
22.000	24.63	27.77	30.91	33.14	35.43	37.62	41.21	44.34	47.03	48.37
24.000	22.84	25.98	28.22	30.91	33.14	34.94	38.07	41.21	43.89	44.79
26.000	21.05	24.19	26.43	28.67	30.91	32.25	35.39	38.07	40.76	41.65

TABLE OF OPTIMUM LENGTHS AT FIRST CAPTURE -- L(INFINITY) = 0.540000E 02

	EXPLOITATION RATE									
M/K	0.15	0.20	0.25	0.30	0.35	0.40	0.50	0.60	0.70	0.75
8.000	68.58	77.22	84.72	91.80	98.82	103.14	113.40	122.04	127.60	132.84
10.000	57.78	65.34	71.82	77.22	82.70	87.48	95.58	103.14	109.62	112.32
12.000	50.22	56.16	62.10	66.96	72.36	75.60	82.62	89.10	95.04	97.20
14.000	43.74	49.68	54.54	58.86	63.72	66.42	72.90	78.84	83.70	85.86
16.420	35.10	43.20	47.52	51.84	55.62	59.32	63.72	69.12	73.44	75.06
18.000	35.64	39.96	44.28	47.52	51.30	54.00	59.40	63.72	67.50	69.66
20.000	32.40	36.72	40.50	43.74	46.98	49.14	54.00	58.32	62.10	63.72
22.000	29.70	33.48	37.26	39.96	43.20	45.36	49.68	53.46	56.70	58.32
24.000	27.54	31.32	34.02	37.26	39.96	42.12	45.90	49.68	52.92	54.00
26.000	25.38	29.16	31.86	34.56	37.26	38.88	42.66	45.90	49.14	50.22

Under hypothesis 2 a different approach was taken with regard to the estimates of mortality parameters. Beverton and Holt (1959) examined the ratio of M to K for a number of species and concluded that a common ratio may exist within related species groups. A species related to Atlantic bluefin tuna, for which reasonable estimates of M and K have been made, is the yellowfin tuna of the eastern Pacific with an M/K on the order of 2. With M/K of about 2 and K of 0.05-0.09, M is 0.1-0.2, which seems reasonable for a species like bluefin tuna that lives 14+ years. Ranges for M = 0.1-0.2 and K = 0.05-0.09 give Q = 1.11-4.00. An estimate of a reasonable range for E is difficult since we have no estimates of F or Z on an ocean-wide basis. We chose, therefore, to compute l_r for E in the range of 0.1-1.0.

Table 22 gives the optimal values of l_r for the ranges in E, Q, and L_∞. The estimates of l_r range from 62 cm (E = 0.1, M/K = 4.0, L_∞ = 355.8) to 405 cm (E = 1.0, M/K = 1.0, L_∞ = 540.0); all values are above 40 cm, the current absolute minimum length, and 60 cm (4.6 kg), the current effective minimum length. If we again initially assume that the fishery has knife-edged recruitment at 40 cm, then increasing l_r from 40 to 62 cm (5.1 kg) would increase the yield per recruit by 1% and to 405 cm (1186 kg) would increase the yield per recruit over 300 fold. Taking our most reasonable estimates Q = 2.0 and L_∞ = 447.9 cm, though, this range in increase of yield per recruit is reduced; with E = 0.1-0.7 the increase in yield per recruit is 2% (E = 0.1) to 225% (E = 0.7). Similarly, with our current effective minimum length of 60 cm (Table 20) for the entire Atlantic fisheries and our most reasonable parameter estimates, the maximum increase in yield per recruit ranges from 1% (E = 0.1, M/K = 2.0, L_∞ = 447.9) to 169% (E = 0.7, M/K = 2.0, L_∞ = 447.9). Increasing the minimum length to 78 cm (10 kg), results in about 1% (E = 0.1) to about a 100% (E = 1.0) increase in yield per recruit.

Table 22. Optimal lengths at first capture as a function of the exploitation rate and M/K for three values of L_∞.

TABLE OF OPTIMUM LENGTHS AT FIRST CAPTURE -- L(INFINITY) = 0.355800E 03

	EXPLOITATION RATE									
M/K	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
1.000	114.92	148.37	172.21	191.42	207.79	222.38	235.18	246.93	257.24	266.85
1.500	100.34	130.22	151.93	169.36	184.30	197.11	208.85	219.53	228.78	237.32
2.000	88.95	115.99	135.92	151.93	165.45	177.19	187.86	197.47	206.01	213.48
2.500	80.06	104.96	122.75	137.69	150.15	161.18	170.78	179.32	187.15	193.91
3.000	72.94	95.71	112.43	125.95	137.34	147.66	156.55	164.38	171.50	177.90
3.500	66.89	87.88	103.54	115.99	126.66	135.92	144.45	151.93	158.33	164.38
4.000	61.55	81.48	95.71	107.45	117.41	126.31	134.14	140.90	146.95	152.64

TABLE OF OPTIMUM LENGTHS AT FIRST CAPTURE -- L(INFINITY) = 0.447900E 03

	EXPLOITATION RATE									
M/K	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
1.000	144.67	186.77	216.78	240.97	261.57	279.94	296.06	310.84	323.83	335.93
1.500	126.31	163.93	191.25	213.20	232.01	248.14	262.92	276.35	288.00	298.75
2.000	111.98	146.02	171.10	191.25	208.27	223.05	236.49	248.58	259.33	268.74
2.500	100.78	132.13	154.53	173.34	189.01	202.90	214.99	225.74	235.60	244.11
3.000	91.82	120.49	141.54	158.56	172.89	185.88	197.08	206.93	215.89	223.95
3.500	84.21	110.63	130.34	146.02	159.45	171.10	181.85	191.25	199.32	206.93

TABLE OF OPTIMUM LENGTHS AT FIRST CAPTURE -- L(INFINITY) = 0.540000E 03

	EXPLOITATION RATE									
M/K	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
1.000	174.42	225.18	261.36	290.52	315.36	337.50	356.94	374.76	390.42	405.00
1.500	152.28	197.64	230.58	257.04	279.72	299.16	316.98	333.18	347.22	360.18
2.000	135.00	176.04	206.28	230.58	251.10	268.92	285.12	299.70	312.66	324.00
2.500	121.50	159.30	186.30	208.98	227.88	244.62	259.20	272.16	284.04	294.30
3.000	110.70	145.26	170.64	191.16	208.44	224.10	237.60	249.48	260.28	270.00
3.500	101.52	133.38	157.14	176.04	192.24	206.28	219.24	230.58	240.30	249.48
4.000	93.42	123.66	145.26	163.08	178.20	191.70	203.58	213.84	223.02	231.66

The general conclusion is that any increase in the minimum size would likely increase yield per recruit provided the assumption that a constant rate of fishing mortality is applied to the entire life span of the bluefin tuna subsequent to recruitment is fulfilled.

Ricker Model of Yield Per Recruit

Another classical approach of analyzing the effects of changes in fishing intensity and/or changes in size at recruitment is with the Ricker yield per recruit model (Ricker, 1958). We used our best estimates of growth (Mather-Jones curve), fishing intensity (or F) of 0.1-2.5, and M = 0.1 and 0.8.

With the two-stock hypothesis, and an M of 0.8 and F = 0.5 (Table 19) for the western stock, the optimum yield per recruit is with an age at recruitment below 1 year (57 cm or 4.1 kg)--Figure 23. That is, if the western fisheries operated in a knife-edge fashion and exploited all ages starting with the youngest fish available, the maximum yield per recruit would accrued. The fisheries currently exploits fish 40 cm long (about 3 months old) and larger, with an effective minimum length at recruitment of 70 cm (age 1.6 years). Decreasing the current effective minimum length of 70 cm to, say, 40 cm would result in about 10% increase in yield per recruit. On the other hand, an increase in effective minimum length to 78 cm (10 kg or age 2) results in a very small decrease in yield per recruit. If we consider only the Canadian-U.S.A. purse seine fishery, however, an increase in the effective length at recruitment from the current 59 cm (age 1.1) to 78 cm, would decrease yield per recruit as much as 16%.

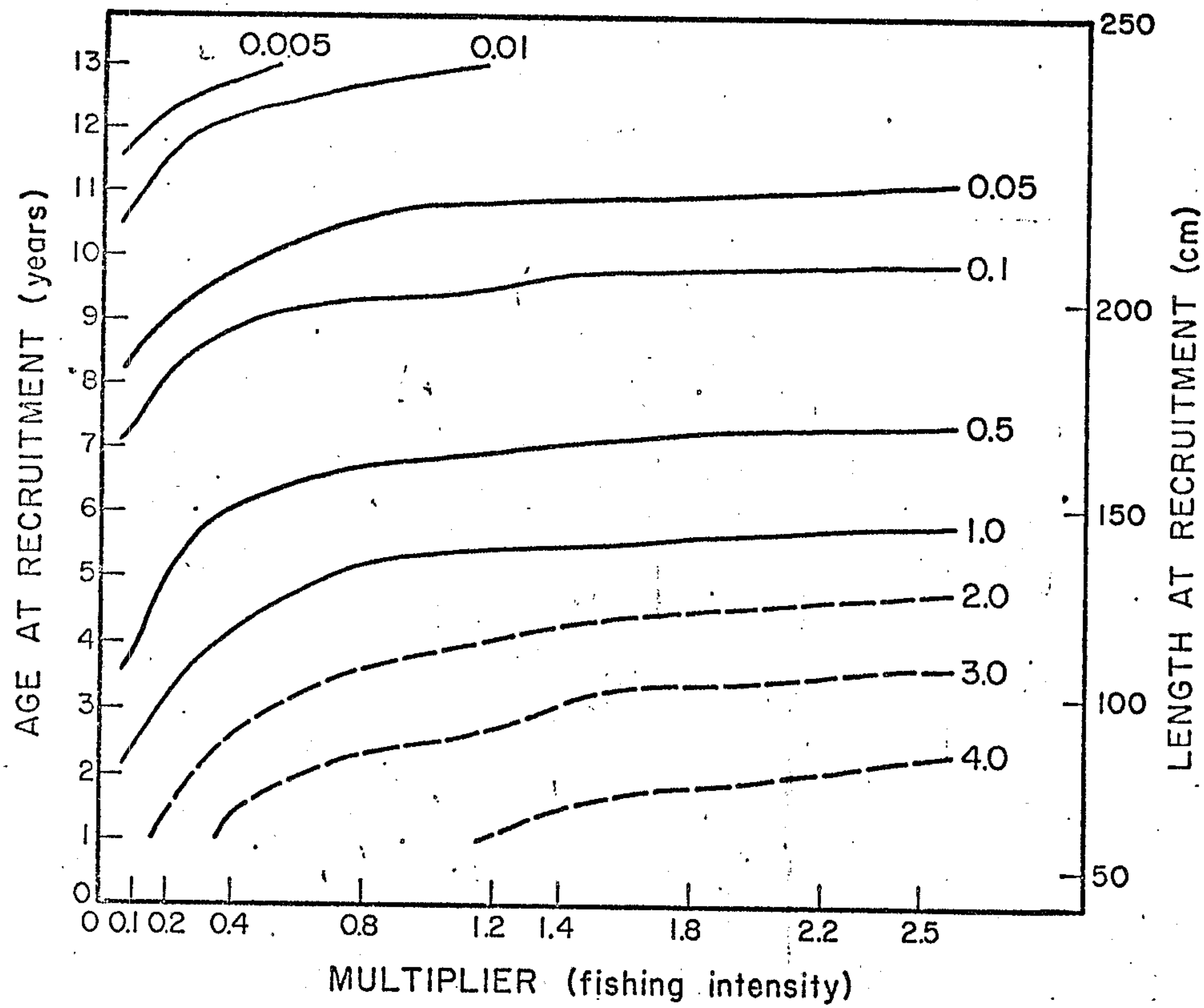

Figure 23. Yield per recruit (kg) isopleths for Atlantic bluefin tuna when M = 0.8. Estimates are based on the Ricker model

