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Distribution and Biology of Atlantic Saury, *Scomberesox saurus* (Walbaum), in the Northwest Atlantic

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Abstract

Investigations on the biology and distribution of Atlantic saury were conducted in the Northwest Atlantic during 1967–76. The data and materials were collected on board of research and commercial vessels. Searching and fishing for saury was facilitated by the positive reaction of this species to artificial light. Side-nets suspended from booms, conical ring-nets and dipnets with mesh sizes of 5–10 mm were the fishing gears. The seasonal distribution of saury is elucidated and a hypothetical model of their migration is presented. Data on reproduction, feeding and growth are analyzed, information on the fishery is given, and a yield-per-recruit curve is presented for a wide range of fishing mortality coefficients.

Introduction

The Atlantic saury, *Scomberesox saurus* (Walb.), is one of the most abundant plankton-eaters inhabiting the open part of the Atlantic Ocean. According to the terminology of Parin (1968), this species belongs to a holoepipelagial group of fishes which inhabit the homogeneous surface layer of the pelagial in the open sea at all stages of its life cycle. Until recently, information on distribution and biology of Atlantic saury in the Northwest Atlantic has been rather limited (Bigelow and Schroeder, 1953; Leim and Scott, 1966).

Large-scale investigations on the biology of saury in the Northwest Atlantic were conducted by USSR scientists during 1967-76 (Zilanov, 1968, 1970; Zilanov and Bogdanov, 1969; Zilanov *et al.*, 1969). These investigations served as the basis for the development of an experimental fishery for this species during 1969-74. This paper presents the results of the biological investigations and a yield-per-recruit model for the stock under conditions of very low exploitation.

Materials and Methods

The biological material used as the basis for this paper was collected on board of USSR research and scouting vessels under the direction of scientists, including the authors, from the Polar Research Institute of Fisheries and Oceanography (PINRO) and the Atlantic Research Institute of Fisheries and Oceanography (AtlantNIRO). The positive phot-reaction of saury to artificial light was the key factor in determining the techniques used in searching for fish concentrations and in conducting the fishing operations. The fishing gears consisted of dipnets and conical ringnets (mesh size 5–10 mm) with electric lights attached, and large nets (20 × 20 × 25 and 15 × 20 × 15 m, mesh size 8–10 mm), with lights attached, suspended from booms along the side of the vessel.

Fish were measured from the anterior point of the elongated lower jaw to the mid-fork of the caudal fin. The degree of fullness of the intestine was recorded as follows: 0 = empty, 1 = small quantity of food, 2 = half full, 3 = full of food, and 4 = very full of food which can be seen through the intestinal wall. The degree of fatness of the gut was recorded as follows: 0 = no fat, 1 = little fat visible, 2 = fat covering most of the gut, and 3 = fat completely covering the gut. Ageing of the specimens was determined from scales (Nesterov, 1974). Six maturity stages (described in the Appendix) were used in determining the maturity of females. Quantitative estimates of abundance of saury were obtained by the visual track survey method described by Chigirinsky (1973) using acoustic instrumentation and by standard hauls. The Beverton and Holt (1957) method was used in the yield-per-recruit analysis.

Results

Distribution and migration

Atlantic saury are distributed widely in the Northwest Atlantic from Cape Hatteras to Newfoundland. In summer and autumn, they are encountered on the Scotian Shelf, on Georges Bank, in the Gulf of Maine and southward around Cape Cod. From time to time they appear in the coastal waters of Newfoundland, Nova Scotia and along the Atlantic coast of the United States. Immature and adult fish have often been observed on Flemish Cap and over the slopes of Grand Bank, Green Bank and St. Pierre Bank.

