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USE OF TIME SERIES ANALYSIS IN FORECASTING FISH CATCH IN SOME POMERANIAN LAKES

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ABSTRACT. Usefulness of time series analysis in forecasting fish catch in some Pomeranian lakes was tested. Forecasting accuracy one year ahead was high for steadily exploited species such as bream, pike-perch or pike, and may be useful in fishery practice.

Key words: AUTOCORRELATIONS, AUTOREGRESSION, CATCH, FISHING GEARS, EXPLOITATION

INTRODUCTION

Time series analysis was used for fish catch forecasting by many authors (Jensen 1976, Saila et al. 1980, Kwang Ming Liu, Jensen 1992). The results obtained using linear autoregression were sufficiently accurate so as to use them for commercial catch forecasting.

Harvest of various fish species in Pomeranian lakes of South Baltic region (Fig. 1) was analysed to verify this hypothesis. Fish yield for each lake was expressed in kg ha^{-1} year^{-1}. Catches of various species in 1951-1992 in Łebsko, Gardno, Jamno, and Bukowo lakes were analysed.

The lakes (Fig. 1) are shallow and connected with the Baltic Sea via channels through which they drain. At high sea water levels caused by north winds, brackish water enters the lakes, resulting in an increase of water level by about 1 m. The lakes are supplied by the rivers and streams, carrying water from local drainage areas. Lake shores are surrounded with dense belts of macrophytes. Large area and low depth of the lakes result in wind water mixing down to the muddy bottom. Due to water mixing and vicinity of cold Baltic Sea, the lakes are considered colder than other inland lakes of the region. Despite similar morphometry, water chemistry and bacterial communities of Pomeranian lakes considerably differ. Zooplankton communities, and their biomass are, however, similar (Żmudziński et al. 1990).

Almost all lake fish species are found in these water bodies. Among coregonid fish, whitefish is sometimes harvested in small numbers in the deepest Łebsko Lake.

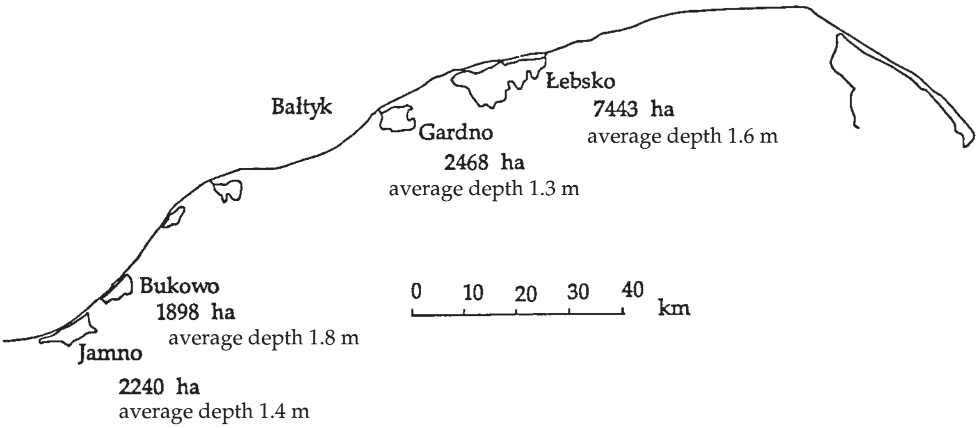

Fig. 1. Situation, area, and average depth of West Pomeranian lakes used for fish catch analysis

Bream and roach predominate in commercial fish landings, and among the predators – pike-perch and perch (Ciepielewski 1992). Most valuable fish – eel – is caught mainly in traps, from spring to autumn, together with other mentioned above species and pike. Other fishing gears are also used, such as drag nets.

Numbers of traps and drag nets used in the lakes did not change much over the time, but frequency of their use changed yearly, depending on weather. Changes of fish exploitation intensity resulted in yearly differences of fish yields. Main tendencies of catch dynamics over the study period are, however, quite clear, indicating that the yield in kg ha^{-1} year^{-1} is a sufficiently accurate measure.

MATERIAL AND METHODS

Yearly catch (kg ha^{-1} year^{-1}) of various fish species in the lakes was analysed using time series analysis. Correlation coefficients (autocorrelations) were calculated between successive values, according to the following formula (Jensen 1976):

$$r_j = \frac{\frac{1}{T}\sum_{i=1}^{T-j}(C_i - \overline{C})\cdot(C_{i+j} - \overline{C})}{\frac{1}{T}\sum_{i=1}^{T-j}(C_i - \overline{C})\cdot(C_i - \overline{C})}$$

where:

r_j – autocorrelation related to time lag j (in years)

T – number of observation periods

C_{i+j}, C_i – catch in i+j and i period

$\overline{C}$ – average catch yield in the observation time

According to Box and Jenkins (1970), at least 50 values should be analysed to obtain autocorrelation useful for accurate forecast. In our study only 42 values were available (1951-1992). Calculated values of series correlation coefficients are shown in graphs (correlograms) as function of time lag (in years). The correlograms were then used to evaluate autoreggresion equation order, indicating catch yield in year t forecasted from values observed in the previous years. In cases of a fading sinus curve, forecasting should be done using linear autoregression equation of the second or higher orders (Box, Jenkins 1970 – in Polish 1983).

For further calculations of forecasted catch yield, 3 equations were used: of the first, second and third order. The results are shown in graphs compared with the actual catch.

Linear autoreggresion equation of the first order was:

$$Y_t = \mu + \varphi_1 (Y_{t-1} - \mu),$$

The second order:

$$Y_t = \mu + \varphi_1 (Y_{t-1} - \mu) + \varphi_2 (Y_{t-2} - \mu),$$

And the third order:

$$Y_t = \mu + \varphi_1 (Y_{t-1} - \mu) + \varphi_2 (Y_{t-2} - \mu) + \varphi_3 (Y_{t-3} - \mu),$$

where:

Y_t – catch yield in year t

μ – average catch in the observation period

φ_1, φ_2, φ_3 – constant equation coefficients calculated separately for each equation order from series correlation coefficients (r_1, r_2, r_3).