With the one stock hypothesis, M is probably 0.1 and F is unknown, but perhaps equal to 1.0, based on estimates of Z from the Canadian-U.S.A. purse seine fishery (Table 18). The optimum yield per recruitment in this case is obtained with an age at recruitment of about 10 years (206 cm or 166 kg)--Figure 24. The current effective minimum length at recruitment is 60 cm (age 1.1) for the entire Atlantic fisheries. If the length at recruitment is increased from 60 to 206 cm, yield per recruit would increase by 529%. With a more modest increase in the current effective length to 78 cm (age 2 years), yield per recruit increases by about 64%.

These results indicate that depending on the stock structure of bluefin tuna, yield per recruit can increase or decrease if the size at recruitment is altered from the current levels. It is also evident from the results, that by increasing fishing effort with M = 0.1 or 0.8, there is little gain in yield per recruit unless the size at recruitment is also altered.

Size-Specific F Model of Yield Per Recruit

Analysis of yield per recruit utilizing size-specific F has been described by Joseph and Tomlinson (MS, 1972) and Lenarz et al. (MS, 1972a) for Atlantic yellowfin tuna. We used this approach for Atlantic bluefin tuna.

Size-specific F's were estimated from average (1965-70) length composition (by 10-cm groupings) of the catch (Table 23). Because the reported catches of bluefin tuna by Argentina and Cuba are suspect, for reasons stated in an earlier section, we

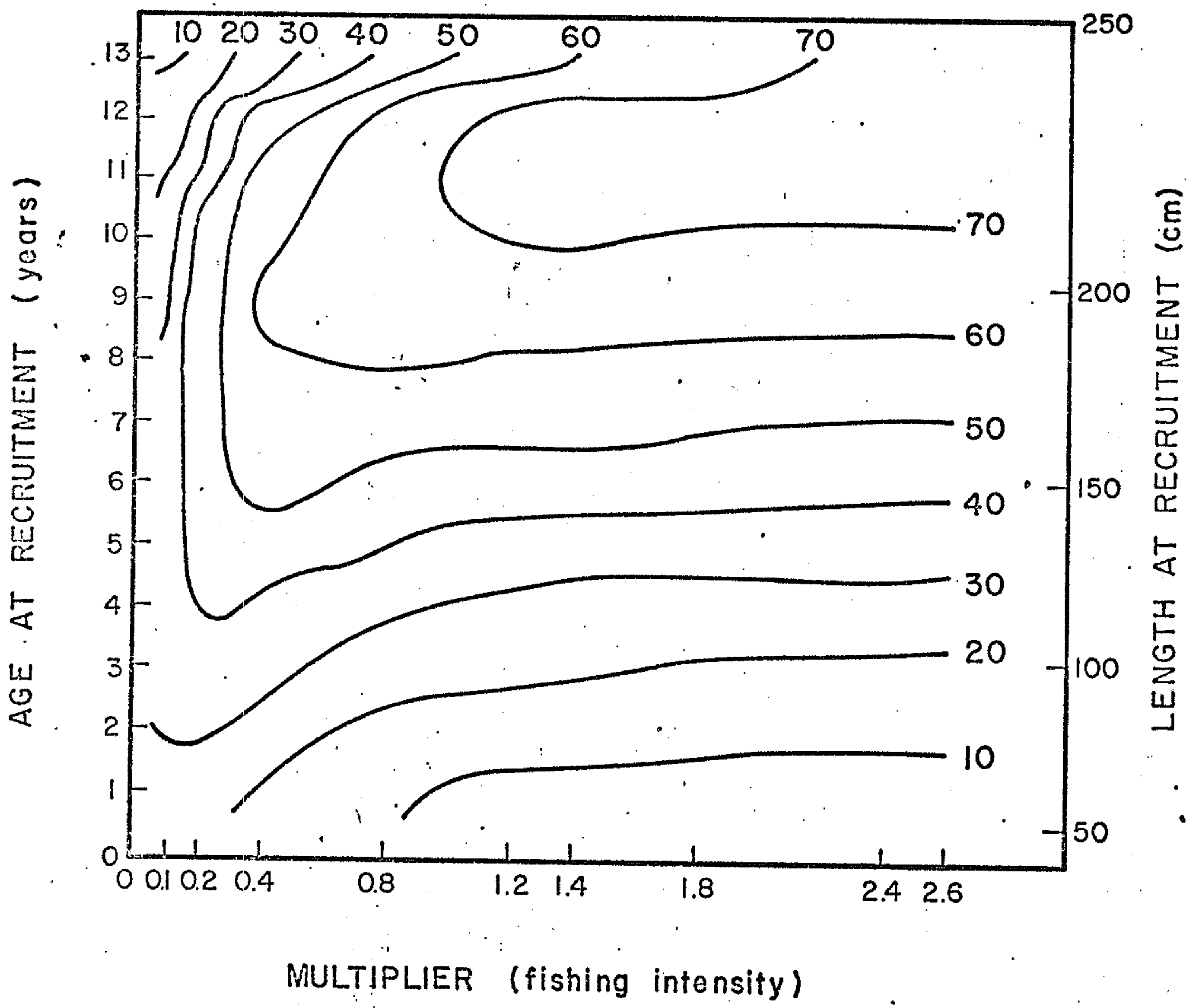

Figure 24. Yield per recruit (kg) isopleths for Atlantic bluefin tuna when M = 0.1. Estimates are based on the Ricker model

Table 23. Average, 1965-70, size composition of the catch of bluefin tuna from the western Atlantic and entire Atlantic fisheries by gear

Length Interval	Western Atlantic				Entire Atlantic			
	Purse Seine	Sport	Others	Total	Purse Seine, Live bait and troll	Sport	Others	Total
40	481	114		595	3,792	114	3	3,909
50-59	30,503	7,932		38,435	250,728	7,932	24	258,684
60	8,167	2,050		10,217	70,269	2,050	21	72,340
70	48,567	6,344		54,911	292,045	6,344	93	298,482
80	22,806	1,773	1	24,580	117,884	1,773	18	119,675
90	24,781	1,360	-	26,141	114,136	1,360	-	115,496
100-109	13,593	2,545	-	16,138	85,600	2,545	12	88,157
110	2,608	399	2	3,009	14,020	399	21	14,440
120	3,753	267	214	4,234	15,081	267	256	15,604
130	1,597	153	16	1,766	6,565	153	95	6,813
140	1,918	198	14	2,130	8,030	198	222	8,450
150-159	866	58	244	1,168	3,139	58	611	3,808
160	325	18	54	397	1,044	18	615	1,677
170	161	8	278	447	451	8	926	1,385
180	189	21	455	665	763	21	1,349	2,133
190	43	7	1,469	1,519	232	7	2,840	3,079
200-209	53	7	3,947	4,007	78	7	5,710	5,795
210	58	26	2,984	3,068	58	26	4,949	5,033
220	64	98	3,253	3,415	64	98	5,738	5,900
230	64	158	2,527	2,749	64	158	5,686	5,908
240	48	177	271	496	48	177	3,067	3,292
250-259	43	75	603	721	43	75	2,453	2,571
260	22	31	117	170	22	31	812	865
270	6	12	39	57	6	12	189	207
280	1	5	7	13	1	5	26	32
Total	160,717	23,836	16,495	201,048	984,163	23,836	35,736	1,043,735

performed analyses with and without the Argentina and Cuban data. Computer runs were made with M = 0.1, 0.2, 0.6, and 0.8, and with (1) the average length composition of fish caught in only the western Atlantic (Table 23), and (2) the average length composition of fish caught in the entire Atlantic (Table 23, and Figure 25).

With M = 0.6 or 0.8 we were unable to obtain reasonable estimates of size-specific F's for the western Atlantic fisheries. The criteria used to judge whether the estimates were reasonable were by comparing the estimates with the exploitation rates (E) estimated by Mather et al. (MS, 1972): E = 0.2 for a single season's returns and E of about 0.3 for all season's returns for bluefin tuna ages 2-4 years (78-115 cm) caught in the New England fisheries. The revealing features of our results are that the estimates of X by Mather et al (MS, 1972) are probably unrealistic estimates of the combined effects of natural mortality and emigration ($X \approx 0.8$), and that their estimates of exploitation rates are too low.

