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A REVIEW OF THE YELLOWFIN TUNA FISHERY OF THE ATLANTIC OCEAN

by

W. H. Lenarz and G. T. Sakagawa

SUMMARY

Catch, effort, and length-frequency statistics from the yellowfin tuna fishery of the Atlantic Ocean were compiled, evaluated, and analysed. Evaluation of the data revealed that although data collection has greatly improved in recent years, there is still need for improvement. Examination of catch-per-effort statistics revealed that they are poorly correlated among various components of the fishery. However, in general, the data suggest that increased fishing effort would not result in significant increases in catches of yellowfin tuna unless other aspects of the fishery are changed.

Catch-per-effort and length-frequency data were used to estimate the instantaneous rate of total mortality to be about 1.4. Weight at recruitment to the fishery was estimated to be between 3 and 10 kg. Yield-per-recruit analysis indicated that modest increases in yield-per-recruit would occur if weight at recruitment is increased.

EXAMEN DE LA PECHERIE DE L'ALBACORE DANS L'OCEAN ATLANTIQUE

par

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RESUME

Des statistiques de captures, d'effort et de fréquences de tailles sur la pêcherie de l'albacore dans l'Atlantique ont été recueillies, étudiées et analysées. L'étude des données a révélé que, bien que la collecte des données ait beaucoup progressé au cours des dernières années, des améliorations sont encore nécessaires. L'analyse des statistiques de captures/effort montre qu'elles sont en faible correlation avec d'autres éléments de la pêcherie. En général, cependant, les données semblent indiquer qu'un effort de pêche plus important n'entraînerait pas d'augmentation appréciable des captures d'albacore, à moins que d'autres aspects de la pêcherie ne soient modifiés.

Les données de captures/effort et de fréquences de tailles ont servi à estimer le taux instantané de mortalité à environ 1,4. Le poids au recrutement dans la pêcherie a été estimé de 3 à 10 kgs. Les analyses du rendement par recrue ont indiqué qu'une augmentation du poids au recrutement entraînerait un accroissement modéré du rendement par recrue.

EXAMEN DE LA PESQUERIA DE RABIL EN EL OCEANO ATLANTICO

por

W. H. Lenarz y G. T. Sakagawa

RESUMEN

Las estadísticas relativas a capturas, esfuerzo y frecuencia de tallas fueron recopiladas, evaluadas y analizadas. La evaluación de los datos reveló que aunque la recopilación de datos ha mejorado notablemente en estos últimos años, todavía es necesario hacer un esfuerzo en este

sentido. Un examen de las estadísticas de capturas-por-esfuerzo reflejó que su correlación con diversos componentes de la pesquería es debil. Sin embargo, en general, los datos parecen indicar que un aumento del esfuerzo pesquero no daría como resultado aumentos importantes en las capturas de rabil, a menos que cambien otros aspectos de la pesquería.

Se utilizaron los datos de capturas-por-esfuerzo y frecuencia de tallas para estimar en un 1,4 aproximadamente, el índice instantáneo de mortalidad total. El peso en el reclutamiento en la pesquería se estimó entre 3 y 10 Kg. Los análisis de producción-por-reclutamiento indican que se producirían débiles aumentos en la producción-por-reclutamiento si el peso en el reclutamiento fuera aumentado.

A REVIEW OF THE YELLOWFIN TUNA FISHERY OF THE ATLANTIC OCEAN[1]

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The commercial yellowfin tuna fishery in the Atlantic Ocean began in 1955 when small baitboats of France and Spain that traditionally fished for albacore off southern Europe began fishing for yellowfin tuna off Africa. With the appearance of the baitboats, the Atlantic surface fishery for yellowfin tuna was established. Purse seiners began appearing in the fishery in the early 1960's. In 1967, the large purse seiners (>400 tons[2] capacity) were first used by Canada and the U.S.A. Two years later France and Spain also began fishing with large seiners. The number of boats in the fishery has increased (Figure 1), but it is uncertain whether the amount of effort has also increased.

The catch of the surface fishery has increased steadily, reaching a peak of 61,800 tons in 1969 and then leveled off to about 45,000 tons (Figure 2). In recent years the catch of the surface fishery has been about 50% more than that of the longline fishery.

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[2]Throughout this report "tons" = metric tons.

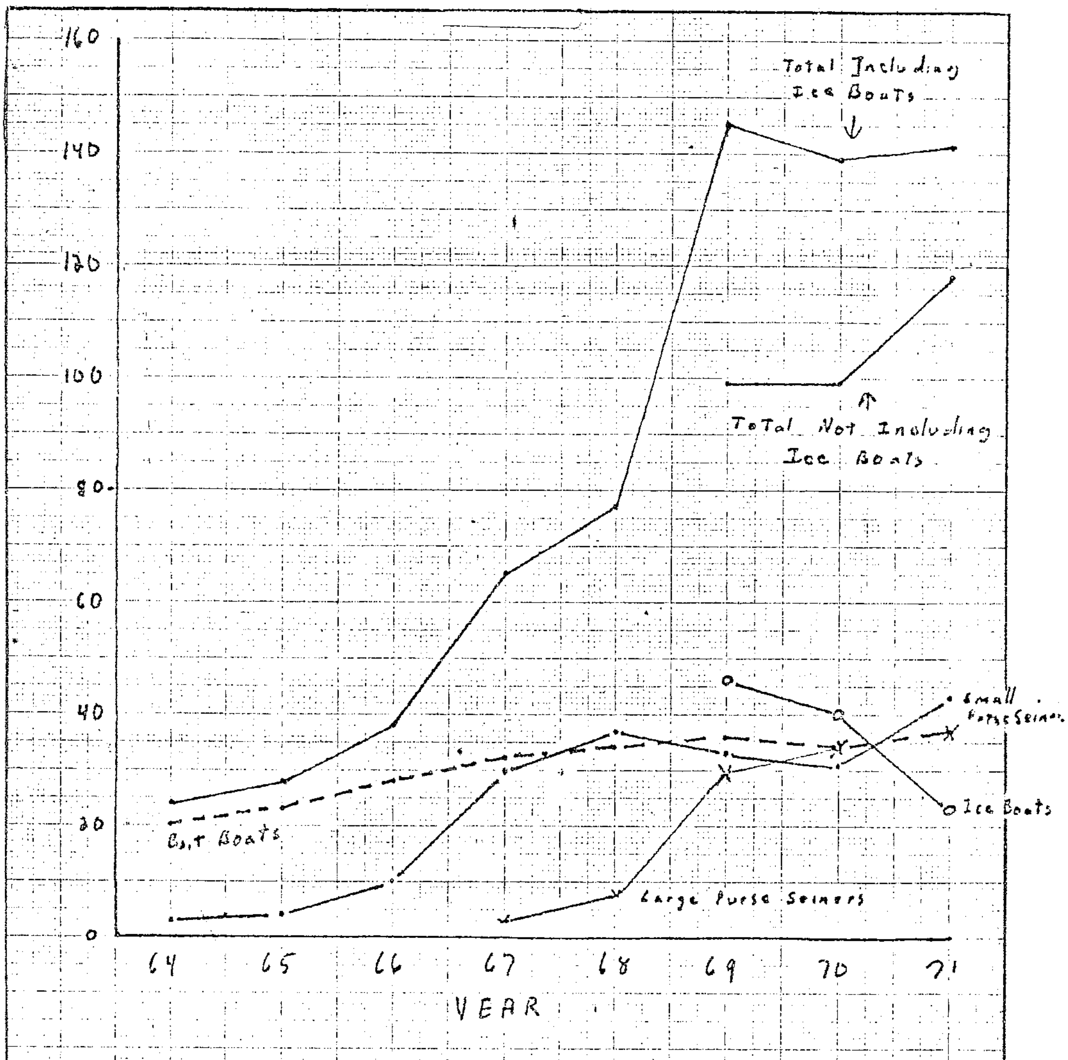

Figure 1. Approximate number of boats fishing in the surface fishery of the eastern tropical Atlantic. Sources of data: 1964-68 from ICCAT (1971a) and ORSTOM publications; 1969-71 from Anonymous (1972).

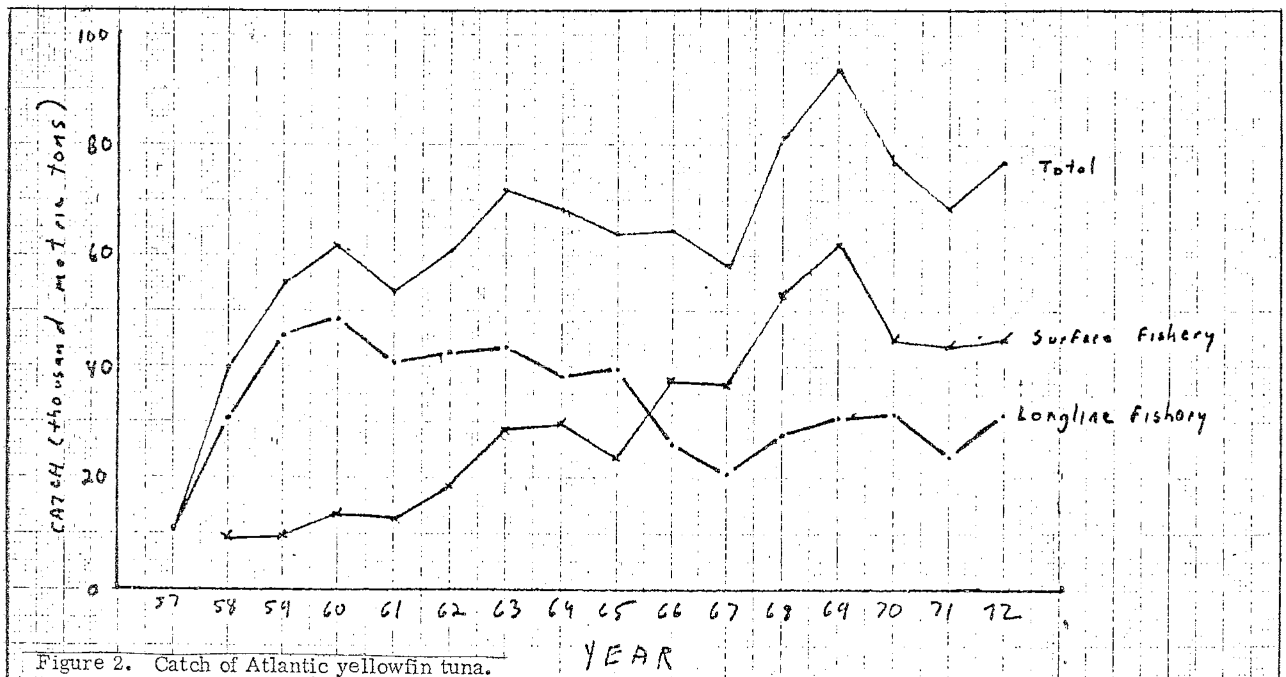

Figure 2. Catch of Atlantic yellowfin tuna.

In 1956, the Japanese conducted exploratory longlining and caught less than 100 tons. From 1957-65 the longline fishery rapidly expanded and the annual catch averaged about 40,000 tons. In recent years the Japanese longline fleet has been reduced but vessels of other nations, primarily Korea and Taiwan, have entered the fishery.

Evidence presented at the 1972 Abidjan meeting of the Special Working Group on Stock Assessment of Yellowfin Tuna of the International Commission for the Conservation of Atlantic Tunas (ICCAT) indicated that the total catch of Atlantic yellowfin tuna declined from 93,400 tons in 1969 to about 68,600 tons in 1971, and that the size of fish caught has also declined. The decline, however, does not appear to be the beginning of a downward trend in catch. Preliminary data for the 1972 season indicates that the surface catch will be higher than that for 1970 or 1971. For example, this year's January-August catch by the French fleet, as reported in "La Peche Maritime," is greater than the catch for a comparable period in 1970 or 1971. As of late-October, reported catches of skipjack and yellowfin tunas by the American fleet was about 22,000 tons. The species composition of the American catch is estimated to be 50% yellowfin, based on landings of 9,000 tons. Our data so far indicate that the 1972 catch of yellowfin by the American fleet will considerably exceed the 1971 catch (3,800 tons) and probably exceed the 1970 catch (9,100 tons). Nevertheless, at Abidjan there were suggestions that a size regulation of 3.2 kg was required and regulations were needed to prevent a rapid increase in fishing effort.

This paper is a compendium of studies on the dynamics of the yellowfin tuna population(s) of the Atlantic Ocean and is prepared as a briefing document for the 1972 Madrid meeting. The studies had two missions: (1) to evaluate the quality of the basic data on the fishery, and (2) to evaluate the effects of the fisheries on the population.

Analysis of Basic Data

Catch Statistics

The catch of yellowfin tuna by the longline and surface fisheries have been compiled for 1957-71 (Table 1). Primary sources of information were FAO (1968) and ICCAT (1972). In order to have as complete a picture of the trend in catch as possible, the catches for 1972 were estimated. We compiled the monthly catches of yellowfin tuna that were landed by French, Ivory Coast, and Senegalese (FIS) vessels as reported in "La Peche Maritime" (Figure 3). The cumulative catches for January-August 1972, shows that the 1972 catch is progressing faster than that of 1970. As previously mentioned, the catch by the American fleet will probably exceed the 1970 catch. We therefore guessed that in 1972 the surface catch will be at least 44,800 tons and the longline catch will be at least 31,100 tons as was landed in 1970.

About nine nations participate in the yellowfin tuna surface fishery, with FIS landing the largest share (60% in 1971). From 1958-69 the surface catch increased from 9,200 tons to 61,800 tons or at an annual rate of 4,700 tons.. In

Table 1. Catches (thousands of metric tons) of yellowfin tuna from the Atlantic Ocean

	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Longline Fishery																
Argentina							0.1	0.1	0.1	0	0	0	0.1	0		
China (Taiwan)							0.5	0.3	0.1	1.0	2.6	7.8	11.5	8.3	4.7	
Cuba							1.7	0.9	0.8	0.8	3.0	1.9	1.6	1.6	1.6	
Japan	10.4	29.8	43.9	46.4	38.7	38.5	37.7	35.1	36.6	22.1	12.8	13.9	9.8	6.6	4.6	
Korea												2.3	6.0	13.2	11.4	
Venezuela	0.6	0.9	1.6	2.1	2.0	3.6	3.1	1.9	1.8	2.1	2.1	1.2	1.6	1.4	1.4	
Total Longline	11.0	30.7	45.5	48.5	40.7	42.2	43.1	38.3	39.4	26.0	20.6	27.3	30.6	31.1	23.7	(31.1)[1]
Surface Fishery																
Canada										0.6	0.7	0.7	0.9	0.2		
France-Ivory Coast-Senegal		9.2	9.6	13.3	12.6	14.2	21.8	21.4	7.0	23.4	23.8	32.5	29.0	26.1	26.4	
Japan						1.1	0.9	2.6	2.4	5.3	6.5	7.9	6.8	2.4	5.3	
Portugal							4.4	4.5	2.8	2.4	1.6	1.6	1.0	0.1	0.1	
Spain						0	1.2	0.9	1.5	6.0	2.8	4.0	5.9	7.0	8.3	
U.S.A.							0.2	0.1			1.0	6.1	18.2	8.9	3.8	
Total Surface		9.2	9.6	13.3	12.6	18.1	28.5	29.5	23.7	37.7	36.4	52.8	61.8	44.8	43.9	(44.8)[1]
Grand Total	11.0	39.9	55.1	61.8	53.3	60.3	71.6	68.0	64.1	64.7	58.0	81.1	93.4	76.9	68.6	(76.9)[1]

[1] Guess, see text.

