Acta Adriat.,32(2):869-884(1991)

ISSN:0001-5113
AADRAY

UDC:597.08:639.2(0:597.5)(262.3)
Conference paper

STOCK SIZE ASSESSMENT OF SARDINE, *SARDINA PILCHARDUS* (WALB.) POPULATION FROM THE CENTRAL EASTERN ADRIATIC ON THE BASIS OF VPA METHOD

PROCJENA VELIČINE POPULACIJE SRDELE, *SARDINA PILCHARDUS* (WALB.) SREDIŠNJEG DIJELA ISTOČNOG JADRANA UPOTREBOM VPA METODE

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This paper presents the assessment of stock size and maximum sustainable yield of the exploited sardine population from the central part of the eastern Adriatic between September 1979 and March 1981. The mean stock size of the exploited sardine population was assessed at 72,925 tons and maximum sustainable yield at 15,314 tons.

The values of growth parameters, weight-length relationship, instantaneous rate of total, natural and fishing mortality, exploitation rate and other relevant parameters were also calculated.

INTRODUCTION

The sardine, *Sardina pilchardus* (W a l b.), is of great importance in the Croatian commercial fishery. It is the most valuable resource in the Adriatic and it has attracted the interest of both fishermen and fishery biologists for a long period and presumably more intensively than any other fishery resource. Among other investigations - a review of many of the earlier research was given by M u ž i n i ć (1979) - several attempts have been made recently to assess the sardine stock size in the eastern Adriatic by various methods (A l e g r i a , 1984; R e g n e r *et al.*, 1985; S i n o v č i ć , 1986, 1987). The assessments are sensitive to the method of analysis and it is advisable to compare the results obtained by different methods. So, the aim of this paper is to present the results of sardine stock assessment on the basis of Virtual Population Analysis and the value of maximum sustainable yield, since the diagnoses of fish stocks are needed for management decisions.

Former sardine stock assessments (op. cit.) showed that the sardine stock state did not give the cause for alarm hereto. In any case, the information on the state of sardine stock should be sufficiently clear and the care should be taken since the nature is not noted for its magnanimity to the improvident.

VIRTUAL POPULATION ANALYSIS

Virtual population analysis (VPA) has been widely applied to commercial fish stocks for more than 20 years since its development (M u r p h y , 1965; G u l l a n d, 1965). It is an iterrative procedure which estimates cohort sizes and fishing mortality rates at each age. Cohort size refers to the number of individuals in some identifiable group of animals. It is customarily used with reference to those animals which were all born during a given year. P o p e (1972) introduced an approximation to VPA called Cohort Analysis and demonstrated that cohort size estimates from Cohort Analysis are stable with respect to error in terminal fishing mortality estimate, given that catch-at-age and natural mortality are known without error.

The virtual population analysis method is based on an assumption that data on the numbers of fish caught provide an useful information about total removals. The data needed for stock size estimation on the basis of the VPA method are:

- length, weight and age structure of sardine population
- catches in numbers
- cohort size in numbers
- growth parameters
- weight/length relationship
- instantaneous total mortality rate
- instantaneous natural mortality rate
- instantaneous fishing mortality rate
- exploitation rate

MATERIAL AND METHODS

Material used for this study was obtained from commercial catches of pelagic fish, taken from inshore waters of the central part of the eastern Adriatic (Fig. 1) from September 1979 to March 1981. A total of 1516 sardine specimens were analyzed.