With M = 0.2 we were also unable to obtain a reasonable fit of the catch data with rates of exploitation comparable to those of Mather et al. (MS, 1972). Our best results were with an initial F = 0.032 and F = 0.035 (Figure 26), which are low. On the other hand, with M = 0.1 a reasonable fit of the data was obtained with high F values (Figure 26) that agree with those estimated by Mather et al. The results

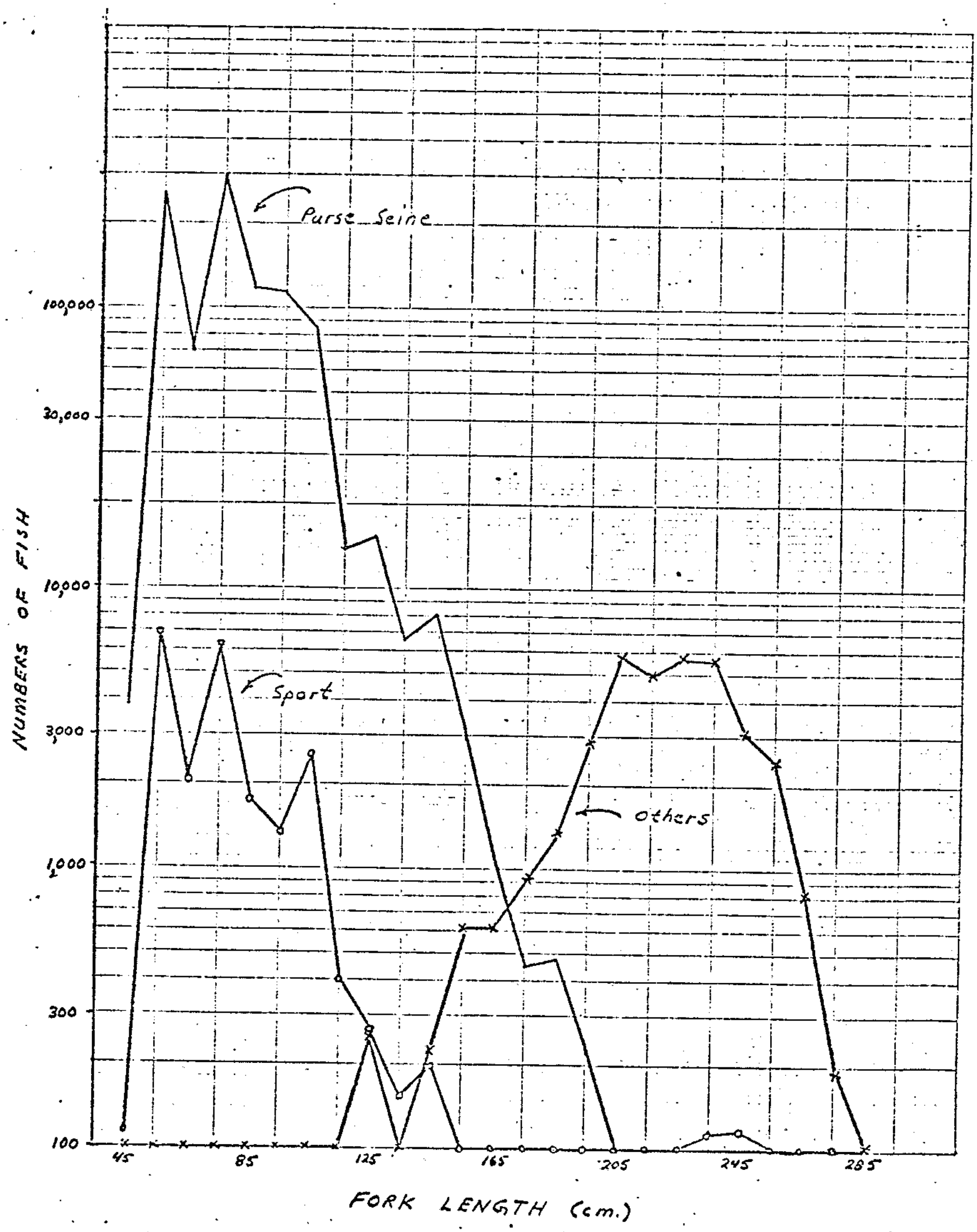

Figure 25. Average length composition, 1965-70, of the catch of bluefin tuna from the entire Atlantic Ocean.

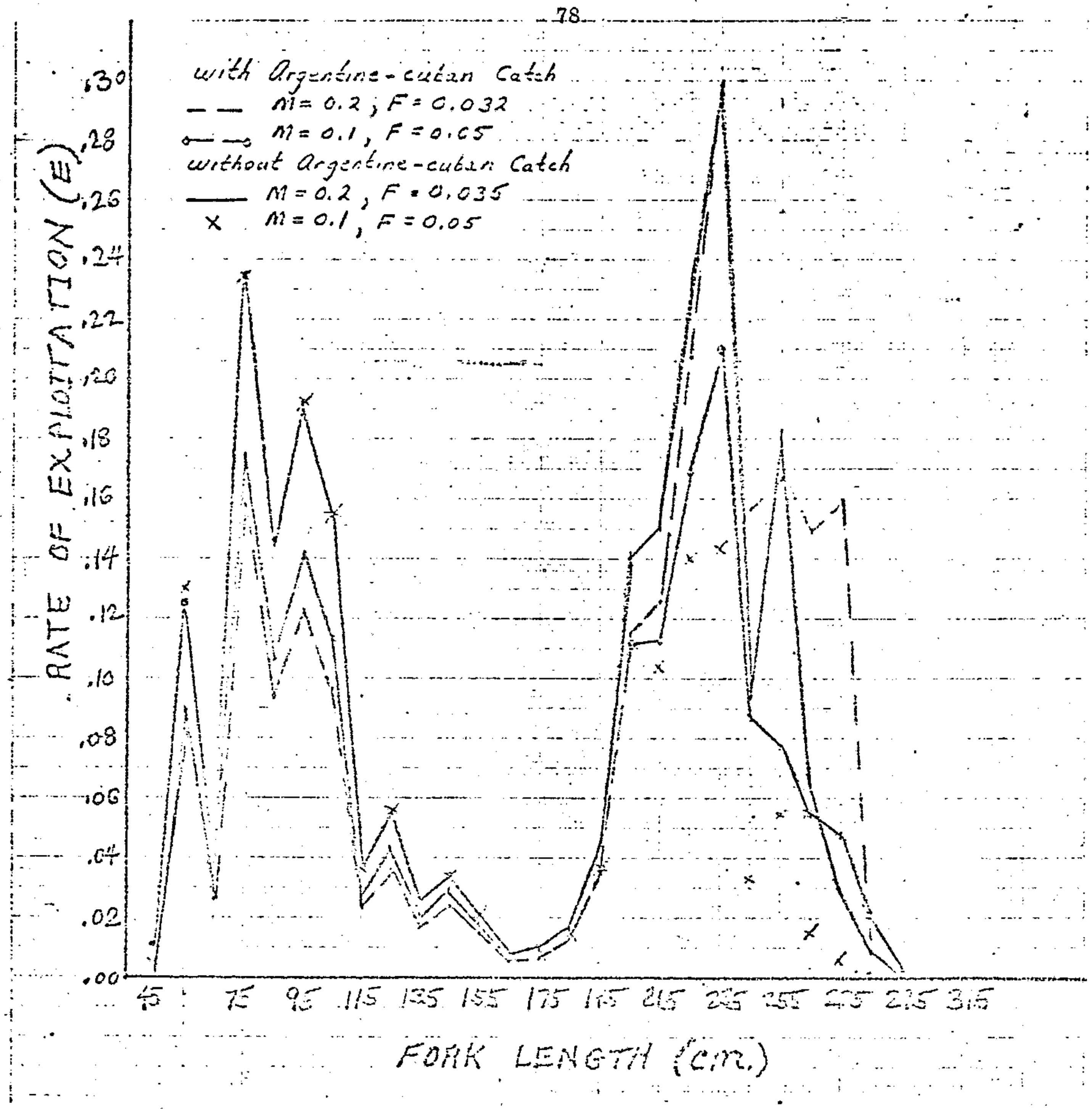

Figure 26. Estimates of size-specific rates of exploitation of bluefin tuna from the western Atlantic with M = 0.1 and M = 0.2.

were the same with and without inclusion of the Argentina-Cuban catches. Again, our results suggest that Mather et al's. estimates of X and F are questionable. Thus, our most reasonable estimates of size-specific F's are with M = 0.1 and initial F = 0.05.

The estimated size-specific F's with M = 0.1 and initial F = 0.05 for the western Atlantic fisheries (including Argentina-Cuban handline fisheries) were partitioned into F's for three types of gear (Figure 27) - (1) purse seine, (2) sport, or rod and reel, and (3) "other" - traps, harpoon, etc., - by proportion of catch. This division of types of gears was based on the fact that purse seiners catch primarily small fish (40-120 cm), rod and reel catch primarily small fish but also a fair amount of large (176-280 cm) fish, and all other gears catch primarily large fish. A notable feature of the size-specific F curves by gear is the low exploitation rate for bluefin tuna between 130 (5 years) and 190 cm (9 years) long. This feature may actually be an artifact, caused by variable year class strength, or the short time series of data we used in our analysis. Further analysis based on a longer series of data on the size composition of the catch is recommended.

Estimates of yield per recruit for the western Atlantic were made with M = 0.1 and 0.2 and our most reasonable estimates of size-specific F's. An examination of the results with respect to effective size at recruitment indicated that the relative values of yield per recruit depended little on whether the Argentina-Cuban data were

