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Habitat quality and fish population: impacts of nutrient enrichment on European perch population in south east Sweden

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Abstract

Degradation of marine ecosystem due to, among others, eutrophication and climate change, has been of concern for sustainable fishery management worldwide, but studies on associated impacts on fish populations are rare. The purpose of this study is to estimate effects of nutrient loads, which cause eutrophication, on the perch population at the Swedish east coast. To this end, we use a modified Gordon-Schaefer logistic growth model for econometric estimation of perch population on the Swedish east coast, which is based on annual time series data for the period 1970–2014. Regression results from the Fully Modified Ordinary Least Square (FMOLS) estimator indicated that phosphorus loads have significant effects on the perch population. A decrease in phosphorus loads by 40% , as suggested by the international Copenhagen agreement, can raise the steady state perch population by 50%.

Key words: nutrient loads, perch populations, logistic growth, econometrics, Swedish east coast

JEL codes Q22, Q53, Q57

1. Introduction

Fishery has been an important human activity in the Baltic Sea region in terms of income generation, food supply, tourism and recreational services. Despite its importance, however, dynamics of marine ecosystem in terms of rising nutrient load, overexploitation, climate change and predation has been jeopardizing the sustainable future of marine biodiversity's, particularly different fish species in the region (Moyle & Leidy, 1992; Engström, 2001; Rice & Garcia, 2011; Larsson *et al.*, 2015) . As an integral parts of Baltic Sea water environment, the east coast of Sweden has experienced these ecological dynamics in the form of overfishing, nutrient load and other socio economic activities. For instance, a significant amount of nutrient load such as nitrogen and phosphorus has been observed between 1970 and 2014 (Svendsen *et al.*, 2013; HELCOM, 2015). This phenomenon has contributed to the increase of filamentous algae, withdrawal of perennial fucoid algae, increased frequency of toxic algal blooms and finally reduction of fish population in the marine system (SwAM, 2013). It is also argued that an increase in sea temperature can cause a major hydrologic changes in the form of physical and chemical properties of water which may impact marine species such as fish, invertebrate, and plant biodiversity in the water system (McGinn, 2002; Roessig *et al.*, 2004). In this regard, evidences showed a rise in mean annual sea temperature in the Baltic Sea region for the past few decades (Böhling *et al.*, 1991; Karas, 1996; EEA, 2015) .

An economic evaluation of these impacts on fish populations requires quantification of the contribution of these factors on the dynamics of fish populations, which provide the basis for evaluating associated economic net benefits. This so-called production function approach to assessing impacts on coastal waters emerges from the literature on coastal habitat quality and its role for provision of ecosystem services (e.g. Barbier 2007, 2013). Habitat quality is then regarded as an input into production of provisioning services, such as fish for food and feed. Effects of factors affecting the habitat quality are calculated as the associated impacts on ecosystem services. However, despite the recognition of several pressures on fish populations, most studies investigate effects of one of them, such as eutrophication and fish populations (e.g. Vitousek et al., 1997; Schmidt et al., 2012; Bergström et al., 2013). There is a relatively large body of literature on the impacts of climate change on fish population in freshwater systems (e.g. Sharma et al. 2007, Hobday and Lough, 2011), but application to large scale brackish waters such as the south east cost of Sweden are lacking.

The main purpose of this study is to estimate the effects of nutrient loads on the dynamics of European perch *(Perca fluviatilis*) at the east coast of Sweden while considering other factors. These other factors are pressure in terms of commercial and recreational fishery, predation on perch by cormorant, and climate change in terms of temperature. The predation of cormorants can be substantial and correspond to that of both harvest and recreational fishery (e.g. Boström et al., 2012). The explanatory power of the different variables will be estimated by means of econometric tools applied to time series data. A crucial assumption is that of a logistic population growth function, which is a common approach in fishery economics (e.g Schaefer, 1954,; Prager, 2002; Kataria, 2007). The estimation of a latent fish population variable is then usually made by means of data on harvest and fishing effort (e.g. Kataria 2007). Similar to several other fish species, European perch is subject to both commercial and recreational harvesting. However, data on effort is available only for commercial harvesting, such as fishing boats and fishermen. We therefore need to construct a model which accounts for these two harvesting pressures, but has access to effort data only for commercial harvest. In our view, this is one contribution of this study. The other is the assessment of the effects of nutrient loads on the European perch population, which, to the best of our knowledge, has not been made for any region by means of econometric tools applied to time series data.

The study is organized as follows. First, we present the fish population model and associated derivation of the econometric regression equation. Section 3 contains description of the data, which is followed by presentation of the results. The study ends with a brief summary and conclusions.

2. The model

Previous works on estimation of fish population growth rate assumed that change in the total stock over a given period of time depends on the natural growth and total harvest (Schaefer, 1954; Kataria, 2007) . Mathematically, the growth function in logistic form is defined as:

$$\frac{dP_t}{dt} = rP_t\left(1 - \frac{P_t}{K}\right) - V_t - H_t \tag{1}$$

$P = P_0$ at $t = t_0$ and $P = P_1$ at $t = t_1$

where P_t is perch population at time period t, r is the intrinsic growth rate, K is the maximum carrying capacity, V_t is commercial harvest at time period t, and H_t is recreational harvest at time period t. Due to lack of data on effort for recreational fishery, we can only relate commercial harvest to an effort variable. According to Schaefer (1954), harvest is assumed to be dependent on fishing effort, E_t and P_t, where the latent variable, P_t can be derived. This relationship is expressed as:

$$V_t = \alpha_i E_t P_t \tag{2}$$

From equation (2), we define the proportional relation between commercial harvest and effort, S_t as:

$$S_t = \alpha_i P_t = \frac{V_t}{E_t} \tag{3}$$

The model given by equation (1) does not account for different types of habitat quality attributes, L_{ti} with $i = 1,2,3...n$ habitat characteristics. These attributes can affect the population growth in two ways; directly as additional exogenous variables at the right hand side of equation (1) or indirectly through its impact on the intrinsic growth rate, r. The intrinsic growth rate measures the growth rate which determines maximum population in ideal condition in absence of any regulatory pressure, such as commercial and recreational harvest or competition of food with other species. Disturbances of habitat conditions are regarded as pressures. On the other hand, habitat quality attributes can be regarded as variables supposed to determine the intrinsic growth rate and maximum viable population of fish species, and hence enter equation (1) as exogenous variables affecting the intrinsic growth rate, r. There is no prior knowledge on which formulation is the most suitable and therefore there is an option of selecting robust estimate.

