Iranian Journal of Fisheries Sciences 17(3) 443-457 2018
DOI: 10.22092/IJFS.2018.116611

Analysis and forecast of Pontic shad (*Alosa immaculata*) catch in the Danube River

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Received: August 2015 Accepted: February 2017

Abstract

The relationship between the Lower Danube River level and Romanian annual catches of Pontic shad (*Alosa immaculata*, Bennett 1835) were analyzed. For analysis of long term data on the Danube River water level and Pontic shad catch, combinations of different methods were applied using statistical programs, SPSS 13.0 and MATLAB 6. Periodograms, containing cyclic patterns, were obtained using Fourier analysis. Significant oscillations were determined with Fisher-Whittle's tests and residuals were calculated after subtracting these significant oscillations from the original signals. Autoregressive moving average (ARMA) models of residuals were finally applied. Results indicated that river water levels, and especially those in May, greatly explained the fluctuations of Pontic shad catch. Annual landings varied greatly and appeared to be cyclic. Varying river flow was considered to be one of the most important factors that cause fluctuations in the size of populations. Forecast indicates gradual increase of the catch in the next decade, followed by a decrease in other decades. Estimated as a vulnerable species of fish by the IUCN, development of the forecasting model of the future catch oscillations could be very helpful to regulate fishing efforts towards the sustainable use of stocks and species conservation.

Keywords: Fish catch, Water level, Oscillations, Model, Prediction

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[DOR: 20.1001.1.15622916.2018.17.3.1.3]

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Introduction

There are three species of the genus *Alosa* present in the north-western part of the Black Sea and only two of them migrate into the Danube River, with Pontic shad (*Alosa immaculata*, Bennett 1835) being the dominant one according to the abundance of migrants (Lenhardt *et al*., 2012). In the past, isolated individuals migrated for spawning into the Danube as far as to Budapest – 1650 km upstream (Bănărescu, 1964), but the construction of the Iron Gate hydroelectric power plants "Iron Gate I" (943 river km, built in 1972) and "Iron Gate II'' (863 river km, built in 1984) blocked shad migrating further upstream.

Pontic shad is the largest representative species of the family Clupeidae inhabiting the Black Sea (Kottelat and Freyhof, 2007). Widely spread throughout the Black and Azov Sea (Kolarov, 1991), distinguished from other two related species, (*Alosa tanaica* and *Alosa maeotica*), Pontic shad migrates for spawning into rivers: Danube, Dniepr, Dniestr, South Bug, Don and Kuban (Navodaru and Waldman, 2003; Kottelat and Freyhof, 2007). In the Danube River it migrates upriver to 864 km after the construction of the Iron Gate II hydroelectric plant (Navodaru and Waldman, 2003). The spawning season is from April to August and the trigger for spawning is water temperature above 15 ^{o}C (Navodaru and Waldman, 2003; Kottelat and Freyhof, 2007). Two populations have been distinguished in the Black Sea. The larger sized shads - eastern, and the smaller - western, enter the Danube River to spawn (Navodaru and Waldman, 2003).

The recent studies indicate that abundance of Pontic shad is constantly decreasing under anthropogenic pressure due to dam construction, habitat loss and fragmentation, exploitation, pollution, invasive species impact and climate change (Kottelat and Freyhof, 2007). Aggravating factors for the management are the poor quality of catch statistics and lack of fishing effort data on this species in the Danube River and Black Sea water. Conservation and management status differs among the Lower Danube Region (LDR) countries. Pontic shad is included on the IUCN Red List as vulnerable (VU) with population trends stated to decrease under anthropogenic pressure (IUCN, 2016). Accordingly, an understanding of the population dynamics of the Pontic shad in LDR is required for resource assessment and conservation.

Annual landings of Pontic shad vary greatly and appear to be cyclic, with several strong years being followed by several low ones (Navodaru and Waldman, 2003). Ivanov and Kolarov (1979) found negative correlation between catch of *A. immaculata* and 11 year solar cycles. Varying river flow is considered to be one of the most important factors that cause fluctuations in the populations, but so far the ratio of the annual class size and flow was not confirmed (Navodaru and Waldman, 2003). Therefore, development of the forecasting model of future catch oscillations could be very helpful to regulate fishing effort.

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In the last decades the solar activity were increasingly considered as having an important effect on the river hydrology and shad population size fluctuations. Different authors (Doan, 1945; Regner and Gačić, 1974; Kawasaki, 1992a, 1992b; Regner, 1996; Anderson, 1998; Baran *et al*., 2001; Klyashtorin, 2001; Guisande *et al.*, 2004; Han *et al.*, 2009; Gorski *et al.*, 2012; Lenhardt *et al.*, 2016; Rabuffetti *et al*., 2016), found a relationship between fluctuations in fish catch and natural cyclical climatic factors, as well as between the hydrological fluctuations of large rivers in the world, including the Danube River (Pekárova *et al*., 2003; Pekárova and Pekár, 2005). Historical data on catch and biological characteristics of fish species may provide valuable information on population dynamics (Myers *et al*., 1995; Han *et al*., 2009).

