Sardine
Adriatic
Abundance

Sardine
Adriatique
Abondance

Variation in abundance and size of the sardine *Sardina pilchardus* (Walbaum) in the eastern Adriatic

Gorenka SINOVČIĆ and Veronica ALEGRIA-HERNANDEZ

Department of Ichthyology and Fisheries, Institute of Oceanography and Fisheries, P.O.B. 500, 21000 Split, Croatia.

Received in revised form 09/07/96, accepted 17/07/96..

ABSTRACT

The catch per unit effort of the sardine, *Sardina pilchardus* (Walbaum, 1792), on the eastern Adriatic fishing grounds has greatly increased in recent years, notably during the past decade. We compared the relationship between annual mean total length and catch per unit effort (CPUE), as an index of population abundance. Decrease in fish size indicated the occurrence of a strong year class and led to an increase abundance in subsequent years. Long-term variations in catch per unit effort for 1963-1988 in relation to primary production, temperature, salinity and oxygen were analysed, with reference to the sardine, in the principal fishing grounds of the eastern part of the Adriatic. This correlation analysis confirmed the impact of these factors on abundance; a population increase was accompanied by a primary production increase and a mean water temperature decrease.

RÉSUMÉ

Variations de l'abondance et de la taille de la sardine *Sardina pilchardus* (Walbaum) dans l'Adriatique orientale.

Les prises par unité d'effort de la sardine *Sardina pilchardus* (Walbaum) dans les zones de pêche de l'Adriatique orientale ont augmenté récemment, en particulier pendant la dernière décennie. L'abondance de la population est mise en évidence dans ce travail à partir du rapport entre les variations annuelles de la longueur moyenne de la sardine et les prises par unité d'effort.
Une diminution de la taille du poisson révèle l'arrivée d'une forte classe d'âge et, en conséquence, une abondance accrue dans les années suivantes. Les variations à long terme des prises par unité d'effort pour la période 1963-1988 ont été analysées en relation avec la production primaire, la température, la salinité et l'oxygène. Les résultats confirment l'effet de ces paramètres sur l'abondance de la sardine. L'accroissement de l'abondance de la population de sardines a été accompagné d'une augmentation de la production primaire et d'une baisse de la température moyenne de l'eau.

Oceanologica Acta, 1997, **20**, 1, 201-206.

INTRODUCTION

The sardine, *Sardina pilchardus* (Walb.), is the most abundant species of the pelagic fish caught in the eastern Adriatic. Studies of the heterogeneity of the sardine population inhabiting the Adriatic showed differences in meristic, morphological, serological, and other characteristics between fish from the northern and from the middle Adriatic (Mužinić, 1954; Krajnović, 1968; Krajnović-Ozretić, 1975; Alegria-Hernandez, 1983*a*, 1985; Alegria-Hernandez *et al.*, 1986). Investigations of this species confirmed the assumption that the eastern Adriatic was inhabited by two sardine sub-populations, differing with regard to the direction, time and extent of their migrations (Mužinić, 1973; Škrivanić and Zavodnik, 1973).

Sardine reproduction in the Adriatic occurs in two well-defined centres which are separated by the Jabuka Pit (Piccinetti *et al.*, 1980, 1981; Regner *et al.*, 1981,

1984, 1987, 1988; Gamulin and Hure, 1983; Fig. 1). However, these two reproduction zones may on occasion be connected (Piccinetti *et al.*, 1981), when sardine biomass increases due to intensive spawning (Casavola *et al.*, 1986).

The two sardine sub-populations are for the most part exploited separately. In the northern Adriatic, where the depth does not reach 50 m, fish are caught by purse-seining and pelagic trawlers, with the former accounting for some 70% of the catch. In the middle Adriatic fishing grounds, where depths are greater than 50 m, with their centre in the Jabuka Pit (Fig. 1), purse-seines are mainly used for small pelagic fish.