In addition to nutrient loads, we allow for the influence of other factors affecting the habitat condition, such as temperature. The direct effects of habitat characteristics, are formulated as:

$$\frac{\partial P}{\partial t}+H_t=rP_t\left(1-\frac{P_t}{K}\right)-\alpha_i E_t P_t+\sum_{i=1}^{n} f_i L_{ti} \tag{4}$$

where f_i represent a parameter explaining the marginal impact of habitat characteristics on the growth rate of perch population.

As shown in equation (3), a fundamental assumption behind the Gordon-Schaefer growth model is that a proportional change in population can be approximated by a proportional change in S_t. Thus, we can replace P_t in equation (4) with S_t from equation (3) and writing the left hand side of equation (4) as $\alpha_i\left(\frac{dP_t}{dt}+H_t\right)$ and dividing by S_t gives:

$$\frac{\frac{dS_t}{dt}}{S_t}=r-\frac{r}{\alpha_i K}S_t-\alpha_i\left(E_t+\frac{H_t}{S_t}\right)+\frac{\sum_{i=1}^{n} f_i L_{ti}}{S_t} \tag{5}$$

The derivative of the dependent variable with respect to t is obtained by making a finite difference approximation and it becomes:

$$\frac{dS_t}{dt}\approx\frac{S_{t+1}-S_{t-1}}{2} \tag{6}$$

Therefore, the regression equation for perch population growth with direct impacts habitat attributes is specified as:

$$Y_t=\theta_1+\theta_2 S_t+\theta_3\left(E_t+\frac{H_t}{S_t}\right)+\sum_{i=1}^{n}\left(\frac{\gamma_i L_{ti}}{S_t}\right)+\varepsilon_t^{iD} \tag{7}$$

where σ_t^{iD} is the error term. The corresponding coefficients in equation (7) in relation to equation (5) are:

$$Y_t\approx\frac{\left(\frac{S_{t+1}-S_{t-1}}{2}\right)}{S_t},\ \theta_1=r,\ \theta_2=\frac{r}{\alpha_i K},\ \theta_3=\alpha_i,\ \gamma_i=f_i \tag{8}$$

The carrying capacity, K , can be calculated from equation (8) as:

$$K = \frac{r}{\theta_2 \theta_3} \tag{9}$$

With respect to the indirect habitat effect specification, it is assumed that the intrinsic growth rate shows a linear dependence in habitat characteristics, $r = b + \sum_{i=1}^{n} c_i L_{ti}$ .Then, equation (1) is modified as:

$$\frac{dP_t}{dt} = \left(b + \sum_{i=1}^{n} c_i L_{ti} \right) P_t \left(1 - \frac{P_t}{K} \right) - V_t - H_t \tag{10}$$

With the same assumption and steps as in the derivation of direct habitat effect model, the indirect habitat effect model gives the logistic function as:

$$\frac{\frac{dS_t}{dt}}{dt} = b + \sum_{i=1}^{n} c_i L_{ti} - \frac{1}{\alpha_i K} S_t - \alpha_i \left(E_t + \frac{H_t}{S_t} \right) \tag{11}$$

The associated regression equation is specified as:

$$Y_t = \beta_1 + \beta_2 S_t + \beta_3 \left(E_t + \frac{H_t}{S_t} \right) + \sum_{i=1}^{n} \psi_i L_{ti} + \grave{o}_t^{iID} \tag{12}$$

where the dependent variable, Y_t, is defined in the same way as in the direct model specification, and the other parameters are related to the logistic model in equation (11) as:

$$\beta_1 = b,\ \beta_2 = \frac{r}{\alpha_i K}, \beta_3 = \alpha_i,\ \psi_i = c_i \tag{13}$$

where $r_t = \beta_1 + \sum_{i=1}^{n} \psi_i L_{ti}$. Carrying capacity is calculated from equation (13) as:

$$K_t = \frac{\beta_1 + \sum_{i=1}^{n} \psi_i L_{ti}}{\beta_2 \beta_3} \tag{14}$$

The difference between the direct and indirect model specification appears in the estimates of the parameters, intrinsic growth rate, and the calculated carrying capacity. In the case of direct effect model, both parameters are constant over time whereas they vary over time with changes in habitat characteristics in the case of indirect effect model.

The size of population can be predicted for both direct and indirect effect models by taking the respective definite integral of logistic growth function expressed in equation (1). For simplicity, the equation can be transformed in a way that total net pressure on the population, including recreational and commercial harvest and habitat characteristics, is represented by a proportion of the total population, λ. Hence, equation (1) can be expressed as:

$$\frac{dP_t}{dt} = rP_t\left(1-\frac{P_t}{K}\right)-\lambda P_t \tag{15}$$

As expressed in Zill (2012), the solution to equation (1.15) with non-linear first order differential equation is given as:

