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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

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Abstract: Data on the catch of Pontic shad in the Lower Danube River Region for the period 1920-2008 were used to make one-component and two-component models. The catch model for Pontic shad showed natural cyclic fluctuations with no sign of population decrease. The oscillation periods were 11.17 years and 9.56 years, which corresponded to solar activity cycles. In addition, as anchovy represents the main food source of Pontic shad in the Black Sea, the catch of anchovy in the Black Sea for the period 1950-2006 was modelled. Pearson's coefficient (cc=0.6785) indicated that 67.86% of the Pontic shad catch was dependent on the anchovy catch during the analysed time period. Besides the necessity for better gathering of data in the Lower Danube River Region on the catch of Pontic shad, there is also a need for more profound studies on this species. It is evident that this valuable fish species requires more attention from fish managers in all countries of the Lower Danube River Region.

Key words: Lower Danube River Region, shad populations, commercial catch, oscillation periods, solar activity

Introduction

The Pontic shad *Alosa immaculata* (Bennet, 1838) is an anadromous fish species migrating for spawning from the Black Sea to the Danube River, with a long tradition of commercially shared fisheries by countries in the Lower Danube River Region. It is highly appreciated by a certain number of consumers because it is the Christian custom of local people to eat Pontic shad during lent (Ciolac & Patriche 2004).

Pioneer research of Pontic shad was conducted by Ukraine and Romania in the years 1950-1960. The most recent papers and scientific research concerning Pontic shad was carried out in Romania. The topics of these papers concerned Pontic shad exploitation (Navodaru 1996, Navodaru 1998, Navodaru & Waldman 2003), the structure of Pontic shad spawning migrants (Ciolac 2004, Ciolac & Patriche 2004) and the drift of Pontic shad larvae (Navodaru 2001). The main study of Pontic shad in Bulgaria is the work of Kolarov (1985), which involved morphological investigation, growth, structure of migrants and analysis of the catch in Bulgaria. The least studied is the species in Serbia, even though the species has been protected in this country since 1993. Papers on age determination (Visnjic-Jeftic *et al.* 2009), geometric morphometric analysis (Visnjic-Jeftic *et al.* 2010) and heavy metal analysis in Pontic shad tissues (Visnjic-Jeftic *et al.* 2013) were published based on investigations of this species in Serbia.

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The Pontic shad fishery has an economic value of about USD 2 million and annual landings of about 1,000 metric tonnes with about 70% of the fish taken by Romanian fishermen (Navodaru & Waldman 2003). Negative impacts on Pontic shad stocks in the Black Sea and the Danube River are due to overfishing and pollution (Navodaru 1996, Navodaru & Waldman 2003), as well as to dam construction. In the past, isolated individuals migrated for spawning into the Danube River as far upstream as Budapest (rkm 1650) (Banarescu 1964). Construction of the Djerdap I and II (the Iron Gates) dams at 943 rkm (1970) and 863 rkm (1984), respectively, on the Danube River shortened the migration routes of this species. There are no fish passes on these two dams but some specimens are able to pass the dams through ship locks and reach rkm 1319.

Even though Pontic shad, together with Caspian shad and Black Sea shad, are commercially and culturally important within their respective distributions, knowledge of the biology and conservation status of these shads is poor (Navodaru & Waldman 2003). Previously, Pontic shad was DD (data deficient) on the IUCN red list (Baillie & Groombridge 1996) and is now VU (Vulnerable) with the population trend stated to decrease (IUCN, 2015). It is also included in Appendix III (protected fauna) of the Bern Convention (Lassalle *et al.* 2008), in Natura 2000 and EU Habitat Directive (92/43/1992). Its status in the Lower Danube River Region varies depending on the country.

The aim of this study was to perform an analysis of fishery data, legislation and scientific research related to Pontic shad in the Lower Danube River Region, which could help us create a sound basis for better management of this valuable species.

Material and Methods

Catch data on Pontic shad were used from the following sources: for the period 1920-1924 after Daia (1926), for 1925-1964 after Niculescu-Duvaz & Nalbant (1965), for 1965-1982 after Kolarov (1991), for 1983-1993 after Froese & Pauly (2015), and for 1994-2008 after data from the Danube Delta Institute for Research and Development, Tulcea, Romania. Data on the catch of anchovy in the Black Sea for the period 1950-2006 were obtained from FAO FishStatPlus.

