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# A REVIEW OF SOME ASPECTS OF THE BLUEFIN TUNA (THUNNUS THYNNUS THYNNUS) FISHERIES OF THE ATLANTIC OCEAN *

by

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## SUMMARY

The catch of Atlantic bluefin tuna has declined markedly from 36,800 tons in 1962 to 18,500 tons or less in 1971. The decline was accompanied by the demise of some fisheries, a reduction of catch in others, and an increased proportion of small (50 to 122 cm) bluefin tuna in the total catch. The quality and quantity of available data on bluefin tuna are reviewed, some population parameters are estimated, and recommendations for improving the understanding of the dynamics of the population are presented.

The review and analyses of available data indicate that there is conflicting evidence on the health of the stocks, precluding formulation at this time of a rational management program based on firm scientific evidence. However, it is recommended that further expansion of the fisheries be discouraged and (1) more accurate statistics on catch, effort and sizes of fish caught on an Atlantic-wide basis be collected; (2) a critical analysis of the stock structure of the population be undertaken; and (3) analyses of the measures of abundance and yield per recruit with size-specific F be initiated to assess the health of the stock(s) more accurately and to assist in formulating a rational management program.

* Data partially reproduced in Data Record, Vol. 3

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## RESUME

Les prises de thon rouge dans l'Atlantique ont baissé sensiblement, de 36.800 tonnes en 1962 à 18.500 ou moins en 1971. Cette baisse a été accompagnée de l'abandon de certaines pêcheries, d'une réduction des prises dans plusieurs autres, et d'une proportion accrue de thon rouge de petite taille (50 à 122 cms) dans l'ensemble des captures. On a évalué le volume et la valeur de l'information disponible concernant le thon rouge, et on a également estimé quelques paramètres de population et formulé des suggestions visant à une meilleure compréhension de la dynamique des populations.

L'examen et l'analyse des données disponibles indiquent que les renseignements portant sur l'état des stocks sont contradictoires, ce qui empêche de formuler à l'heure actuelle un programme défini de contrôle s'appuyant sur une base scientifique concrète. Il est cependant conseillé de décourager toute expansion ultérieure des pêcheries et d'effectuer les travaux suivants: (1) rassembler des statistiques plus précises sur les prises, l'effort et la taille des poissons capturés dans l'ensemble de l'Atlantique, (2) faire l'analyse critique de la structure des populations, et (3) commencer l'analyse des mesures d'abondance et de rendement par recrue avec F spécifique de la taille afin d'estimer l'état du(des) stock(s) de façon plus précise et d'aider à établir un programme rationnel de contrôle.

* Données partiellement reproduites dans le Recueil de Données Statistiques, Vol. 3

1/ National Marine Fisheries Service

RESUMEN

La captura del Atún Atlántico ha descendido notablemente, de 36.800 toneladas en 1962 a 18.500 toneladas o una cifra inferior en 1971. El descenso llevó consigo el abandono de algunas pesquerías, una reducción de capturas en otras y un aumento en la proporción de pequeños atunes (50 a 122 cm) en la captura total. Se hace un examen de la calidad y cantidad de datos disponibles sobre el atún, se hacen estimaciones de algunos parámetros de poblaciones y se presentan recomendaciones para mejorar el entendimiento de la dinámica de poblaciones.

El examen y análisis de datos disponibles revela que existen pruebas contradictorias sobre la abundancia de los stocks que impiden formular ahora un programa racional de ordenación, basado en pruebas científicas sólidas. Sin embargo, se recomienda que no se promueva una mayor expansión de las pesquerías y que (1) se recojan estadísticas más exactas sobre capturas, esfuerzo y tallas de peces capturados en todo el Atlántico, (2) se efectúe un análisis crítico de la estructura del stock de la población y (3) se inicien análisis de las medidas de abundancias y rendimiento-por-recluta con talla específica F para evaluar la abundancia del stock con más precisión y para ayudar a formular un programa racional de ordenación.


* Datos reproducidos parcialmente en el Vol. 3 de la Colección de Datos Estadísticos

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

The fisheries for bluefin tuna are divided into the surface fisheries, which are located close inshore on both the eastern and western sides of the Atlantic Ocean, and the longline fishery, which is located primarily in the mid-Atlantic. Handline, pole-and-line (baitboat), purse seine, rod-and-reel (sport), trap, and trolling gears are used in the surface fisheries to catch bluefin tuna, generally greater than 50 cm long, that occur close to the surface. Argentina, Canada, Cuba, Denmark, France, Germany, Morocco, Norway, Portugal, Spain, Sweden and the U.S.A. have engaged in surface fishing for Atlantic bluefin tuna. The longline gear is used in the longline fishery to catch deep-swimming bluefin tuna, usually greater than 122 cm long. Brazil, Canada, Cuba, Japan, Korea, South Africa, and Taiwan have participated in this fishery.

The total catch of bluefin tuna from the Atlantic Ocean declined from a peak of about 36,800 tons in 1962 to about 18,500 tons or less in 1971 (Table 1). The decline was accompanied by the demise of several fisheries (e.g., the German and Danish handline fisheries), substantial reduction in catch and effort in some other (e.g., the Moroccan and Spanish trap fisheries), and increased importance of small bluefin tuna (50 to 122 cm) in the total catch (e.g., from the French-Spanish baitboat and Canadian-U.S.A. purse seine fisheries).

In view of this situation, the United Nations Food and Agriculture Organization (FAO) and the International Commission for the Conservation of Atlantic Tunas (ICCAT) each reviewed the status of the stocks and estimated that the optimum size at first capture should be at least 10 kg (78 cm) (FAO, 1968; ICCAT, 1971). They urged that the capture of bluefin tuna less than 10 kg be discouraged because the capture of these small fish would cause a "loss in sustained yield." At the same time, ICCAT proposed a thorough Atlantic-wide investigation of the dynamics of bluefin tuna, to provide a scientific basis for rational management of the resource. Because of the U.S.A. commercial and sport fisheries for bluefin tuna and our vested interest in the rational conservation of the resource, a compilation and analysis of the available data on the dynamics of Atlantic bluefin tuna is presented in this paper.

Our objectives are to determine the nature of available data, to estimate some population parameters, to examine trends in production both on a regional and on an Atlantic-wide basis, to draw conclusions, as possible, on the status of the Atlantic bluefin tuna stocks, and to make recommendations on methods for improving the quality of the data required for determining the status of the population. These procedures are the first steps toward a better understanding of the dynamics of the bluefin tuna population, as needed for the rational management of the resource.

**Table 1.** Catch (in thousands of metric tons) of bluefin tuna from the Atlantic Ocean and Mediterranean Sea. Sources of data are Hamre et al. (1966) and Miyake and Tibbo (1972).

| Region and nation | Year of catch | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 |
| Northeast Atlantic | | | | | | | | | | | | | |
| Denmark | <0.1 | 0.2 | 0.2 | <0.1 | 0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | |
| France[1] | 0.6 | 2.0 | 1.7 | 1.2 | 1.7 | 1.4 | 1.6 | 1.0 | 0.6 | 0.6 | 0.6 | 0.8 | |
| Germany | 0.4 | 0.3 | 0.2 | <0.1 | <0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Morocco[1,2] | 6.0 | 2.3 | 1.6 | 3.9 | 4.4 | 2.9 | 3.6 | 3.4 | 1.3 | 0.8 | 0.7 | 0.2 | |
| Norway | 3.3 | 8.0 | 8.2 | 0.2 | 1.5 | 2.5 | 1.0 | 1.9 | 0.7 | 0.9 | 0.4 | 0.6 | |
| Portugal[1,3] | 0.9 | 1.6 | 1.3 | 0.9 | 0.9 | 0.4 | 0.2 | 0.2 | 0.3 | 0.5 | 0 | - | |
| Poland | - | - | - | - | - | - | - | - | - | - | - | 0.1 | |
| Spain[1,2] | 9.7 | 6.8 | 15.6 | 10.8 | 8.2 | 11.2 | 8.7 | 10.6 | 8.7 | 7.1 | 5.5 | 3.9 | |
| Total northeast | 21.1 | 21.2 | 28.8 | 17.0 | 16.8 | 18.4 | 15.1 | 17.1 | 11.6 | 9.9 | 7.4 | 5.6 | |
| Southeast Atlantic | | | | | | | | | | | | | |
| South Africa | - | - | - | 0.4 | 0.2 | - | - | - | - | - | <0.1 | <0.1 | |
| Northwest Atlantic | | | | | | | | | | | | | |
| Canada | <0.1 | 0.1[4] | 0.2[4] | 0.7[4] | 1.0[4] | 0.7[4] | 0.3[4] | 0.4[4] | 0.4[4] | 0.6[4] | 1.6[4] | 1.1[4] | 0.4[4,5] |
| Cuba | - | - | - | - | - | 0.1 | 0.5 | 2.4 | 1.4 | 0.5 | 0.2 | 0 | |
| U.S.A. | 0.6 | 1.1 | 4.0 | 5.7 | 5.1[4] | 3.4[4] | 1.5[4] | 2.4[4] | 0.7[4] | 1.7[4] | 3.4[4] | 3.4[4] | 2.1[4,5] |
| Total northwest | 0.6 | 1.2[4] | 4.2[4] | 6.4[4] | 6.1[4] | 4.2[4] | 2.3[4] | 5.2[4] | 2.5[4] | 2.8[4] | 5.2[4] | 4.5[4] | |
| Southwest Atlantic | | | | | | | | | | | | | |
| Argentina | - | - | 0.1 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | <0.1 | <0.1 | <0.1 | - | |
| Longline Atlantic | | | | | | | | | | | | | |
| Brazil | - | - | - | - | - | - | - | - | - | - | - | 0.1 | |
| Japan | 0.8 | 0.6 | 3.7 | 7.8 | 12.6 | 9.6 | 2.9 | 0.9[6] | 0.4[6] | 0.8[6] | 4.4[6] | 5.2[6] | |
| Korea | 0 | 0 | 0 | 0 | 0 | 0 | - | - | - | - | - | 3.0[7] | |
| Taiwan | 0 | 0 | 0 | 0 | 0 | 0 | <0.1[7] | <0.1[7] | 0.1[7] | 0.2[7] | 0.1[7] | 0.1[7] | |
| Total longline | 0.8 | 0.6 | 3.7 | 7.8 | 12.6 | 9.6 | 2.9 | 0.9[6] | 0.5[6] | 1.0[6] | 4.5[6] | 8.4[6] | |
| Total Atlantic | 22.5 | 23.0[4] | 36.8[4] | 31.9[4] | 35.9[4] | 32.3[4] | 20.4[4] | 23.3[4,6] | 14.6[4,6] | 13.7[4,6] | 17.1[4,6] | 18.5[4,6] | |
| Mediterranean | | | | | | | | | | | | | |
| Algeria | 0.3 | <0.1 | - | <0.1 | <0.1 | <0.1 | 0.1 | 0.2 | 0.1 | 0.2 | 0.1 | 0.1 | |
| France | 0.4 | 0.6 | 0.2 | 0.3 | 0.5 | 0.3 | - | - | - | 1.5 | 1.2 | 1.9 | |
| Greece | - | 1.1 | 1.0 | - | 0.6 | 0.7 | 0.5 | 0.6 | 0.5 | - | 0.5 | - | |
| Italy | 1.4 | 2.0 | 2.0 | 2.4 | 2.5 | 2.1 | 1.7 | 4.0 | 3.4 | 5.5 | 3.2 | 4.5 | |
| Libya | - | - | - | - | 0.4 | 0.6 | 0.7 | 0.8 | 1.0 | 2.9 | 0.5 | 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 | |
| Spain | - | - | 0.6 | 0.3 | 0.4 | 0.6 | 0.2 | 0.5 | 0.1 | 0.2 | 0.2 | 0.1 | |
| Tunisia | - | - | - | - | 0.5 | 0.8 | 0.6 | 0.7 | 0.7 | 0.6 | 0.3 | 0.5 | |
| Turkey | 0.3 | 0.3 | 0.2 | 0.1 | <0.1 | 0.1 | 0.1 | 1.5 | 0.3 | 0.4 | 0.1 | <0.1 | |
| Yugoslavia | 0.1 | 0.1 | 0.1 | 0.3 | 0.3 | 0.1 | 0.2 | 0.3 | 0.2 | 0.3 | 0 | 0.3 | |
| Total Mediterranean | 2.6 | 4.2 | 4.1 | 3.5 | 5.3 | 5.4 | 4.2 | 8.7 | 6.4 | 11.6 | 6.1 | 8.0 | |
| Total Atlantic and Mediterranean | 25.1 | 27.2[4] | 40.9[4] | 35.4[4] | 41.2[4] | 37.7[4] | 24.6[4] | 32.0[4,6] | 21.0[4,6] | 25.3[4,6] | 23.2[4,6] | 26.5[4,6] | |

[1]Estimates for these countries vary considerably depending on source and probably includes other species of tunas. They are not necessarily the same as in Table 7--see text.

[2]Estimates include some catches from the Mediterranean.

[3]Estimates do not include "Island" catches of Miyake and Tibbo (1972), which are presumed to be mostly other tuna species.

[4]Some sport catches are included. See Table 16 and text for estimation of U.S.A. sport catches.

[5]Preliminary estimates.

[6]Estimates include southern bluefin tuna caught by the Japanese.

[7]Dressed weight.

## ANALYSIS OF FISHERIES DATA

### Catch Statistics

Catch statistics on Atlantic bluefin tuna by nations have been compiled and published by FAO (1968), the International Council for the Exploration of the Sea (ICES), (Hamre et al., 1966, 1968, 1971; ICES, 1964-71), and ICCAT (Miyake and Tibbo, 1972). These organizations use different sources and methods of compiling statistics and in many cases the total catch by countries do not agree.

### Estimate of Quality of Catch Data

We compiled a table of Atlantic Ocean and Mediterranean Sea catches (Table 1), gleaned primarily from statistics published by Miyake and Tibbo (1972), supplemented with statistics from Hamre et al. (1966). We are aware that some of the reported catches in Table 1, as well as in the sources we used, are incomplete or even erroneous, owing to poor reporting of statistics or to inclusion of unknown quantities of other species of tunas by some countries. For example, the U.S.A. catch includes a crude estimate of fish caught by the sport fishery; the Cuban, Moroccan, Portuguese and Spanish catches probably are not all bluefin tuna but include other tuna species as well; and the 1967-71 Japanese total longline catch includes southern bluefin tuna which apparently constitutes the bulk of the reported catch. Therefore, the total figures in Table 1 should be considered crude estimates and at best only useful for analysis of general trends over the series of years.

## Analysis of Catch Data

The total bluefin tuna catch from the Atlantic Ocean from 1960-71 fluctuated, but had an overall downward trend in 1964-69 and an upward trend in 1969-71 (Figure 2). The upward trend is probably an anomaly caused by the increased Japanese catches of southern bluefin tuna which are reported together with bluefin tuna statistics (Table 1). If we take this into account, the trend in total Atlantic bluefin tuna catch appears to have actually leveled off or declined at a slower rate during 1969-71, with the decline occurring in the catch from the eastern Atlantic, not from the western Atlantic (Table 1).

In the Mediterranean, on the other hand, the total catch shows a slight upward trend. This difference in trends in the Atlantic and Mediterranean has been used as evidence that independent stocks are exploited in the two regions (Hamre et al., 1971). However, there is evidence, e.g., from tagging, sizes of fish, and trap catches, that some mixing occurs between stocks in the Atlantic and Mediterranean (Aloncle, 1964; Rodriguez-Roda, 1969). In this review, we have assumed that mixing is negligible, and the stocks are essentially separate.

Small bluefin tuna (50 to 122 cm) are caught in commercial quantities off the east coast of the U.S.A. and in the Bay of Biscay and adjacent waters.[2] In recent years (1965-71), small bluefin have been increasingly important in the total surface catch from the western and eastern Atlantic. Miyake and Tibbo (1972) reported the total catch of small bluefin caught commercially in the western Atlantic; we estimated the catch of small bluefin in the sport fishery from tagging data (see section on Estimation of Age Composition). The major portion of the estimated catches of French and Spanish boats are small bluefin tuna (Bard et al. (1972[3]). Morocco and Portugal also catch small bluefin tuna in the eastern Atlantic but the exact quantity is not known. As an approximation, we estimated the small-fish catch of Morocco by assuming that all bluefin caught by gears other than traps were small fish. We assumed that the Portuguese small-fish catch was negligible, although we are uncertain about the validity of this assumption because the Portuguese report their catch of other species of tuna with that of bluefin tuna (see Miyake and Tibbo, 1972). We then pooled the small bluefin tuna catches of all fleets (see Table 7--French-Moroccan-Spanish baitboat and troll). The results (Figure 3) indicate that in the eastern Atlantic the catch of small bluefin tuna has been nearly constant since 1968, whereas in the western Atlantic the catch of small bluefin tuna has fluctuated. Perhaps part of this difference is attributable to the different histories of the two fisheries. The western Atlantic fishery is relatively young (peak catch in 1964), whereas the eastern Atlantic fishery is relatively old (apparently peak catch in 1954--Aloncle, 1972[4]) Another possible contributing factor to this difference is the transatlantic migration of small bluefin tuna in certain years (Mather et al., 1972).

### 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 of apparent abundance of the bluefin tuna population.

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

| Nation | Gear | Catch Area | Catch Years | Effort Area | Effort Years | Comments |
|---|---|---|---|---|---|---|
| Argentina | Handline | none | none | none | none | Probably southern bluefin tuna. |
| Brazil | Longline | none | none | none | none | Catch is small |
| Canada | Longline | none | none | none | none | Catch of longline is small, mostly discarded and not landed. |
| | Purse seine | 1° x 1° square | 1963-71 | 1° x 1° square | 1963-71 | Effort is in day's fished. |
| | Trap | District | 1962-71 | none | none | |
| | Sport | District | 1962-71 | District | 1961-70 | Effort is in number of boats. |
| Cuba | Handline | none | none | none | none | Catch is small. |
| | Longline | none | none | none | none | Catch is probably small. None caught in 1971. |
| Denmark | Handline | none | none | none | none | Catch is small. |
| France | Troll | Bay of Biscay | 1965-71 | Bay of Biscay | 1965-71 | Catch and effort is not separated by gear. Effort is estimated as days at sea. |
| | Baitboat | Bay of Biscay | 1965-71 | Bay of Biscay | 1965-71 | |
| Germany | Handline | Northeast Atlantic | 1952-63 | Northeast Atlantic | 1952-63 | Effort is in fishing trips. Fishery collapsed in 1963. |
| Japan | Longline | 5° x 5° square | 1957-71 | 5° x 5° square | 1957-71 | Effort is in number of hooks. |
| Korea | Longline | Atlantic | 1971 | none | none | |
| Morocco | Purse seine | none | none | none | none | |
| | Trap | East Atlantic | 1927-70 | East Atlantic | | Effort is in number of traps. |
| | Troll | none | none | none | none | |
| | Baitboat | none | none | none | none | |
| Norway | Purse seine | Northeast Atlantic | 1954-64 | Northeast Atlantic | 1954-64 | Effort is in number of boats. Recent catch is small. |
| Portugal | Trap | District | 1950-71 | District | 1950-62 | Effort is in number of traps. Fishery collapsed in 1971. |
| | Troll | none | none | none | none | Catch is small. |
| South Africa | Longline | none | none | none | none | Substantial catch only in 1963 and 1964. Probably some southern bluefin tuna. |
| Spain | Trap | District | 1929-72 | District | 1929-72 | Effort is in number of traps. Recent catch is small. |
| | Baitboat | Bay of Biscay | 1965-71 | Bay of Biscay | 1965-71 | Effort is an estimate of days at sea. |
| Sweden | Handline | none | none | none | none | Catch is small. |
| Taiwan | Longline | 5° x 5° square | 1967-69 | 5° x 5° square | 1967-69 | Data may not be representative of the fleet's catch. Effort is in number of hooks. |
| U.S.A. | Handline | State | 1946-71 | none | none | |
| | Harpoon | State | 1930-71 | none | none | |
| | Purse seine | 1° x 1° square | 1962-71 | 1° x 1° square | 1962-71 | Effort is in days fished. |
| | Trap | State | 1929-71 | none | none | |
| | Sport | none | none | none | none | |

## Estimate of Quality of Catch-Effort Data

For the available catch-effort statistics, catch is reported in metric tons, or in numbers of fish caught. Fishing effort is reported in numbers of traps (Morocco, Portugal, and Spain); trap days (Spain); numbers of boats (Canada, France and Norway); numbers of hooks (Japan); numbers of days at sea (France and Spain); and numbers of day's fishing (Canada and the U.S.A.). Effort in terms of numbers of traps and boats is imprecise because it does not account for the length of the fishing season, which can affect the catch, although we found that catch-per-trip was closely correlated with crude estimates of catch-per-trap day (Rodríguez-Roda, 1972[5]) for the Spanish trap fishery, 1966-72. It is also conceivable that if different sizes of traps and boats are employed during a season, these measures of effort would not account for differences in fishing power owing to size of gear. Competition among traps is another drawback to using effort measured as numbers of traps: Bluefin tuna apparently approach the trap fisheries from particular directions. Consequently, the location of a trap in respect to the migration route and to other traps can influence the effectiveness of the gear.

Number of hooks is generally a reasonable measure of longline fishing effort. However, the longline gear is primarily set for other tunas and for billfishes rather than for bluefin tuna. Thus, in most cases, the nominal effort is only a gross measure of effective effort.

Bard et al. (1972[3]) estimated fishing effort for the small-fish fishery of the Bay of Biscay. Their measure of effort is days at sea, which is only a crude estimate of effective fishing effort since it includes time to and from the fishing grounds as well as fishing time on the grounds. In addition, Bard et al. based their estimates on data from a small percentage of boats in the fleet. Consequently, their estimates of fishing effort for the Bay of Biscay baitboat fishery may not be representative of the fleet in general.