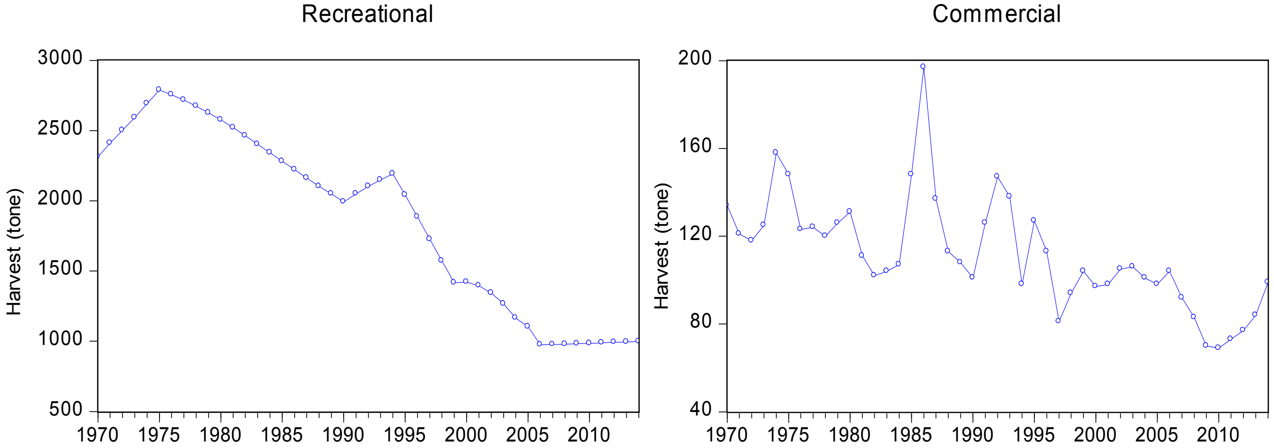
$$P(t)=\frac{(r-\lambda)K}{r+\left(\frac{r(K-P_0)-\lambda K}{P_0}\right)e^{-(r-\lambda)t}} \tag{16}$$

where $\lim\limits_{t\to\infty} P(t)=K\left(1-\frac{\lambda}{r}\right)$.

3. Description of data

Time series data on commercial catches of perch in south east coast of Sweden are available for the period 1970-2014, in Annual Fishery Statistics for the period 1970 to 1992, and at Swedish Statistics (2015) and Swedish Agency for Marine and Water Management (2015) for the years 1993-2014. Since there is no official data on harvest from recreational we use the data constructed by Zeller *et al.* (2011). Figure 1 presents the compiled data on annual commercial and recreational harvest of European perch at the east coast of Sweden (ECS).

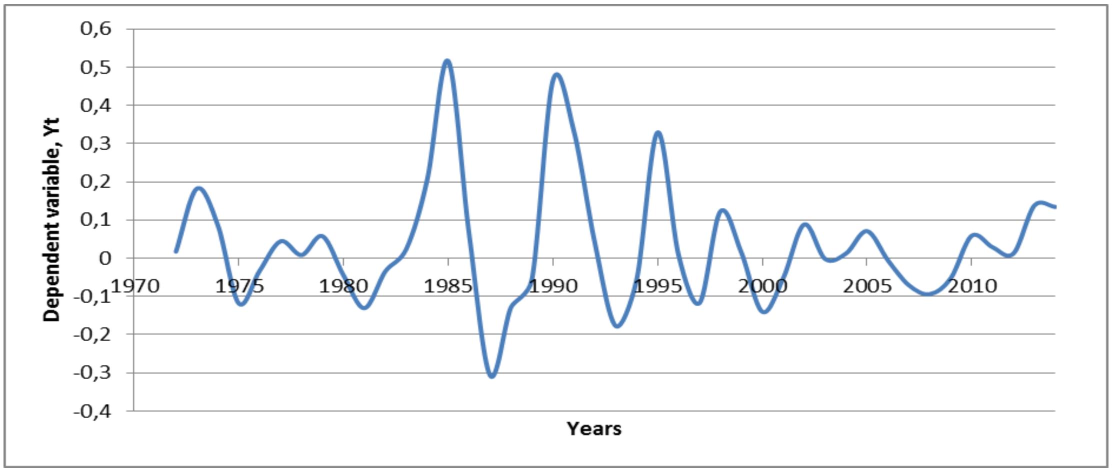
Figure 1: Commercial and recreational harvest for perch population in ECS (1970-2014)



As shown in Figure 1, commercial landing for perch is relatively low compared to recreational landing. The harvest of commercial fishery is relatively constant whereas the constructed data for recreational harvest showed an average decline of 2%.

The standard way of constructing an effort variable requires data on number and types of fishing vessels or boats and fishing day (Foley *et al.*, 2010). However, such data are not available and we therefore use the total number of registered fishing boat as a proxy for effort variable (Transportstyrelsen, 2015). Our dependent variable, where we divide commercial harvest with the effort variable and take the difference as shown by eq. (8), then shows differing fluctuations over the years.

