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# Application of Econometric Model for Water Economy Management

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**Abstract.** The econometric model can be a precise instrument for the analysis of the impact of the natural environmental degradation on the fishing economy. This paper aims at analysing the influence of the water quality changes in Charzykowskie Lake on the fishing economy. The economic-ecological models have been constructed, explaining the changes of economic effects of the lake fishery in the conditions of an increasing water pollution in the hypolimnion on the example of the catch of *Rutilus rutilus*, *Blicca bjoerkna*, *Coregonus lavaretus*, *Anguilla anguilla* and *Esox lucius* in Charzykowskie Lake. Performed empirical research focuses on the influence of the environmental factors on the size of fish catch. Calculations and analysis show clearly that even though the habitat factors have an influence on the catch size of each studied fish species, they do it with different intensity and in various combinations. Both, lake water quality and climate factors changes, cause measurable effects on fishing industry of Charzykowskie Lake. Among the examined *Rutilus rutilus* and *Blicca bjoerkna, Blicca bjoerkna* has the highest high environmental requirements regarding the water quality. Empirical calculations showed as well that *Coregonus lavaretus* has considerably higher water cleanness requirements than *Rutilus rutilus* and *Blicca bjoerkna*. While considering *Rutilus rutilus* and *Blicca bjoerkna*, most water characteristics still rather stimulate a development of these species, but when it comes to *Coregonus lavaretus*, in general they suppress its development. The model has also proved quite high habitat requirements for *Anquilla anquilla* and correctness of the thesis that *Esox lucius* avoids polluted water. Climatic factors influence is significant for the endogenous variables. The above prejudges the itineration of *Rutilus rutilus*, *Blicca bjoerkna*, *Coregonus lavaretus*, *Anquilla anquilla* and *Esox lucius* catch in Charzykowskie Lake. The results of the modelling can be used in managing the fishing economy of the lake.

**Keywords:** econometric model, water economy, lake water pollution, managing.

**Conference topic:** Environmental protection.

## Introduction

The increase in environmental pollution is a threat not only to biological human being, but also for the economy of the country. Hence, it is important, among others, to analyse the impact of the deterioration of the lake water quality on the economic effects of the fisheries management. Due to significant difficulties to obtain full statistical data about the economic effects resulting from the use of a specific area, the analysis was limited to the results for fisheries management.

Therefore, observation and analysis of the relationship between the effects of fishing economy and changes in water quality in a lake are possible only in a place where the degree of pollution is relatively low, thereby leading to fishing. A structured system of quality water changes and volume in catches is also essential. These conditions are satisfied in relation to Charzykowskie Lake in Pomerania province. Therefore, the article presents the results of analysis covering the lake.

Econometric models showing the effects of pollution of the natural environment on the elements of the country economics has appeared in the literature (Agnew 1979; Dyer, Gillooly 1979; Jorgensen 1980). The aim of the paper is to analyse the impact of water quality changes in Charzykowskie Lake on the catch of fish. The article presents the research results regarding the impact of the lake water pollution on the effects of fishing industry. Designed environmental and economic models explain the changes of the economic effects of the lake fishery at the time of increasing water pollution in the hypolimnion.

## Method

In Poland, attempts to estimate the environmental losses were based on fragmentary empirical generalizations for a long time. Deterministic and stochastic modelling methods were not used to determine such losses until 1989. Ramczyk's article (Ramczyk 1989), published in 1989, launched an interest of econometricians in modelling the losses of the lake water degradation. Other papers have been published as a result, e.g.: Ramczyk and Wiśniewski's article (Ramczyk, Wiśniewski 1988), Ramczyk's papers (Ramczyk 2006, Ramczyk 2007, Ramczyk 2008, Ramczyk 2010, Ramczyk 2012), as well as Ramczyk and Giryn's articles (Ramczyk, Giryn 2010; Ramczyk, Giryn 2013).

The paper focuses on the analysis of the impact of the deterioration of the lake water quality on the economic effects of the fisheries management. An econometric model can be a precise instrument for the analysis of the impact of natural environment degradation on the effects of management. Consider the following model consisting of $G$ stochastic equations:

$$y_{it} = \sum_{j=0}^{k} \alpha_{ij} x_{tj} + \eta_{ti}, (i = 1, 2, ..., G \quad and \quad t = 1, 2, ..., n) \tag{1}$$

where:
$y_{it}$ – $i$-th effect of an economic activity during time $t$,
$x_{tj}$ ($j$=1, 2, .., $k$) – meters of natural environment descriptions among $k$ during time $t$,
$\alpha_{ij}$ – model parameters which are the measures of separate impact of each of the environmental characteristics on $i$-th result of management,
$\eta_{ti}$ – random component of $i$-th equation,
$t$ – observation time (quarter).