Therefore, the aim of this study was to analyze catch statistics of *A. immaculata* from the Danube River in Romania and long-term data series of Danube water level fluctuations and especially spring flooding pulse, to try to forecast future fluctuations in the catch, and to check the correlation found by Ivanov and Kolarov (1979) between the catch of *A. immaculata* and solar activity using longer series of data.

Materials and methods

The long data series on the annual catch of Pontic shad from the Romanian Danube River were gathered for 94 years (1920-2013) from different sources (Daia, 1926; Nicolescu-Duvaz and Nalbant, 1965; Kolarov, 1991) including FishStatPlus Database of FAO and Danube Delta National Institute, Romania fish catch data series.

Data on the water level of the Danube River were taken from the Hydrometeorological Service of the Republic of Serbia for 16 water gauge stations. Of these 16 stations only one station, Prahovo (861 r. km), lies downstream from Iron Gate dam II, in the area to which *A. immaculata* can reach during the migration period (Fig. 1).

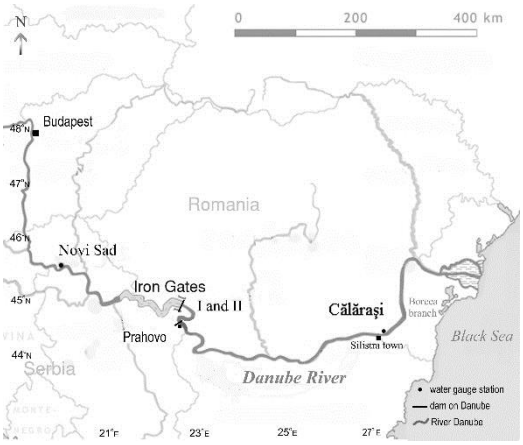


Figure 1: Study area.

To compare fluctuations of mean annual water levels between the upstream stations and stations situated in LDR, we took the data on water levels also from 1920 to 2013 from station No. 18, in Borcea branch near Călăraşi town, Romania (96 r. km), close to Silistra town at 371 Danube r. km (Fig. 1), which is the middle of the spawning sector river for shads.

Data on river levels from these two stations were compared with *A.*

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immaculata annual catches in the Danube and the adjacent sea from 1920 to 2013 years (Fig. 2).

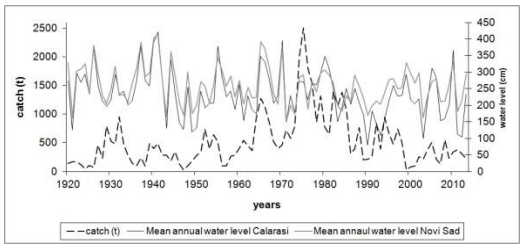


Figure 2: Fluctuations of mean annual Danube water level at Novi Sad and Călăraşi stations and fluctuation of *Alosa immaculata* annual catch.

Data on solar activity, expressed as Yearly Sun Spot Number (YSSN) were taken from the Solar Influence Data Center (www.sidc.be).

Basic methods used in this study comprised statistical data analysis of the Pontic shad catch and analysis of hydrological data (river level and water temperature) and mathematical modelling of the relationship of these key environmental driven factors and catch that may explain resource fluctuations, by combining different methods, and using statistical programs, SPSS 13.0 and MATLAB 6 (Lenhardt *et al.*, 2016).

We used spectral analyses to determine whether there are cyclic (deterministic) components in time series. Besides mean annual Danube River level data, we analyzed mean river level data in May, when the migration of *A. immaculata* reaches a peak.

Cross-correlation functions (CCF) have been used to analyze whether the functional connection exists between river water level and *A. immaculata* catch.

For the forecasts, we used a model which combines cyclic (deterministic) and random (stochastic) components of the analyzed sequences (Klyashtorin, 2001; Pekárova *et al*., 2003):

$$x_t = A_o + \sum_{i=1}^{m}\left[A_i \cos(\omega_i t) + B_i \sin(\omega_i t)\right] + ARMA + C + \varepsilon_t \quad (1),$$

Where x_t is the measured value in time t, A_o is basic amplitude i.e. signal mean value, A_i is amplitude of the i-th cosine component, B_i amplitude of the i-th sine component, ω_i is the frequency $\left(\frac{2\pi}{t_i}\right)$ of the i-th significant period determined by the periodogram, ARMA is the autoregressive component (Box and Jenkins, 1970; Anderson, 1971; Kashyap and Rao, 1976), C presents the regressive component of an external (exogenous impact) influence on the system, and ε_t is the pure stochastic component.