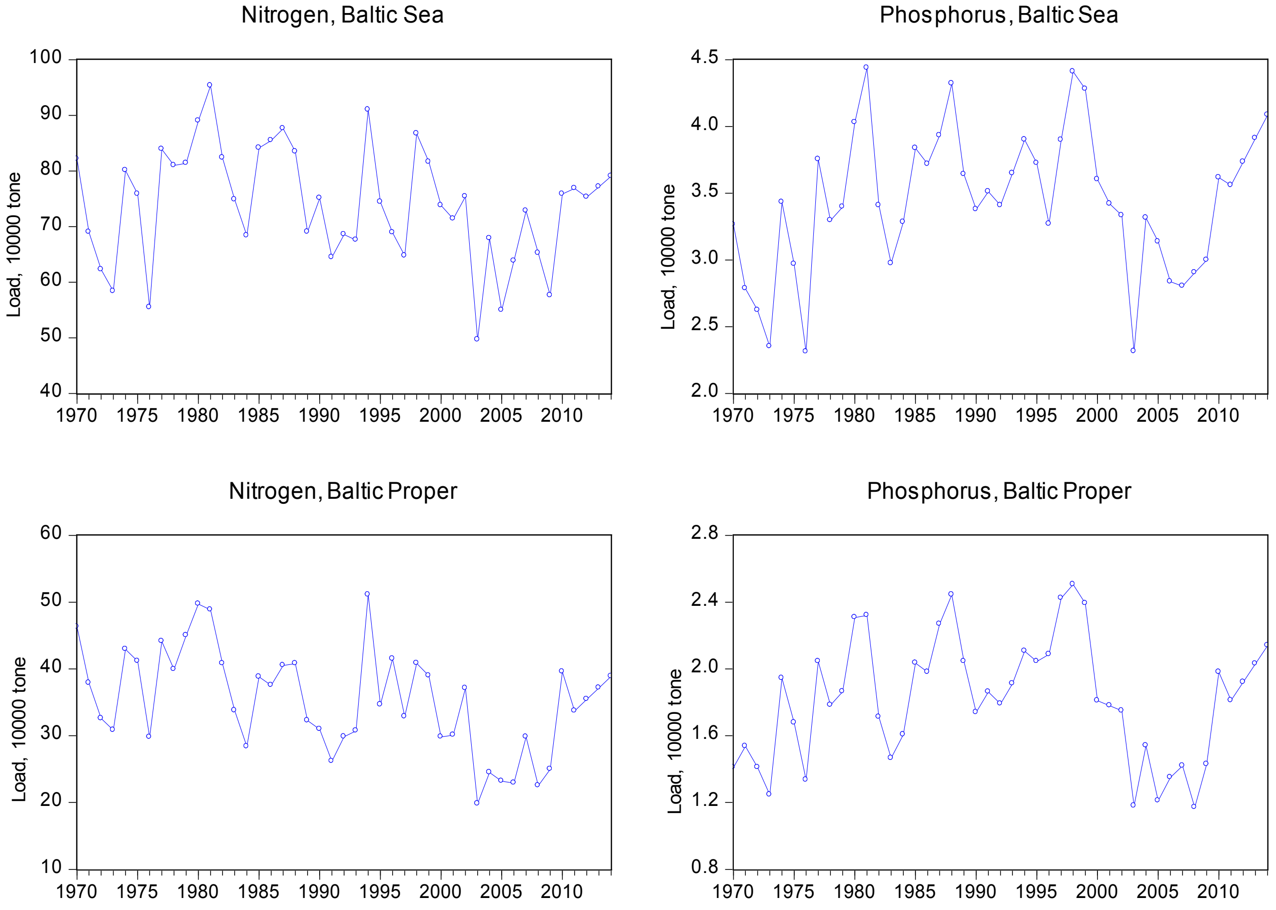
Figure 2: Development of the dependent variable $Y_t = \frac{S_{t+1} - S_{t-1}}{S_t}$ over 1970-2014



Similar to the development of commercial harvest as shown in Figure 1, the fluctuations are relatively large over the period 1984-2000. The number of registered fishing vessels has decreased steadily from 2100 to 495 over the entire period 1970-2014 which explains the average annual positive growth rate of 0.034 over the period.

Excessive nutrient, nitrogen (N) and phosphorus (P), loads affect reproduction conditions and create food-web changes (e.g. Larsson et al. 2015). However, nutrient loads into any of the seven marine basins of the Baltic Sea are dispersed in the entire sea because of streams and other oceanographic conditions (e.g. Savchuck and Wulff, 2009). Therefore, we test the impact of two alternative nutrient load variables; one on nutrient loads to the marine basin Baltic Proper (BP) where the Swedish east coast is located, and the other on nutrient loads to the entire Baltic Sea (BalticNest, Institute, 2015, Helcom, 2015). The volume of nitrogen and phosphorus load to the Baltic Sea increased on average by 1 % per year between 1970 and 2014, whereas it increased by 2% to the Baltic proper for the same period of time. The graphical illustration of nitrogen and phosphorus load in the Baltic Sea and Baltic Proper is given in Figure 3.

Figure 3: Nitrogen and phosphorus load in Baltic Sea (BS) and Baltic Proper (BP) (1970-2014)


Nitrogen, Baltic Sea

Phosphorus, Baltic Sea

Nitrogen, Baltic Proper

Phosphorus, Baltic Proper

Data on the annual average bottom sea surface temperature (°C) in the Baltic and cormorant population is compiled from Swedish Environmental Protection Agency (2013). Descriptive statistics of all included variables are presented in Table 1.

Table 1: Descriptive statistics of variables used in the regression equation

Variables	Description	Mean	Std. Dev.	Min	Max
PerchC	Perch, commercial landing per year in east coast of Sweden (tone/year)	112	25.16	69	197
PerchR	Perch, recreational harvest per year in east coast of Sweden (tone/year)	1886.5	634.4	975	2789
BoatC	Total number of commercial fishing boat per year in east coast of Sweden (x100)	11.11	6.31	4.41	21.25
N_bs	Nitrogen load per year to Baltic Sea (x10000 tone /year)	73.96	10.29	49.66	95.32
P_bs	Phosphorus load per year to Baltic Sea (x10000 tone /year)	3.44	0.53	2.31	4.44
N_bp	Nitrogen load per year to Baltic proper (x10000 tone /year)	35.31	7.65	19.8	51.1
P_bp	Phosphorus load per year to Baltic proper (x10000 tone /year)	1.82	0.36	1.17	2.51
Temp_bottom	Mean annual bottom sea surface temperature at east coast of Sweden (°C)	5.87	0.96	4.8	7.8
Cormorant	Total number of cormorant at the east coast of Sweden (1000)	1.43	1.56	0.02	4.38

4. Regression specification and results

Empirical models based on equations (7) and (12), representing the direct and indirect effect model, respectively, are specified. The regression models with direct and indirect specification including all explanatory variables are then given as:

Model 1: Direct effect model

$$Y_t = \theta_1 + \theta_2 S_t + \theta_3 \left(E_t + \frac{H_t}{S_t} \right) + \gamma_1 \left(\frac{N_t}{S_t} \right) + \gamma_2 \left(\frac{P_t}{S_t} \right) + \gamma_3 \left(\frac{LagN_t}{S_t} \right) + \gamma_4 \left(\frac{LagP_t}{S_t} \right)_t + \gamma_5 \left(\frac{Tem_t}{S_t} \right) + \gamma_6 \left(\frac{Corm}{S_t} \right) + \varepsilon_t \qquad (17)$$

Model 2: Indirect effect model

$$Y_t = \beta_1 + \beta_2 S_t + \beta_3 \left(E_t + \frac{H_t}{S_t} \right) + \psi_1 \left(N_t \right) + \psi_2 \left(P_t \right) + \psi_3 (\mathrm{L}\,agN_t) + \psi_4 (LagP_t) + \psi_5 (Tem_t) + \psi_6 (\mathrm{Corm}) + \varepsilon_t \tag{18}$$

It is assumed that the load of nitrogen and phosphorus may take certain period of time until it affects the growth rate of perch population. Hence, the model includes the lag value of nitrogen and phosphorus load.