The area to the west of the Gulf Stream core is the main habitat of Atlantic saury in the open sea of the Northwest Atlantic, although the species has been taken by research vessels eastward of the Gulf Stream. Generally, the area of distribution extends from coastal waters eastward to 40°W and from 32°N northward to 50°N. The northward extension of distribution is determined by hydrological conditions, active migration of adults, and passive drift of larvae and juveniles by currents. Saury spend most of their life cycle in the warm homogeneous surface layer in the open sea, far from the shallow waters of the continental shelf (Parin, 1968; Zilanov, 1968, 1970, 1977). Only in summer and autumn are some concentrations found in coastal waters. In order to elucidate the seasonal distribution and migration of Atlantic saury, all available observations made during 1967-74 are shown by month in Fig. 1.

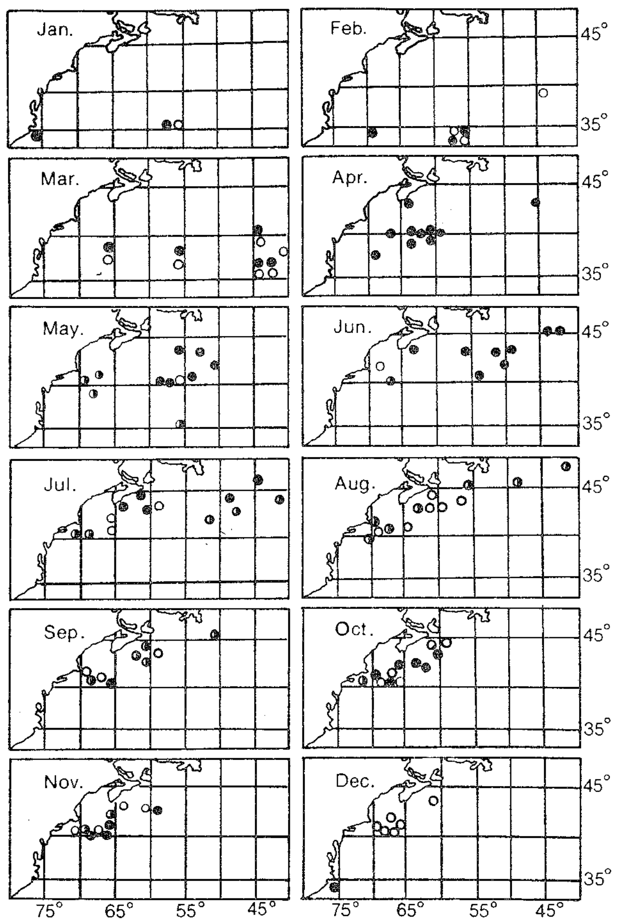

Fig. 1. Monthly distribution of locations where Atlantic saury were caught in the Northwest Atlantic. (Open circles indicate the occurrence of small fish, closed circles for large fish, and half-circles for mixed concentrations.)

In winter, saury are concentrated in the most southern part of the area of distribution. Schools found on the southern part of Georges Bank in December had moved southward to Cape Hatteras in late December and early January, where the water temperature was higher than 16°C. These concentrations consisted of large fish (age 3 and older and greater than 30 cm in length) in spawning condition. In addition, concentrations of immature and adult saury were found far offshore in January to March, generally south of 40°N. In April and May, they migrate northward across the Gulf Stream frontal zone and begin to penetrate the colder shelf water on Georges Bank.

In summer, the saury gradually move farther northward simultaneous with the warming of the surface water. In June, they are found on the Scotian Shelf and eastward to the southern slope of the Grand Bank. In July, concentrations are distributed over the Scotian Shelf, over the southern part of the Grand Bank and eastward over the southern slope of Flemish Cap. The northward movement at this time extends to about 46°N, and the most northerly concentrations consist of large fish. In August, as in the previous