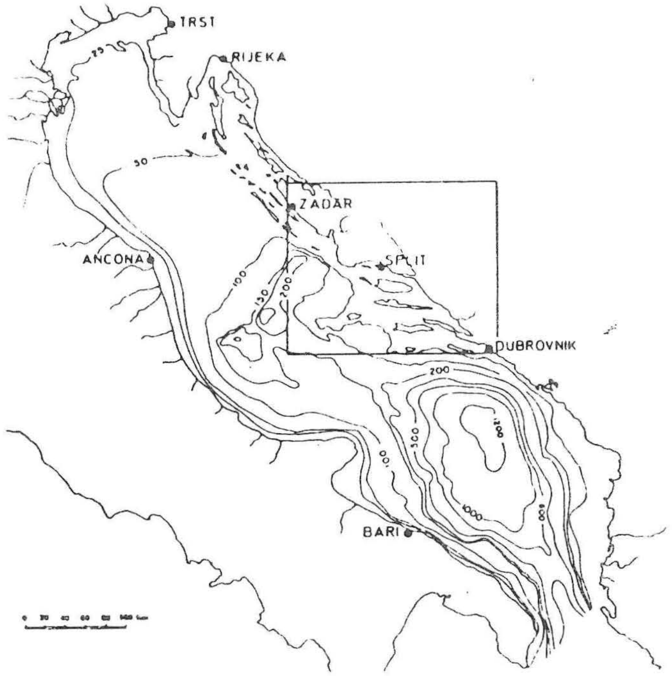

Fig. 1. Study area

Sardine length given in centimetres refers to their total length. Length classes were established as to the nearest half centimetre.

Weight was expressed in grams.

Age was determined from otoliths. The method used for this estimation was formerly described (S i n o v č i ć , 1986).

Data on sardine growth parameters were published in papers by S i n o v č i ć (1984, 1986).

Growth in weight of sardine was expressed by von B e r t a l a n f f y equation

$$w_t = W_\infty \, [\![1 - e^{-K(t-t_0)}]\!]^b$$

where W_∞ is the mean weight the fish would reach if they were to grow to a very old age infinitely, in fact.

K is the growth coefficient.

t_0 is the "age" the fish would have had at length zero if they had always grown according to the equation.

Allometric weight (W) - length (L) relationship was computed as GM functional regression (R i c k e r , 1975):

$$\log W = \log a + b \log L$$

$$\text{i.e. } W = a L^b$$

where b = allometric factor of weight-length relationship and a = constant.

Instantaneous total mortality (Z) was calculated by applying B e v e r t o n and H o l t (1975) equation:

$$Z = \frac{K (L_\infty - \bar{L})}{\bar{L} - L'}$$

where L_∞ and K are parameters of the von B e r t a l a n f f y growth equation, $\bar{L}$ is the mean length in the catch and L' is the smallest length of sardine that are fully represented in catch samples.

Instantaneous natural mortality rate (M) was calculated by the formula proposed by T a y l o r (1959):

$$M = 0.996/A_{0.95}$$

where $A_{0.95}$ is the age at which the fish reach 95% of L_∞.

Instantaneous fishing mortality rate (F) was calculated as the difference between instantaneous total mortality rate (Z) and instantaneous natural mortality rate (M):

$$F = Z - M$$

Exploitation rate (E) was computed from:

$$E = \frac{F}{F + M}$$

Stock size was assessed by VPA method accepting the procedure proposed by J o n e s (1981).

Maximum sustainable yield (MSY) was calculated by the equation proposed by G u l l a n d (1968):

$$MSY = Z_t \times X \times B_t$$

where Z_t is instantaneous total mortality rate in the year t, B_t stock size in that year, X a constant representing the fraction of total annual production which can be taken by fishing.

RESULTS AND DISCUSSION

Input parameters

Obtained results are as follows:

Structure of sardine population

Total length of sardine individuals ranged from 7.5 to 20.3 cm and weight from 2.3 to 56.6 g. In this study, the sardine life span was eight years. Individual age group proportions are presented in Fig. 2. Age groups ranged from 2.5 to 30.4%. Apart from

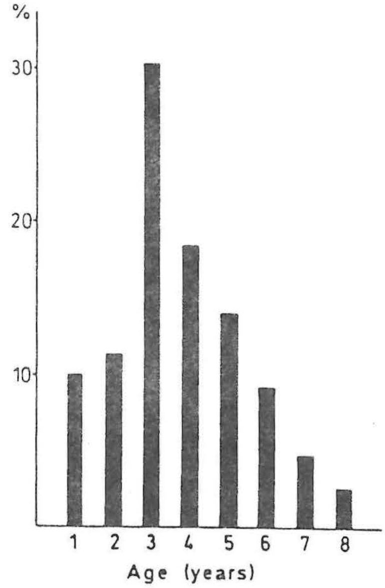

Fig. 2. Age composition of sardine, *Sardina pilchardus;* central part of the eastern Adriatic; September 1979 - March 1981

the relatively low percentage of older sardine age groups, the most conspicuous feature of the distribution in Fig. 2 is the dominance of age group 3+. According to S i n o v č i ć (1984) sardine specimens were fully mature in the second year of life. Taking into consideration the length at first maturity of sardine (M u ž i n i ć , 1954) and converting them to age (S i n o v č i ć , 1986) the same results were obtained. So, the greatest presence of fully mature specimens of sardine is favourable for the state of sardine population.