Regarding estimation procedure, Stock and Watson (2012) suggested that OLS estimator can be best, linear, unbiased and efficient (BLUE) if the series fulfils stationarity property. However, as most economic time series datasets are nonstationary with varying statistical properties over time, it is vital to check whether the variables used in the model have unit root or not. Otherwise, the estimator violates the asymptotic properties of the OLS regression even if it provides unbiased and consistent result (Wooldridge, 2012). Moreover, the potential occurrence of serial correlation and heteroskedasticity in the error term makes the OLS estimator inefficient but still unbiased and consistent (Phillips, 1986; Giles, 2007) . Therefore, it is important to begin estimation process by checking stationarity property of the regressors from equation (17) and equation (18) using Augmented-Dickey fuller test[1].

Accordingly, the conducted test statistics is failed to reject the null hypothesis in all variable cases showing the presence of unit root (Table A1). The implication is that the variables are nonstationary and thus OLS estimator cannot be efficient. Furthermore, this requires diagnosing OLS estimator for serial correlation and heteroskedasticity in the error term as it will gives the final decision whether to accept or reject OLS estimator as BLUE estimate. In this case, the Breusch-Godfrey test for serial correlation rejects the null hypothesis for equation (17) and equation (18), indicating absence of serial correlation in the error term (Table A2). Despite absence of serial correlation in equation (17) and equation (18), still it is vital to check whether the variances of the standard errors are constant or not over time using the Breusch-Pagan test for heteroskedasticity test. The test statistics rejects the null for equation (17) indicating the presence of heteroskedasticity. Therefore, OLS estimator will not be BLUE as it violates the asymptotic properties of OLS estimator.

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[1] The null hypothesis is that the variable contains a unit root, and the alternative is that the variable was generated by a stationary process.

In order to address the issue of unit root in OLS regresors and related problem of serial correlation and heteroskedasticity in the stochastic error term, an alternative robust estimator called Fully Modified Least Square (FM-OLS) is developed by Phillips (1987). Basically, FM-OLS estimator uses the OLS estimate but corrects the standard errors for fairly arbitrary forms of serial correlation and heteroskedasticity (Davidson & MacKinnon, 1993). Further, the estimator takes into account the issue of endogeneity in the model (Phillips, 1995). More elaborative technical details of FM-OLS estimator can be referred at Phillips (1995), Vogelsang and Wagner (2014), and Inder (1993).

The regression result for direct and indirect effect model is presented in Table 2.

Table 2: FM-OLS estimate of growth function of perch population in the east coast of Sweden

Model 1: direct effect model			*Model 2: indirect effect model*		
Variables	Coefficient	Std. Err.	Variables	Coefficient	Std. Err.
Constant	0.330*	(0.016)	Constant	-1.598***	(0.000)
S	-0.006	(0.230)	S	-0.00695	(0.102)
E+H/S	-0.002***	(0.000)	E+H/S	-6.E-05	(0.798)
N_bprop/S	0.0119	(0.575)	N_bprop	0.003	(0.164)
P_bprop/S	-1.174**	(0.008)	P_bprop	-0.104*	(0.015)
lagN_bprop/S	-0.003	(0.108)	lagN_bprop	-0.004	(0.057)
lagP_bprop/S	-0.038	(0.348)	lagP_bprop	-0.072	(0.096)
Bottom Temp/S	1.259***	(0.000)	Bottom Temp.	0.421***	(0.000)
Cormorant/S	-1.714***	(0.000)	Cormorant	-0.264***	(0.000)
R-squared	0.27		R-squared	0.11	
Long run S.e.	0.043		Long run S.e.	0.045	
F-statistics	86.13***		F-statistics	84.23***	
Observations	42		Observations	42	

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

The coefficients of *S* and *E+H/S* are negative as expected, but the latter is significant only for the direct model. Both models have significant estimates of the constants. This shows the intrinsic growth rate for the direct model, which amounts to 0.33. This seems to be adequate when considering that the population can be doubled within 1.5-4.5 years (Rowinski et al. 2015). The intrinsic growth rate in the indirect model depends on the level of the explanatory variables as shown in eqs. (10) and (13). When evaluated at the mean of these variables it amounts to 0.30

which is quite close to that of the direct model. However, since the direct model gives a better fit as measured by R^2 and F-statistics, we discuss results from this model in the following.