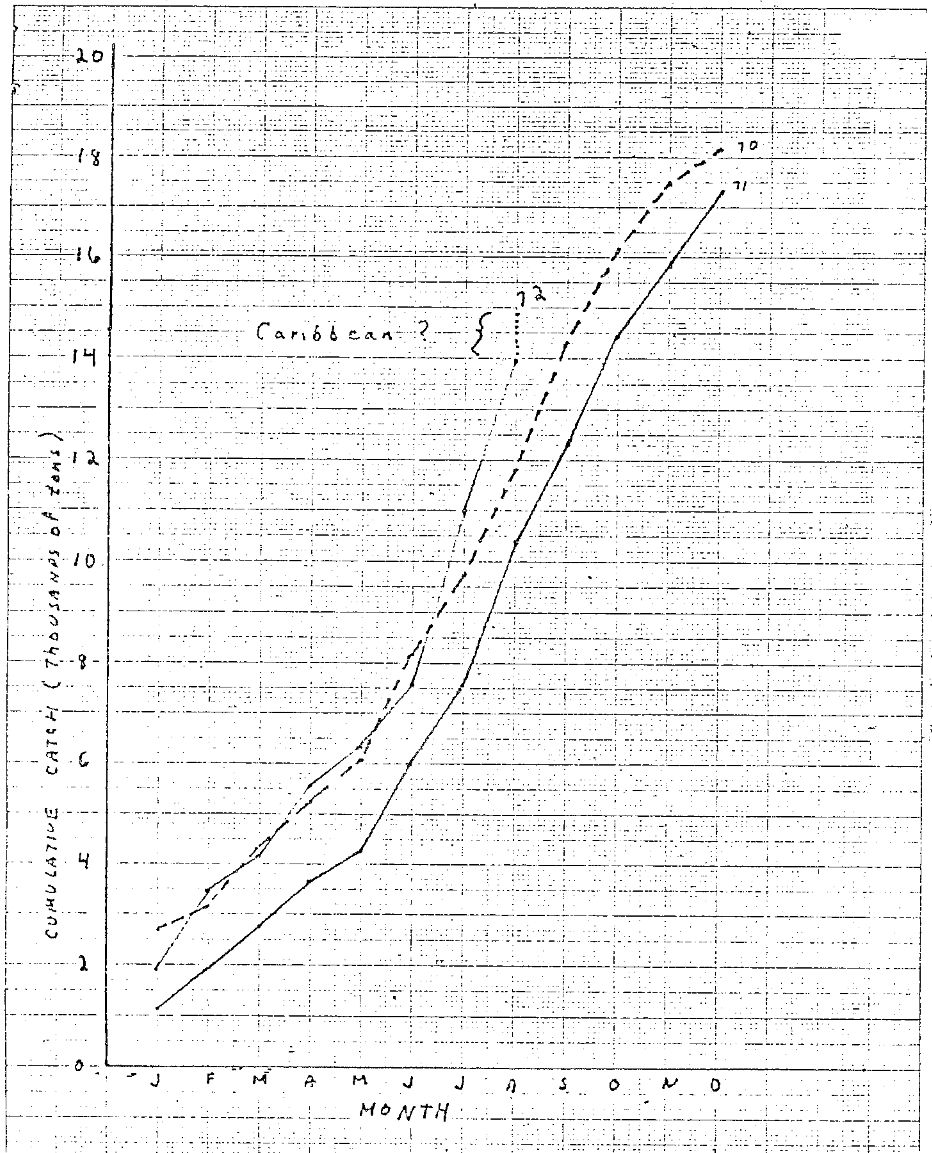

Figure 3. Cumulative catch of yellowfin tuna as reported in "La Peche Maritime" for FIS vessels for 1970-72.

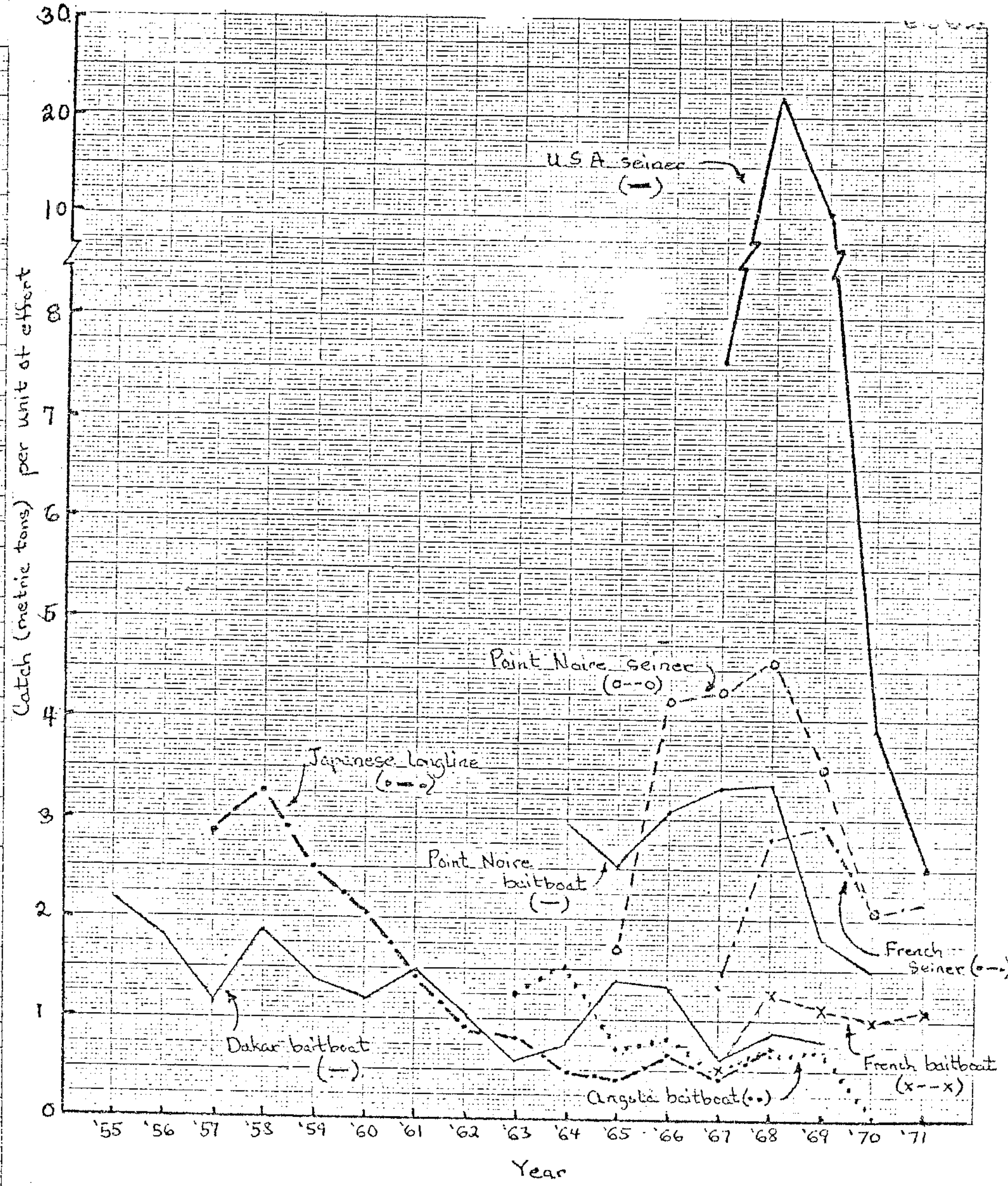

Figure 4. Apparent abundance of yellowfin tuna. Unit of effort for the Japanese longline is 1000 hooks, for U.S.A. seiner day's fishing, and for all others day at sea.

1970, there was a noticeable decline to 44,800 tons. A decline also occurred in 1971, but in 1972 it appears that the catch is up (Figure 2). At the present time, most of the surface catch is landed by purse seiners (Table 2).

Korea, Japan, and Taiwan are the nations that land most of the longline-caught Atlantic yellowfin tuna. The longline fishery was first started by Japan in 1956, and most of the longline catch was landed by the Japanese longline fleet until only recently. The longline catch attained a peak in 1960, 4 years after the start of the fishery, and since then the catch has decreased and leveled off. The most pronounced decline occurred in 1965-67 when the catch declined from 39,400 tons to 20,600 tons. The catch increased to 31,100 tons in 1970 and then declined to 23,700 tons in 1971. It is important to note that despite the phenomenal increase in catch of the surface fishery in the late 1960's, the longline catch has remained relatively constant at about 26,000 tons. Also, the decline in the catch of the longline fishery occurred before the expansion of the surface fishery.

In Table 3, a few clarifying comments on the reported catches in Table 1 are given. In summary, the catch statistics can be improved by having all landings reported in round weight, landings of yellowfin tuna reported separately from other tuna species, and actual catch statistics (as opposed to estimated catch) reported by all countries.

Table 2. Catch (thousands of metric tons) of yellowfin tuna caught by baitboats and purse seiners. Catches were from the eastern tropical Atlantic

Country	Year													
	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
Canada														
Seiner									0.6	0.7	0.7	0.9	0.2	
FIS														
Baitboat	9.2	9.6	13.3	12.6	14.2	21.8	21.4	17.0	23.4	12.3	16.7	14.3	8.0	7.8
Seiner										8.5	9.8	14.7	18.1	17.7
Japan														
Seiner							0.5	1.1	4.8	5.2	7.5	6.4	~2.0	
Baitboat					1.1	0.9	2.1	1.3	0.5	1.3	0.4	0.4	~0.4	
Portugal														
Baitboat						4.4	4.5	2.8	2.4	1.6	1.6	1.0	0.1	
U.S.A.														
Seiner						0.2	0.1			1.0	6.1	18.2	8.9	3.8[1]

[1] Figure is for Canadian and U.S.A. seiners.

Table 3. Summary of available statistics on the catch of Atlantic yellowfin tuna for the major fleets

Country	Years	Collected by	Fishing Area	Comments
Longline fishery				
Argentina	1963-70	Government	Western Atlantic?	Annual catch <100 tons
China	1963-71	Government	Entire Atlantic	Reported as dressed weight
Cuba	1963-70	Government	Entire Atlantic	1963-64 catches include other tuna species
Japan	1957-71	Government	Entire Atlantic	Longest series of data
Korea	1968-71	Government	Entire Atlantic	Catches for earlier years not reported. Catches reported as dressed weights
Venezuela	1957-70	Government	Western Atlantic	1957-66 catches include other tuna species
Surface fishery				
Canada	1966-71	Government	Sierra Leone to Angola	Annual catch <1,000 tons
France	1957-71	ORSTOM	Senegal to Angola West Indies in 1972	Complete statistics for the years 1969-71. Partial results from 1966-68. The data from 1955-65 need to be reviewed
Ivory Coast	1970-71	ORSTOM	Senegal to Angola	Catches reported by ORSTOM
Japan	1962-71	Government	Ivory Coast to Congo	Catches by two-boat seiners, seiners, &baitboats
Portugal	1963-70	Government	Angola	Landings of a small fleet of baitboats
Senegal	1966-71	ORSTOM	Senegal to Angola	Catches reported by ORSTOM
Spain	1963-71	ICCAT	Canary Islands to Angola	Catches have been estimated by ICCAT
U.S.A.	1963-71	Government	Sierra Leone to Angola	Catches from logbooks and landing statistics; includes Panamanian flag vessels

Catch Per Unit of Effort (CPUE) Statistics

CPUE is a general index that is frequently used in fisheries to measure apparent abundance. For Atlantic yellowfin tuna, there are several sources of CPUE data, e.g., Fonteneau (personal communication), ICCAT (1971a, 1971b), and NMFS. We have graphed (Figure 4) eight time series of CPUE: Angola baitboat (ICCAT, 1971b), Dakar baitboat (ICCAT, 1971a, 1971b), FIS baitboat (1969-71: Fonteneau, personal communication; 1967-68: estimated by NMFS), FIS small seiner (1969-71: Fonteneau, personal communication; 1967-68: estimated by NMFS), Japanese longline (NMFS), Point Noire baitboat (ICCAT, 1971b), Point Noire seiner (ICCAT, 1971b), and American (= Canada, Panama, U.S.A.) seiner (NMFS). The graphs are generally different for the different types of boats. A few correlations of CPUE of the different types of vessels are shown in Figure 5. The poorest correlation is between the Point Noire baitboat and the Dakar baitboat, and the best correlation is between the Angola baitboat and the Dakar baitboat.

A close look at the fishing area (Figure 6) of each type of vessel indicates that the Point Noire baitboats and seiners fish in the same area, and their CPUE's are well correlated. The FIS baitboats and seiners, and the American seiners also fish in generally the same area, but their CPUE's are not very well correlated. Possible reasons for this are: (1) the fishing areas for the American seiners, and probably for the FIS boats too, have varied from year-to-year; (2) the proportion

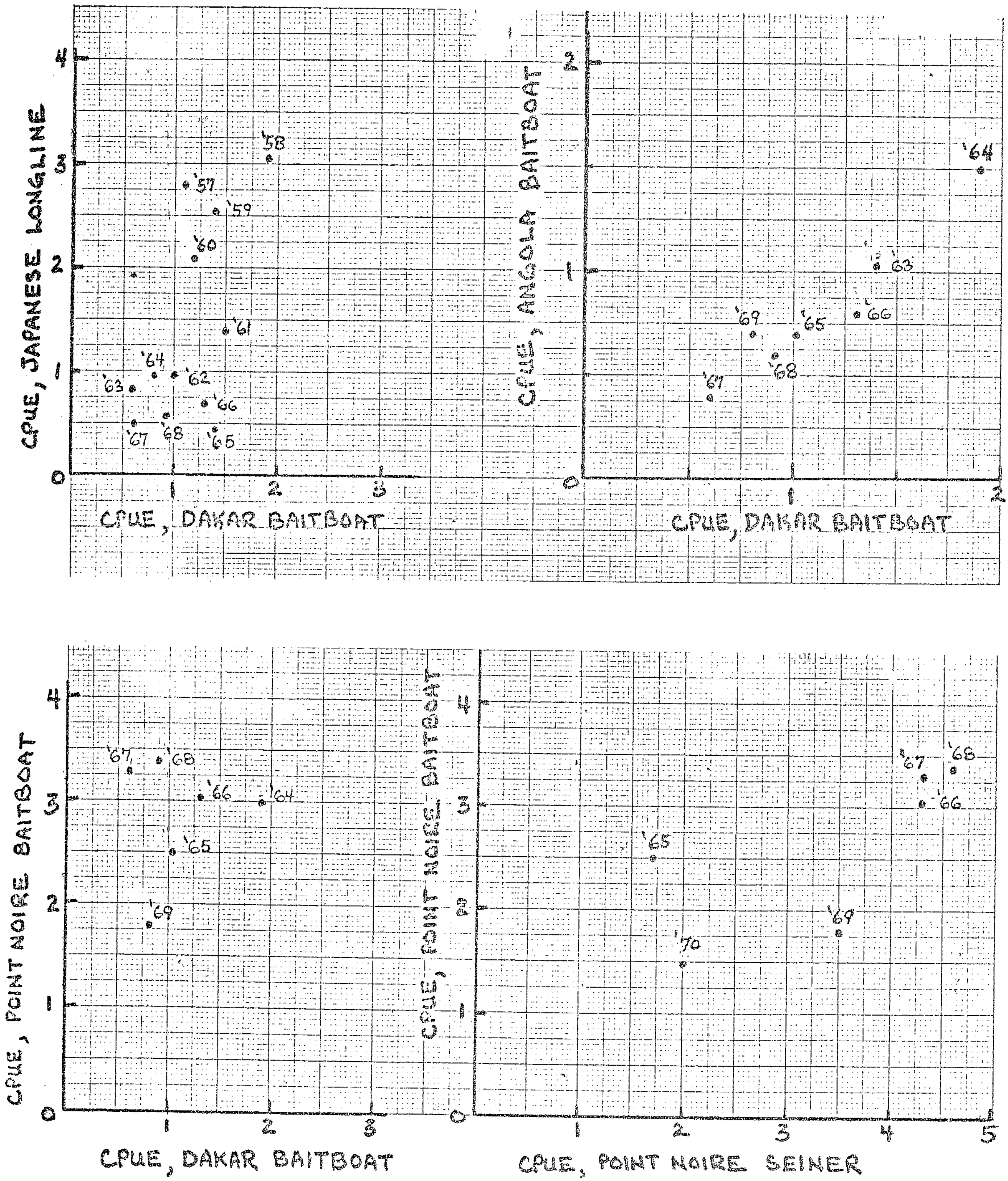

Figure 5. Graphical comparison of some CPUE's of different types of boats.