Harmonic (periodical) components of the model were obtained when ARMA and C were omitted from the formula (1). After excluding, components A_i and B_i were estimated by the formulae:

$$A_i = \frac{2}{N}\sum_{t=1}^{N} x_t \cos(\omega_i t) \quad (2),$$

$$B_i = \frac{2}{N}\sum_{t=1}^{N} x_t \sin(\omega_i t) \quad (3),$$

where x_t and N stand for the measured value and number of cyclic components, respectively. To separate cyclical from stochastic components in

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the analysed time series, we tested spectral densities obtained by Fisher–Whittle test (in the following text FW test) (Fisher, 1929; Whittle, 1952; Pekárova *et al.*, 2003) which distinguishes statistically significant *m* amplitudes. After that, harmonic reconstruction of measured data was made using only significant periodical components

$$x_t = A_o + \sum_{i=1}^{m} \left[A_i \cos(\omega_i t) + B_i \sin(\omega_i t)\right] \quad (4)$$

If we exclude the harmonic reconstructed signal from measured values, the residual represents the stochastic component of the time series analyzed.

The harmonic prediction part, for the following period *p*, can be approximated by the formula:

$$x_{N+p} = A_o + \sum_{i=1}^{m} \{A_i \cos[\omega_i (N+p)] + B_i \sin[\omega_i (N+p)]\} \quad (5)$$

After subtracting reconstructed harmonic values (equation 4), the residuals obtained may be considered as stochastic components of the time series. They were modelled by the ARMA method (SPSS 13.0), where the order of the autoregressive component (AR) is determined by the partial autocorrelation function (PACF), while the moving average component (MA) is determined by the autocorrelation function (ACF). Finally, the total forecast was obtained by summing the harmonic, equation (5), and stochastic (ARMA model) components for a period of *p* years. In this way, we made the forecast of fluctuations for the next 20 years.

Furthermore, these time series are compared with the annual activity of the Sun, in order to examine whether any correlation exists among them.

Results

Comparing the data from all river gauge stations, we found that all the Danube River water level data from different gauge stations were in phase and showed a high degree of correlation. Exceptions were only stations located inside of the Iron Gate reservoir, and they showed the opposite phase compared to stations that are located upstream and downstream of the reservoir. Station Prahovo village had a series of water level data for 79 years (1935 - 2013), what was much shorter than *A. immaculata* catch series (94 years, from 1920 to 2013). Therefore, we selected Novi Sad town station with the longest water level data series (foundation year 1819, 1254.98 km from river mouth) to compare with station Prahovo (Fig. 1). Water levels of the Danube River from both stations Prahovo and Novi Sad and catch were matched in phase, and they showed a highly significant correlation coefficient, r=0.70, $p<0.001$.

The fluctuations of the analyzed parameters (mean annual river water levels and catch of Pontic shad) are shown in Fig. 2. Fluctuations of the Danube River water level at upstream Novi Sad and downstream Călăraşi are highly positive correlated (r=0.904, $p<0.001$).

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Average catch of Pontic shad in the period 1920-2013 was 518 t with a minimum of 23 t and a maximum of 2500 t recorded in 1999 and 1975, respectively.

Spectral analysis of the catch of Pontic shad showed that periods with the highest amplitudes were 2.47, 2.54, 3.24, 4.27, 7.23, 10.44, 15.67, 23.50 and 47.00 years. The highest amplitudes of mean annual Danube River water levels at Novi Sad and at Călăraşi were 2.47, 3.62, 4.27, 4.95, 10.44, 13.43, 18.80, 31.33 and 47.00 years. Amplitudes of the mean Danube River water level in May at Novi Sad were 2.47, 2.54, 3.62, 4.27, 4.95, 6.27, 10.44, 18.8 and 31.33 years, while at the Călăraşi they were: 2.47, 2.54, 3.62, 4.27, 4.95, 10.44, 13.43, 18.8 and 47.00 years.

The solar cycle is prominent in the catch of *A. immaculata* (10.44 years), as well as in all the series of river water levels at both stations (11.75 for mean annual river water levels, and 10.44 for mean river water levels in May).

To verify the relationship between analyzed data series we used the cospectral density functions. Cospectral density, computed by smoothing the real part of the cross-periodogram values, is a measure of the correlation of the in-phase frequency components of two time series. The periods of water levels which had the highest correlation with the catch of *A. immaculata* are presented in Table 1.

Table 1: Cospectral densities of river water level periods and the catch *of Alosa immaculata.*

Water level stations	Significant periods			
Mean annual water level Novi Sad	2.47	4.27		11.75
Mean water level in May Novi Sad	2.47	4.27	10.44	
Mean annual water level Călăraşi	2.47	4.27		11.75
Mean water level in May Călăraşi	2.47	4.27	10.44	

The cross-correlation function between mean Danube River water levels and *A. immaculata* catch showed that fluctuations, even during the same periods, were not synchronous (Table 2).

