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Results of Soviet Investigations of the Biology of the Atlantic Saury, Scomberesox saurus (Walbaum), in the Northwestern Atlantic

by

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The Atlantic saury Scomberesox saurus (Walb.) is one of the most mass fish-plankton-eaters inhabiting the open part of the Atlantic Ocean. According to the terminology of N.V.Parin (1968), this fish species relates to a holoepipelagial fish groupping, which inhabit a surface homogeneous layer of the pelagial in the open sea at all stages of its life cycle.

Data on the distribution and the biology of the Atlantic saury were very scarce for the North-Western Atlantic up to the last years. Only separate data were available on its distribution, morphological signs (Bigelow and Schroeder, 1953; Leim and Scott, 1966). Due to this fact, large scale investigations on the biology of the Atlantic saury of the North-Western Atlantic were conducted by Soviet specialists in 1967-1976. These investigations served as base for the realization of the experiments relating to the industrial fishery of this fish species. This article deals with the results of the biological investigations of the Atlantic saury. Then, the assessment of this fish species stock condition and the value of the allowable catch in the North-Western Atlantic are given in this paper.

Material and Methods

Material, which served as a base for this paper was collected on board the vessels of the Polar Research Institute of Fisheries and Oceanography, the Atlantic Research, Institute of Fisheries and Oceanography, the Administration of the North Fish Scouting (Murmansk), the Administration of the West Fish

Scouting (Kaliningrad) in time of the research, scouting and fishery trips during the period since 1967 to 1976[x/]. A positive photoreaction of the Atlantic saury to artificial light sources was used while conducting searches of this fish species concentrations and the fishery operations. A lighted net suspended from booms alongside a vessel and hauled toward it (20 x 20 x 25 m, 15 x 20 x 15 m, mesh size 8-10 mm) dip nets and conical ring nets having mesh size 5-10 mm with electric light were used as fishing gears. Fish were measured from the beginning of a lower elongated jaw up to the end of the middle rays of the caudal fin. The filling of the intestine with food was determined with use of a five-point scale (0-empty, 1 - very low rate of filling, 2 - half filling, 3 - full of food; 4 - full, food is seen through the intestine cover). The rate of fatness was determined by four-point scale (0 - no fat in the guts, 1 - low rate of fatness, 2 - the greatest part of guts is covered with fat, 3 - guts are covered with fat completely). Age of fish was determined with use of the scale (Nesterov, 1974). While determining the sex maturity in females, a six - point scale of maturity stage was used (see Appendix). The quantitative counting of the Atlantic saury was performed with application of the method of visual track survey (Chigirinsky, 1973) and the control haules. The value of the maximum sustainable yield per year was determined by Beverton and Holt (1957).

Area of the Atlantic saury distribution, their migration paths

The Atlantic saury are distributed in the North-West Atlantic eastwards and southwards from Newfoundland and further up to Hutteras Cape. In summer and autumn this fish are encountered close to Sable Island, on the Banquereau, Emerald and Georges Banks, then, along the Cape Cod and in the Gulf of Maine and the Massachusetts Gulf. The Atlantic saury appear from time

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x/ The authors of this scientific paper took part in the trips of scouting, research and fishing vessels. Besides, V.K. Zilanov was in chief of the experimental fishery expeditions for the Atlantic saury in the North-West Atlantic during the period since 1969 to 1973.

to time in the coastal waters of Newfoundland, Nova Scotia and along the Atlantic coast of the USA. Immature fish, adult fish were observed many times on the slopes of the Flemish Cap, Green, St.Pierre Banks and on the southern slopes of the Grand Newfoundland Bank.

The area situated to the left of the Gulf Stream core is the main habitat of the Atlantic saury in the open area of the North-Western Atlantic, though this fish species were many times encountered to the right of the Gulf Stream by the research and scouting vessels as well. The area of the Atlantic soury distribution is limited by the coordinates given below: from the south to the north, from 32°00' up to 50°55'N, and from the west to the east - from coastal waters up to 45°W. The penetration of the Atlantic saury to the north is determined by the hydrological conditions, acitive migrations of adult fish and a passive drift of immature fish by currents.

The whole life cycle of the Atlantic saury takes place in the homogeneous layer of the pelagial in the open part of the ocean, namely, far from the shallow waters of the continental shelf (Parin, 1968; Zilanov, 1968, 1969, 1970, 1977). Concentrations of the fish at their first stage of maturity and of mature ones appear in the shallow waters only during their feeding period, in summer and in autumn.

In order to make clear the problem of this fish species migrations, maps of the Atlantic saury stocks distribution were drawn by months for the period since 1967 up to 1974 (Fig.1).