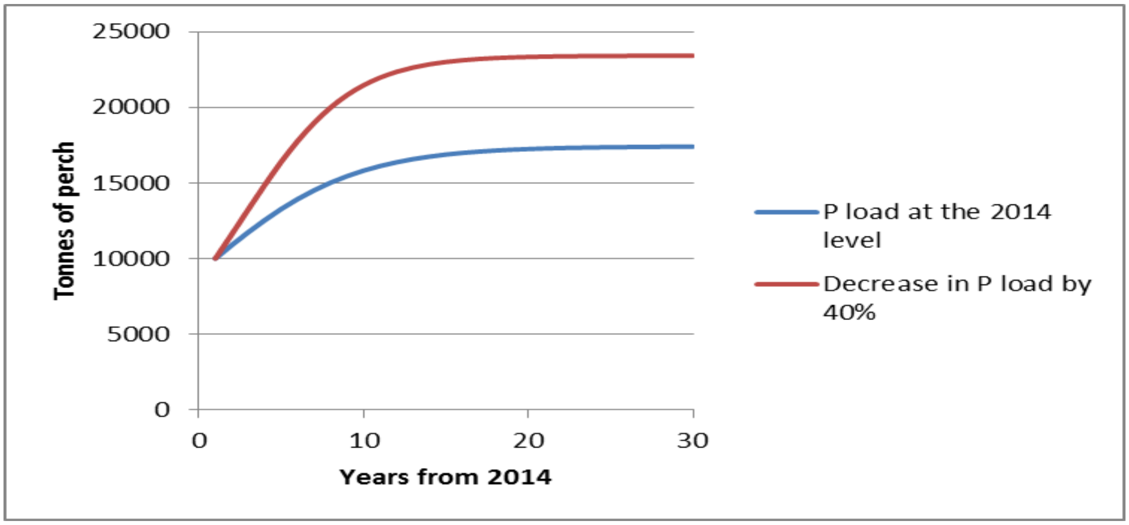
With respect to nutrient loads, only phosphorus loads give significant estimates. This is in line with results from studies showing that phosphorus is the limiting nutrient for biological production in the Baltic Proper (e.g. Savchuck and Wulff, 2009). A reduction in phosphorus load to the Baltic Proper by 10000 tone, which corresponds to a decrease by 55% in the average total load to the Baltic Proper, gives an increase in perch population growth by 0.091 at the average level of *S* (which amounts to 12.92), holding other factors constant. The positive effect on the population from *Temp* is supported by the evidence that rise in temperature along the Baltic Sea have a beneficial effect on growth rates of fresh water origin fish species, such as perch and pikeperch (Lappalainen *et al.*, 2000; Ložys, 2004; Mackenzie *et al.*, 2007). It is also well known that cormorants' pressure on fish is substantial, and can correspond to that of both harvest and recreational fishery (e.g. Boström *et al.,* 2012). The estimated effects on perch growth rate of marginal increases in temperature and predation by cormorants are 0.098 and -0.133, respectively.

5. Predicted population growth under different phosphorus load scenarios (2014-2050)

In order to predict populations based on eq. (17) we need to calculate population level and carrying capacity, as shown by equations (2) and (9), respectively, and the net pressure on the population. The population size in 2014 at the levels of *V* and *E* in this year (99 and 4.95, respectively), then amounts to 10000. Similarly, we can calculate carrying capacity, which gives *K*=27500 (0.33/(-0.006*-0.002)). Unfortunately, it is difficult to compare our results with hose from other studies since such estimates have not been carried out for European perch at the south east coast of Sweden. Calculations of population of cod, sprat, and herring in the entire Baltic Sea point out relations between commercial harvest and population biomass that vary between approximately 4 and 15 (Sparholt, 1994). Our results show a relation of 10 for the year 2014, which is within this range.

The net pressure on the population is given by the sum marginal effects of Temp, Cormorant, P loads, and E+H/S. When evaluated at the 2014 levels, this gives a net pressure of -0.12 (Temp 0.56, Cormorant -0.20, P load -0.18, E+H/S -0.31). We predict future development of the population at this unchanged level, which is compared with a development where P load is reduced by 40% as suggested by the latest intergovernmental agreement on nutrient loads to the Baltic Sea (Helcom, 2013).

Figure 4: Development of perch population under different assumptions of phosphorus (P) load



As illustrated in Figure 4, an unchanged load of approximately 21000 ton P to the Baltic Proper would result in steady state population level at 17500 ton. A reduction in P load by 40% would increase the steady state level to 24000 tons of European perch. In both cases, the steady state levels are reached within 15 years. However, it is likely that the harvest increases as a response to the increased population when phosphorus load decreases, which counteracts the reduction in pressure on the population.

6. Conclusions

The main purpose of this study was to examine effects of nutrient loads on the growth rate of European perch population at the east coast of Sweden. We then accounted for other pressures in terms of commercial and recreational harvest, predations by cormorants, and temperature. A relatively simple logistic population growth function was assumed, by means of which two alternative regression functions were derived depending on assumption of the impacts of habitat characteristics. One assumption was that the impacts occur directly on growth of the population, and the other was that the characteristics affect the intrinsic growth rate. Since the estimation procedure relies on time series data ranging from 1970 to 2014, we have considered the stationerity property of the variables and found that all the explanatory have a unit root. As a result, we use Fully Modified Ordinary Least Square (FMOLS) estimator as it gives much robust parameter estimates than the usual OLS estimator.

We found the direct effect model more robust in explaining the dynamics of perch population as it satisfies most of the presumed statistical properties. Thus, the estimated result indicated that fishing effort, phosphorus load, bottom sea level temperature and number of cormorants are statistically significant at 1%, 10%, 1% and 1% level, respectively, in determining the growth rate of perch population. The estimated intrinsic growth rate was 0.33, which shows the growth of the perch population under ideal condition. The results indicated that phosphorus loads reduce the growth of the perch population, the magnitude of which can correspond to that of predation of cormorants in 2014. On the other hand, rise in the level of bottom sea level temperature turned out to have a positive effect on the growth rate of perch population.

We used the estimated perch population model to simulate future populations under two alternative scenarios on phosphorus loads; unchanged at the 2014 level and a 40% reduction as suggested by the international agreement in Copenhagen 2013 (Helcom, 2013). The results showed that the steady state population can increase by approximately 50% if the Copenhagen declaration had been implemented in 2014.

Admittedly, our estimates rely on the assumption of a logistic growth function, which has been criticized because of the neglect of composition of population cohorts, proportional relation between population growth and pressure intensity, and disregard of stochastic shocks to the population (e.g. Clark, 1990). Choices of other functions, such as age-structured models, might give other predictions of population developments. Lack of long term time series data on biological parameters such as reproduction and survival rates for different cohorts makes it difficult to estimate such functions. Nevertheless, our estimates of the intrinsic growth rate of European perch population are in the same order of magnitude as estimates from other models.