Table 2: Correlations between Danube River water levels and *Alosa immaculata* catch.

Cross-correlation function between water level and catch	Lag (years)	corr. coef.	*p*<
Mean annual water level Novi Sad	-3	-0.206	0.057
Mean water level in May Novi Sad	-3	-0.167	0.124
Mean annual water level Călăraşi	-2	-0.046	0.675
Mean water level in May Călăraşi	-2	-0.040	0.705

The cross-correlation functions between mean Danube River water levels and catch have shown negative correlation with the phase lag of 2-3 years (highest

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correlation coefficient was for the 3 years lag with mean annual water level at Novi Sad station) (Table 2). CCF between river water levels and Pontic shad also showed prominent phase lags of 10-11 years.

Thus, the results of spectral analysis and CCF show that the increased catch of Pontic shad occurs two to three years after the annual low water level of the Danube.

In order to check whether there is a possible correlation between the water level of the Danube River and catch of *A. immaculata* with solar activity, we smoothed the data on river water levels and catches with the 5 year running means, which is enough to dim high frequency periods from 2.5 to about 6 years, and compared them with data on solar activity (Fig. 3).

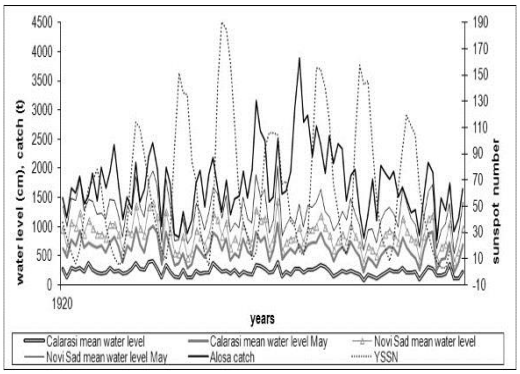


Figure 3: Relationship between mean annual Danube water levels and water levels in May at both stations, Novi Sad and Călăraşi, and catch of *Alosa immaculata* and solar activity.

CCF, performed on smoothed data, showed negative correlation between river water levels and *A. immaculata* catch again. This time we obtained increased correlation coefficients for river water levels at Novi Sad, and phase lag of three years for both stations (Table 3).

Table 3: Correlations between mean annual river water levels and *Alosa immaculata* catch, smoothed with five years running mean.

Water level at station Novi Sad	Lag (years)	corr. coef.	*p*<
Mean annual water level	-3	-0.309	0.005
Mean water level in May	-3	-0.232	0.036
Water level at station Călăraşi	Lag (years)	corr. coef.	*p*<
Mean annual water level	-3	-0.007	0.946
Mean water level in May	-3	-0.053	0.630

Next step of the analysis was to compare smoothed time series with yearly sunspot numbers.

From Fig. 3 it is clear that the increased level of the Danube nearly perfectly fitted with periods of increased solar activity, while the catch of *A. immaculata* was the highest during periods of quiet Sun and low river water levels (Fig. 3).

The results of CCF between YSSN and water levels and the catch of *A. immaculata* are presented in Table 4.

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Table 4: Correlation between YSSN and time series of Danube River water levels and *Alosa immaculata* catch, all smoothed with five year running means.

Correlation between YSSN and water levels at Novi Sad	Lag (years)	corr. coef.	*p*<
Mean annual water level	3	0.209	0.055
Mean water level in May	3	0.232	0.036
Correlation between YSSN and water levels at Călăraşi	Lag (years)	corr. coef.	*p*<
Mean annual water level	3	0.200	0.065
Mean water level in May	3	0.192	0.077
Correlation between YSSN and *A. immaculata* catch	0	-0.196	0.073

The results obtained show that there is an obvious positive correlation between the solar activity and the fluctuation of Danube water levels. Maximums of river water levels precede maximums of solar activity for three years. Correlations obtained were statistically significant for the 92% to 96% probability levels.

There is also a negative relationship between annual catch of *A. immaculata* and YSSN statistically significant for 93% probability level. The minimum annual catch occurs at the maximum of solar activity. Therefore, we can conclude that Ivanov and Kolarov (1979) were right when they found a negative relationship between the catch of *A. immaculata* and solar activity.

Inserting statistically significant amplitudes (10.44, 47.00, 94,00) of *A. immaculata* catch (Fig. 4) in equation (1), and summing them with the results of ARMA analysis of stochastic component of time series, reconstruction of the current data series was made, as well as the forecast of the catch for the period from 2013 to 2033 (Fig. 5).

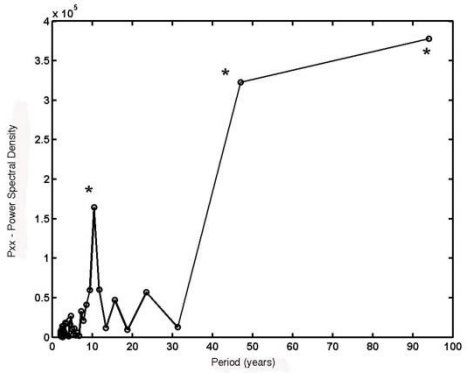


Figure 4: Spectral density of the catch of *Alosa immaculata*. (*) significant amplitudes.

