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INTRODUCTION

Long ago it was observed that sardine catch shows the periodical fluctuations, in the whole area of its distribution. Since sardine has an important role in the fisheries of many countries, it is understandable that fluctuations of catch have been the subject of many investigations in order to find their cause. So Anadon (1954) stated that the crises of sardine catch along the north-eastern coast of Spain, were mostly connected with the long-term changes in the environment. Županović (1968), analysing sardine catch along the eastern Adriatic coast for the interval from 1835 to 1960, has found the fluctuations with the period of about 8,1 years. Besides that, according to his opinion basic period, he has mentioned the cycles of 3, 11, 17,5, 23, 37, and 57 years. He has supposed that the fluctuations are affected by ingressions of the Mediterranean water in the Adriatic (Buljan, 1953a), and by cold winters preceding the years of good catch. Furthermore, Županović (1968) has found that sardine catch fluctuations in the Adriatic coincide, not only with the fluctuations of catch in the other areas of its distribution, but also with the catch of the other sardine species (Japanese, Californian etc.). By basing it on this he has concluded, just like some other authors (Uda, 1959; Andreu, 1962, according to Županović, 1968), that the cause of sardine catch fluctuations should be studied in relation to world-wide weather conditions and fluctuations of the ocean currents.

Buljan (1953b) has shown that the Mediterranean water during the ingressions brings the increased quantity of nutrient salts into the Adriatic, what cause the favourable conditions for the organic production. These increases of the organic production he brings to the connection with the increase of the pelagic fish catch (Buljan 1968). Further investigations have shown (Zore-Armanda, 1970; Zore-Armanda et al., 1971; Pucher-Petković and Zore-Armanda, 1973) that gradients of the air pressure upon the eastern Mediterranean and the penetration of dry polar air, connected with the location of the large baric centres (Island cyclone and Syberian anticyclone), regulate the amount of advection of the Mediterranean water into the Adriatic. The increase of primary production, caused by ingressions, has a favourable influence on spawning and survival of the early stages of pelagic fish, what reflects on catch increase, about three years later. This confirms the presumptions of Uda, Andreu and Županović that the causes of sardine catch fluctuations have to be searched in the planetary climatic and hydrographyc changes.

Solar activity is one of the factors which is supposed to be of influence on the climatic changes of planetary dimensions. Some authors (Le Danois, 1938; King, 1973; Roberts and Olson, 1973; Kowalik and Wróblewski, 1973) have found the relation between changes of meteorological and hydrographycal factors and solar activity. On the other hand, Ljungman (1879), according to Le Danois (1938), and Jensen (1927) have found the correlation between herring catch and sun-spot numbers. Županović (1968) has also connected the cold winters, preceding good sardine catch, with negative correlation found (Elton, 1924; Adams and Nicholson, 1933, according to Allee et al., 1950) between the sun-spot numbers and annual temperatures.

Therefore in this paper, we have done spectral analyses of data of sun-spot numbers and long-term data of sardine catch along the eastern Adriatic coast, in order to investigate whether the relation between them exists.

METHODS AND MATERIAL

One of the methods for the investigation of the connection between time series data is their decomposition on the simple harmonic functions. For such investigation we used Tukey's method (1949), according to Gohin (1960). According to that method if z(t) are obtained by subtracting the mean from the original values of the observed interval, they could be expressed by the relation:

$$z(t) = \sum_{p=o}^{p=\infty} a_p \cos \left[\frac{2\Pi p}{\Theta} t + \varphi_p \right], \qquad (1)$$

where Θ is basic period, and a_p are coefficients of the form:

$$a_p^2 = \frac{4}{\Theta} \int_0^{\frac{\Theta}{2}} 2R(\tau) \cos \frac{2\Pi p}{\Theta} \tau \, d\tau. \qquad (2)$$

R (τ) is autocovariance function:

$$R(\tau) = \lim_{\Theta \to \infty} \frac{1}{\Theta} \int_0^{\Theta} z(t) \, z(t + \tau) \, dt. \qquad (3)$$

In the practice, numerical integration of relation (2) is done:

$$a_p^2 = \frac{2}{m} \left[R(O) + (-1)^p \cdot R(m\Delta t) + 2 \sum_{q=1}^{q=m-1} R(q\Delta t) \cdot \cos \frac{\Pi pq}{m} \right]. \qquad (4)$$

m in the relation (4) is calculated to satisfy the significance level of 95% according to the following equation:

$$\varepsilon \cong 85 - 600 \frac{m}{N} = 0. \tag{5}$$

N is the total number of data.

