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The Two-sector Economic Problem Of Persistent Organic Pollution and Baltic Sea Salmon Fisheries

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Abstract

The paper describes the general nature of two-sector environmental and natural resource problems and highlights the issue of two sector models where one sector imposes a one-sided negative externality on the other sector, e.g. the polluting sector causes changes in the economic value of the fishery sector. The paper sets up a general social planner model and demonstrates it in simple functional form, using the problem of persistent organic pollution in the Baltic Sea and its effects on the regulation and economic value of the Baltic Salmon. The paper illustrates how a modified golden rule can be used to describe the optimal link between the two sectors.

Lay-Person's Abstract

The problem of Persistent Organic Pollution (POPs) in the Baltic Sea has been widely studied by biologists and chemists, however the economic impacts of the pollution have not been sufficiently examined. This paper explores possibilities for sustainable development which accommodate both the fishery and industrial sectors. It focuses on the Baltic Sea salmon fishery and the effects on its value resulting from different pollution levels. The paper aims to find balance and an optimal link between sectors.

Author's Note

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1. Introduction

Problems in the management of marine resources are often treated in a one-dimensional way, while they are actually affected by other economic sectors. One example is agriculture, where run-off causes eutrophication, and thereby a decrease in stocks and changes in fishery conditions. A similar problem occurs with Persistent Organic Pollution (POP) where industrial emissions lead to the presence of pollutants in water. To handle externalities linking different economic sectors, a social planner must adapt a broader modelling tool which considers both sectors at once. This paper focuses on the application of a two-sector model to pollution problems in fisheries, as there is a common agreement that fisheries should not be analysed in isolation from other economic sectors (Neiland and Béné, 2004).

Presented here is a dynamic two-sector bio-economic model which incorporates both fisheries and the dioxin polluting sector. Following Lane and Stephenson's (1995) suggestion of an integrated approach in fisheries management, this model shows the complexity of marine environmental systems and the interconnections between various factors. The aim is to use a dynamic maximisation approach for reaching the maximised present value of net benefits, which in this case is the sum of utilities from both sectors. The model uses the fundamental equation of renewable resource management, called the 'golden rule', which describes the balance between the benefits of current exploitation and future profits from unharvested stock growth. The results suggest an efficient management policy under open-access conditions in this case, where integrated modelling of two sectors allows a broader and more realistic view which may be more useful in practical applications.

The paper with the closest link to the model presented here is a study by Murillas-Muza (2003). The author introduces two separate economic sectors, which exploit the sea either as a fish source or a sink for contaminants. The joint bioeconomic model shows that it is possible to reach a steady state by applying a modified golden rule designed to consider fisheries influenced by other sectors. The bioeconomic model developed in this paper offers an extended illustration by introducing a time delay in the model and in the functional forms applied. Another difference is that while the base model assumes that there is only a stationary state while pollution is eliminated, the model in this paper includes pollution in the function of price continuously. The results differ as well, as Murillas-Muza predict exhaustion of the fish resource together with pollution increase, while this study predicts an increase in fish stocks, but a degradation of value.

The focus in this model is on the population of Salmon (*Salmo salar*,) in the Baltic Sea within the Danish fishery area. The aim is to explore the linkages between pollution release into the sea and the dynamics of the fishery, as well as economic damages triggered by it. The specific focus is dioxin contamination, which is negatively affecting the environment for a substantial period of time. In general, this project will focus on two major issues in environmental economics, the regulation of pollution activities and the valuation of environmental amenities and services (Cropper and Oates, 1992).

Following an introduction on the Baltic Sea and its contamination with POPs, a general two-sector bioeconomic model is introduced and discussed. The consequences are then illustrated by applying the model to an example with offset in the Baltic Sea. The paper ends with a summary and conclusions.