For equation of the first order:

$$\varphi_1 = r_1,$$

for the second order:

$$\varphi_1 \quad \frac{r_1(1 \quad r_2)}{1 \quad r_1^2}$$

$$\varphi_2 \quad \frac{r_2 \quad r_1^2}{1 \quad r_1^2}$$

and for the third order:

$$\varphi_1 \quad \frac{r_1 \quad r_1^2 r_3 \quad r_2^2 r_1 \quad r_2 r_3 \quad r_1^3 \quad r_2 r_1}{(r_2 \quad 1)(2r_1^2 \quad r_2 \quad 1)}$$

$$\varphi_2 \quad \frac{r_2 \quad r_1^2 r_2 \quad r_1 r_2 r_3 \quad r_2^3 \quad r_1 r_3 \quad r_1^2}{(r_2 \quad 1)(2r_1^2 \quad r_2 \quad 1)}$$

$$\varphi_3 \quad \frac{r_3 \quad r_1 r_2^2 \quad r_1^3 \quad 2r_1 r_2 \quad r_1^2 r_3}{(r_2 \quad 1)(2r_1^2 \quad r_2 \quad 1)}$$

Calculated values of linear autoregression were compared with the actual catch yield.

RESULTS

AUTOCORRELATIONS

Correlograms of different shape were obtained for various fish species (Figs. 2-7). It may be, however, assumed that in the majority of cases they represented a fading sinus curve, indicating that higher order (second or third) equations should be used. Jansen (1976), however, concluded that the third order equation applied for forecasting of menhaden (*Bevortia tyrannis*) catch did not increase forecasting accuracy.

AUTOREGRESSIONS

Autoregression curves were plotted for catches of bream, pike, and pike-perch. No forecast was done for eel, although autocorrelation results indicate strong relation between catch in t year and previous years (Fig. 3). Regular shapes of correlograms (fading sinus curve) for Jamno and Łebsko lakes confirm the hypothesis that equations of the second and third order should be used. However, it was taken into consideration that these lakes were sporadiccally stocked during study period (1951-1992) with various numbers of eel fry, while regular stocking of other inland lakes with this species was discontinued in the last 20 years. Presumably this resulted in strongly reduced migration of eel to Pomeranian lakes, which might have caused high error of catch forecasting.

No forecast was also done for roach and perch, although the correlograms were similar to those for bream and pike, respectively. However, roach and perch catches considerably varied over time, which made forecasting very inaccurate.

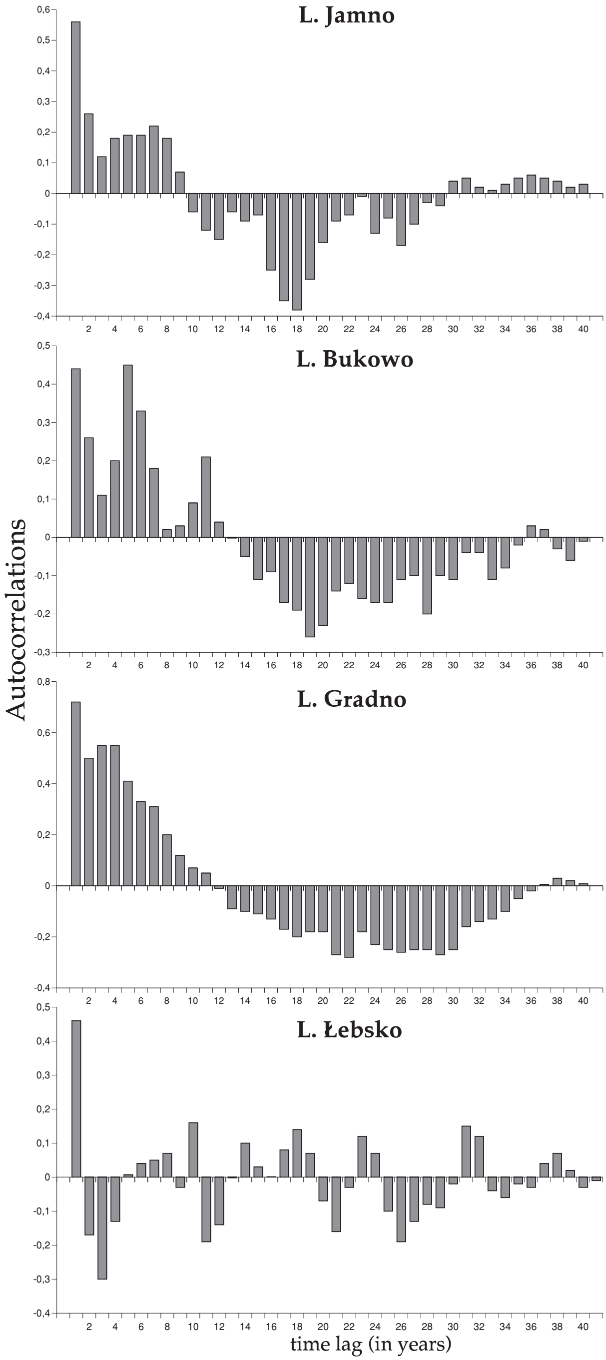

Fig. 2. Correlograms of roach catch.