Then the filtration of obtained values a_p^2 was done by Hamming's filter, and the spectrum of the following form was considered:

$$W_p = \frac{2m\Delta t}{2\Pi} \left[0{,}23 \cdot (a_{p+1}^2 + a_{p-1}^2) + 0{,}54 a_p^2 \right]. \tag{6}$$

Distribution of W_p value as a function of periods of simple harmonic function is spectral density, e.g. distribution of squares of harmonic function amplitudes to which time series of some values are decomposed.

In that way the set of sardine catch data along the eastern Adriatic coast from 1873 to 1972 was analysed. The data from 1873 to 1960 are taken from Županović (1968), and from 1961 to 1972 from the statistical bulletins of SFRJ.

According to the source, these data may be divided to the following time intervals:

1. 1873 — 1911 sardine catch along the eastern Adriatic coast
2. 1912 — 1929 quantity of sardine sold in the fishmarket in Trieste
3. 1930 — 1940 sardine catch along the eastern Adriatic coast
4. 1941 — 1946 quantity of sardine sold in the fishmarket in Trieste
5. 1947 — 1972 sardine catch along the eastern Adriatic coast.

The absolute values of the sold sardine quantity in the fishmarket in Trieste are not comparable with the data of catch. Therefore, we calculated the average for each of five intervals, and we relativised them according to the relation:

$$Z(t) = \frac{z(t)}{S_i}; i = 1{,}5, \tag{7}$$

where S_i is the average for i-th interval.

It also may be supposed that fishing efficiency and somehow fishing effort have increased in the interval from the World War II up to now. That is visible from trend of + 102 tons per year, which we calculated for the interval from 1947 to 1969 including. The trend was calculated by means of the least squares method and the average was aproximated by relation $S_5 = 8345 + + 102 (x - 1958)$.

The spectral analysis of absolute data of sardine catch was done, as well as those relativised according to the relation (7).

In our further consideration we started from the supposition that the fluctuations of sardine catch were mainly affected by fluctuations of the stock. That supposition certainly includes errors, caused by the influence of socialy-economical and technological factors on the catch, possible errors of statistical data etc.

Data of solar activity (the annual averages of Wolf's number) from 1749 to 1972. were analysed too.*

The calculations were done on terminal of UNIVAC 1106 in Split.

RESULTS

For the calculation of spectral distribution the intervals for the significance level of 95%, according to relation (5), were determined. For the both sets of sardine catch data they were 14, and for solar activity 32 years. The functions of autocovariance were calculated even for longer intervals (for sardine catch 40, and for solar activity 100 years), but the distribution obtained outside the significance interval may be taken into the consideration only tentatively.

The autocovariance functions are shown on the Fig. 1. Absolute data of catch show, within the significant interval, two basic periods of about 8 and