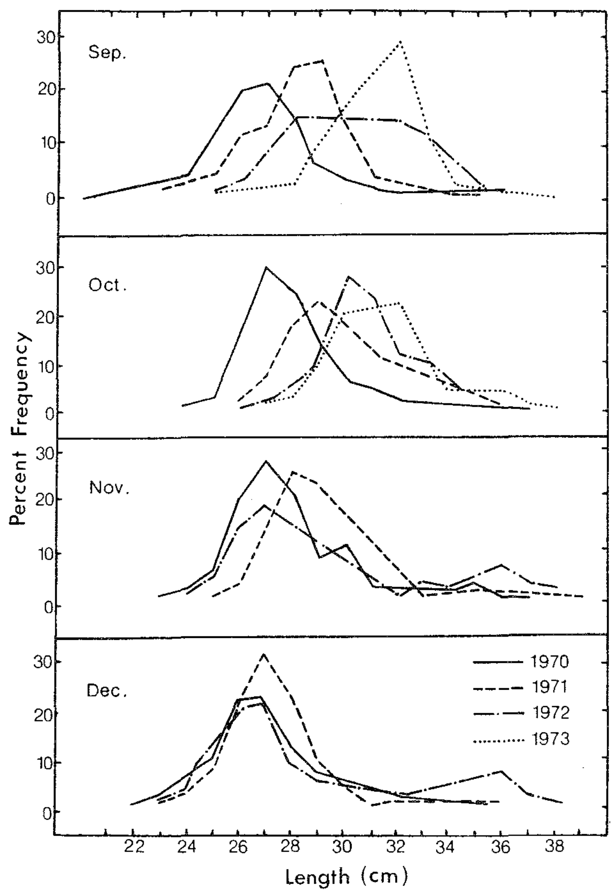

Fig. 2. Size composition of Atlantic saury caught on Georges Bank in 1970-73.

month, mixed concentrations of small and large fish were found on Georges Bank and the Scotian Shelf, and schools of large fish were prevalent off Newfoundland and as far north as 47° N on the Flemish Cap.

In autumn, the saury concentrations begin to move southward. Schools observed on the Scotian Shelf in October have moved southward in November and December to the southern slope of Georges Bank. During this period, the concentrations of large fish tend to move southward earlier and farther than the small fish, thus accounting for the presence of schools consisting almost exclusively of small fish on Georges Bank in December. This phenomenon is clearly evident in the length composition of saury catches on Georges Bank in the autumn (Fig. 2).

It is obvious that Atlantic saury undertake long distance migrations annually, as illustrated in Fig. 3. They migrate northward in late spring and summer and move southward in the autumn. The larger fish (age 3 and older) undergo both their northward and southward migrations earlier than the smaller fish (age-groups 1 and 2). Data on the spatial distribution of saury at different stages of their life cycle indicate that spawning occurs in the southern part of the area of distribution (south of 40°N) during the winter, following which intensive feeding occurs in the spring during their northward migration (Fig. 3). The intensity

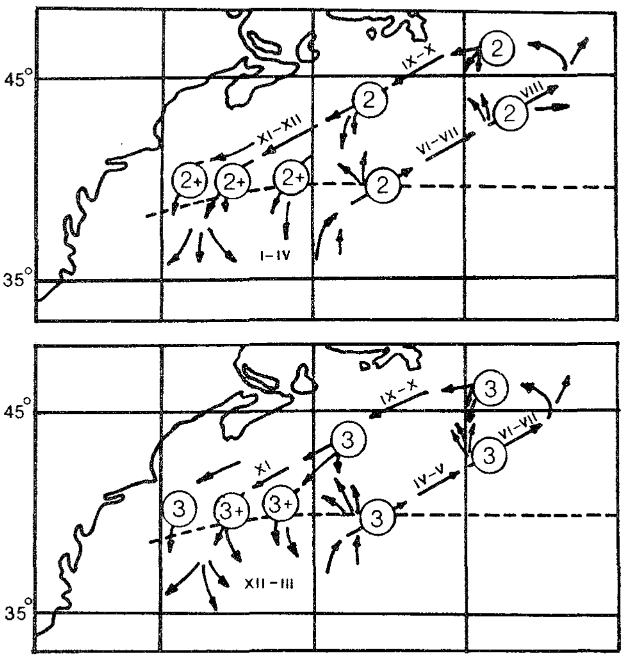

Fig. 3. Migration cycles of Atlantic saury in the Northwest Atlantic. A, age-group 2; B, age-group 3. (Roman numerals indicate the months, and the dashed line indicates the northern limit of spawning.)

of feeding gradually decreases during the summer and autumn with improvement in physiological condition as indicated by a gradual increase in the fatness of the gut.