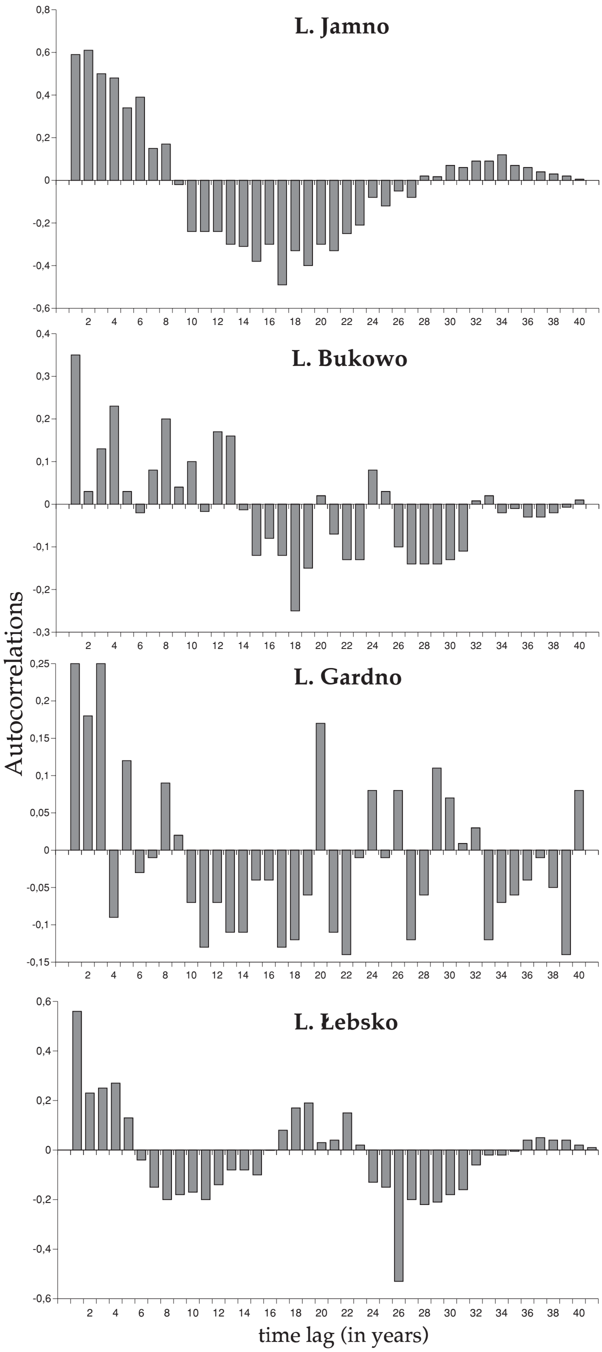

Fig. 3. Correlograms of eel catch

Plotted linear autoregression curves for bream (individuals over 0.5 kg) in all lakes did not considerably differ from the actual values (Fig. 8). The smallest deviation of calculated values from the real ones was observed for Jamno Lake, and the greatest – for Gardno and Bukowo lakes in which theoretical values were almost 100% higher than the real values of maximum and minimum catches. Values calculated using 3 types of equations for Gardno and Jamno lakes do not considerably differ. For Łebsko and Bukowo – the forecasted values obtained using equation of the third order differed from the real values, and values calculated using the first and second order equations - up to 100%. This was especially true for the years of maximum and minimum catches.

The curves for pike in Łebsko, Bukowo, and Gardno lakes (Fig. 9) plotted using forecasted values fit better real values than the data for bream in the same lakes.

Theoretical values for pike obtained using all three types of equations are very similar for Łebsko and Bukowo lakes, but for Gardno the third order equation values are higher in the years of high catch (over 1 kg ha^{-1} $year^{-1}$), and lower for the years of minimum catch (under 1 kg ha^{-1} $year^{-1}$).

Very regular correlograms (fading sinus curve) obtained for pike from these lakes (Fig. 5) confirm the hypothesis that in such cases, the first or second order equations are sufficient for accurate forecasting.

No forecast was done for pike catches in Jamno Lake despite regular correlogram and high linear correlation values in the first two years ($r_1 > 0.8$, $r_2 > 0.7$). In the last decades, however, pike catches considerably decreased under 0.1 kg ha^{-1} $year^{-1}$, thus the error would be very high.

Pike-perch was observed every year in Jamno, Bukowo, and Łebsko lakes. Theoretical curves for this species are, however, less similar to those plotted using actual data compared to the curves for bream or pike. In the years of maximum, and minimum catches, theoretical values differed from empirical ones several fold – in plus or in minus (Fig. 10). Moreover, in Bukowo and Łebsko lakes, values obtained using all three types of equations were similar, and in Jamno lake, the third order equation values considerably differed from the first and second order ones, and produced curve was least similar to the one plotted using the actual values.

The curves for theoretical data indicate that the highest forecasting accuracy was obtained for the periods in which fish catch did not differ over 100% in some successive years, and for the periods of high fluctuations of catch, the forecasts were inaccurate.