We assumed that if in model (1) $y_{it}$ is a size of $i$-th sort of the catch and $x_{tj}$ is the level of consistence $j$-th substance in water ($j$=1,2, ..., $k$), then the structural parameter $\alpha_{ij}$ can give information about three different situations:

a) if $\alpha_{ij} = 0$, then the concentration of $j$-th substance in the lake is indifferent for the size of $i$-th sort of the catch, which means the pollution of the lake is not significant for considering $i$-th effect;
b) when $\alpha_{ij} > 0$, then the content of $j$-th substance in the lake water is below the zone of indifference, thereby it would by a stimulator for development of the particular fish population, which means it would have a positive impact on the catch of the fish;
c) when $\alpha_{ij} < 0$, then we are dealing with the lake water pollution which is above the zone of indifference. Among observed content of $j$-th substance, water is dominated by the observations of exceeded level of the zone of indifference. Consequently, the weight gain of the component in the lake is detrimental for its fish stocks and, thereby, it has a negative impact on considered $i$-th economic effect.

Therefore, the empirical linear econometric model was developed and it describes the reaction of the size of $i$-th sort of the catch on the water quality changes of the epilimnion of Charzykowskie Lake. The model is assumed to give a statistical estimation of the impact of different sequences of environmental factors (19 exogenous variables) on the size of the catch of *Rutilus rutilus*, *Blicca bjoerkna*, *Coregonus lavaretus*, *Anguilla anguilla* and *Esox lucius* (5 endogenous variables). The parameters for each endogenous variable were estimated, depending on different environmental factors. Estimates of particular equations were carried out on the basis of 26 quarterly observations, whereby the acceptance of three-month data sequence regarding variables was based on the assumption of adequately reflect of their intensity in typical limnological seasons of the lake. Many versions of relationships between economic and environmental variables were considered during the model development. The principle of specification for the model equations was as follows: one of exogenous variables was eliminated during each iteration of maximum set of exogenous variables. A variable which obtained the lowest empirical value of Student's t-distribution was eliminated. Due to this step at a time manner, the set of variables was formed, in which all of the variables can be classified as statistically significant. Ultimately, the only exogenous variables included in the particular equations were these which have statistically significant impact on the endogenous variables.

## Results and discussion

The following presents the results of estimation of the parameters of structural equations of the linear econometric model which describes the influence of many different characteristics of the lake water in the epilimnion on the size of fish catch in Charzykowskie Lake with a different sets of environmental variables. In each of equations, the calculated values of Student's t-distribution are given in brackets under the parameter estimates. Furthermore, the equations show the following measures which describe random fluctuations of the fish catch: $R^2$ – the multiple correlation coefficient, $\overset{\frown}{\alpha}_{\eta}$ – the estimation of the standard deviation of the random component, $DW$ – the Durbin–Watson statistic, $\overset{\frown}{\rho}_1$ – the first-order autocorrelation coefficient.

Ramczyk's articles (Ramczyk 2006, Ramczyk 2007, Ramczyk 2008, Ramczyk 2010) present the sets of equations regarding the catch of *Rutilus rutilus, Anguilla Anguilla, Abramis brama, Esox lucius, Blicca bjoerkna, Coregonus albula* and *Coregonus lavaretus* with taking into consideration habitat conditions in different layers of the lake, while Ramczyk's paper (Ramczyk 2012) shows generalised empirical equations of these catches, depending on the water quality of entire Charzykowskie Lake. Ramczyk and Giryn's paper (Ramczyk, Giryn 2013) considers generalised empirical equations of the catches, depending on the water quality in the epilimnion (surface layer) of Charzykowskie Lake. Whereas, this article focuses on generalised empirical equations of the catch of *Rutilus rutilus*, *Anguilla Anguilla,* *Esox lucius, Blicca bjoerkna* and *Coregonus lavaretus* conditioned by the water quality in the hypolimnion (bottom layer) of the lake.