Canada and the U.S.A. have reported nominal fishing effort of purse seiners in terms of days fished. However, they use different sizes (classes) of purse seiners with different fishing powers, and there has been an evolution towards greater dependence on searching for schools with airplanes, which suggests that their reported nominal effort is a poor approximation of effective effort. An example of such use is by the small seiners (< 182 tons capacity), the "local boats," that regularly operate out of New England ports. In 1958-71 the "local boats" produced approximately 39 to 100% of the total western Atlantic purse seine landings of bluefin tuna (Table 3). Larger seiners ( >181 tons capacity), on the other hand, generally are based in California, Puerto Rico, or New Brunswick. These boats fish off the east

Table 3. Number of purse seiners and approximate percentage of total catch by tonnage class for the western Atlantic bluefin tuna fishery.

| Type of seiner | Year | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 |
| < 182tons capacity | | | | | | | | | | | | | | | |
| Number of boats | 1 | 1 | 1 | 2 | 5 | 8 | 8 | 8 | 6 | 4 | 4 | 3 | 4 | 3 | 3 |
| Percentage of total catch | 100 | 100 | 100 | 100 | 55 | 50 | 39 | 47 | 88 | 73 | 100 | 100 | 63 | 61 | 82 |
| >181 tons capacity | | | | | | | | | | | | | | | |
| Number of boats | 0 | 0 | 0 | 0 | 2 | 10 | 13 | 5 | 1 | 7 | 1 | 1 | 4 | 9 | 6 |
| Percentage of total catch | 0 | 0 | 0 | 0 | 45 | 50 | 61 | 53 | 11 | 27 | 0 | 0 | 37 | 39 | 18 |
| Total | | | | | | | | | | | | | | | |
| Number of boats | 1 | 1 | 1 | 2 | 7 | 18 | 21 | 13 | 7 | 11 | 5 | 4 | 8 | 12 | 9 |
| Percentage of total catch | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

Table 4. Catch rate of bluefin tuna from the Atlantic Ocean.

| Year | French baitboat and troll (Hamre et al., 1966) | | | German handline (Hamre et al., 1966) | | | Norwegian purse seine (Hamre et al., 1966) | | | French-Spanish baitboat (Bard et al., 1972[1]) | | | Canadian sport (Miyake and Tibbo, 1972) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Catch (metric tons) | Effort (boats) | Catch rate | Catch (metric tons) | Effort (fishing trips) | Catch rate | Catch (metric tons) | Effort (boats) | Catch rate | Catch (metric tons) | Effort (days at sea) | 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 | 3,946 | 5,700 | 0.7 | | | |
| 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 | 3,436 | 12,550 | 0.3 | | | |
| 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 | 1,580 | 11,900 | 0.1 | 41 | 41 | 1.0 |
| 1962 | 965 | 81 | 11.9 | 191 | 28 | 6.8 | 6,794 | 129 | 52.7 | - | - | - | 40 | 47 | 1.2 |
| 1963 | | | | | | | 129 | 11 | 11.7 | 1,428 | 47,600 | <0.1 | 90 | 56 | 0.6 |
| 1964 | | | | | | | 1,041 | 43 | 24.2 | - | - | - | 99 | 64 | 0.6 |
| 1965 | | | | | | | | | | 2,128 | 9,750 | 0.2 | 90 | 67 | 0.7 |
| 1966 | | | | | | | | | | 3,287 | 15,100 | 0.2 | 102 | 70 | 0.7 |
| 1967 | | | | | | | | | | 1,939 | 8,600 | 0.2 | 56 | 74 | 1.3 |
| 1968 | | | | | | | | | | 1,643 | 7,200 | 0.2 | 180 | 81 | 0.5 |
| 1969 | | | | | | | | | | 1,420 | 3,900 | 0.4 | 170 | 85 | 0.5 |
| 1970 | | | | | | | | | | 2,150 | 3,750 | 0.6 | 151 | 91 | 0.6 |
| 1971 | | | | | | | | | | 2,134 | 3,700 | 0.8 | | | |

[1]Bard, F. X., C. Bessineton, O. Cendrero, and J. C. Dao. 1972. La pecherie de thon rouge du Golfe de Gascogne. Resultat des recherches 1972. Unpublished manuscript, 7 p, 8 figs. Centre Oceanologique de Bretagne, B. P. 337, 29200, Brest, France.

coast of the United States when fishing is reportedly good for bluefin and skipjack (Katsuwonus pelamis) tunas. Otherwise they proceed to the yellowfin-skipjack fishing grounds off west Africa. These large seiners also use airplanes for spotting tuna schools but their catch rates are considerably less than that for the "local boats" (Figure 4). The nominal effort of the different classes of seiners is therefore rather different.

## Analysis of Catch-Effort Data

With these inadequacies in the catch-effort statistics in mind, we analyzed the data shown in Tables 4 and 5. In the eastern Atlantic, the trend in catch rate is downward for every fishery that exploits medium (123 to 184 cm) and large (> 184 cm) bluefin tuna (Figure 5). The German handline and the Portuguese trap fisheries have collapsed, and the Norwegian purse seine and Moroccan and Spanish trap fisheries have substantially reduced fishing effort. The reduction in effort apparently is a response to the unavailability of medium- and large-sized bluefin tuna, sizes of fish that are primarily harvested by those fisheries.

Table 5. Catch rate of bluefin tuna caught in three trap fisheries of the eastern Atlantic. Data are from Aloncle et al. (1971, 1972), Dias and Barraca (1972), Hamre et al. (1966, 1968, 1971), Mather (personal communication) and Rodríguez-Roda (1964, 1972[1]).

| Year | Morocco | | | Portugal | | | Spain | | |
|---|---|---|---|---|---|---|---|---|---|
| | Catch (numbers) | Effort (traps) | Catch rate | Catch[2] (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 | | | | 26,094 | 2 | 13,047 |
| 1930 | 9,533 | 1 | 9,533 | | | | 54,183 | 3 | 18,061 |
| 1931 | 6,368 | 1 | 6,368 | | | | 43,476 | 3 | 14,492 |
| 1932 | 4,755 | 1 | 4,755 | | | | 28,726 | 3 | 9,575 |
| 1933 | 12,236 | 1 | 12,236 | | | | 25,104 | 3 | 8,368 |
| 1934 | 6,287 | 1 | 6,287 | | | | 18,470 | 3 | 6,157 |
| 1935 | 12,769 | 2 | 6,384 | | | | 12,447 | 3 | 4,149 |
| 1936 | 3,214 | 2 | 1,607 | | | | 33,889 | 3 | 11,296 |
| 1937 | 11,036 | 1 | 11,036 | | | | 70,237 | 3 | 23,412 |
| 1938 | - | 0 | - | | | | 56,064 | 3 | 18,688 |
| 1939 | 3,407 | 1 | 3,407 | | | | 42,868 | 3 | 14,289 |
| 1940 | 14,636 | 3 | 4,879 | | | | 24,256 | 3 | 8,085 |
| 1941 | 15,353 | 2 | 7,676 | | | | 27,891 | 3 | 9,297 |
| 1942 | 9,963 | 3 | 3,321 | | | | 33,153 | 3 | 11,051 |
| 1943 | 16,589 | 2 | 8,294 | | | | 69,846 | 3 | 23,282 |
| 1944 | 6,459 | 2 | 3,229 | | | | 54,499 | 3 | 18,166 |
| 1945 | 12,354 | 2 | 6,177 | | | | 46,387 | 3 | 15,462 |
| 1946 | 9,590 | 3 | 3,197 | | | | 59,589 | 3 | 19,863 |
| 1947 | 22,480 | 4 | 5,620 | | | | 58,596 | 3 | 19,532 |
| 1948 | 17,493 | 5 | 3,499 | | | | 41,341 | 3 | 13,780 |
| 1949 | 17,675 | 5 | 3,535 | | | | 75,881 | 3 | 25,294 |
| 1950 | 21,604 | 5 | 4,321 | 16,879 | 5 | 3,376 | 49,143 | 3 | 16,381 |
| 1951 | 14,132 | 5 | 2,826 | 17,549 | 5 | 3,510 | 26,401 | 3 | 8,800 |
| 1952 | 11,180 | 5 | 2,236 | 21,481 | 5 | 4,296 | 38,221 | 3 | 12,740 |
| 1953 | 13,369 | 5 | 2,674 | 24,934 | 5 | 4,987 | 54,372 | 3 | 18,124 |
| 1954 | 9,428 | 5 | 1,886 | 12,031 | 5 | 2,406 | 40,976 | 3 | 13,659 |
| 1955 | 11,839 | 3 | 3,946 | 10,270 | 5 | 2,054 | 47,115 | 2 | 15,705 |
| 1956 | 17,576 | 3 | 5,859 | 19,260 | 5 | 3,852 | 47,078 | 3 | 15,693 |
| 1957 | 25,125 | 3 | 8,375 | 7,434 | 5 | 1,487 | 47,943 | 3 | 15,981 |
| 1958 | 29,038 | 3 | 9,679 | 5,753 | 5 | 1,151 | 44,531 | 3 | 14,844 |
| 1959 | 15,142 | 3 | 5,047 | 15,844 | 5 | 3,169 | 27,584 | 3 | 9,195 |
| 1960 | 17,572 | 3 | 5,857 | 7,702 | 5 | 1,540 | 35,774 | 3 | 11,925 |
| 1961 | 5,054 | 3 | 1,685 | 11,514 | 5 | 2,303 | 29,509 | 3 | 9,836 |
| 1962 | 12,713 | 3 | 4,238 | 5,165 | 5 | 1,033 | 27,034 | 3 | 9,011 |
| 1963 | | | | 3,316 | 5 | 663 | 9,802 | 3 | 3,267 |
| 1964 | | | | 11,246 | 5 | 2,249 | 12,117 | 3 | 4,039 |
| 1965 | | | | 870 | 5 | 174 | 14,163 | 3 | 4,721 |
| 1966 | | | | 1,695 | 3 | 565 | 7,784 | 2 | 3,892 |
| 1967 | | | | 1,651 | 3 | 550 | 14,048 | 2 | 7,024 |
| 1968 | | | | 399 | 2 | 200 | 5,360 | 2 | 2,680 |
| 1969 | | | | 3,875 | 2 | 1,938 | 7,570 | 2 | 3,785 |
| 1970 | | | | 492 | 2 | 246 | 7,119 | 2 | 3,559 |
| 1971 | | | | | | | 2,522 | 2 | 1,261 |
| 1972 | | | | | | | 388 | 1 | 388 |

[1] Rodríguez-Roda, J. 1972. Las capturas de atun, Thunnus thynnus (L.), por las almadrabas del sur de España en el año 1972 y variacion del rendimiento en el periodo de 1962 a 1972. Unpublished manuscript, 3 p., 5 tables, 1 fig. Instituto de Investigaciones Pesqueras, Laboratorio de Cádiz, Cádiz, Spain.

[2] Catch is primarily bluefin tuna but also includes other tuna species.

Data are meager on catch and effort of fisheries that primarily exploit small bluefin tuna in the eastern Atlantic. The catch of the baitboat and trolling fleets of the Bay of Biscay which have exploited small bluefin tuna since the late 1940's, peaked in the mid-1950's (Aloncle, 1972[4]; Bard et al., 1972[3]). The available catch-effort statistics for those fleets are poor because data are from only a few boats. However, the catch rates of the combined French and Spanish baitboat fleets indicate an upward trend since 1964 (Figure 5).

In the western Atlantic we find a different situation with catch-effort data. Adequate data are available for small bluefin tuna that are primarily caught by the purse seine fishery, but such data are meager or lacking for the trap, harpoon, and sport fisheries that catch large bluefin tuna. For the purse seine fishery, the catch rate of Class 3 seiners (92 to 181 tons capacity), which are mostly "local boats" and which account for most of the recent catch from the western Atlantic, showed an upward trend in the late 1960's and a downward trend in 1971 and 1972 (Figure 4). In the early 1960's the catch rate was relatively low and reasonably constant, but the catch fluctuated. In the late 1960's, on the other hand, the catch rate increased and the catch also increased. Since the fishery first began in the late 1950's and Class 3 boats entered the fishery in the early 1960's (Squire, 1959; Wilson, 1965), one conclusion is that these boats became more efficient in their operations. In fact, the upward trend in CPUE and catch occurred soon after some operators of the small vessels (<182 tons) began coordinating their operations. At the same time, the number of small vessels decreased (Table 3) Then in 1971 and 1972 the catch rate declined but not to the low level of 4 tons/day's fishing of 1966.

A similar trend in catch rate for the 1960's is not evident for Class 6 seiners (> 363 tons capacity), which are not "local boats" (Figure 4). Their catch rate has fluctuated but has remained relatively low and substantially lower than that of Class 3 boats, even though the Class 6 seiners use larger nets and have larger holding capacities than do the Class 3 seiners. The Class 6 seiners more often search for both skipjack and bluefin tuna than do the Class 3 boats, and this can partly account for their lower catch rate of bluefin tuna in some years. In the 1970's, however, the catch rate of Class 6 seiners declined to a record low of about 2 tons/day's fishing in 1972.

It is evident from the above discussion that in the western Atlantic purse seine fishery the efficiency of the different classes of seiners is not identical, nor is it identical from year-to-year within a class of seiners. If the catch rate of the western Atlantic purse seine fishery is to be used as an index of year-to-year fluctuations in abundance of the bluefin tuna stock(s) exploited in the western Atlantic, it is necessary to adjust the nominal effort to account for differences in vessel efficiency, or to use a different set of effort data that is free of variations associated with the class of seiners, such as number and size of schools sighted by airplane spotters within a specific area, catch-effort of one particular class of seiners, etc.

Mather et al. (1972) have shown from tagging data that transatlantic migration of bluefin tuna does occur in some years, suggesting that the fisheries in the eastern and western Atlantic may be exploiting fish from identical stocks. The apparent abundance of small bluefin tuna from the eastern and western regions were examined to determine whether they are correlated. For the western Atlantic, the catch rate of Class 3 vessels was assumed to be representative of the apparent abundance of small bluefin tuna from that region, and for the eastern Atlantic, the catch rate of the French-Spanish baitboat fishery of the Bay of Biscay (Bard et al., 1972[3]) was assumed to be representative--both fisheries catch fish of about the same sizes (Bard et al., 1972[3]). The correlation coefficient is 0.73 (Figure 6), which is marginally significant at $\underline{P} = 0.05$. Although there are imprecisions in the data, the correlation suggests that a single stock is exploited by the small-fish fisheries of the eastern and western Atlantic.

There has been speculation (Hamre, undated[6]) that recent declines in the catch of the large-fish fisheries in the eastern Atlantic (e.g., Danish handline, German handline, Norwegian purse seine, etc.) are the result of poor recruitment into those fisheries, presumably from heavy fishing of the small fish by other fisheries, such as the French-Spanish baitboat, and Canadian-U.S.A. purse seine (Figure 7). If this is true and a particular relation (see Ricker, 1958) exists between the spawning stock (large fish) and recruitment (small fish), we would expect recruitment to the small-fish fisheries to be also affected by the decline in large fish. We examined this hypothesis using the catch rates of the Norwegian purse-seine fishery (Figure 8), Spanish trap fishery, and the French-Spanish baitboat fishery. We assumed a 2-year period between spawning and recruitment, because the data of Bard et al. (1972[3]) indicated that age II fish predominate in the catch of the baitboat fishery. The results indicated no perceptible relation, at least for the available data.

The Japanese longline fleet operates throughout the Atlantic, although fishing effort is concentrated in certain regions during particular months (Hiyasi et al., 1970; Wise and Davis, 1973). We divided the Atlantic Ocean into seven regions (Figure 9) for the purpose of analyzing the Japanese longline data. Catch rates were computed for each region by averaging monthly catch rates of 5° x 5° areas. The time series of catch rates (Figure 10) indicate that since about 1963 the rates have generally been low and constant, except in regions II (off Canada and the U.S.A.) and V (off Brazil) where a peak in catch rate occurred in the mid-1960's and thereafter dropped off sharply. Regions II and V are also where the highest annual catches occurred and where fishing effort correspondingly declined with the catch rate (region II--6 million hooks in 1965 to 4 million hooks in 1970; region V--29 million hooks in 1964 to 6 million hooks in 1970). It is important to note that while the Japanese were decreasing their longline effort in the Atlantic during the 1960's, the Korean and Taiwanese longline fleets were increasing their's (Table 1). How this event, together with fluctuation in year-class strength, affected the Japanese catch rate of bluefin tuna is uncertain. Consequently, we cannot state conclusively that the decline and present low catch rate of the Japanese longline fleet is symptomatic of an unhealthy Atlantic bluefin tuna population.

Lastly, we examined the relation between the catch rates of the Japanese longline fleet and the Spanish trap fishery, to determine whether these fisheries were affecting one another. The catch rate for regions II and V was considered representative for that of the Japanese longline fleet. Our results were negative, with no specific relation between the two catch rates being apparent.

## Size-Frequency Statistics

### Estimate of Quality of Size-Frequency Data

ICES 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[4]). 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 others, such as the small-fish fishery of the Bay of Biscay and adjacent waters the statistics are in Form 2. Because Form 2 groups fish of several year classes together, it is inadequate for detailed analysis of the catch.

### Analysis of Size-Frequency Data

Mather and Jones (1972[7]) compiled a time series of size frequencies of bluefin tuna caught in the various Atlantic fisheries, which showed that in fisheries for medium or 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. We estimated the average weight of fish in the catch of the various fisheries (Figure 11), and our results show the same trend observed by Mather and Jones. We also illustrated (Figure 12) one of the longest time series of catch and average size of bluefin tuna caught by a single Spanish trap off Barbate, Spain (Rodriguez-Roda, 1964, 1972[5]). From 1946-61 the trap catch fluctuated around about 20,000 fish, but the average weight of fish caught increased from 88 kg in 1946 to 145 kg in 1961. From 1961-71, the catch decreased sharply from 19,000 fish in 1961 to 2,500 fish in 1971 but the average weight of fish caught increased from 145 kg to 223 kg. The Barbate trap data thus suggest that the recent increase in average size of bluefin tuna in the catch of certain fisheries may be associated with sharp decrease in recruitment, a hypothesis proposed by Hamre (1958) and Mather and Jones (1972[7]).

A list of available data on size-frequency of bluefin tuna by fleets is shown in Table 6. Fleets for which there are inadequate data are identified. These are primarily the baitboat and trolling fleets of the eastern Atlantic and the sport fleet of the western Atlantic that catch small bluefin tuna, and the longline fleets, mostly in mid-Atlantic, that catch primarily large fish.

Table 6. Available data on size-frequency distributions of bluefin tuna from the Atlantic Ocean.

| Nation | Gear | Area | Years | Comments |
|---|---|---|---|---|
| Argentina | Handline | none | none | Catch is possibly southern bluefin tuna. |
| Brazil | Longline | none | none | Catch is small. |
| Canada | Longline | none | none | Catch is small: |
| | Purse seine | 1° x 1° square | 1963-71 | Form 1. [1] |
| | Trap | none | none | |
| | Sport | District | 1946-71 | Form 1. |
| Cuba | Handline | none | none | Catch is small. |
| | Longline | none | none | Catch is small. |
| Denmark | Handline | North Atlantic | 1962-71 | Recent catch is small. Form 1 |
| France | Troll | Bay of Biscay | 1972 | Form 1 and some data for earlier years are available in Form 2.[1] |
| | Baitboat | Bay of Biscay | 1949, 1972 | Form 1 |
| Germany | Handline | North Atlantic | 1951-62 | Fishery collapsed in 1963. Form 1. |
| Japan | Longline | 5° x 5° square | 1965-69 | Samples are small and for scattered years. Form 1. |
| Korea | Longline | none | none | |
| Morocco | Purse seine | none | none | |
| | Trap | Eastern Atlantic | 1957 | Form 1. |
| | Troll | none | none | |
| Norway | Purse seine | North Atlantic | 1956-70 | Recent catch is small. Form 1 |
| Portugal | Trap | Eastern Atlantic | 1930-70 | Fishery collapsed in 1971. Form 2. |
| | Troll | Eastern Atlantic | 1960, 1961 | Form 1. |
| South Africa | Longline | none | none | Substantial catch only in 1963-64. Probably some southern bluefin tuna. |
| Spain | Trap | Districts | 1956-70 | Mostly from one trap. Form 1. |
| | Troll | none | none | |
| | Baitboat | Bay of Biscay | 1972 | Form 1. |
| Sweden | Handline | none | none | Catch is small. Form 1. |
| Taiwan | Longline | none | none | |
| U.S.A. | Handline | District | 1962-71 | Samples for some years are small; not a complete series. Form 1. |
| | Harpoon | District | 1958-71 | Not a complete series. Form 1. |
| | Purse seine | 1° x 1° square | 1962-72 | Form 1. |
| | Trap | District | 1947-72 | Samples for some years are small; not a complete series. Form 1. |
| | Sport | District | 1956-72 | Samples for some years are small. Form 1. |

[1] See section "Estimate of Quality of Size-Frequency Data" for explanation of Forms 1 and 2.

## Age Composition of Catch

Data on catch and size-frequency were used to estimate the age composition of the catch of various fleets. Estimates were made for all fleets from 1960-71 except the Canadian-U.S.A. purse seine and U.S.A. sport fleets, for which estimates were for 1960-72. Two procedures were used in assigning ages: (1) modal groups were identified in the size composition of the yearly catch, and then ages were assigned to the modal groups according to estimated size at age from the growth equation (see section on Growth); (2) when modes were not present or difficult to identify, estimated size at age from the growth equation was used to estimate age.

A summary of the data set by fleet and ocean region is shown in Table 7. Because several assumptions were used in our estimation procedure, a few specific comments about the assumptions and data set are appropriate. We indicate at the outset that in some cases the total catch in numbers reported in the literature do not exactly agree with those we present. The difference is not large and is due to rounding errors.

Table 7.--Summary of catches of bluefin tuna that were used to estimate the age composition, 1960-72

| Fishery by region and nation | Unit of measure | Catch | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 |
| Eastern Atlantic | | | | | | | | | | | | | | |
| Danish handline | Metric tons | 47 | 144 | 152 | 3 | 43 | 23 | - | - | - | - | - | - | |
| | Numbers | - | - | - | - | - | - | - | 38 | 26 | 17 | 1 | 9 | |
| French-Moroccan-Spanish baitboat and troll | Metric tons, France[1] | 500 | 900 | 900 | 600 | 400 | 1,000 | 1,700 | 1,100 | 700 | 600 | 800 | 700 | |
| | Metric tons, Morocco[1] | - | - | - | 1,500 | 2,100 | 1,000 | 1,300 | 2,000 | 500 | 700 | 400 | 72 | |
| | Metric tons, Spain[1] | 500 | 900 | 900 | 800 | 400 | 1,100 | 1,600 | 900 | 1,000 | 900 | 1,400 | 1,400 | |
| German handline | Numbers | 1,624 | 1,088 | 734 | | | | | | | | | | |
| Moroccan-Portuguese-Spanish trap | Metric tons, Morocco[1] | 6,000 | 2,300 | 1,600 | 2,400 | 2,300 | 1,900 | 1,800 | 1,400 | 800 | 100 | 300 | 450 | |
| | Metric tons, Portugal[1] | 900 | 1,500 | 800 | 400 | 400 | 100 | 100 | 100 | 100 | 400 | - | - | |
| | Numbers, Spain[1] | 35,881 | 29,598 | 27,198 | 9,861 | 12,177 | 14,248 | 7,785 | 14,062 | 5,383 | 7,571 | 7,176 | 2,522 | |
| Norwegian purse seine | Metric tons | - | - | - | - | - | - | - | - | - | 900 | - | - | |
| | Numbers | 16,915 | 38,822 | 37,268 | 621 | 4,648 | 8,385 | 3,544 | 6,770 | 2,274 | - | 818 | 1,637 | |
| Western Atlantic | | | | | | | | | | | | | | |
| Canadian-U.S.A. purse seine | Metric tons | 307 | 936 | 3,781 | 6,780 | 5,592 | 3,341 | 1,014 | 2,318 | 657 | 1,567 | 4,209 | 3,746 | 1,964 |
| Canadian-U.S.A. handline, harpoon and trap | Metric tons | 491 | 301 | 325 | 443 | 590 | 478 | 436 | 529 | 363 | 512 | 464 | 412 | |
| Canadian sport | Metric tons | 40 | 40 | 40 | 90 | 99 | 90 | 102 | 53 | 180 | 170 | 151 | 134 | |
| U.S.A. sport | Metric tons[2] | - | - | - | - | 220 | 230 | 330 | 80 | 110 | 470 | 80 | 110 | 180 |
| | Numbers[2] | 23 | 28 | 50 | 86 | 86 | 32 | 37 | 82 | 50 | 225 | 250 | 442 | 272 |

[1] Catches do not necessarily equal those in Table 1. See section, Analysis of Catch Data for explanation.

[2] Small bluefin tuna were estimated in metric tons from tagging data; large bluefin tuna were estimated in numbers from tournament records.