In Tab. 1 forecast of bream, pike, and pike-perch catch is shown for 1993, which

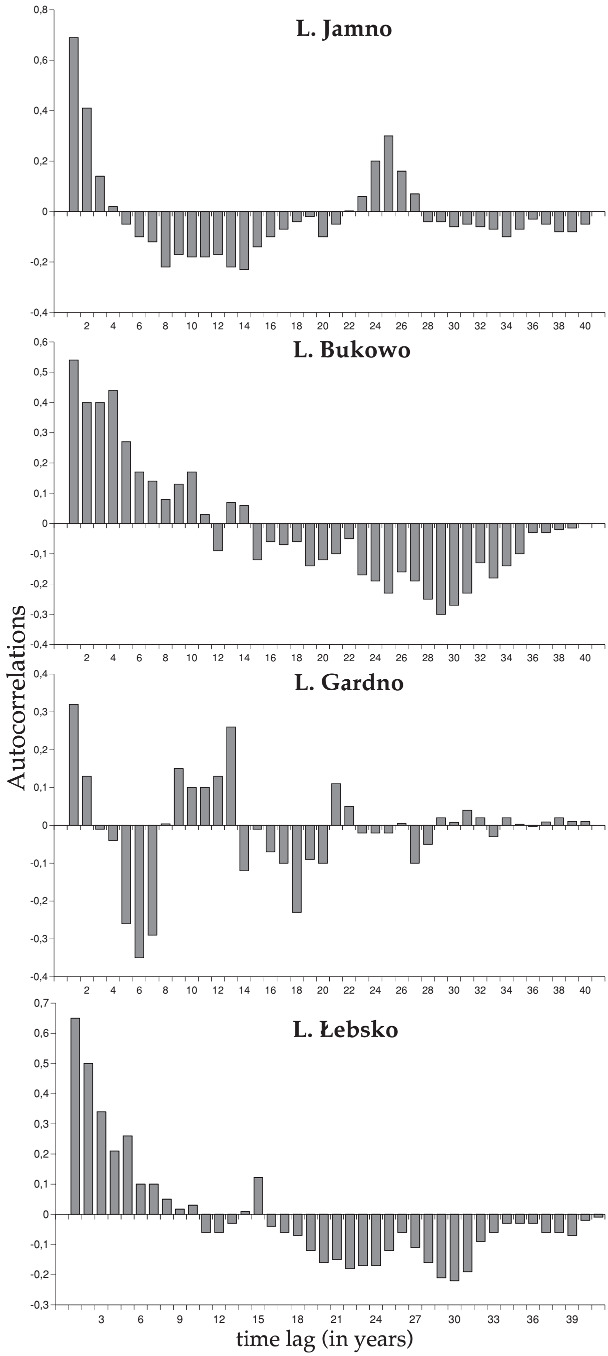

Fig. 4. Correlograms of bream catch

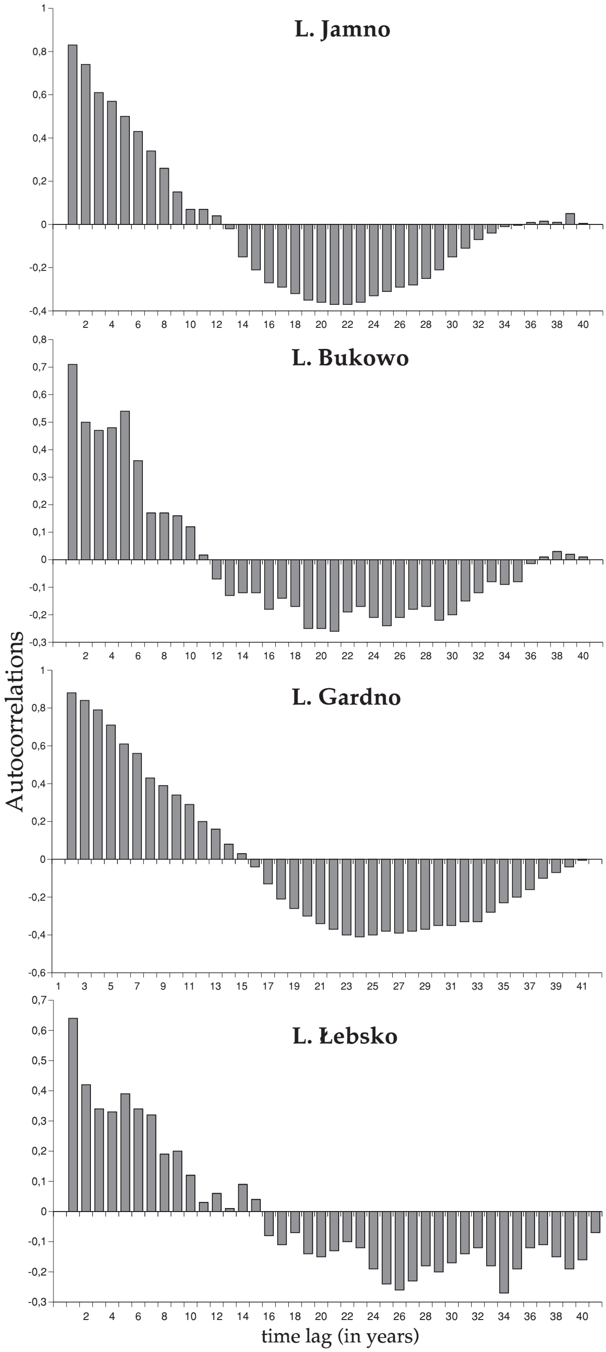

Fig. 5. Correlograms of pike catch

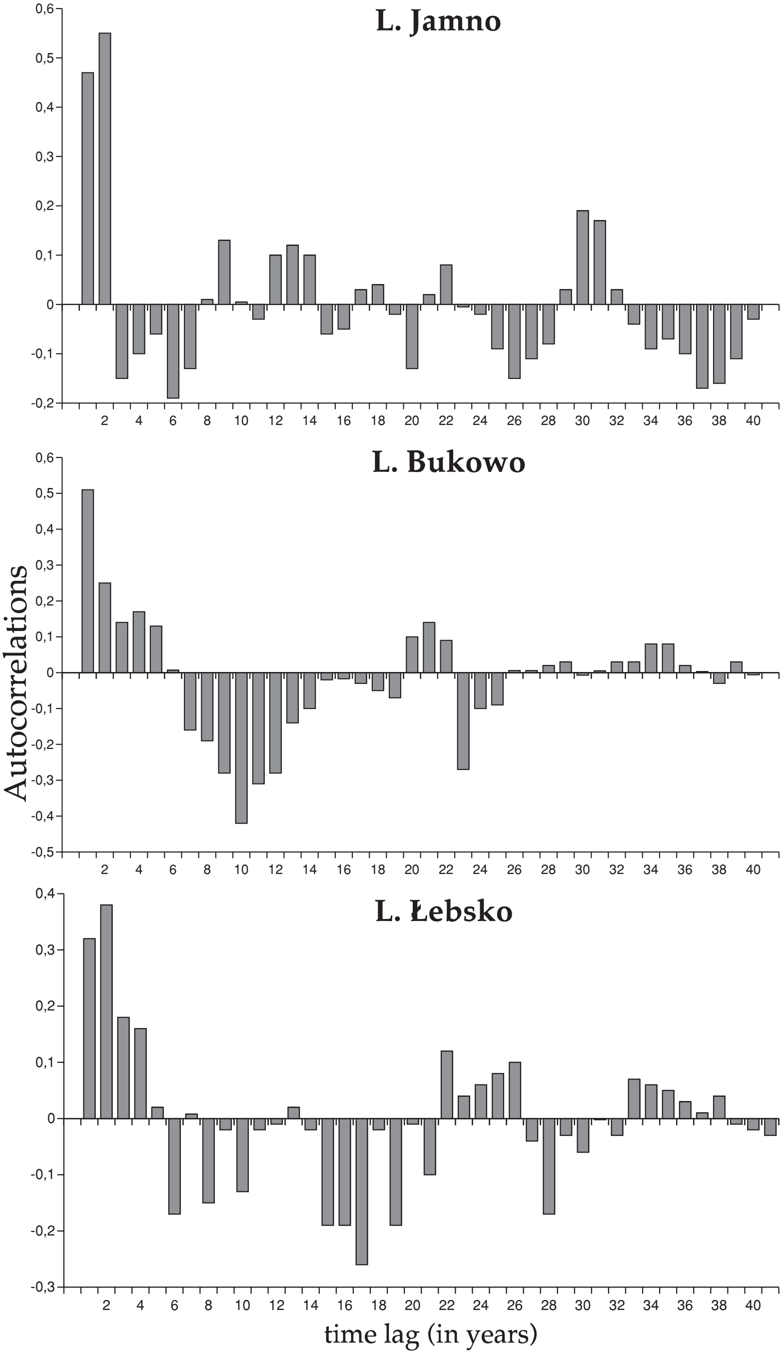