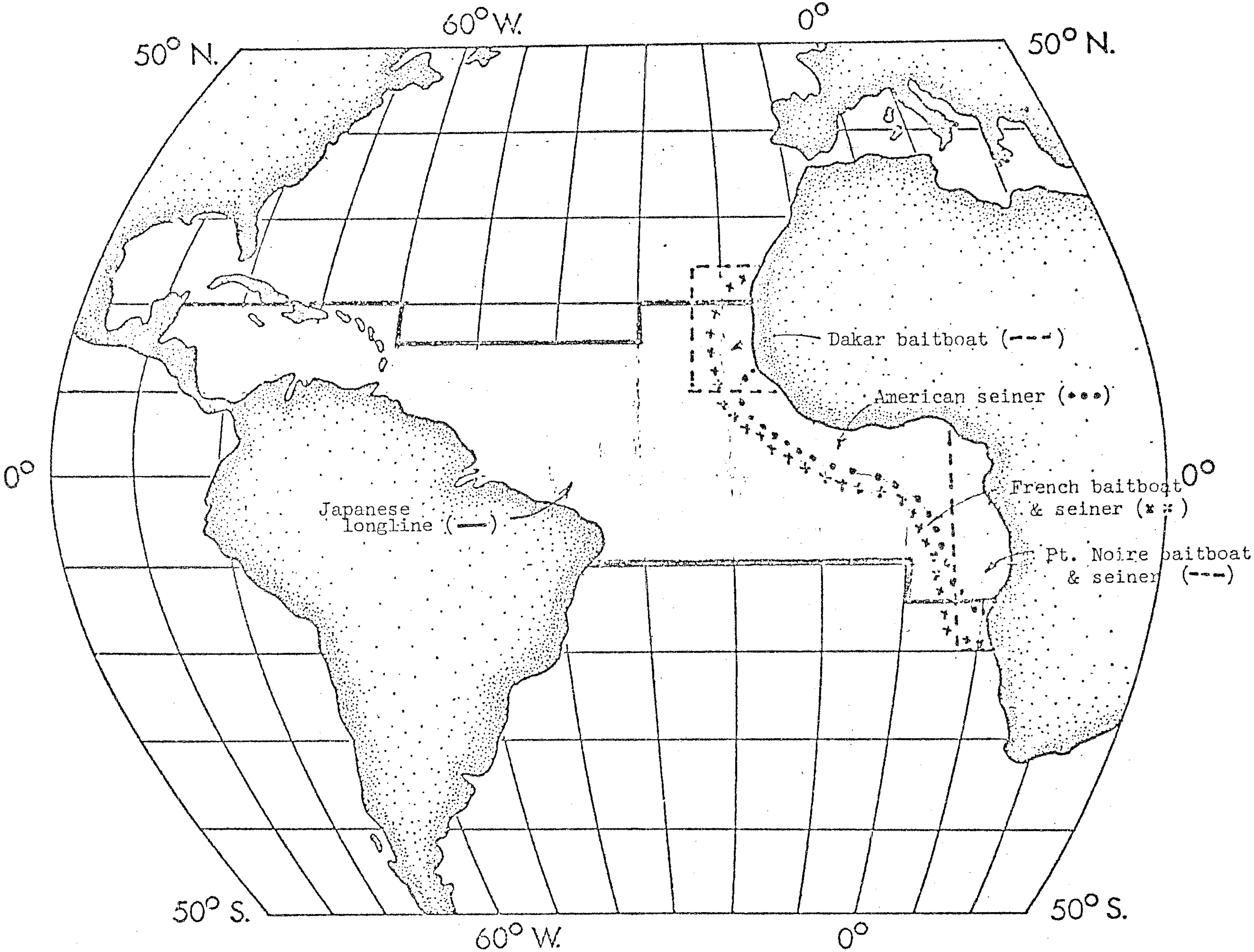

Figure 6. Fishing areas of various fleets that fish for yellowfin tuna in the Atlantic Ocean.

of skipjack in the catch has increased while that of yellowfin has decreased (Table 4); and (3) the fishing season for the FIS boats is for the entire year, whereas for the American seiners the season is only from July to November. On the other hand, the CPUE's of the Japanese longline fleet and Dakar baitboats are reasonably correlated, although their fishing areas are quite different. It thus appears that the data on catch and effort are not complete enough for us to select, at this time, any one or more CPUE series as a reliable index of yellowfin abundance.

In Table 5 the countries that have and have not reported catch and effort statistics are identified. Clearly there is a need for more samples of catch-effort statistics from the longline fleets, and a longer time series of catch-effort statistics for the surface fleets. We note in regard to the surface fleet, that better stratification of catch and effort for yellowfin and skipjack tuna by type of boat, 5° area, and time is needed. These are prerequisites for a complete analysis of apparent abundance, since the fleets apparently have different fishing areas during different times of the year, and concentrate on catching skipjack tuna in certain fishing areas during different times of the year. There is also a need for the catch-effort data to be made available soon after collection. For in order for us to evaluate the status of the stocks for rational management of the fishery, we will need data on a more real-time basis.

Table 4. Proportion of yellowfin and skipjack tuna in the combined catch of both species from the eastern tropical Atlantic

Year	Yellowfin Catch		Skipjack Catch		Total	
	Metric tons	%	Metric tons	%	Metric tons	%
France [1]						
1969	26,370	77.0	7,855	23.0	34,225	100
1970	21,400	65.1	11,449	34.9	32,849	100
1971	20,091	56.1	15,722	43.9	35,813	100
Ivory Coast [1]						
1970	590	58.9	412	41.1	1,002	100
1971	1,126	57.0	848	43.0	1,974	100
Senegal [1]						
1969	2,519	79.6	645	20.4	3,164	100
1970	4,000	65.7	2,091	34.3	6,091	100
1971	4,676	61.9	2,880	38.1	7,556	100
American [2]						
1967	977	67.4	473	32.6	1,450	100
1968	6,199	66.0	3,193	34.0	9,392	100
1969	19,849	81.7	4,442	18.3	24,291	100
1970	9,048	44.2	11,426	55.8	20,474	100
1971	3,750	18.2	16,875	81.8	20,625	100

[1] Data from Fonteneau (personal communication).

[2] Data from NMFS; includes Canada, Panama and U.S.A.

Table 5. Summary of available statistics on catch and effort of Atlantic yellowfin tuna for the major fleets

Country	Catch-effort by 5° areas	Years	Comments
Longline fishery			
Argentina	None		Need data
China	Yes	1967-69	Log book coverage is low; need data on undressed weight of catch
Cuba	None		Need data
Japan	Yes	1957-70	Need data on weight of catch
Korea	Yes	1966-69	Log book coverage is only 2-18% of the boats; need data on weight of catch
Venezuela	None		Need data
Surface fishery			
Canada	Yes	1967-71	Reported together with American statistics
France	Yes	1969-71	Reported separately for baitboats and seiners; includes Ivory Coast and Senegalese statistics
Dakar baitboats		1955-68	
Pt. Noire baitboats		1964-70	Not broken down into 5° areas
Pt. Noire seiners		1964-70	
Ivory Coast	Yes	1969-71	Reported together with French statistics
Japan	None		Need data
Portugal	None	1963-70	Data available for baitboats that fish off Angola; but data not broken down into 5° area; need data
Senegal	Yes	1969-71	Reported together with French statistics
Spain	None		Need data
American	Yes	1967-71	Includes Canadian, Panamanian and U.S.A. statistics

Size-Frequency Samples

A list of available statistics on size-frequency samples of yellowfin tuna is shown in Table 6. The longest and best series is available for the FIS and American fleets. Data for the FIS fleet dates back to 1965 (ORSTOM, 1971) howéver, the coverage of the different types of vessels by region and month has been poor, especially for years previous to 1969. Data for the American fleet are available for 1968-72 (NMFS). Thd coverage is also poor for some month-area strata in which large catches of yellowfin tuna were made.

A small number of length-frequency samples are available for catches of the Japanese baitboat and purse seine fleet. The coverage has been poor and fragmentary. Sampling has been done primarily by the French (ORSTOM, 1971).

The only real source of size-frequency samples for the longline fishery is from the Japanese (ICCAT, 1972). However, as is evident in Table 1, the recent catch of the other longline fleets; e.g., Korea and Taiwan, far exceeds the Japanese catch.

We conclude that size-frequency samples are needed from the surface and longline fisheries by type of gear, month, and 5° area.

Table 6. Summary of available statistics on size-frequency of catch of Atlantic yellowfin tuna for the major fleets

Country	Years	Months	Areas	Comments
Longline fishery				
Argentina	None			Need data
China	None			Need data
Cuba	None			Need data
Japan	1955-60; 1965-70	?	Entire Atlantic 10 x 20° areas	Better coverage in some time-area strata needed
Korea	1970	July-Oct.	5° areas	Very few samples; need data
Venezuela	None			Need data
Surface fishery				
Canada	1968-71	July-Nov.	5° areas and NMFS areas	Reported together with American statistics
France	1965-71	Jan-Dec.	ORSTOM areas	Better coverage in some time-area strata needed; includes Ivory Coast and Senegalese statistics
Ivory Coast	1965-71	Jan-Dec.	ORSTOM areas	Reported together with French statistics
Japan	1965, 1967-68	July-Nov.	Pt. Noire	Better coverage is needed; e.g., Abidjan landings are not sampled
Portugal	None			Need data
Senegal	1965-71	Jan-Dec.	ORSTOM areas	Reported together with French statistics
Spain	None			Need data
American	1968-71	July-Nov.	NMFS areas	Better coverage in some time-area strata needed; includes Canadian, Panamanian and U.S.A. statistics

Analysis of Some Population Parameters

Age Composition of the Surface Catch

Materials and Methods

About 55-80% of the yellowfin tuna landed by the Atlantic yellowfin surface fishery is caught off Africa by Canadian, FIS, Panamanian, and U.S.A vessels. A fairly complete series of data on length-frequency distributions, and catch and effort by type of vessel, month of capture, and area of capture is available for these four fleets. The sources of data are as follows:

FIS fleet

(1) Length-frequency distributions: Anonymous, 1971a; Champagnat and L'Homme, 1970; ICCAT, 1972.

(2) Catch-effort statistics: Anonymous, 1971b; Champagnat and L'Homme, 1970; ICCAT, 1971; Fonteneau (unpublished data); Marcille and Poinsard, 1970.

American (Canada-Panama-U.S.A.) fleet

(1) Length-frequency distributions: NMFS (MS).

(2) Catch-effort statistics: NMFS (MS).

These data were used to estimate the age composition of the catch of the fleets. For the aggregate age composition of the catch of other nations, estimates were based on the data for the FIS fleet. Thus, it was assumed that the data for the FIS fleet are applicable to the catches of the other nations.

The procedure of analysis was to stratify the landings and length-frequency samples by nation (FIS, American, and others), type of vessel (baitboat, small seiner, and large seiner), area of capture (Abidjan, Dakar, and Point Noire for the FIS data; and NMFS areas for the American data), and month of capture. The number of fish in the landings by stratum was then calculated. For strata in which there were landings but no other information, data from adjoining strata were used in the calculations. The pooled age composition of various strata was used to draw inferences about the population of yellowfin tuna.

The age of fish of a particular length was based on the growth curve of Le Guen and Sakagawa (in press):

Age (years)	Fork length (cm)
0	0- 29
1	30- 60
2	61-106
3	107-137
4	138-157
5	158-170
6+	> 171

Note that a range of lengths correspond to a particular age, and the lengths are continuous from one age to another. Thus, ages used in this study are somewhat average ages. For example, a fish that is assigned an age of 2 years may be between 1.5 years and 2.5 years old. An exception to this rule is for fish assigned an age of 1 year. Since there were very few fish smaller than 40 cm long, the fish's age may be between about 1.0 and 1.5 years.

Results and Discussion

Catch by Type of Vessel

The age composition of the catch of FIS baitboats, FIS small seiners (< 350 tons capacity), and American large seiners (>400 tons capacity) are compared in Figure 7 for years in which data for all three types of vessels were available. As expected the results show that purse seiners generally catch a higher proportion of older fish than do the baitboats.

Two-year-old fish were the dominant age group caught by all three types of vessels in 1968. In 1969, the situation was mixed; the American seiners caught primarily 3-year-old fish, the FIS seiners and baitboats 2-year-old fish. It appears that the strong year-class that entered as 2-year-old fish in 1968 was responsible for the large catch of 3-year-olds in 1969 (Table 7). In 1970, we find that the fleets again concentrated on a single age group, but of a younger age than in the previous years. It is difficult to identify the spe'cific cause of this shift, because changes in the fishing area of the fleets, in the yellowfin-skipjack mix of the catch and possibly in recruitment were taking place in 1970. It is interesting to note, however, that the shift was evident in the catches of all three types of vessels (Figure 7).

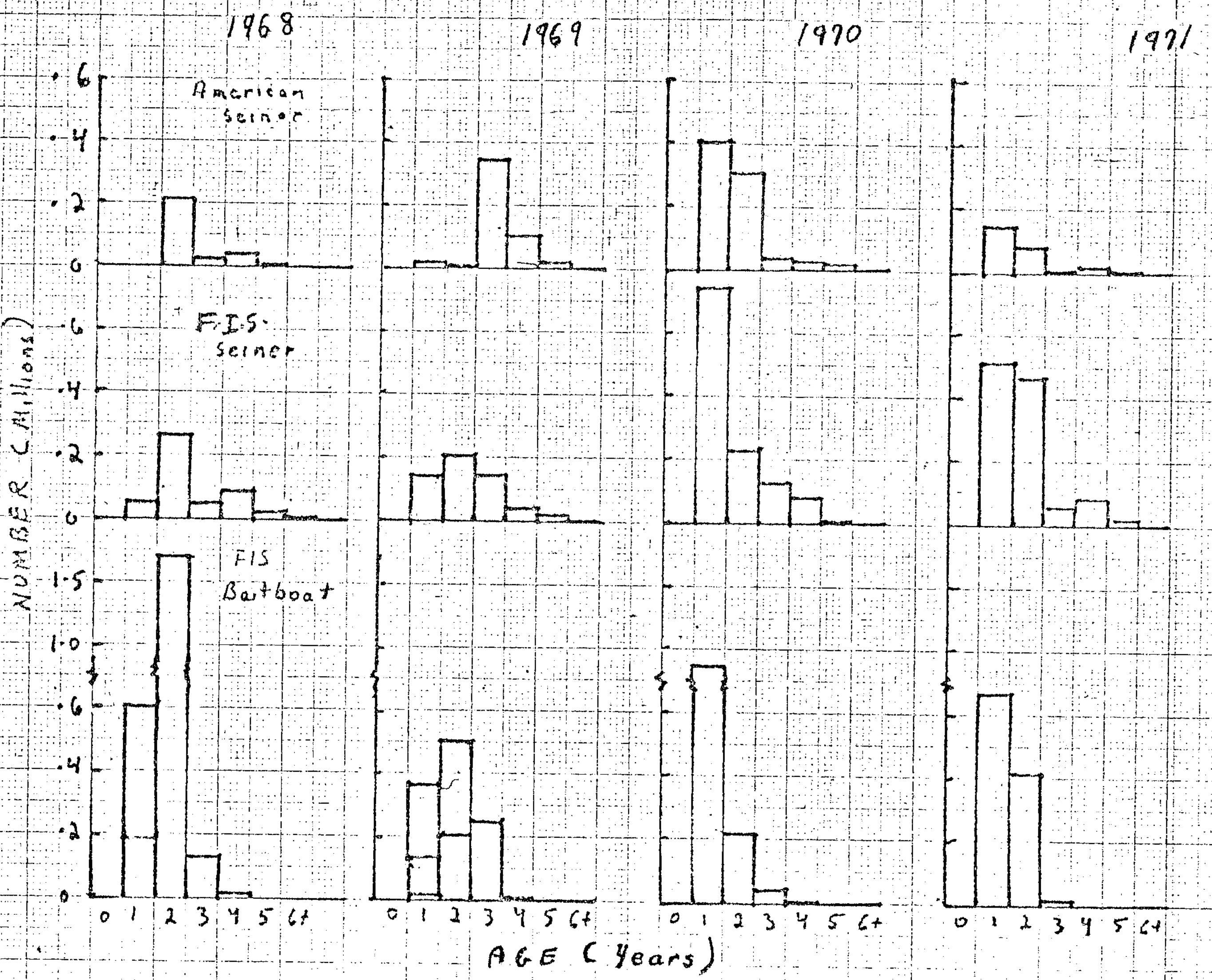

Figure 7. Age composition of catch of yellowfin tuna for three types of vessels.