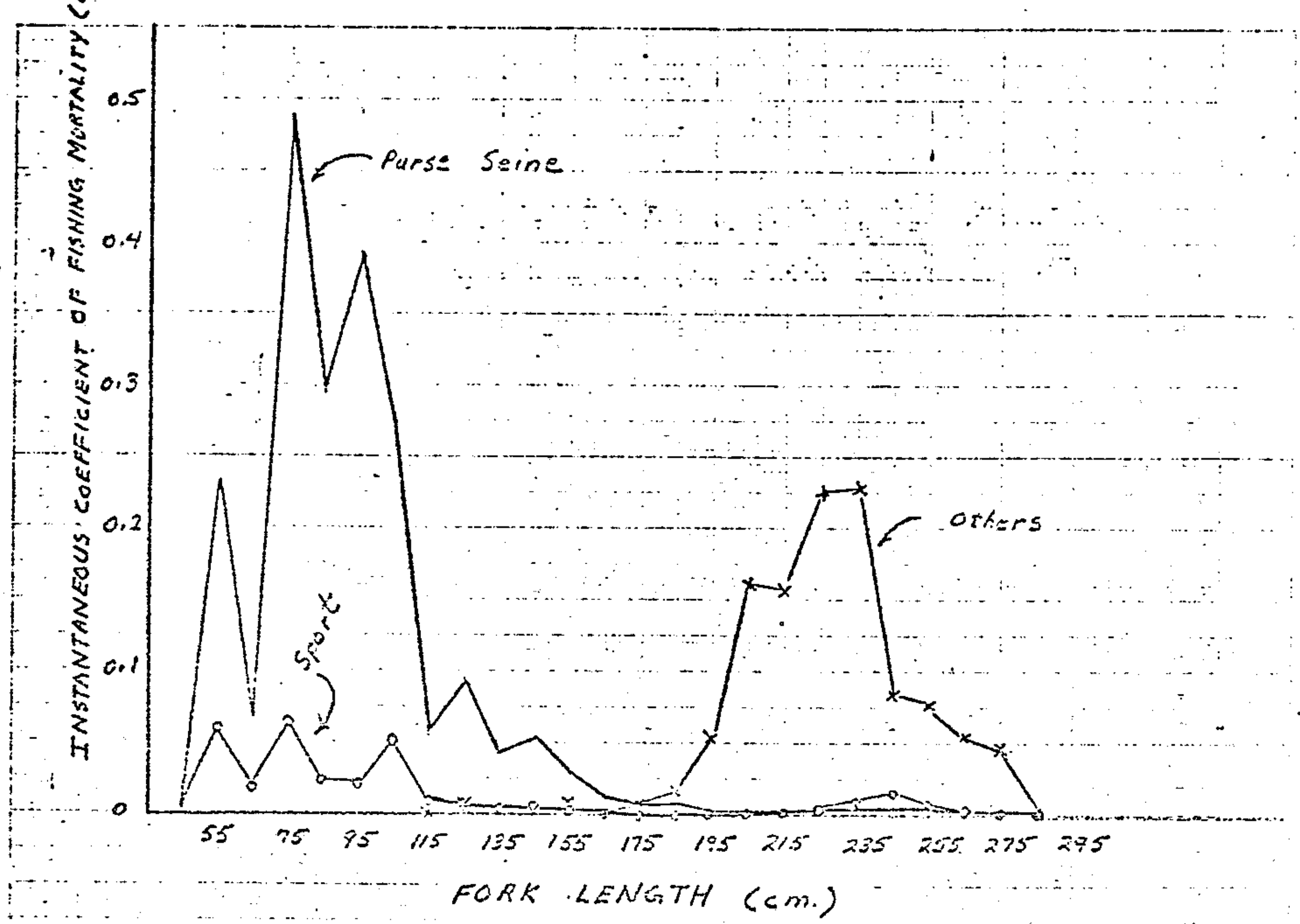

Figure 27. Estimates of size-specific F for bluefin tuna caught by three types of gears in the western Atlantic. Estimates are based on M = 0.1 and initial F = 0.05.

included (Figure 28). Our subsequent analyses, therefore, included data from the Argentina-Cuban fishery. The results with both M = 0.1 and 0.2 indicate that a substantial increase in yield per recruit can be obtained for the western Atlantic fisheries as a whole with increase in the effective size at recruitment. The change in yield per recruit by types of gear, with increase in effective size at recruitment is shown in Figure 29. An increase in the effective size at recruitment is most beneficial to the "others" category of gear and to the sport fishery. These are the fisheries that exploit large bluefin tuna. Although a small increase in yield per recruit with increase in size at recruitment would also result for the purse seine fishery, any increase beyond about 80 cm (11 kg) long would produce a decrease in yield per recruit.

Since the average size of fish in the catch is important, especially to the sport fishery, it is instructive to examine the change in average size with alteration in the effective size at recruitment. In Figure 30 the results for the western fisheries are shown. They are based on a constant M = 0.1 and our most reasonable estimates of size-specific F. Average size of fish caught by "others" increase only slightly with increase in the effective size at recruitment. On the other hand, the average size of fish in the catch of purse seiners and sportsmen increases considerably with increase in the effective size at recruitment, beyond 70 cm long. For example, if we increase the effective length at recruitment from our current 59 cm for the Canadian-U.S.A. purse seine fishery to 78 cm (10 kg), the average weight of fish in the catch increases from 16 to 22 kg. We can demonstrate a similar

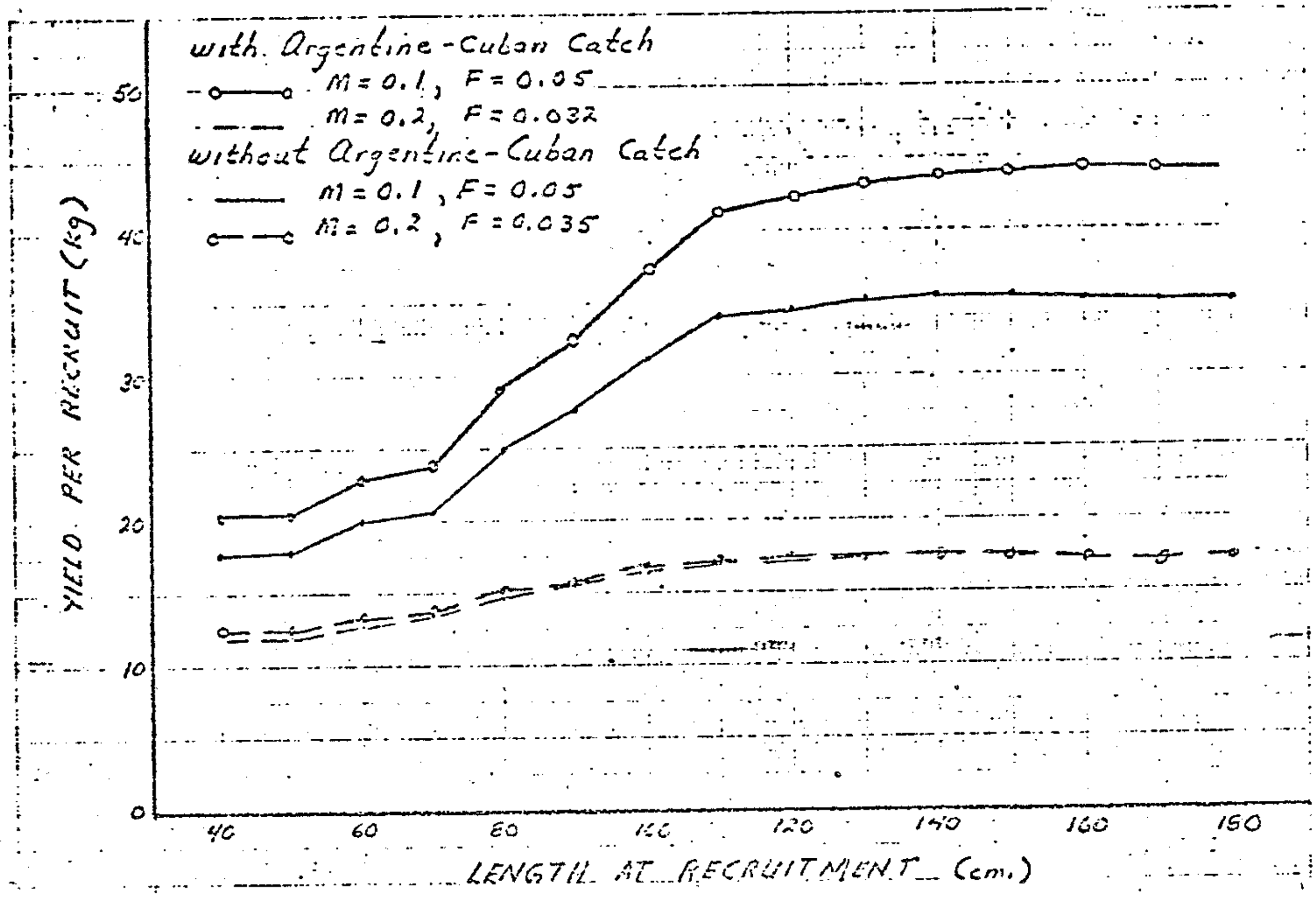

Figure 28. Yield per recruit of bluefin tuna from the western Atlantic as a function of length at recruitment. Four series of size-specific F's are used.