From 1965 onwards sardine landings increased greatly without notable change in fishing effort (Alegria-Hernandez, 1983*b*, 1984, 1986). This may be related to an increase of the population itself, as inferred by Alegria-Hernandez (1983*b*, 1986), Regner *et al.*, (1984) and Sinovčić (1986, 1990), applying different methods. The conclusion was that the sardine was underexploited (Regner *et al.* 1984; Sinovčić, 1986, 1990). Populations have sometimes fluctuated greatly, and many attempts have been made to explain these fluctuations in a variety of ways (Županović, 1968; Pucher-Petković *et al.*, 1971; Vučetić and Kačić, 1973; Karlovac *et al.*, 1974; Alegria-Hernandez, 1984, 1986; Regner *et al.*, 1987). Population size variations may be due to the impact of different factors on the sardine life cycle, particularly during early stages up to recruitment.

This paper deals with long-term variations in catch per unit effort (CPUE), as an index of sardine population abundance, in relation to primary production, temperature, salinity and oxygen.

MATERIAL AND METHODS

Data on sardine yield and fishing effort in the open waters of the middle Adriatic (Fig. 1) were taken from the official statistics of the fishing companies for the period 1965-1988. Annual mean catch per unit effort was calculated from these data. Daily landing data from 1975 to 1985 were obtained directly from 10 fishing boats. These data were used to validate the annual mean value obtained from catch statistics. Hydrographic data were collected by the Physiographic Laboratory of the Institute of Oceanography and Fisheries, Split, and published by Buljan and Zore-Armanda (1979) and Zore-Armanda *et al.* (1991). Annual mean temperature, salinity and oxygen concentration data, measured between depths of 50 and 150 m (mainly at the stations in the middle Adriatic) were used. Data on primary production were collected from the same area by the Laboratory for Phytoplankton.

Mean catch per unit effort was correlated to the annual mean values of hydrographic parameters and to mean primary production with lags of two, three and four years. Assuming that the above factors could have an effect throughout the life span of the sardine, mean values were calculated by the following equation:

$$X = (X_n + X_{n-1} + X_{n-2})/3$$

$$\bar{X} = (X_n + X_{n-1} + X_{n-2} + X_{n-3})/4,$$

where n is the year of the estimated CPUE.

This mean was used for calculating the correlation with the catch per unit effort.

RESULTS

The data used for these observations were obtained from approximately 50% of the Croatian purse-seining commercial sardine catch (eastern part of the Adriatic, Fig. 1). In the small pelagic fish purse-seine catches during the 1965-1988 period, sardine proportions increased from 50% in 1965 to 90% in 1988. It should be pointed out that the fishing effort was concentrated on the population of sardines – commercially the most important species.

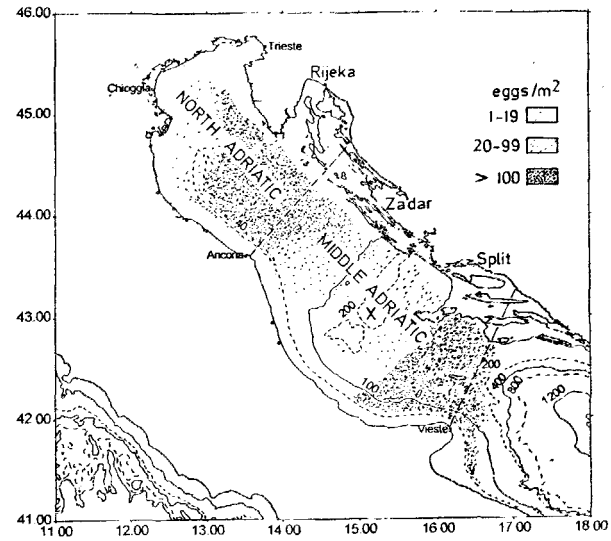

Figure 1

Fishing grounds and spawning area (egg distribution-according to Hure and Gamulin, 1983) of the sardine, Sardina pilchardus *(Walb.) separated by the Jabuka Pit (x).*

The mean CPUE for 1975-1985 broadly agreed with the mean catch per day calculated from the daily landings. Results proved highly reliable ($r^2 = 0.999$). CPUE is considered to be a good indicator of abundance in the exploited fish population. According to this indicator, the sardine population shows a trend towards continuous increase, particularly during 1980-1988 (Fig. 2), with fluctuations which may be indicative of the year classes' strength. Abundance suddenly increased in 1967, possibly indicating a strong year class, and remained at the same level until 1970, when a slight decrease was recorded. Thereafter, together with an overall trend of constant increase, drops were recorded in 1974, 1979 and 1988.