Table 7. Estimated catch (in numbers) and catch rate for three types of vessels that fished for yellowfin tuna off Africa in 1967-71

Vessel	Age (years)	1967 C	1967 C/f	1968 C	1968 C/f	1969 C	1969 C/f	1970 C	1970 C/f	1971 C	1971 C/f
FIS baitboat	0	0	0	0	0	0	0	400	0.05	0	0
	1	187,100	7.61	610,800	48.84	368,600	29.77	953,100	111.97	668,800	89.92
	2	635,700	25.84	1,704,300	136.27	507,500	40.99	217,900	25.60	414,200	55.68
	3	168,200	6.84	65,300	5.22	145,200	11.72	39,800	4.67	12,100	1.63
	4	6,000	0.24	17,500	1.40	9,900	0.80	9,900	1.16	2,600	0.34
	5	100	<0.01	1,300	0.02	2,500	0.20	800	0.10	500	0.06
	6+	100	<0.01	300	<0.01	200	0.02	200	0.03	100	0.01
	Total	997,200	40.54	2,399,500	191.85	1,033,900	83.50	1,222,300	143.59	1,098,200	147.65
	Effort [1]	24,600		12,507		12,382		8,512		7,438	
FIS seiner [3]	0	0	0	0	0	0	0	0	0	0	0
	1	89,600	17.15	58,800	16.67	137,200	30.58	772,000	113.84	514,700	69.31
	2	190,700	36.50	261,700	74.20	209,700	46.74	231,800	34.17	465,800	62.72
	3	181,000	34.64	58,000	16.44	143,900	32.06	126,600	18.66	62,700	8.45
	4	20,900	4.00	91,700	26.00	43,600	9.71	82,100	12.10	88,800	11.96
	5	2,800	0.54	20,700	5.87	21,300	4.75	15,400	2.28	20,000	2.69
	6+	400	0.08	5,900	1.67	5,700	1.26	3,300	0.49	1,700	0.23
	Total	485,400	92.90	496,800	140.86	561,400	125.11	1,231,200	181.54	1,153,800	155.35
	Effort [1]	5,225		3,527		4,487		6,782		7,427	
American Seiner [4]	0	-	-	0	0	0	0	0	0	0	0
	1	-	-	1,000	7.75	26,200	98.50	407,000	180.65	147,300	97.98
	2	-	-	219,000	1,697.67	16,600	62.41	313,100	138.97	78,800	52.42
	3	-	-	27,100	210.08	346,700	1,303.38	41,900	18.60	10,800	7.18
	4	-	-	40,600	314.73	106,900	401.88	35,500	15.76	19,600	13.04
	5	-	-	8,000	62.02	21,200	79.70	20,200	8.97	8,500	5.65
	6+	-	-	700	5.43	2,000	7.52	1,200	0.53	200	0.13
	Total	-	-	296,400	2,297.67	519,600	1,953.38	818,900	363.47	265,200	176.41
	Effort [2]	-	-	129		266		2,253		1,503	

[1] Effort is in days at sea.

[2] Effort is in fishing days.

[3] < 350 metric tons capacity.

[4] > 400 metric tons capacity.

Catch of the Surface Fishery

Approximately 2.4 to 5.3 million yellowfin tuna were caught annually by the surface fishery during 1965-70 (Table 8). With the entry of large purse seiners (>400 tons capacity) in 1967, fish 3 years and older were more frequently caught by the surface fishery (Figure 8). It appears that yellowfin tuna between ages 1.5 and 2 years are fully recruited to the surface fishery.

The number of yellowfin tuna caught of age 3 years and older has fluctuated from about 216,900 fish to 1,024,900 fish. This can be compared to the catch of the Atlantic longline fishery that primarily harvest yellowfin tuna 3 years and older, of 400,000 to 1,000,000 fish annually in 1965-69. Thus, it appears that the surface fishery competes directly with the longline fishery by reducing the availability of fish of age 3 years and older to the longline fishery, and, of course, indirectly by removing young fish before they are recruited into the longline fishery.

A word of caution that these results are preliminary and probably only reflect general trends. The lack of data in some spatial-temporal-vessel strata necessitated the use of certain untenable assumptions, which undoubtedly affected the results. Whether the affects cancelled each other or whether they are significant are unknown. Also, year-to-year changes in the age composition may be affected by the method of assigning ages. For example, the recent shift in the catch of predominately age 1 fish as opposed to predominately age 2 fish in the 1960's is actually a shift of only about 5-10 cm or a few months rather than a whole year.

Table 8. Catch (in numbers) by age of yellowfin tuna caught by the surface fishery in the eastern tropical Atlantic

Age [1] (years)	Length [1] (cm)	Fishing season						
		1965	1966	1967	1968	1969	1970	1971
0	0- 29	0	0	0	0	0	500	0
1	30- 60	247,000	285,200	70,400	161,100	770,700	2,766,900	1,945,000
2	61-106	1,954,900	3,563,100	1,403,700	3,650,000	1,072,300	928,300	1,415,000
3	107-137	206,200	211,800	593,700	244,000	772,300	269,500	124,400
4	138-157	9,300	83,600	45,600	234,406	185,700	161,400	158,400
5	158-170	1,400	4,200	5,000	47,100	56,200	42,400	39,600
6+	171>	-	-	600	11,200	10,700	6,000	2,900
Total		2,418,800	4,147,900	2,519,100	5,347,800	2,867,900	4,175,000	3,685,800
Total weight (thousand metric tons)		23.7	37.7	36.4	52.8	61.8	44.8	43.9
Average weight (kg)		9.8	9.1	14.0	9.9	21.5	10.7	11.9

[1] Based on growth curve of Le Guen and Sakagawa (in press).

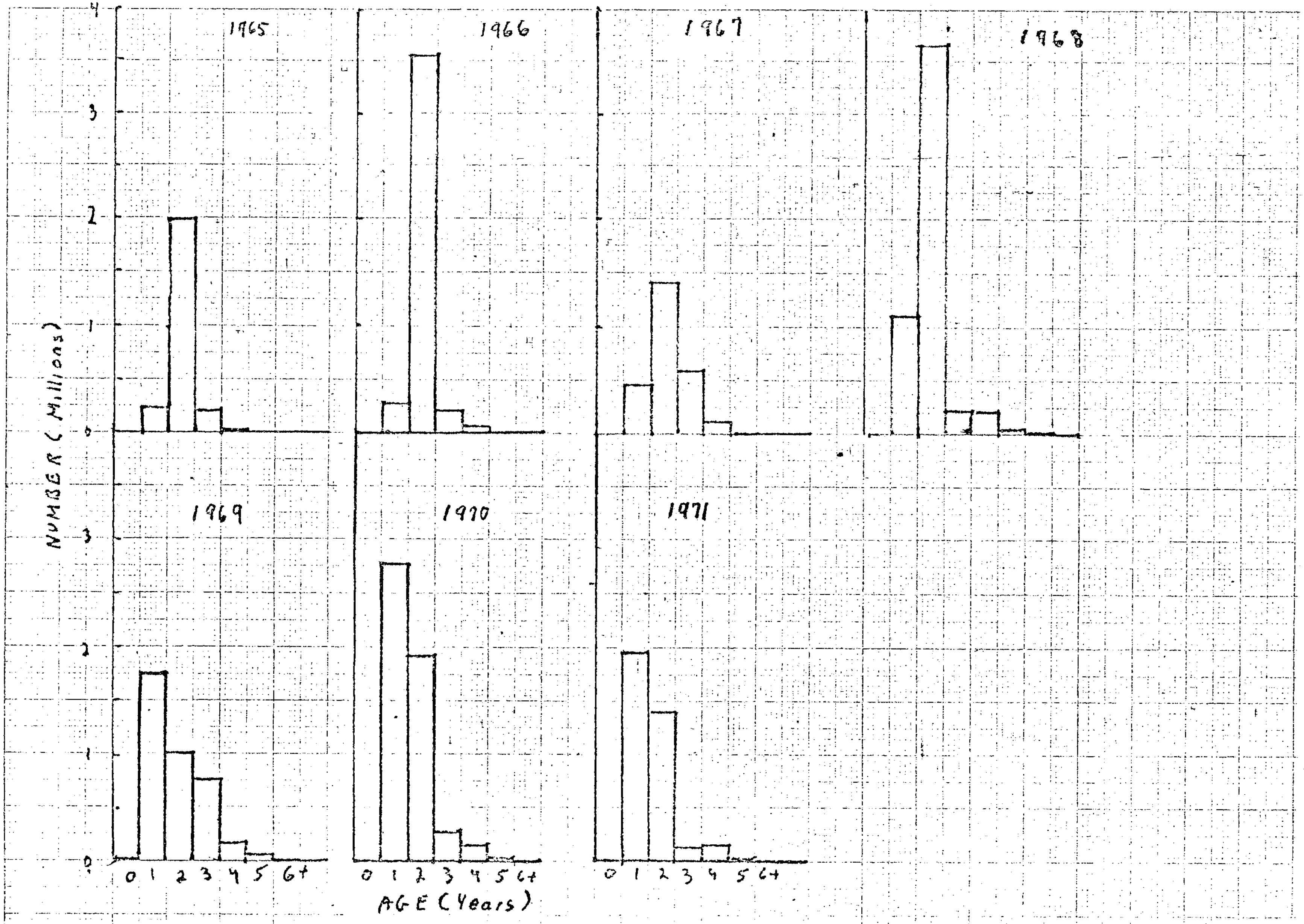

Figure 8. Age composition of the yellowfin tuna catch of the surface fishery in the eastern tropical Atlantic.

It might be argued that the shift to smaller yellowfin tuna in 1970 and 1971 was largely the result of a change in fishing strategy--from concentrating on yellowfin to skipjack schools, which at times contain a mixture of small yellowfin--on the part of seiners and not a reflection of changes in recruitment. Because fishing is by pole-and-line, baitboats are quite selective for small yellowfin tuna. Thus, a comparison of the size composition of the catch of baitboats with that of seiners should indicate whether the shift to smaller fish in 1970 and 1971 was attributed to a change in fishing strategy of the seiners. For this comparison we used FIS data for all baitboats combined (glaciers and congelateurs) and for the small seiners. The results (Figures 9-11) clearly show that in 1970 and 1971 there were few large yellowfin tuna (>80 cm long) caught by both baitboats and seiners, probably because of poor recruitment of the 1968 year-class, and the seiners were indeed catching primarily small fish (as compared to 1969--Figure 9). It thus appears that in 1970 and 1971 the shift in the catch to smaller fish was partly a result of change in fishing strategy of purse seiners and partly a lack of large yellowfin tuna.

Comments on Analysis of Age Composition

With our recent acquisition of more reliable data on the size composition of the FIS catch, our analysis needs to be redone and refined. One refinement is modal analysis on the size composition of the catch, instead of assigning ages, since the apparent changes in average size of the incoming year-class is only 5-10 cm long but with our ageing method the changes appear as whole years.

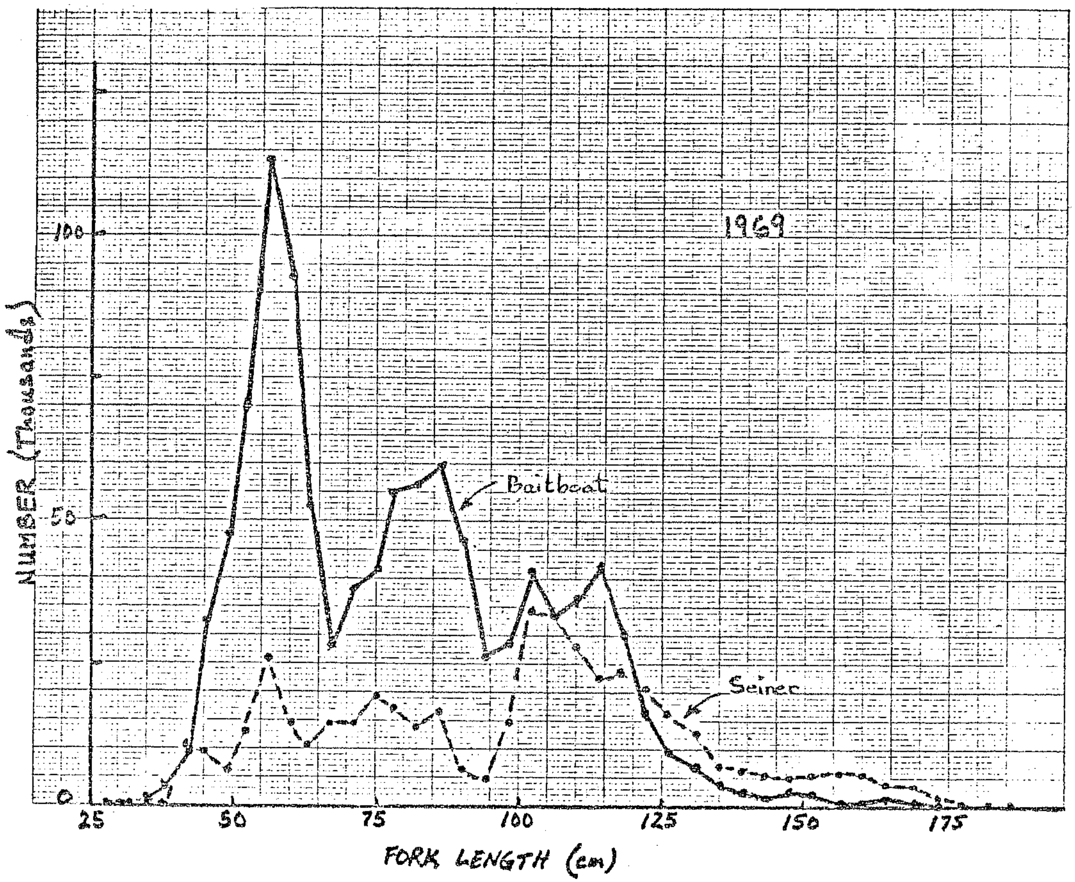

Figure 9. Length-frequency distribution of catch of yellowfin tuna caught by FIS baitboats and small seiners in 1969. Data are from Fonteneau (personal communication).