2. Background of POPs existence in the Baltic Sea

The Baltic Sea covers an area of 374 000 km,[2] with a drainage area about four times greater (Glasby and Szefer, 1998). This is a catchment area inhabited by 85 million people,[1] with well-developed industry and agriculture (Glasby and Szefer, 1998). Pollution comes from three main sources: river inflow, direct discharge from the land and atmospheric input. Overall pollution levels are high, causing effects like eutrophication (Szlinder-Richert et al., 2009a).

The late 1960s brought deep concern about the deterioration of water quality and biota and resulted in the Convention on the Protection of the Marine Environment of the Baltic Sea in Helsinki in 1974. All the Baltic countries signed, starting a monitoring programme and periodic assessments of environmental conditions (Sheppard, 2000).

A narrow connection to the North Sea via Kattegat and an inlet of the Belt Sea and Sound (Sheppard, 2000) with a slow water exchange rate of 22 years (MacKenzie et al., 2004) makes the Baltic Sea water reservoir very vulnerable to pollutant accumulation. The rapid growth of this problem can be used as an indicator of what may happen to other seas in the near future.

This study focuses on substances with dioxin-like toxicity, including polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and dioxin-like polichlorinated biphenyls (dl-PCBs). There are 75 possible PCDD congeners with 7 toxic, 135 possible PCDFs with 10 toxic and 209 PCBs with 12 toxic (NORA, 2003). In total there are 29 substances which are here referred to as dioxins.

High levels of dioxin contamination are present in the Baltic Sea (Karl et al., 2010). They are by-products of various processes, originating from chemical, paper and metal industries, incineration of waste (both municipal and hazardous), burning fossil fuels and transportation. The high current concentrations are largely a result of emissions from the pulp and paper industry, which used chlorine for bleaching until the early 1990s (Helcom, 2004). The main release route is emission into the air, which makes it difficult to trace the exact source and allows pollutants to be transported over great distances and spread all over the Baltic Sea. These emissions are called Non-Point Pollution, (NPP) because of their diffuse nature with no specific discharge point, hampering source localisation, following Segerson (1988).

Dioxins, because of their very low solubility in water, settle in sediments. Sediments are the major aggregation of dioxins in the aquatic environment (Kitamura et al., 2009). Concentration in the Baltic Sea is around 500-1500 ng/kg dry weight, which corresponds to 10-30 ng WHO-TEQ/kg dry weight (dioxin toxicity equivalence) (Helcom, 2004). Disintegration of dioxins in the Baltic Sea is very slow and uncertain, and half-life is estimated to be between 20 and 275 years (Helcom, 2004). Dioxins, re-suspended in the sediment, can re-enter the aquatic environment when natural disturbances occur, such as waves or water

[1] Countries bordering with the sea: Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia, Sweden; and in the drainage basin: Belarus, Czech Republic, Norway, Slovakia, Ukraine

flow (Kitamura et al., 2009). As a fat-soluble substance, these also have a tendency to accumulate in the food chain when they are suspended in the water column. This leads to high dioxin concentrations in commercially important fatty fish species like herring, sprat and salmon (Karl et al., 2010).

The main management tool of Baltic Sea fisheries is the Total Allowable Catch (TAC) assigned for each fish stock under ICES auspices. The quotas are divided between member countries. Apart from that, other regulatory policies apply, including pollution concentration level control (Sheppard, 2000). Because of potential harmful impact caused by exposure to dioxins, the European Commission (EC) has indicated a maximum acceptable level of these substances in food products. Recent regulations from November 2006 allow concentration in muscle meat of fish and fishery products of 4 pg WHO-PCDD/PCDF-TEQ /g fresh weight (fw) and to 8 pg WHO-TEQ /g fw for the sum of WHO-PCDD/PCDF-TEQ and WHO- PCB-TEQ (WHO-TEQ) (European Commission, 2006).