The equation of the catch of *Rutilus rutilus*, depending on the level of environmental factors in the bottom layer of Charzykowskie Lake, is as follows (each equation of the model consists of a random residual component (e.g. $\eta_{td}^{(ODP\text{Ł})}$) and indices next to the variables, which have the following meaning: $ODP\text{Ł}$ – the catch of *Rutilus rutilus*, $ODK$ – the catch of *Blicca bjoerkna*, $ODSJ$ - the catch of *Coregonus lavaretus*, $ODW$ – the catch of *Anguilla anguilla*, $ODSZ$ – the catch of *Esox lucius* and $d$ – the bottom layer of the lake, which means the hypolimnion):

$$ODP\text{Ł}_t = \underset{(2.000)}{0.838} - \underset{(2.629)}{0.123}\ TWOG_t^{(d)} + \underset{(2.951)}{0.036}\ MG_t^{(d)} + \eta_{td}^{(ODP\text{Ł})}, \tag{2}$$

where:

$ODP\text{Ł}_t$ – the catch of *Rutilus rutilus* (in kilograms),

$TWOG_t^{(d)}$ – total water hardness of the bottom layer of the lake (in German degrees),

$MG_t^{(d)}$ – magnesium concentration in the hypolimnion (in mg/dm$^3$)

and:

$R^2 = 0.316$; $\hat{\alpha}_\eta = 0.4214$; $DW = 2.142$; $\hat{\rho}_1 = -0.2873$.

The equation of the catch of *Blicca bjoerkna,* depending on environmental factor changes in the hypolimnion of the lake, is presented as follows:

$$\begin{gathered}ODK_t = -\underset{(4.126)}{21.529} + \underset{(2.487)}{1.092}\ OW_t^{(d)} + \underset{(1.980)}{0.259}\ NOG_t^{(d)} + \underset{(2.306)}{0.148}\ TR_t^{(d)} + \underset{(2.996)}{2.162}\, FF_t^{(d)} + \underset{(4.022)}{0.070}\, PZOS_t^{(d)} + \\ \underset{(2.191)}{0.213}\, TWOG_t^{(d)} + \underset{(2.639)}{1.030}\, PW_{t-1} + \eta_{td}^{(ODK)},\end{gathered} \tag{3}$$

where:

$ODK_t$ – the catch of *Blicca bjoerkna* (in kilograms),

$OW_t^{(d)}$ – pH of water in the bottom layer of the lake,

$NOG_t^{(d)}$ – total nitrogen concentration in the hypolimnion (in mg/dm$^3$),

$TR_t^{(d)}$ – dissolved oxygen content in the hypolimnion (in mg/dm$^3$),

$FF_t^{(d)}$ – concentration of phosphates in the hypolimnion (in mg/dm$^3$),

$PZOS_t^{(d)}$ – organic substance content in dry matter of seston in the hypolimnion (in percentage),

$TWOG_t^{(d)}$ – total water hardness of the bottom layer of the lake (in German degrees),

$PW_{t-1}$ – average wind speed with quarterly delay (in m/s)

and:

$R^2 = 0.7205$; $\hat{\alpha}_\eta = 0.8365$; $DW = 1.631$; $\hat{\rho}_1 = -0.1626$.

The equation of the catch of *Coregonus lavaretus*, depending on the water quality in the hypolimnion and climate variables, has the following empirical form:

$$\begin{gathered}ODSJ_t = \underset{(2.265)}{2.669} - \underset{(4.144)}{0.075}\ BZT5_t^{(d)} + \underset{(3.382)}{0.087}\ TWOG_t^{(d)} - \underset{(3.345)}{0.026} MG_t^{(d)} + \underset{(2.218)}{0.061} CL_t^{(d)} + \underset{(3.073)}{0.168} NMIN_t^{(d)} + \\ -\underset{(2.056)}{0.055} NOG_t^{(d)} - \underset{(1.934)}{0.029} TR_t^{(d)} - \underset{(3.452)}{0.378} OW_t^{(d)} - \underset{(3.578)}{0.021} PZOS_t^{(d)} + \underset{(1.699)}{0.048} PZOOD_t^{(d)} - \underset{(2.468)}{0.040} WW_t + \underset{(1.751)}{0.033} TW_t^{(d)} + \eta_{td}^{(ODSL)},\end{gathered} \tag{4}$$

where:

$ODSJ_t$ – the catch of *Coregonus lavaretus* (in kilograms),

$BZT5_t^{(d)}$ – biochemistry oxygen demand in the hypolimnion (in mg/dm$^3$),

$TWOG_t^{(d)}$ – total water hardness of the bottom layer of the lake (in German degrees),

$MG_t^{(d)}$ – magnesium concentration in the hypolimnion (in mg/dm$^3$),

$CL_t^{(d)}$ – chloride content in the hypolimnion (in mg/dm$^3$),

$NMIN_t^{(d)}$ – mineral nitrogen concentration in the hypolimnion (in mg/dm$^3$),