The model applied here for catches of Pontic shad and anchovy was based on the model introduced in our previous work (Lenhardt *et al.* 2006),

$$I(t) = \left[A\sin(2\pi f_r t + \varphi) + c\right]e^{-k_e t},$$

where $I(t)$ represents annual fish catch expressed in tonnes, A, f_r φ and c stand for amplitude, frequency, initial phase and steady state of the oscillatory component, respectively, while k_e denotes the time constant of the decay process. It was developed for situations where fish catch was diminishing with time, at the same time exhibiting an oscillatory component. In this case we faced a situation where oscillatory amplitudes were modulated via a bell-shaped process, rather than simple decay. Under these circumstances, a natural modification of the previous model would be to substitute the exponential decay with a Gaussian factor:

$$I(t) = \left[A\sin(2\pi f_r t + \varphi) + c\right]e^{-k_e(t-t_0)^2},$$

where I(t_0) stands for time of maximal catch of the bell-shaped component, while parameter k_e, instead of the extinction coefficient, should be interpreted as the inverse of the width of the Gaussian process. Six-parameter nonlinear fitting of the two catch data series was performed using the Nelder-Mead algorithm, implemented by the authors in MATLAB 6.5 (MathWorks Inc., Natick, MA 01760-2098 United States).

Results

Catch of Pontic shad

Data on Pontic shad for the period 1920-2008 were used by applying the model presented in Fig. 1. Parameter values, obtained for the Pontic shad catch model, are:

A= 511.35 t, f_r=0.0995 1/year (corresponding period T=10.05 years), φ=4.91,

c= 1112.73 t, k_e= 0.00242 1/year^2, t_0=1976.32 years;

However, this model is not able to explain multiple bell-shaped processes modulating the oscillatory component. This is best seen for the period 1920-1950 (Fig. 1). Therefore, we applied a generalised version of the present model on the same catch data:

$$I(t) = \sum_{i=1}\left[A_i \sin(2\pi (f_r)_i t + \varphi_i) + c_i\right]e^{-(k_e)_i(t-(t_0)_i)^2},$$

where i denotes an index of the current component, while n stands for the number of components. Such fitting, presented in Fig. 2, for n=2 resulted in the following values of model parameters:

A_1=264.07 t, $(f_r)_1$=0.0895 1/year (T_1=11.17 years), $(\varphi)_1$=3.07, c_1=340.00 t, $(k_e)_1$=0.001823 1/year^2, $(t_0)_1$=1935.83 years;