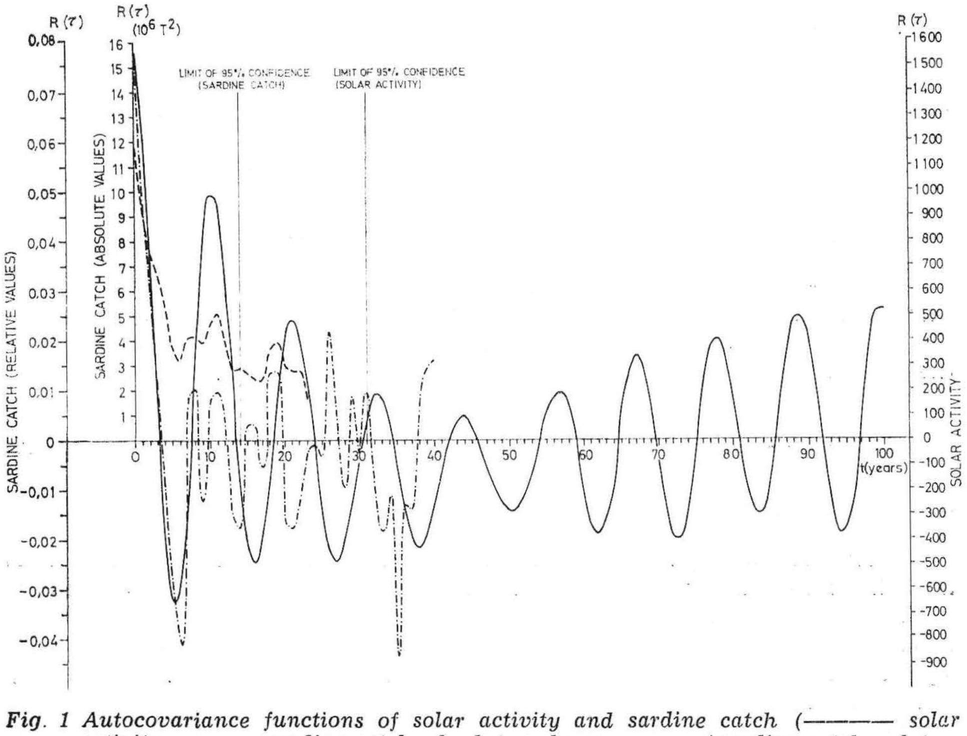

Fig. 1 Autocovariance functions of solar activity and sardine catch (——— solar activity; — — — sardine catch, absolute values; — . — . — sardine catch, relative values).

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* Data for the interval from 1749 to 1943 were taken from Kiepenheuer (1954), and for the interval from 1944 to 1964 from Waldmeier (1965). Data from 1965 to 1972 were taken from Astronomische Mitteilungen der Eidgenossischen Sternwaste, Zürich (numbers from 1966 to 1972).

11 years, with the eleven-year period being more significant. Out of that interval, period of about 19 years stands out. After the twenty-third year, values of autocovariance function are negative and for practical reason, they are not shown on the figure. Relativised data have similar distribution, but the period of eight years is as significant as that of eleven. Outside the confidence limit, beside the nineteen-year period, the periods of about 26 and 40 years stand out. Solar activity shows much more regular oscillations with characteristic period of about 11 years, and all other periods are its multiples. The increase of maxima from 44-th year to the end of a hundred-year interval, was not the consequence of the existence of the longer period, but it is probably due to the decreased number of data.

On the bases of obtained autocovariances, spectral density was calculated (Fig. 2.). The shape of the both curves shows that for both sets of sardine catch data the periods of about 8 and 11 years, which were obtained by calculation of autocovariance, could not be distinguished. It was caused by the position of these periods near the limit of the significant interval, where the resolution is very low. However, the shape of curves for both sets of data shows maximal concetration of energy in that part of spectra, where these periods are situated. To check that, we calculated spectral density for 22-year interval, although it did not satisfy the confidence level of 95%. That calculation showed maximal amplitudes concentrated within 8—11 years interval. From these three curves of spectral distribution of catch, one can see that two less important periods of 2,3 and 3,5 years stand out.