The distribution of saury by depth is limited to the warm surface layer above the thermocline. They are found very close to the surface at night and deeper in the daytime, the maximum depth being about 50 m. The eggs and larvae are distributed mostly in the surface layer at 0–1 m.

Water temperature is one of the main factors which determine the distribution of saury. The temperature range of their habitat varies from 8.2° to 24.8°C, and the occurrence of fish in various parts of this range depends largely on their physiological condition. Eggs and larvae are found at temperatures of 16.8° to 23.7°C, the optimum range for mass concentrations being from 17.3° to 21.0°C. During the feeding period, saury were found in areas where the water temperature ranged from 8° to 21°C.

Spawning

From data on the distribution of Atlantic saury eggs, larvae and juveniles, spawning occurs south of the frontal zone of the Gulf Stream (Nesterov and Shiganova, 1976). Data on the distribution of saury maturity stages by month indicate that spawning occurs mainly during the winter-spring period (Table 1). Spawning in both males and females occurs when they reach a minimum length of 26 cm, and the bulk of the spawning fish belong to age-groups 2 and 3.

Microscopic examination of the ovaries shows considerable variation in the size of the oocytes. This penomenon may indicate an extended spawning period during which batches of eggs are spawned at different times (Chigirinsky, 1973; Nesterov, 1973). The asynchronous growth of oocytes indicates that

TABLE 1. Maturity composition of Atlantic saury in the Northwest Atlantic by month, from observations in 1967–73.

Month	Percent by maturity stages					No. of fish
	II	III	IV	V	VI–VII	
Jan	26.4	9.3	34.3	28.6	1.4	140
Feb	—	67.6	16.2	16.2	—	179
Mar	—	2.7	56.8	35.1	5.4	37
Apr	—	23.9	71.8	4.3	—	46
May	—	71.8	24.9	3.3	—	245
Jun	33.3	64.2	1.1	1.4	—	136
Jul	—	100.0	—	—	—	55
Aug	97.2	2.8	—	—	—	532
Sep	75.3	22.6	1.6	—	0.5	3,585
Oct	54.2	38.5	5.7	1.4	0.2	6,149
Nov	60.9	21.6	10.6	6.1	0.8	6,890
Dec	86.2	9.3	3.9	0.3	0.3	2,207

Atlantic saury may be typical of species which exhibit irregular spawning over an extended period (Kazansky, 1949).

The Atlantic saury eggs when ripe for spawning are spherical, nearly transparent and 2.5-3.2 mm in diameter. Development occurs in the near-surface layer and the larvae metamorphose at about 25 mm in length (Dudnik, 1975).

Feeding

Analysis of the stomach contents of Atlantic saury indicates that they are typical plankton-eaters, feeding mainly on copepods, euphausiids and amphipods. Larvae of polychaetes, decapods, isopods, ostracods, cirripeds and siphonophores, fish eggs and larvae, protozoans, and algae were present but in lesser quantities (Nesterov, 1976; Zilanov and Nesterov, MS 1974). The qualitative composition of the food items varied with the seasonal distribution of saury and their prey. In spring and summer, copepods (mainly *Calanus finmarchicus*), siphonophores, and fish larvae constituted the main component of the diet on Georges Bank and the Scotian Shelf, secondary items being euphausiids and decapod larvae. In autumn, copepods (*Centropages* sp.), various calanoids and euphausiids were the major prey organisms in the same areas. In winter, most of the saury caught in the southern part of the area (34°N) were found to be feeding on larvae of decapods, hyperiids, molluscs and foraminifers.