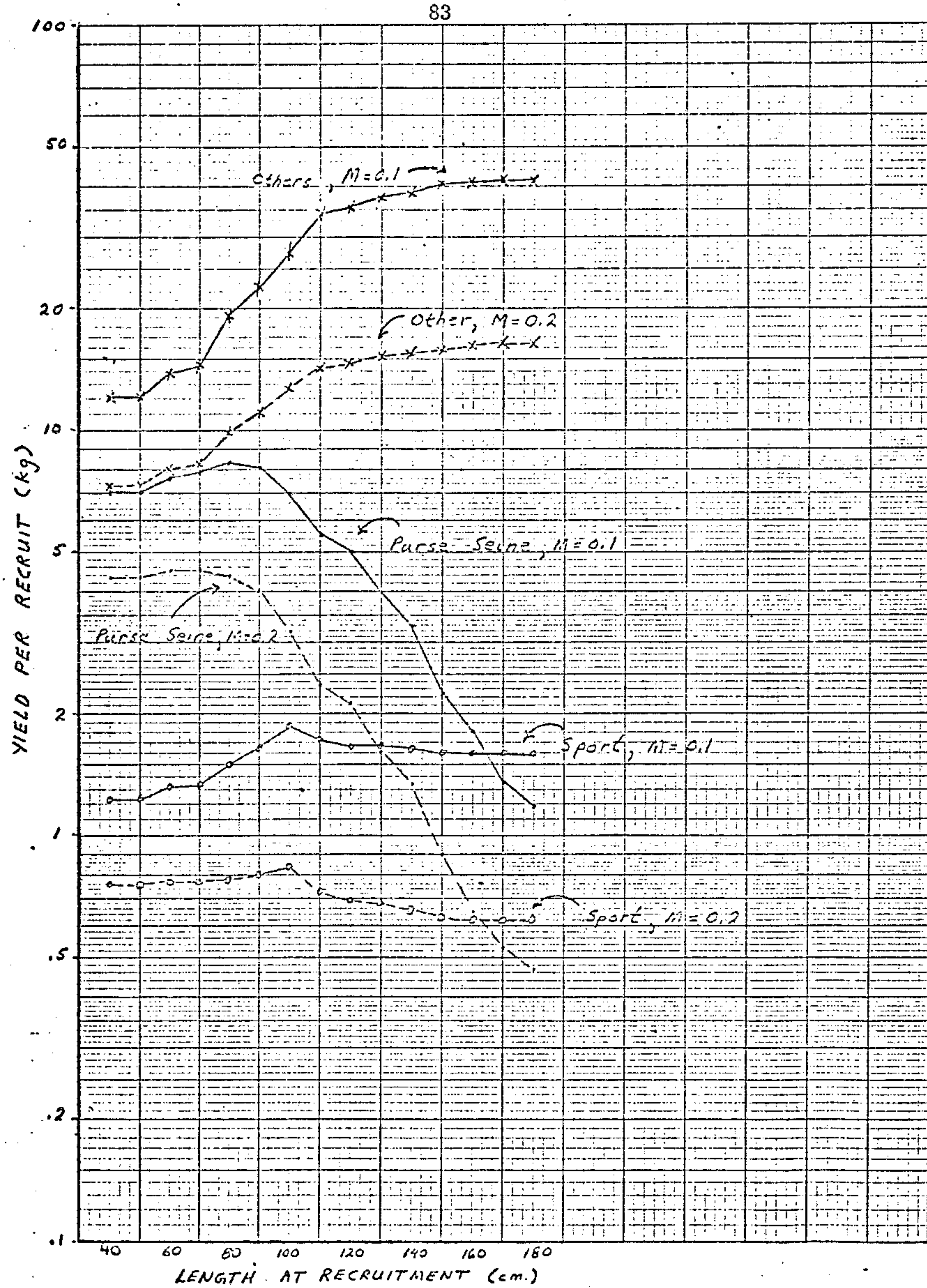

Figure 29. Yield per recruit of bluefin tuna from the western Atlantic as a

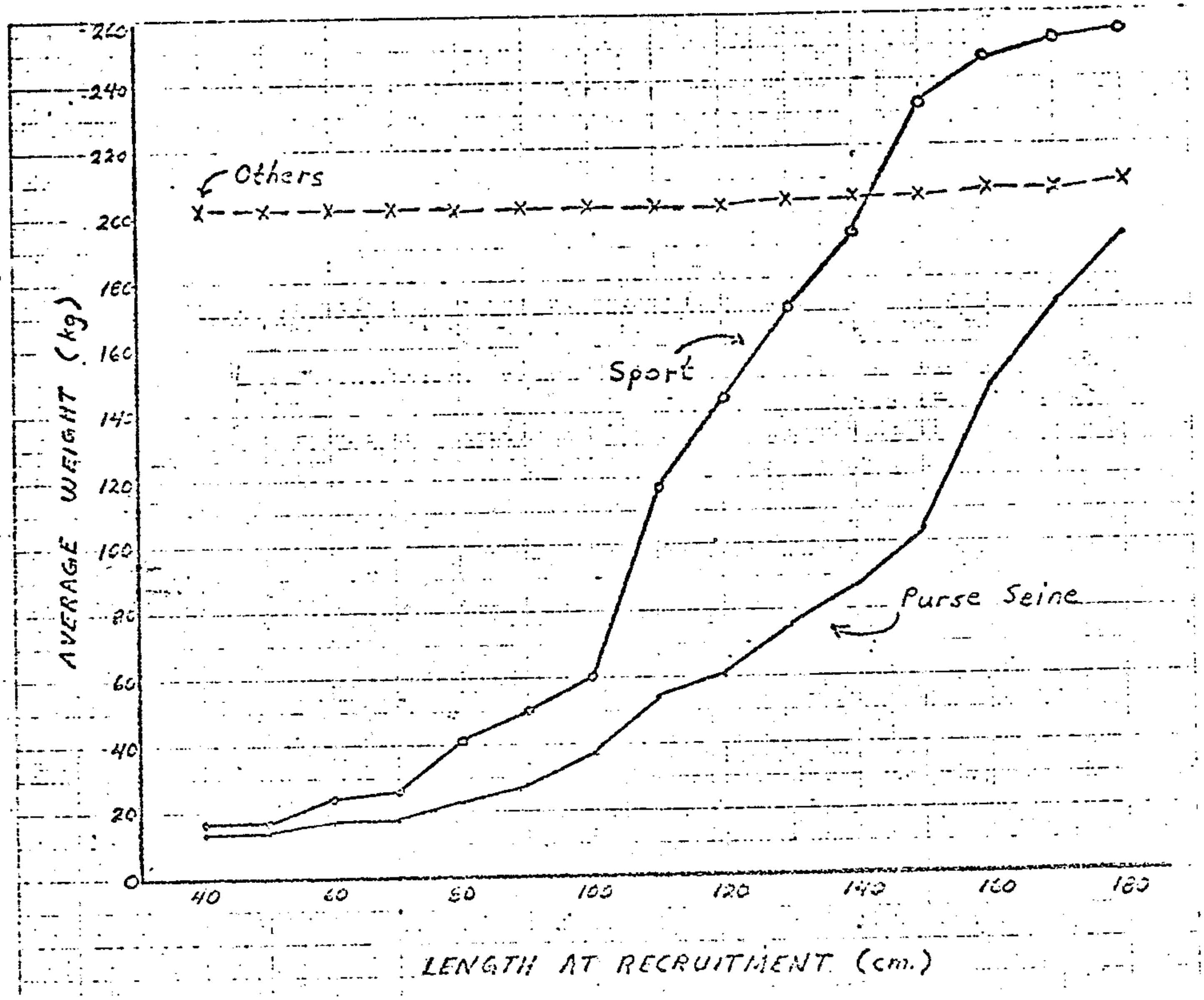

Figure 30. Average weights of bluefin tuna from the western Atlantic as a function of length at recruitment. Estimates are based on size-specific F's that were obtained with M = 0.01 and initial F = 0.05.

increase for the sport fishery. Thus, there appears to be some advantage in increasing the effective size at recruitment from the current level. We indicate, however, that for the purse seiner fleet and probably the majority of sportsmen who fish for small bluefin tuna, any significant increase in the effective size at recruitment would probably result in a decrease in yield per recruit to these users, unless, of course, these users shift their fishing effort onto large bluefin tuna. Presently, it is uncertain whether the purse seine fleet can make this shift, since there is no major domestic (Canadian or U.S.A) market for large bluefin tuna. It is also doubtful that the majority of sportsmen would make the shift, since sport fishing for large bluefin tuna is relatively expensive.

We also examined the effects, under current conditions of fishing intensity = 1 and effective length at recruitment of about 70 cm, on yield per recruit of increasing fishing intensity in the western Atlantic fisheries (Figure 31). With our reasonable estimates of size-specific F's and M (M = 0.1, F = 0.05) if fishing intensity is, say, doubled, yield per recruit decreases by about 35%. On the other hand, if fishing intensity is reduced from our current level to 0.5, there is no change in yield per recruit. The important conclusion from these results is that increasing fishing effort without increasing the size at recruitment would result in decrease in yield per recruit.

The average size composition of the catch of bluefin tuna caught in the entire Atlantic (Table 15) was utilized to estimate size-specific F's. With estimates of M = 0.1 and 0.2 we were able to obtain size-specific F's with a wide

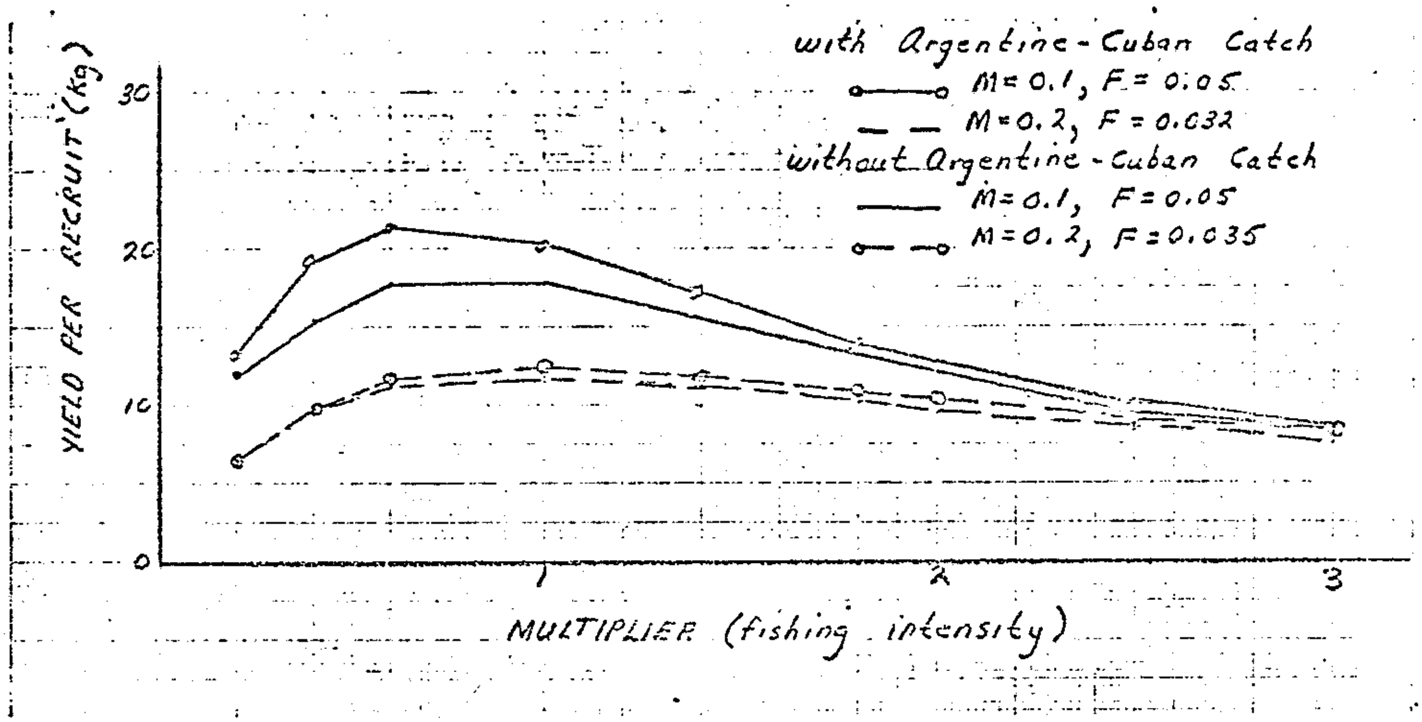

Figure 31. Yield per recruit of bluefin tuna from the western Atlantic as a function of fishing intensity. Estimates are based on current conditions in the western Atlantic fisheries, where effective length at recruitment is about 70 cm.