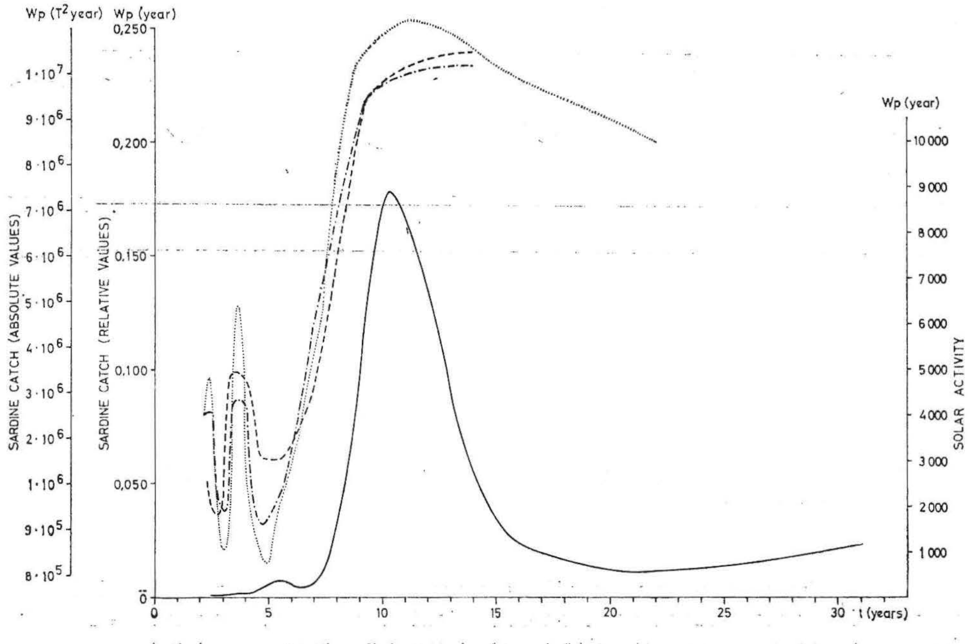

Fig. 2 The spectral distribution of solar activity and sardine catch (——— solar activity; — — — sardine catch, absolute values; — . — . — sardine catch, relative values; . . . . sardine catch, relative values for m=22).

Spectral distribution of solar activity has shown, as it might have been expected, that the most significant is the harmonic with a period of about 11 years. A less significant harmonic of 5,6-year period appears too.

The existence of significant eleven-year period of both sardine catch and solar activity, points out their mutual relation. Similar shapes of spectral density curves of the both sets of data show that too.

After having concluded that in sardine catch and solar activity the most significant were the periods of about 11 years, e.g. that the relation between them exists, we tried to investigate whether the phase lag between them exists. That was done by calculating the lagged coefficients of the linear correlation between relativised data of catch and solar activity from 1 to 39 years (Fig. 3.). Phase lag was found to be 2-3 years.