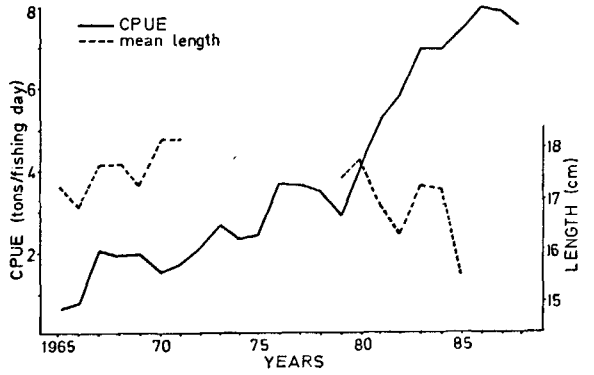

Figure 2

Fluctuations in catch per unit effort (CPUE) and mean length of sardine in the middle Adriatic from 1965 to 1988.

Data on mean sardine length are not complete from 1972 to 1978. One group of data refers to a mean length from 1965 to 1971 of between 17.1 and 18.3 cm, with relatively small variation (Mužinić, 1974). In the 1979-1985 period, smaller fish were caught than in the preceding period, and showed a tendency to decrease, ranging between 17.8 cm in 1979 and 15.5 cm in 1985.

Specimens of 15.5 cm mean length were three years old (Sinovčić, 1986). Correlation between these aspects of population dynamics is low and not significant. Sudden reductions in mean length in 1966, 1969, 1982, 1985 and most probably 1977, were indicative of the predominance of the younger age class in sardine stock, reflecting a large recruitment of the three-year old class. This allowed strong recruitment, since sardine stocks were considerably larger after these years.

Catch per unit effort for the sardine was significantly correlated to mean primary production (Fig. 3). The correlation is strong if a three-year lag between sardine CPUE and mean primary production is taken into consideration.

Changes in population abundance in successive years have been related to variations in hydrographic conditions (Tab. 1). It is believed that the effects of hydrological parameters in certain years reflect upon the catch per unit effort, as an indicator of sardine population abundance, with a lag of two to three years.

Table 1

Correlation coefficient between CPUE and different values of primary production and some abiotic factors (temperature, salinity, oxygen content) from the middle Adriatic in 1965-1988.

Factors	A	B	C	D
Primary production	0.796*	0.697*	0.881*	0.896*
Water temperature	−0.368*	−0.595*	−0.558*	−0.716*
Salinity	0.150	0.262	0.409*	0.264
Oxygen content	−0.062	−0.040	−0.186	−0.103

* significant ($p < 0.05$)
A: value at the year of $n - 3$; (n is the years when CPUE was estimated);
B: value at the year of $n - 4$;
C: mean value of the years n, $(n - 1)$ and $(n - 2)$;
D: mean value of the years n, $(n - 1)$, $(n - 2)$ and $(n - 3)$.

The correlation between mean temperature and CPUE is negative. The best and most significant correlation was obtained for the three-year interval. Correlations between temperature and CPUE were calculated for all three years and for a four-year period (Fig. 4). Results show significant correlation, particularly for the four-year period.