Fig. 6. Correlograms of pike-perch catch

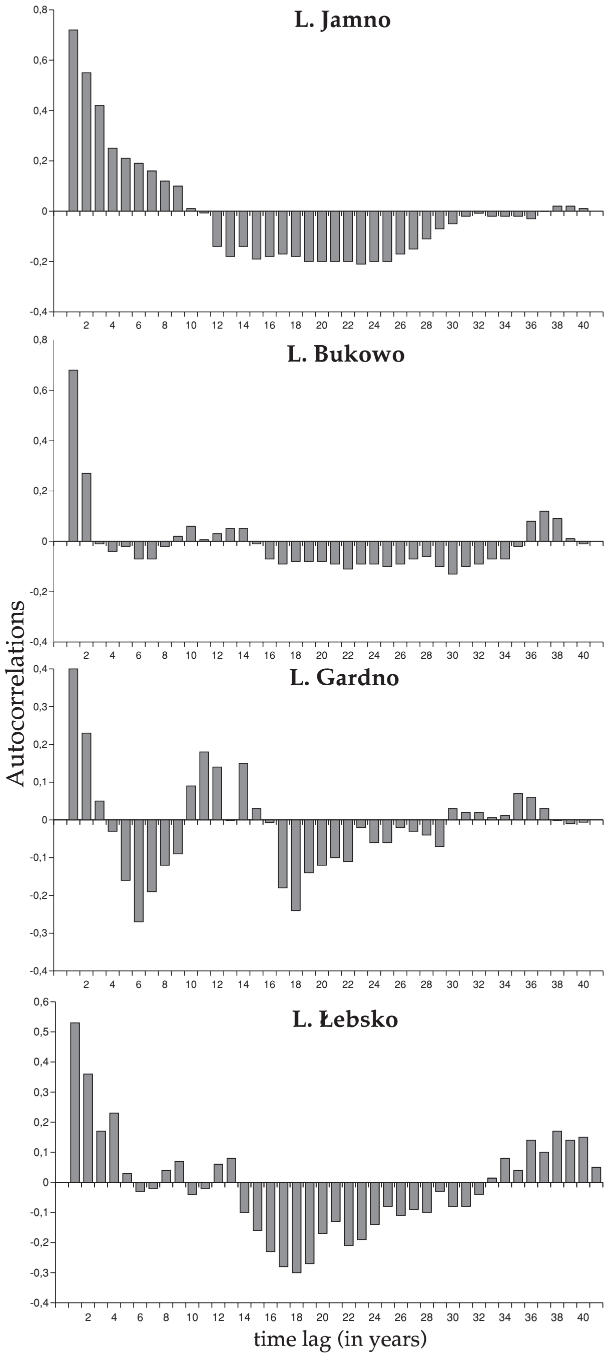

Fig. 7. Correlograms of perch catch

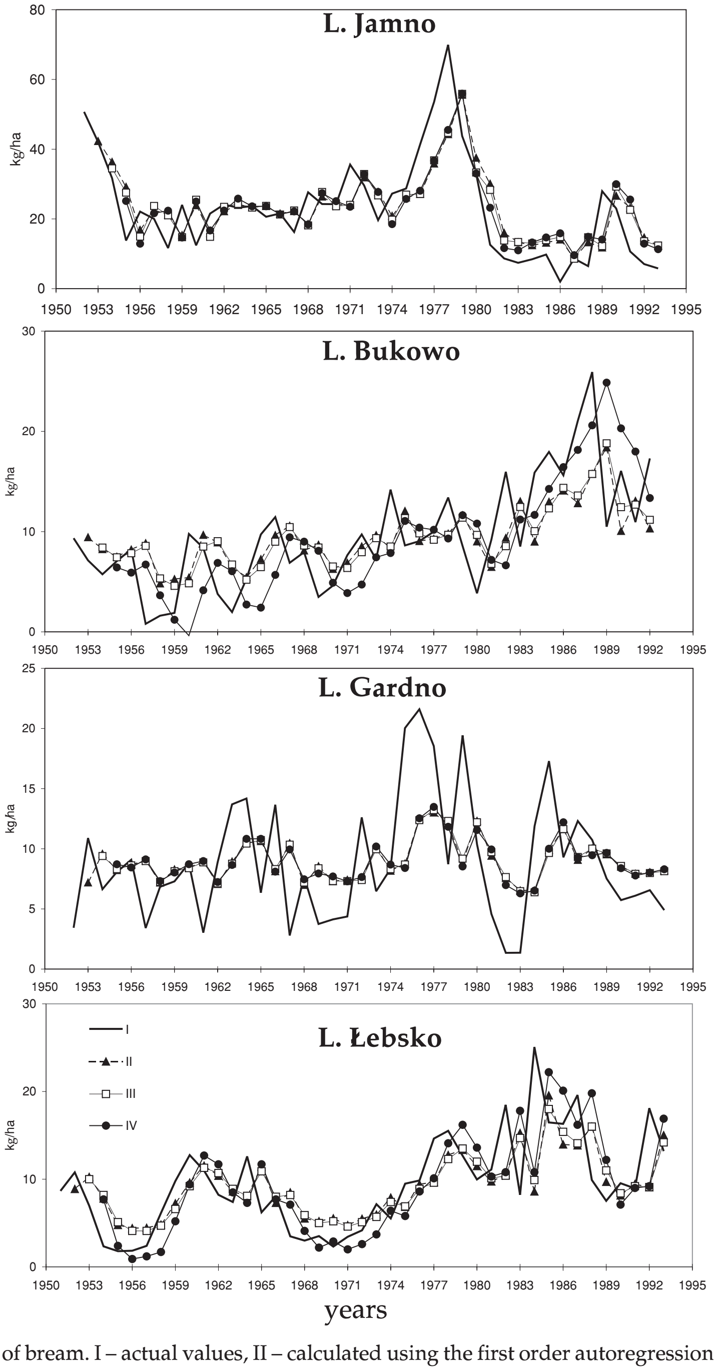

Fig. 8. Catches of bream. I – actual values, II – calculated using the first order autoregression equation, III – using the