Forecast of *A. immaculata* catch indicates gradual increase of the catch from 2015 to 2027. Relative increase of the catch is expected from 2024 to 2028, while the maximum will be in 2027. After that, towards 2033, the catch will decrease (Fig. 5).

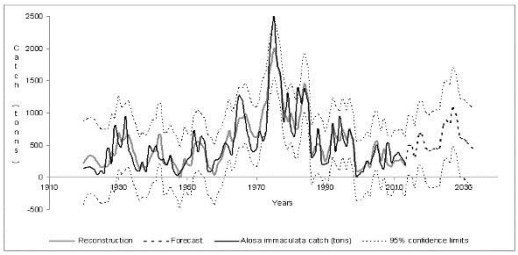


Figure 5: Reconstruction (1920-2013) and forecast (2014 - 2033) of the mean annual catch of *Alosa immaculata* from the Danube River in Romania, obtained by summing cyclical and stochastic components.

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Discussion

There are about 5,000 fishermen on the Danube River in Romania, Bulgaria, Serbia and Ukraine that catch Pontic shad (Navodaru and Waldman, 2003). According to Raikova-Petrova *et al*. (2013) in the period 2003-2011, the annual catch of Pontic shad, in Bulgaria, in the Black Sea and the Danube has dropped 3.5 times. Population size appears to be increasing again and the last minimum was in 1999 (Ciolac and Patriche, 2004). Pontic shad fishery is productive but variable and annual landings are about 1,000 metric tons, while Romania prevails in the harvest (Navodaru and Waldman, 2003).

Fluctuations of Romanian catch, compared with Ukrainian catch during the period from 1945 to 2005 in the northern branch of Danube delta, Kiliya and the adjacent sea (Bušuev, 2006) are perfectly correlated. Since these series of data were collected completely independently, they can be considered as very reliable.

Along time scientists stated that there is a positive relationship between recruitment of Pontic shad and the Danube River flow (Vladimirov, 1953; Cautis and Teodorescu-Leonte, 1964; Niculescu-Duvaz and Nalbant, 1965; Navodaru and Waldman, 2003; Ciolac and Patriche, 2004). Positive correlation between size of adult migratory stocks and river flow during their year of birth was controversially discussed (Navodaru and Waldman, 2003). Migration of the Pontic shad depends on the water temperature (Raikova-Petrova *et al.*, 2013). When the water level in the Danube rises, migration starts (Ciolac and Patriche, 2004), reaching a peak during April-May when the water temperature is 9–17°C, finishing in June-July when the water temperature is around 22–26°C (Navodaru and Waldman, 2003; Ciolac and Patriche, 2004; Raikova-Petrova *et al.*, 2013).

On the basis of Fourier analyses performed, it could be concluded that the water levels, and especially those in May when the Pontic shad migration reaches a peak, greatly regulate the yearly fluctuations of its catch.

Crecco and Savoy (1987) and Aprahamian (2001) consider that there is a negative correlation between strength of the cohort and river flow due to egg and larval mortality driven by turbidity effects, for American shad (*A. sapidissima*), and Twaite shad (*Alosa falax*), respectively. According to Navodaru and Waldman (2003) in the case of Pontic shad migrating in the Danube River, the flood could increase ecological productivity and fast growth of shads, but extreme spring floods could have a negative influence on survival of eggs and larvae due to high turbidity.

According to "narrow gate" theory (Ricker, 1954; Hempel, 1965; Houde, 1987), only a limited number of individuals reach sexual maturity. The "width" of this gate changes from year to year, due to variations of ecological factors which positively or negatively influence survival of fish eggs and particularly larvae and juveniles,

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causing the fluctuations of the number of individuals that reach maturity. In this case, it seems that developmental stages of Pontic shad survive better in the years of low water level, with lower water turbidity and vice versa. According to the data obtained, the generation spawned in the year of low water level yields a strong class of mature individuals two or three years later. After Ciolac and Patriche (2004) the explanation of this fact could be the age structure of Danube shad in which 3 year old spawners participate from 41.2% to 50.2%.

In an analysis of a long data series of catch statistics and solar activity, Ivanov and Kolarov (1979) found a negative correlation between catch and solar activity with a cycle of 11 years. They concluded that solar activity, through climatic and hydrological cycles, best explained Pontic shad population dynamics.

In a 94 year series of data on catch of Pontic shad from the Danube River, the 10.44-year solar cycle is prominent, and it is also prominent (10.44 and 11.75 years) in all analyzed data on Danube River water levels, which corroborates Ivanov and Kolarov (1979) findings.