Weight-length relationship

Weight and length data were available for all examined specimens of sardine. Weight-length relationship of 1516 studied sardine specimens may be described by the following equation:

$$W = 3.3 \times 10^{-3} L^{3.2764}$$

or by its logarithmic form:

$$\log W = 3.2764 \log L - 2.4810$$

By applying this equation, the predicted weight was comparable to the determined weight for each class interval (0.5 cm). Positive allometry was established, that is higher rate of sardine growth in weight than that of sardine growth in length, the allometric growth factor being 3.2764. The correlation coefficient for this relation was high ($r = 0.9998$) and significant at $P<0.001$ approaching theoretical ideal value of 1. This is indicative of the fact that only a smaller number of sardine specimens cannot be accounted for by this relationship. The allometric growth factor of 3.2764 is higher than values obtained by M u ž i n i ć (1980) and A l e g r í a (1983). Both of them established the negative allometry for sardine from the middle Adriatic, allometric factor being 2.914 and 2.757. Unfortunately, those results are not comparable owing to different physiological states of sardine during the time of investigations. Namely, specimens analyzed by M u ž i n i ć were from August 1922 (time of inactivity in sexual cycle), those studied by A l e g r í a were from autumn-winter 1980-81 (spawning period) while ours were from September 1979 to March 1981 and practically included all the specimens regardless of their physiological state.

Graphical representation of weight-length relationship is given in Fig. 3. The weight-length relationship alternates, emphasizing some critical stages in the biology of sardine: change from juvenile into adult, maturation and spawning. The sardine growth in weight increased sharply after a steady but slow rise. On the other hand, sardine growth in length is much higher up to the 8 cm which is a limit-length of juvenile individuals of sardine (K a r l o v a c , J., 1967). Subsequently, at lengths between 8.0 and 14.0 (maturation) growth in weight as well as in length is uniform. At lengths from 14.0 to

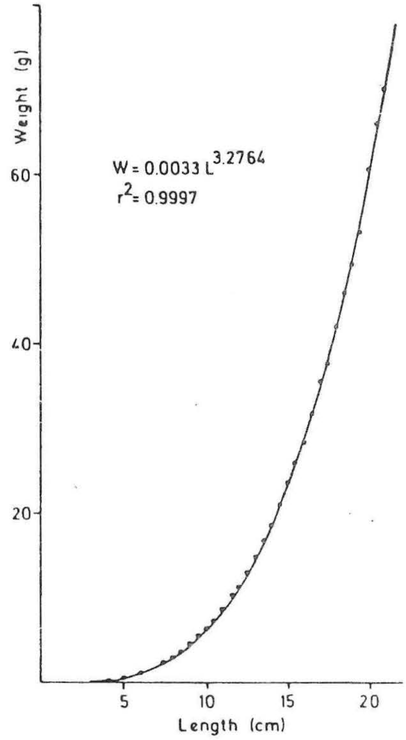

Fig. 3. Weight-length relationship of sardine, *Sardine pilchardus;* central part of the eastern Adriatic; September 1979 - March 1981

18.0 (spawning) sardine growth in weight is much more intensive in relation to length which is poor, and becomes most rapid at length exceeding 18.0 cm when individuals of sardine become practically senile.

