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Prediction of fish catch in the Danube River based on long-term variability in environmental parameters and catch statistics

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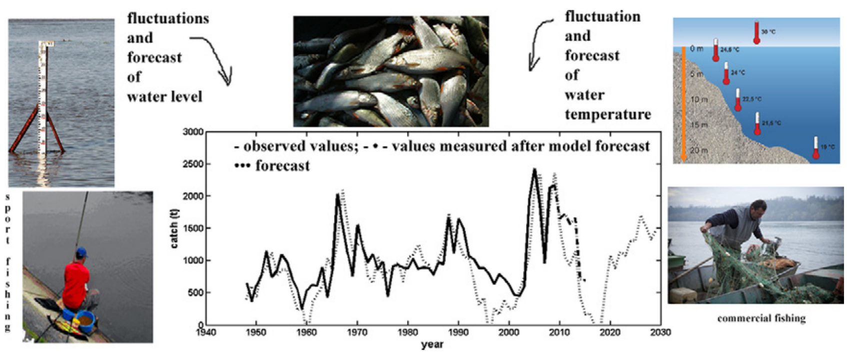
HIGHLIGHTS

- Relationship between long-term fluctuations of hydrological data and fish catch
- Statistical analysis and prediction modeling of catch and hydrological data
- Forecasts of catch decrease with lower water level and higher temperature

GRAPHICAL ABSTRACT



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ABSTRACT

The effects of physical factors on fish catch in the Serbian part of the Danube River were studied for period of six decades. The data on total catch for the Danube River from river kilometre 845 to river kilometre 1433 were collected from Statistical Office of the Republic of Serbia, while water level and water temperature data were collected from 16 water gauge stations along the investigated part of the Danube River for the period 1948–2009. Cross-correlation functions have been used to analyse the functional connection between Danube water level, water temperature and fish catch while ARMA model which combines cyclic (deterministic) and random (stochastic) components of the analysed sequences was used for the forecasts. The cross-correlation function showed negative correlation between water level and temperature as well as between water temperature and catch and positive correlation between water level and catch. The Danube water level and catch were coherent at the periods of 2.06, 4.13, 6.2, 10.33, 20.66 years, while the cross correlation function between these time series did not show phase lag. The results of reconstruction and forecast of water level, temperature, and catch of fish in the Danube River, obtained by summing the cyclic and stochastic components, was used for the forecast till 2029. In 2016, seven years after, the initial forecasts were made, validity of the model was checked by obtaining data for water temperature, water level and fish catch in the Danube River for the period 2010–2015. Model gave the best prediction for water temperature; average standard error was 1.6 times higher for predicted value than

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for model value while for fish catch and water level they were 1.96 and 4.97, respectively. Methods used in this work could be powerful tool for prediction of fish catch and serve as the basis for better fisheries management.

1. Introduction

Water level fluctuations could have a strong impact on fish species community in rivers (Kahl et al., 2008) and commercial fish stocks are expected to be linked to natural pulse dynamics (Górski et al., 2012). Several migratory fish species are characterized by a high degree of synchronization between their reproductive cycle and seasonal river flow dynamics (Górski et al., 2012). Any other possible factors influencing year class strength of fish, such as food, temperature, winter duration may only play a role if the water level after spawning remained relatively stable (Kahl et al., 2008). Thus, there is an urgent need to understand drivers of populations of commercially important fish species in order to implement informed management strategies (Rabuffetti et al., 2016).

The Danube, with a length of 2857 km and runoff of about 6500 m^3/s is the second largest river in Europe and like many large-river ecosystems it has been changing rapidly, chiefly as a result of human activities. The Danube River is an important natural resource of Europe and is recognized as a multifunctional source of water, transport, electricity, tourism, fish, industry, agriculture, etc. Dam construction (Iron Gate I on 943 rkm in 1970 and Iron Gate II on 863 rkm in 1984) had significant impact on fish community and commercial fishery (Lenhardt et al., 2004).