There was considerable variation in the size of food organisms eaten by different sizes of saury. Fish up to 23 cm long fed on organisms not longer than 20 mm. Adult saury fed on macroplankton up to 60 mm in length, but crustaceans greater then 1 mm were not common. The occurrence of different types of food organisms in the feeding spectrum of saury indicates that it is not very selective in its choice of food. The most active feeding of saury occurs in spring and summer (Fig. 4). The intensity of food consumption decreases in the autumn and is at a minimum during the winter. The increase in fatness during the summer and autumn is a consequence of the active feeding in the spring and summer.

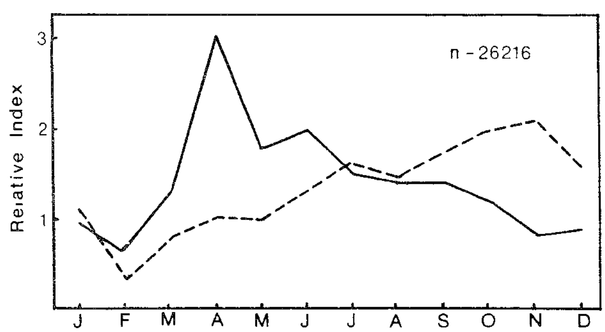

Fig. 4. Monthly variation in fullness of the intestine (solid line) and fatness of the gut (dashed line) for Atlantic saury sampled in 1968-73.

In addition to being an active predator on planktonic organisms, Atlantic saury serve as food for many other inhabitants of the sea, such as squids, swordfish, marlins, sharks, tunas, hakes, cod, pollock, dolphins, whales and birds. The high abundance of saury and its widespread distribution makes it an important link in the food chain of the ocean, involving the transfer of energy from lower to higher trophic levels.

Length, weight and growth

The size of Atlantic saury in catches on Georges Bank during 1970-73 (Fig. 3) ranged from 18 to 39 cm in length and from 19 to 200 g in body weight. Two size-groups, 23-30 cm and 31-39 cm, are distinguishable in the length frequencies which are characteristic of the sizes of saury caught during the autumn-winter period. The corresponding average weights for these two groups are 55 and 110 g. The relationship between weight (grams) and length (cm) is expressed by the equation

$$W = 0.003328\ L^{3.0045}$$

The ages of saury were determined from scales. No difference in growth was found between males and females. Consequently the average length-at-age values in Table 2 represent the growth of saury for sexes combined. Bertalanffy equations for growth in length and weight are as follows:

$$L_t = 45.437\left[1 - e^{-0.279(t+0.728)}\right]$$

and

$$W_t = 312.199\left[1 - e^{-0.279(t+0.728)}\right]^3$$

where L_t is the fish length (cm), W_t is the body weight (g) and t is the age in years.

The Atlantic saury fishery

There is at present no fishery for saury in the Northwest Atlantic, but an experimental fishery was conducted by USSR vessels during 1969-74. Type SRT

TABLE 2. Mean length-at-age of Atlantic saury in the Northwest Atlantic based on back-calculation from scales.

Age	Mean length (cm) at age				No. of
(yr)	1	2	3	4	fish
1	17.59	—	—	—	162
2	17.38	24.49	—	—	384
3	16.83	23.79	29.16	—	42
4	16.60	23.80	29.60	33.40	5

TABLE 3. Nominal catches (metric tons) of Atlantic saury in the Northwest Atlantic, 1970–75[a].

Country	1970	1971	1972	1973	1974	1975
Bulgaria	—	—	2	—	—	—
Fed. Rep. Germany	—	—	—	—	—	490
German Dem. Rep.	—	—	12	—	—	—
USSR	1,054	2,144	3,415	2,443	1,551	—
Total	1,054	2,144	3,429	2,443	1,551	490

[a] Source: ICNAF Statistical Bulletins, Vol. 21–26.