Salmon (*Salmo salar*) is an diadromous fish, living in the sea and breeding in fresh waters. In the sea it usually lives a migratory, solitary life in pelagic waters. Spawning migration into fresh, native waters occurs between June and November. That is the time when fat resources are converted into energy and sexual products. Spawning takes place in late autumn in clean, cool streams with gravelly and stony bottoms at a depth of 0.5-3m. Due to this process salmon lose 60-70% of their weight, and mostly don't survive the spawning (European Commission, 2009). Eggs hatch into larvae between April and May and stay in fresh waters for 1 to 6 years, reaching the stadium smolt. After migration to the sea, a rapid growth is documented, reaching 1.5-3.5 kg in the first year, 4-8 kg in the second and 8-13 kg in the third (Muus et al., 1999). Because of positive correlation between dioxin concentration and size (sea age) of salmon (Larsson et al., 1996; Persson et al., 2007), the maximum allowable pollution level is exceed by salmon with sea age of 2-3 years (ICES, 2009). Furthermore, the Baltic Sea salmon shows a significant overlap in POP content compared with European fishing waters (Karl and Ruoff, 2008).

3. Methods and methodology

In this section a dynamic two-sector bio-economic model of the Baltic Sea salmon fishery in discrete time is developed. The theoretical background is based on Conrad (1999) who describes fishery and polluting sectors separately. The constrained optimisation problem is solved using a mean of Lagrange multipliers.

3.1. Benefit functions

The model aims to maximise the sum of benefits originating from both sectors jointly. The benefits from the fishery sector can be described by the following equation (1), which is the function of stock, harvest rate and pollution.

$$\pi_t = \pi(x_t, h_t, p_t) \tag{1}$$

π: benefits from the fishery

x: fish resource stock

h_t: harvest rate at time t, where $h \in [0; h_{max}]$, h_{max} is maximum harvest capacity

p: pollution (here dioxin) level

The benefit function first derivatives are: $\delta\pi_t / \delta p_t < 0$, $\delta\pi_t / \delta h_t > 0$, $\delta\pi_t / \delta x_t > 0$. Here, the typical fishery benefit function is extended with the pollution externality, whose ambient level is treated as a non-point pollution (NPP) (Segerson, 1988). Defining it this way is indicating the observable combined effect of all individual polluters from other economic activities (description below). The value is the stock of dioxins stored ahead of time *t*.

The benefits from the other economic activities are defined as the utility function:

$$U_t = U(Y_t) \tag{2}$$

where U'>0 and U"<0. Utility is an argument of social welfare which is increasing with consumption of good Y. Here consumption is associated with production in other economic activities, which is the sum of individual utilities gained by each production activity. Those, however, produce pollution, affecting the profit from the fishery sector. This is the link interconnecting both sectors.

3.2. Salmon fishery sector

The evolution of the salmon stock in the steady state variable is described by the equation (3).

$$x_{t+1} - x_t = F(x_t) - h_t \tag{3}$$

F (x): biomass growth function

Here, the biomass net growth function is assumed to follow the commonly accepted Schaefer's logistic function. In this type of growth curve, the growth is at first slow, but then accelerates, slowing down afterwards due to environmental constraints (carrying capacity). It presents evolution from period to period of the stock and depends on the stock of the resource and the harvest function.

3.3. Polluting sector

The polluting sector is represented by other economic activities. Other economic activities in this context are defined as all actions contributing to the overall stock of dioxins stored in the sediments. The change in the stock is ($Y_{t-\tau}$) reduced by $G(p_t)$, which is a decay function describing the self-cleaning effect of the ecosystem. Compared to other models in the literature (Conrad, 1999; Murillas-Maza, 2003), the contribution to the equation is τ, which is the lag from the pollution occurrence until it is problematic for the fishery, assumed to be constant. The evolution of the pollution stock originating from other economic activities is described by equation (4).

$$p_{t+1} - p_t = Y_{t-\tau} - G(p_t) \tag{4}$$

Y – pollution production by other economic activities

G - self-cleaning effect of the ecosystem, where $G' \geq 0$ and $G'' \leq 0$

3.4. Social planner optimisation

The social planner (4) maximizes the present value of net benefits from both sector over a fixed time horizon T, where β is the weight on the fishery sector and (1- β) is the weight on the other economic activities sector determined by the social planner.