Growth in weight

According to S i n o v č i ć (1986) sardine growth parameters are:

$$L_\infty = 20.5;\ K = 0.46;\ t_0 = -0.5$$

W_∞ was calculated and this value is $W_\infty = 56.6$ g. Entered into the von B e r t a l a n f f y equation, this gives the means of estimated weight at age for sardine from the middle Adriatic:

$$w_t = 56.6 \left[1 - e^{-0.46(t+0.5)} \right]^{3.2764}$$

The weights for each age group calculated from this equation are graphically presented in Fig. 4. It is obvious that the most rapid growth in weight occurred during

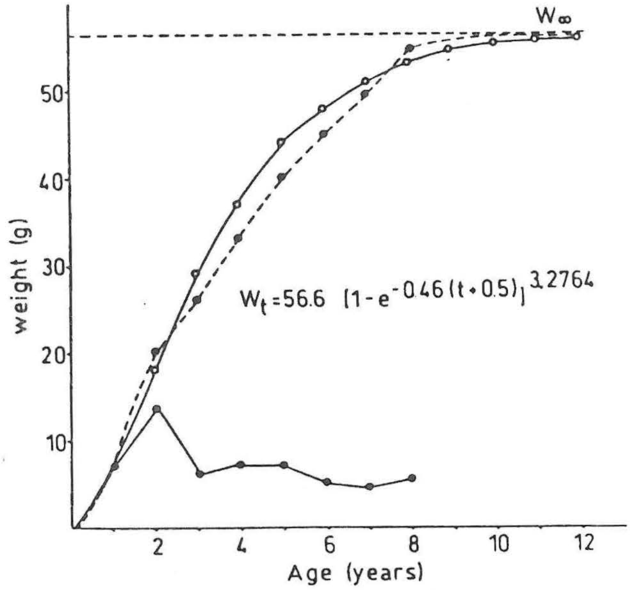

Fig. 4. Growth in weight of sardine, *Sardina pilchardus* during its life span; central part of the eastern Adriatic; September 1979 - March 1981

the first and second year of age and gradually decreased with the greater age and practically ceased at the age of 6+. A significant reduction in growth after the second year is probably the result of energy conversion to gonad maturation.

The growth of sardine was studied earlier but with respect to length (S i n o v č i ć, 1986). It was established that growth in length of sardine had similar trend i.e. it was evident during the first and second year of age and gradually decreases with the age. At any rate, it is the privilege of the species to finish the growth potential earlier through the life cycle. Thereby, it makes possible to realize one's own reproductive potential.

The number of sardine specimens per kilogram

The total sardine catches in the central part of the eastern Adriatic varied between 10,348 and 16,433 tons, mean 12,417.67 tons for the period of this study. On the average, a kilogram contained 35 sardines. So, the cohort size in numbers for each sardine age group varied between 10.9 and 131.3 million individuals (Table 1).

The exploitation rate (E)

The estimates of instantaneous total, natural and fishing mortality rates are also needed for estimation of the exploitation rate of oldest sardine age groups. Sensitivity of yield appears to be mainly due to terminal mortality rate and age-specific weights, and to a lesser extent to catches and natural mortality (P e l l e t i e r , 1990). So, it is assumed that instantaneous natural mortality rate is not year dependent and persists in constant over all ages. If the exploitation rate and instantaneous fishing mortality remain stable over the period covered by the catch-at-age data, relative changes in fish stocks will be correctly identified by the VPA independently on the chosen values of instantaneous natural mortality rate (H i l d e n , 1988). According to the equation proposed by T a y l o r (1959), the value of instantaneous natural mortality rate was calculated to be 0.3.

On the basis of the B e v e r t o n and H o l t (1957) equation, instantaneous total mortality rate for the oldest sardine age group was $Z_8 = 0.6$, whereas the value of the instantaneous fishing mortality rate of the oldest sardine age group $F_8 = 0.3$ was obtained as the difference between instantaneous total (Z) and instantaneous natural mortality rate (M).

Ž u p a n o v i ć (1955) calculated fishing mortality of sardine population from the same fishing area - central part of the eastern Adriatic from tagging data in 1949 (M u ž i n i ć , 1950) and obtained value of F = 0.17. This author holds that F is lower than actual owing to some technical errors in tagging experiment. Since the data refer to the stock state of the immediate post-war period, stock vulnerability to fishing gear was reduced.

By means of the instantaneous fishing mortality rate and instantaneous total mortality rate for the oldest age group, exploitation rate of sardine oldest age group was calculated to be 0.5 according to the equation proposed by B e v e r t o n (1963).