Maps were completed with using the material of observations at the light stations, at the light fish searching, as well as according to data obtained as result of the haulings.

In winter period, the Atlantic saury are concentrated in the most southern part of their Area of distribution. The Atlantic saury were registered in the southern part of Georges Bank and westwards of it at this time. But, in the second half of December the concentrations shifted already southwards in waters having the temperature higher than 16°C, where the

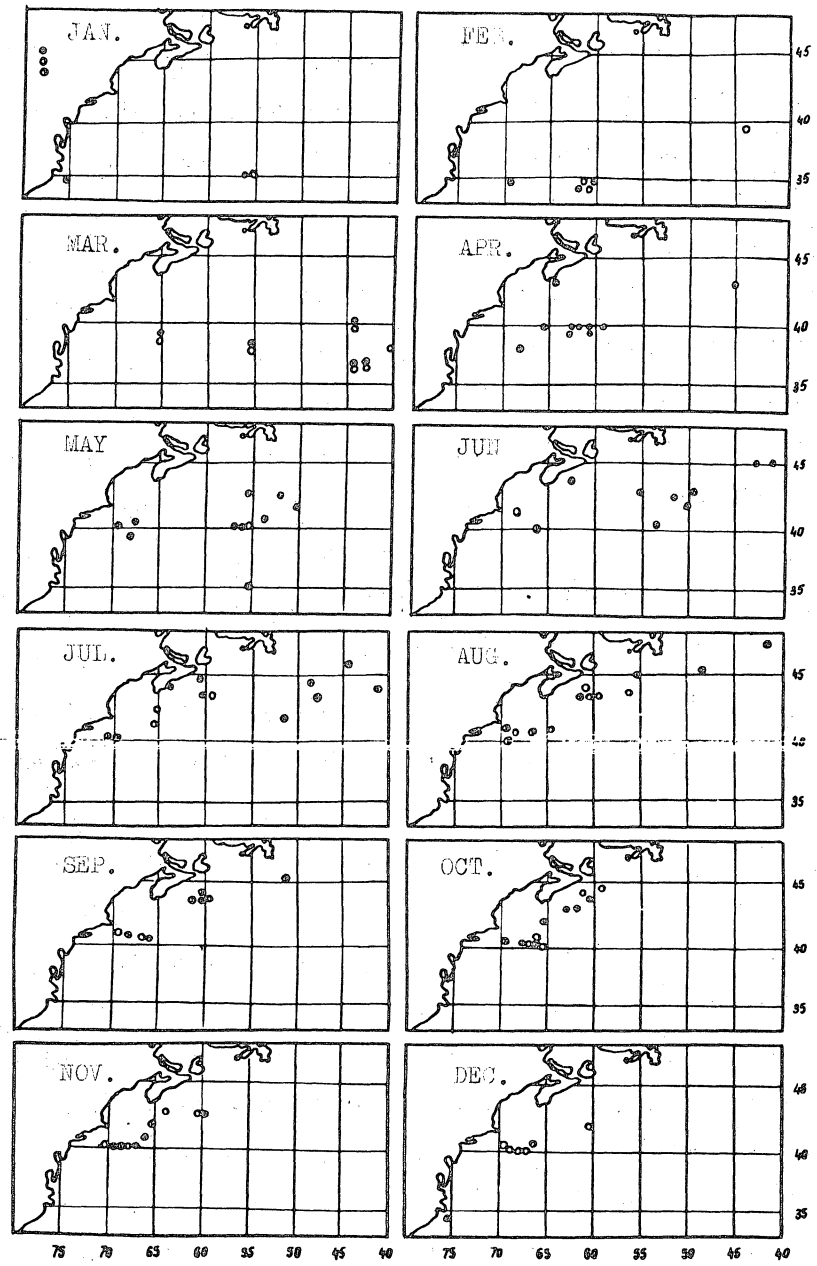

Fig.1. Areas of fisheries of the Atlantic saury in the North-Western Atlantic by months. 1(2) - the occurrence of large (small) Atlantic saury; 3. - locality of mixed concentrations.

fish are spawning. Late in December or early in January, large concentrations of the Atlantic saury at the spawning condition, big in their sizes (length - more than 30 cm, age - 3-3+) were encountered to the south from the Hutteras Cape. In winter, the fish were found throughout a large area in the open

part of the Ocean. In March, large and small fish were registered throughout the area between 30°N and 40°N. In April and May, the Atlantic saury begin to migrate intensively northwards. Fish concentrations cross the Gulf Stream Front, penetrate into a relatively cold waters and distribute in the shelf waters of the USA and on the Georges Bank.