This is a two sector model, with two state variable, x_t, p_t and two control variables, the pollution from the other economic activities (pollution flow), Y_t, and the harvest in the fishery, h_t. The full optimisation problem is described in (5) with the resource constraints in (5a) and (5b).

$$\underset{h_t, Y_t}{Max} \sum_{0}^{T} \rho^t \left(\beta \pi \left(x_t, h_t, p_t \right) + \left(1 - \beta \right) U\left(Y_t \right) \right) \tag{5}$$

subject to:

$$x_{t+1} - x_t = F(x_t) - h_t \tag{5a}$$

$$p_{t+1} - p_t = Y_{t-\tau} - G(p_t) \tag{5b}$$

x_0 given

p_0 given

In order to find the steady state and describe the properties of the system, the Lagrangian is defined (6).

$$L = \sum_{t=0}^{T} \rho^{t} \{\beta \pi (x_t, h_t, p_t) + (1-\beta) U(Y_t) + \rho \lambda_{t+1}[x_t + F(x_t) - h_t - x_{t+1}] + \rho \mu_{t+1}[p_t + Y_{t-\tau} - G(p_t) - p_{t+1}]\} \quad (6)$$

The costate variables λ and μ are shadow prices; λ indicating the marginal value of an incremental increase in x_t in period t and μ indicating the shadow price on the pollution in p_t in period t. Here ρ is a discount factor ($\rho=1/(1+\delta)$) with discount rate denoted by δ. The rate of discount is assumed to be constant.

3.5. Dynamic efficiency and steady state

Solving the Lagrangian for steady state ensures all the variables reaching constant value. This requires resource growth equal to harvest, as well as polluting level equal to environmental self-cleaning rate. Lastly, the implicit equations imply the modified version of golden rule for both sectors separately (7a) and (7b) and integrated one (8). The time subscript is omitted in the steady-state. Therefore, time lag included in the first-order partial derivatives disappears further on.

Salmon fishery sector	**Polluting sector**
(7a) $\delta = F'(x) + \dfrac{\beta (\partial \pi (\bullet)/\partial x)}{(\partial \pi (\bullet)/\partial h)}$	(7b) $\delta = -G'(p) - \dfrac{\beta (\partial \pi (\bullet)/\partial p)}{(1-\beta)(\partial U(\bullet)/\partial Y)}$

$$\delta = F'(x) + \frac{\beta (\partial \pi (\bullet)/\partial x)}{(\partial \pi (\bullet)/\partial h)} = -G'(p) - \frac{\beta (\partial \pi (\bullet)/\partial p)}{(1-\beta)(\partial U(\bullet)/\partial Y)} \quad (8)$$

The right side of equation (7a) is defined as "resource internal rate of return" (Conrad, 1999) where the sum of the marginal net growth rate and marginal value of the stock with weight of the sector in relation to marginal value of harvest is equal to the discount rate. In case where β is approaching 1, the equation is traditional golden rule. On the other hand, when β is close to zero, the discount rate equals internal growth rate. In (7b), the right side of the equation is the sum of marginal rate of environmental self-cleaning (where the minus in front indicates that the function is describing the reduction of state variable p) and marginal loss in fishery sector due to pollution stock (with weight of matching sector) in relation to marginal value of pollution flow with weight of other economic activities sector. It is equal to the discount rate as well. The fishery sectors appear here as the polluting sector is affecting the benefits from the fishery (as described in (1)). Both (7a) and (7b) lead to the integrated equation (8). According to Conrad (1999) the discount rate here can be interpreted as an alternative use or a return from the investment in the economy elsewhere. Therefore, in the steady state, the investments in both sectors should be equal as is confirmed in (8).