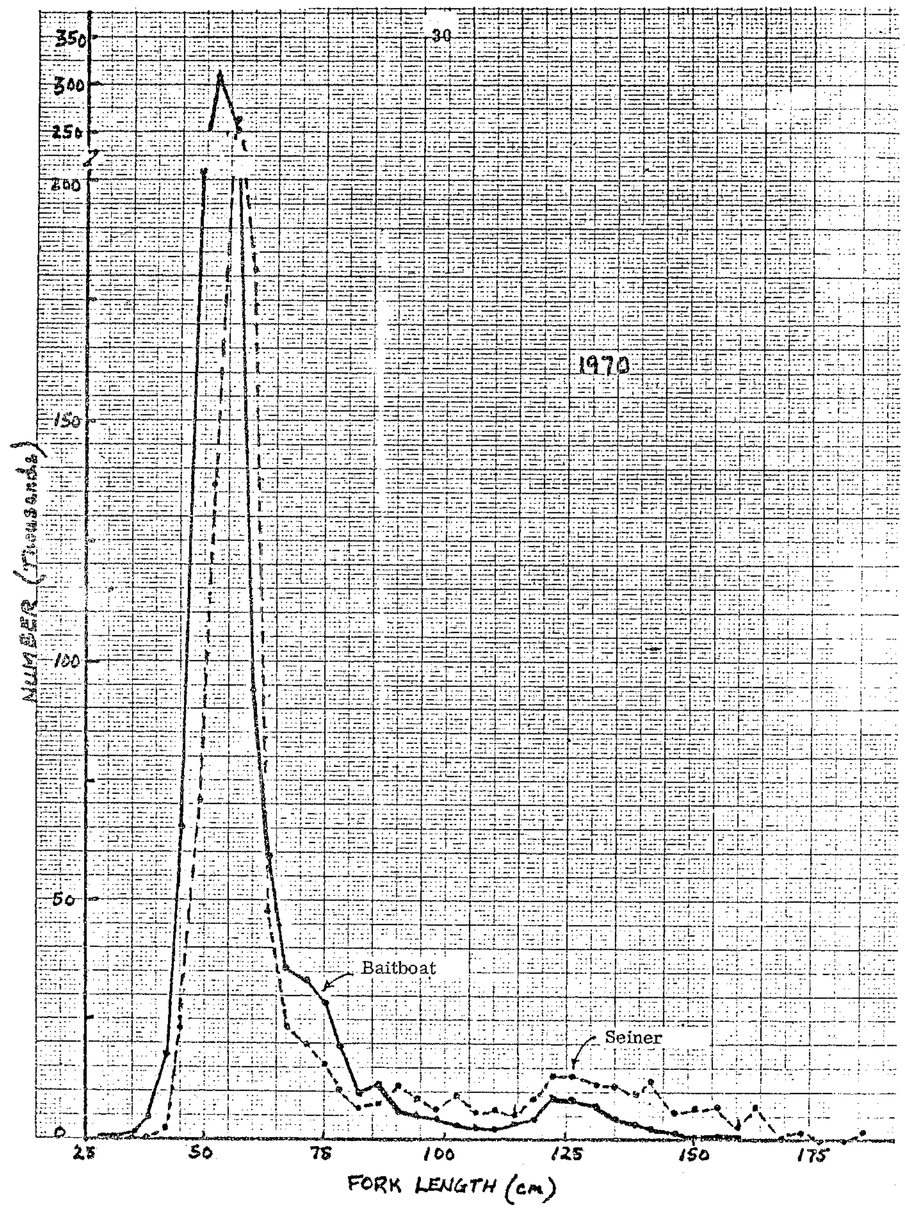

Figure 10. Length-frequency distribution of catch of yellowfin tuna caught by FIS baitboats and small seiners in 1970. Data are from Fonteneau (personal communication).

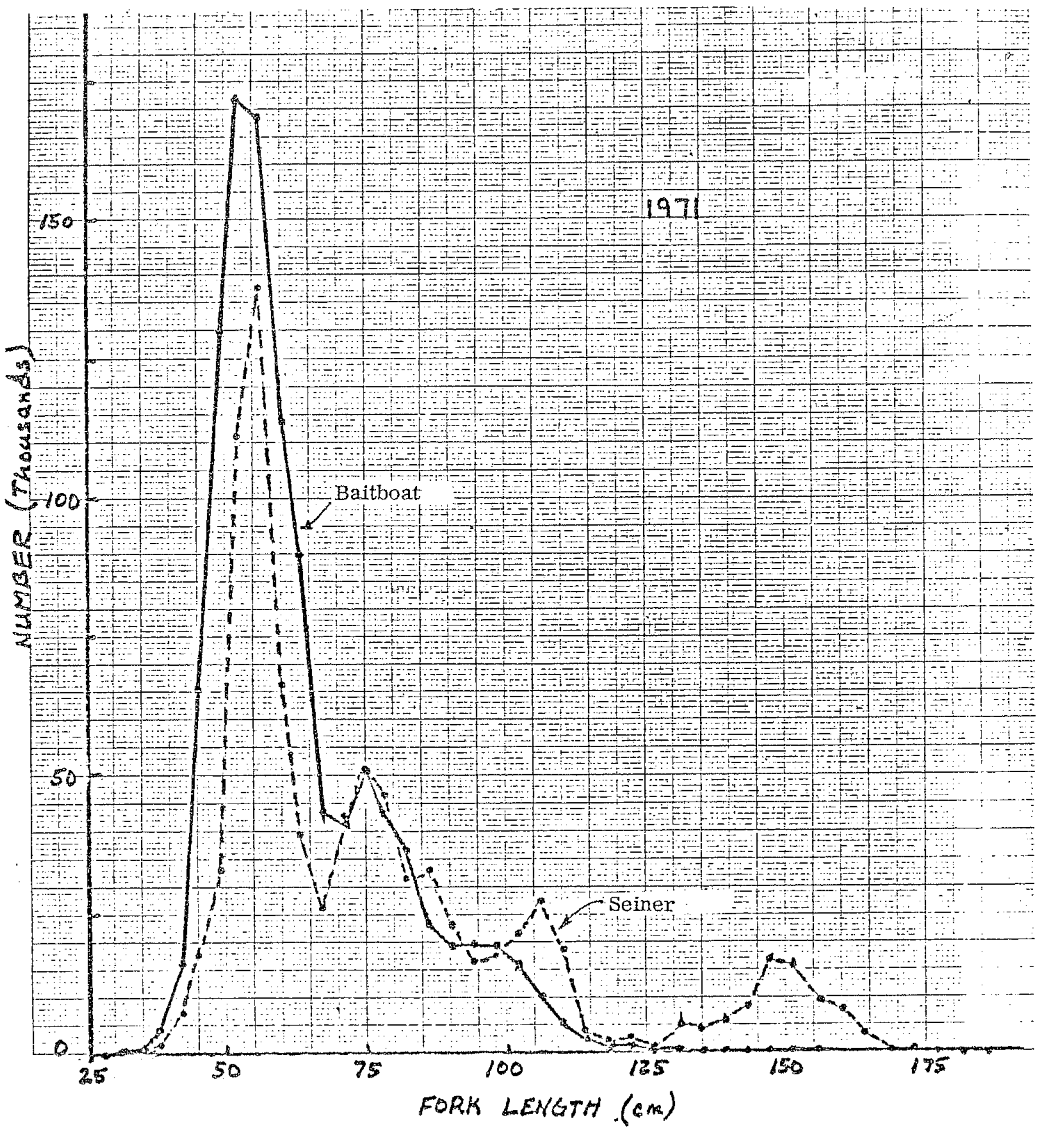

Figure 11. Length-frequency distribution of catch of yellowfin tuna caught by baitboats and small seiners in 1971. Data are from Fonteneau (personal communication).

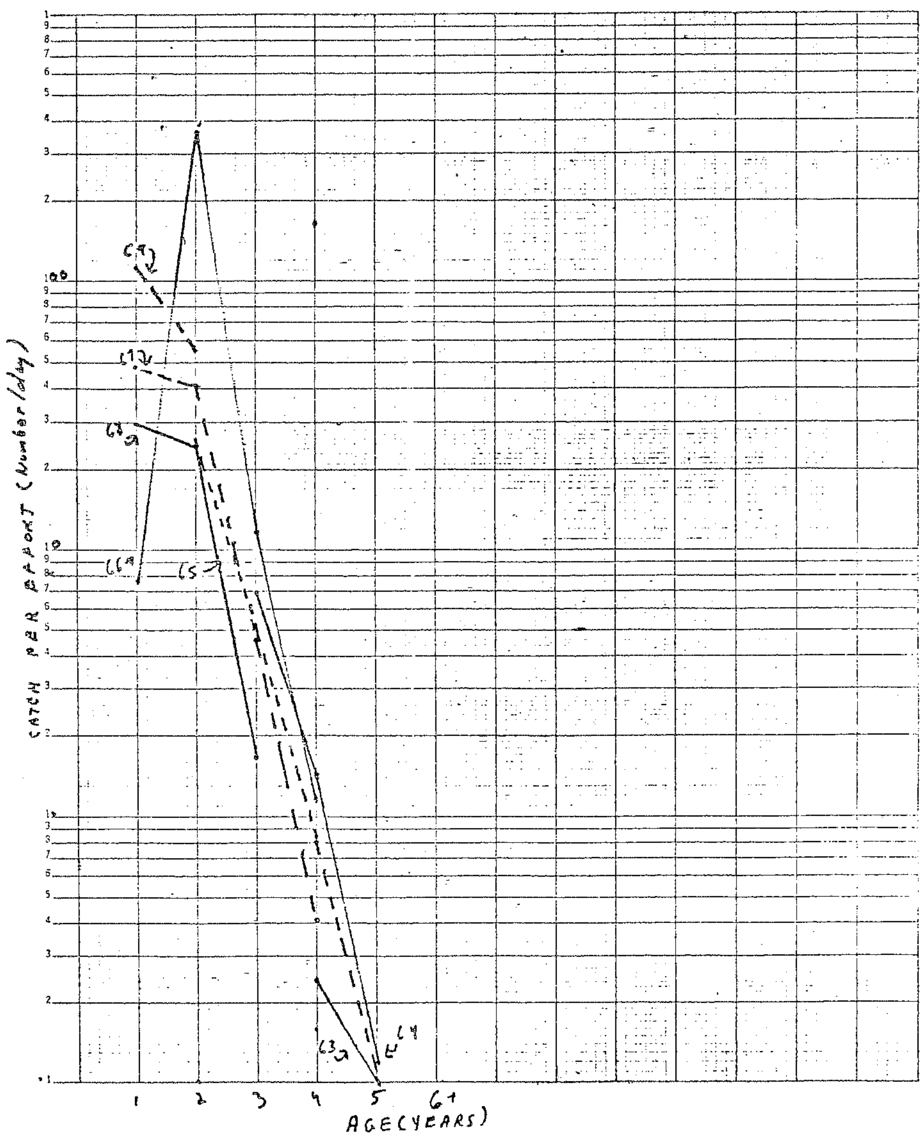

Figure 12. Apparent abundance of the 1963-69 year-classes of yellowfin tuna caught by FIS baitboats in 1967-70.

Estimates of Total Mortality

Estimates of Z, the instantaneous rate of total mortality, for Atlantic yellowfin tuna were derived by analysis of apparent abundance (CPUE) of individual year-classes, 1963-67 (Table 9). Data for three types of vessels -- FIS bait-boat, FIS seiner (<350 tons capacity), and American seiner (>400 tons capacity)-- were analyzed separately and for only ages that were fully recruited (Figures 12-14). Z was estimated by regression.

The range of Z based on data from the FIS baitboats is 1.24 to 2.55 from the FIS seiners, 0.58 to 1.45 and from American seiners, 1.21 to 3.80 (Table 10). Analysis of covariance indicated that the Z's within type of vessel were not significantly different from each other (P = 0.05).

The average Z based on data from the American seiners is 2.53. This seems unreasonably large. A possible causal factor is that in 1970 the American seiners concentrated their fishing effort on catching primarily skipjack tuna, unlike that in previous years. For example, the percentage of yellowfin tuna by weight that was caught in 1967-69 was about 66-82% of the total tuna catch, whereas in 1970 only 44% of the catch was yellowfin tuna (Table 4). Thus, the catch per unit of effort for age groups caught in 1970 is not a reliable estimate of apparent abundance and is not comparable to that of previous years. The effect of including the 1970 data in the analysis was to overestimate Z.

Table 9. Catch per unit effort[1] of year classes of yellowfin tuna that were exploited in 1967-70

Type of vessel	Age (years)	Year class							
		1962	1963	1964	1965	1966	1967	1968	1969
FIS baitboat	1					7.61	48.84	29.77	111.97
	2				25.84	136.27	40.99	25.60	55.68
	3			6.84	5.22	11.72	4.67	1.63	
	4		0.24	1.40	0.80	1.16	0.41		
	5	<0.01	0.02	0.20	0.10	0.06			
	6+	<0.01	0.02	0.03	0.01				
FIS seiner	1					17.15	16.67	30.58	113.84
	2				36.50	74.20	46.74	34.17	62.72
	3			34.64	16.44	32.06	18.66	8.45	
	4		4.00	26.00	9.71	12.10	11.96		
	5	0.54	5.87	4.75	2.28	2.69			
	6+	1.67	1.26	0.49	0.23				
American seiner	1						7.75	98.50	180.65
	2					1697.67	62.41	138.97	
	3				210.08	1303.38	18.60		
	4			314.73	401.88	15.76			
	5		62.02	79.70	8.97				
	6	5.43	7.52	0.53					

[1] Catch per unit of effort is in numbers of fish/day at sea for FIS baitboats and seiners, and numbers of fish/day's fishing for American seiners.

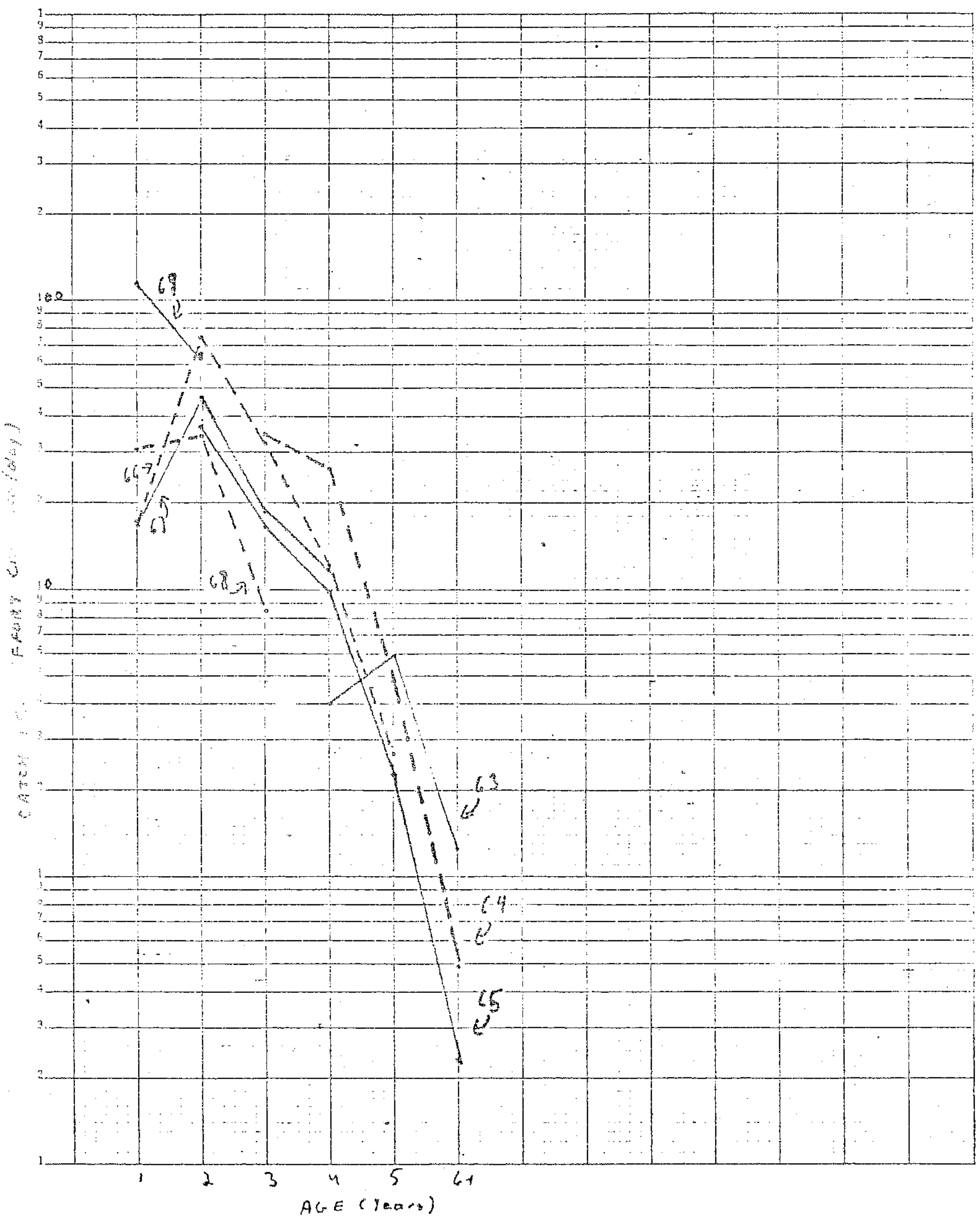

Figure 13. Apparent abundance of the 1963-67 year-classes of yellowfin tuna caught by French seiners in 1967-70.