## Eastern Atlantic Surface Fisheries

Danish handline fishery.--The catch of the Danish handline fleet has been small; in 1971, only nine bluefin tuna were reportedly caught (Aloncle et al., 1972). A complete set of catch statistics for this fleet was given by Aloncle et al. (1971, 1972) and Hamre et al. (1966, 1968, 1971). Weight-frequency samples are available for 1962 and 1964-71 (Aloncle et al., 1971, 1972; Hamre and Tiews, 1964; Hamre et al., 1966, 1968, 1971): these were used to estimate the age composition of the catch for those years (Table 8). To estimate the age composition of the catch for the remaining years, we assumed that the 1962 weight-frequency distribution was identical to that of 1960 and 1961 and the 1964 weight-frequency distribution was identical to that of 1963.

French-Moroccan-Spanish baitboat and troll fisheries.--French and Spanish catches were reported by Bard et al. (1972[3]) and Moroccan catches (which apparently include some purse seine catches) by Miyake and Tibbo (1972). For some years, however, these sources did not give adequate statistics. Missing data are for the French and Spanish fleets for 1960, 1961, 1962 and 1964. Aloncle (1972[4]) gave the catches for the French fleet for 1948 to 1970. The accuracy of Aloncle's data is uncertain, but 1960, 1961, 1962 and 1964 figures were used for the French fleet and to estimate the catch of the Spanish fleet, by assuming that the Spanish catches were equal to those of the French fleet. This assumption is based on the fact that catches of both fleets were nearly identical in the mid-1960's

Table 8. Estimated ages and numbers of bluefin tuna caught by the Danish handline fishery.[1] No catch was made in 1966.

| Age (years) | Approximate length (cm) | Numbers of fish by age and year of capture | | | | | | | | | | | Average 1960-71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1967 | 1968 | 1969 | 1970 | 1971 | |
| 9 | 185-198 | 13 | 41 | 44 | | | | | | | | | 9 |
| 10 | 199-210 | 8 | 25 | 28 | | 6 | | | | | | | 6 |
| 11 | 211-223 | 21 | 63 | 67 | | 14 | 2 | | | | | | 15 |
| 12 | 224-234 | 45 | 136 | 143 | 3 | 43 | 22 | 3 | | | | | 36 |
| 13 | 235-245 | 72 | 219 | 232 | 6 | 56 | 19 | 13 | 4 | 2 | | | 57 |
| 14+ | 246+ | 38 | 113 | 123 | 1 | 49 | 42 | 19 | 19 | 12 | 1 | 9 | 39 |
| Total | | 197 | 597 | 637 | 10 | 168 | 85 | 35 | 23 | 14 | 1 | 9 | 162 |

[1]See section, "Age Composition of Catch" for estimation procedure.

Table 9. Estimated ages and numbers of bluefin tuna caught by the French-Moroccan-Spanish baitboat and trolling fleets.[1]

| Age (years) | Approximate length (cm) | Numbers of fish by age and year of capture | | | | | | | | | | | | Average 1963-71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960[2] | 1961[2] | 1962[2] | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | |
| 1 | 46- 66 | | | 186 | 45,150 | 25,193 | 34,944 | 700,125 | 15,034 | 12,767 | 1,250 | 16,730 | 40,906 | 99,122 |
| 2 | 67- 85 | | | 731 | 26,755 | 34,080 | 131,480 | 163,194 | 204,742 | 105,520 | 38,515 | 57,130 | 100,455 | 95,763 |
| 3 | 86-104 | | | 10,845 | 21,924 | 53,555 | 37,017 | 36,019 | 85,102 | 46,485 | 65,457 | 69,941 | 15,747 | 47,916 |
| 4 | 105-122 | 9,113 | 5,890 | 26,980 | 14,616 | 18,779 | 829 | 11 | 3,564 | 878 | 3,299 | 5,374 | 19,548 | 7,433 |
| 5 | 123-139 | 19,186 | 12,407 | 7,513 | 15,059 | 13,277 | 6,321 | 23 | 5,111 | 94 | 7,175 | 8,653 | 3,982 | 6,633 |
| 6 | 140-155 | 2,529 | 1,630 | 388 | 13,551 | 3,509 | 10,418 | 190 | | 0 | 3,038 | 1,357 | 181 | 3,583 |
| 7 | 156-170 | 6,192 | 4,010 | 604 | 429 | 6,043 | 845 | 67 | | 0 | 0 | 387 | 181 | 884 |
| 8 | 171-184 | 5,233 | 3,384 | 942 | 443 | 139 | 1,099 | 252 | | 45 | 299 | 23 | | 256 |
| 9 | 185-198 | 959 | 626 | 638 | 235 | | 148 | 112 | | 45 | | 17 | | 62 |
| 10 | 199-210 | 393 | 251 | 167 | 97 | | 233 | 134 | | 45 | | | | 57 |
| 11 | 211-223 | | | 59 | 97 | | 285 | 190 | | 87 | | | | 73 |
| 12 | 224-234 | | | 5 | 42 | | 317 | 168 | | 110 | | | | 71 |
| 13 | 235-245 | | | | 14 | | 481 | 711 | | 198 | | | | 156 |
| 14+ | 246+ | | | | | | 154 | 980 | | 353 | | | | 165 |
| Total | | 43,605 | 28,198 | 49,058 | 138,412 | 154,576 | 224,571 | 902,176 | 313,553 | 166,627 | 119,033 | 159,617 | 181,000 | 262,174 |

[1] See section, "Age Composition of Catch" for estimation procedure.

[2] The catch of the Spanish fleet is estimated and that of the Moroccan fleet is assumed to be zero. See section, "French-Moroccan-Spanish Baitboat and Troll Fisheries" for further explanation of assumptions.

(Table 7) Total catch data are unavailable for the Moroccan fleet for 1960-62. Because the available catch statistics (1963-70) of this fleet are themselves estimates, we did not estimate the catches of 1960-62 by the above procedure, but assumed that the Moroccan catch for those years was zero. This assumption is probably invalid and the 1960-62 estimated total catch of the fishery is conservative.

There are no size-frequency statistics for this fishery for 1960-70. However, since the sizes of fish caught are about the same as those caught in the Canadian-U.S.A. purse seine fishery (Bard et al., 1972[3]), the length-frequency samples of the Canadian-U.S.A. purse-seine fishery were used to estimate the age composition of the catch of the French-Moroccan-Spanish baitboat and troll fishery (Table 9).

We point out that Aloncle (1972[4]), Bard et al. (1972[3]), ICES (1965-71), and Letaconnoux (1972[8]) reported the total French landings of bluefin tuna from the Bay of Biscay and vicinity. For most years, the reported statistics of these sources do not agree with one another. We used primarily Bard et al's statistics in our study because they are current estimates and they seem most reliable. Also, in regard to our assumption of sizes of fish in the French-Moroccan-Spanish baitboat and troll fishery, we are aware that this assumption may be invalid if, as Mather and Jones (1972[7]) hypothesized, two stocks exist in the Atlantic and substantial numbers of a stock migrate from one side of the Atlantic to the other in some years. Thus, the estimates in Table 9 may be imprecise.

German handline fishery.--The German handline fishery collapsed in 1963. Catch and weight-frequency statistics for this fishery are found in Hamre and Tiews (1964), and Hamre et al. (1966). They were used to estimate the age composition of its catch for 1960-62 (Table 10).

Moroccan-Portuguese-Spanish trap fishery.--Catch data of the trap fishery of the eastern Atlantic were compiled by Miyake and Tibbo (1972) and Rodríguez-Roda (1972[5]). Size-frequency samples of bluefin tuna caught by Moroccan, Portuguese and Spanish fisheries are available (Table 6) but only data from the Spanish fishery (Aloncle et al., 1971; Hamre et al., 1966, 1968, 1971) are in adequate form for our use. To estimate the age composition of the catch of this fishery (Table 11) we assumed that fish caught by the Spanish traps were representative of fish caught by the fishery as a whole. This assumption is not entirely valid, since some crude data suggest that the Moroccan and Portuguese traps caught a larger proportion of small bluefin tuna than did the Spanish traps (Hamre et al., 1964).

Norwegian purse-seine fishery.--Data on the catch (Aloncle et al., 1971, 1972; Hamre and Tiews, 1964; Hamre et al., 1966) and on weight frequencies (Aloncle et al., 1971, 1972; Hamre et al., 1966, 1968, 1971) are available for the Norwegian purse-seine fishery. They were used to estimate the age composition of its bluefin tuna catch (Table 12).

Table 10. Estimated ages and numbers of bluefin tuna caught by the German handline fishery.[1]

| Age (years) | Approximate length (cm) | Numbers of fish by age and year of capture | | | Average 1960-62 |
|---|---|---|---|---|---|
| | | 1960 | 1961 | 1962 | |
| 10 | 199-210 | 2 | | | 1 |
| 11 | 211-223 | 47 | 24 | 14 | 28 |
| 12 | 224-234 | 283 | 189 | 123 | 198 |
| 13 | 235-245 | 544 | 443 | 286 | 424 |
| 14+ | 246+ | 748 | 432 | 311 | 497 |
| Total | | 1,624 | 1,088 | 734 | 1,148 |

[1]See section, "Age Composition of Catch" for estimation procedure.

Table 11. Estimated ages and numbers of bluefin tuna caught by the Moroccan-Portuguese-Spanish trap fishery.[1]

| Age (years) | Approximate length (cm) | Numbers of fish by age and year of capture | | | | | | | | | | | | Average 1960-71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | |
| 1 | 46- 66 | | | | | | | | | | 182 | | | 15 |
| 2 | 67- 85 | | | | | | | | | | 742 | | | 62 |
| 3 | 86-104 | | | | | | 26 | | | | 11 | | | 3 |
| 4 | 105-122 | | | 41 | 28 | 28 | 201 | 100 | 23 | | 0 | | | 35 |
| 5 | 123-139 | 87 | 56 | 412 | 273 | 281 | 254 | 301 | 111 | 20 | 0 | 9 | | 150 |
| 6 | 140-155 | 4,258 | 2,730 | 742 | 491 | 506 | 682 | 982 | 554 | 100 | 51 | 26 | 18 | 928 |
| 7 | 156-170 | 5,734, | 3,678 | 701 | 465 | 561 | 1,288 | 1,343 | 1,617 | 417 | 153 | 201 | 24 | 1,348 |
| 8 | 171-184 | 10,339 | 6,631 | 1,031 | 683 | 758 | 1,037 | 2,506 | 1,285 | 627 | 630 | 481 | 45 | 2,171 |
| 9 | 185-198 | 33,190 | 21,283 | 4,330 | 2,867 | 1,713 | 936 | 2,907 | 3,124 | 956 | 1,554 | 1,827 | 238 | 6,244 |
| 10 | 199-210 | 18,333 | 11,756 | 11,547 | 7,645 | 4,327 | 1,214 | 1,563 | 3,390 | 1,283 | 945 | 1,967 | 312 | 5,365 |
| 11 | 211-223 | 11,990 | 7,689 | 16,123 | 10,676 | 11,856 | 5,713 | 3,528 | 3,411 | 3,066 | 1,961 | 1,836 | 553 | 6,533 |
| 12 | 224-234 | 2,433 | 1,560 | 4,289 | 2,839 | 5,254 | 6,623 | 3,306 | 2,359 | 1,443 | 1,494 | 936 | 372 | 2,767 |
| 13 | 235-245 | 608 | 390 | 1,649 | 1,092 | 2,108 | 5,131 | 2,446 | 3,301 | 1,015 | 1,250 | 787 | 461 | 1,686 |
| 14+ | 246+ | 174 | 112 | 619 | 410 | 843 | 2,325 | 1,062 | 2,703 | 965 | 1,190 | 734 | 949 | 1,007 |
| Total | | 87,146 | 55,885 | 41,484 | 27,469 | 28,234 | 25,430 | 20,044 | 22,178 | 9,991 | 10,163 | 8,804 | 2,972 | 28,314 |

[1] See section, "Age Composition of Catch" for estimation procedure.

Table 12. Estimated ages and numbers of bluefin tuna caught by the Norwegian purse seine fishery.[1]

| Age (years) | Approximate length (cm) | Numbers of fish by age and year of capture | | | | | | | | | | | | Average 1960-71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | |
| 7 | 156-170 | 164 | | | | | | | | | | | | 14 |
| 8 | 171-184 | 2,075 | 332 | | | | | | | | | | | 201 |
| 9 | 185-198 | 2,588 | 2,278 | 81 | | | | | | | | | | 412 |
| 10 | 199-210 | 5,139 | 6,078 | 1,752 | 5 | 10 | 8 | 8 | | | | | | 1,083 |
| 11 | 211-223 | 5,569 | 11,974 | 8,925 | 38 | 196 | 370 | 50 | 76 | 4 | 6 | 1 | 5 | 2,208 |
| 12 | 224-234 | 595 | 10,310 | 13,390 | 120 | 965 | 1,737 | 399 | 493 | 108 | 95 | 7 | 20 | 2,353 |
| 13 | 235-245 | 508 | 5,491 | 8,779 | 198 | 1,519 | 3,009 | 1,115 | 1,500 | 374 | 595 | 70 | 100 | 1,939 |
| 14+ | 246+ | 277 | 2,369 | 4,341 | 259 | 1,868 | 3,261 | 1,972 | 4,701 | 1,788 | 2,259 | 740 | 1,503 | 2,110 |
| Total | | 16,915 | 38,822 | 37,268 | 621 | 4,548 | 8,385 | 3,544 | 6,770 | 2,274 | 2,955 | 818 | 1,637 | 10,330 |

[1] See section, "Age Composition of Catch" for estimation procedure.

Other fisheries.--South Africa reported landings of 400 and 200 tons of bluefin tuna in 1963 and 1964, respectively, and it is probable that the landings consisted of some southern bluefin tuna. Since no size data are available for the landings, the age composition of the catch was not estimated.

The Portuguese fleet fishes for bluefin tuna with trap and troll gears. The total landings by trollers are uncertain, so no estimate was made of the age composition of the troll catch.

Western Atlantic Surface Fisheries

Canadian-U.S.A. purse-seine fishery.--Catch and length-frequency samples for the Canadian-U.S.A. purse-seine fishery are available for most years, 1960-72. Included in the catch are small amounts ($\leq 5\%$) of bluefin tuna caught by miscellaneous gears, i.e., troll, trawl, and gill nets. The data were used to estimate the age composition of the catch for 1960-72 (Table 13) based on the following two assumptions: (1) the 1961 length-frequency sample was assumed to be representative of the 1960 and 1961 catches; (2) in 1965, 1966, 1968, 1971, and 1972, some large bluefin tuna were caught by purse seiners that in most years concentrated on only small- and medium-sized bluefin tuna. Length-frequency samples for those years were from the catches of only small- and medium-sized fish. To convert the tonnage of large fish caught to numbers caught we assumed that the size-frequency distribution of large fish in the purse seine catch is identical to that for the U.S.A. trap fishery, a fishery for which we have length-frequency samples and that currently catches primarily large bluefin tuna.

Table 13. Estimated ages and numbers of bluefin tuna caught by the Canadian-U.S.A. purse-seine fishery.[1]

| Age (years) | Approximate length (cm) | Numbers of fish by age and year of capture | | | | | | | | | | | | | Average 1960-72 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | |
| 1 | 46- 66 | | | 445 | 89,033 | 48,568 | 37,617 | 138,332 | 8,715 | 4,068 | 891 | 27,612 | 67,790 | 30,717 | 34,907 |
| 2 | 67- 85 | | | 1,765 | 52,943 | 65,729 | 142,305 | 31,797 | 118,689 | 33,637 | 27,445 | 94,980 | 165,725 | 75,114 | 62,318 |
| 3 | 86-104 | | | 25,375 | 43,984 | 103,261 | 40,094 | 7,061 | 49,334 | 14,814 | 46,643 | 115,442 | 26,148 | 30,702 | 38,681 |
| 4 | 105-122 | 2,798 | 3,445 | 43,205 | 16,851 | 36,211 | 689 | 2 | 2,066 | 279 | 2,351 | 8,892 | 32,322 | 477 | 11,507 |
| 5 | 123-139 | 5,890 | 7,258 | 35,541 | 31,662 | 25,609 | 6,955 | 4 | 2,963 | 29 | 5,113 | 14,304 | 6,622 | 2,651 | 11,123 |
| 6 | 140-155 | 776 | 953 | 3,759 | 30,522 | 6,758 | 10,824 | 26 | | 0 | 2,165 | 2,457 | 265 | 2,370 | 4,683 |
| 7 | 156-170 | 1,901 | 2,346 | 1,642 | 7,622 | 11,639 | 1,179 | 28 | | 0 | 0 | 412 | 172 | 36 | 2,075 |
| 8 | 171-184 | 1,606 | 1,979 | 3,074 | 1,388 | 257 | 1,210 | 42 | | 7 | 213 | 47 | 15 | 397 | 787 |
| 9 | 185-198 | 295 | 367 | 852 | 469 | | 280 | 36 | | 20 | | 28 | 6 | 350 | 208 |
| 10 | 199-210 | 121 | 147 | 201 | 187 | | 252 | 28 | | 13 | | | 12 | 104 | 82 |
| 11 | 211-223 | | | 71 | 23 | | 478 | 58 | | 43 | | | 99 | 101 | 67 |
| 12 | 224-234 | | | 12 | 69 | | 335 | 48 | | 30 | | | 196 | 55 | 57 |
| 13 | 235-245 | | | | 23 | | 259 | 75 | | 30 | | | 130 | 135 | 50 |
| 14+ | 246+ | | | | | | 262 | 254 | | 121 | | | 155 | 119 | 70 |
| Total | | 13,387 | 16,495 | 115,942 | 274,776 | 298,032 | 242,739 | 177,791 | 181,767 | 53,091 | 84,821 | 264,174 | 299,657 | 143,328 | 166,815 |

[1]See section, "Age Composition of Catch" for estimation procedure.

Canadian-U.S.A. handline, harpoon and trap fisheries.--Data on Canadian and U.S.A. catches of bluefin tuna by handline, harpoon, and trap are available. However, the Canadian trap catch data are available only for 1962-71 and were reported with the longline catch data by Aloncle et al. (1972). The longline fraction of the Canadian catch, however, is small and presumably negligible (Frank J. Mather, III, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, pers. comm). We assumed that the Canadian trap catch for 1960 and 1961 was the same as in 1962.

These gears are somewhat selective in the sizes of fish they capture. All three generally take large bluefin tuna (> 184 cm) but the trap fishery takes a larger proportion of smaller fish (about 123 to 185 cm). Length-frequencies of bluefin tuna caught by all three gears are unavailable for every year in the 1960-71 period (Table 6). Consequently, in estimating the age composition of the catch (Table 14) when a length-frequency sample was unavailable, we made the assumption that sizes of fish caught among gears within a year are not different and substituted a length-frequency sample from another gear, usually that for trap, in our calculations.

Canadian sport fishery.--Catches of bluefin tuna caught by the Canadian sport fishery have been reported by Aloncle et al. (1972). To estimate the age composition of the catch (Table 15), we used weight-frequency data that were provided by James S. Beckett (Fisheries Research Board of Canada, St. Andrews, N. B., pers. comm.).

U.S.A., sport fishery.--The total catch of Atlantic bluefin tuna caught by the U.S.A. sport fishery is not compiled by any agency. Some data on large (> 184 cm) bluefin tuna are available from tournament records, but no data are available for the bulk of the catch, which are mostly smaller fish, less than 123 cm. Moss (1967) reported that the sport catch of small bluefin tuna (50 to 122 cm) probably exceeded 2,268 tons per season. However, the sport catch is probably quite variable and dependent on availability and fishing intensity of the purse-seine fleet (Mather, pers. comm.), which competes with the sport fleet.

We estimated the sport catch of small fish for those years, 1964-72, in which there were tag returns (Table 16) from fish tagged in previous years by the Woods Hole Oceanographic Institution and the Canadian Fisheries Research Board of Canada. The estimation procedure was by proportion, based on the ratio of tag returns from sportsmen to tag returns from seiners, and the Canadian-U.S.A. purse seine catch of small fish. 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. The assumption may not hold because a larger number of sportsmen than commercial fishermen apparently do not return tags they recover (Mather, pers. comm.).

Length-frequency data are also unavailable for the sport catch of small bluefin tuna, but some data are available for large fish caught in tournaments. To estimate the age composition of small bluefin tuna caught by sportsmen, we used length-frequency samples of the purse-seine catch. Presumably, this is

Table 14. Estimated ages and numbers of bluefin tuna caught by the Canadian-U.S.A. handline, harpoon and trap fisheries.[1]

| Age (years) | Approximate length (cm) | Numbers of fish by age and year of capture | | | | | | | | | | | | Average 1960-71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | |
| 2 | 67- 85 | | | | 19 | | | | | | | | | .. |
| 3 | 86-104 | 656 | 413 | 127 | 38 | 5 | 4 | | | | | | 15 | 105 |
| 4 | 105-122 | 277 | 1,241 | 187 | 207 | 18 | 18 | 10 | | | | | 113 | 173 |
| 5 | 123-139 | 1,141 | 48 | 174 | 257 | 144 | 96 | 5 | | | | | 5 | 158 |
| 6 | 140-155 | 16 | 55 | 375 | 577 | 99 | 69 | 45 | | | 9 | 5 | 77 | 111 |
| 7 | 156-170 | 1,268 | 296 | 0 | 269 | 412 | 289 | 99 | 6 | | 26 | 17 | 89 | 220 |
| 8 | 171-184 | 0 | 143 | 240 | 150 | 407 | 290 | 115 | 63 | 31 | 9 | 5 | 30 | 124 |
| 9 | 185-198 | 187 | 267 | 283 | 802 | 236 | 144 | 80 | 69 | 91 | 17 | 12 | 15 | 181 |
| 10 | 199-210 | 107 | 335 | 253 | 169 | 261 | 188 | 70 | 107 | 61 | 35 | 23 | 25 | 136 |
| 11 | 211-223 | 464 | 221 | 271 | 69 | 697 | 400 | 150 | 190 | 238 | 400 | 350 | 203 | 297 |
| 12 | 224-234 | 300 | 290 | 143 | 617 | 597 | 432 | 203 | 551 | 163 | 431 | 330 | 426 | 374 |
| 13 | 235-245 | 135 | 0 | 174 | 22 | 267 | 303 | 233 | 581 | 155 | 449 | 318 | 390 | 257 |
| 14+ | 246+ | 163 | 90 | 258 | 163 | 367 | 313 | 817 | 632 | 771 | 661 | 623 | 460 | 445 |
| Total | | 4,714 | 3,399 | 2,485 | 3,349 | 3,410 | 2,612 | 1,827 | 2,199 | 1,510 | 2,037 | 1,683 | 1,874 | 2,594 |

[1]See section, "Age Composition of Catch" for estimation procedure.

Table 15. Estimated ages and numbers of bluefin tuna caught by the Canadian sport fishery.[1]

| Age (years) | Approximate length (cm) | Numbers of fish by age and year of capture | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | |
| 4 | 105-122 | | 100 | | | | | | | | | | | 8 |
| 5 | 123-139 | | 29 | | | | | | | | | | | 2 |
| 6 | 140-155 | | 29 | | | | | | | | | | 10 | 3 |
| 7 | 156-170 | | 72 | | 1 | | | | | | | | 18 | 8 |
| 8 | 171-184 | | 43 | | 0 | | | | | | | | 18 | 5 |
| 9 | 185-198 | 13 | 14 | | 1 | | | 1 | | | | 1 | 8 | 3 |
| 10 | 199-210 | 0 | 14 | | 52 | 6 | 5 | 2 | | | | 1 | 8 | 7 |
| 11 | 211-223 | 0 | 0 | 87 | 106 | 20 | 48 | 78 | 17 | 98 | 36 | 12 | 42 | 45 |
| 12 | 224-234 | 25 | 43 | 16 | 167 | 110 | 88 | 141 | 41 | 202 | 88 | 54 | 111 | 90 |
| 13 | 235-245 | 0 | 29 | 48 | 58 | 196 | 119 | 124 | 73 | 246 | 169 | 123 | 122 | 109 |
| 14+ | 246+ | 102 | | 20 | 13 | 55 | 98 | 75 | 88 | 173 | 315 | 310 | 203 | 122 |
| Total | | 140 | 373 | 171 | 398 | 387 | 353 | 421 | 219 | 718 | 608 | 507 | 540 | 402 |

[1]See section, "Age composition of catch" for estimation procedure.