second order equation, IV – using the third order equation

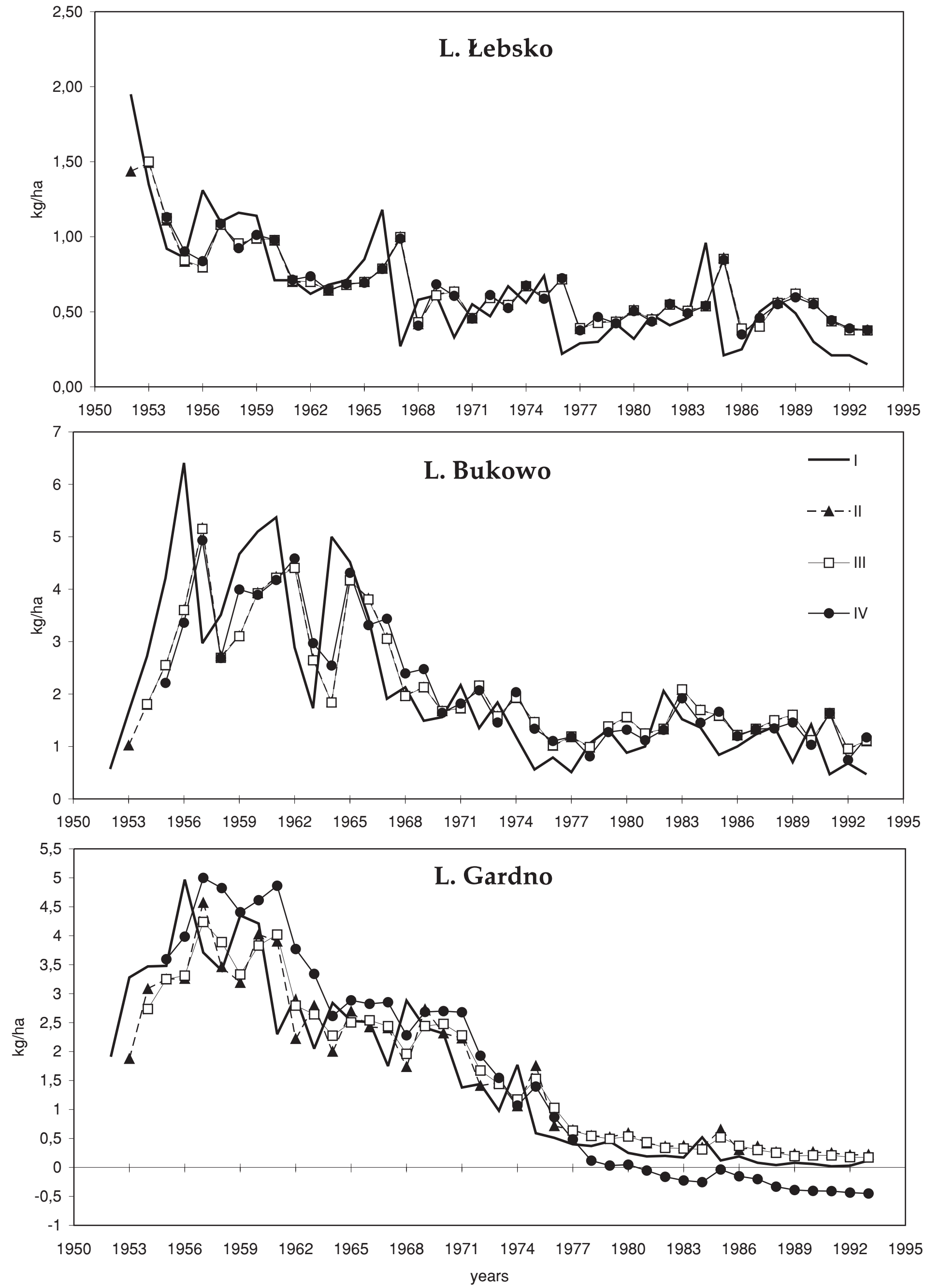

Fig. 9. Catches of pike. I – actual values, II – calculated using the first order autoregression equation, III – using the second order equation, IV – using the third order equation