$NOG_t^{(d)}$ – total nitrogen concentration in the hypolimnion (in mg/dm$^3$),

$TR_t^{(d)}$ – dissolved oxygen content in the hypolimnion (in mg/dm$^3$),

$OW_t^{(d)}$ – pH of water in the bottom layer of the lake,

$PZOS_t^{(d)}$ – organic substance content in dry matter of seston in the hypolimnion (in percentage),

$PZOOD_t^{(d)}$ – organic substance content in dry matter of the bottom sediments of the hypolimnion (in percentage),

$WW_t$ – water exchange (in percentage),

$TW_t^{(d)}$ – water temperature of the bottom layer of the area (in degrees Celsius)

and:

$R^2 = 0.8123$; $\overset{\frown}{\alpha}_\eta = 0.1554$; $DW = 2.477$; $\overset{\frown}{\rho}_1 = -0.2468$.

The empirical equation of the catch of *Anguilla Anguilla,* depending on environmental factors of the bottom layer of Charzykowskie Lake, is as follows:

$$\begin{aligned} ODW_t = & \underset{(0.927)}{-2.025} + \underset{(1.632)}{0.235}\, KRS_t^{(d)} + \underset{(1.940)}{0.453}\, MG_t^{(d)} + \underset{(2.274)}{0.232}\, BZT5_t^{(d)} + \underset{(4.806)}{0.257}\, NMIN_t^{(d)} + \underset{(2.179)}{1.701} FF_t^{(d)} + \\ & - \underset{(1.457)}{0.008} PEL_t^{(d)} - \underset{(2.235)}{0.004} U_{t-1} - \underset{(1.800)}{0.007} O_{t-1} + \eta_{td}^{(ODW)}, \end{aligned} \tag{5}$$

where:

$ODW_t$ – the catch of *Anguilla anguilla* (in kilograms),

$KRS_t^{(d)}$ – hypolimnion water transparency (measured by the Secchi disk in centimetres),

$MG_t^{(d)}$ – magnesium concentration in the hypolimnion (in mg/dm$^3$),

$BZT5_t^{(d)}$ – biochemistry oxygen demand in the hypolimnion (in mg/dm$^3$),

$NMIN_t^{(d)}$ – ammoniacal and nitrate nitrogen concentration in the hypolimnion (in mg/dm$^3$),

$FF_t^{(d)}$ – concentration of phosphates in the hypolimnion (in mg/dm$^3$),

$CA_t^{(d)}$ – calcium concentration in the hypolimnion (in mg/dm$^3$),

$PEL_t^{(d)}$ – hypolimnion electrolytic conductivity (in microsiemens),

$U_{t-1}$ – total sunshine quarterly delay (in hours),

$O_{t-1}$ – quarterly precipitation delayed by 1 period (in millimetres)

and:

$R^2 = 0.7038$; $\overset{\frown}{\alpha}_\eta = 0.7371$; $DW = 2.387$; $\overset{\frown}{\rho}_1 = -0.2045$.

The equation parameter estimation of the catch of *Esox lucius,* depending on changes of water purity in the hypolimnion of Charzykowskie Lake and climate change of the region, gives the following results:

$$\begin{aligned} ODSZ_t = & \underset{(3.536)}{2.842} + \underset{(1.952)}{0.025}\, TWOG_t^{(d)} - \underset{(2.545)}{0.174}\, OW_t^{(d)} + 0.045 CL_t^{(d)} - \underset{(3.147)}{0.029}\, TR_t^{(d)} - \underset{(2.330)}{0.001}\, PEL_t^{(d)} + \\ & + \underset{(1.855)}{0.165}\, FF_t^{(d)} + \underset{(2.668)}{0.081}\, NMIN_t^{(d)} - \underset{(2.054)}{0.008}\, MG_t^{(d)} - \underset{(2.922)}{0.026}\, BZT5_t^{(d)} - \underset{(2.849)}{0.010}\, PZOS_t^{(d)} + \underset{(1.769)}{0.017}\, TW_t^{(d)} + \\ & - \underset{(6.040)}{0.029}\, TP_{t-1} - \underset{(2.534)}{0.127}\, PW_{t-1} - \underset{(2.646)}{0.027} WW_t + \eta_{td}^{(ODSZ)}, \end{aligned} \tag{6}$$

where:

$ODSZ_t$ – the catch of *Esox lucius* (in kilograms),

$TWOG_t^{(d)}$ – total water hardness of the bottom layer of the lake (in German degrees),