VPA results

Stock size

Sardine occurring in the central part of the eastern Adriatic is a homogeneous population (M u ž i n i ć , S. 1936; M u ž i n i ć , R., 1954; A l e g r í a *et al.*, 1986). Consequently, all presented parameters and obtained values are most likely good representatives for all sardine specimens from that region.

On the basis of the attending procedure proposed by J o n e s (1981), stock size assessment was performed applying the Virgin Population Analysis. Results are given

Table 1. Sardine stock size in the central part of the eastern Adriatic (VPA method ; September 1979 - March 1981)

Age class	%	W (g)	E_t	Yield		Residual fish		Stock size	
				t	10^6 individuals	t	10^6 individuals	t	10^6 individuals
1 +	10.0	6.7	0.476	290.8	43.4	6,142.7	916.8	6,433.5	960.2
2 +	11.4	20.9	0.555	1,034.5	49.5	14,800.4	708.2	15,834.9	757.7
3 +	30.3	25.1	0.641	3,300.7	131.5	13,438.8	535.4	16,739.5	666.9
4 +	18.4	32.0	0.657	2,556.8	79.9	10,266.1	320.8	12,822.9	400.7
5 +	13.9	38.6	0.685	2,327.6	60.3	7,351.4	190.5	9,679.0	250.8
6 +	9.0	44.4	0.687	1,736.0	39.1	4,502.1	101.4	6,238.1	140.5
7 +	4.5	49.3	0.635	961.4	19.5	2,354.1	47.7	3,315.0	67.2
8 +	2.5	56.6	0.5	616.9	10.9	1,245.2	22.0	1,862.1	32.9
Total	100.0			12,824.7	434.1	60,100.8	2,842.8	72,925.0	3,276.9

in Table 1. Stock size of the exploitable sardine population in the central part of the eastern Adriatic was estimated to be 72,925 tons. Graphical representation of sardine stock size, yield and value of residual fish are shown in Fig. 5. These values are given as to the mean weight for each age group. It is evident that the weight proportion of age group 3+ was predominant in the catch while age group 2+ was predominant in the sea. However, if we present the sardine stock size, yield and the value of residual fish in mean numbers of sardine individuals for each age group, it is obvious that sardine of younger ages occur in greatest numbers which is reduced with age.

A large number of authors dealt with the sardine stock assessment in the Adriatic with different methods (Županović, 1955; Štirn, 1969; Pucher-Petković and Zore-Armanda, 1973; Grubišić *et al.*, 1974; Karlovac *et al.*, 1974; Štirn and Kubik, 1974; Azzali *et al.*, 1976; Vučetić, 1976; Kačić, 1978, 1980; Regner *et al.*, 1981; Alegría, 1983; Sinovčić, 1986, 1987). They used different assessment methods of sardine population originating from different Adriatic fishing areas.

Unfortunately, we can only compare the results from this paper with those of Županović (op. cit.), because they originate from the same fishing area, that is from the central part of the eastern Adriatic. Consequently, after this author, the assessed sardine stock size by the method of Schnabel (1938) from sardine tagging results (Mužinić, 1950) in the central part of the eastern Adriatic amounted to 2.311.466 individuals in 1949, what, if recalculated , would make a quantity of 74,000 tons supposing the actual mean weight of represented sardine specimens w = 34.2 g would have been good representative of sardine population in 1949. It is evident that this estimation is very similar to that obtained in this paper.

Maximum sustainable yield (MSY)

To estimate the extent to which an average sardine catch may be increased without overfishing, maximum sustainable yield (MSY), or maximum equilibrium catch, was calculated by the equation proposed by Gulland (1986):

$$MSY = Z_t \times X \times B_t$$

where Z_t is instantaneous total mortality rate in the year t, B_t the stock size in that year, X a constant representing the fraction of total annual production which can be taken by fishing.