Table 16. Estimated U.S.A. sport catch of small bluefin tuna (approximately 50 to 122 cm) from tag returns.

| Recovery year | Numbers of tag returns | | | Ratio $\frac{a}{b}$ | Catch (1,000's metric tons) of small bluefin tuna from western Atlantic | | |
|---|---|---|---|---|---|---|---|
| | Sport fishery a | Purse-seine fishery b | Total | | Purse-seine fishery c | Sport fishery (estimated) $c\frac{a}{b}$ | Total |
| 1964 | 4 | 101 | 105 | 0.040 | 5.6 | 0.22 | 5.82 |
| 1965 | 15 | 177 | 192 | 0.085 | 2.7 | 0.23 | 2.93 |
| 1966 | 169 | 406 | 575 | 0.416 | 0.8 | 0.33 | 1.13 |
| 1967 | 23 | 674 | 697 | 0.034 | 2.3 | 0.08 | 2.38 |
| 1968 | 30 | 169 | 199 | 0.178 | 0.6 | 0.11 | 0.71 |
| 1969 | 12 | 41 | 53 | 0.293 | 1.6 | 0.47 | 2.07 |
| 1970 | 3 | 156 | 159 | 0.019 | 4.2 | 0.08 | 4.28 |
| 1971 | 4 | 135 | 139 | 0.030 | 3.6 | 0.11 | 3.71 |
| 1972 | 7 | 71 | 78 | 0.099 | 1.8 | 0.18 | 1.98 |

reasonable because the sport fishery operates in the same area as the purse-seine fishery. However, this assumption may be unreasonable because fish of ages I and II (46 to 85 cm) seem to be more vulnerable to the sport fishery than older fish (Mather, pers. comm.). If this is true, then our estimate of the age composition of the catch underestimates the numbers of ages I and II fish and overestimates the numbers of older fish.

The age composition of the sport catch of large fish, from tournament records, was then added to the estimated age composition of the sport catch of small fish to get a total age composition of the catch by sportsmen (Table 17). In Table 17, the data for age composition are incomplete because the sport catch of small fish is not known for 1960-63 and only some of the sport catch of large fish is shown.

Other fisheries.--We were unable to estimate the year-to-year age composition of the Argentinian and Cuban fisheries because: (1) the amount of bluefin tuna caught by these two countries is uncertain and probably is less than values given by Miyake and Tibbo (1972), and (2) there are no published accounts on the sizes of fish caught.

## Longline Fishery

Japan, Korea and Taiwan have published estimates of bluefin tuna caught by their Atlantic longline fleets (see Miyake and Tibbo, 1972). However, data on the sizes of fish caught are scarce. Hayasi and Shingu (undated[9]) gave length-frequencies for samples collected in the 1960's. The sample sizes were all less than 12 fish except for a 1966 sample of 68 fish. To estimate the age composition of the Japanese, Korean and Taiwanese catches, we assumed that the 1966 sample was, on the average, representative of sizes of fish caught by the longline fleets during 1960-71. We are aware that this estimation procedure is crude at best, since Hayasi and Shingu's data for some years suggest that a higher proportion of medium-sized fish was caught in years other than 1966.

## Summary of Age Composition of Catch--All Fisheries

All Atlantic fisheries for bluefin tuna can be divided into two general types, based on sizes (ages) of fish caught from 1960-71 (Figure 13). One type captures primarily small fish (46 to 122 cm--ages I to IV) and the other captures primarily large fish (> 184 cm--age IX+). Neither type of fishery currently catches significant numbers of medium-sized fish (123 to 184 cm--ages V to VIII). It has been suggested (Hamre, undated[6]; Mather and Jones, 1972[7]) that the lack of medium-sized fish in recent catches (since the early 1960's) is the result of heavy exploitation on the small fish, thus reducing the number of fish surviving to larger sizes. Consequently, only large fish of year classes that were not exposed to the recent heavy exploitation are currently caught by the

Table 17. Estimated ages and numbers of bluefin tuna caught by the U.S.A. sport fishery.[1]

| Age (years) | Approximate length (cm) | Numbers of fish by age and year of capture | | | | | | | | | | | | | Average 1964-72 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960[2] | 1961[2] | 1962[2] | 1963[2] | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | |
| 1 | 46- 66 | | | | | 1,911 | 3,009 | 52,396 | 300 | 712 | 279 | 516 | 2,079 | 3,038 | 7,138 |
| 2 | 67- 85 | | | | | 2,591 | 11,347 | 12,190 | 4,081 | 6,888 | 8,231 | 1,758 | 5,083 | 7,285 | 6,495 |
| 3 | 86-104 | | | 1 | | 4,058 | 3,201 | 2,694 | 1,694 | 2,588 | 13,973 | 2,151 | 802 | 2,988 | 3,794 |
| 4 | 105-122 | | 5 | 6 | 3 | 1,430 | 58 | 0 | 69 | 46 | 711 | 167 | 990 | 240 | 412 |
| 5 | 123-139 | | 5 | 13 | 9 | 1,008 | 556 | 0 | 100 | 9 | 1,524 | 265 | 203 | 262 | 436 |
| 6 | 140-155 | 5 | 2 | 5 | 20 | 274 | 863 | 0 | 0 | 0 | 660 | 44 | 15 | 232 | 232 |
| 7 | 156-170 | 11 | 5 | 0 | 15 | 460 | 59 | 2 | 0 | 0 | 0 | 14 | 19 | 1 | 62 |
| 8 | 171-184 | 3 | 3 | 7 | 2 | 14 | 59 | 1 | 0 | 0 | 78 | 8 | 15 | 21 | 22 |
| 9 | 185-198 | 1 | 1 | 4 | 1 | 5 | 1 | 1 | 1 | 0 | 6 | 0 | 7 | 6 | 3 |
| 10 | 199-210 | 1 | 1 | 3 | 4 | 1 | 0 | 0 | 0 | 1 | 19 | 21 | 7 | 1 | 6 |
| 11 | 211-223 | 0 | 1 | 3 | 13 | 6 | 3 | 1 | 6 | 10 | 51 | 32 | 36 | 21 | 18 |
| 12 | 224-234 | 1 | 3 | 1 | 7 | 33 | 7 | 5 | 17 | 6 | 38 | 46 | 90 | 52 | 33 |
| 13 | 235-245 | 1 | 1 | 3 | 8 | 8 | 8 | 9 | 29 | 10 | 32 | 61 | 100 | 75 | 37 |
| 14+ | 246+ | | 1 | 4 | 4 | 23 | 11 | 18 | 29 | 23 | 76 | 78 | 165 | 114 | 60 |
| Total | | 23 | 28 | 50 | 86 | 11,822 | 19,182 | 67,317 | 6,326 | 9,293 | 25,678 | 6,181 | 9,610 | 14,336 | 18,748 |

[1] See section, "Age Composition of Catch" for estimation procedure.

[2] Estimated catch is incomplete. Numbers of small bluefin caught are not known.

large-fish fisheries, accounting for the increase in average size of fish in the catch (Figure 11). It is also conceivable that the medium-sized fish are less vulnerable to the gears, or that the present fisheries are not fishing in areas where the medium-sized fish are available. Mather (pers. comm.) believes that these possibilities are remote, since medium-sized fish were caught by present gears in fair numbers in the 1950's and early 1960's (Mather and Jones, 1972[7]). An examination of the Barbate (Spanish) trap catch of medium- (ages V to VIII) and large- (ages IX to XII) sized fish, however, indicates that relative vulnerability of the medium-sized fish does vary markedly in some years (Figure 14). The 1956-58 year classes, for example, as compared to the 1951-55 and 1959 year classes, were considerably less vulnerable as 5- to 8-year old fish than as 9- to 12-year old fish. This suggests that changes in vulnerability might have caused the apparent disappearance of medium-sized fish from the surface catch. Variation in year-class strength and possibly increased catches of medium-sized fish by the longline fleets might have also contributed to the apparent disappearance.

## ESTIMATES OF SOME POPULATION PARAMETERS

### Growth

Several studies have dealt with growth of bluefin tuna (see Tiews, 1962; Rodriguez-Roda, 1964). Mather and Schuck (1960) described growth of bluefin tuna from the western Atlantic and developed a length-age key. Recently, Mather and Jones (1972[7]) gave a slightly different version of the key. We used both sets of data to estimate parameters of the von Bertalanffy growth equation, $L_t = L_\infty$ [1 - exp - ($K$ ($t$ - $t_o$)], with $L_t$ = length at age $t$, $L_\infty$ = asymptotic length, $K$ = the rate at which $L_\infty$ is attained, and $t_o$ = theoretical age at which $L_t$ = 0.

| Parameter | Source of data and parameter estimates | |
|---|---|---|
| | Mather and Schuck (1960) | Mather and Jones (1972)[7] |
| $K$ (yearly) | 0.055 | 0.053 |
| $L_\infty$ (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 estimates for parameters of the growth equation:

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

His estimates were based primarily on large fish that were aged by enumerating rings on vertebrae.

A comparison of these three growth curves (Figure 15) 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 used the Mather-Jones curve.

Weight-length relations are available for Atlantic bluefin tuna (e.g., Mather and Jones, 1972[7]; Rodríguez-Roda, 1964, 1971). For fish from the western Atlantic, Mather (pers. comm.) calculated the following relation:

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

where $\underline{W}$ = weight in kilograms and $\underline{L}$ = fork length in centimeters. Although this relation is subject to seasonal variation, especially for large fish as reported by Rodríguez-Roda (1964), it was used in our study to convert length measurements to weight measurements. Table 18 is the age-length-weight key used in our study.

Table 18. Age-length-weight key for Atlantic bluefin tuna. Data are from Mather and Jones (1972[7]) and Mather (pers. comm.).

| Age (years) | Fork length (cm) | Weight (kg) | Size groups |
|---|---|---|---|
| 1 | 46- 66 | 2.1- 6.2 | small |
| 2 | 67- 85 | 6.3- 12.9 | |
| 3 | 86-104 | 13.0- 23.2 | |
| 4 | 105-122 | 23.3- 36.8 | |
| 5 | 123-139 | 36.9- 53.6 | medium |
| 6 | 140-155 | 53.7- 73.6 | |
| 7 | 156-170 | 73.7- 96.2 | |
| 8 | 171-184 | 96.3-120.9 | |
| 9 | 185-198 | 121.0-149.5 | large |
| 10 | 199-210 | 149.6-177.4 | |
| 11 | 211-223 | 177.5-211.0 | |
| 12 | 224-234 | 211.1-242.7 | |
| 13 | 235-245 | 242.8-277.2 | |
| 14+ | 246+ | 277.3+ | |

## Mortality

### Instantaneous Coefficient of Total Mortality (Z)

Estimation procedures and results.--Two methods were used to estimate $\underline{Z}$. The first method (Method 1) was based on the average age composition of the catch of each fishery (Figure 13) and the assumptions of exponential decline in numbers of fish with age, constant $\underline{Z}$ with age and constant fishing effort and recruitment. The results from this method is a $\underline{Z}$ of 0.5 to 1.3 (Table 19). If we disregard the $\underline{Z}$ of 1.3 on the basis that it was estimated from an imprecise set of data (see section on French-Moroccan-Spanish baitboat and troll fisheries), $\underline{Z}$ ranges from 0.5 to 0.7.

Table 19. Mortality estimates for Atlantic bluefin tuna.

| Source | Fishery | Ages | Instantaneous coefficient of mortality: Natural (M) | Fishing (F) | Disappearance (X + M) | Total (Z) |
|---|---|---|---|---|---|---|
| Lenarz (1972)[1] | Atlantic-wide | I-XIV+ | 0.2-0.4 | - | - | - |
| Mather et al. (1972)[2] | Northwest Atlantic | II-IV | - | 0.28-1.00 | 0.30-1.11 | 0.59-1.75 |
| Present study | Atlantic-wide | I-XIV+ | 0.1-0.2 | - | - | - |
| Method 1 | Canadian-U.S.A. purse seine (1960-72) | II-XIV+ | - | - | - | 0.66 |
| | French-Moroccan-Spanish baitboat and troll (1971) | II-VII | - | - | - | 1.33 |
| | Longline (1960-71) | XI-XIV+ | - | - | - | 0.74 |
| | Moroccan-Portuguese-Spanish trap (1960-71) | XI-XIV+ | - | - | - | 0.61 |
| | U.S.A. sport | I-XIV+ | - | - | - | 0.48 |
| Method 2 | Canadian-U.S.A. purse seine | I-X | - | - | - | 0.68-2.96 |
| | Norwegian trap | XI-XIV+ | - | - | - | 0.21-0.82 |
| | Spanish trap | VII-XIV+ | - | - | - | 0.29-1.03 |

[1]Lenarz, W. H. 1971. Estimates of biomass per recruit of an unfished population of bluefin tuna in the North Atlantic Ocean. Unpublished manuscript, 6 p. Southwest Fisheries Center, National Marine Fisheries Service, La Jolla, Calif. 92037.

[2]Mather, F. J., III, B. J. Rothschild, G. J. Paulik and W. H. Lenarz. 1972. Preliminary analysis of bluefin tagging data. Unpublished manuscript, 25 p. Woods Hole Oceanographic Institution, Woods Hole, Mass. 02543.

Table 20. Apparent abundance of bluefin tuna by year classes.

Canadian-U.S.A. purse seine (catch in numbers/day's fishing)

| Age (years) | Year class: 1950 | 1951 | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | 0.91 | 187.12 | 73.81 | 90.17 | 651.37 | 55.87 | 52.52 | 11.14 |
| 2 | | | | | | | | | | | 3.52 | 110.86 | 99.39 | 339.27 | 151.83 | 760.83 | 434.08 | 343.00 | 512.73 |
| 3 | | | | | | | | | | 52.28 | 90.83 | 150.93 | 95.52 | 33.51 | 316.24 | 191.23 | 583.04 | 627.71 | |
| 4 | | | | | | | | | 130.06 | 60.56 | 55.03 | 2.14 | 0.01 | 13.24 | 3.61 | 29.39 | 48.23 | | |
| 5 | | | | | | | | 36.23 | 62.41 | 38.92 | 16.31 | 0.02 | 18.99 | 0.39 | 63.91 | 77.66 | | | |
| 6 | | | | | | | 1.87 | 56.16 | 10.27 | 26.88 | 0.12 | 0 | 0 | 27.06 | 12.18 | | | | |
| 7 | | | | | | 2.92 | 1.78 | 17.69 | 2.18 | 0.14 | 0 | 0 | 0 | 0 | | | | | |
| 8 | | | | | 4.55 | 1.85 | 0.39 | 2.84 | 0.20 | 0 | 0.08 | 2.66 | 0.15 | 0.26 | | | | | |
| 9 | | | | 3.09 | 0.98 | 0 | 0.38 | 0.17 | 0 | 0.25 | | | | | | | | | |
| 10 | | | 0.80 | 0.42 | 0 | 0.60 | 0.14 | 0 | 0.16 | | | | | | | | | | |
| 11 | | 0.29 | 0.39 | 0 | 0.74 | 0.28 | 0 | 0.55 | | | | | | | | | | | |
| 12 | 0.03 | 0.19 | 0 | 0.82 | 0.23 | 0 | 0.37 | | | | | | | | | | | | |
| 13 | 0.05 | 0 | 1.24 | 0.35 | 0 | 0.37 | | | | | | | | | | | | | |
| 14+ | | 0.40 | 1.20 | | 1.65 | | | | | | | | | | | | | | |

Spanish (Barbate) trap (catch in numbers/trap)

| Age (years) | Year class: 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 | 1951 | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | 2,780 | | | | | | |
| 2 | | | | | | | | | | | | | 110 | 0 | | | | | | |
| 3 | | | | | | | | | | 85 | | | 0 | 0 | | | | | 8 | |
| 4 | | | | | | | | | 128 | 482 | 55 | 552 | 0 | 0 | 13 | 6 | 9 | 66 | 22 | 10 |
| 5 | | | | | | | | 1,043 | 1,874 | 1,486 | 33 | 18 | 19 | 132 | 57 | 91 | 83 | 66 | 48 | 8 |
| 6 | | | | | | | 1,298 | 2,463 | 2,945 | 786 | 864 | 914 | 238 | 103 | 164 | 224 | 216 | 241 | 42 | 28 |
| 7 | | | | | | 3,447 | 6,639 | 3,633 | 2,274 | 1,163 | 1,231 | 225 | 98 | 182 | 423 | 296 | 704 | 176 | 84 | 128 |
| 8 | | | | | 4,043 | 6,692 | 4,706 | 2,492 | 2,098 | 2,220 | 330 | 144 | 246 | 340 | 552 | 559 | 263 | 346 | 306 | 22 |
| 9 | | | | 7,022 | 2,436 | 4,486 | 3,663 | 6,734 | 7,126 | 1,389 | 604 | 556 | 307 | 640 | 1,359 | 401 | 854 | 1,162 | 117 | |
| 10 | | | 3,022 | 2,142 | 1,431 | 2,291 | 3,719 | 3,936 | 3,703 | 1,610 | 1,405 | 398 | 344 | 1,475 | 581 | 519 | 1,251 | 154 | | |
| 11 | | 1,298 | 1,901 | 3,220 | 2,392 | 2,433 | 2,574 | 5,171 | 2,248 | 3,849 | 1,873 | 777 | 1,485 | 1,287 | 1,078 | 1,167 | 273 | | | |
| 12 | 21 | 562 | 1,156 | 1,003 | 494 | 522 | 1,375 | 698 | 1,706 | 2,171 | 728 | 1,157 | 606 | 821 | 595 | 183 | | | | |
| 13 | 580 | 605 | 836 | 123 | 131 | 529 | 230 | 684 | 1,682 | 539 | 1,436 | 426 | 687 | 500 | 227 | | | | | |
| 14+ | 853 | 368 | 35 | 37 | 198 | 86 | 274 | 762 | 234 | 1,176 | 405 | 653 | 467 | 469 | | | | | | |

The second method (Method 2) was based on catch-per-unit-effort (CPUE) data of a year class and assumptions of exponential decline in numbers of fish with age, constant _Z_ during all years in which the year class was exploited, and CPUE as a reasonable measure of apparent abundance. This method was applied to data from the Canadian-U.S.A. purse-seine, Norwegian purse-seine and Spanish trap fisheries. Only fish that were fully recruited were considered. A description of the data and results based on this method follow.

Full recruitment in the Canadian-U.S.A. purse-seine fishery varies between ages I and IV (Table 20). Because in only some years the fishery caught medium- and large-sized fish, sizes that are not the mainstay of the fishery, a measure of apparent abundance is missing for some ages (Table 20). Consequently, to minimize sources of error owing to availability and/or vulnerability of medium- and large-sized fish to this fishery, we estimated _Z_ for only the ages from age at first full recruitment to age with zero CPUE, or to age with a higher CPUE than the CPUE of the previous age. The range of _Z_ estimates was 0.68 to 4.48 (Table 21). Since a _Z_ of 4.48 (for the 1961 year class) is unusually large when compared to the other estimates, it was considered unrepresentative. It is possible that this high _Z_ was caused by an unusually high emigration of the 1961 year class to the eastern Atlantic in 1965-66, years in which Mather et al. (1972)

Table 21. Total mortality coefficient (Z) for bluefin tuna estimated from catch-per-unit-of-effort data of three fisheries.

| | Canadian-U.S.A. purse seine | | Norwegian purse seine | | Spanish trap | |
|---|---|---|---|---|---|---|
| Year class | Ages | Z | Ages | Z | Ages | Z |
| 1944 | | | 12-14+ | 0.82 | | |
| 45 | | | 11-14+ | 0.61 | 11-14+ | 0.37 |
| 46 | | | 11-14+ | 0.64 | 10-14+ | 0.97 |
| 47 | | | 11-14+ | 0.21 | 9-14+ | 1.03 |
| 48 | | | 11-14+ | -0.10[1] | 8-14+ | 0.57 |
| 49 | | | 11-14+ | 0.30 | 8-14+ | 0.67 |
| 1950 | | | 11-14+ | 0.33 | 7-14+ | 0.48 |
| 51 | | | 11-13 | 0.34 | 9-14+ | 0.52 |
| 52 | | | | | 9-14+ | 0.56 |
| 53 | | | | | 11-14+ | 0.49 |
| 54 | | | | | 11-14+ | 0.39 |
| 55 | | | | | 12-14+ | 0.29 |
| 56 | 6-10 | 0.68 | | | 11-14+ | 0.33 |
| 57 | 5-9 | 1.37 | | | 10-14+ | 0.32 |
| 58 | 4-8 | 1.63 | | | 9-13 | 0.36 |
| 59 | 3-7 | 1.86 | | | | |
| 1960 | 3-6 | 2.11 | | | | |
| 61 | 3-5 | 4.48[1] | | | | |
| 62 | 1-4 | 2.96 | | | | |
| 63 | 2-5 | 2.12 | | | | |
| 64 | - | - | | | | |
| 65 | 2-4 | 1.63 | | | | |
| Average | | 1.79 | | 0.46 | | 0.52 |

[1]Estimates considered unrepresentative and were not included in average.

recorded high emigration, but this is uncertain. The average of the remaining $Z$'s is 1.79 (range 0.68 to 2.96), which is for ages I to X. This average estimate applies for the years 1962-69 during which the year classes were exploited by the fishery.

In the Norwegian purse-seine fishery, first full recruitment occurs at about age XI. Estimates of $Z$ were calculated for fully recruited fish of the 1944-51 year classes. One estimate gave an increase in abundance which is impossible with the mortality model. The remaining estimates ranged from 0.30 to 0.82 with an average of 0.46 for ages XI to XIV+ (Table 21). This average $Z$ is for 1956-64, years in which the year classes were exploited.

The catch and sizes of fish from the Spanish Barbate trap fishery were recorded for a series of years by Rodríguez-Roda (1964). We estimated the age composition of the catch from those data and calculated the apparent abundance of year classes (Table 20). Although the age at first full recruitment is quite variable, ages VII to XII, estimates of $Z$ were based only on ages that were fully recruited. For the 1945-58 year classes, $Z$ ranged from 0.29 to 1.03 with an average of 0.52 (ages VII to XIV+--Table 20). This average $Z$ is for the 1956-71 fishing seasons.

Discussion.--The Canadian-U.S.A. purse-seine fishery exploits primarily small bluefin tuna of ages I to IV, whereas the Norwegian purse-seine and Spanish trap fisheries exploit primarily larger fish of presumably one stock, judging from tag returns off Spain of fish tagged off Norway (Mather et al., 1972). Thus, the $Z$ estimates for fish caught by these latter two fisheries are more similar to each other than they are to the $Z$'s for fish caught by the Canadian-U.S.A. purse seine fishery (Table 21).