4. The example of POPs and the Baltic Salmon

4.1. Danish salmon fishery

The Danish salmon fleet is a typical open sea fishery. The harvest takes place in the cold months, in water below 10ºC, and when garfish is not active. Danish catches mostly cover the area surrounding Bornholm Island because of the small size of vessels which cannot operate in the open sea. The commercial fishing fleet's dominant method is longline fishing, especially after a ban was enforced on driftnet fisheries in 2007 (FG&FRI, 2009). There are regulations on the maximum weight, and salmon with a weight below 2 kg (gutted weight) can be marketed without restrictions, between 2 and 5.5 kg after deep skinning and trimming, and above 5.5 kg can be sold only outside the European Union. Regulations concerning the dioxin levels which increase with weight have caused a significant drop in the number of fish caught in recent years. Furthermore, they have led to the targeting of specific marketable sizes, and the available data shows that most (99.5% in 2007, 98% in 2008) of Danish catches are in a weight range indicating a maximum sea age of two years (ICES, 2009).

This paper aims to evaluate the economic perspectives of food quality when persistent pollution is present, as fish consumption is a commonly known source of human dioxin intake. An average intake in the European Union is estimated to be 13.3-14.7 pg WHO-TEQ/kg bodyweight (bw) (Danish Ministry of Food, Agriculture and Fisheries, 2003), where the tolerable weekly intake (TWI) is 14 pg WHO-TEQ/kg bw (Helcom, 2004). Exceeding the TWI may result in carcinogenic risk, hormone disturbance or congenital malformation (Helcom, 2004). According to surveys from previous years concerning dioxin levels (Szlinder-Richert et al., 2009b; Isosaari et al., 2006), the EC limits in fatty tissues of salmon were exceeded in the years 2003-2005. This extremely high content of dioxin caused a closure of the salmon fishery (Danish Ministry of Food, Agriculture and Fisheries, 2004).

4.2. A simulation example of the model applied to the case of POPs in the Baltic Salmon

This section sets up an example of how the fishery affected by a stock pollutant originating from another economic sector can be modelled. The example simulates the dioxin pollution in the Baltic Sea and how it affects the price of salmon from the area. As described in the methods section, a full bio-economic model of the selected case is extremely complex (see also ICES (2009)) and beyond the scope of this paper. Therefore, the following paragraph demonstrates a simple, illustrative example, where functional forms of functions based on Conrad (1999) are employed. The model uses steady-state calculations adjusted to this particular example and chooses coefficients to draw the graphs.

The biological growth function is based on traditional logistic growth and a Schaefer production function. Costs of harvesting are assumed constant marginally. Thus, the fishery sector functional forms are (9-11).

$$F(x_t) = rx_t\left(1 - \frac{x_t}{K}\right) \tag{9}$$

$$h_t(x_t, E_t) = qx_tE_t \tag{10}$$

$$\pi_t(x_t, h_t, p_t) = m(p_t)h_t - cE_t \tag{11}$$

Where:

r – intrinsic growth rate, where r > 0

K – environmental carrying capacity, where K > 0

q – catchability coefficient, where q > 0

E - effort input to the fishery

m – price per unit, where m > 0

$m(p_t)=m_0(1-p_t)$, where $p \in <0;1>$

c – cost per unit, where c > 0

What distinguishes the model from the traditional Gordon-Schaefer model is the price of the harvest, which is linked to the other economic sector. The price (m) is given exogenously and is a relative measure of pollution assumed to decrease linearly together with increasing pollution levels measured as a fraction, starting from the maximum price indicated by m_0. The price reaches zero when p=1, when the fish is not tradable due to dioxin restrictions. To relate to the actual example the price can be determined by the average price. More pollution likely results in more fish exceeding the threshold and therefore the average price decreases with pollution.