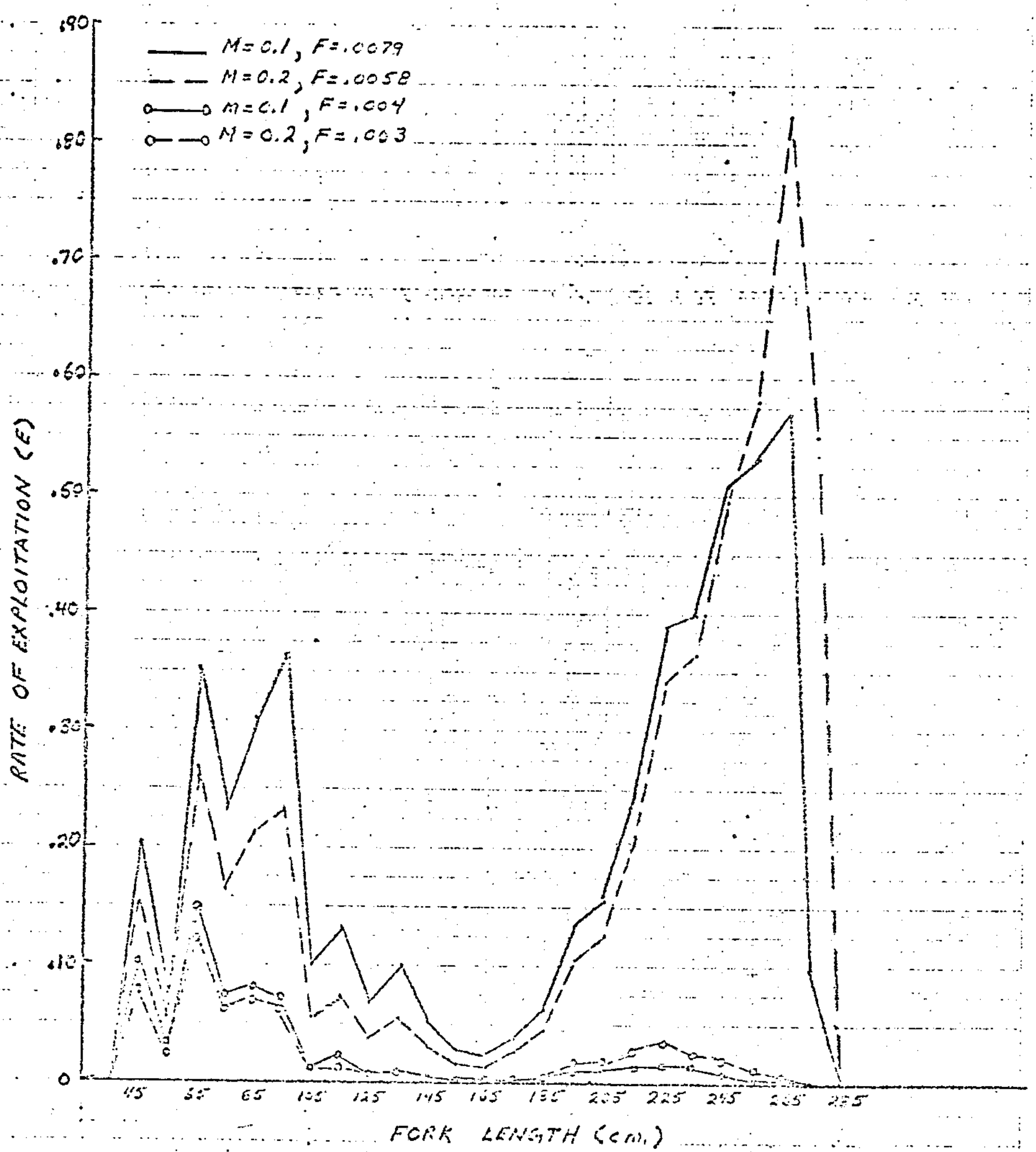

Figure 32. Estimates of size-specific rates of exploitation of bluefin tuna from the entire Atlantic.

range of initial F values. Since there is no estimate of exploitation rate of bluefin tuna on an Atlantic-wide basis, we were unable to select any one series of size-specific F's as most reasonable. However, we arbitrarily selected (1) the highest series and (2) a series with approximately half the values in the highest series for examination (Figure 32). With series 1, generally, yield per recruit increases with increase in size at recruitment (Figure 33). With series 2 the opposite effect occurs; yield per recruit decreases with increase in size at recruitment.

The effects of changes in fishing effort on yield per recruit was examined. Figure 34 shows yield per recruit as a function of fishing intensity with fishing intensity = 1 as the current level and effective length at recruitment of about 60 cm. The results indicate that there is little, if any, gain in yield per recruitment with increase in fishing effort. On the other hand, with size-specific F's of series 1 a decrease in fishing effort would result in a substantial increase in yield per recruit.

We caution the reader that this model assumes constant recruitment and our earlier analysis of age composition of the catch suggests that recruitment is variable.

DISCUSSION

Since 1965, there has been a downward trend in total catch of Atlantic bluefin tuna and the demise of several fisheries for large (176-280 cm) bluefin tuna. It has been suggested that the decline is attributable to increased exploitation of small bluefin tuna along the New England coast and in the Bay of Biscay and adjacent waters (Hamre, MS). Mather et al. (MS, 1972) and Lenarz et al. (MS, 1972b) have presented

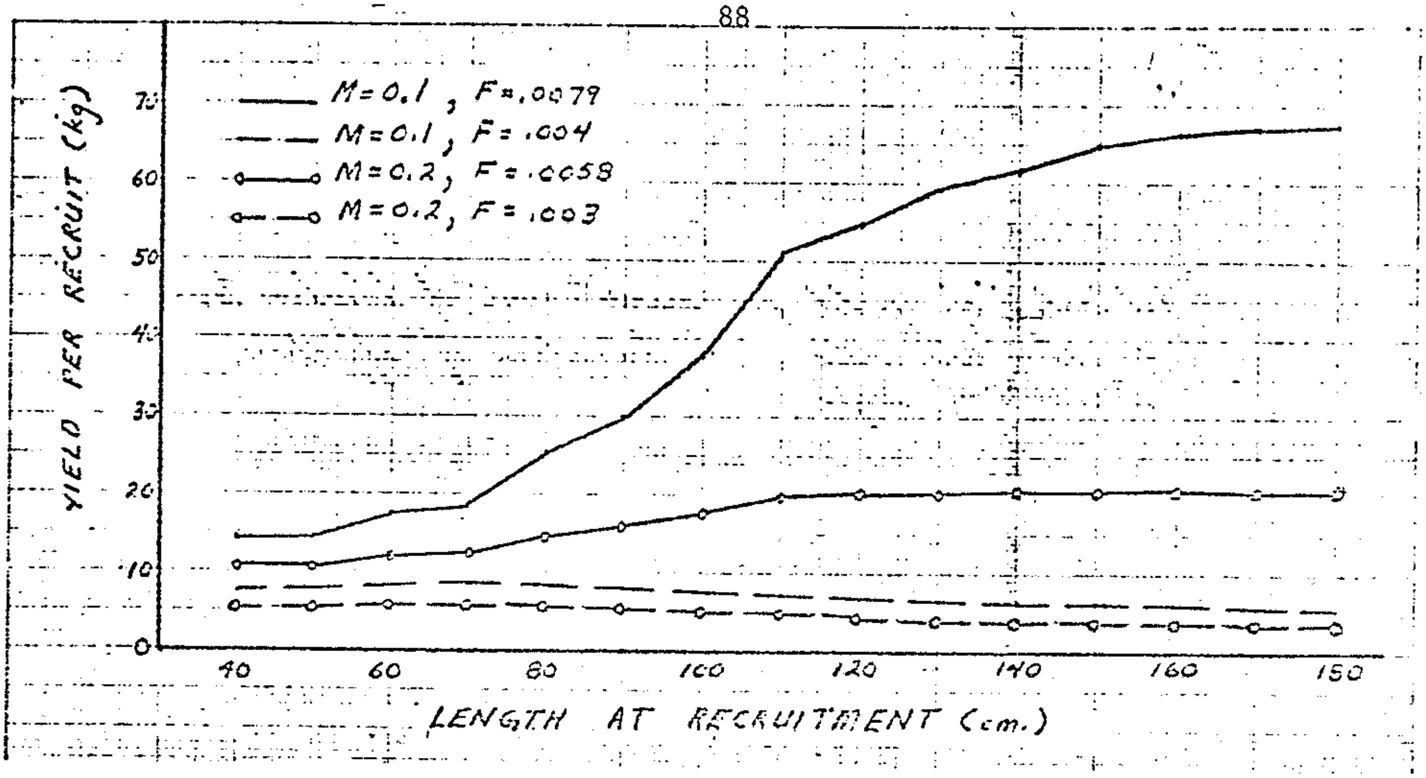

Figure 33. Yield per recruit of bluefin tuna from the entire Atlantic as a function of length at recruitment.

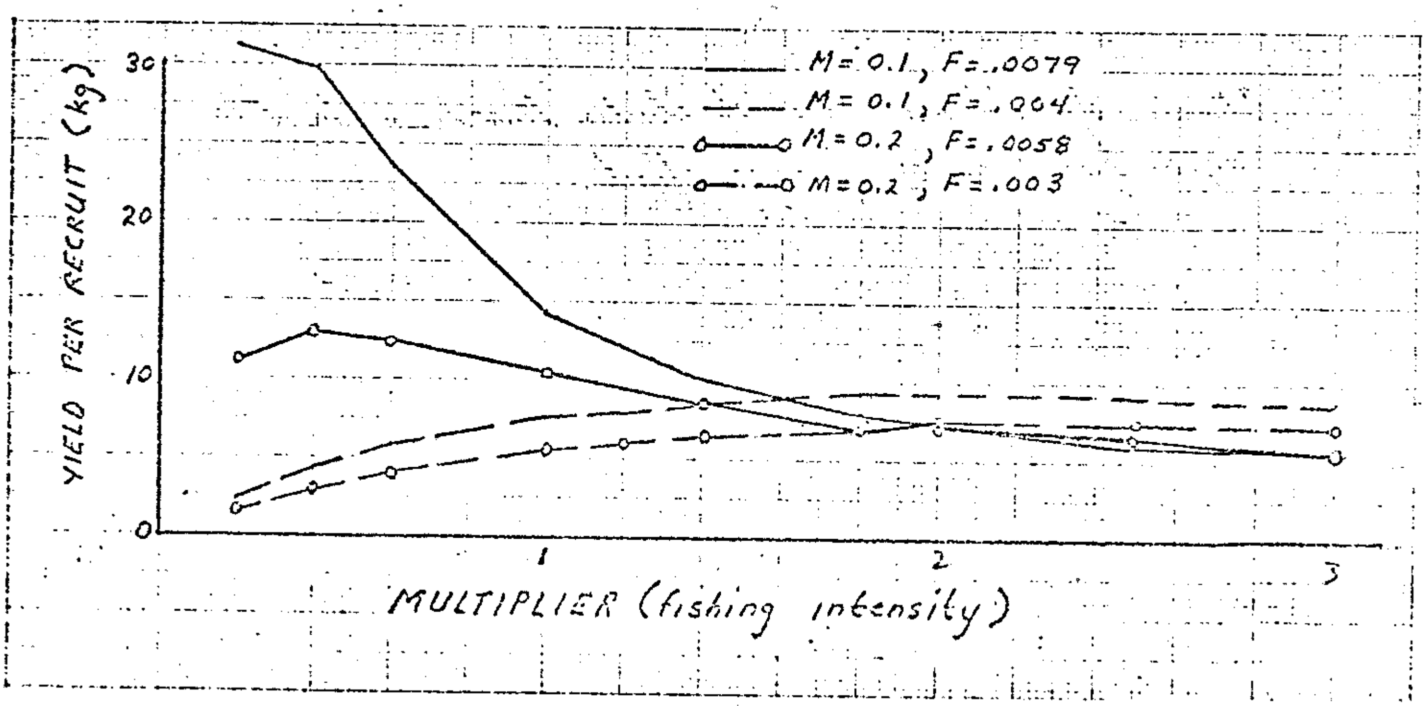

Figure 34. Yield per recruit of bluefin tuna from the entire Atlantic as a function of fishing intensity. The current level of fishing intensity = 1, and the effective length at recruitment is about 60 cm.

data that indicate the rate of exploitation of bluefin tuna ages 2-4 years in the New England fisheries has indeed increased from 0.281 in 1964 to at least 0.590 in 1968.