The high $Z$'s for fish caught by Canadian-U.S.A. seiners are not unexpected, since exploitation in this fishery is high and has possibly increased since the mid-1960's over that of early years. For example, the average $Z$ for the 1956-60 year classes is 1.53, whereas the average $Z$ for the more recent 1962-65 year classes is 2.24. Of course, this example is not free from error since it compares the $Z$'s of fish of different ages. Also, it is known that migration behavior, which affects the estimate of apparent $Z$, varies with age.

It is important to note that our estimates of $Z$ are approximations only, because of deficiencies in the data from which they were derived. One significant deficiency is the weakness 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 $Z$ with Method 2. Another deficiency is in the fluctuating availability of bluefin tuna, which can vary from year-to-year and thus affect the measure of apparent abundance (Hamre, 1958). Still another deficiency is that the mortality models assume constant mortality for all ages, although in reality mortality probably varies with age. Finally, our aging technique is inaccurate, although this inaccuracy is generally not a serious problem in bluefin tuna smaller than about 120 cm long. Nevertheless estimates of $Z$ from data with inaccurate aging information are biased (Robson and Chapman, 1961).

Published estimates of $Z$ range from 0.59 to 1.75 (average 1.25) for bluefin tuna exploited off the U.S.A. east coast in 1964-68 (Mather et al., 1972[10]) These estimates are somewhat similar to ours although they were based on tagging data. There are no published estimates of $Z$ for the Atlantic bluefin tuna population as a whole, and it is difficult to obtain such an estimate because the different fisheries exploit different sizes of fish. A best guess, however, would be a $Z$ of about 0.8, based on the fact that $Z$'s obtained from Method 1 (Table 18) are near 0.7; also, if the $Z$'s from the Spanish trap and the Canadian-U.S.A. purse seine data for the year classes, 1956-58 (Table 20) are averaged (admittedly a dubious procedure) a $Z = 0.8$ is obtained.

Instantaneous Coefficient of Natural Mortality (M)

Bluefin tuna older than 14 years were reported by Mather and Schuck (1960). In view of the relatively long life-span of this species, it has been assumed that their natural mortality is low, with an $M$ of about 0.2 to 0.4 (Lenarz, 1971[11]).

We used two procedures to estimate $M$. The first was developed by Beverton and Holt (1959) who examined the ratio of $M$ to $K$ (parameter of the von Bertalanffy growth equation) 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 estimates of $M$ (Hennemuth, 1961) and $K$ (LeGuen and Sakagawa, 1973) were made, is the yellowfin tuna of the eastern Pacific. For this species, $M/K = 0.80/0.36$, or about 2. With $K$ of 0.05 to 0.09 for bluefin tuna and $M/K = 2$, $M$ is 0.1 to 0.2 which seems reasonable.

The second, also a procedure developed by Beverton and Holt (1956), was simplified by Paloheimo (1961). The procedure uses estimates of $Z$ and average fishing effort ($\bar{f}$), fitted to the equation, $Z = M + q\bar{f}$ where q is the coefficient of catchability and is assumed constant during the period for which $Z$'s and $\bar{f}$'s are estimated. Applying this procedure to data from the Canadian-U.S.A. and Norwegian purse seine fisheries, $M = 1.91$ and 0.01 respectively (Figure 16). Both estimates are unreasonable, and their large 95% confidence interval--0 to 4.07 for $M = 1.91$, 0 to 0.40 for $M = 0.01$--places doubt as to their accuracy. Also, since both fisheries underwent changes in fishing operations, it is probable that $q$ varied enough to affect the analysis.

An interesting quasi-$M$ was estimated by Mather et al. (1972[10]) based on tag returns along the New England coast. They estimated a "rate of disappearance ($M + X$)," or mortalities owing to natural causes and changing migration patterns with age, of 0.68 (range 0.30 to 1.11). If $M$ is 0.1 to 0.2, then $X$ is 0.48 to 0.58. This indicates that about 38 to 44% of bluefin tuna, ages II to IV, become unavailable annually to the fisheries along the New England coast because of changing migration patterns. If this fraction is completely unavailable to all fisheries of the Atlantic, then "natural mortality" is essentially $M + X$, or 0.68 for the stock exploited along the New England coast.

### Instantaneous Coefficient of Fishing Mortality (F)

Mather et al. (1972[10]) estimated $F$ to be 0.28 to 1.00 for the New England bluefin tuna fishery of 1964-68. This corresponds to an annual fishing mortality rate of 24 to 63% (average 43%), which is primarily exerted on ages II and III.

An estimate of exploitation rate, perhaps imprecise, can be calculated from tag return rates. FAO (1968) estimated an exploitation rate of at least 28% for 2 years for the fisheries along the New England coast. Mather et al. (1972) reported the number of tag returns for fish tagged off New England in 1954-71. Return rates were calculated from releases made in 1964-69 and from returns made in the first 3 years during which the bulk of the releases was available to the fisheries (purse seine and sport). The rates are 15 to 44% (average 29%) for 3 years, or about 5 to 15% (average 10%) annually. These underestimated the true tag return rates for the population of the western Atlantic because they were not adjusted for initial tag loss and shedding which are known to occur (Lenarz et al., in press a), and for tag loss due to transatlantic migration (Mather et al., 1972).

Another method of estimating fishing mortality is to assume that a reasonable estimate of $M$ is 0.1 to 0.2, and that $F = Z - M$ (Ricker, 1958). $Z$ for the Norwegian purse seine fishery averaged 0.46, to give an $F$ = 0.26 to 0.36. Similarly, for the Spanish trap fishery average $Z$ = 0.52, to give an $F$ = 0.32 to 0.42. These results indicate that, on the average, bluefin of ages 7 to 14+ years experience an annual fishing mortality rate of about 23 to 34%. It is interesting that these older fish experience about the same fishing mortality rate, 24 to 63% (Mather et al., 1972[10]), as the younger fish that are exploited along the New England coast.

### Size at Recruitment

A review of methods of estimating size at recruitment was made by Lenarz et al. (in press b). In their review, the equation

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

which is similar to that of Beverton and Holt (1956), was proposed as a means of estimating the effective length at recruitment ($l_r$) from an estimate of average length ($\bar{l}$) of fish in the catch. Thus, given an estimate of $K$, $L_\infty$ and $\bar{l}$, the effective size at recruitment can be easily estimated for a fishery. With parameters of the weight-length relation (see Growth section), $l_r$ can be converted to weight at recruitment ($w_r$):

$$w_r = 0.00003171_r^{2.90444}$$

Estimates of $\bar{l}$ were calculated for bluefin tuna from the Atlantic Ocean (Table 22); we assumed that the average size of fish caught by the Japanese longline fleet in 1966 was representative for the longline fleet as a whole and for all years. Since $Z$ varied and most likely increased in 1960-71, we estimated $l_r$ for a range of $Z$'s (0.5 to 1.7), given our most reasonable estimates of $K = 0.053$, $L_\infty = 447.88$ cm, and $\bar{l}$'s (Figure 17).

For the Atlantic bluefin tuna population as a whole, we assumed a $Z$ of 0.8 (see page ). With $Z = 0.8$, the effective weight at recruitment in 1971 was about 9 kg (76 cm--Figure 17), which is slightly less than the 10 kg suggested by FAO (1968, page 23) as an interim minimum size limit to stem the loss in sustained yield. We note that this weight of 10 kg, suggested by FAO, was based on a model with knife-edged recruitment and is not directly comparable to estimates of $w_r$ (see Lenarz et al., in press b).

## PRODUCTION AND SIGNIFICANCE OF RESULTS

### Trends in Production

In the foregoing review of catch and effort statistics of Atlantic bluefin tuna, we presented a summary of available statistics, and identified those fisheries with adequate statistics. In order to forecast trends in production, we examined the relation between total catch and total nominal fishing effort for fisheries with

Table 22. Estimated average length ($\bar{l}$ in cm) and average weight ($\bar{w}$ in kg) of bluefin tuna caught in the Atlantic Ocean, 1960-70.

| Year | Surface fisheries | | | | Longline fishery | | All fisheries[1] | |
|---|---|---|---|---|---|---|---|---|
| | Western Atlantic[1] | | Eastern Atlantic | | Mid-Atlantic[2] | | | |
| | $\bar{w}$ | $\bar{l}$ | $\bar{w}$ | $\bar{l}$ | $\bar{w}$ | $\bar{l}$ | $\bar{w}$ | $\bar{l}$ |
| 1960 | 45 | 131 | 110 | 179 | 181 | 212 | 105 | 176 |
| 1961 | 64 | 148 | 147 | 197 | 181 | 212 | 136 | 192 |
| 1962 | 35 | 120 | 136 | 192 | 181 | 212 | 112 | 174 |
| 1963 | 23 | 104 | 46 | 132 | 181 | 212 | 49 | 135 |
| 1964 | 21 | 101 | 49 | 136 | 181 | 212 | 48 | 134 |
| 1965 | 16 | 91 | 37 | 123 | 181 | 212 | 42 | 128 |
| 1966 | 8 | 71 | 9 | 76 | 181 | 212 | 12 | 84 |
| 1967 | 16 | 92 | 30 | 114 | 181 | 212 | 26 | 109 |
| 1968 | 21 | 102 | 26 | 109 | 181 | 212 | 26 | 108 |
| 1969 | 24 | 106 | 38 | 124 | 181 | 212 | 34 | 119 |
| 1970 | 19 | 97 | 26 | 109 | 181 | 212 | 22 | 103 |
| 1971 | 14 | 88 | 17 | 94 | 181 | 212 | 20 | 99 |

[1] Estimates for 1960-63 are too high because they do not include small bluefin tuna caught by the U.S.A. sport fishery.

[2] Estimates are assumed constant for all years and are based on 1966 samples from the Japanese longline fleet.

adequate statistics. These fisheries are: German handline, Norwegian purse seine, Portuguese trap, and Spanish trap (Figure 18); Japanese longline (Figure 19); and Canadian-U.S.A. purse seine (Figure 20).

Estimates of total catch of the Japanese longline, Portuguese trap and Spanish trap fisheries are reported in numbers of fish. Ideally, analysis of the relation between total catch and fishing effort should be based on catch in weight rather than in numbers of fish, in order to account for changes in sizes of fish caught. We examined the bias with estimated weight of the Spanish trap catch, based on numbers of fish and average weight of fish caught in the Barbate trap. The relation was not significantly different for catch in numbers or catch in weight. Thus, at least for the Spanish trap fishery, analysis of total catch and effort is not affected by the unit measure of catch.

The German handline, Norwegian purse-seine, Portuguese trap and Spanish trap fisheries caught primarily medium and large bluefin tuna (> 122 cm) during the years of high production. The catch is a linear, increasing function of fishing effort in each of these fisheries (Figure 18). Since the early 1960's, the catch and effort of these fisheries decreased to a negligible or low level and the catch was primarily large fish (> 184 cm). Apparently, these fisheries have responded to the low availability of fish by decreasing their fishing effort proportionately to the catch.

Since 1956, the Japanese longline fleet operated in the mid-Atlantic. The trend of Japanese longline catch as a function of effort for two regions in the western Atlantic (Figure 9, regions II and VII) is somewhat a curvilinear, increasing function (Figure 19). In 1967-70, the catches were only a few hundred fish per region as compared to several thousand fish per region during the peak years, 1965 in region II and 1964 in region VII. Fishing effort in 1967-70 was also low, compared to that of the peak years (Figure 19).

The trend in CPUE for different classes of seiners in the Canadian-U.S.A. purse-seine fishery was very different. To estimate total fishing effort for this fishery, we used the total catch divided by (1) the CPUE of Class 3 seiners and (2) the CPUE of Class 6 seiners.

The Canadian-U.S.A. purse-seine fishery began essentially in 1958 with one vessel of 41 tons capacity (Squire, 1959; Wilson, 1965)--Table 3. Four years later, the first Class 3 seiner (92 to 181 tons capacity) appeared in the fishery and 5 years later the first Class 6 vessel (>363 tons capacity) appeared. Figure 20 shows that the catch is a linear, increasing function of estimated total fishing effort based on Class 3 CPUE's and that apparent fishing intensity has decreased since 1966 from a high level of about 520 days fishing in the early 1960's. With total fishing effort based on Class 6 CPUE's, the plot of catch against estimated total effort shows that the 1972 point is at the right-hand corner of Figure 20. This suggests that the stock(s) is being excessively exploited. Not accounted for in our analysis are changes in fishing efficiency of the fleet, especially in Class 3 seiners during recent years (as discussed in an earlier section). In addition, in 1964-71, the fishing area expanded and the center of fishing shifted from Cape Cod Bay to an area south of Cape Cod, to Cape May-Martha's Vineyard (Figure 21); the period of intensive fishing, July and August, remained the same. Fishermen claim that very few schools of small bluefin tuna are now sighted north of Cape Cod. This was not the case in early years when most small bluefin tuna were caught in Cape Cod Bay and off Maine (Squire, 1959; Wilson, 1965). Apparently the seiners are now catching a large portion of the available fish before they get past Cape Cod. It thus seems that in our analysis, total fishing effort for about 1966-72 is underestimated relative to that for earlier years.

Our results do not provide firm clues for forecasting trends in bluefin tuna production, but they indicate that as production decreases nominal fishing effort decreases proportionally.

## Age Groups and Year-Class Strength

A number of characteristics are prominent in the historic record of bluefin tuna catches; one is the change in age composition of the catch. In the western Atlantic, prior to 1963, the catch was composed of primarily ages IV and older fish (> 104 cm)--Figure 22. In 1963 and 1964, significant numbers of younger fish were caught, together with ages IV and older fish, and the catch reached a high of 6,000 tons (Table 1). In 1965-72, the catch was dominated by fish of ages I to III (46 to 104 cm), and the annual catch fluctuated between 1,000 and 5,000 tons. In short, prior to 1963 the fisheries of the western Atlantic were supported by several age groups of old fish, in 1963 and 1964 they were supported by significant numbers of both young and old fish, and in 1965-72 only a few age groups primarily of young fish supported the fisheries. The transition from older to younger fish in the catch occurred shortly after the introduction of purse seine fishing in 1958.

Another characteristic of the catch is variation in recruitment strength. The index of abundance of the 1961-66 year classes (Table 19) during their first 4 years (ages I to IV) in the Canadian-U.S.A. purse-seine fishery was summed and divided by four The results are as follows:

Index of abundance by year class

| 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|
| 68 | 96 | 115 | 140 | 408 | 280 |

They show that the 1965 year class was apparently considerably stronger than the other year classes and that it contributed substantially to the purse seine and total western Atlantic catch (Figure 22). The ratio of the strongest to the weakest year class is 6.0. Although this ratio is a crude estimate of variation in year-class strength and is probably affected by variation in migration pattern with the fish's age (Mather et al., 1972), it is considerably higher than that for yellowfin tuna of the eastern tropical Pacific (Davidoff, 1969), a species with a much shorter life-span (5 to 6 years).

On an Atlantic-wide basis, our data similarly indicate that changes in age composition and year-class strength have affected the catch (Figure 23). However, because data from fisheries in the eastern and mid-Atlantic are limited, the estimated age composition of the entire Atlantic catch is imprecise. On the other hand, other investigators (e.g., Hamre, 1958; Rodriguez-Roda, 1964) analyzed detailed data from individual fisheries of the eastern Atlantic and concluded that variation in year-class strength, changes in fishing effort, and changes in migration patterns of bluefin tuna seriously affected the catch.

## Exploitation and Size of Fish

Since the introduction of purse-seine and live-bait fishing, exploitation of small bluefin tuna has increased. As result, the average size of fish in the total catch has decreased (Table 22). The current effective minimum size at recruitment, however, is about the same as the absolute (knife-edged) minimum size at recruitment of 10 kg, which was proposed by FAO (1968) as an interim minimum size limit. It seems more likely though that because of the Atlantic bluefin tuna's long life-span, a more rigorous analysis than the FAO analysis of yield per recruit will result in finding that there is an optimum minimum size at recruitment greater than 10 kg. To obtain an optimum minimum size greater than 10 kg, the average size of fish in the catch would have to be increased. This might be accomplished by a decrease in the catch of small fish and/or an increase in the catch of large fish. Since it appears that large fish are becoming scarce and medium-sized fish are either scarce or unavailable, the obvious course would be to reduce the catch of small fish. It is not clear, however, how much reduction is necessary, since the amount is dependent on several factors, foremost being the number of stocks in the Atlantic. For instance, if there are several stocks of bluefin tuna in the Atlantic, and fish of the western stock are not completely available at medium and large sizes, and exploitation is high, then not much reduction in catch of small fish may be necessary In this case, natural mortality would be equal to the high quasi-$\underline{M}$ of Mather et al. (1972[10]), and the optimum size at recruitment would be close to the current size at recruitment. On the other hand, if there is only one stock in the Atlantic and once recruited into the small-fish fisheries a cohort remains fully available for capture, a substantial reduction in catch of small fish may be necessary to obtain the maximum yield per recruit. In this case $\underline{M}$ would be about 0.1 to 0.2.

## Summary of Results

The results of our study are summarized as follows:

(1) Statistics on the total Atlantic bluefin tuna catch are incomplete owing to poor reporting or inclusion of unknown quantities of other species of tunas by some countries. The available statistics, however, indicate that the total Atlantic catch has declined markedly from a peak of about 36,800 tons in 1962 to 18,500 tons or less in 1971, and the decline has occurred primarily in the catch of the eastern Atlantic and in the large-fish fisheries.

(2) The trend in catch rates is downward for fisheries that exploit medium (123 to 184 cm) and large (> 184 cm) bluefin tuna, and upward for the French-Spanish baitboat fishery that exploits small bluefin tuna (< 123 cm) in the eastern Atlantic.

The trend in catch rates is downward since 1970 for the Canadian-U.S.A. purse-seine fishery that exploits small bluefin tuna in the western Atlantic.

(3) Correlation analyses suggest that the catch rates for the Canadian-U.S.A. purse-seine fishery are positively correlated with those of the French-Spanish baitboat fishery; the catch rates for the Norwegian purse-seine fishery and Spanish trap fishery are not correlated with those for the French-Spanish baitboat fishery; and the catch rates for the Japanese longline fishery are not correlated with those of the Spanish trap fishery.

(4) Adequate size-frequency statistics for population analyses are available for most of the major Atlantic bluefin tuna fisheries, except for the surface fisheries of the Bay of Biscay, the longline fisheries of the mid-Atlantic, and the surface fisheries off North Africa.

(5) The average size of fish in the catch of the large-fish fisheries has increased owing to reduction in medium-sized fish in the catch.

(6) Fluctuations in vulnerability of medium-sized bluefin tuna (123 to 184 cm) probably have affected the Spanish trap catch of this size group.

(7) Two general types of Atlantic fisheries for bluefin tuna can be identified, based on sizes (ages) of fish caught from 1960-71. One type captures primarily small fish (50 to 122 cm--ages I to IV) and the other captures primarily large fish (> 184 cm--age IX+).

(8) Growth of bluefin tuna from the eastern and western Atlantic is similar.

(9) Estimates of $Z$ range from 0.21 to 1.33.

(10) $M$ probably ranges from 0.1 to 0.2 for the Atlantic population as a whole.

(11) The effective size at recruitment has decreased since the introduction of purse-seine and live-bait fishing for small fish. $w_r$ was about 9 kg (75 cm) in 1971, which appears to be below the optimum minimum size on a yield-per-recruit basis.

(12) The relation between bluefin tuna production and nominal effort is a linear, increasing function for most fisheries; that is, as production has decreased nominal fishing effort has decreased proportionately.

(13) The dominate age groups in the total catch from the western Atlantic have changed since introduction of purse-seine fishing. Prior to 1963 the catch was composed of primarily ages IV and older fish. In 1963 and 1964, significant numbers of ages I to III fish were first caught together with significant numbers of ages IV and older fish. Since 1964, ages I to III have dominated the catch.

(14) Crude estimates of year-class abundance indicate that there was a six-fold difference in apparent abundance between the weak year-class of 1962 and the strong year-class of 1965.

## Recommendations

We recommend four actions, implementation of which would improve our present understanding about the population dynamics of the bluefin tuna and lead to more rational management of the resource. These actions are:

(1) Accurate statistics on catch, effort and size frequencies must be collected and made available on a timely basis. It is imperative that this collection be instituted on an Atlantic-wide basis if the fisheries are to be monitored and the stocks rationally managed. As yet, there is no uniformity in the quality and quantity of statistics on bluefin tuna being collected on an Atlantic-wide basis. It is important that those nations that are engaged in fishing for Atlantic bluefin tuna strive towards improving their procedures for collecting and reporting fishery statistics. We recommend that landing and catch-effort statistics be reported accurately and broken down by species, gear, country and ocean region or area of capture and that size-frequency statistics be compiled by 5-cm or smaller groupings and by month and 5° x 5° area of capture. The need for more accurate statistics from especially the Bay of Biscay fleets, the North African fleets, the longline fleets and the sport fishing fleets is critical. Examination of Tables 2 and 6 will be helpful in identifying deficiencies in the statistics of each fleet. ICCAT's Field Manual (Miyake and Hayasi, 1972) should be consulted for data collection procedures.

(2) The stock structure of the bluefin tuna population in the Atlantic must be defined. Mather and Jones (1972[7]) recently reviewed the stock structure of bluefin tuna, and concluded that available evidence best supports a two-stock (eastern and western stocks) hypothesis. Our results and evidence from other sources, on the other hand, show a positive correlation in apparent abundance of small fish from the eastern and western Atlantic (Figure 6), an increase in average size of large fish in the catch of the large-fish fisheries on both sides of the Atlantic (Figure 11), the transatlantic migration of small and large bluefin tuna (Mather et al., 1972), and a similarity in heart-muscle protein of fish from the Bay of Biscay and the western Atlantic (Edmund and Sammons, 1973), all suggesting, for management purposes, that only one stock is exploited in the Atlantic. The question of how many stocks of bluefin tuna are exploited in the Atlantic Ocean is therefore still unanswered. This point is important since the optimum size at recruitment on a yield-per-recruit basis is likely to be largely dependent on the number of stocks being exploited. If there is only one stock in the Atlantic, the advice, perhaps, might be to reduce the number of small fish currently being caught in order to improve the yield on a yield-per-recruit basis. If several independent stocks are being exploited, then the advice might be to retain the high exploitation of small fish, such as in the western Atlantic. In addition, although we have treated the Atlantic population separately from the Mediterranean population, the interaction between the two should be investigated since there appears to be some mixing between the two populations (Aloncle, 1964; Bellon, 1954; Mather et al., 1972), and this might affect a management strategy.

(3) Further expansion of the fisheries must be discouraged, until the health of the stock(s) is assessed more accurately. In view of the marked decline in total catch of Atlantic bluefin tuna, the increase in numbers of small fish in the catch, the apparent reduction in abundance of medium- and large-sized fish, and the high rate of tag returns in the western Atlantic (Mather et al., 1972), regulation of the small-fish fisheries has been suggested. However, an argument against regulation of the small-fish fisheries at this time - at least in the Canadian-U.S.A. purse-seine fishery - is based on the 1970 and 1971 high catches of small fish (Figure 3), the high CPUE's of Class 3 seiners (Figure 4), the increase in CPUE's of French-Spanish baitboats (Figure 5), the location of the 1966-72 catches at the lower left-hand corner of the production graph, based on Class 3 CPUE's (Figure 20), and the large variability in apparent year-class strength. We point out, however, that although on the surface these results would indicate that the bluefin tuna stocks are healthy, the evidence may be misleading because of inaccuracies in our data. Other indices suggest that, contrary to this appearance of a healthy state, the stocks have been adversely affected by exploitation. For example, in the western Atlantic, Z is high and appears to have remained constant or increased, although the number of vessels (Table 3) and nominal fishing effort have decreased. With increased cooperation among small seiners of the Canadian-U.S.A. purse-seine fleet in the mid-1960's, fishing efficiency apparently improved and the catch rate increased, although actual abundance of bluefin tuna might have decreased. Currently, commercial fishermen have reported seeing fewer and smaller schools than in the 1960's, and the schools that they spotted were almost always caught (Mather, pers. comm.). In other words, fishing efficiency, including searching efficiency, might have improved. Other signs that suggest the stocks are being heavily exploited are the apparent downward trend in CPUE's in the 1970's for the Canadian-U.S.A. purse seine fishery (Figure 4) and the location of the 1972 catch at the lower right-hand corner of the production graph, based on Class 6 CPUE's (Figure 20). Thus, there is opposing evidence as to the health of the Atlantic bluefin stocks, and there appears to have been no spawning failure to date. Further analyses on the measures of apparent abundance of bluefin tuna on both an Atlantic-wide basis and a regional-basis are recommended as a step towards determining the true health of the stock(s).