A_2=568.86 t, $(f_r)_2$=0.1046 1/year (T_2=9.56

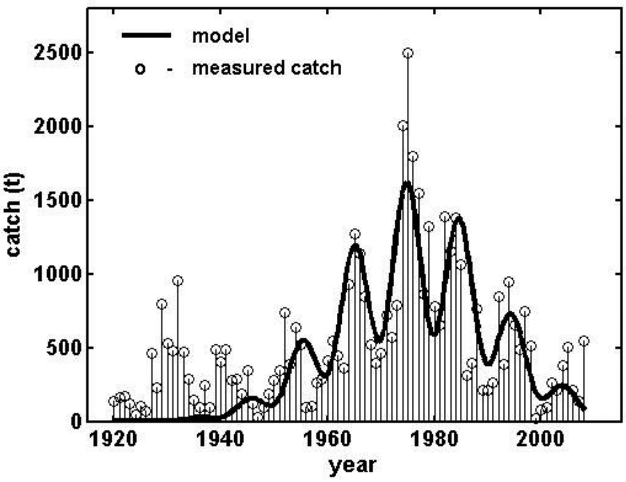

Fig. 1. The catch of Pontic shad for the period 1920-2008

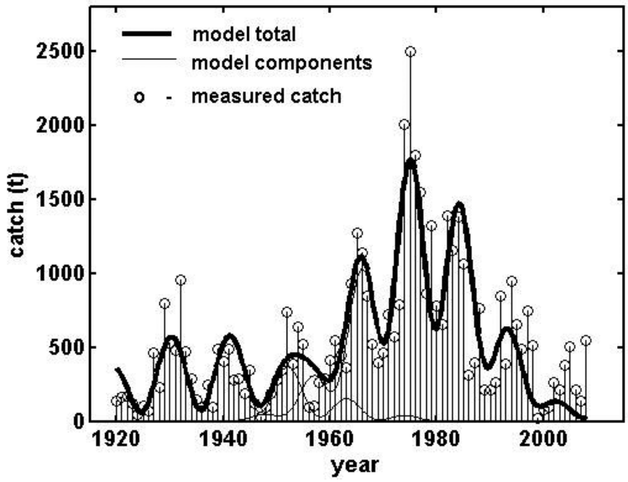

Fig. 2. Fitting of Pontic shad catch for the period 1920-2008

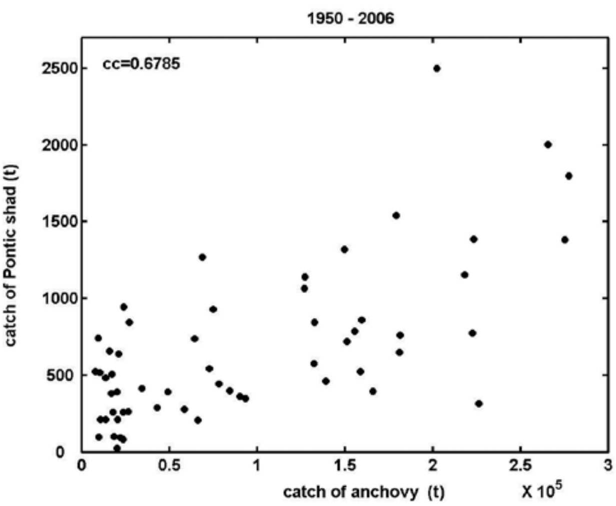

Fig. 3. Dependence of the Pontic shad catch on the anchovy catch during the period 1920-2008

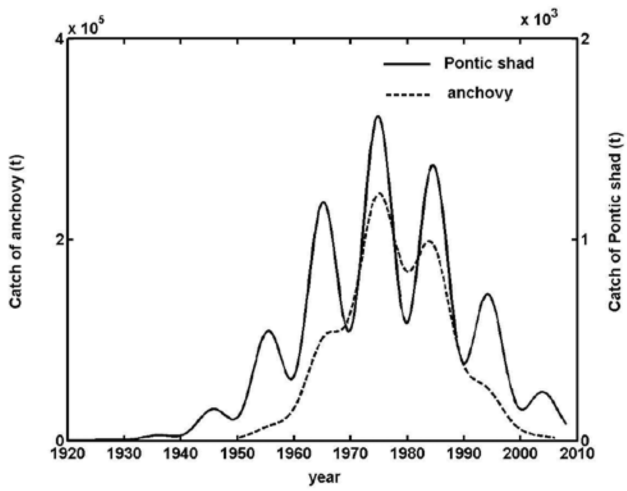

Fig. 4. The two catch models: Pontic shad and anchovy

years), $(\varphi)_2$=4.71, c_2=1200.42 t, $(k_e)_2$=0.003955 1/year^2, $(t_0)_2$=1977.41 years.

Bearing in mind that according to SVETOVIDOV (1964) 73.3% of the Pontic shad's diet in the Black Sea is comprised of fish, mainly represented by anchovy, we also modelled the anchovy catch in the Black Sea. Parameter values for the anchovy catch model were:

A= 42201.15 t, f_r=0.0944 1/year (corresponding period T=10.59 years), φ=2.24,

c= 215518.80 t, k_e= 0.00561 1/year^2, t_0=1977.65 years.

In order to test any correlations between catches of the two species, both data series, I_1(t) and I_2(t), referring to actual catch per year, were presented on a scatter plot (Fig. 3). In addition, Pearson's coefficient of the linear correlation was calculated for the two series (cc=0.6785) indicating that 67.85% of the Pontic shad catch was dependent on the anchovy catch during the analysed time period.

By comparing the two catch models (Fig. 4), one for the Pontic shad and one for the anchovy, we could conclude that both species had very similar oscillatory periods, 10.05 and 10.59 years, respectively. Also, both species showed very similar locations of maxima of non-oscillatory components (positioned at years 1976.32 and 1977.65), as well as local maxima of the oscillatory components, at least in the middle section of the time period.