Our analyses of available data on Atlantic bluefin tuna indicate that the average size of fish in the fisheries for large bluefin tuna has increased and the catch rate has decreased. Based on data from the Canadian-U.S.A. purse seine fishery, it appears that the catch and the average size of fish caught by fisheries for small bluefin tuna has remained relatively stable. Evidently, then, the decline in the total Atlantic catch is due primarily to poor recruitment into the large fish fisheries.

There are several actions that can be taken to boost the production of bluefin tuna. Our study has examined two possible actions: (1) change in fishing effort, and (2) change in the size at recruitment. The results indicate that the appropriate action depends on the stock structure. If there are separate stocks in the Western and Eastern Atlantic, the results using the constant fishing mortality approach (simplified Beverton and Holt and Ricker models) with high values of X (e.g., 0.8) suggest that a loss in yield per recruit would occur if the effective size at recruitment is increased. However, the results with the size-specific F approach suggest that considerable gains could be made by increasing size at recruitment. The conflict in the results of the two approaches is probably caused by the high values of X used in the constant F approach. Lenarz et. al. (MS, 1972b) suggested that their estimate of X may include tagging mortality and thus may be too high. On the other hand, the results using size-specific F are dependent on the assumptions of constant recruitment, which is probably invalid. We can venture a guess that the real effects of increases in effective size at recruitment, if indeed there are two stocks in the Atlantic, lie between the results of the two approaches. If there is only one stock of bluefin tuna in the Atlantic, our results from both approaches suggest that gains in yield per recruit would be substantial if the effective size at recruitment is increased. However, we wish to point out that with recruitment probably quite variable, an increase in the effective size at recruitment should be considered jointly with any intended catch quota (see Lenarz et. al., 1972a).

Over a number of years there has been a considerable amount of studies on the Atlantic bluefin fisheries, but information on many of the components of the population dynamics of bluefin tuna is lacking (Table 24). If rational management of the fisheries is to be achieved, the quality and quantity of data on the fisheries must be improved.

Table 24. Status of available information on the population dynamics of Atlantic bluefin tuna. Rating is on a decreasing scale of adequate, poor and none.

Types of Information	Western Atlantic	Eastern Atlantic
Catch	Adequate	Adequate/poor
Effort	Poor	Poor
Size composition	Adequate	Poor
Subpopulations	Poor	Poor
Length-weight	Adequate	Adequate
Growth	Adequate	Adequate
Natural mortality	Poor	None
Fishing mortality	Poor	None
Size-specific F	Poor	Poor
Virtual population	Poor	None
Surplus production	Poor	Poor
Yield per recruit	Adequate	Adequate

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APPENDIX 1. LENGTH, WEIGHT, AND AGE OF BLUEFIN TUNA FROM THE ATLANTIC OCEAN

LENGTH		WEIGHT		AGE	
CM	IN	KG	LB	MO	YR
40.0	15.7	1.43	3.14	2.1	0.17
41.0	16.1	1.53	3.39	2.6	0.22
42.0	16.5	1.64	3.62	3.2	0.27
43.0	16.9	1.76	3.89	3.7	0.31
44.0	17.3	1.88	4.15	4.3	0.36
45.0	17.7	2.01	4.43	4.9	0.41
46.0	18.1	2.14	4.72	5.4	0.45
47.0	18.5	2.28	5.02	6.0	0.50
48.0	18.9	2.42	5.34	6.6	0.55
49.0	19.3	2.57	5.67	7.1	0.59
50.0	19.7	2.73	6.01	7.7	0.64
51.0	20.1	2.89	6.37	8.3	0.69
52.0	20.5	3.06	6.74	8.8	0.74
53.0	20.9	3.23	7.12	9.4	0.78
54.0	21.3	3.41	7.52	10.0	0.83
55.0	21.7	3.60	7.93	10.6	0.88
56.0	22.0	3.79	8.35	11.1	0.93
57.0	22.4	3.99	8.79	11.7	0.98
58.0	22.8	4.20	9.25	12.3	1.02
59.0	23.2	4.41	9.72	12.9	1.07
60.0	23.6	4.63	10.21	13.5	1.12
61.0	24.0	4.86	10.71	14.0	1.17
62.0	24.4	5.09	11.23	14.6	1.22
63.0	24.8	5.34	11.76	15.2	1.27
64.0	25.2	5.59	12.31	15.8	1.32
65.0	25.6	5.84	12.88	16.4	1.37
66.0	26.0	6.11	13.46	17.0	1.42
67.0	26.4	6.38	14.06	17.6	1.47
68.0	26.8	6.66	14.68	18.2	1.51
69.0	27.2	6.95	15.32	18.9	1.56
70.0	27.6	7.24	15.97	19.4	1.61
71.0	28.0	7.55	16.64	20.0	1.66
72.0	28.3	7.86	17.33	20.6	1.71
73.0	28.7	8.18	18.04	21.2	1.76
74.0	29.1	8.51	18.77	21.8	1.82
75.0	29.5	8.85	19.52	22.4	1.87
76.0	29.9	9.20	20.28	23.0	1.92
77.0	30.3	9.56	21.07	23.6	1.97
78.0	30.7	9.92	21.87	24.2	2.02
79.0	31.1	10.29	22.70	24.8	2.07
80.0	31.5	10.69	23.54	25.4	2.12
81.0	31.9	11.07	24.40	26.1	2.17
82.0	32.3	11.47	25.29	26.7	2.22
83.0	32.7	11.88	26.20	27.3	2.28

APPENDIX 1. LENGTH, WEIGHT, AND AGE OF BLUEFIN TUNA FROM THE ATLANTIC OCEAN—CONTINUED.

LENGTH		WEIGHT		AGE	
CM	IN	KG	LB	MO	YR
84.0	33.1	12.30	27.12	27.9	2.33
85.0	33.5	12.73	28.07	28.5	2.38
86.0	33.9	13.17	29.04	29.2	2.43
87.0	34.3	13.62	30.03	29.8	2.48
88.0	34.6	14.08	31.05	30.4	2.54
89.0	35.0	14.55	32.08	31.1	2.59
90.0	35.4	15.03	33.14	31.7	2.64
91.0	35.8	15.52	34.22	32.3	2.69
92.0	36.2	16.02	35.33	33.0	2.75
93.0	36.6	16.53	36.45	33.6	2.80
94.0	37.0	17.06	37.60	34.2	2.85
95.0	37.4	17.59	38.79	34.9	2.91
96.0	37.8	18.13	39.97	35.5	2.96
97.0	38.2	18.69	41.20	36.2	3.01
98.0	38.6	19.25	42.44	36.8	3.07
99.0	39.0	19.83	43.71	37.5	3.12
100.0	39.4	20.41	45.01	38.1	3.18
101.0	39.8	21.01	46.33	38.8	3.23
102.0	40.2	21.62	47.67	39.4	3.28
103.0	40.6	22.24	49.04	40.1	3.34
104.0	40.9	22.88	50.44	40.7	3.39
105.0	41.3	23.52	51.86	41.4	3.45
106.0	41.7	24.18	53.31	42.0	3.50
107.0	42.1	24.85	54.78	42.7	3.56
108.0	42.5	25.53	56.28	43.4	3.61
109.0	42.9	26.22	57.81	44.0	3.67
110.0	43.3	26.93	59.36	44.7	3.73
111.0	43.7	27.64	60.94	45.4	3.78
112.0	44.1	28.37	62.55	46.1	3.84
113.0	44.5	29.11	64.18	46.7	3.89
114.0	44.9	29.87	65.85	47.4	3.95
115.0	45.3	30.64	67.54	48.1	4.01
116.0	45.7	31.42	69.26	48.8	4.06
117.0	46.1	32.21	71.01	49.4	4.12
118.0	46.5	33.02	72.79	50.1	4.18
119.0	46.9	33.83	74.59	50.8	4.24
120.0	47.2	34.67	76.43	51.5	4.29
121.0	47.6	35.51	78.29	52.2	4.35
122.0	48.0	36.37	80.18	52.9	4.41
123.0	48.4	37.24	82.11	53.6	4.47
124.0	48.8	38.13	84.06	54.3	4.52
125.0	49.2	39.03	86.05	55.0	4.58
126.0	49.6	39.94	88.06	55.7	4.64
127.0	50.0	40.87	90.11	56.4	4.70
128.0	50.4	41.81	92.18	57.1	4.76