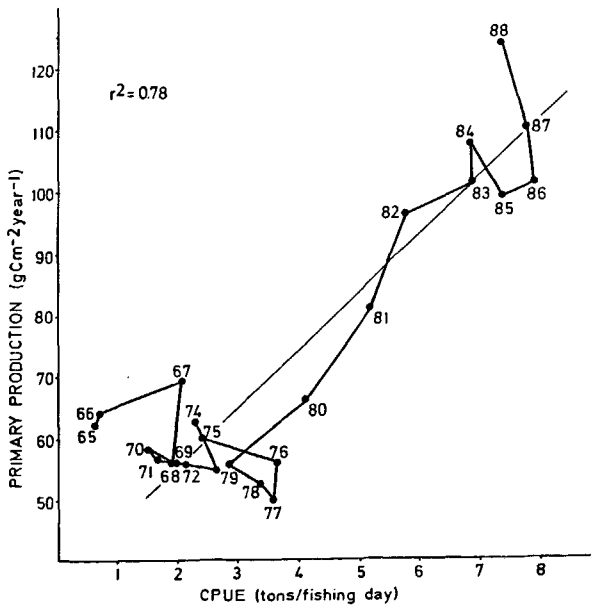

Figure 3

Relationship between sardine catch per unit effort (CPUE) and mean primary production in the middle Adriatic from 1965 to 1988. Primary production mean = in years: $[n + (n - 1) + (n - 2)]/3$.

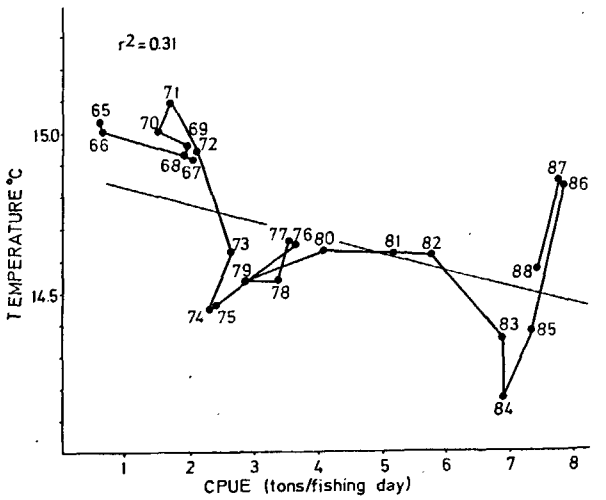

Figure 4

Relationship between sardine catch per unit effort (CPUE) and mean sea water temperature in the middle Adriatic from 1965 to 1988. Temperature mean = in years: $[n + (n - 1) + (n - 2)]/3$.

The correlation between sea water salinity and CPUE is positive to a certain extent, but not significant. The only exception is the three-year mean salinity (Fig. 5). This

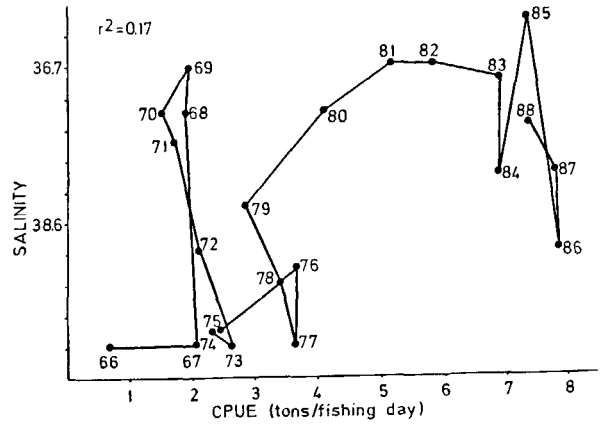

Figure 5

Relationship between sardine catch per unit effort (CPUE) and mean salinity in the middle Adriatic from 1965 to 1988. Salinity mean = in years: $[n + (n-1) + (n-2)]/3$.

correlation probably refers to the beginning of the first maturation of sardine gonads.

The available data did not offer any reliable conclusion as to the actual impact of oxygen concentration on catch per unit effort fluctuations or on sardine population abundance (Tab. 1).

DISCUSSION

Variations in population increase and vulnerability depend on the effects of different physiological changes and environmental factors affecting consecutive stages of fish life, particularly during spawning and early developmental stages, when high larval and postlarval mortality occurs.

Many authors have attempted to establish a relationship between the fluctuations in small pelagic fish catches and certain biotic factors (Vučetić and Kačić, 1973, Marasović *et al.*, 1988) or climatic and hydrological factors (Županović, 1968; Pucher-Petković *et al.*, 1971; Pucher-Petković and Zore-Armanda, 1973; Karlovac *et al.*, 1974) in the Adriatic.