Taking into consideration the fact that owing to the vertical distribution and different seasonal aggregation of sardine in the eastern Adriatic (Mužinić, 1954; Gamulin, 1954; Karlovac, 1964 and Alegría, 1983) only 35% of the stock size could be caught (Gulland, 1970). On the basis of this fact and calculated

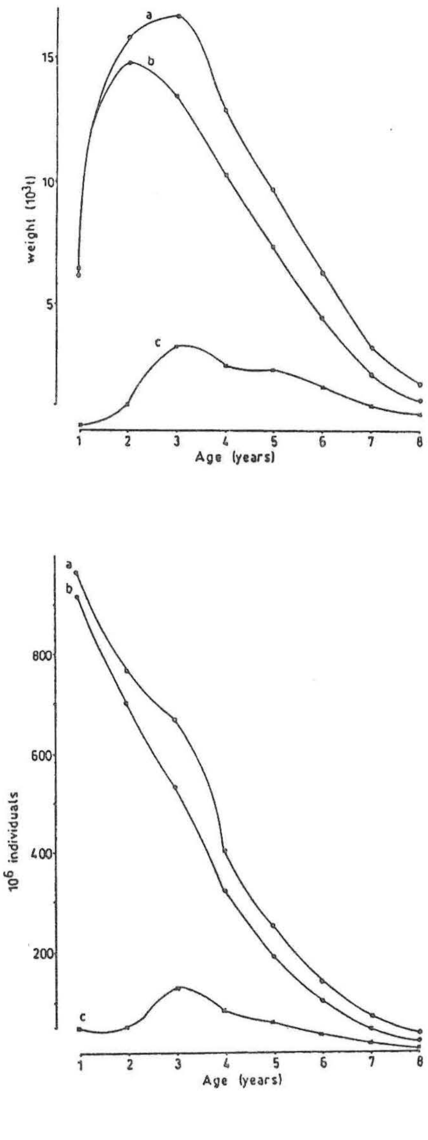

Fig. 5. Curves of: a) stock size, b) residual fish and c) yield of sardine, *Sardina pilchardus*; central part of the eastern Adriatic; September 1979 - March 1981

values of instantaneous total mortality rate and sardine stock size, estimated maximum sustainable yield (MSY) was 15,314.25 tons. Comparing the value of maximum sustainable yield with the amount of sardine catches during the period of investigation in the central part of the eastern Adriatic, it is evident that existing exploited resources of sardine population varied about optimum values of sardine population biological production.

CONCLUSIONS

The Virgin Population Analysis (VPA) was applied for the sardine, *Sardina pilchardus* (W a l b .), population from the central part of the eastern Adriatic. The stock size of the exploitable sardine population in that region was assessed to be 72,925 tons. Particular attention was given to the value of maximum sustainable yield or maximum equilibrium catch to estimate by how much the mean sardine catch may be increased not causing overfishing. The value of 15,314.25 tons was obtained. Reported mean catch by state firms was 12,417.67 tons, an amount below obtained value of maximum sustainable yield. Taking into account this fact and the data on sardine biological parameters that is the fact that sardine of eight years were present in the catches, that the third year class was best represented in the catches, that the instantaneous natural mortality rate and instantaneous fishing mortality rate were equal and exploitation rate optimum, it might be concluded that sardine population was underexploited during the time and in the area of our study.

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Accepted: November 9, 1990

PROCJENA VELIČINE POPULACIJE SRDELE, *SARDINA PILCHARDUS* (WALB.) SREDIŠNJEG DIJELA ISTOČNOG JADRANA UPOTREBOM VPA METODE

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KRATKI SADRŽAJ

Cilj je ove studije bio da se utvrdi veličina populacije srdele, *Sardina pilchardus* (Walb.) u središnjem dijelu istočnog Jadrana, koja u ovom području predstavlja jedinstveno naselje.

U radu se iznose njezini biološki parametri, sastav naselja obzirom na dužinu, težinu i starost, rastenje, dužinsko-težinski odnos, keficijent smrtnosti (ukupne, prirodne i ribolovne) te razina iskorištavanja, na osnovi kojih je izvršena procjena veličine populacije na vrijednost od 72.925 tona (VPA metoda).

Procijenjena je i vrijednost biološki maksimalno dozvoljene razine iskorištavanja srdele na 15.314,25 tona zbog utvrdjivana mogućeg povećanja njezina srednjeg ulova bez opasnosti od prelova, a u svrhu racionalnog upravljanja zalihama ove vrste.