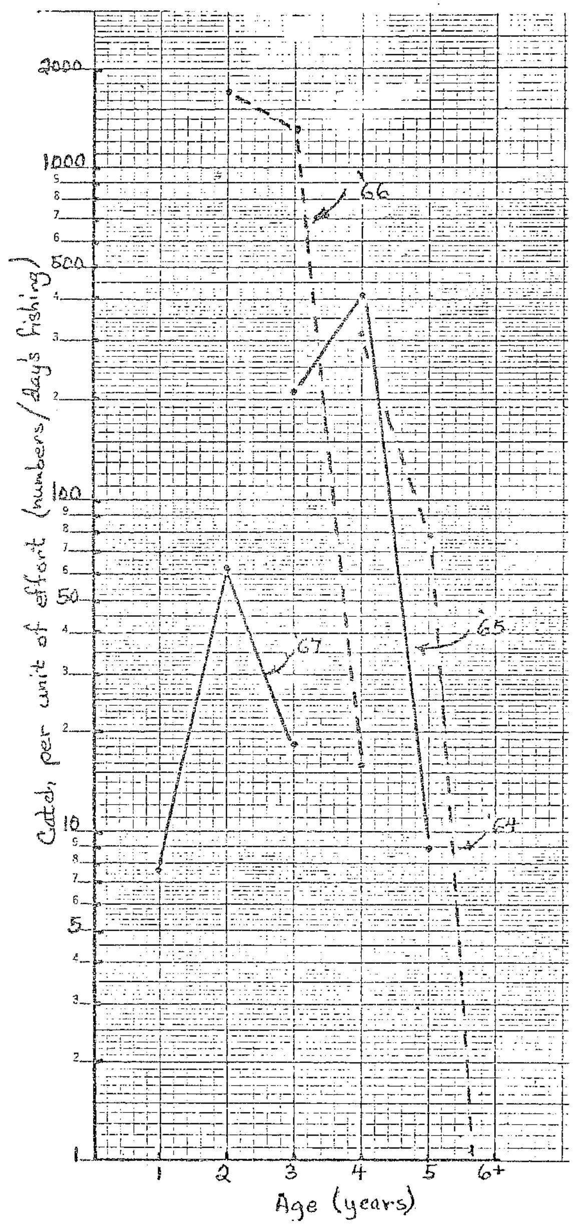

Figure 14. Apparent abundance of the 1964-67 year-classes of yellowfin tuna caught by American seiners in 1968-70.

Table 10. Estimates of instantaneous rate of total mortality (Z) for yellowfin tuna from the eastern tropical Atlantic

Year class	FIS baitboat	FIS seiner	American seiner	Average: FIS baitboat and seiner	Average: All vessels
1963	1.24	0.58	2.11	0.91	1.31
1964	1.82	1.45	3.19	1.63	2.15
1965	1.97	1.21	3.80	1.59	2.33
1966	2.55	1.09	2.34	1.82	1.99
1967	1.65	0.68	1.21	1.16	1.18
Average	1.85	1.00	2.53	1.42	1.79

The average Z for the period 1967-70 based on data from FIS baitboats and seiners is 1.42 (Table 10). This is probably our best estimate for Atlantic yellowfin tuna caught by the surface fishery, although probably it is an overestimate because of variable availability and vulnerability.

Comments on estimation of total mortality

A tacit assumption of our method of estimating Z is that CPUE is an index of abundance. Yet in our earlier discussions we indicated that the CPUE data of Atlantic yellowfin tuna, which we used here, were not complete enough for us to determine whether the CPUE is a reliable index of abundance. We are cognizant of this possibly source of error in the estimates. Our estimates of Z must therefore be considered as crude approximations.

Another possible source of error is our method of ageing. Since our Z's are based on age specific CPUE's, errors in ageing are carried into the estimate of Z. One method of minimizing the ageing error is to estimate Z directly from the length-frequency distribution.

A third problem involves the assumption, in this analysis, that fish of all ages are equally "available" to all types of gears in the fishery. Yet, it was shown earlier (Figure 7) that this is not the case; availability of fish to the FIS baitboat becomes reduced with increasing age.

Analysis of Yield

Yield and effort

Our analysis of CPUE data indicated that we are presently unable to select with confidence any one series of CPUE as a measure of apparent abundance of Atlantic yellowfin tuna. If we had to make a choice, however, the series for Point Noire baitboats and seiners, and FIS baitboats and seiners (Figure 4) would be our choice, because the data were gathered from vessels that have not changed too much through the years and they fish during the entire year off Africa (Figure 6).

The CPUE's of these vessels were used to estimate the fishing effort for the surface fishery by dividing surface catch by CPUE (Table 11). Surface catch was then graphed as a function of fishing effort (Figure 15). The results indicate that the surface catch in 1965-71 leveled off at between 30,000 and 60,000 tons, although fishing effort appears to have varied between 2- and 4-fold during the same period. Of course, this analysis holds only if the CPUE's are representative measurements of CPUE for the entire surface fishery.

Estimates of Z for the 1963-67 year-classes were made in an earlier section (Table 10). It was indicated that the estimates are not entirely free from errors and are approximations. Evidence was also presented which indicated that the Z's from CPUE of American seiners were too high, and probably our best estimates for the surface fishery were the average Z's based on CPUE's of FIS baitboats and seiners.

Table 11. Estimated fishing effort for the surface fishery from estimates of CPUE of baitboats and seiners

Year	Surface catch (tons)	Pt. Noire baitboat		Pt. Noire seiner		FIS baitboat		FIS seiner	
		CPUE[1]	Estimated[2] effort	CPUE[1]	Estimated[2] effort	CPUE[3]	Estimated[2] effort	CPUE[3]	Estimated[2] effort
1964	29,500	3.0	9,800						
1965	23,700	2.3	10,300						
1966	37,700	3.1	12,200	4.3	8,806				
1967	36,400	3.3	11,000	4.3	8,500	0.50	72,800	1.60	22,800
1968	52,800	3.4	15,500	4.6	11,500	1.30	40,600	2.80	18,900
1969	61,800	1.8	34,300	3.5	17,700	1.14	54,200	2.99	20,700
1970	44,800	1.5	29,900	2.0	22,400	0.94	47,700	2.09	21,400
1971	43,900	1.4	31,400	1.9	23,100	1.06	41,400	2.18	20,100

[1] tons/day at sea, ICCAT (1972).

[2] days at sea.

[3] tons/day at sea; 1967-68: estimated NMFS; 1969-70: Fonteneau (personal communication).

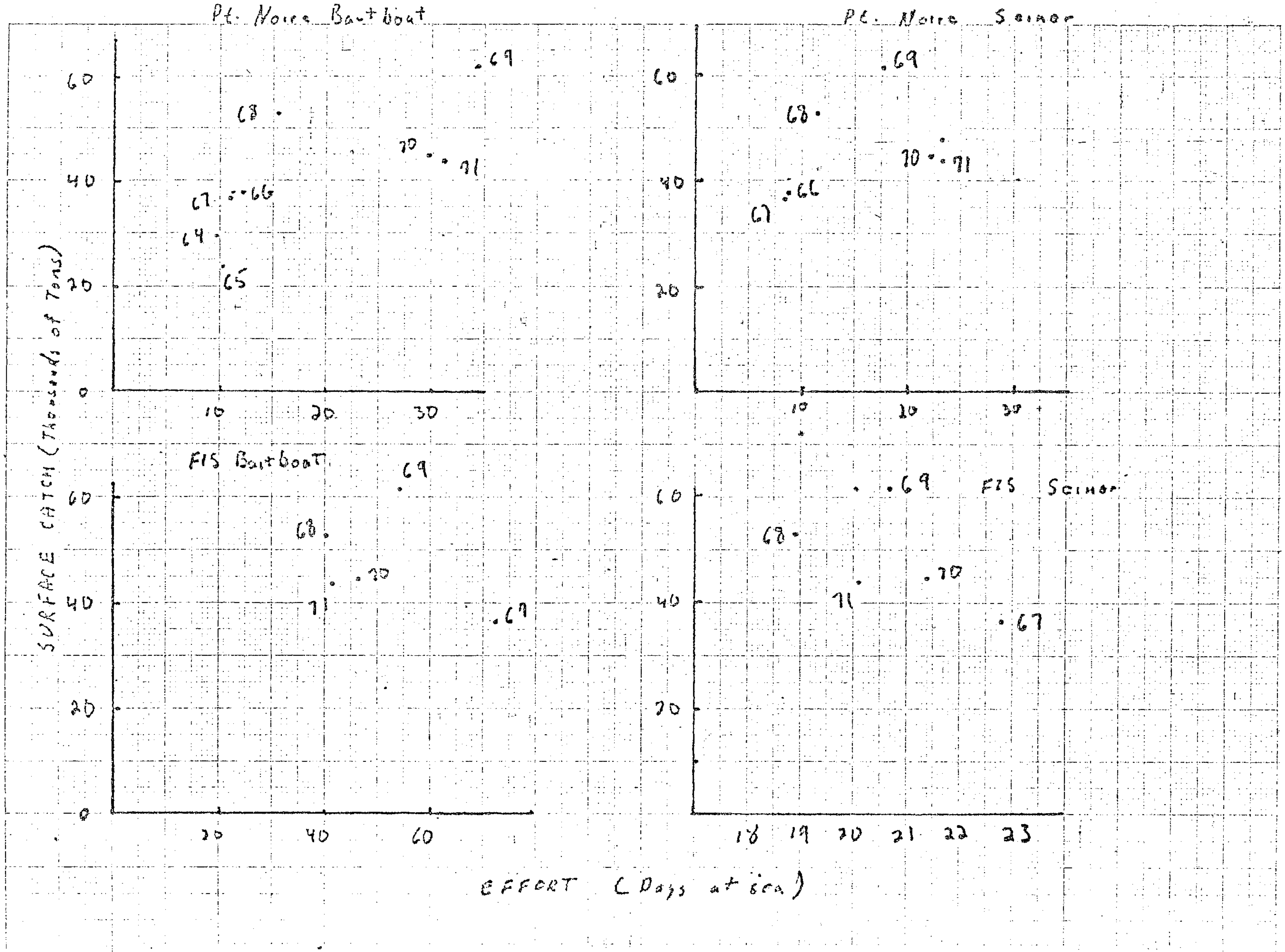

Figure 15. Surface catch as a function of estimated fishing effort. Fishing effort was estimated from each years catch and CPUE of a particular fleet.

We assumed that the instantaneous rate of natural mortality (M) is 0.8, and the instantaneous rate of fishing mortality (F) of fish exploited by the surface fishery is (Z - 0.8), from

$$F = Z - M.$$

Thus, with our best estimates of Z we obtained (Table 12) another measure of fishing effort for the surface fishery.

Since the surface fishery exploits primarily fish of ages 1-3 years (Table 8), we averaged the catches of the first 3 years in which a year class was present in the surface fishery. This gave a catch statistic that was comparable in time with our year-class specific F. A graph of the average catch as a function of F (Figure 16) is not too different from earlier graphs, based on CPUE data of FIS vessels.

A method of estimating fishing effort without relying on the CPUE data of the surface fishery is to use data on the longline fishery. Let us assume that the number of fish entering the longline fishery in year i is

$$R_i = R_s e^{-(F_{i-1} + M)t}$$

Table 12. Mortality rates for yellowfin tuna caught in the surface fishery of the eastern tropical Atlantic

Year class	Z	M	F	Years	Average catch (metric tons)
1963	0.91	0.80	0.11	1964-1966	30,300
1964	1.63	0.80	0.83	1965-1967	32,600
1965	1.59	0.80	0.79	1966-1968	42,300
1966	1.82	0.80	1.02	1967-1969	50,300
1967	1.16	0.80	0.36	1968-1970	53,100
Average	1.42	0.80	0.62		

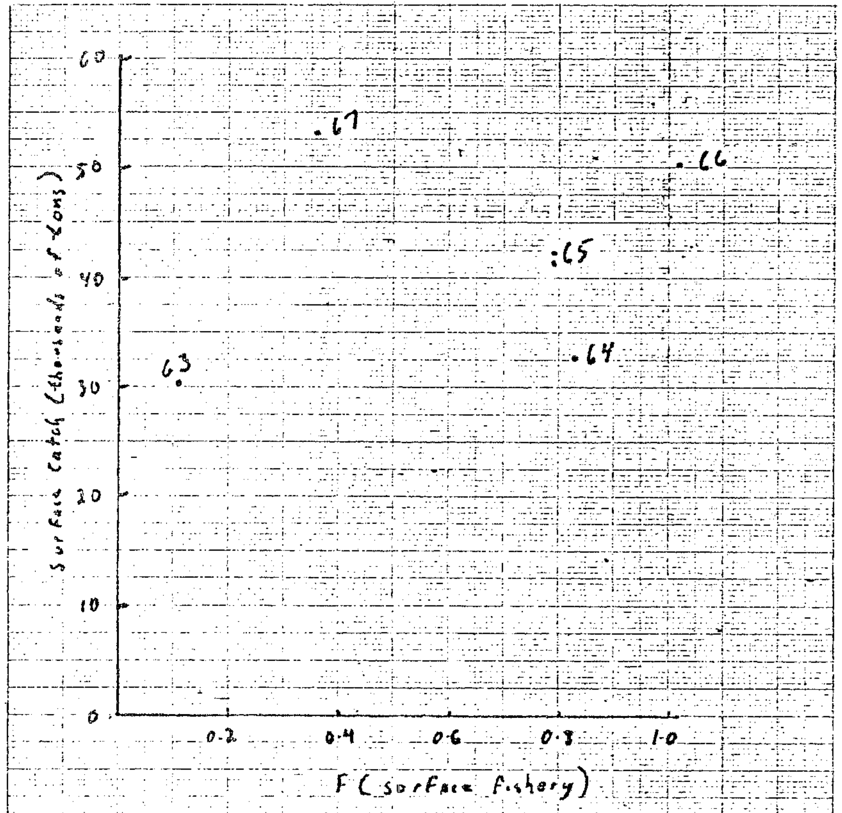

Figure 16. Catch of yellowfin tuna as a function of the instantaneous rate of fishing mortality (F) for the Atlantic surface fishery. Years designate year-classes for which F was estimated.