The mean length of all the first matured specimens was 14.0 cm, corresponding to two years of age (Sinovčić, 1984). Maturation begins in the late summer and early autumn and spawning takes place in winter, extending to early spring (Mužinić, 1979; Sinovčić, 1983, 1983-1984). The spawning of the sardine in the Adriatic occurs mainly within two well-defined centres, one along Dugi Otok island to the north of the Jabuka Pit and the other to the south, which is our study area (Fig. 1). Both centres are located in open waters. In our study area, sardine spawn at 60-150 m depth at temperatures between 12.5 °C and 19.2 °C and salinities between 37.00 and 38.70 (Karlovac *et al.*, 1974). The ranges of hydrographic conditions, reported by Regner *et al.* (1988), are less wide – with temperatures between 11 °C and 15 °C at the margins of the frontal zones of the middle Adriatic; here, production is relatively higher. A maximum number of sardine eggs were recorded at 12.1 °C-13.9 °C and 38.57-38.71 salinity (Regner *et al.*, 1987).

Decrease in the mean length of fish caught presumably signifies a large recruitment of young year classes, since it has been observed that a decrease in mean length in the sardine population results in a catch increase – *i.e.* a catch per unit effort increase – several years later. Fish in the fourth- and fifth-year classes (3+ and 4+) dominated in the catches in the eastern Adriatic (Sinovčić, 1985,1986). Reduced mean length in catches from the open middle Adriatic waters was observed in 1947-1955 (Mužinić, 1974), dropping during that period to 16.5 cm. Each reduction in length was followed by a catch increase (Fig. 2).

Even though primary production may be expected to have a strong impact on the early developmental stage of a defined year class, the correlation between primary production in the year of the larval stage and CPUE three or four years later was shown to be poorer than that between the constant primary production effect and catch per unit effort. Thus, primary production is the first step of food source affecting the sardine population throughout its life span, and particularly during the period of rapid growth up to the adult stage (Sinovčić, 1985, 1986, 1990).

Pucher-Petković *et al.* (1971) established that the catch of small pelagic fish in the eastern Mediterranean followed climatic changes, with a three-year lag. The relationship between sardine concentration in the middle Adriatic and the same factors showed the same variations at the same intervals, which were taken to be usable for catch-forecasting. Pucher-Petković and Zore-Armanda (1973), and Karlovac *et al.* (1974) came to the same conclusion, taking a three-year interval to be a quite appropriate statistical average for secondary production fluctuations lagging behind primary production in the Adriatic. Primary production is followed by fluctuations in the quantity of eggs, larvae and postlarvae and their survival in the middle Adriatic.

The most productive season in the 1962-1971 period was spring, when fish were already spent, creating conditions that were presumably advantageous for larval and postlarval survival (Karlovac *et al.*, 1974). This trend towards intensified spring production continued during 1980s (Pucher-Petković, pers. comm.): this finding is in agreement with the results of the present study.

A sudden increase in production in the coastal area of the eastern part of the Adriatic was recorded for the first time as early as in 1970, with the same process being recorded in the open sea some ten years later. Increased phytoplankton biomass and primary production have been recorded, together with an increase in small pelagic fish (Marasović *et al.*, 1988).

The negative and most significant correlation between catch per unit effort and mean temperature for the three-year period suggests that temperature greatly affects the sardine during spawning. The impact of this parameter was observed throughout all developmental stages of sardine up to the age of three years (2+), when all specimens had reproduced for the first time (Sinovčić, 1984), and up to

the four-year stage (3+) when the sardine dominated in the catches (Sinovčić, 1985, 1986). The results of correlations between temperature and catch per unit effort for all three years and for the four-year period (Fig. 4) show significant correlation, particularly for the four-year interval.

Increase of the catch per unit effort, expressed as an increase in sardine catches in the middle Adriatic (particularly after 1980) may be due to an increase in population biomass, but may also be due to the increased vulnerability of the species presumably as a consequence of certain environmental changes. For the past decade, Zore-Armanda *et al.* (1991) have established certain climatic changes, together with some changes in the environmental properties of the Adriatic Sea.