(4) Finally, an analysis of yield per recruit with size-specific F (Gulland, 1965; Murphy, 1965) must be undertaken immediately, to gain insight into the optimum size at recruitment (Lenarz et al., in press b) and into year-class variation. Such an analysis could serve as a basis for devising management strategies.

## ACKNOWLEDGEMENTS

We wish to thank our many colleagues who contributed data and information on the bluefin tuna of the Atlantic. We are especially grateful to Frank J. Mather, III, of the Woods Hole Oceanographic Institution (WHOI) for providing data and information on the fisheries. His knowledge of the bluefin tuna fisheries is unsurpassed. James S. Beckett of the Fisheries Research Board of Canada and John Mason of WHOI provided data on the bluefin tuna fisheries of the western Atlantic. William W. Fox, Jr., David Kramer, William H. Lenarz and Brian J. Rothschild of the National Marine Fisheries Service, Southwest Fisheries Center (SWFC), and Frank Mather, III, reviewed the manuscript and provided valuable suggestions that improved the manuscript immensely. Makoto Kimura of SWFC assisted in the tedious chore of compiling the data.

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FOOTNOTES

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FIGURES

Figure 1. Location of bluefin tuna fisheries in the Atlantic Ocean. Dash lines delineate the distributional boundaries of northern bluefin tuna.

Figure 2. Catches of bluefin tuna from the Atlantic Ocean and Mediterranean Sea. Total Atlantic catches are probably overestimates because they contain catches of southern bluefin tuna by the Japanese longline fleet, and catches of other tuna species by Portugal, Morocco and Spain. Canadian-U.S.A. catches Include bluefin tuna caught by sport gear, and the 1972 catch is a preliminary estimate.

Figure 3. Estimated catches of primarily small bluefin tuna (< 123 cm) caught in the eastern and western Atlantic. The eastern Atlantic catch has been on a declining trend since about 1954, which is not shown in this figure.

Figure 4. Catch rates for two classes (Class 3 = 92 to 181 tons capacity, and Class 6 = > 363 tons capacity) of purse seiners that operate in the Canadian-U.S.A. purse-seine fishery for Atlantic bluefin tuna. Catch rates for 1972 are preliminary. Dashes indicate years in which Class 6 seiners did not participate in the fishery (1969) or had insignificant amount of fishing effort (1968).

Figure 5. Catch rates for various fleets that participate in the Atlantic bluefin tuna fisheries. The French and Spanish baitboat and troll fleets catch primarily small (< 123 cm) bluefin tuna; the other fleets catch primarily fish larger than 122 cm long.

Figure 6. Relation between catch rates of bluefin tuna from the eastern Atlantic and from the western Atlantic. Catch rates are for primarily small bluefin tuna; no data point for 1964.

Figure 7. Approximate fishing season and average length of bluefin tuna caught in various fisheries in 1960-71.

Figure 8. Relation between spawners, catch rate of the Norwegian purse seine fishery in year t, and recruits, catch rate of the French-Spanish baitboat fishery in year t + 2. The Norwegian fishery catches primarily large fish (> 184 cm or age IX+), whereas the French-Spanish fishery catches primarily small fish, with age II (67 to 85 cm) the dominant group.

Figure 9. Regions used in analysis of Japanese longline catch of Atlantic bluefin tuna.

Figure 10. Catch rate of Atlantic bluefin tuna by region for the Japanese longline fleet.

Figure 11. Estimated average weight of Atlantic bluefin tuna caught by various fleets.

Figure 12. Average weight and catch of bluefin tuna from the Spanish Barbate trap. Data are from Rodríguez-Roda (1964, 1972 -- Las capturas de atun, Thunnus thynnus (L.), por las almadrabas del sur de España en el año 1972 y variacion del rendimiento en el periodo de 1962 a 1972. Unpublished manuscript, 3 p, 5 tables, 1 figure. Instituto de Investigaciones Pesqueras, Laboratorio de Cadiz, Cadiz, Spain).

Figure 13. Average age composition of the catch of Atlantic bluefin tuna caught by various fisheries.

Figure 14. Catch of medium (ages V to VIII) and large (ages IX to XII) bluefin tuna by the Spanish Barbate trap. Ratio of large to medium fish from same year class indicates relative vulnerability of a year class.

Figure 15. Growth of bluefin tuna from the eastern Atlantic (Rodriguez-Roda) and western Atlantic (Mather and Jones; Mather and Schuck). See section on Growth for data sources.

Figure 16. Relation between instantaneous coefficient of total mortality and average fishing effort.

Figure 17. Isopleths of effective weight at recruitment (in kilogram). The dash line indicates the presumed level of Z for the Atlantic bluefin tuna population 1969-71.

Figure 18. Total catch of bluefin tuna as a function of total fishing effort for various eastern Atlantic fisheries.

Figure 19. Total Japanese catch of bluefin tuna as a function of total fishing effort for two regions (II = off Canada and the U.S.A.; VII = off northeast South America; see Figure 9) in which the Japanese longline fleet operates.

Figure 20. Total catch of bluefin tuna as a function of estimated total effort for the Canadian-U.S.A. purse seine fishery. Panel A, total effort is estimated from the catch rate of Class 3 seiners; Panel B, total effort is estimated from the catch rate of Class 6 seiners.

Figure 21. Fishing area of the Canadian and U.S.A. purse-seine fleets for Atlantic bluefin tuna. In the early 1960's the fishery was centered in Cape Cod Bay; in 1971 the center was off Cape May-Martha's Vineyard

Figure 22. Estimated ages and numbers of bluefin tuna caught by the western Atlantic surface fisheries, 1960-71. *Estimates for 1960-63 are incomplete because they do not include the unknown numbers of small bluefin tuna caught by U.S.A. sportsmen.

Figure 23. Estimated ages and numbers of bluefin tuna caught in the entire Atlantic, 1960-71. *Estimates for 1960-63 are incomplete because they do not include the unknown numbers of small bluefin tuna caught by U.S.A. sportsmen.