TABLE 4. Age composition of Atlantic saury in the Northwest Atlantic, 1970–73.

	Percent age composition				Mean	Mean
Year	1	2	3	4	age (yr)	length (cm)
1970	2.16	72.56	21.18	4.10	2.27	27.70
1971	0.36	63.49	31.25	4.90	2.41	28.90
1972	0.42	52.00	35.68	11.90	2.59	30.02
1973	0.04	44.74	46.71	8.51	2.64	30.27

and SRTM vessels caught saury in nets suspended from booms along the side of the vessels, the fish being attracted to the surface by bright lights (Zilanov, 1977). A review of published statistics indicates that the bulk of the catches during 1970–74 was taken by USSR vessels (Table 3).

The experimental fishery conducted in the Georges Bank and Scotian Shelf areas was based on feeding concentrations of saury during their southward migration. Eddies formed by the interaction of the shoreward cold water masses from the Labrador Current and Cabot Strait and the seaward warm Gulf Stream water cause intensive mixing over the slopes of these banks, and provide relatively stable conditions for the existence of commercial concentrations of saury in these areas during the autumn.

The duration of the fishing period is determined by temperature conditions in the area. When the surface temperature drops below 9° C, the saury move southward along the southern parts of the banks, being generally available up to the middle of December. However, in 1968, concentrations were found in the area in January, whereas, in 1973, they were not available in December. Optimum temperatures in the areas of concentration gradually decline during the autumn. Observations made, during 2,039 sets with catches, in 1969–73 showed that the average monthly temperatures from September to December were 16.9°, 14.3°, 11.8° and 11.5° C respectively.

The efficiency of fishing for saury depends on the reaction of the fish to light sources. This reaction is determined by a number of circumstances, the most important being the physiological condition of the fish and the phase of the moon (Fig. 5). Consequently, the saury fishery is most efficient during 12–18 nights per month.

The age compositions of Atlantic saury taken in the commercial fishery during 1970–73 are given in Table 4. The bulk of the catches consisted of age-groups 2 and 3.

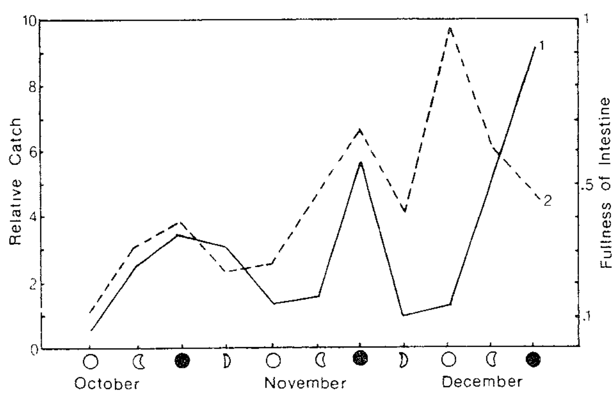

Fig. 5. Relationships of catch per haul of net (solid line) and fullness of the intestine (dashed line) to the moon's phases for Atlantic saury during October–December.