In summer, the Atlantic saury distribute gradually further to the north simultaneously with the warming of the surface waters. In June, the shoals of this fish are found further to the sea from the Gulf of Maine and on the Nova Scotian Shelf up to 44°N, on the southern slopes of the Grand Newfoundland Bank. In July, the Atlantic saury concentrations are distributed in the areas lying southerner Newfoundland, in the southern areas of the Flemish Cap Bank and some easterner in the open areas of the Ocean. The schoals of large fish exclusively are found in the most northern areas, mixed concentrations of large and small fish are registered southerner. In August, like in the previous months fish were encountered everywhere on the USA Shelf, to the north of 40°N and throughout all the Nova Scotian Shelf.

Early in autumn, the area of the Atlantic saury distribution is the same as in summer, but in September-November, the fish concentrations begin to shift southwards. In October, the fish shoals are observed along the whole Nova Scotian Shelf, but in November, they are registered in the area of Georges Bank. During the period mentioned above, the concentrations of large fish are keeping in waters having higher temperatures and are encountered some southerner than small sized Atlantic saury. This phenomena diminishes the Atlantic saury average size in their catches taken on Georges Bank in the autumn period, this is connected with leaving their habitats to warmer waters by the mature Atlantic saury (Fig.2).

Basing on materials got, a scheme of the Atlantic saury migrations was constructed (Fig.3). This fish species performs long distance migrations. Late in spring and in summer the Atlantic saury migrate northwards, whereas in autumn and early

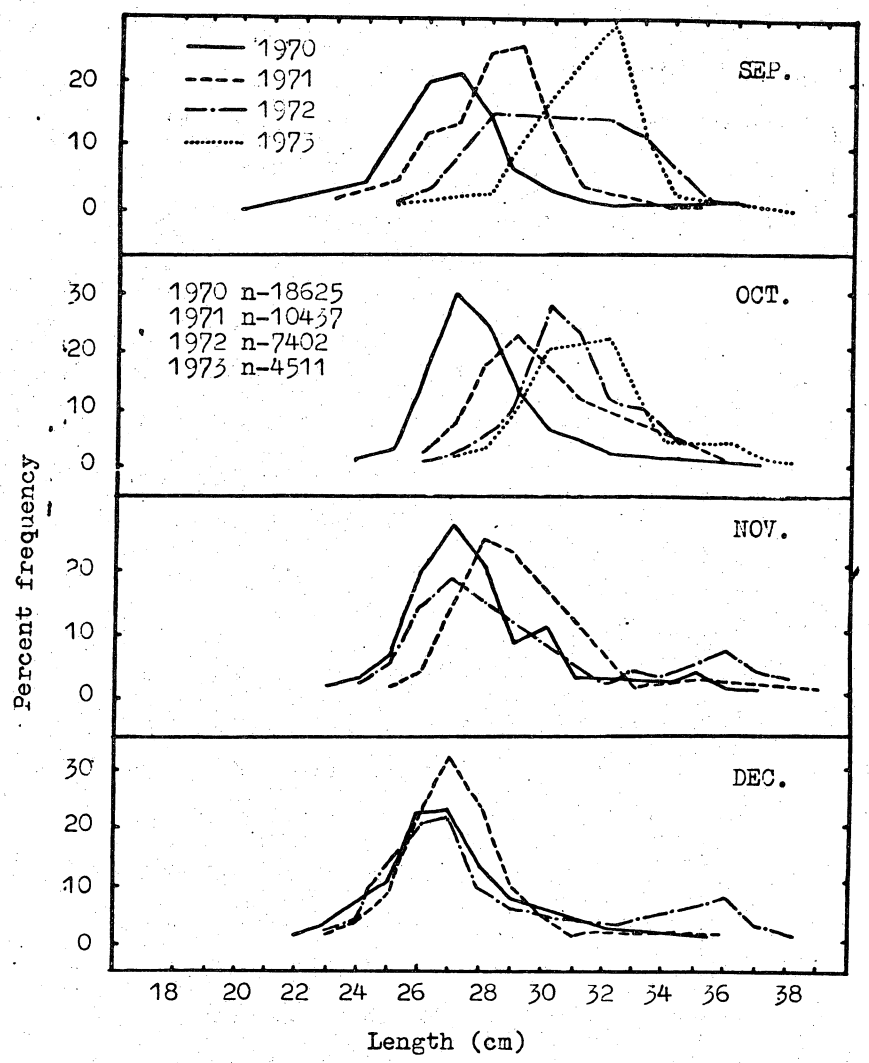

Fig.2. Size composition of the Atlantic saury on Georges Bank in 1970-73.

in winter the fish displace to the south. The elder age group of the Atlantic saury represented in mass by individuals at age 3 and 3+ perform their spring-summer migration to the north and the autumn one to the south at earlier terms compared fish aged 2-2+.