CONCLUSION

Several factors have been shown to be significantly related to fluctuations in the catch per unit effort concerning the sardine population in the middle Adriatic. Temperature and other hydrographic factors are correlated with primary production, directly affecting the size and variation of a population. However, the degree of correlation of these factors may vary.

There is no doubt, however, that observed factors are not the only ones that might account for abundance fluctuations in the sardine population. This is particularly true in the case of sudden increase that has occurred over the past ten years. Presumably, certain individual and population factors also determine year class strength and recruitment.

REFERENCES

Alegria-Hernandez V. (1983*a*). A comparison of length-weight relationship in sardine *Sardina pilchardus* (Walb.) from the northern and central Adriatic fishing grounds, *Rapp. Comm. int. Mer Médit.* **28**, 5, 25-26.

Alegria-Hernandez V. (1983*b*). Assessment of pelagic fish abundance along the eastern Adriatic Sea coast with special regard to sardine, *Sardina pilchardus* (Walb.) population, *Acta Adriat.* **24**, 1/2, 55-95.

Alegria-Hernandez V. (1984). Aplication of production model to the eastern Adriatic sardine, *Sardina pilchardus* (Walb.) population, *FAO Fish. Rep.* **290**, 191-193.

Alegria-Hernandez V. (1985). A contribution to the study of heterogeneity of the Adriatic sardine, *Sardina pilchardus* (Walb.) population, *Acta Adriat.* **26**, 2, 109-122.

Alegria-Hernandez V. (1986). Catch per unit effort as an index of sardine, *Sardina pilchardus* (Walb.) distribution changes along the eastern Adriatic, *FAO Fish. Rep.* **345**, 127-136.

Alegria-Hernandez V., I. Jardas, G. Sinovčić (1986). Observation on the differences between sardine, *Sardina pilchardus* (Walb.) subpopulations from the eastern Adriatic, *FAO Fish. Rep.* **345**, 137-152.

Buljan M., M. Zore-Armanda (1979). Hydrographic properties of the Adriatic Sea in the period from 1965 through 1970. *Acta Adriat.* **20**, 1-2, 1-368.

Casavola N., G. Marano, L. Furlan, M. Specchi, C. Piccinetti, G. Piccinetti-Manfrin (1986). Considération sur la distribution des clupeiformes: *Engraulis encrasicolus* et *Sardina pilchardus* en Adriatique, *FAO Fish. Rep.* **354**, 153-155.

Gamulin T., J. Hure (1983). The spawning and spawning areas of pelagic fishes in the Adriatic Sea (in Croatian), *Acta Adriat.* **24**, 97-131.

Karlovac J., T. Pucher-Petković, T. Vučetić, M. Zore-Armanda (1974). Evaluation of biological resources in the Adriatic Sea based on plankton investigations (in Croatian), *Acta Adriat.* **16**, 9, 157-184.

Krajnović M. (1968) . A serological approach to the population analysis of the Adriatic sardine *Clupea pilchardus* (Walb.), *Rev. int. Océanogr. Méd.* **10**, 69-74.

Krajnović-Ozretić M. (1975). Application of the cluster analysis to the population studies of the Adriatic sardine, *Sardina pilchardus* (Walb.), *Biosistematika* **1**, 1, 15-29.

Marasović I., T. Pucher-Petković, V. Alegria-Hernandez (1988). Relationship between phytoplankton productivity and *Sardina pilchardus* catch in the middle Adriatic, *FAO Fish. Rep.* **394**, 121-126.

Mužinić R. (1954). Contribution à l'étude de l'écologie de la sardine, *Sardina pilchardus* (Walb.) dans l' Adriatique orientale, *Acta Adriat.* **5**, 10, 239-457.

Mužinić R. (1973) . Migrations of adult sardines in the central Adriatic, *Neth. J. Sea Res.* **7**, 19-30.

Mužinić R. (1974). On the spatial and temporal characteristics of some pelagic resources of the Adriatic (in Croatian), *Acta Adriat.* **16**, 16, 251-304.