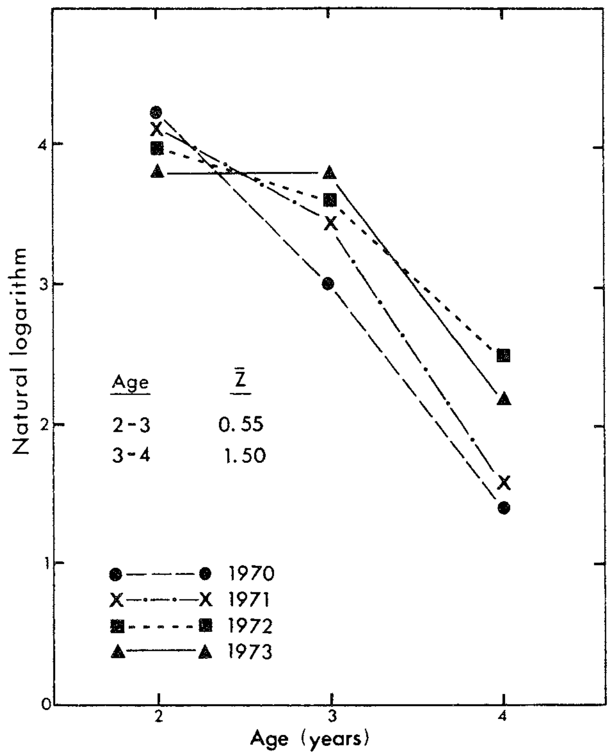

Fig. 6. Logarithmic plot of age compositions of Atlantic saury caught on Georges Bank in 1970–73.

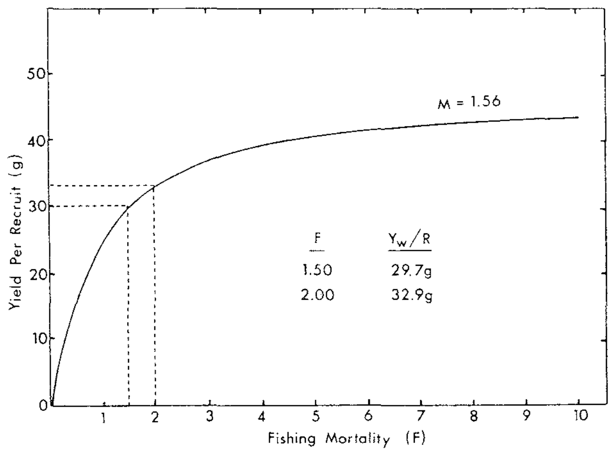

Fig. 7. Relationship between yield-per-recruit and fishing mortality for Atlantic saury in the Northwest Atlantic, with M = 1.50.

Yield-per-recruit

Logarithmic plots of the catch frequencies in Table 4 suggest that recruitment to the fishery is probably not complete until age 3 (Fig. 6), after which the decline in numbers to age 4 indicates an average total mortality coefficient (Z) of about 1.50. Because the commercial fishery for Atlantic saury was carried out on a very small scale (Table 3), the fishing mortality was close to zero. Therefore, a natural mortality coefficient (M) of 1.50 was used in the yield-per-recruit calculations. The average age at recruitment was assumed to be about 2 years, and the maximum age was taken as one year beyond the greatest age of saury in the samples (Table 4). Using the terminology of Beverton and Holt (1957), the yield-per-recruit curve (Fig. 7) is based on the following parameters:

$M = 1.50$	$t_0 = -0.728$ yr
$K = 0.279$	$t_\rho = t_{\rho} = 2.0$ yr
$W_\infty = 312.2$ g	$t_\lambda = 5.0$ yr

The relationship between yield-per-recruit (Y_W/R) and F is asymptotic with no defined maximum yield-per-recruit. However, an estimate of the yield-per-recruit at a point on the curve where the slope is 10% of that near the origin indicates that $F_{0.1}$ is in the range of 1.5–2.0, corresponding to yield-per-recruit values in the range of 29.7–32.9 g. If this yield-per-recruit function is considered representative of the Northwest Atlantic saury under equilibrium conditions for an unexploited stock, the curve could change drastically following intensive exploitation approaching the $F_{0.1}$ values indicated above. Major changes would likely occur in the growth parameters, and the natural mortality coefficient would be expected to decrease as more of the saury are caught and fewer are subject to predation and senile mortality. Thus M would decrease somewhat as F increases, and the total mortality coefficient (Z) under new equilibrium conditions would probably be less than the range (3.0–3.5) implied by the present yield-per-recruit model, if fishing takes place at the $F_{0.1}$ level.