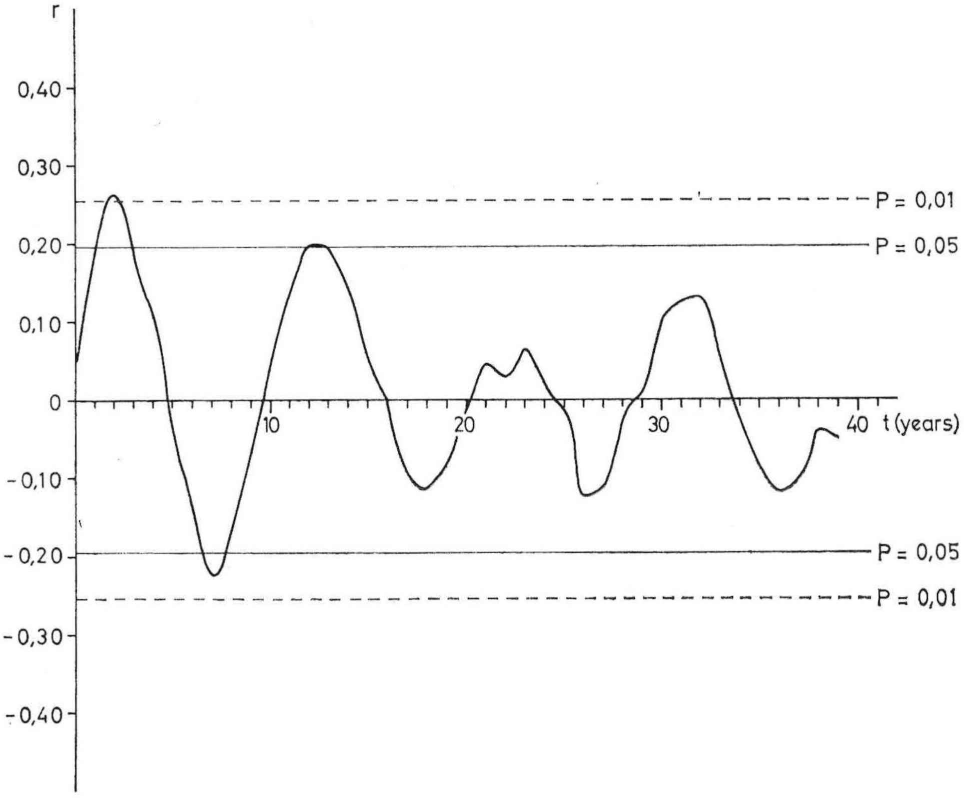

Fig. 3 Distribution of correlation cofficients between solar activity and sardine catch (relative values).

The highest correlation coefficient was obtained for two-year lag and it is +0,264, what according to t-test is significant for the confidence level of 99%. The appearance of correlation coefficient maxima in the intervals from 9 to 11 years could be one more argument that the relation between solar activity and sardine stock fluctuations really exists. Relatively low, although significant maximal value of correlation coefficient is probably due to the existence of the other harmonics, particularly that one of 8-year period, which is almost as significant as that of 11 years.

DISCUSSION

Long-term fluctuations of sardine catch on the eastern Adriatic coast, according to our results, could be approximated by the sum of harmonics with the periods of 2,3, 3,5, about 8 and 11 years. The periods that we found, fairly well coincide with those found by Županović (1968), and the differences could be explained by using the different methods. The main difference is, that Županović estimated the 8,1-year period to be most significant, while our results show that the period of eleven is as, or even more significant than that of 8 years.

We have to emphasize, once more, that the set of sardine catch data is not homogeneus, and insufficient reliability of one part has to be taken into the consideration. That especially refers to the data of quantity of sardine sold in the fishmarket in Trieste, and somehow to the interval from 1873 to 1911. Therefore, we have to discuss whether the obtained results are real or occasional. We tried to eliminate the insecurity of statistical data by subtracting the means from the original values for each group of data e.g. to relativise them. Regularity of distribution of correlation coefficients between sardine catch and solar activity (Fig. 3.) shows that we succeded in our attempt, because there is small possibility for such distribution to be occasional. On the other hand, obtained periods of sardine catch fluctuations very well coincide with the periods of fluctuations of the other phenomena, as it is shown on the table 1.

From table 1, it can be seen that in almost all mentioned phenomena, the periods of 8 and 11 years stand out. After all, it must be mentioned that almost all these periods were obtained by different methods. That confirms our opinion, that obtained spectral density of sardine catch is not occasional. The influence of the factors which cause such periodicity is so strong, that even our data including all insufficiencies, show it.

The found connection between fluctuations of sardine catch and solar activity, could be explained by the influence of solar activity on the changes in the atmosphere and marine environment. Namely, results of Zore-Armanda (1970), Zore-Armanda et al. (1971) and Pucher-Petković and Zore-Armanda (1973) show that the fluctuations of the pelagic fish and sardine catch too (which participated in the period from 1957 to 1972 on the average 52,0%), depend upon climatic changes on a part of northern hemisphere. Fairly good coincidence of our function of autocovariance of relativised data of sardine catch with the same function for the mean January air pressure values in the centre of Asiatic anticyclone (Sorkina and Penjkov, 1973), confirms it. There are also numerous recently published papers, which show that changes of solar activity affect the climatic changes on the Earth. According to Roberts and Olson (1973), 300-mb troughs in Gulf of Alaska are formed four days after the geomagnetic storms. King (1973) has found that extremely wet springs in England appear at

Table 1. The periods of fluctuations of some climatic, hydrographyc and biological factors