Mužinić R. (1979). On some pelagic fishes in the mid-Dalmatian island region (in Croatian), *Acta Biologica* **8**, 1-10, 123-176.

Piccinetti C., S. Regner, M. Specchi (1980). Etat des stocks d'anchois et de sardine en Adriatique, *FAO Fish. Rep.* **239**, 43-52.

Piccinetti C., S. Regner, M. Specchi (1981). Distribution des oeufs de sardine en Adriatique, *Rapp. Comm. int. Mer Médit.* **27**, 5, 167-170.

Pucher-Petković T., M. Zore-Armanda (1973). Essai d'évaluation et pronostic de la production en fonction des facteurs du milieu dans l'Adriatique, *Acta Adriat.* **15**, 1, 1-32.

Pucher-Petković T., M. Zore-Armanda, I. Kačić (1971). Primary and secondary production of the middle Adriatic in relation to climatic factors, *Thalassia Jugosl.* **7**, 1, 301-311.

Regner S., C. Piccinetti, M. Specchi, G. Sinovčić (1981). Preliminary statistical analysis of sardine stock estimation from data obtained by egg surveys, *FAO Fish.Rep.* **253**, 143-154.

Regner S., C. Piccinetti, M. Specchi (1984). Estimate of spawning biomass of sardine in the northern and central Adriatic from 1979 to 1982 by means of eggs surveys, *FAO Fish. Rep.* **290**, 223-232.

Regner S., D. Regner, I. Marasović, F. Kršinić (1987). Spawning of sardine, *Sardina pilchardus* (Walb.) in the Adriatic under upwelling conditions, *Acta Adriat.* **28**, 1-2, 161-198.

Regner S., G. Piccinetti-Manfrin, C. Piccinetti (1988). The spawning of the sardine, *Sardina pilchardus* (Walb.) in the Adriatic as related to the distribution of temperature, *FAO Fish. Rep.* **394**, 127-132.

Sinovčić G. (1983). The fecundity-age relationship of sardine, *Sardina pilchardus* (Walb.) in the Central Adriatic, *Rap. Comm. int. Mer Médit.* **28**, 5, 31-32.

Sinovčić G. (1983-84). Fecundity of sardine, *Sardina pilchardus* (Walb.) in the Central Adriatic, *Nova Thalassia* **6** (Suppl.), 351-363.

Sinovčić G. (1984). Summary of biological parameters of sardine, *Sardina pilchardus* (Walb.) from the Central Adriatic, *FAO Fish., Rep.* **290**, 147-148.

Sinovčić G. (1985). Observation on age and growth of sardine, *Sardina pilchardus* (Walb.) in the middle Adriatic, *Rapp. Comm. int. Mer Médit.* **29**, 8, 81-82.

Sinovčić G. (1986). Estimation of growth, mortality, production and stock size of sardine, *Sardina pilchardus* (Walb.) from the middle Adriatic, *Acta Adriat.* **27**, 1-2, 67-74.

Sinovčić G. (1990). Stock size assessment of sardine, *Sardina pilchardus* (Walb.) in the middle Adriatic, *Acta Adriat.* **32**, 2, 869-884.

Škrivanić A., D. Zavodnik (1973). Migrations of the sardine, Sardina pilchardus in relation to hydrographical conditions of the Adriatic sea, *Neth. J. Sea Res.* **7**, 7-18.

Vučetić T., I. Kačić (1973). Seasonal and annual fluctuations of zooplankton and echo traces abundance in the fishing ground of the Central Adriatic, *GFCM Stud. Rev.* **53**, 19-38.

Zore-Armanda M., M. Bone, V. Dadić, M. Morović, D. Ratković, L. Stojanoski, I. Vukadin (1991). Hydrographic properties of the Adriatic Sea in the period from 1971 through 1983, *Acta Adriat.* **31**, 1, 5-547.

Županović S. (1968). On the causes of fluctuations in sardine catches along the eastern coast of the Adriatic Sea (in Croatian), *Anali Jadranskog Instituta* **4**, 401-491.