Conclusions

The Atlantic saury is distributed widely in the Northwest Atlantic. The onset of migration northward in the spring is associated with the existence of favorable feeding conditions in the northern part of its range, whereas the southward migration to warmer areas in late autumn and winter is associated with the reproductive part of its life cycle. The larger saury tend to undergo their northward and southward migrations somewhat earlier than the smaller fish, presumably because of differences in physiological condition, thus reducing intraspecific competition for food.

Water temperature in the area of distribution of saury varies from 8.2° to 24.8°C. The high rate of growth in saury is typical of species with a short life-span. Fish of ages 2 and 3 prevailed in the commercial catches, which did not exceed 4,000 tons annually during the short period of the fishery in the early 1970's. Natural mortality, a significant part of which may be predation by larger marine animals, appears to be high (1.50), and a yield-per-recruit function indicates that the optimum fishing mortality ($F_{0.1}$) may be in the range of 1.5–2.0.

The investigations, reported in this paper, were limited mostly to those areas of the Northwest Atlantic extending seaward from the edges of the continental shelves, and the results are very inadequate for fully understanding the biology and population dynamics of this species. Before any realistic estimates of the stock size is possible, investigations covering the whole area of saury distribution in both inshore and offshore waters are required. Because of the very large area involved (Subarea 3 to 6), the investigations could best be undertaken through international cooperation following the elaboration of a scientific program.

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APPENDIX

Maturity Stages of Atlantic Saury Ovaries

I. Three types of sexual cells are observed in microscopic sections: oogonia and oocytes of the premeiotic and postmeiotic phases, the last type being in the initial phase of protoplasmic growth. Most of the cells are of the second type (36–50 μ in diameter) and can only be seen through a microscope. The ovaries appear as thin threads (1.2–2.0 mm in diameter) and are white or slightly gray in color. A lengthwise blood vessel is barely visible on the surface of each ovary.

II. In addition to the presence of stage I cells, this stage is typified by oocytes in the phase of protoplasmic growth having a follicular wall, their diameter being 140–170 μ. The ovaries have increased in size (1.8–2.5 mm in diameter) and tend to be white with a slightly pink tint. Oocytes cannot be distinguished through the ovarian wall without a microscope. Lengthwise and transverse blood vessels can be seen on the surface of the ovaries.

III. Ovaries contain oocytes which have increased substantially in size (430–860 μ in diameter) and which are beginning to accumulate yolk. Oocytes of all previous stages are also present. The ovaries are tapered in shape, the greatest diameter (2.2–3.3 mm) occurring near the anterior end. They have a pink or rose coloration, and transverse blood vessels on the surface are branching. The eggs are visible through the ovarian wall without the aid of a microscope.

IV. This stage is characterized by large oocytes up to 2,900 μ in diameter and filled with yolk, but oocytes of all previous stages are also present. The ovaries occupy almost all of the body cavity of the fish and 7–13 mm at their greatest diameter. The ovarian surface is covered with blood vessels, giving a bright orange appearance. Eggs of three generations are clearly visible through the transparent ovarian wall.

V. In addition to the ripe oocytes characteristic of this stage (up to 3,200 μ in diameter), yolky oocytes of stage IV and eggs of all earlier stages are also present. The ovary is almost transparent due to the presence of large colorless eggs which fill most of the ovary volume and are densely packed adjacent to the ovarian wall. Some yolky eggs and oocytes of earlier stages are located in the central part of the ovary. The ovary is very elastic, and eggs flow out under slight pressure.

VI. A typical feature of this stage (spent condition) is the presence of empty (broken) follicles observed in histological preparations, with occasional ripe oocytes sometimes visible through the shrunken ovarian wall, which is covered with blood vessels, giving the ovary a bright red appearance. Recovery from this "spent" condition leads to stage IV, and ovaries intermediate between stages VI and IV contain oocytes about 1,000 μ in diameter which are accumulating yolk. Sexual cells of earlier stages are also evident.