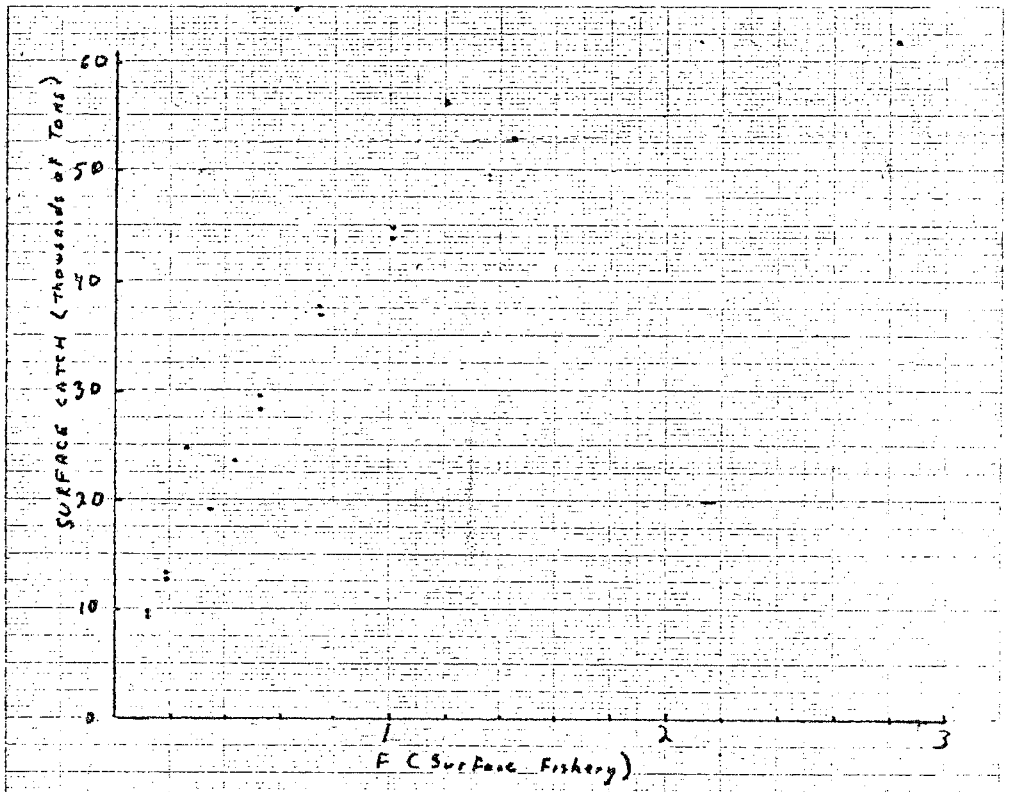

Figure 17. Surface catch as a function of the instantaneous rate of fishing mortality (after Suda, 1970).

where: R_s = recruitment to the surface fishery

F_i = average instantaneous rate of fishing mortality in year i that affected R_s

M = average instantaneous rate of natural mortality

t = time period

The number of fish entering in year i+1 is then,

$$R_{i+1} = R_s e^{-(F_i + M)t}$$

If we assume that R_s, M, and t to be unchanging, then:

$$\frac{R_{i+1}}{R_i} = \frac{R_s e^{-(F_i + M)t}}{R_s e^{-(F_{i-1} + M)t}}$$

Taking natural logs of both sides, we get

$$\ln\left(\frac{R_{i+1}}{R_i}\right) = -F_i t + F_{i-1} t$$

Suda (1970) gave a method of estimating the recruitment of fish to the longline fishery when recruitment to the surface fishery is constant. We used his method to estimate the recruitment of yellowfin tuna (R_i's) to the Atlantic longline fishery (Table 13) for 1957-71. Since in 1957 there was essentially no catch (Table 1) made by the surface fishery, F_1 was set equal to zero. With t = 1 year, F_i was then estimated for 1958-71 (Table 13);

$$-F_i = \ln(R_{i+1}/R_1)$$

A graph of surface catch as a function of F_i (Figure 17), shows that the surface catch increased substantially with increase in effort from 1957. However, in 1969 when effort (2.83) was about two times the amount in 1968 (1.45), the catch only increased by 17%. It thus appears that the catch has leveled off and any increase in fishing effort by the surface fishery would result in no appreciable increase in the yield. Of course, this conclusion is conditioned on three factors: (1) the surface and longline fisheries operate as they have in the past, (2) that recruitment to the surface fishery remains constant as assumed in Suda's model, and (3) that Suda's estimate of the parameters of his models and his assumptions are correct.

Table 13. Estimates of the instantaneous rate of fishing mortality (F) of yellowfin tuna recruited to the Atlantic surface fishery relative to F = 0

Year (i)	R_i	R_{i+1}/R_1	F_{i-1}	Catch of surface fishery (thousands of metric tons)
1957	1.7	1.000	0	0
1958	1.7	0.882	0	9.2
1959	1.5	0.882	0.12	9.6
1960	1.5	0.824	0.12	13.3
1961	1.4	0.824	0.19	12.6
1962	1.4	0.706	0.19	18.1
1963	1.2	0.588	0.35	28.5
1964	1.0	0.588	0.53	29.5
1965	1.0	0.647	0.53	23.7
1966	1.1	0.471	0.44	37.7
1967	0.8	0.471	0.75	36.4
1968	0.8	0.235	0.75	52.8
1969	0.4	0.059	1.45	61.8
1970	0.1	0.353	2.83	44.8
1971	0.6	0.353	1.04	43.9
1972	0.6		1.04	

Yield per Recruitment

Yield per recruit isopleths, based on the Ricker model, for yellowfin tuna in the Atlantic were estimated using the computer program FRG708 (Abramson, 1971). Recruitment was assumed to be knife edged and natural mortality (M) constant over age. Growth was estimated from Le Guen and Sakagawa (in press). Yield isopleths for two values of M (0.8 and 1.0) are shown in Figures 18 and 19. The results are slightly different. For example, when M = 1.0 and fishing mortality (F) = 1.0, maximum yield per recruit is obtained when age at recruitment is about 2 years, but when M = 0.8 and F = 1.0, maximum yield per recruit is obtained when age at recruitment is about 2.3 years.

The different results are interesting because yellowfin tend to become less available to surface fishing as they grow larger (which could be considered equivalent to an increase in M), whereas they tend to become more available to longline fishing as they grow larger. A way to examine this phenomenon is to plot isopleths of the difference between yield per recruit when M = 0.8 and when M = 1.0. The resulting isopleths indicate the relative strategies that should be employed by longline and surface gears. The isopleths (Figure 20) are all positive because more yellowfin survive to a given age when M = 0.8 than when M = 1.0. The highest value is obtained when F = 3.0 and age at recruitment = 3.2 years. The lowest value is obtained when F = 3.0 and age of recruitment = 1 year. The results suggest that the best yield per recruitment is obtained with a lower age at recruitment for the surface fishery than that for the longline fishery.

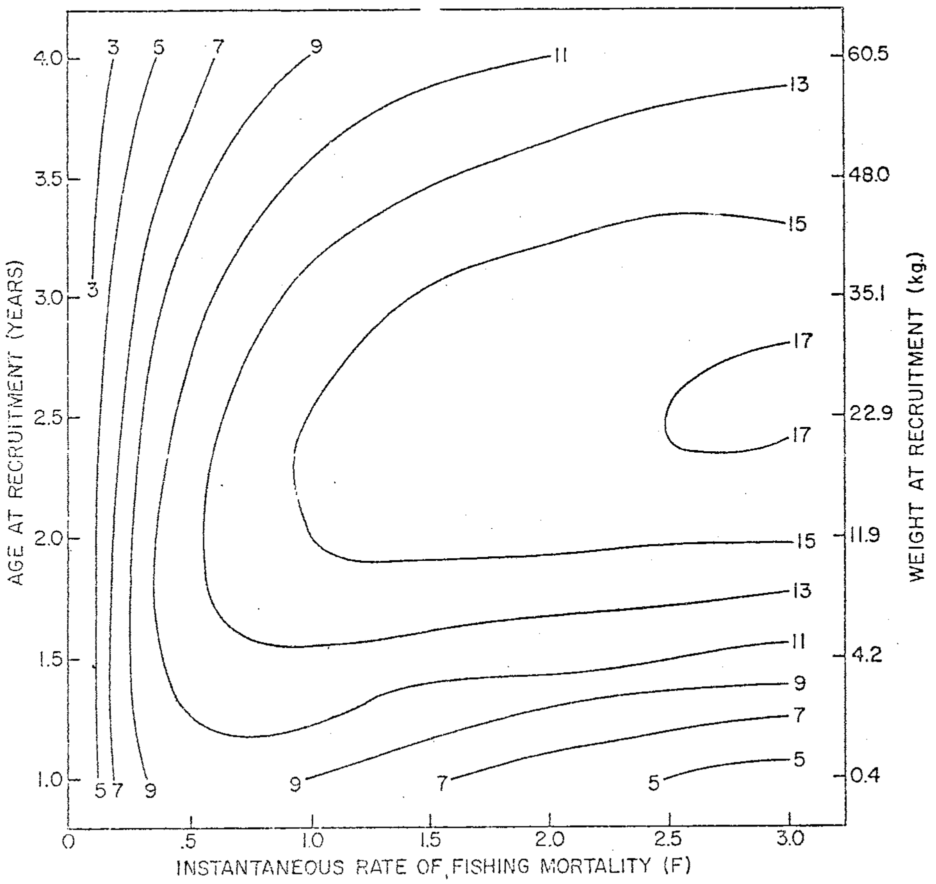

Figure 18. Yield per recruit isopleths as function of fishing mortality, age at recruitment and weight at recruitment when M = 0.8.

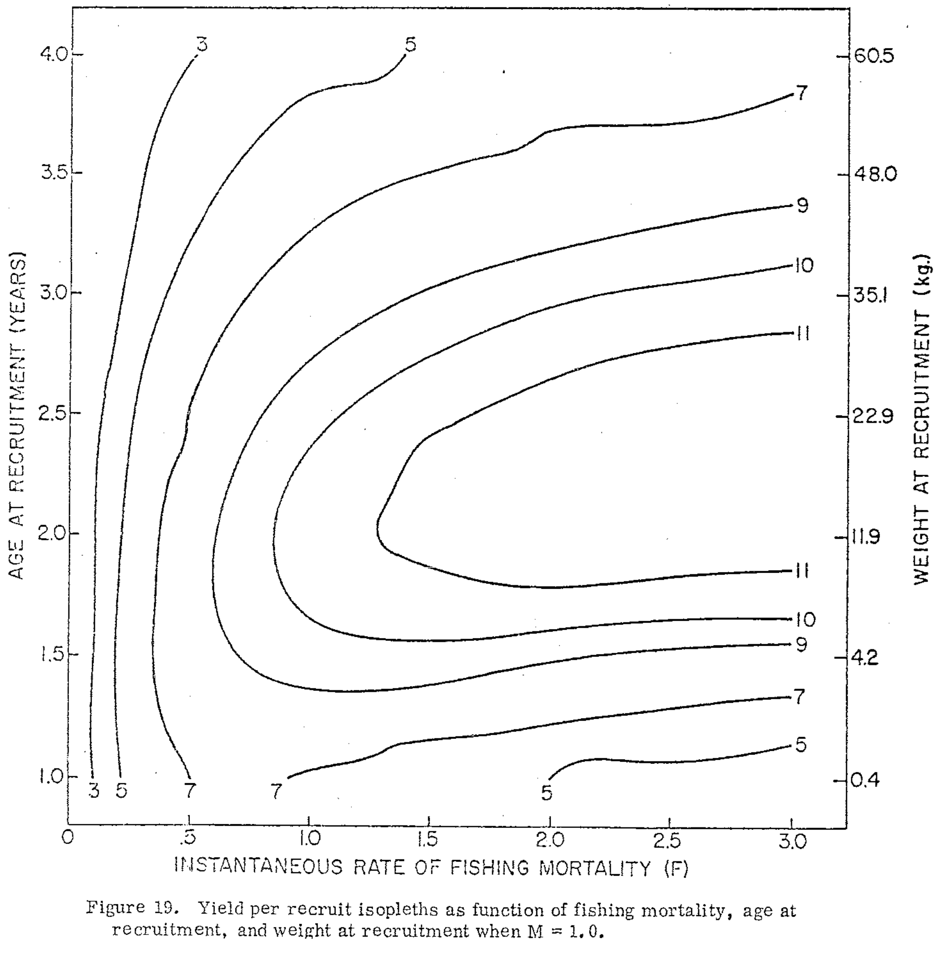

Figure 19. Yield per recruit isopleths as function of fishing mortality, age at recruitment, and weight at recruitment when M = 1.0.

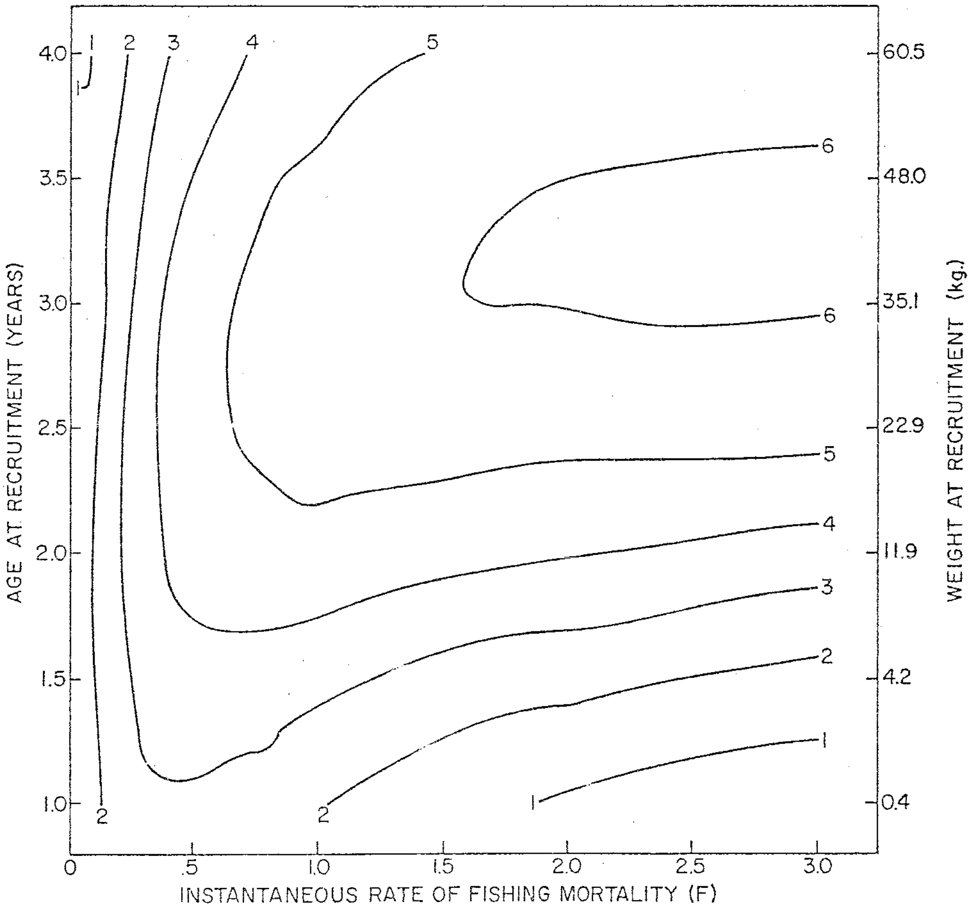

Figure 20. Isopleths of differences between yield per recruit when M = 0.8 and when M = 1.0 as function of fishing mortality, age at recruitment, and weight at recruitment.