Besides the solar one, all the other periods that we found using Fourier transform, except the 47 years one, belong to the well-known natural climatic cycles (Lamb, 1977).

Similar a study on the relationship between solar activity and fish catch was done by Regner and Gačić (1974), who found dependence between the sardine catch in the Adriatic and the 11-year solar cycle. They concluded that solar activity, through climatic factors, affects inflow of Mediterranean geostrophic current into Adriatic. In the years of solar maxima, the current is stronger; it brings increased quantity of nutrients which increase organic production.

Guisande *et al*. (2004), found that annual sardine *Sardina pilchardus* landings along northwest coast of the Iberian Peninsula also vary according to solar activity. They found that, when the solar cycle is short, there is a trend towards increasing water transport onshore, which favours larval retention in areas close to the coast and, hence, sardine catches increase. Oppositely, when the solar cycle is longer, the trend is toward increasing water transport offshore, carrying eggs and larvae into areas where there is not enough food to survive and, therefore, decreasing sardine catches.

In the case of *A. immaculata* it is obvious that a fluctuation of its recruitment depends on the fluctuations of Danube River water levels, which depend on precipitation. So far, there is evidence that solar UV variations, solar wind and cosmic rays affect the formation of clouds, and therefore precipitation (Young *et al*., 1982; van Geel *et al*., 1999; Rycroft *et al*., 2000; Svensmark, 2007).

The fact that the years of high water level precede maximums of solar activities by three years, is in good agreement with the results obtained by Juan *et al*. (2004). They found that about 1–2 years before the sunspot

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minimum the Beijing area was always arid, but in the minimum year and for about 1–2 years after, the precipitation always increased.

To forecast natural processes, especially nowadays when possible anthropogenically induced changes are a phenomenon that affect all global processes, is one of the most difficult tasks. The forecast of the cyclic components is reliable, while it is practically impossible to forecast stochastic effects. Catch forecast should be considered as less reliable, because this parameter is most sensitive to possible drastic changes, primarily due to human activity. Unfortunately, the model cannot forecast the effects of human activities, economic crises, lack of catch statistics, decrease or increase of number of commercial and recreational fishermen, etc.

Navodaru and Waldman (2003) presented catch statistics of Pontic shad in the Romanian part of the Danube River, in the period from 1920 to 2000, which nicely coincides with our results. Annual landings of the Pontic shad vary greatly, but seem to be cyclic to a large extent, with several strong years of catch being followed by several low years of catch. In the next two decades, as presented in our results, the annual catch of Pontic shad will be above average values that were recorded in the last decade. In the period from 2024 to 2027 it will have an upward trend reaching 1000 tons.

Pontic shad, like all other alosines species, are highly sensitive to multiple stresses, both natural and anthropogenic. Regarding that, fishery management and regulations should focus on the multinational approach in order to estimate stock size and exploitation at regional rather than national levels (Navodaru and Waldman, 2003). The relationship between river flow and shads is not completely clear, but another factor that explains variation in population size of shads is water temperature (Aprahamian, 2001).

Pontic shad population trends and catch prognosis require studies of species biology (studies of eggs, larvae and juveniles) and correlation of spatio-temporal monitoring (fishing pressure, catch per unit effort, environmental factors).

Acknowledgements

The authors acknowledge the support of the Project No. IO173045 and TR37009, both funded by the Ministry of Education, Science and Technological Development of Republic Serbia.

References

Anderson, T.W., 1971. The statistical analysis of time series. New York, John Wiley & Sons, Inc., 689P.

Anderson, J.J., 1998. Decadal climate cycles and declining Columbia River salmon. Sustainable Fisheries, Conference Proceedings. pp. 1-22 (School of Fisheries, Box 358218, University of Washington, Seattle, Washington 98195, USA).

Aprahamian, M.W., 2001. The influence of water temperature and

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[DOR: 20.1001.1.15622916.2018.17.3.1.3]

flow on year-class strength of twaite shad (*Alosa fallax*) from the River Severn, England. *Bulletin Français de la Pêche et de la Pisciculture*, pp. 362/363, 953–973.

Bănărescu P., 1964. Fauna republicii populare Romane. Pisces-Osteichthyes. Editura Academiei Republici Populare Romane, Bucuresti, Romania, 962 pp.

Baran, E., Van Zalinge, N. and Ngor, P.B., 2001. Floods, floodplains and fish production in the Mekong Basin: present and past trends. pp. 920-932 in Ahyaudin Ali *et al*. (Eds.) (Proceedings of the Second Asian Wetlands Symposium, Penang, Malaysia 27-30 August, 2001). Penerbit Universiti Sains Malaysia, PulauPinang, Malaysia. 1116 P.

Box, G.E.P. and Jenkins, G.M., 1970. Time series analysis. Forecasting and control. San Francisco, Holden-Day, 576P.