References

Baltic Nest Institute (2015). The Nest system. at http://www.balticnest.org/balticnest/thenestsystem.4.2beb0a011325eb5811a8000127598.html (October 15 2015, latest access date)

Barbier E. (2007). Valuing ecosystem services as productive inputs. Economic Policy, 22, 177-229.

Barbier, E. B. (2013). Valuing ecosystem services for coastal wetland protection and restoration: Progress and Challenges. Resources, 2, 213-230.

Bergström, U., Sundblad, G., Downie, A-L., Snickars, M., Boström, C., Lindegarth, M. (2013). Evaluating eutrophication management scenarios in the Baltic Sea using species distribution modelling. Journal of Applied Ecology, 50, 680-690.

Boström, M., Lunneryd, K., Hanssen, H., Karlsson, L., Ragnarsson, B. (2012). Diet of the Great Cormorant (Phalcrocorax carbo sinensis) at two areas on the Bay Lovstabukten, South Bothnian Sea, Sweden, based on otholith size-correction factors. Ornis Fennica, 89.

Böhling, P., Hudd, R., Lehtonen, H., Karås, P., Neuman, E., & Thoresson, G. (1991). Variations in year-class strength of different perch (Perca fluviatilis) populations in the Baltic Sea with special reference to temperature and pollution. Canadian Journal of Fisheries and Aquatic Sciences, 48(7), 1181-1187.

Clark, C. W. (1990). Mathematical bioeconomics: The optimal management of renewable resources (2nd ed.). New York: Wiley.

Davidson, R., & MacKinnon, J. G. (1993). Estimation and inference in econometrics. OUP Catalogue.

EEA. (2015). Sea surface temperature (CLIM 013). from European Environmental Agency (EEA) Accesed from: http://www.eea.europa.eu/data-and-maps/indicators/sea-surface-temperature-1/assessment-1

Engström, H. (2001). Effects of Great Cormorant predation on fish populations and fishery. (Doctoral dissertation), Uppsala: Acta. Uppsala Univeristy

Foley, N. S., Kahui, V., Armstrong, C. W., & Van Rensburg, T. M. (2010). Estimating linkages between redfish and cold water coral on the Norwegian Coast. Marine Resource Economics, 25(1), 105-120.

Giles, D. E. (2007). Spurious regressions with time-series data: further asymptotic results. Communications in Statistics—Theory and Methods, 36(5), 967-979.

HELCOM (2013) HELCOM Copenhagen ministerial declaration. at http://helcom.fi/Documents/Ministerial2013/Ministerial%20declaration/2013%20Copenhagen%20Ministerial%20Declaration%20w%20cover.pdf (January 28 2016, date of access).

HELCOM. (2015). Review of the Fifth Baltic Sea Pollution Load Compilation for the 2013 HELCOM Ministerial Meeting (HELCOM PLC-5.5).

Hobday, A. J., Lough J.M.(2011). Projected climate change in Australian marine and freshwater environments. Marine and Freshwater Research 62:1000-1014.

Inder, B. (1993). Estimating long-run relationships in economics: a comparison of different approaches. Journal of econometrics, 57(1), 53-68.

Karas, P. (1996). Recruitment of perch (Perca fluviatilis L.) from Baltic coastal waters. Archiv für Hydrobiologie, 138(1), 99-121.

Kataria, M. (2007). A cost-benefit analysis of introducing a non-native species: The case of signal crayfish in Sweden. Marine Resource Economics, 22(1), 15-28.

Lappalainen, J., Erm, V., Kjellman, J., & Lehtonen, H. (2000). Size-dependent winter mortality of age-0 pikeperch (Stizostedion lucioperca) in Pärnu Bay, the Baltic Sea. Canadian Journal of Fisheries and Aquatic Sciences, 57(2), 451-458.

Larsson, P., Tibblin, P., Koch-Schmidt, P., Engstedt, O., Nilsson, J., Nordahl, O., & Forsman, A. (2015). Ecology, evolution, and management strategies of northern pike populations in the Baltic Sea. Ambio, 44(3), 451-461.

Ložys, L. (2004). The growth of pikeperch (Sander lucioperca L.) and perch (Perca fluviatilis L.) under different water temperature and salinity conditions in the Curonian Lagoon and Lithuanian coastal waters of the Baltic Sea. In H. Kautsky & P. Snoeijs (Eds.), Biology of the Baltic Sea (Vol. 176, pp. 105-113): Springer Netherlands.

Mackenzie, B. R., Gislason, H., MÖLlmann, C., & KÖSter, F. W. (2007). Impact of 21st century climate change on the Baltic Sea fish community and fisheries. Global Change Biology, 13(7), 1348-1367.

McGinn, N. A. (2002). Fisheries in a changing climate: American Fisheries Society.

Moyle, P., & Leidy, R. (1992). Loss of Biodiversity in Aquatic Ecosystems: Evidence from Fish Faunas. In P. Fiedler & S. Jain (Eds.), Conservation Biology (pp. 127-169): Springer US.

Phillips. (1987). Time Series Regression with a Unit Root. Econometrica, 55(2), 277-301.

Phillips. (1995). Fully modified least squares and vector autoregression. Econometrica: Journal of the Econometric Society, 63 (5), 1023-1078.

Phillips, P. C. (1986). Understanding spurious regressions in econometrics. Journal of econometrics, 33(3), 311-340.

Prager, M. H. (2002). Comparison of logistic and generalized surplus-production models applied to swordfish (Xiphias gladiu), in the north Atlantic Ocean. Fisheries Research, 58(1), 41-57.

Rice, J. C., & Garcia, S. M. (2011). Fisheries, food security, climate change, and biodiversity: characteristics of the sector and perspectives on emerging issues. ICES Journal of Marine Science: Journal du Conseil, 68(6), 1343-1353.