APPENDIX 1. LENGTH, WEIGHT, AND AGE OF BLUEFIN TUNA FROM THE ATLANTIC OCEAN—CONTINUED

LENGTH		WEIGHT		AGE	
CM	IN	KG	LB	MO	YR
129.0	50.8	42.77	94.29	57.8	4.82
130.0	51.2	43.74	96.43	58.5	4.88
131.0	51.6	44.72	98.60	59.2	4.94
132.0	52.0	45.72	100.80	60.0	5.00
133.0	52.4	46.74	103.04	60.7	5.06
134.0	52.8	47.76	105.30	61.4	5.12
135.0	53.1	48.81	107.60	62.1	5.18
136.0	53.5	49.86	109.93	62.9	5.24
137.0	53.9	50.94	112.30	63.6	5.30
138.0	54.3	52.02	114.69	64.3	5.36
139.0	54.7	53.13	117.13	65.0	5.42
140.0	55.1	54.24	119.59	65.8	5.48
141.0	55.5	55.38	122.09	66.5	5.54
142.0	55.9	56.53	124.62	67.2	5.60
143.0	56.3	57.69	127.19	68.0	5.66
144.0	56.7	58.87	129.79	68.7	5.73
145.0	57.1	60.07	132.42	69.5	5.79
146.0	57.5	61.28	135.09	70.2	5.85
147.0	57.9	62.50	137.80	71.0	5.91
148.0	58.3	63.75	140.54	71.7	5.98
149.0	58.7	65.01	143.31	72.5	6.04
150.0	59.1	66.28	146.12	73.2	6.10
151.0	59.4	67.57	148.97	74.0	6.17
152.0	59.8	68.88	151.85	74.8	6.23
153.0	60.2	70.20	154.77	75.5	6.29
154.0	60.6	71.55	157.73	76.3	6.36
155.0	61.0	72.90	160.72	77.1	6.42
156.0	61.4	74.28	163.75	77.8	6.49
157.0	61.8	75.67	166.82	78.6	6.55
158.0	62.2	77.08	169.93	79.4	6.62
159.0	62.6	78.50	173.07	80.2	6.68
160.0	63.0	79.95	176.25	81.0	6.75
161.0	63.4	81.41	179.47	81.8	6.81
162.0	63.8	82.88	182.72	82.5	6.88
163.0	64.2	84.38	186.02	83.3	6.94
164.0	64.6	85.92	189.35	84.1	7.01
165.0	65.0	87.42	192.73	84.9	7.08
166.0	65.4	88.97	196.14	85.7	7.14
167.0	65.7	90.53	199.59	86.5	7.21
168.0	66.1	92.12	203.09	87.3	7.28
169.0	66.5	93.72	206.61	88.2	7.35
170.0	66.9	95.34	210.19	89.0	7.41
171.0	67.3	96.98	213.79	89.8	7.48
172.0	67.7	98.63	217.45	90.6	7.55
173.0	68.1	100.31	221.14	91.4	7.62

APPENDIX 1. LENGTH, WEIGHT, AND AGE OF BLUEFIN TUNA FROM THE ATLANTIC OCEAN—CONTINUED

LENGTH		WEIGHT		AGE	
CM	IN	KG	LB	MO	YR
174.0	68.5	102.00	224.87	92.3	7.69
175.0	68.9	103.71	228.65	93.1	7.76
176.0	69.3	105.44	232.46	93.9	7.83
177.0	69.7	107.19	236.32	94.7	7.90
178.0	70.1	108.96	240.22	95.6	7.97
179.0	70.5	110.75	244.16	96.4	8.04
180.0	70.9	112.55	248.14	97.3	8.11
181.0	71.3	114.38	252.17	98.1	8.18
182.0	71.7	116.23	256.23	99.0	8.25
183.0	72.0	118.09	260.34	99.8	8.32
184.0	72.4	119.97	264.50	100.7	8.39
185.0	72.8	121.88	268.69	101.5	8.46
186.0	73.2	123.80	272.93	102.4	8.53
187.0	73.6	125.74	277.22	103.3	8.61
188.0	74.0	127.71	281.55	104.1	8.68
189.0	74.4	129.69	285.92	105.0	8.75
190.0	74.8	131.69	290.33	105.9	8.82
191.0	75.2	133.72	294.79	106.8	8.90
192.0	75.6	135.76	299.30	107.6	8.97
193.0	76.0	137.83	303.85	108.5	9.04
194.0	76.4	139.91	308.44	109.4	9.12
195.0	76.8	142.01	313.08	110.3	9.19
196.0	77.2	144.14	317.77	111.2	9.27
197.0	77.6	146.29	322.50	112.1	9.34
198.0	78.0	148.45	327.29	113.0	9.42
199.0	78.3	150.64	332.10	113.9	9.49
200.0	78.7	152.85	336.97	114.9	9.57
201.0	79.1	155.07	341.89	115.8	9.65
202.0	79.5	157.33	346.86	116.7	9.72
203.0	79.9	159.60	351.87	117.6	9.80
204.0	80.3	161.90	356.92	118.5	9.88
205.0	80.7	164.21	362.03	119.5	9.95
206.0	81.1	166.55	367.18	120.4	10.03
207.0	81.5	168.91	372.39	121.3	10.11
208.0	81.9	171.29	377.63	122.3	10.19
209.0	82.3	173.69	382.93	123.2	10.27
210.0	82.7	176.12	388.28	124.2	10.35
211.0	83.1	178.57	393.67	125.1	10.43
212.0	83.5	181.03	399.11	126.1	10.51
213.0	83.9	183.53	404.61	127.0	10.59
214.0	84.3	186.04	410.15	128.0	10.67
215.0	84.6	188.58	415.74	129.0	10.75
216.0	85.0	191.13	421.38	129.9	10.83
217.0	85.4	193.72	427.07	130.9	10.91
218.0	85.8	196.32	432.81	131.9	10.99

APPENDIX 1. LENGTH, WEIGHT, AND AGE OF BLUEFIN TUNA FROM THE ATLANTIC OCEAN-CONTINUED

LENGTH		WEIGHT		AGE	
CM	IN	KG	LB	MO	YR
219.0	86.2	198.95	438.60	132.9	11.07
220.0	86.6	201.60	444.45	133.9	11.16
221.0	87.0	204.27	450.34	134.9	11.24
222.0	87.4	206.97	456.28	135.9	11.32
223.0	87.8	209.69	462.28	136.9	11.41
224.0	88.2	212.43	468.33	137.9	11.49
225.0	88.6	215.20	474.42	138.9	11.58
226.0	89.0	217.99	480.57	139.9	11.66
227.0	89.4	220.80	486.78	141.0	11.75
228.0	89.8	223.63	493.03	142.0	11.83
229.0	90.2	226.50	499.34	143.0	11.92
230.0	90.6	229.38	505.70	144.0	12.00
231.0	90.9	232.29	512.11	145.1	12.09
232.0	91.3	235.22	518.57	146.1	12.18
233.0	91.7	238.18	525.09	147.2	12.27
234.0	92.1	241.16	531.67	148.2	12.35
235.0	92.5	244.17	538.29	149.3	12.44
236.0	92.9	247.20	544.97	150.4	12.53
237.0	93.3	250.25	551.71	151.4	12.62
238.0	93.7	253.33	558.49	152.5	12.71
239.0	94.1	256.43	565.34	153.6	12.80
240.0	94.5	259.56	572.23	154.7	12.89
241.0	94.9	262.71	579.19	155.8	12.98
242.0	95.3	265.89	586.20	156.9	13.07
243.0	95.7	269.10	593.26	158.0	13.16
244.0	96.1	272.33	600.38	159.1	13.26
245.0	96.5	275.58	607.55	160.2	13.35
246.0	96.9	278.86	614.78	161.3	13.44
247.0	97.2	282.17	622.07	162.4	13.54
248.0	97.6	285.50	629.41	163.6	13.63
249.0	98.0	288.85	636.81	164.7	13.73
250.0	98.4	292.23	644.27	165.8	13.82
251.0	98.8	295.64	651.78	167.0	13.92
252.0	99.2	299.08	659.35	168.1	14.01
253.0	99.6	302.54	666.98	169.3	14.11
254.0	100.0	306.02	674.67	170.5	14.21
255.0	100.4	309.54	682.41	171.6	14.30
256.0	100.8	313.07	690.21	172.8	14.40
257.0	101.2	316.64	698.07	174.0	14.50
258.0	101.6	320.23	705.99	175.2	14.60
259.0	102.0	323.85	713.97	176.4	14.70
260.0	102.4	327.49	722.00	177.6	14.80
261.0	102.8	331.17	730.10	178.8	14.90
262.0	103.1	334.87	738.25	180.0	15.00
263.0	103.5	338.59	746.47	181.2	15.10

APPENDIX 1. LENGTH, WEIGHT, AND AGE OF BLUEFIN TUNA FROM THE ATLANTIC OCEAN—CONTINUED

LENGTH		WEIGHT		AGE	
CM	IN	KG	LB	MO	YR
264.0	103.9	342.34	754.74	182.5	15.21
265.0	104.3	346.12	763.07	183.7	15.31
266.0	104.7	349.93	771.47	184.9	15.41
267.0	105.1	353.77	779.92	186.2	15.52
268.0	105.5	357.63	788.43	187.4	15.62
269.0	105.9	361.52	797.01	188.7	15.73
270.0	106.3	365.43	805.65	190.0	15.83
271.0	106.7	369.38	814.34	191.2	15.94
272.0	107.1	373.35	823.10	192.5	16.04
273.0	107.5	377.35	831.92	193.8	16.15
274.0	107.9	381.38	840.80	195.1	16.26
275.0	108.3	385.44	849.75	196.4	16.37
276.0	108.7	389.52	858.75	197.7	16.48
277.0	109.1	393.64	867.82	199.1	16.59
278.0	109.4	397.78	876.95	200.4	16.70
279.0	109.8	401.95	886.14	201.7	16.81
280.0	110.2	406.15	895.40	203.1	16.92
281.0	110.6	410.37	904.72	204.4	17.04
282.0	111.0	414.63	914.10	205.8	17.15
283.0	111.4	418.91	923.55	207.2	17.26
284.0	111.8	423.23	933.06	208.5	17.38
285.0	112.2	427.57	942.63	209.9	17.49
286.0	112.6	431.94	952.27	211.3	17.61
287.0	113.0	436.34	961.98	212.7	17.73
288.0	113.4	440.78	971.74	214.1	17.84
289.0	113.8	445.24	981.58	215.5	17.96
290.0	114.2	449.72	991.47	217.0	18.08
291.0	114.6	454.24	1001.44	218.4	18.20
292.0	115.0	458.79	1011.46	219.9	18.32
293.0	115.4	463.37	1021.56	221.3	18.44
294.0	115.7	467.98	1031.72	222.8	18.57
295.0	116.1	472.62	1041.94	224.3	18.69
296.0	116.5	477.28	1052.23	225.7	18.81
297.0	116.9	481.98	1062.59	227.2	18.94
298.0	117.3	486.71	1073.02	228.8	19.06
299.0	117.7	491.47	1083.51	230.3	19.19
300.0	118.1	496.26	1094.07	231.8	19.32