Discussion

The catch model for Pontic shad showed natural cyclic fluctuations with no sign of population decrease. This is in accordance with the statement made by LUZHNYAK & KORNEEV (2006) where some increase in the number of *A. immaculata* spawners entering the River Don (Ukraine) for spawning was observed during recent years. However, it contradicts to findings for sturgeon migrants in the Lower Danube River Region, beluga (*Huso huso*) and Russian sturgeon (*Acipenser gueldenstaedtii*), where a decrease in the populations of these two species (Lenhardt *et al*. 2006) was recorded, with extinction risk for Russian sturgeon estimated to occur around the middle of the century and for beluga around the middle of the millennium. The main threats to anadromous Pontic shad are almost the same as those identified for sturgeons, with the only additional point being the slightly better state of shad stock compared to that of sturgeon, due to their natural ability for rapid recovery (Popescu 2010).

In a two-component model for the catch of Pontic shad, the oscillation periods were 11.17 years and 9.56 years – which corresponds to solar activity cycles (Regner & Gacic 1974, Regner & Gacic 1977). Kolarov (1985) also showed significant (r=0.63-0.79) impact of solar activity on the catch of Pontic shad and a moderate correlation of Pontic shad catch with water turbidity and water levels (r=0.649).

Fluctuations in the catch model of Pontic shad followed fluctuations in the catch model of anchovy, which is in accordance with the statement of Svetovidov (1964) that anchovy is the main food source of Pontic shad in the Black Sea. The high catch of anchovy during the 1970s was probably connected to the high productivity of the Black Sea during these years (Prodanov & Stoyanova 2001, Eremeev & Zuyev 2007). Anchovies in the Black Sea have an extremely high reproductive potential (Lisovenko & Andrianov 1996) due to a number of factors (early maturation, long period of spawning, multiplicity of spawning, high level of individual fecundity, high ability to restore reproduction). However, since 1988 the status of the anchovy stock in the Black Sea has changed dramatically and a great decrease in populations has occurred, caused by excessive capture and by an additional negative factor, the intrusion of a jellyfish (Chashchin 1996).

The other problem connected with modelling the Pontic shad catch relates to the absence of data about changes in catch per unit effort and coefficients of vulnerability, which may be improved in the future.

Diadromous species are strongly linked to the history of their basins and constitute an important heritage (Lassalle *et al*. 2008, 2009). This work is a contribution to the better understanding of Pontic shad populations in the Lower Danube River Region. Out results demonstrated that additional research is needed before a common management plan can be designed and implemented. It is evident that this valuable fish species needs more attention from fish managers in all countries in the Lower Danube River Region.

In view of the present results and interpretations, we could comment the measures for management of Pontic shad. During 1958-1989, monitoring and regulation of commercial fisheries in the Lower Danube River Region, especially of sturgeons and Pontic shad, were under the "Convention concerning fishing in Danube waters" signed by Romania, Bulgaria, Yugoslavia and the Soviet Union, but following the collapse of socialism this Convention was no longer in effect. Nowadays, we have differences in the conservation and exploitation status for Pontic shad in these four countries. The Pontic shad has been protected in Serbia since 1993 by the Decree on the Protection of Natural Rarities. In Bulgaria it is included in the new Red Book as vulnerable (VU) because the catch of Pontic shad in the country has been decreasing in recent years. The prohibited period for exploitation in the Bulgarian part of the Danube River is from 15 April to 15 May. In Romania, Pontic shad is proclaimed as not threatened and it is not included in the Red Book of vertebrates from Romania. The prohibited period for exploitation in the Romanian part of the Danube River varies, depending on the river kilometre (Black Sea – rkm 43, for 5-7 days in April; rkm 43 – rkm 238, for 20 days in April-May; rkm 238 – rkm 845.6, for 30 days in April – May). In the Ukraine, Pontic shad has the status of data deficient (DD). For better management, further investigation and more collaboration among countries in the Lower Danube River Region is needed: monitoring of stocks, studies on factors that influence change in stocks, molecular genetic investigation of migrants, determination and protection of spawning and nursery places in the Danube River and its floodplains and delta as well as the costal shelf of the Black Sea.

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