Roessig, J. M., Woodley, C. M., Cech Jr, J. J., & Hansen, L. J. (2004). Effects of global climate change on marine and estuarine fishes and fisheries. Reviews in Fish Biology and Fisheries, 14(2), 251-275.

Rowinski, P., Mateor-Gonzales, F., Sandblom, E., Jutfelt, F., Ekström, A., Sundström., F., 2015. Warming alters the boddy shaper of European perch Perca fluviatilis. Journal of Fish Biology 87 DOI: 10.1111/jfb.12785

Savchuk, O. P., Wulff, F., (2009). Long-term modelling of large-scale nutrient cycles in the entire Baltic Sea. Hydrobiologia 629: 209-224.

Sharma, S., D. A. Jackson, C. K. Minns, and B. J. Shuter. 2007. Will northern fish populations be in hot water because of climate change? Global Change Biology 13:2052-2064.

Schaefer, M. B. (1954). Some aspects of the dynamics of populations important to the management of the commercial marine fisheries: Inter-American Tropical Tuna Commission.

Schaefer, M. B. (1991). Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Bulletin of Mathematical Biology, 53(1–2), 253-279.

Schmidt, A. L., J. K. C. Wysmyk, S. E. Craig, and H. K. Lotze. (2012). Regional scale effects of eutrophication on ecosystem structure and services of seagrass beds. Limnology and Oceanography 57, 1389-1402.

Sparhole, H., (1994). Fish species interaction in the Baltic Sea. Dana 10, 131-162.

Stock, J. H., & Watson, M. W. (2012). Introduction to Econometrics: Global Edition: Pearson Education.

SwAM. (2013). Baltic Sea –Our Common Treasure: Economics of Saving the Sea (Vol. 4): Swedish Agency for Marine and Water Management (Havs- och vattenmyndighetens).

SwAM. (2015). Swedish Agency for Marine and Water Management (online database).

Swedish Agency for Marine and Water Management (2015). Fångsstatistik för yrkesfisket. at https://www.havochvatten.se/hav/fiske--fritid/yrkesfiske/statistik-och-kartor/fangststatistik-yrkesfisket.html (November 27 2015, latest date of access).

Swedish Environmental Protection Agency (2013). Nationell förvaltningsplan för skarv 2014. Available at http://www.naturvardsverket.se/upload/miljoarbete-i-samhallet/miljoarbete-i-sverige/regeringsuppdrag/2014/forvaltningsplan-skarv/ru-forvaltningsplan-skarv-2014.pdf (February 15 2016, date of access)

Swedish Statistics 2015. Det yrkesmässiga fisket i havet. at http://www.scb.se/sv_/Hitta-statistik/Statistik-efter-amne/Jord--och-skogsbruk-fiske/Fiske/Det-yrkesmassiga-fisket-i-havet/ (November 25 2015, latest date of access)

Svendsen, L. M., Staaf, H., Gustafsson, B., Pyhälä, M., Kotilainen, P., Bartnicki, J., . . . Durkin, M. (2013). Review of the fifth Baltic Sea pollution load compilation for the 2013 HELCOM ministerial meeting: Helsinki Commission-HELCOM.

Transportstyrelsen (2015) Sjöfart at http://www.transportstyrelsen.se/sv/sjofart/Fartyg/Skeppslistan/ (March15 2015, latest date of access).

Vitousek, P. M., J. D. Aber, R. W. Howarth, G. E. Likens, P. A. Matson, D. W. Schindler, W. H. Schlesinger, and D. G. Tilman. 1997. Human alteration of the global nitrogen cycle: Sources and consequences. Ecological Applications 7,737-750

Vogelsang, T. J., & Wagner, M. (2014). Integrated modified OLS estimation and fixed-b inference for cointegrating regressions. Journal of Econometrics, 178(2), 741-760.

Wooldridge, J. (2012). Introductory econometrics: A modern approach: Cengage Learning.

Zeller, D., Rossing, P., Harper, S., Persson, L., Booth, S., & Pauly, D. (2011). The Baltic Sea: Estimates of total fisheries removals 1950–2007. Fisheries Research, 108(2–3), 356-363.

Zill, D. (2012). A first course in differential equations with modeling applications: Cengage Learning. The book chapter can be accessed from: http://www.cengage.com/math/book_content/0495108243_zill/projects_archive/de7e/ProjectModule1.pdf.

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Appendix: Tables A1-A2

Table A1: Augmented Dickey-Fuller test for unit root

Variable	**Obs.**	**Test Statistic**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**	**p-value**
y_per_t	37	-2.416	-3.668	-2.966	-2.616	0.137
eff_perc_t	44	-1.306	-3.621	-2.947	-2.607	0.627
Perchc	44	-2.810	-3.621	-2.947	-2.607	0.057
Perchr	44	0.675	-3.621	-2.947	-2.607	0.989
Boat	44	-1.306	-3.621	-2.947	-2.607	0.627
n_bs	44	-0.567	-2.630	-1.950	-1.608	0.574
p_bs	44	-0.234	-2.630	-1.950	-1.608	0.816
n_bp	44	-0.890	-2.630	-1.950	-1.608	0.379
p_bp	44	-0.205	-2.630	-1.950	-1.608	0.838
temp_surface	44	1.668	-3.621	-2.947	-2.607	0.998
temp_bottom	44	5.331	-3.621	-2.947	-2.607	1.000
Cormorant	44	1.241	-3.621	-2.947	-2.607	0.996

Table A2: Breusch-Godfrey LM Test for Serial correlation

Direct Model: Breusch-Godfrey LM Test for Serial correlation

lags(p)	**chi2**	**df**	**Prob > chi2**
10	25.037	10	0.0053

Indirect Model: Breusch-Godfrey LM Test for Serial correlation

lags(p)	**chi2**	**df**	**Prob > chi2**
10	25.562	10	0.0044

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