Basing on data of space distribution of the Atlantic saury at different stages of their life cycle within the area of their distribution, one can distinguish the area components as follows:

a) a spawning or a reproductive part of the area;

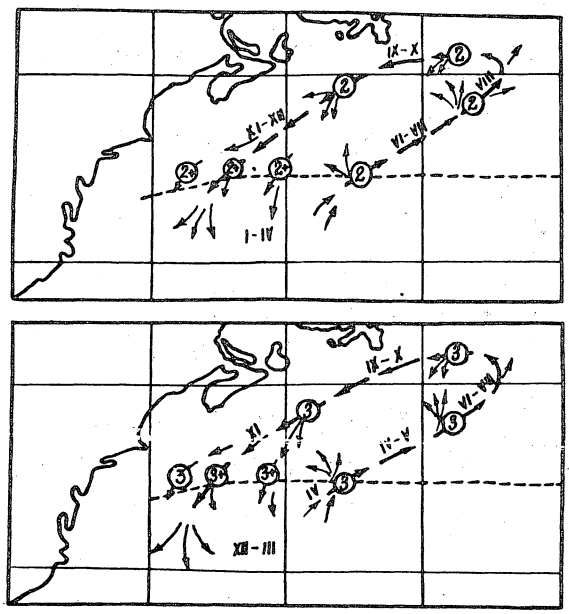

Fig.3. The model of the migration cycle of the Atlantic saury in the North-Western Atlantic. Age of migrating fish: A-2-2t; B-3-3t; Numbers in circles show age of fish, roman numerals show months. Dotted line means a northern limit in the area of the Atlantic saury reproduction.

b) a feeding part of the area;

c) an area of larvae and fries moving.

Data on space distribution of adult Atlantic saury in different parts of the area correspond to the physiological condition of fish and, in particular, to the dynamics of the intesting filling, the rate of the fattness of the guts and the maturity rate (Fig.4).

The distribution of the Pacific saury depthwise is limited by the surface isothermal water layer, where the fish perform their diurnal migrations. In night time fish prefer to keep near the surface line, in day time they are keeping in deeper layers. The greatest depth from the surface, where the Atlantic saury were registered, was 50 m. Eggs and larvae are distributed in the most upper water layer 0-I m.

The water temperature is one of the main factors determining the horizontal distribution of the Atlantic saury. The tem-

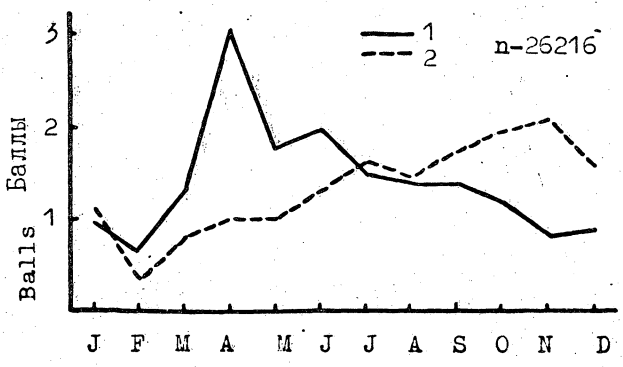

Fig.4. Change of the rate of the intestine filling (1) and fatteness of the guts (2) of the Atlantic saury during the period 1968-1973.

perature range of their habitat varies from 8.2° up to 24.8°. The occurrence of this fish within the range of these temperatures depends on their physiological condition. Fish eggs and larvae are encountered in waters at the temperatures from 16.8° up to 23.7°. Basing on data of the mass occurrence, one can conclude that the optimum temperature for eggs and larvae is within the range from 17.3° up to 21.0°. During the feeding period, fish are registered within the range from 8.2° up to 21.0°.

The Atlantic saury spawning

The Atlantic saury spawning takes place southerner the frontal zone of the Gulf Stream, that can be concluded basing on data characterizing the occurrence of eggs, larvae, fries and of the spawning individuals (Nesterov, Shiganova, 1976). The annual dynamics of the number of the encountered spawning fish shows that the Atlantic saury spawns mainly during the winter-spring period (Table I). Males and females taking part in the spawning process reach, as minimum, 26 cm in their length at age 2.