Bušuev, C.G., 2006. Ship locks renewal of deep draught "Danube-Black Sea" and perspectives of Pontic shad trade. *Ukrainian Fisheries Management*, 1(2), 18-24 (in Ukrainian).

Cautis, I. and Teodorescu-Leonte, R., 1964. Correlation between flood and dynamics of herring (*Alosa pontica pontica* Eichw.) entering the Danube for reproduction. *Bulletin of the Research Institute for Fisheries and Aquaculture*, 23(**1**), 34–43 (in Romanian).

Ciolac, A. and Patriche, N., 2004. Structure of Danube Shad (*Alosa pontica* Echelwald, 1838) spawner flocks migrating for reproduction in Danube River. *Applied Ecology and Environmental Research*, 2(**2**), 53-58.

Crecco, V. and Savoy, T., 1987. Fishery management plan for American shad in the Connecticut River. Connecticut Department of Environmental Protection, Bureau of Fisheries, Research Report, Waterford, Connecticut.

Daia, P.P., 1926. Exploatarea pescariilor statului. *Tipografia Copuzeanu*, 201 P.

Doan, K.H., 1945. Catch of *Stizostedion vitreum* in relation to changes in lake level in Western Lake Erie during the winter of 1943., *American Midland Naturalist*, 33(**2**), 455-459.

Fisher, R., 1929. Tests of significance in harmonic analysis. *Proceedings of the Royal Society, Series A*, 125, 54–59.

Górski, K., Van Den Bosch, L.V., Van De Wolfshaar, K.E., Middelkoop, H., Nagelkerke, L.A.J., Filippov, O.V., Zolotarev, D.V., Yakovlev, S.V., Minin, A.E., Winter, H.V., De Leeuw, J.J., Buijse, A.D. and Verreth, J.A.J., 2012. Post-damming flow regime development in a lage lowland river (Volga, Russian Federation): Implications for floodplain inundation and fisheries. *River Research and Applications*, 28, 1121-1134.**Guisande, C., Ulla, A. and Thejll, P., 2004.** Solar activity governs abundance of Atlantic

[Downloaded from jifro.ir on 2026-11-16]

[DOR: 20.1001.1.15622916.2018.17.3.1.3]

Iberian sardine *Sardina pilchardus. Marine Ecology Progress Series,* 269, 297-301.

Han, Y.S., Tzeng, W.N. and Liao, I.C., 2009. Time series analysis of taiwanese catch data of Japanese glass eels *Anguilla japonica*: possible effects of the reproductive cycle and el niño Events. *Zoological Studies,* 48(**5**), 632-639.

Hempel, G., 1965. On the importance of larval survival for the population dynamics of marine food fish. *California Cooperative Oceanic Fisheries Investigations Reports*, 10, 13-23.

Houde, E.D., 1987. Fish early life dynamics and recruitment variability. *American Fisheries Society Symposium*, 2, 17-29.

Ivanov, L. and Kolarov, P., 1979. The dependency of the catch of the Danube shad (*Alosa pontica pontica* Eichw.) of the solar activity. Jubiläumstagung Donauforschung, SIL-Ban, *Sofia*, 19, 389–395 (In Bulgarian).

IUCN, 2016. IUCN Red List of Threatened Species. Version 2016.1 IUCN 2016. IUCN Red List of Threatened Species. http://www.iucnredlist.org/details/907/0

Juan, Z., Yan-Ben, H. and Zhi-An, L., 2004. The effect of solar activity on the annual precipitation in the Beijing area. *Chinese Journal of Astronomy and Astrophysics*, 4(**2**), 189–197.

Kashyap, R.L. and Rao, A.R., 1976. Dynamic stochastic models from empirical data. New York, Academic Press, 352P.

Kawasaki, T., 1992a. Climate-dependent fluctuations in far eastern sardine population and their impacts on fisheries and society. In: Climate Variability, Climate Change and Fisheries (M.Glantz, ed.), Cambridge Univ. Press, pp. 325-355.

Kawasaki, T., 1992b. Mechanisms governing fluctuations in pelagic fish populations. In Benguela trophic functioning. *South African Journal of Science*, 12, 873-879.

Klyashtorin, L.B., 2001. Climate change and long-term fluctuations of commercial catches: the possibility of forecasting. FAO Fisheries Technical Paper. No. 410. Rome, FAO, 86 P.

Kolarov, P., 1991. *Alosa pontica pontica* (Eichwald 1938). In H. Hoestlandt (ed.) The freshwater fishes of Europe. Vol. 2. Clupeidae, Anguillidae. AULA-Verlag Wiesbaden. pp. 337-368.

Kottelat, M. and Freyhof, J., 2007. Handbook of European freshwater fishes. Publications Kottelat Cornol Switzerland, 646 P.

Lamb, H.H., 1977. Climate: present, past and future. Vol. 2, Climatic History and the Future. Methuen, London. 837 P.