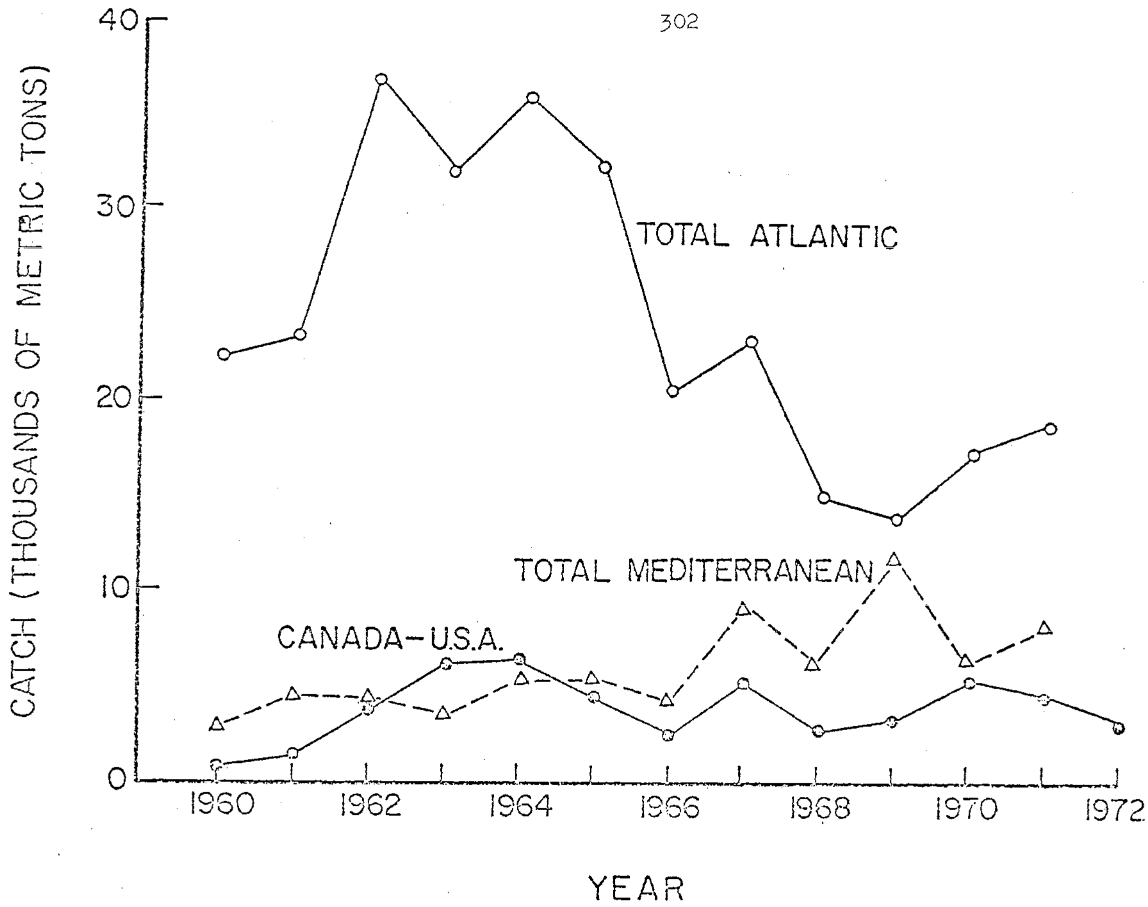



Figure 2

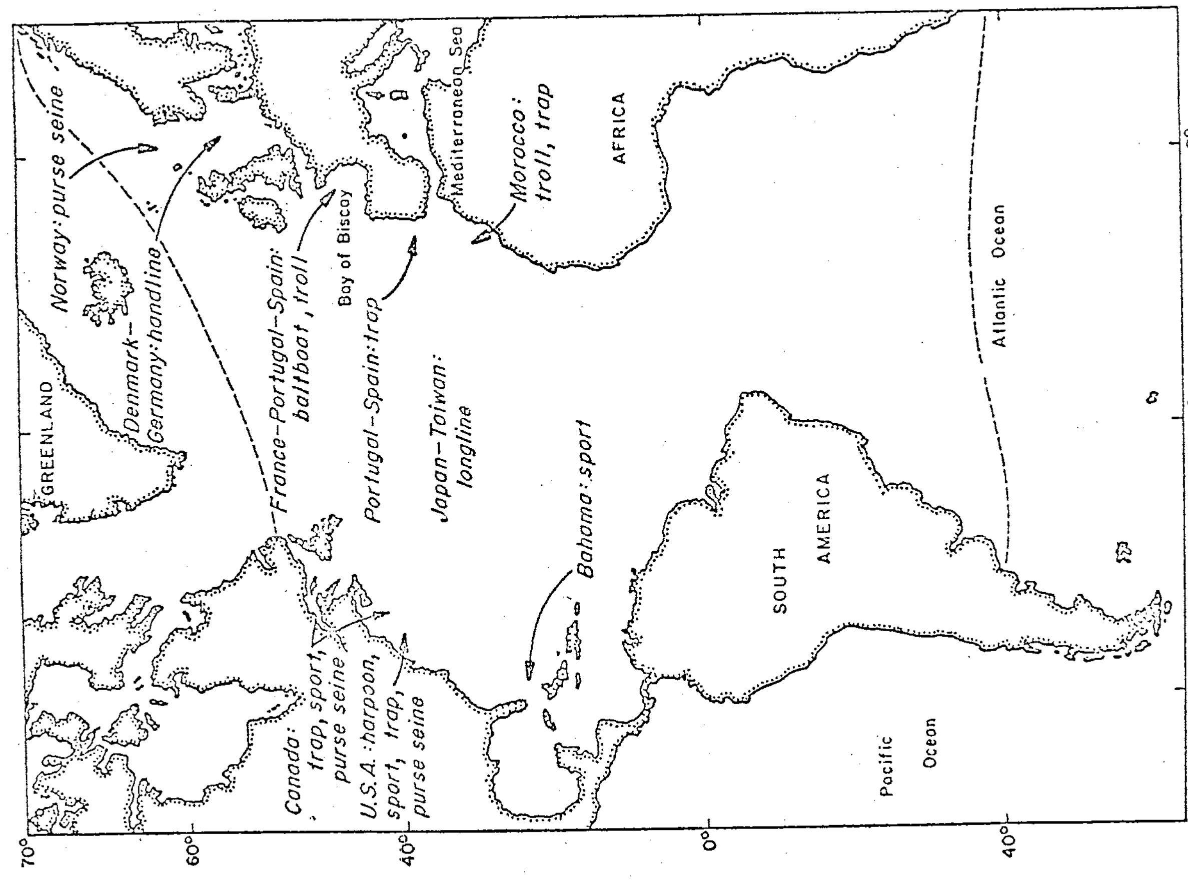



Figure 1

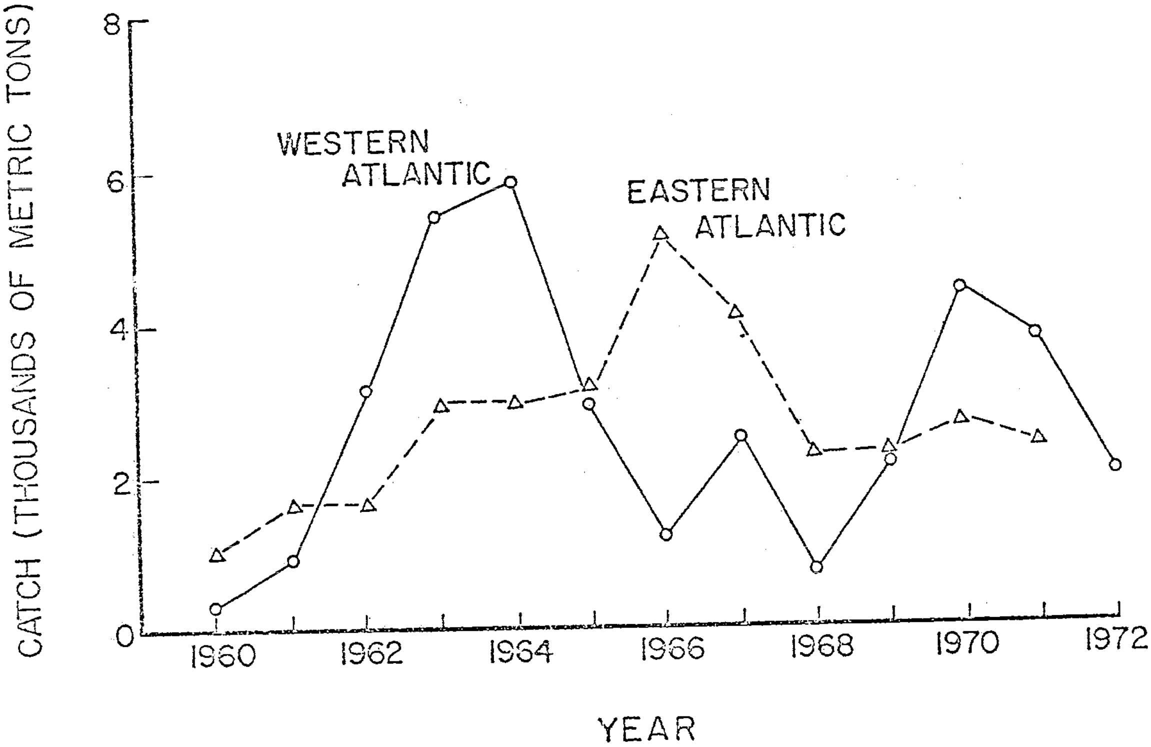



Figure 3

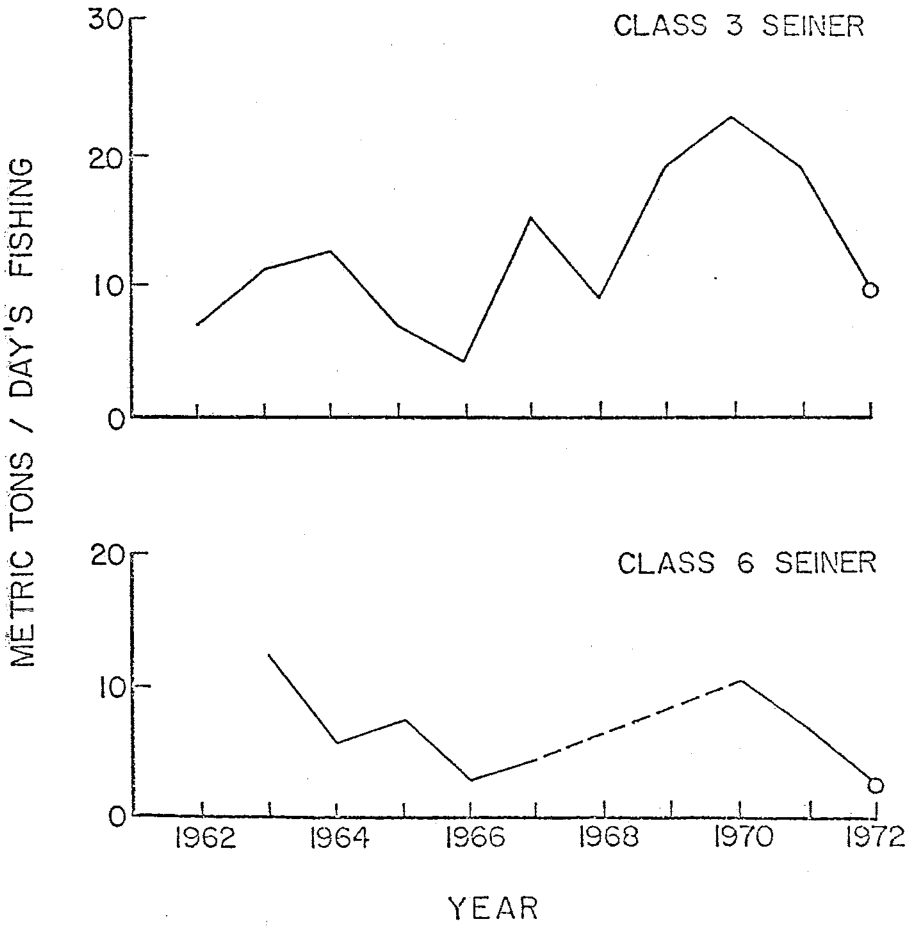



Figure 4

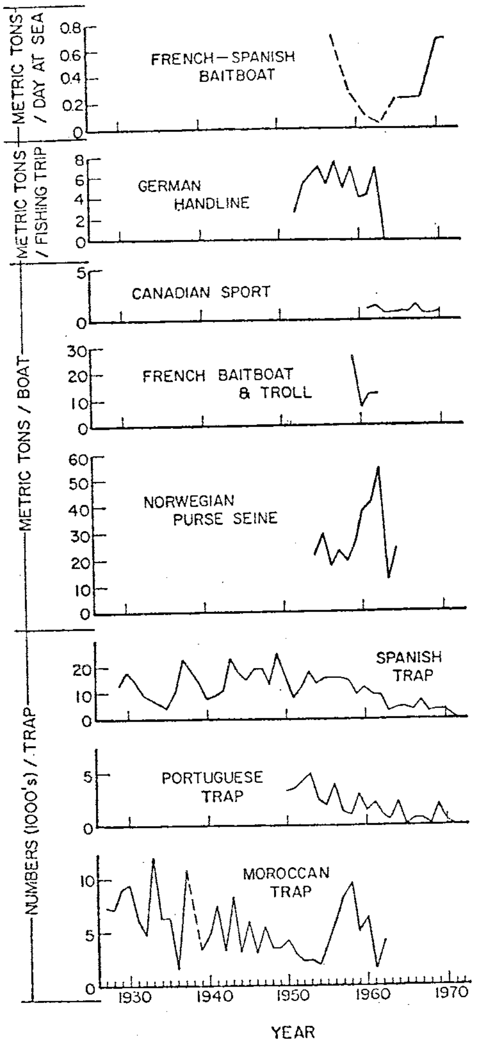



Figure 5

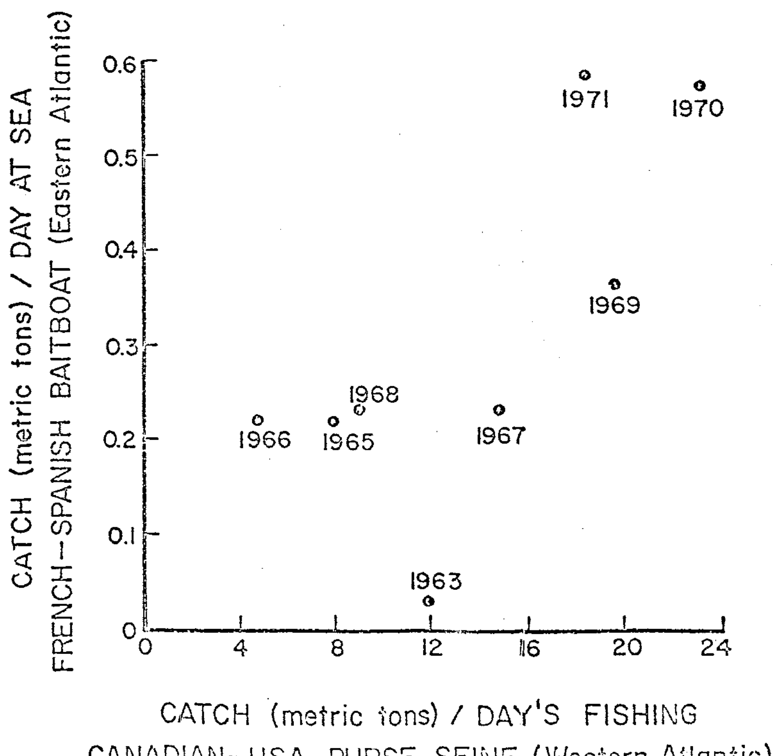



Figure 6

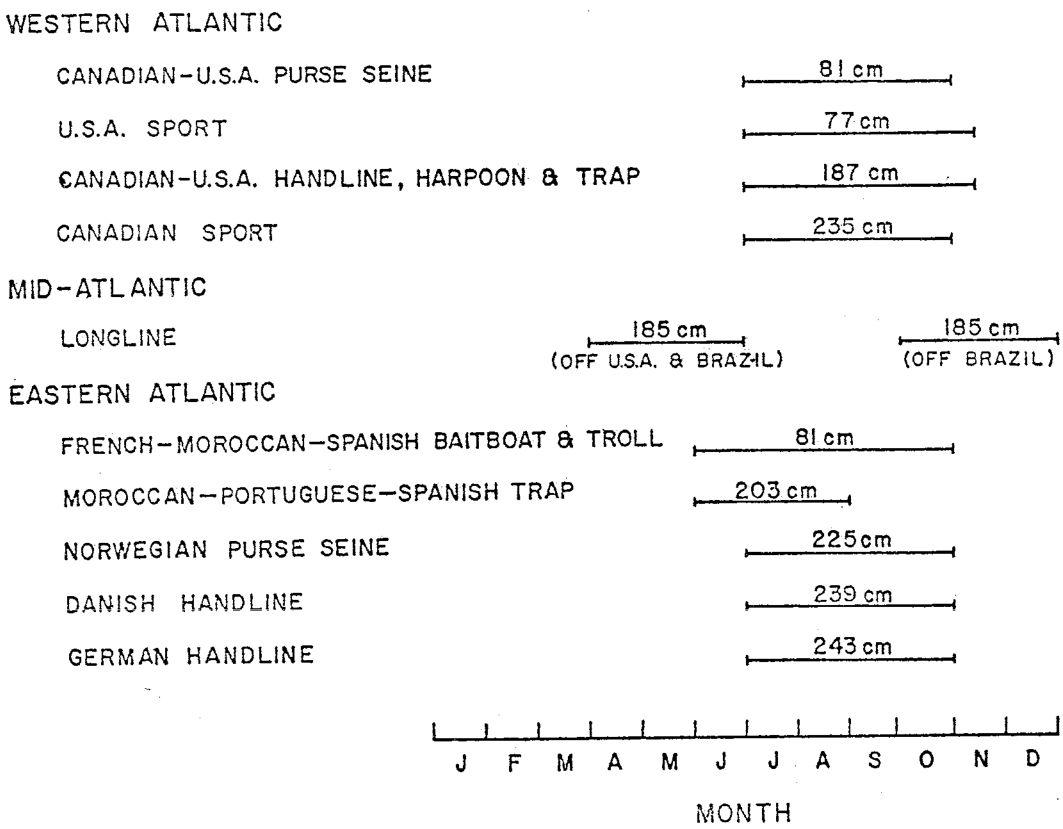



Figure 7

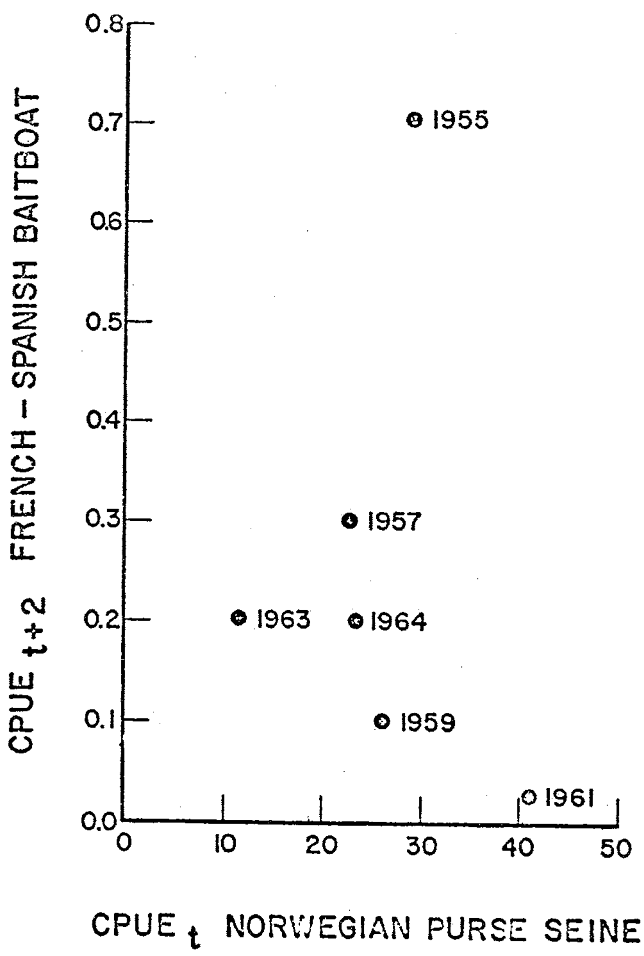



Figure 8

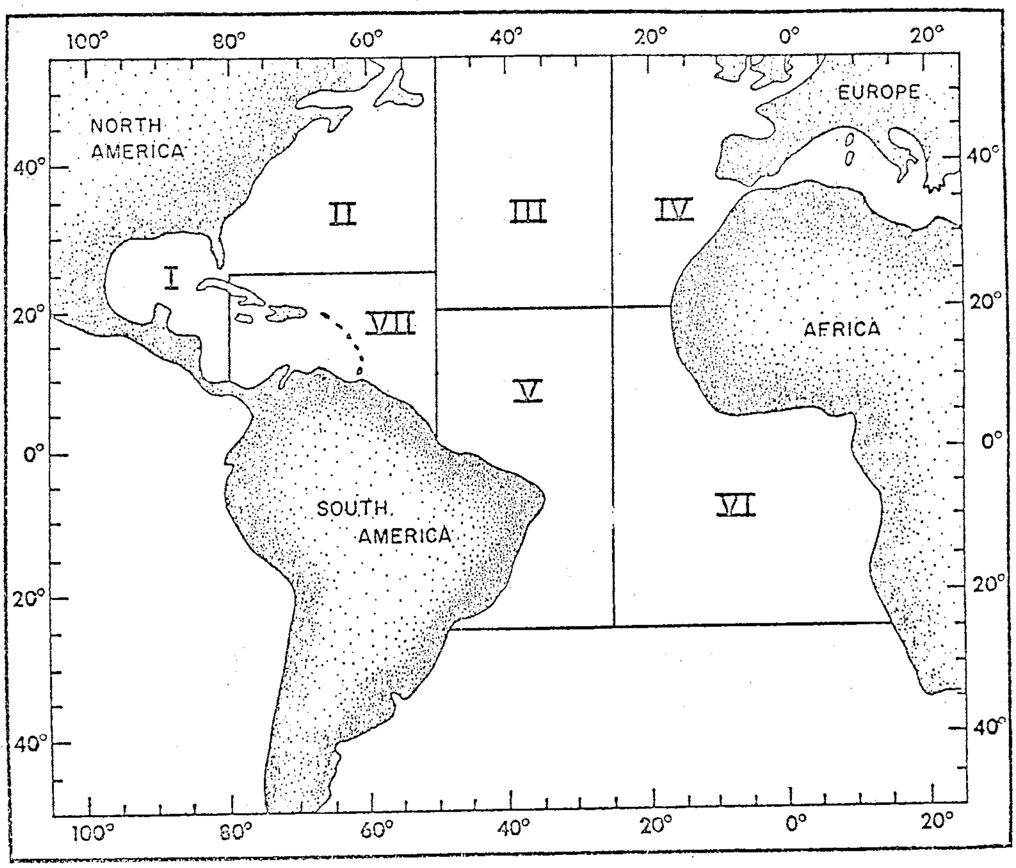



Figure 9

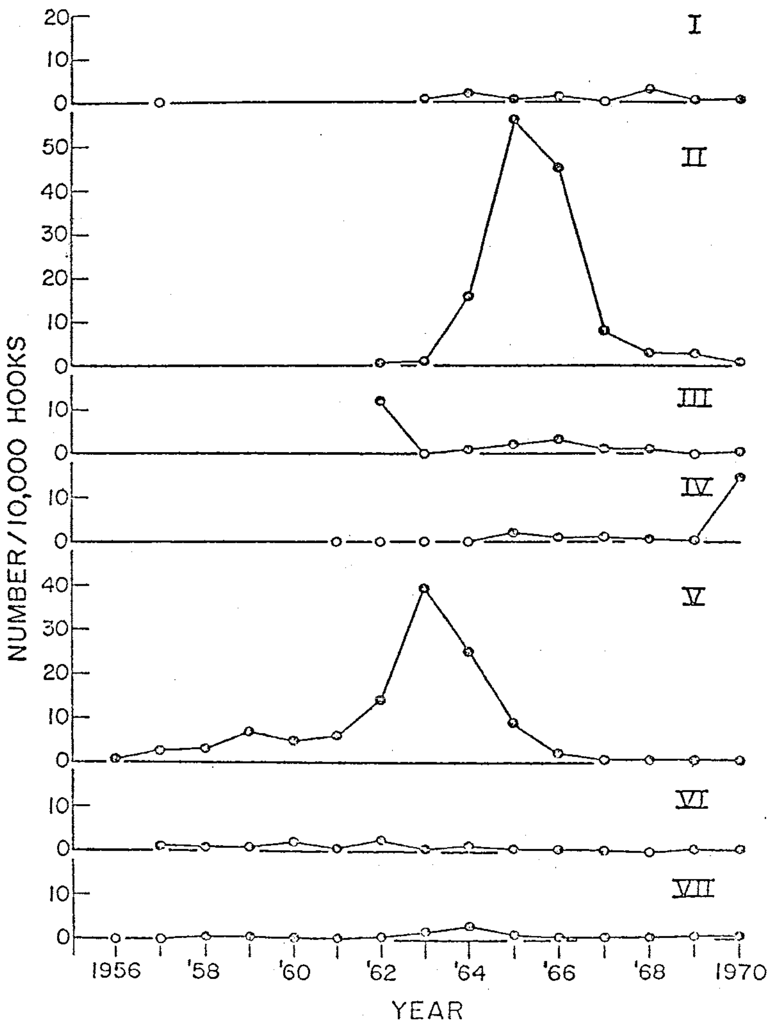



Figure 10

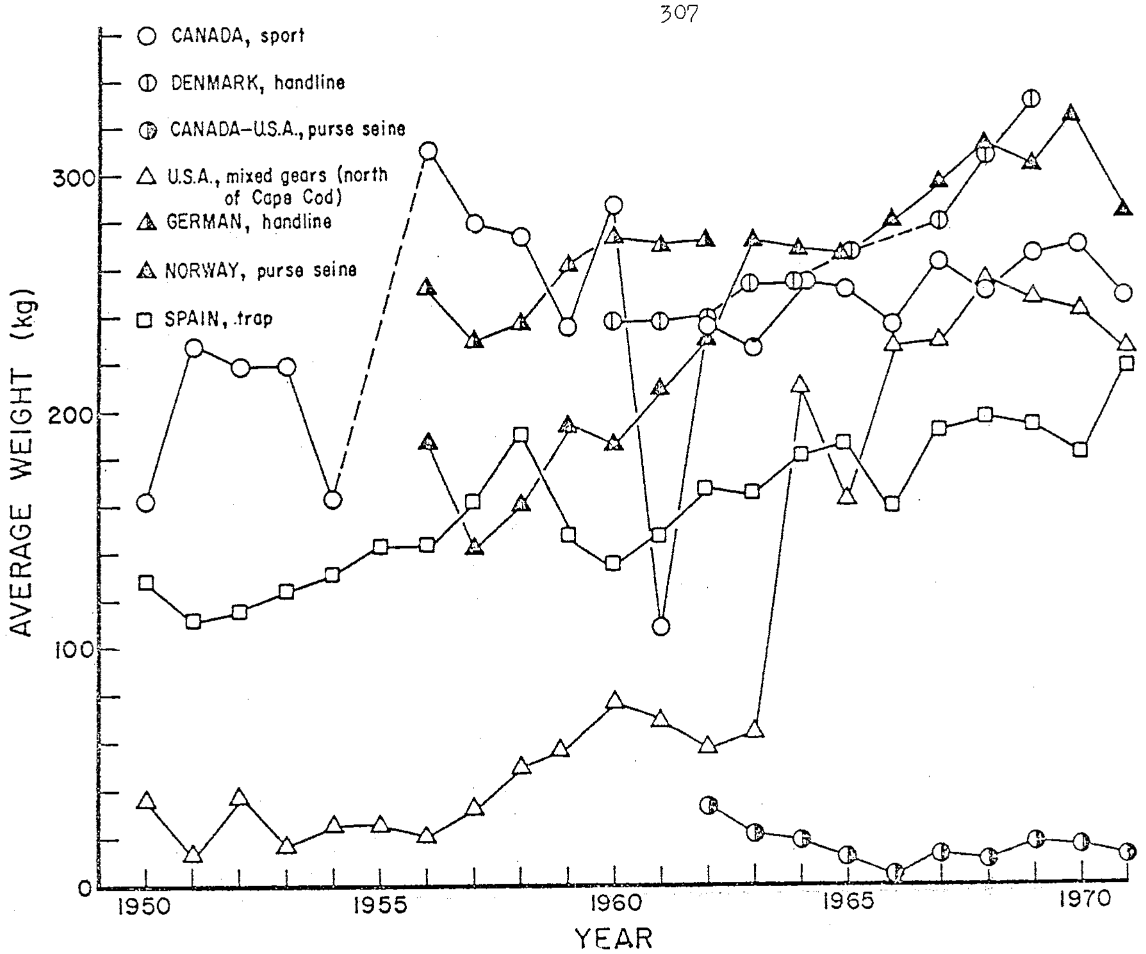



Figure 11

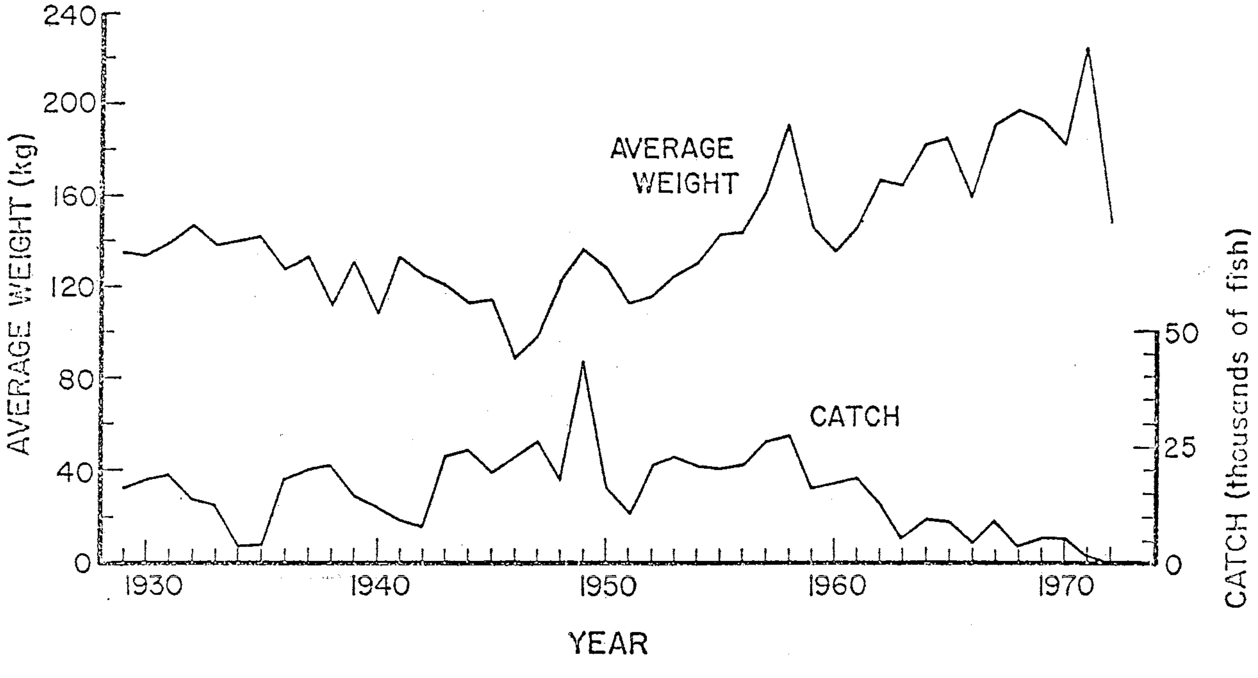



Figure 12

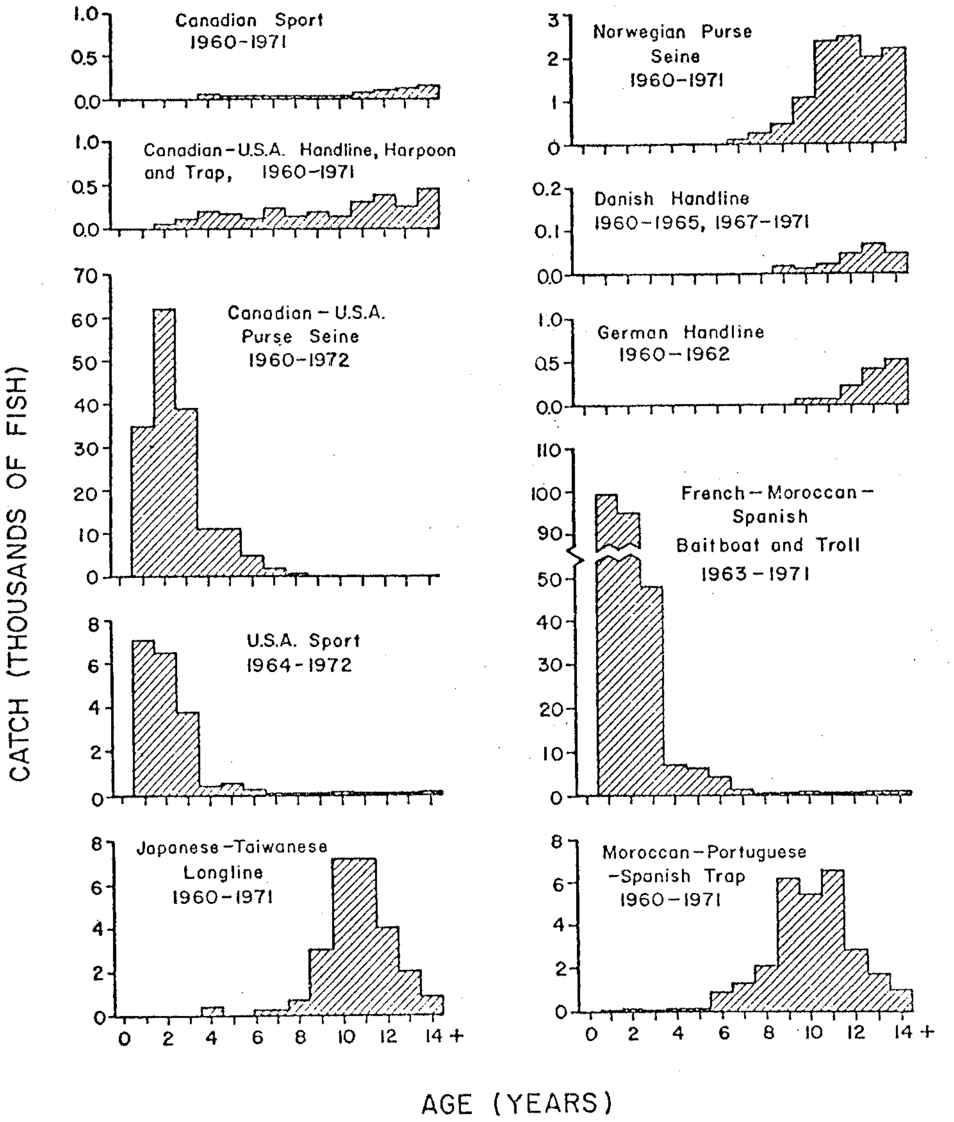