The main mass of the spawning fish consist of the Atlantic saury aged 2-2+, 3-3+.

Microscopic studies of the Atlantic saury ovaries showed that the oocytes are growing and developping unevenly. This phe-

nomena may explain in its turn, why the Atlantic saury are spawning by portions (Chigirinsky, 1979; Nesterov, 1973). The Atlantic saury can be related to fish having a continuous asynchronous ability of the oocytes growth according to the type of their spawning (Kazansky,1949).

Table I. Maturity condition of the sexual products of the Atlantic saury during the whole years (in %%)

Months x/	Maturity stages					
	II	III	IV	V	VI-VII	n
January	26,4	9,3	34,3	28,6	1,4	140
February	-	67,6	16.2	16.2	-	179
March	-	2.7	56.8	35.1	5.4	37
April	-	23.9	71.8	4.3	-	46
May	-	71.8	24.9	3.3	-	245
June	33.3	64.2	1.1	1.4	-	136
July	-	100.0	-	-	-	55
August	97.2	2.8	-	-	-	532
September	75.3	29.6	1.6	-	0.5	3585
October	54.2	38.5	5.7	1.4	0.2	6149
November	60.9	21.6	10.6	6.1	0.8	6890
December	86.2	9.3	3.9	0.3	0.3	2207

x/ Summarized monthly data for the period from 1967 to 1973. The main mass of the spawning fish consist of the Atlantic saury aged 2-2+, 3-3+.

The Atlantic saury eggs are pelagic, half transparant and have a spherical form. The diameter of the ovarian eggs is 2.5mm - 3.2 mm. Eggs are developping in the most surface water layer. Larval stage of the Atlantic saury finishes, when its length is not less than 25 mm (Dudnik, 1975).

Feeding habits of the Atlantic saury

The analysis of the content of the Atlantic saury intestine testifies to the fact that the bulk of the feeding items is rep-

resented by Copepoda, euphausids and amphipods. Larvae of Decapoda, Siphonophora, fish, Protozoa, chitinous items, larvae of polychaetes and Cirripedia, Isopoda, Ostracoda, insects, fish eggs and algae are found among the items of the Atlantic saury feeding spectrum in a less number (Nesterov, 1976). Thus, the Atlantic saury is a typical plankton - eater according to their food composition.

A seasonnal fluctuation in the qualitative composition of food is proper to the Atlantic saury depending on the availability of the fish in parts of the area different by their functional peculiarities. In spring and in summer, Copepoda, mainly Calanus finmarchicus, Siphonophora, fish serve as the main components in the Atlantic saury feeding on the Georges Bank and the Nova Scotian Shelf. The secondary items are euphausids and Decapoda larvae. In autumn, Copepoda genus Centropages, different Calanoida and euphausids prevail in the same areas. In winter, a food lump of an individual of the Atlantic saury caught at 34°N comprised larvae of Decapoda, Hyperiidae, mollusks and Foraminifera.

The age fluctuations are observed in the feeding of the Atlantic saury. The accessibility of the food organisms is determined by the sizes of a fish itself. Thus, the individuals of 23 cm long are feeding on the organisms not longer than 20 mm. Adult fish can feed on the macroplankton being up to 60 mm in its length, at the same time adult fish is able to feed on small crustaceans, not more than 1 mm in their length. The increase of the accessibility of the food organisms with age allows to make larger the fish feeding spectrum.

A similar distribution of the frequencies of the occurrence of different numbers of the food organisms in the feeding spectrum of the Atlantic saury shows that this fish species is feeding on any accessible organisms inhabiting any area of the Ocean and possesses a low food selectivity. Change of the qualitative food composition depending on the areas and the time testifies to a high food plasticity of this fish species.

The most active feeding of the Atlantic saury takes place in spring and summer months. In autumn, the intensity of the food consumption drops, and, as the consequence of an active feeding in summer, the fatness rate becomes higher. In winter, the feeding intensity is a minimum one.

The Atlantic saury fed on different forms of the plankton serves as a food item in its turn to many other inhabitants of the Ocean. This fish species serves as food item to coastal and marine squid species, swordfish, marlins, sharks, bonito, tunas, Coryphaenidae, hakes, cod, saithe, dolphins and whales, and to marine birds as well.

A high abundance of the Atlantic saury and its large distribution determine the role proper to it as an important link in the food chains of the Ocean while transferring the energy of low trophical levels to higher ones following them.