Parameter	Periods (years)							Author
Herring catch (Denmark)			3,7		11			Jensen (1927)
Growth rings of *Abies* and *Pinus* (Sweden)		2,75		8,5	11		23	Erlandsson (1936) according to Anadon (1954)
Salinity (Adriatic)				9				Buljan (1953a)
Air pressure (Trieste)	2,3	3,0	4,0	8	11,2		21,3	Polli (1955)
Air pressure (Venice)	2,1	2,8	4	8	11	16		Polli (1955)
Sea level (Germany)	2	2,9	4	8	11,2	16,5		Polli (1955)
Air temperature (Trieste)	2	2,9	4	8	11,2	16,5		Polli (1955)
Air temperature (Berlin)				8	10	15		Trepinska (1971)
Air temperature (Krakow)				7,7	10,1—10,9	14,6		Trepinska (1971)
Sea level (Baltic)		3			11			Kowalik & Wróblewski (1973)
Air pressure (Asiatic anticyclone)		3		7	11	18	22	Sorkina & Penjkov (1973)
Sardine catch	2,3	3,5		8	11	19*	27*	Regner & Gačić

* Outside the limit of 95% confidence level

minima, and extremely dry at maxima of sun-spots. According to him, dry winters in North Africa and India are caused by strong solar activity. On the simposium »Possible Relationships between Solar Activity and Meteorological Phenomena« (Anonymous, 1973) was concluded that there were enough evidences which proved that the relation between solar activity and climate exists, but that the mechanism of interaction is not yet clear. Furthermore, the long-term fluctuations caused by periodical changes of solar activity, seems to appear in the marine environment too. Le Danois (1938) has shown that the transgressions of Atlantic water depend, between others, on the long-term changes of solar activity. Kowalik and Wróblewski (1973) have found that long-term changes of the Baltic sea level, show the characteristic period of 11 years, which is connected with the solar activity.

According to these facts, it may be consequently supposed, that through the climatic factors, periodical changes of solar activity also affect the ingressions of the Mediterranean water into the Adriatic, which cause changes of the organic production too. The phase lag of sardine catch of 2-3 years in relation to the solar activity which we found, and which coincides good with the phase lag between the maxima of pelagic fish catch and climatic and hydrographic factors (Zore-Armanda, 1970; Zore-Armanda et al., 1971; Pucher-Petković and Zore-Armanda, 1973), supports that.

It could also be confirmed by relatively large quantity of sardine's eggs in plankton in the Central Adriatic during the spawning season 1968/69 and 1969/70 (K a r l o v a c, 1973), when it was the maximum of the last (twentieth) sun's cycle. Two years later (1971—1972) considerable increase of sardine catch happened. The cause of that increase might have been the favourable conditions for the survival of the early stages of sardine, because of the influence of climatic and hydrographic factors on the increase of the organic production in the Adriatic.

In fact, the phase lag would represent time interval which needs the year-class 0, from the year of the active sun to prevail in the catch. Phase lag of 2-3 years very well coincides with the data of FAO sinopsis, that year-classes II and III are dominant in the commercial catch of sardine in the Adriatic (L a r r a ñ e t a, 1960). However, M u ž i n i ć S. (1936) has found that in 1931 younger year-classes (II and III) were dominant in the coastal region of the central Adriatic, and the older (III, IV and V) at the open sea. According to M u ž i n i ć R. (1954) in the interval from 1947 to 1952 too, the older year-classes (IV-VI) predominated at the open sea. The differences between the year-class distribution obtained by quoted authors and phase lag obtained by us, are probably due to the fact that obtained phase lag represents the mean age composition of sardine, for the whole eastern Adriatic coast, in a hundred-year interval.

However, except the solar activity, other factors also seem to affect the sardine catch fluctuations, what comes from the existence of the characteristic harmonics of 2,3, 3,5 and about 8 years, and from relatively low value of correlation coefficient ($r = +0,264$) between the solar activity and sardine catch.

Climatic factors might be the cause of even the other harmonics of sardine catch fluctuations, what is shown by the appearance of the similar periods of many atmospheric and hydrographic phenomena (Tab. 1.). Ž u p a n o v i ć (1968) considers that too, especially for the eight-year period.