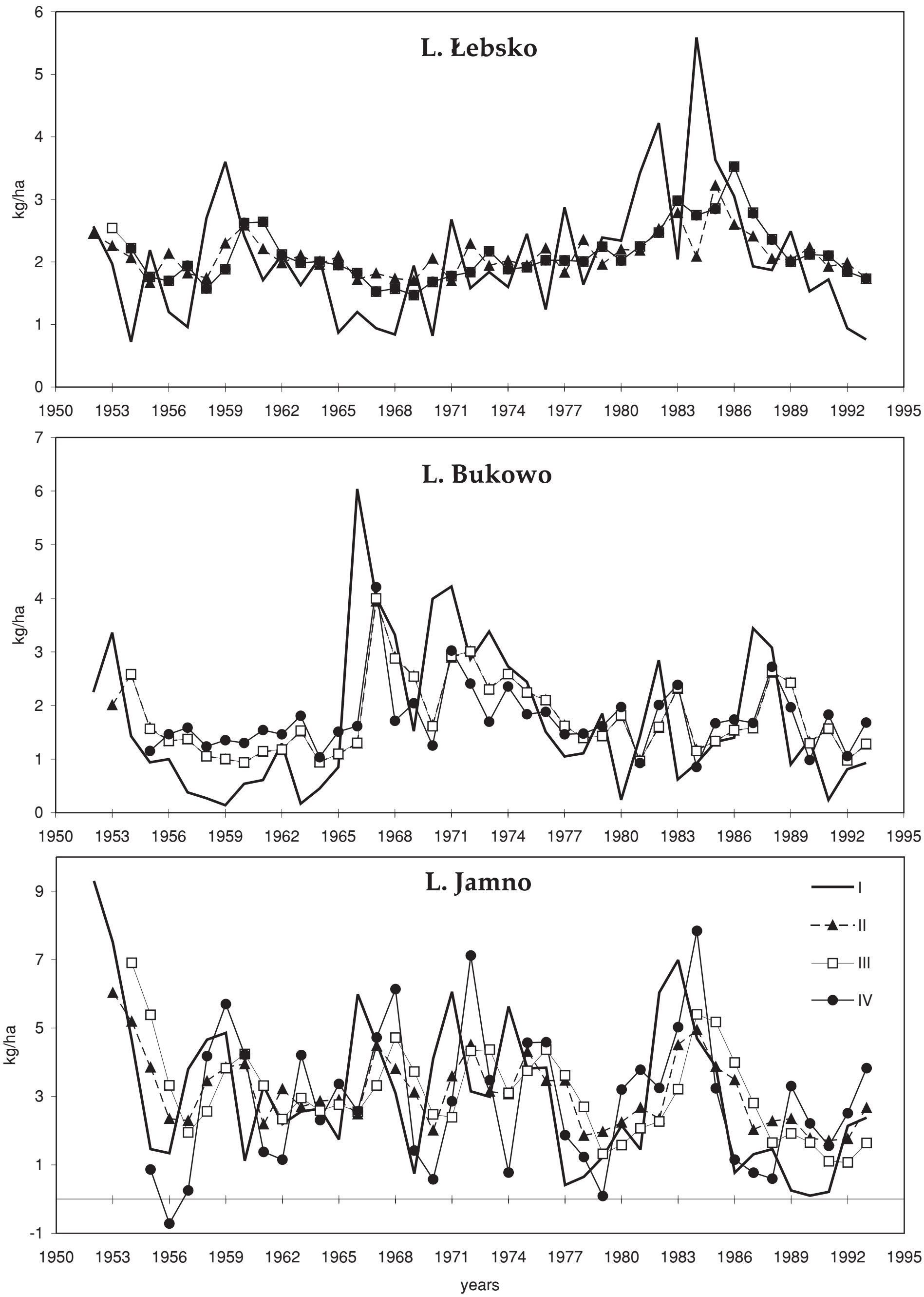

Fig. 10. Catches of pike-perch. I – actual values, II – calculated using the first order autoregression equation, III – using the second order equation, IV – using the third order equation

was excluded from the time series analysis. Calculated values of bream catch are most similar to the actual ones for Bukowo and Łebsko lakes – the differences are equal to 14 and 21%, respectively. For Gardno Lake the difference is 110%, and for Jamno – 67%.

The forecast of pike catch is even more inaccurate. Values calculated for all lakes are over 100% higher compared to the empirical ones. The differences for pike-perch were: 12% in Jamno, 36% in Bukowo, and 127% in Łebsko.

DISCUSSION

Fishery catch forecast obtained using linear autoregression equations is accurate when fish population numbers do not considerably fluctuate over the study period, and exploitation remains at a constant level.

It was already mentioned that fishery techniques, and type and numbers of the fishing gear in the lakes under study did not highly vary over the study period. The fish were harvested using traps and drag nets. Occasionally gill nets were used. Exploitation, however, differed due to different frequency of discharge limited by the weather.

Some data on fish catch in 1991-1993 are shown in Tab. 2.

TABELA 1

Theoretical and actual fish catch yield values in 1993 (kg ha^{-1})

Lake	Species	Real catch	Theoretical catches		
		I	II	III	IV
Łebsko	Bream	13,2	15,0	14,2	16,9
	Pike	0,15	0,38	0,37	0,38
	Pike-perch	0,76	1,73	1,73	1,73
Gardno	Bream	4,9	8,2	8,1	8,3
	Pike	0,12	0,22	0,17	0,45
Bukowo	Bream	11,3	13,7	13,3	16,1
	Pike	0,47	1,1	1,1	1,2
	Pike-perch	0,93	1,27	1,28	1,3
Jamno	Bream	5,8	12,2	12,4	11,3
	Pike	0,1	0,21	0,2	0,21
	Pike-perch	2,38	2,67	1,64	3,83

High intensity of traps is characteristic for Pomeranian lakes, in which eel is of particular fishery interest. Eel traps are set in the lake usually from April to November, and are removed before the first frosts.

In autumn and winter fish are harvested using drag nets. In these periods over 90% of hauls take place, usually one haul a day. The data in Tab. 2 show that drag nets are used about 1 month a year.

TABLE 2

Number of days of drag nets use (P), number of trap inspections (N), and total fish catch in the lakes in 1991-1993

Lake	1991			1992			1993			Drag net	Traps
	P	N	Total catch $kg \cdot ha^{-1}$	P	N	Total catch $kg \cdot ha^{-1}$	P	N	Total catch $kg \cdot ha^{-1}$	V%	V%
Jamno	17	16710	33,1	29	17100	43,5	18	19440	29,1	25,5	6, 8
Bukowo	28	7440	28,9	40	10320	35,4	20	13200	25,4	28	22,8
Gardno	24	41400	16,2	36	39200	18,5	21	62800	17,5	24	22,2
Łebsko	47* (19+28)	39100	21,2	108* (51+57)	45850	27,5	84* (38+46)	43400	22,2	31,5	6,5

* - *Fish caught with two drag nets*

$V\% \quad \frac{\text{standard deviation}}{\text{mean}}$

The traps are checked almost every day,depending on the weather. In 1991-1993 six fishermen used traps in Jamno, 4 in Bukowo, 8 in Gardno, and 14 in Łebsko. In Jamno, Bukowo, and Gardno lakes each fisherman used 30 traps, and in Gardno – 25. Exceptionally, in 1993, each Gardno fisherman used 50 traps.