Length, weight, growth

The body length of the Atlantic saury from the catches taken by a net suspended from booms alongside a vessel varies from 18cm up to 39 cm, the body weight being 19-200 g. Two size groups, namely, 23-30 cm and 31-37 cm, are distinguished on the curves characterizing the size composition of the fish caught in the autumn-winter period, an average weight of these two groups is 55 g and 110 g correspondingly. The relationship between the weight and the length is expressed by the formula as follows:

$$W = b \cdot L^n,$$

where W is the fish weight in g;

L is the fish length in cm;

b = 0, 0068; n = 3,0045.

The age of the Atlantic saury was determined with use of scale (Table 2). Differencies in the growth rate were not found between males and females.

According to Berthalanffy equation, a linear growth of the Atlantic saury is expressed by a formula as follows:

$$Lt = 45.437 \, /I\text{-}e^{-0,279}(t + 0,728);$$

The increase in weight is given as

$$Wt = 312.199/(I - e^{-0,834}(t + 0,834)/^{3},$$

where Lt - Length (cm); Wt - Weight (g).

Table 2. Average length and age of the Atlantic saury according to data of the inverse calculations by scale

Age (years)	Length (cm)				n
	1	2	3	4	
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

The Atlantic saury fishery

Presently, the fishery of the Atlantic saury is not conducted in the North-Western Atlantic. During the period since 1969 to 1974, an experimental expeditionary fishery of this fish species was conducted by the USSR. Vessels type SRT and SRTM were used for the Atlantic saury fishing, the vessels were managed with a light equipment allowing to concentrate fish within the area caught by a net suspended from booms alongside a vesel and hauled toward it (Zilanov, 1977).

The fishery in the area of Georges Bank and the Nova Scotian Shelf is based on fish migrating southwards and feeding there. These areas are effected by warm Gulf Stream waters and cold water masses brought with the Labrador Current and the Cabot Current. Eddies are foming at the limits of the currents interaction, which cause an intensive mixing of water masses. The Atlantic saury concentrations are timed to such zones and are distributed from side of cold waters. Gulf Stream waters having high temperatures serve as a barrier preventing fish from their shifting to the south. Since August to December,

stable commercial concentrations of the Atlantic saury are creating both in the Georges Bank Area and on the Nova Scotian Shelf.

The duration of the fishery period is determined by temperature conditions of the area. When water temperature drops below 9.2°, the Atlantic saury are migrating southwards. Usually fish are keeping in the southern areas of the Bank. up to the midst of December. But, in 1968, the concentrations were found even in January, and in 1973, fish concentrations were not available already in December. Optimum temperatures, when the Atlantic saury concentrations were observed, differed by months. The temperature analysis and that of the catch values showed while conducting 2039 sets of net suspended from booms alongside a vessel and hauled toward it during the period since 1969 up to 1973 showed that the average value of monthly temperatures are decreasing from September to December and is correspondingly 16.9, 14.3, 11.8, 11.5.

The efficiency of the Atlantic saury fishing depends on the reaction of fish to the artificial light sources. This reactipn is determined by a number of circumstances and, first of all, by the physiological condition of the individuals, the moon's phase, the time conditions (Fig.5). Due to this, the Atlantic saury fishery based on the using of the positive fish reaction to light can be conducted during 12-18 nights per month.

Below are given the values characterizing the catches taken in time of the experimental fishing of the Atlantic saury, they are as following: 1970 - 1.023t; 1971 - 2.11t; 1972 - 3415t; 1973 - 2.443t (Sratistical Bulletin ICNAF, 1971, 1972, 1973, 1975). The fishery is based on the regulation of the Atlantic saury behaviour with using of the light fields (Zilanov, 1968, 1977). Acoustic instruments were used in time of the scouting work.

Age composition of the Atlantic saury taken from the commercial catches is given in Table 3. The bulk of catches consists of the Atlantic saury aged 2 and 3.

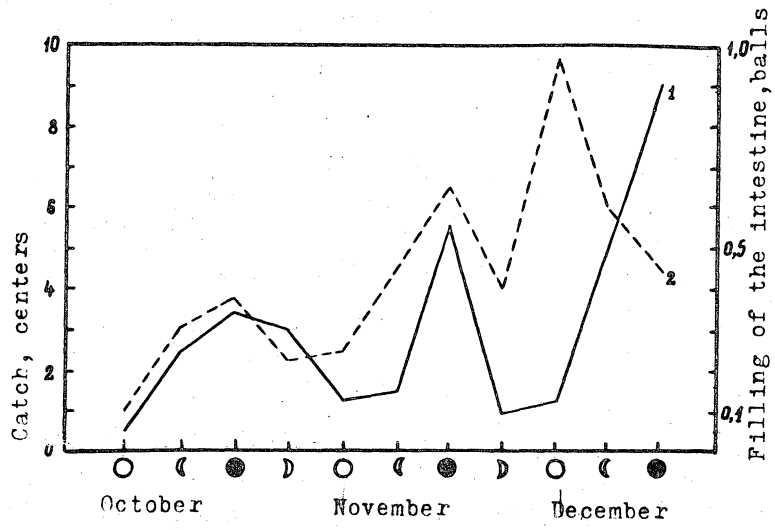

Fig.5. Relationship between the value of catch per one set of the side net and of the intestine filling from the moon's phase: 1 - value of catch; 2 - filling of the intestine.