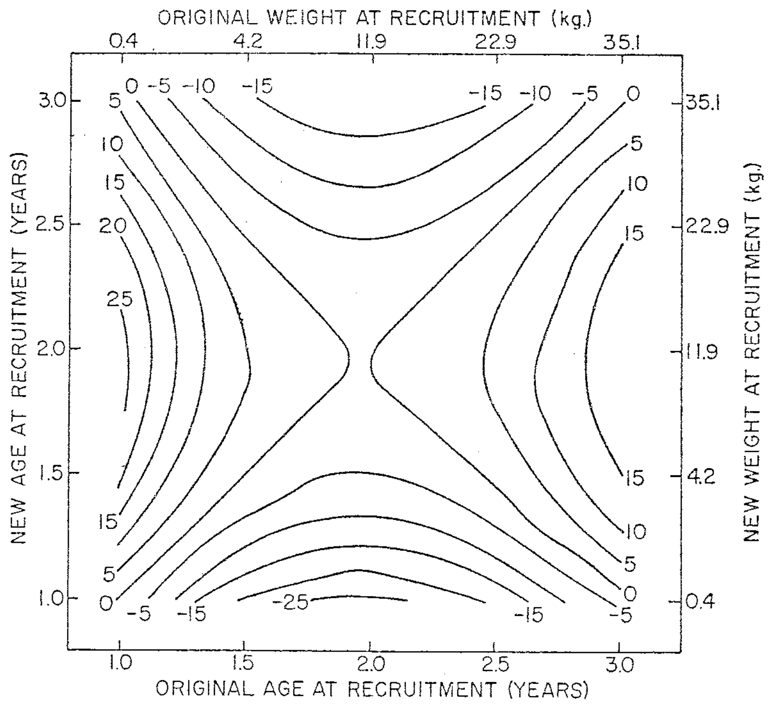

Figure 21. Percentage change in yield per recruit when age or weight at recruitment is changed from original to new and M = 0.8 and f = 0.5.

While the yield isopleths shown in Figure 18 indicate that yield per recruit can be maximized by adjusting age at recruitment, the percentage change in yield per recruit should be examined before recommendations are made for regulation. This is done in Figures 21, 22, and 23. These figures illustrate the percentage change in yield per recruit when age at recruit is changed from the original age at recruitment to the new age at recruitment when $M = 0.8$, and $F = 0.5$, 1.0, and 1.6 respectively. For example if $F = 1.0$ and the original age of recruitment = 1.7 years, a change to age of recruitment = 2.0 years results in a 7.5% increase in yield per recruit.

Estimates of Age at Recruitment

Yield per recruitment models are useful for estimating the theoretical size at recruitment that results in optimum yield per recruitment. From the more practical management point of view, however, the average size at recruitment that results in the optimum yield is more important. This subject is covered in more detail by Lenarz, Fox, Sakagawa, and Rothschild (MS). In this report we present one method of estimating the average size at recruitment of fish caught in the Atlantic yellowfin fishery.

The following equation (Beverton and Holt, 1956) was used to estimate the length at recruitment in centimeters (l_r) when the average length in centimeters ($\bar{l}$) of fish in the catch, Z, and the parameters (K and L_∞) of the von Bertalanffy growth function are known:

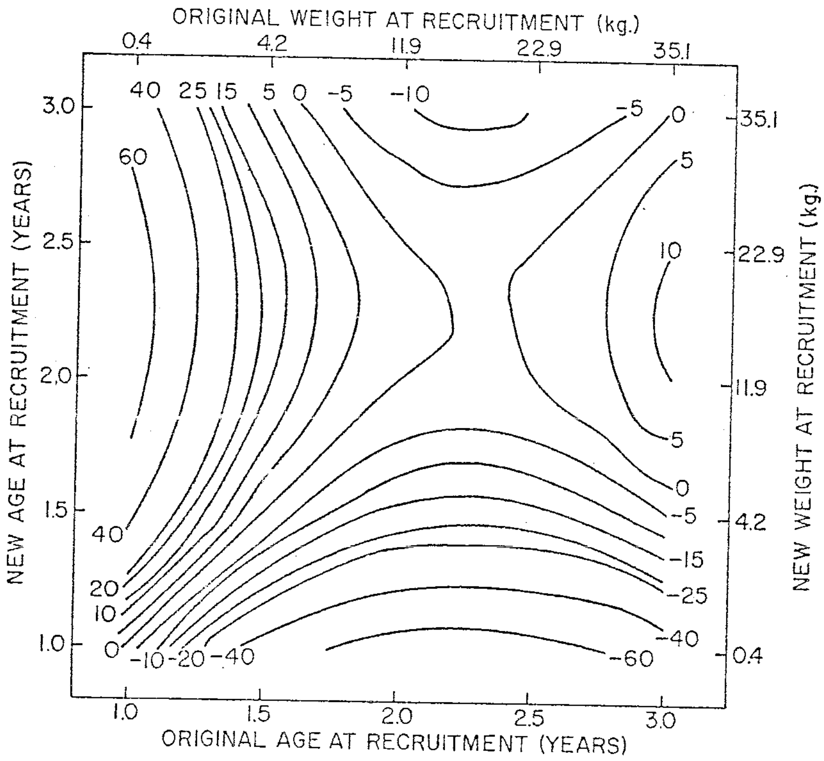

Figure 22. Percentage change in yield per recruit when age or weight at recruitment is changed from original to new and M = 0.8 and f = 1.0.

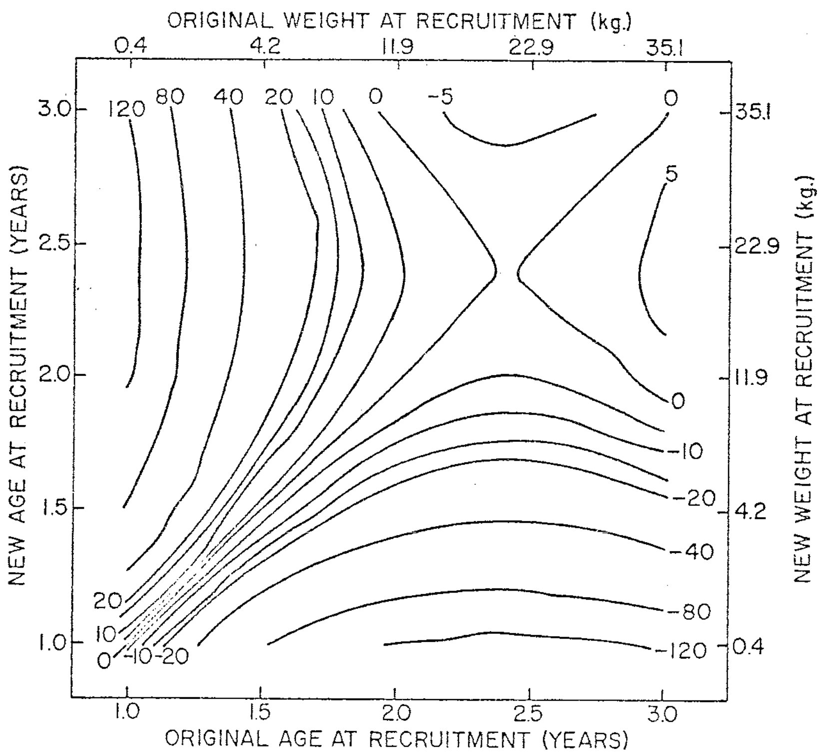

Figure 23. Percentage change in yield per recruit when age or weight at recruitment is changed from original to new and M = 0.8 and f = 1.6.

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

$K = 0.42$ and $L_\infty = 194.8$ were from Le Guen and Sakagawa (in press). Estimates of l_r for the 1968-70 catches of two types of FIS vessels are shown in Table 14. l_r was converted to w_r, or weight at recruitment in kilograms with the weight-length relation of Lenarz (see Le Guen and Sakagawa, in press).

The results indicate that w_r was lower than 12 kg, the weight at age at recruitment of 2 years for optimum yield based on yield per recruitment (Figure 24). It appears that if the average size of fish caught is increased, yield per recruitment can be increased.

We assumed $Z = 1.42$ for the surface fishery (1967-70) and $Z = 1.33$[3] for the longline fishery (1965-69), and averaged the two to get $Z = 1.38$ for the Atlantic yellowfin tuna population. The average length of the catch for the combined surface and longline fisheries was calculated for 1965-71 by weighting the average length of the catch of each fishery by the number of fish caught and then taking the average (Table 15). The average length of fish caught by the Japanese longline fleet was assumed to be identical to that for the entire longline fishery.

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[3] Estimated from age composition of longline catch (ICCAT, 1971c).

Table 14. Estimated length at recruitment in centimeters (l_r) and weight at recruitment in kilograms (w_r) of yellowfin tuna caught by French vessels

Type of vessel	Fishing season			
	1968	1969	1970	1971
FIS baitboat				
Z	1.85	1.85	1.85	1.85
$\bar{l}$	72[1]	80[2]	60[2]	63[2]
l_r	44	54	29	33
w_r	1.6	3.0	0.5	0.7
FIS seiner				
Z	1.00	1.00	1.00	1.00
$\bar{l}$	99[1]	99[2]	76[2]	79[2]
l_r	59	59	26	30
w_r	4.0	4.0	0.4	0.5

[1] Estimated from ORSTOM's data.

[2] Estimated from Fonteneau's (personal communication) data.

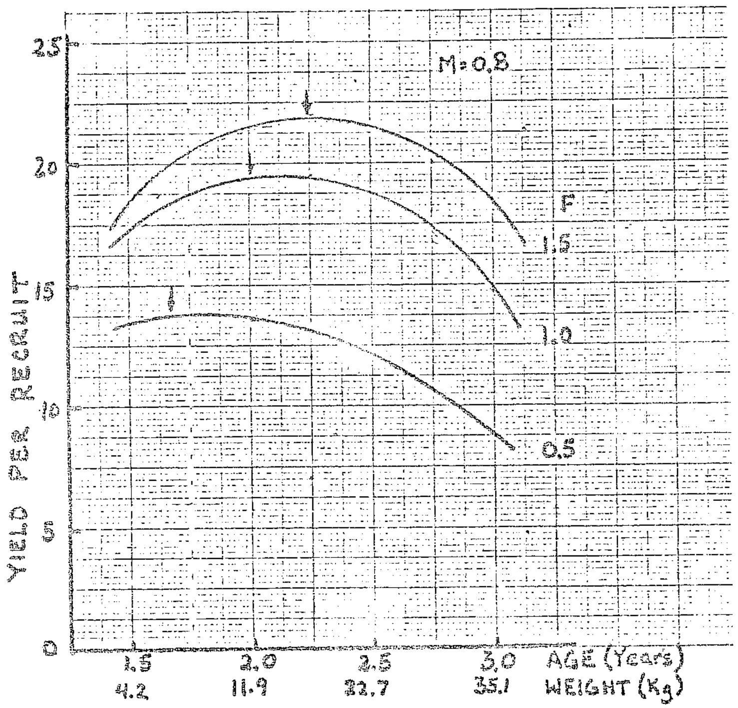

Figure 24. Yield per recruit of yellowfin tuna as a function of age (size) at first capture for various instantaneous rates of fishing mortality (F). The instantaneous rate of natural mortality (M) is constant at 0.8. Arrows indicate the maximum yields per recruit. (Data from ICCAT, 1971b.)

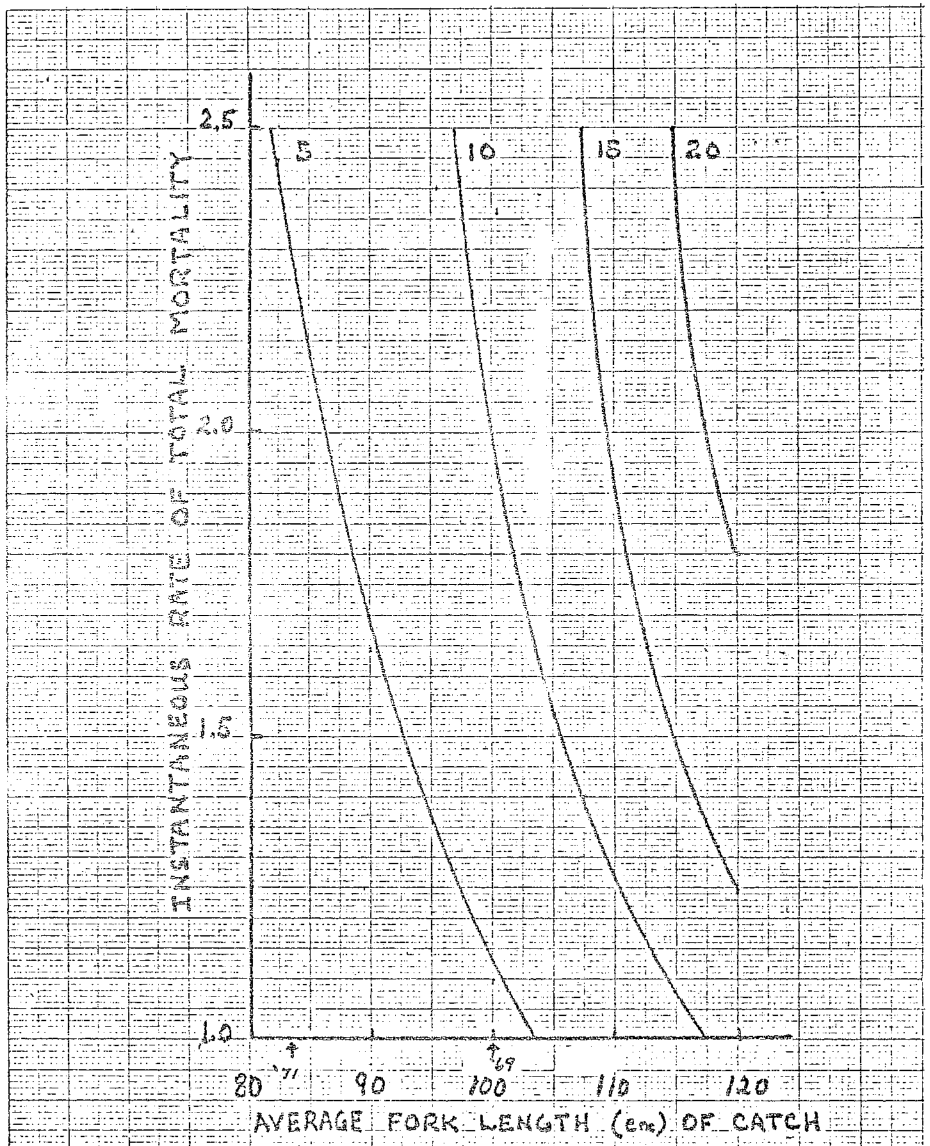

Figure 25. Average weight (in kilograms) at recruitment isopleths for yellowfin tuna. See text for explanation.

Table 15. Estimated average length ($\bar{l}$) of the catch of yellowfin tuna from the Atlantic Ocean

Year	Surface fishery		Longline fishery		All fisheries	
	Catch (1000's fish)	$\bar{l}$ (cm)	Catch (1000's fish)	$\bar{l}$ (cm)	Catch (1000's fish)	$\bar{l}$ (cm)
1965	2,418.8	80	961.2	138	3,380.0	96
1966	4,147.9	78	459.9	143	4,607.8	84
1967	2,519.1	91	426.7	134	2,945.8	97
1968	5,347.8	77	581.5	131	5,929.3	82
1969	2,867.9	92	634.4	133	3,502.3	99
1970	4,175.0	68	882.3	119	5,057.3	77
1971	3,685.8	71	672.4	119[1]	4,358.2	78

[1] Estimate assumed to be the same as 1970.

Probably Z has not remained constant at 1.38 but has varied, presumably increasing with the increase in number of boats in the fishery. If we assume that Z was between 1.5 and 2.0 in recent years (1969-70), w_r is between about 3 kg and 10 kg (Figure 25). This indicates that an increase in the average length of fish caught can increase the yield per recruitment. However, as discussed earlier, the marginal increase in yield should also be examined. As an example, with $F = 1.0$, $M = 0.8$, if w_r is increased from 2 to 12 kg the increase in yield per recruitment is about 25%, and if w_r is increased from 7 to 12 kg the increase in yield per recruitment is 9%.

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