In that period (1991-1993) the highest intensity of trawling was noted in 1992 (Tab. 2), when number of hauls was much higher than in 1991. In case of Łebsko Lake, the difference was 130%. Also number of trap inspections was in 1992 higher than in 1991. In Jamno – by 2.3%, in Bukowo – 38.7%, and in Łebsko – 14.7%. Only in Gardno Lake number of trap inspections was 5.3% lower. Total fish catch in all lakes was higher in 1992 than in 1991.

In 1993 drag net use was less frequent by 22-50% than in 1992. Number of trap inspections in Jamno, Bukowo, and Gardno was higher by 14, 28, and 60% respectively. In Łebsko Lake it was lower by 5.3%. Fish catch yield dropped in all lakes.

Thus, it may be concluded that total fish catch per 1 ha was higher in the years of more intense drag net use. This is confirmed by the fact that despite higher frequency of trap use in Jamno, Bukowo, and Gardno in 1993 compared to 1992, fish catch was lower due to lower number of hauls.

Observations of age structure of the harvested fish carried out by the author for three decades (unpublished) did not reveal any „strong" age-classes of bream, roach, pike-perch or pike which would predominate over some period causing higher fish catch. It should be mentioned that all exploited fish species are long-living (bream, roach), so share of new age-classes was not so well pronounced as in case of species with short life span.

It seems that unstable exploitation intensity, dependent on weather, and number of fishing gears used, were the main factors causing the differences in fish catch in Pomeranian lakes. This resulted in high differences between the successive years and rapid changes of the trends.

Thus, forecasting of fish catch one year ahead seems highly inaccurate, and only for some species (bream, pike-perch, pike), under conditions of stable exploitation, forecasting accuracy may be sufficiently high for practical use.

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STRESZCZENIE

PRZYDATNOŚĆ ANALIZY SZEREGÓW CZASOWYCH (TIME SERIES ANALYSIS) W PROGNOZOWANIU POŁOWÓW RYBACKICH W KILKU JEZIORACH PRZYMORSKICH

Aby sprawdzić przydatność analizy szeregów czasowych do prognozowania wielkości odłowów przemysłowych, poddano analizie połowy rybackie różnych gatunków ryb z jezior przymorskich południowego Bałtyku (rys. 1). Analizowano połowy leszcza, płoci, sandacza, okonia, szczupaka i węgorza z lat 1951-1992. Przyjęto, że roczny odłów ($kg \cdot ha^{-1} \cdot rok^{-1}$) jest odpowiednim parametrem do tego rodzaju analizy. A mianowicie, obliczono współczynniki korelacji szeregowej i sporządzono korelogramy połowów wspomnianych gatunków (rys. 2-7). Do obliczeń wielkości przewidywanych odłowów wykorzystano trzy równania autoregresji liniowej,

pierwszego rzędu

$$Y_t=\mu+\varphi_1(Y_{t-1}-\mu),$$

drugiego,

$$Y_t=\mu+\varphi_1(Y_{t-1}-\mu)+\varphi_2(Y_{t-2}-\mu)$$

i trzeciego,

$$Y_t=\mu+\varphi_1(Y_{t-1}-\mu)+\varphi_2(Y_{t-2}-\mu)+\varphi_3(Y_{t-3}-\mu),$$

gdzie, Y_t – odłów w roku t

μ - średni odłów w analizowanym okresie obserwacji

φ_1, φ_2, φ_3 – stałe parametry równania obliczone oddzielnie dla równania każdego rzędu z współczynników korelacji szeregowej (r_1 , r_2, r_3).

Dla równania autoregresji pierwszego rzędu

$$\varphi_1=r_1,$$

drugiego

$$\varphi_1 \quad \frac{r_1(1 \quad r_2)}{1 \quad r_1^2}$$

$$\varphi_2 \quad \frac{r_2 \quad r_1^2}{1 \quad r_1^2}$$

a dla trzeciego

$$\varphi_1 \quad \frac{r_1 \quad r_1^2 r_3 \quad r_2^2 r_1 \quad r_2 r_3 \quad r_1^3 \quad r_2 r_1}{(r_2 \quad 1)(2r_1^2 \quad r_2 \quad 1)}$$

$$\varphi_2 \quad \frac{r_2 \quad r_1^2 r_2 \quad r_1 r_2 r_3 \quad r_2^3 \quad r_1 r_3 \quad r_1^2}{(r_2 \quad 1)(2r_1^2 \quad r_2 \quad 1)}$$

$$\varphi_3 \quad \frac{r_3 \quad r_1 r_2^2 \quad r_1^3 \quad 2r_1 r_2 \quad r_1^2 r_3}{(r_2 \quad 1)(2r_1^2 \quad r_2 \quad 1)}$$

Obliczone z każdego z trzech rodzajów (rzędów) równań autoregresji liniowej, przewidywane wielkości odłowów, porównano z rybackimi (rys. 8-10). Krzywe autoregresji wykreślono tylko dla leszcza,

szczupaka i sandacza wychodząc z założenia, że duża zmienność odłowów węgorza, okonia i płoci w poszczególnych latach analizowanego okresu, przy braku widocznych trendów połowowych obniża praktycznie do zera trafność przewidywań. Z przebiegu krzywych wykreślonych dla danych teoretycznych wynika, że najwyższą trafność prognozy uzyskano dla lat w których odłowy rzeczywiste nie różniły się w kilku kolejnych latach o ponad 100%. W latach dużych wahań połowów trafność prognozy była niewielka. Dlatego, prognozowanie odłowów z rocznym wyprzedzeniem jest obarczone dużymi błędami i tylko, jak się wydaje, w przypadku niektórych gatunków (leszcz, sandacz, szczupak), może mieć praktyczne zastosowanie, jeżeli podlegają one względnie ustabilizowanej eksploatacji.

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