Table 3. Age composition of the Atlantic saury (%,%)

Age (number of years)	Years			
	1970	1971	1972	1973
1	2,16	0.36	0.42	0.04
2	72.56	63.49	52.00	44.74
3	21.18	31.25	35.68	46.71
4	4.10	4.90	11.90	8.51
Mean age	2.27	2.41	2.59	2.64
Mean length (cm)	27.70	28.90	30.02	30.27

The stock value and the allowable commercial catch

Data got for a number of years as result of investigations in the North-Western Atlantic make possible to determine an approximate total allowable catch of the Atlantic saury in this area. While determining the value of the biomass of the commercial part of the Atlantic saury stock, we used the results of its abundance determination got in time of the track counting

survey conducted in 1971-1973. It was determined that mean value of the fish biomass was about 900.0 thousand tons. The value of the total mortality factor (Z) of the Atlantic saury estimated with use of Beverton and Holt method appeared to be 1.50. Taking into account that Z = M + F, and the value of the commercial mortality (F) for the Atlantic saury is close to 0, the factor of the natural mortality (M) can be 1.50. As initial data for calculations, we used the parameters given below:

$$M = 1.50;\quad t_p = t_p' = 1.97;\ t = 4;\ t_o = -0.874;\ W = 319.2.$$

A mean weight of fish taken from the commercial catches was 68 g. A relative number of the recruitment is represented on the average as a value 59.0% of the number characterizing the commercial part of the stock. Therefore, the recuitment number is:

$$R = 530.0 \text{ thousand tons} = 0.78.10^{10} \text{ species.}$$

The curve of the relationship $\frac{YW}{R}$ from F has an asymptotic character (Fig.6). Thus, an allowable catch per year increases up to 530.0 thousand tons at $R = 0.78.10^{10}$ species. The relationship $\frac{YW}{R}$ from F shows that the optimum value is within the ranges 1.5-2.0 F, that corresponds to a value $\frac{YW}{R}$ from 25.64 up to 28.49 g and to a possible catch - 340.0-380.0 thousand tons.

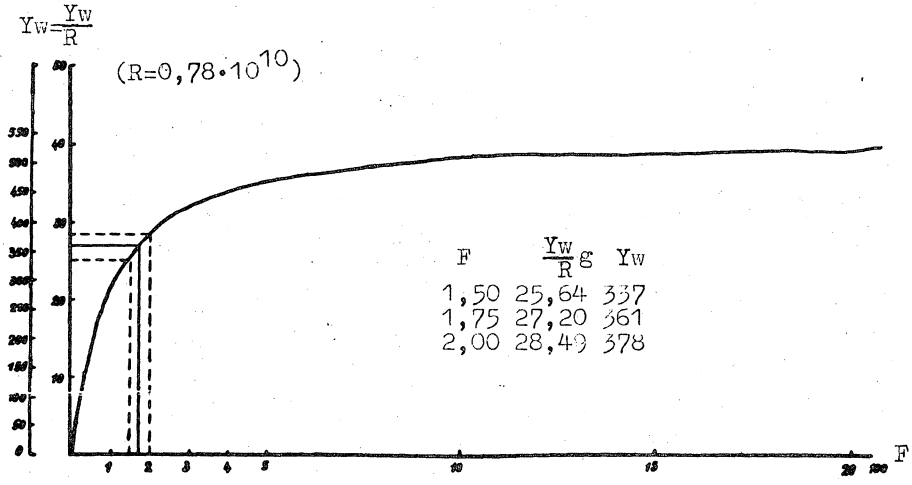

Fig.6. Relationship between the factor of the allowable catch ($\frac{YW}{R}$) as well as . of the allowable catch at $R = 0.78.10^{10}$ pieces from the rate of the fishery mortality - F.