$OW_t^{(d)}$ – pH of water in the bottom layer of the lake,

$CL_t^{(d}$ – chloride content in the hypolimnion (in mg/dm$^3$),

$TR_t^{(d)}$ – dissolved oxygen content in the hypolimnion (in mg/dm$^3$),

$PEL_t^{(d)}$ – hypolimnion electrolytic conductivity (in microsiemens),

$FF_t^{(d)}$ – concentration of phosphates in the hypolimnion (in mg/dm$^3$),

$NMIN_t^{(d)}$ – ammoniacal and nitrate nitrogen concentration in the hypolimnion (in mg/dm$^3$),

$MG_t^{(d)}$ – magnesium concentration in the hypolimnion (in mg/dm$^3$),

$BZT5_t^{(d)}$ – biochemistry oxygen demand in the hypolimnion (in mg/dm$^3$),

$PZOS_t^{(d)}$ – organic substance content in dry matter of seston in the hypolimnion (in percentage),

$TW_t^{(d)}$ – water temperature of the bottom layer of the area (in degrees Celsius),

$TP_{t-1}$ – average air temperature with quarterly delay (in degrees Celsius),

$PW_{t-1}$ – average wind speed with quarterly delay (in m/s),

$WW_t$ – water exchange (in percentage)

and:

$R^2 = 0.8617$; $\hat{\alpha}_\eta = 0.076$; $DW = 2.330$; $\hat{\rho}_1 = -0.1754$.

The carried out empirical studies consider the impact of environmental factors on the size of the fish catch. Calculations and analysis clearly show that the habitat factors significantly affect the size of the fish catch, but with a different intensity and in various combinations. The changes of the lake water quality and climatic factors cause the measurable impact on the fisheries management of Charzykowskie Lake. *Blicca bjoerkna* has the highest requirements of the water quality among discussed Cyprinidae. The empirical equations also show that Coregoninae have significantly higher requirements of water quality than Cyprinidae. While in the case of cyprinids, most of the characteristics of the water rather stimulate the development of these species, the grow of freshwater whitefish is actually inhibited by those characteristics. The model also confirms quite high habitat requirements of *Anguilla Anguilla*, as well as the thesis that *Esox lucius* avoids polluted water.

Climatic factors have a significant impact on the variables: $ODPŁ_t$, $ODK_t$, $ODSJ_t$, $ODW_t$ and $ODSZ_t$. This conclusion proves seasonality of the catch of *Rutilus rutilus*, *Anguilla Anguilla, Esox lucius, Blicca bjoerkna* and *Coregonus lavaretus* in Charzykowskie Lake.

## Conclusions

The model of the impact of changes in the lake water quality on the effects of fisheries management is stable to the conditions that existed in the past. It proves the importance of dependence in observed intervals of variation of exogenous variables. The linearity can be valid only within narrow intervals of variation. Their extension can reveal the predominance of curvilinear correlation. Moreover, the high values of intercepts and standard deviation of random component in some of the empirical equations can also result from the consideration of only environmental factors among exogenous variables of the fishery economy econometric model of Charzykowskie Lake, i.e. physical, chemical and biological characteristics of water and climatic factors. The following variables in the set were intentionally omitted: the amount of food and its rate of consumption, the dynamics of fish populations and genetic factors, which are extent determined by the changes of environmental conditions. Economic conditions, especially the classic factors of production, were not included deliberately. It was found that the involvement of labour and capital, as well as fishing techniques during the research were stable, which means that they do not affect the examined effect of economic activity. It can be concluded that limnologists and ichthyologists have established optimum environmental conditions for the development of each of the economically important species and it enables a precise analysis of the impact of deviations from these optimal habitat conditions on the effectiveness of the fisheries management.

The studies show that Chrzykowskie Lake, from an economic point of view, is ecologically pure in terms of most indicators of the water quality. Depending on the species of fish, only some of the components have reached the level of pollution threatening their being, and thus the effectiveness of fisheries management. The methodology and results of the research should encourage its continuation. The econometric models can be useful for both, simulation and prediction of water management, as well as its management. In the field of water management, they indicate trends of specific actions to ensure the optimal use of water resources (e.g. optimum fish catches) with maintaining a good water quality. For example, the modelling results show that if the concentration of phosphates in water is too high (e.g. water is dominated by the observations of exceeded level of the zone of indifference for the certain species of the fish), then it lowers the mass increase and, consequently, the catch of fish. From water management point of view that means that it should be decided to restrict the flow of household sewage and industrial water waste to a water reservoir, raise the quality standards of the water waste or plan to build a new sewage treatment plant.

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