Lenhardt, M., Višnjić-Jeftić, Ž., Navodaru, I., Jarić, I., Vassilev, M., Gačić, Z. and Nikčević, M., 2012. Fish stock management cooperation in the Lower Danube Region: a case study of sturgeons and Pontic shad. In: Lagutov, L.

[Downloaded from jifro.ir on 2026-11-16]

[DOR: 20.1001.1.15622916.2018.17.3.1.3]

(eds) Environmental security in watershads: The Sea of Azov, Springer, ISBN 978-94-007-2462-4, pp. 127-140.

Lenhardt, M., Navodaru, I., Vassilev, M., Kalauzi, A., Regner, S., Višnjić-Jeftić, Ž., Tošić, K. and Smederevac-Lalić, M., 2016. Model of the Pontic shad *Alosa immaculata* (Bennet, 1835) and Anchovy *Engraulis encrasicolus* (Linnaeus, 1758) catch in the Danube River and Black Sea for the period 1920-2008. *Acta Zoologica Bulgarica*, 68(**4**), 557-561.

Myers, R.A., Barrowman, N.J., Hutchings, J.A. and Rosenberg, A.A., 1995. Population dynamics of exploited fish stocks at low population levels. *Science*, 269, 1106-1108.

Navodaru, I. and Waldman, J.R., 2003. Shads of eastern Europe from the Black Sea: review of species and fisheries. *American Fisheries Society Symposium*, 35, 69–76.

Niculescu-Duvaz, M. and Nalbant, T., 1965. Consideratii asupra sistematicii scrumbiei de Dunare (*Alosa pontica pontica* Eichw.) si asupra unor fenomene specifice legate de migratia si prognoza acestei specii in apele Dunarii. Buletinul Institutului de Cercetare pentru Pescuit si Piscicultura XXIV 1, 15–25 (In Romanian).

Pekárova, P., Miklánek, P. and Pekár, J., 2003. Spatial and temporal runoff oscillation analysis of the main rivers of the world during the 19th–20th centuries. *Journal of Hydrology*, 274, 62–79.

Pekárova, P. and Pekár, J., 2006. Long-term discharge prediction for the Turnu Severin station (the Danube) using a linear autoregressive model. *Hydrological Process*, 20, 1217-1228.

Rabuffetti, A.P., Górski, K., Espínola, L.A., Abrial, E., Amsler, M.L. and Paira, A.R., 2016. Long-term hydrologic variability in a large subtropical floodplain river: Effects on commercial fisheries. *River Research and Application*, DOI: 10.1002/eea.3100

Raikova-Petrova, G., Velikova, S. and Hamwi, N., 2013. Sex structure and fecundity of Pontic shad (*Alosa immaculata* Bennett, 1835) in the Bulgarian sector of Danube. *Bulgarian Journal of Agricultural Science*, 19 (**Supplement 1**), 88–93.

Regner, S. and Gačić, M., 1974. The fluctuation of Sardine catch along the Eastern Adriatic Coast and Solar Activity. *Acta Adriatica*, 15(**11**), 15.

Regner, S., 1996. Changes in solar activity in the lower frequencies and sardine catch in the Adriatic Sea. 5th Congress of ecologists of Yugoslavia. 22-27. September 1996, Belgrade. *Proceedings of Abstracts*, 20 P (in Serbian).

Ricker, W.E., 1954. Stock and recruitment. *Journal of the Fisheries Research Board of Canada*, 11(**5**), 559-623.

Rycroft, M.J., Israelsson, S. and Price, C., 2000. The global atmospheric electric circuit, solar

[Downloaded from jifro.ir on 2026-11-16]

[DOR: 20.1001.1.15622916.2018.17.3.1.3]

activity and climate change. *Journal of Atmospheric and Solar-Terrestrial Physics*, 62, 1563-1576.

Svensmark, H., 2007. Cosmoclimatology: a new theory emerges. *Astronomy and Geophysics*, 48(**1**), 118-124.

van Geel, B., Raspopov, O.M., Renssen, H., van der Plicht, J., Dergachev, V.A. and Meijer, H.A.J., 1999. The role of solar forcing upon climate change. *Quaternary Science Reviews*, 18(**3**), 331-338.

Vladimirov, V.I., 1953. The Danube shad and the biological fundamentals of its fishery. pp. 5–9 in Academy of Ukraine SSR, Kiev, Ukraine (In Ukrainian).

Whittle, P., 1952. Tests for fit in time series. *Biometrika*, 39, 309.

Young, D.T., Balsiger, H. and Geiss, J., 1982. Correlations of magnetospheric ion composition with geomagnetic and solar activity, *Journal of Geophysical Research*, 87(**A11**), 9077–9096.

[Downloaded from jifro.ir on 2026-11-16]

[DOR: 20.1001.1.15622916.2018.17.3.1.3]