CONCLUSIONS

By parallel spectral analysis and correlation of sardine catch data on the eastern Adriatic coast and solar activity, following results are obtained:

1. Sardine catch fluctuations and solar activity, have outstanding period of about eleven years. From that, it can be concluded that the connection between sardine catch fluctuations and solar activity exists. The found dependence of sardine catch upon the solar activity, can be explained by the influence of the sun on the periodical changes of climatic and hydrographic factors which, as it has been earlier proved, affect the organic production in the Adriatic.

2. Besides the eleven-year period, another almost so significant period of about eight years was found. Two less significant periods of 2,3 and 3,5 years also stand out. Nature of these periods we could not explain for the present.

3. The coefficients of linear correlation have shown that sardine catch in relation to the solar activity has the phase lag of 2—3 years. The highest correlation was obtained for the lag of two years ($r = +0,264$; $P < 0,01$). The

cause of its relatively low value, is probably the existence of the other significant harmonics of sardine catch, particularly that of eight years.

4. According to the results of our investigations, the increase of sardine catch, might be expected two or three years after maximum of solar activity, e.g. in the period of about 11 years. The outstanding of this period will not probably always be the same, and it will depend on superposition of all four harmonics obtained.

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FLUKTUACIJE ULOVA SRDELE NA ISTOČNOJ OBALI JADRANA I AKTIVNOST SUNCA

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KRATAK SADRŽAJ

Dosadašnja istraživanja fluktuacija ulova srdele i ostale plave ribe u Jadranu pokazala su da one zavise o promjenama klimatsko-hidrografskih faktora planetarnih razmjera. Pošto se za aktivnost sunca pretpostavlja da utječe na stanje u atmosferi i moru, u ovom smo radu pokušali ispitati da li postoji veza između fluktuacija ulova srdele u Jadranu i promjena sunčeve aktivnosti. U tu smo svrhu izvršili spektralnu analizu podataka o ulovu srdele na istočnoj obali Jadrana u intervalu od 1873. do 1972. i godišnjih srednjaka Wolfovog broja od 1749. do 1972. godine. Pri tome smo pošli od pretpostavke da su fluktuacije ulova srdele, uglavnom, odraz fluktuacija njezinog stocka.

Analizom funkcija autokovarijanse našli smo kod ulova srdele i kod sunčeve aktivnosti dobro izražene oscilacije s periodom od oko 11 godina (sl. 1). Kod ulova srdele ističu se još, gotovo isto tako značajne, oscilacije s periodom od oko 8 godina i dvije manje značajne od 3,5 i 2,3 godine. Postojanje izrazitih oscilacija s jedanaestogodišnjim periodom i sličnost krivulja spektralne raspodjele (sl. 2) ukazuje na vezu između aktivnosti sunca i fluktuacija ulova, a time i stocka srdele. Ta bi se povezanost mogla protumačiti utjecajem sunca na promjene klimatsko-hidrografskih faktora, za koje je već dokazano da djeluju na organsku produkciju, a time i na ulov ribe u Jadranu (Zore-Armanda, 1970; Zore-Armanda et al., 1971; Pucher-Petković i Zore-Armanda, 1973).

Da bismo ispitali da li postoji fazni pomak između ulova srdele i aktivnosti sunca i još jednom provjerili realnost nađene veze, izračunali smo koeficijente linearne korelacije za pomake od 1 do 39 godina. Raspodjela vrijednosti koeficijenata korelacije (sl. 3) je pokazala da ulov srdele ima fazno zakašnjenje od 2—3 godine u odnosu na aktivnost sunca. Ponavljanje maksimuma u intervalima od 9 do 11 godina još je jedna potvrda da se promjene aktivnosti sunca odražavaju na ulovu srdele. Najviši koeficijent korelacije, $r = +0{,}264$ dobijen je za pomak od dvije godine i statistički je značajan za razinu vjerojatnosti od 99%. Njegova relativno niska vrijednost pokazuje da na ulov, odnosno stock, srdele u Jadranu, osim promjena aktivnosti sunca, utječu i drugi faktori, čije se djelovanje očituje pojavom perioda od oko 8, 3,5 i 2,3 godina.