Figure 13

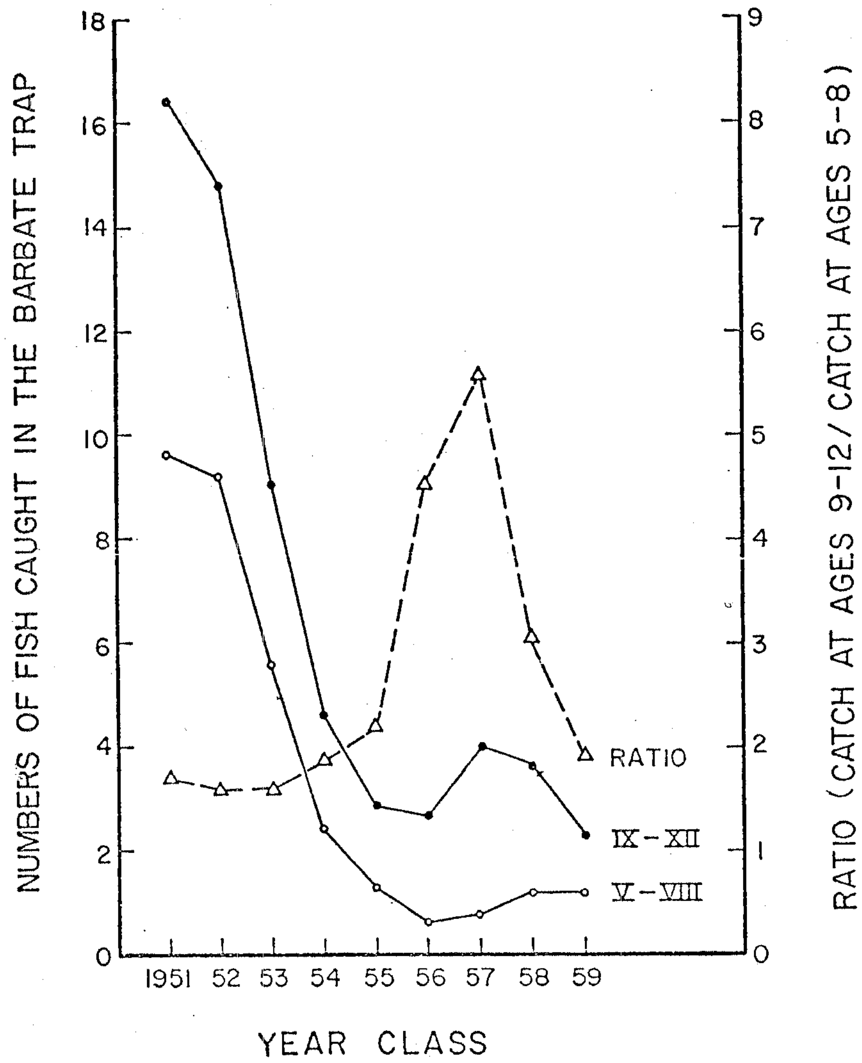



Figure 14

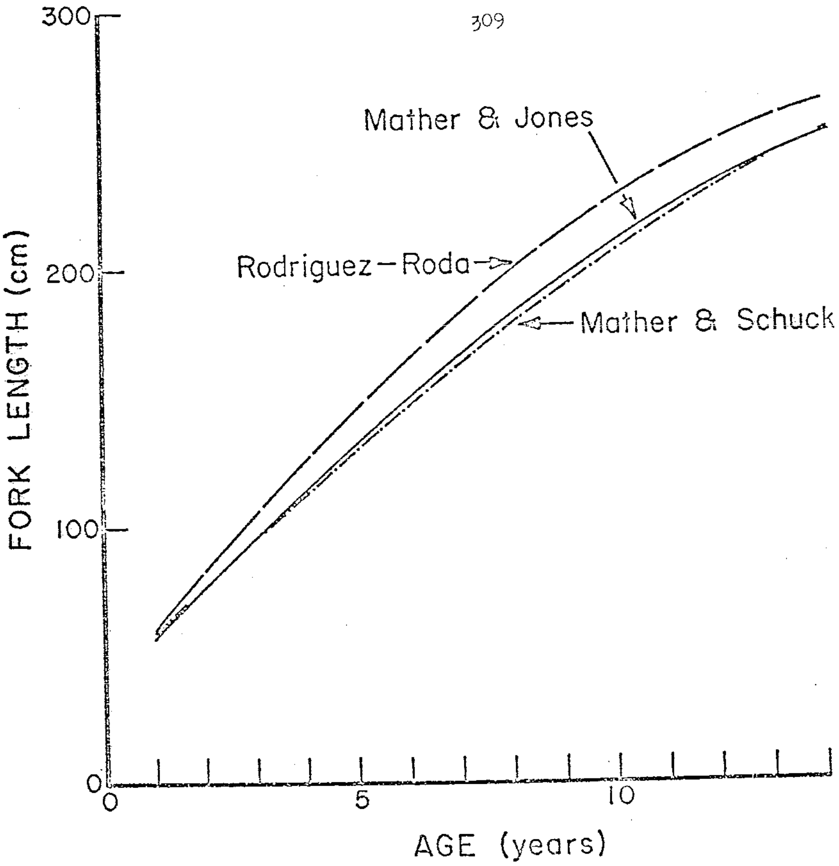



Figure 15

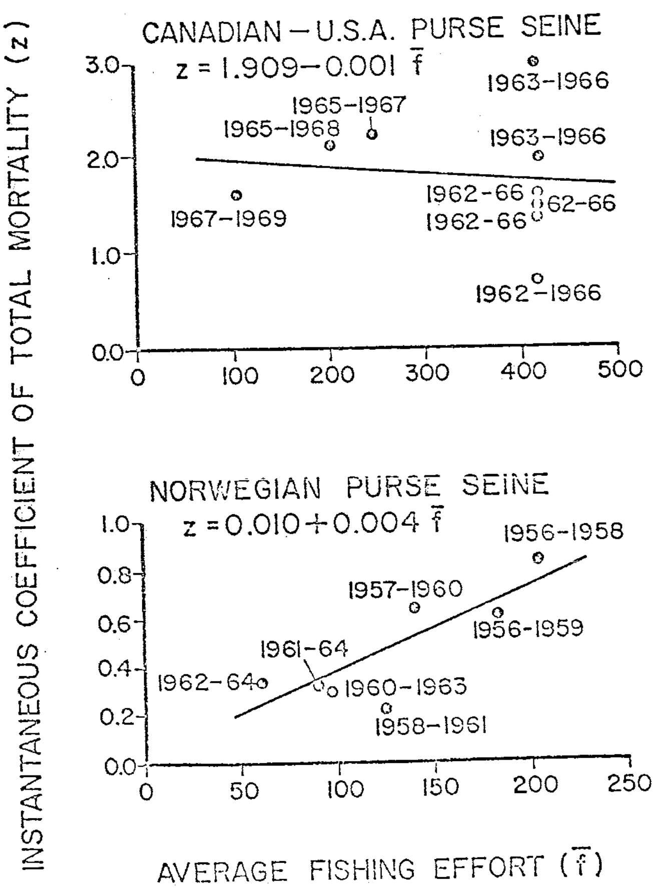



Figure 16

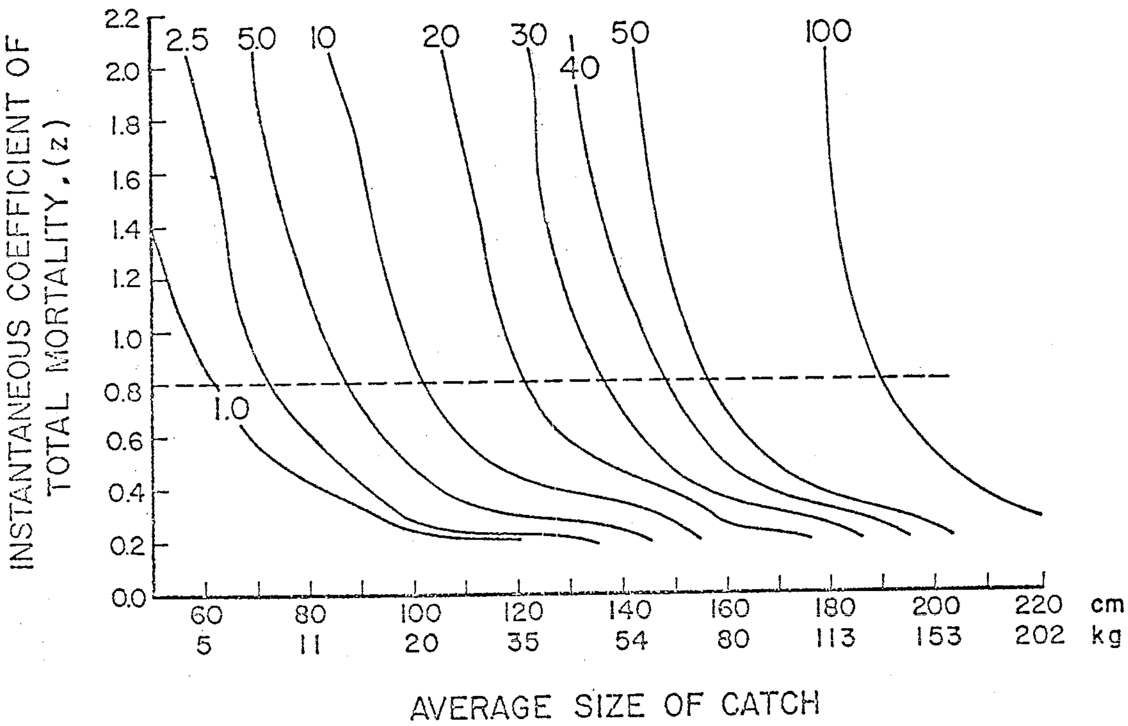



Figure 17

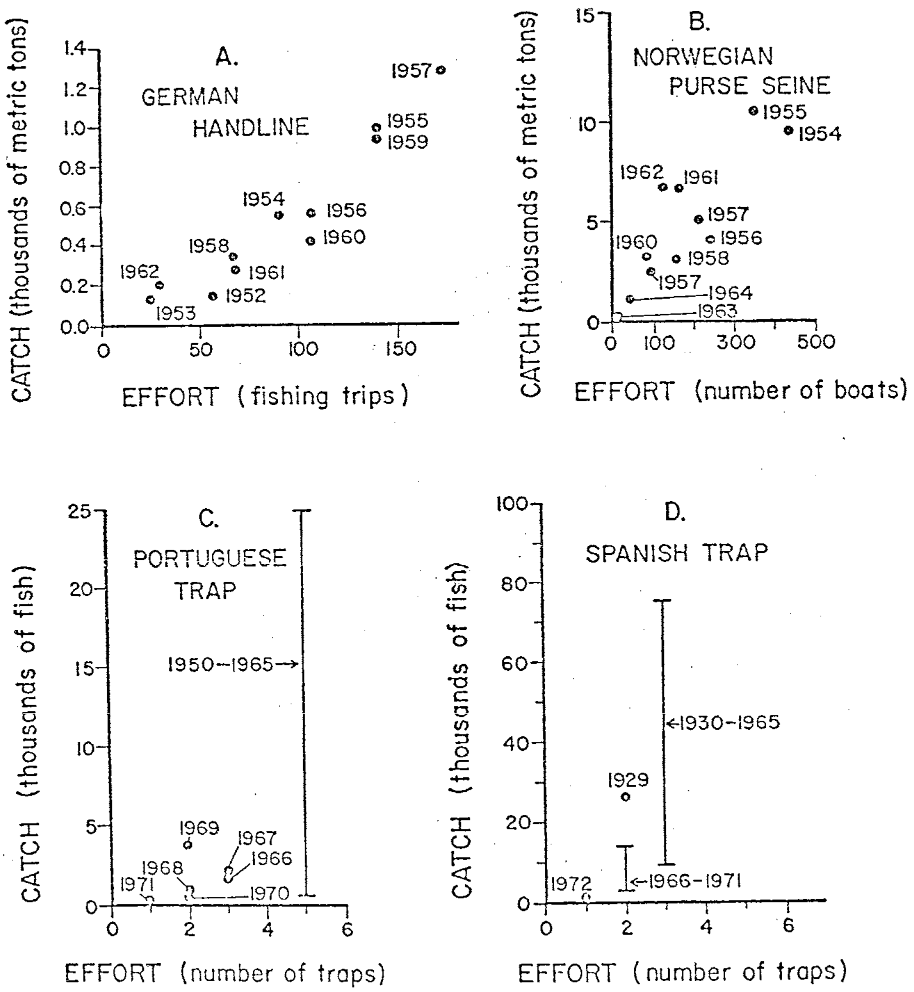



Figure 18

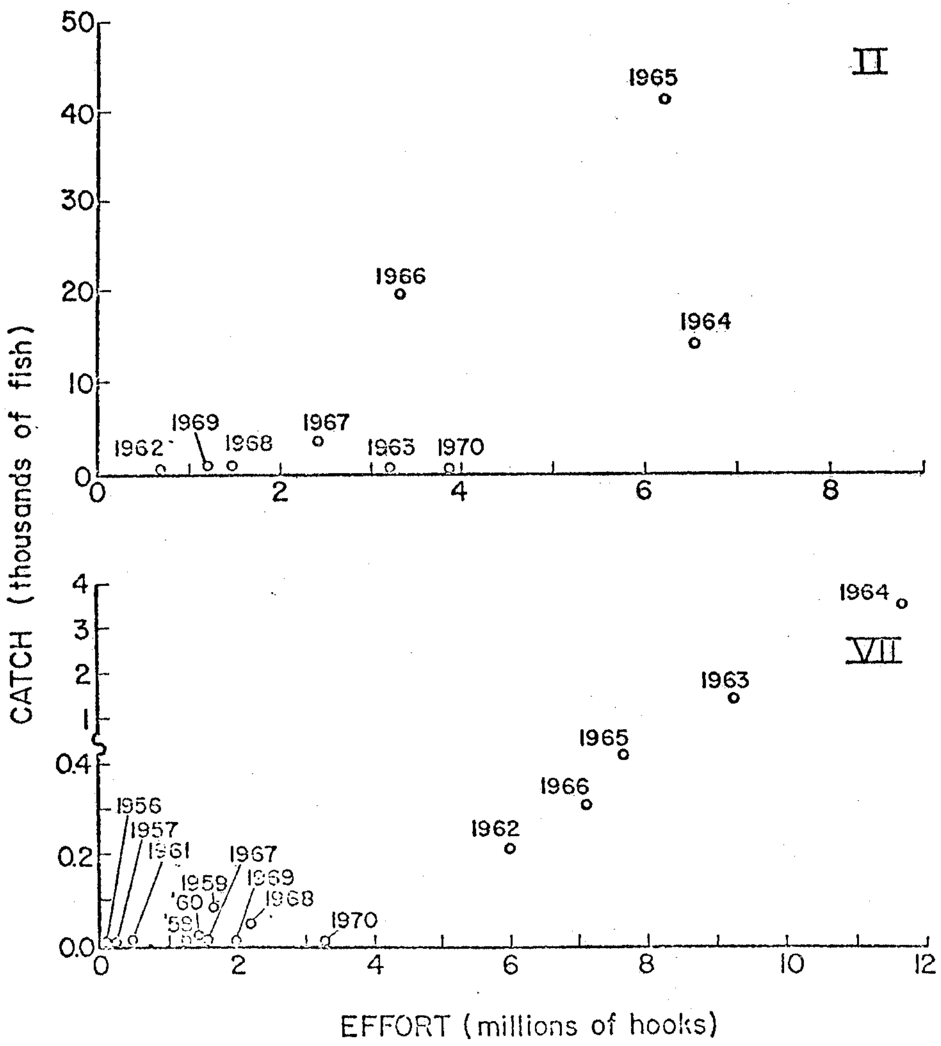



Figure 19

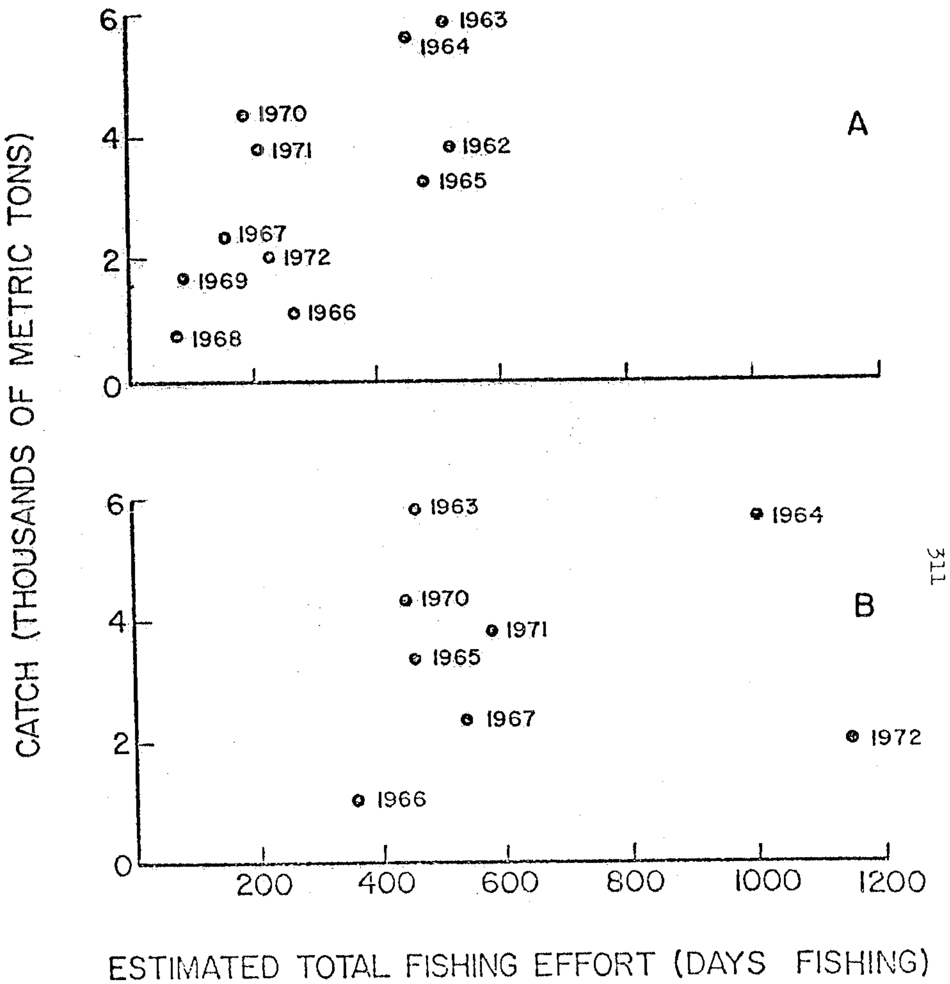



Figure 20

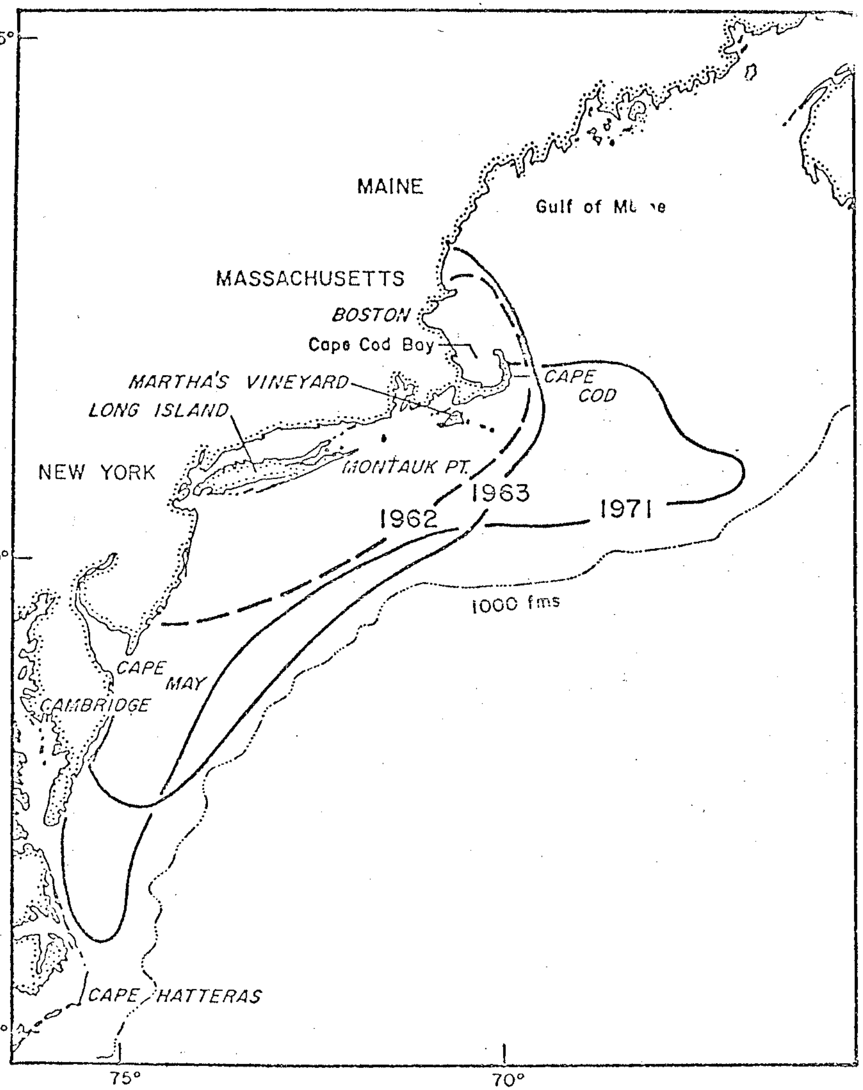



Figure 21

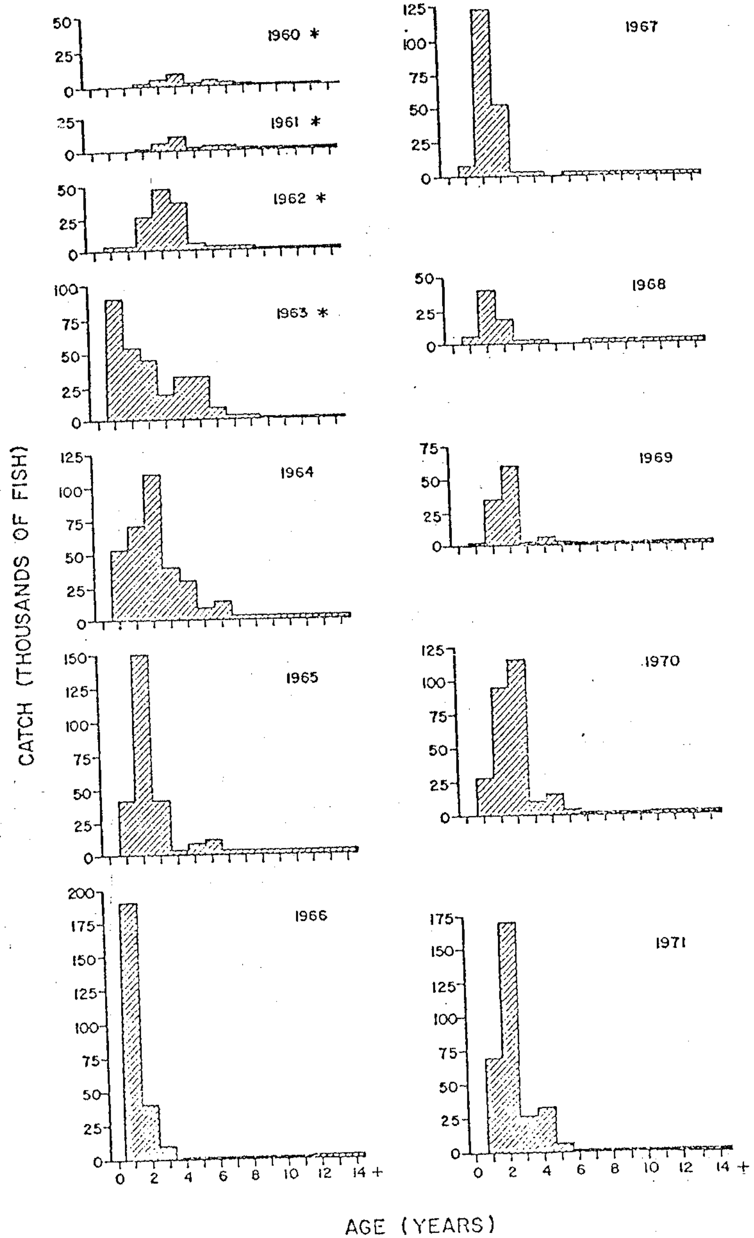
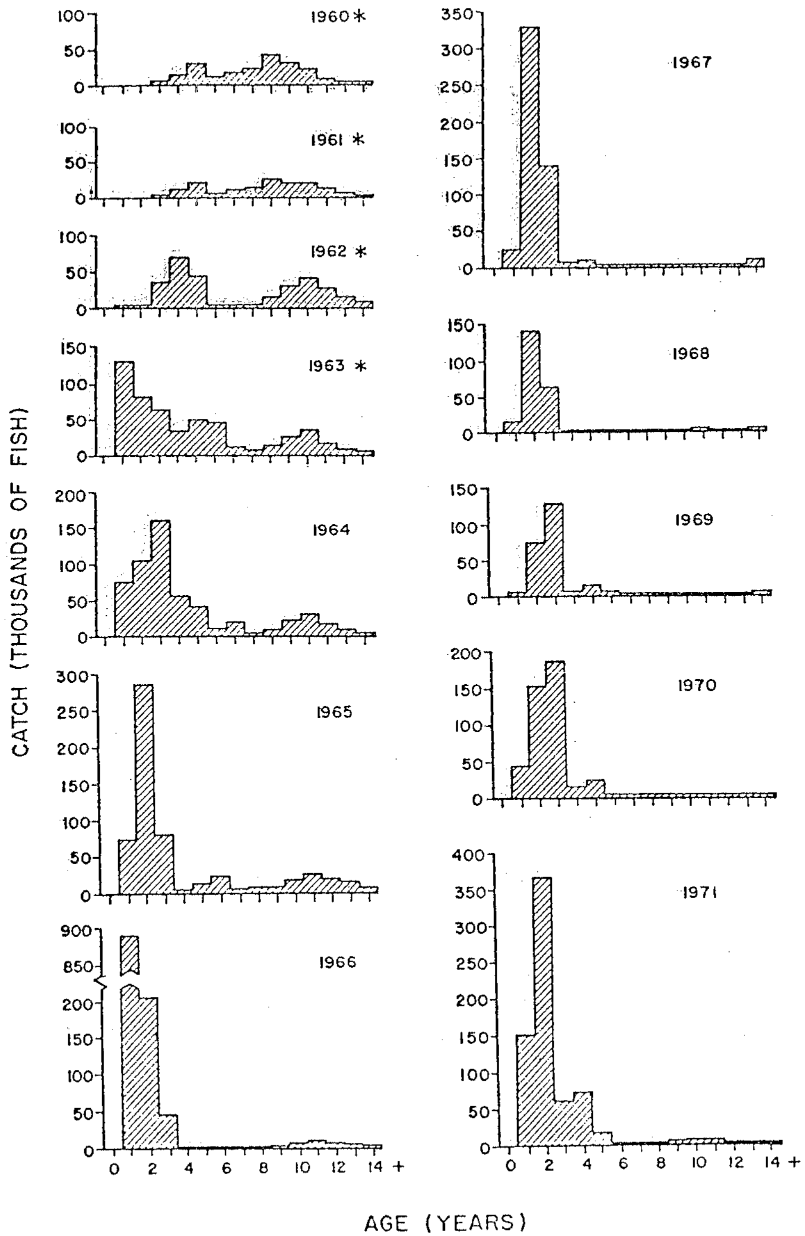



Figure 22



CATCH (THOUSANDS OF FISH)
AGE (YEARS)
1960 *
1961 *
1962 *
1963 *
1964
1965
1966
1967
1968
1969
1970
1971
0 2 4 6 8 10 12 14 +


Figure 23