According to the statistics supplied by the "Joint Commission for the Application of the Fishery Convention in the Danube", the average annual catch of commercial fisheries in tones per year for the period from 1958 to 1983 was approximately 150 in Slovakia, 900 in Hungary, 1300 in Serbia, 800 in Bulgaria, 20,000 in Romania and 3000 in the Ukraine (Schiemer et al., 2004). Nowadays, in Germany, Austria and Slovakia, commercial fisheries are practically non-existent and in Hungary commercial fishing has been forbidden in all of the waters of Hungary since 1st of January 2016. The Danube River Basin holds between 75 and 85 fish species and is the largest and the only one where commercial fishing is allowed in Serbia (Smederevac-Lalić et al., 2012). Sturgeons *Acipenseridae*, European catfish *Silurus glanis* (Linnaeus, 1758), pike-perch *Sander lucioperca* (Linnaeus, 1758), common carp *Cyprinus carpio* (Linnaeus, 1758), Northern pike *Esox lucius* (Linnaeus, 1758) are native and economically important fish species while from 1977, three non-native fish species: gibel carp *Carassius gibelio* (Bloch, 1782), silver carp *Hypophthalmichthys molitrix* (Valenciennes, 1844) and bighead carp *Hypophthalmichthys nobilis* (Richardson, 1845), have became economically important for fisheries in Serbia (Jarić et al., 2016; Smederevac-Lalić, 2013; Spasić et al., 2013; Smederevac-Lalić et al., 2011a). Due to overfishing, dam building and pollution, the sturgeon anadromous fish species have decreased and fishing for their catch has been banned; only potamodromous sterlet is still available for catch (Smederevac-Lalić et al., 2012).

The effects of cyclic factors, solar and lunar cycles on the natural fluctuation of climatological phenomena and biological fluctuations have been intensely investigated in the last decades. Many authors: Doan (1945); Polli (1955); Regner and Gačić (1974); Kawasaki (1992a, 1992b); Regner (1996); Anderson (1998); Tomasino and Dalla Valle (2000); Baran et al. (2001); Klyashtorin (2001); Pekárova et al. (2003); Perry (2006, 2007) found a link between global climate phenomena and local climate and hydrological characteristics. These presume that long-term catch fluctuations are accompanied by changes of the abundance and distribution of fish, generally attributed to climatic changes. The identification of cyclicity could be beneficial for optimizing the economic value of water resources.

The objective of this study was to quantitatively analyse existing data on long-term fluctuations of the annual water level and water temperature in the Serbian part of the Danube River and assess whether these relate to fluctuations in commercial fish catch in the investigated area. Data from 1948 to 2009 were used and the forecast of fluctuations were calculated for 20 years. Seven years after the initial forecasts were made; validity and model accuracy were verified for the period 2010–2015 for which data were previously obtained.

2. Material and methods

The study area included the part of Danube River running through Serbia, which extends from the state border with Hungary, river kilometre 1433, to the mouth of the tributary river Timok, river kilometre 845, perpendicular to the stream of water on the state border with Romania. The first systematic observations of water levels in Serbia started at the beginning of the XIX century with a water gauge station that was established in 1812 near the City of Novi Sad, followed by the Bezdan gauge station in 1856, Zemun in 1859, and Slankamen in 1888 with 12 more gauge stations established later on investigated part of the Danube River (Fig. 1). Data on the water level and temperature of the Danube River were taken from the Hydrometeorological Service of the Republic of Serbia for 16 mentioned water gauge stations.

The Novi Sad station was selected as a reference station due to the longest continuous records of water level (1892–2009) and average annual water temperature for the investigated period (1948–2009).

The data on the total annual catch of fish from the Danube River were collected from the Statistical Office of the Republic of Serbia including the total catch in the watercourse of the Danube River flowing through Serbia for the period 1948–2009.

To prove the possibility of using the total catch for analysis, multiple regression analysis was performed between all individual species with the total catch, to justify that total fish catch data are sufficient for analysis.

Cross-correlation functions (CCF) have been used to analyse the functional connection between the Danube water level, water temperature and fish catch.

The method of squared coherency (standardized cross-amplitude values squared and divided by the product of the spectrum density estimates for each series, which in fact is the squared correlation coefficient between the cyclical components in the two series at the respective frequency) was used to find a possible functional relationship between two sets of data: the average annual water levels and the total catch from the Danube River.

A model combining cyclic (deterministic) and random (stochastic) components of the analysed sequences was used for the forecast (Klyashtorin, 2001; Pekárova et al., 2003):

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

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 $(\frac{2\pi}{t_i})$ of the i-th period, 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. Periodical, harmonic,