CONCLUSION

The Atlantic saury has a large area of its distribution in North-Western Atlantic. An active migration of the fish to the north is connected with the approach of the feeding period. The Atlantic saury shifts to warmer southern areas during the spawning-winter migrations. Long distance migrations performed by the Atlantic saury are caused by the disconnection of the spawning and reproductive parts of the areas. The Atlantic saury finds favourable feeding conditions in the northern feeding part of the area, whereas it finds convenient conditions for its reproduction in the southern part of the area. A time disconnection observed in the migrations of different age groups of the Atlantic saury is apparently caused by different physiological condition of fish and it is directed to the relaxation of the intraspecific food competition.

The temperature range of the Atlantic saury inhabitance covers values from 8.2° up to 24.8°. The Atlantic saury possess a high rate of the growth and relates to fish having a short life cycle. Fish at age 2 and 3 prevail in the catches. The maximum yield of the Atlantic saury per year did not prevail 4.0 thousand tons in the North-Western Atlantic, but, a total maximum sustainable yield can be 340.0-380.0 thousand tons. Thus, we conclude that the stocks of this fish are not practically used.

The Atlantic saury investigations are limited by an open part of the North-West Atlantic, that is quite insufficient for understanding the dynamics of the biological processes of this species. It seems to be reasonable to begin with the elaboration of a common scientific program of the studying the Atlantic saury biology throughout the whole area of its distribution and, then, to realize this program under the aegis of NAFO Scientific Committee or under ICES.

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Appendix

SCALE OF MATURITY OF THE ATLANTIC SAURY OVARIES

I Stage. Sexual cells of three types are observed in the ovary, they are as follows: oogonia and ooxytes of the period of premeiotic transformation and the initial phase of the protoplasmic growth. The main mass consists of cells of the second type, their sizes are 36-50 μ. The sell mentioned here can be distinguished only with help of the microscope.

The ovaries have a configuration of thin threads (diameter 1.2-2.0 mm), they are of white or slightly gray colour. A lenghwise hardly seen blood vessel is on the ovaries.

II stage. Besides sexual cells proper to the I stage, there are observed oocytes at the phase of the protoplasmic growth having a formed follicle cover, their diameter is 140-170 u. Thus, the ooxytes having different phases of the protoplasmic growth are in the ovary of the II stage of maturity.

Diameter of the ovaries at their cut is 1.8-2.5mm. They have a white pigmentation with a slightly pink tint Oocytes can not be distinguished through the cover of the ovary without the microscope. Lengthwise and transversal blood vessels can be observed on the surface of the blood vessels.

III stage. Ovaries contain oocytes at the first stage of the prophoplasmic growth. The sizes of the oocytes at a phase of the first filling with yolk fluctuate within a range from 430 up to 860 μ. Besides, sexual sells at all the previus phases of development are in the ovaries having a III stage of maturity.

The greatest diameter of the ovaries at the cut is 2.2-3.3 mm. The ovary has a larger diameter in their fore part than in the back one. The limits on an ovary are sharpened, they

have a pink or rose pigmentation. Cross blood vessels are branching. Eggs are transparent through a cover without microscope.

IV stage.corresponds to the phase of the oocyte filled with the yolk and fusion of the yolk. The oocytes size reach 2900 μ. Simultaneously, oogonia and oocytes of premeiotic transformations of the protoplasmic growth are observed in their ovaries. Ovaries occupy almost all the cavity of fish body, their limits have a round shape. The diameter of the ovaries is 7-13 mm. The cover of the ovaries is pierced by blood vessels. Ovaries are of a bright orange colour, eggs are perfectly transparent through the cover, eggs can be visually related to three generations.

V stage. Cells at the condition of the beginning of the yolk homogenization are on the hystological preparations in addition to ripe oocytes having a maximum size (up to 3200 u). These cells correspond to a stage of the oocyte filled will a yolk. The ovary iclude also a whole set of the previous stages cells.

The ovaries distinguish by their appearance from the previous stages mainly by their pigmentation. They are almost transparant due to large colourless eggs of the elder generation, the ovary volume is filled almost completely with these eggs, which are densely adjacent to the ovary cover. Eggs of the following generation are also transparant, but, they have a dark yellow pigmentation. The ovary is elastic, eggs run out at their light pressing.

VI-IV-stages. The peculiarity of the ovaries at this stage is the availability of empty (broken) follicles. Sometimes, rare, not run out ripe oocytes can be observed on the hystological preparations. Oocytes of the elder generation have in their size about 1000 μ and are at the stage of oocyte filled with a yolk. Sexual cells represent in the ovary all the following phases.

The ovary is soft, not run eggs, rare enough are sometimes observed through its cover. The ovary is of red pigmentation, especially bright in its back part.