The functions above allow us to rewrite the benefit function:

$$\pi_t(x_t, h_t, p_t) = m(p_t)h_t - cE_t = m(p_t)h_t - \frac{ch_t}{qx_t} = h_t\left(m(p_t) - \frac{c}{qx_t}\right) \tag{12}$$

For the steady-state calculations the 'golden rule', modified for this particular two-sector example, is required (8). The time subscript is therefore omitted, as the variables in steady-state adopt the constant values. The only variable remains the pollution. Derivatives from equations (12) and (9) substituted to the modified version of golden rule for salmon fishery sector (7a) yields (13).

$$\delta = r\left(1 - \frac{2x}{K}\right) + \frac{\beta ch}{x(m(p_t)qx - c)} \tag{13}$$

By solving (13) for harvest, (14) is obtained.

$$h = \phi(x) = \frac{\left[\delta - r\left(1 - \frac{2x}{K}\right)\right] x\left(m(p_t)qx - c\right)}{\beta c} \tag{14}$$

$\phi(x)$ depends on the entire set of bio-economic parameters, as well as the share of the fishing sector. Thus, changes imply shifts in stock-harvest space.

The optimum can be achieved when harvest is equal to growth. That is why h in (14) is substituted with (9). It yields (15) and when solving for x, (16).

$$rx\left(1 - \frac{x}{K}\right) = \frac{\left[\delta - r\left(1 - \frac{2x}{K}\right)\right] x(mqx - c)}{\beta c} \tag{15}$$

$$x(p_t) = \frac{K}{4}\left\{\frac{c(2r-\beta)}{Km_0(1-p_t)qr} + 1 - \frac{\delta}{r} + \sqrt{\left(\frac{c(2r-\beta)}{Km_0(1-p_t)qr} + 1 - \frac{\delta}{r}\right)^2 + \frac{8c}{Km_0(1-p_t)qr}\left(\frac{\delta}{r} - 1 + \beta\right)}\right\} \tag{16}$$

This equation shows changes in the stock with any change in all bio-economic parameters and is as such a reaction function of the optimal biomass level to different levels of pollution.

Polluting sector functional forms are (17-18).

$$G(p_t) = \gamma p_t \tag{17}$$

$$U(Y) = \ln(Y) \tag{18}$$

γ – degradation coefficient, where $\gamma > 0$

Derivatives from the rewritten benefit function (12) and decay function (17) substituted to the modified version of golden rule for polluting sector (7b) yields (19).

$$\delta = -G'(p) - \frac{\beta(\partial\pi(\bullet)/\partial p)}{(1-\beta)(\partial U(\bullet)/\partial Y)} = -\gamma - \frac{\beta hm'(p)}{(1-\beta)\frac{1}{Y}} = -\gamma + \frac{\beta hm_0 Y}{1-\beta} \tag{19}$$

By solving (19) for Y, (20) is obtained.

$$Y = \frac{(\delta+\gamma)(1-\beta)}{\beta hm_0} \tag{20}$$

This is the reaction function of the economic activities to a different level of harvest. The level of economic activity decreases with the relative importance of the fishing sector. The activities in this sector decrease with increasing β-values and the activities of the other economic sector decrease with increase in the maximum revenue (hm_0) in the fishing sector.

The polluting sector optimum can be achieved when the polluting process is equal to self-cleaning of the environment. That is why Y in (20) is substituted with (17). It yields (21) and when solving for p, (22).

$$\gamma p = \frac{(\delta + \gamma)(1-\beta)}{\beta h m_0} \tag{21}$$

$$p^* = \frac{(\delta + \gamma)(1-\beta)}{\beta h m_0 \gamma} \tag{22}$$

In order to identify trends in solved equations, numbers for coefficients were selected. Those are presented in table 1.

K	c	m0	r	δ
1	0,001	1	0,01	0,03

Table 1: Numbers for coefficients.

4.3. Results

The results of the model highlight the effects of two-sector profit maximisation on the fishery sector. As presented in Fig. 1, the steady state stock level is increasing exponentially with the increasing amount of pollution. For lower levels of pollution, the importance of the fishing sector relative to other economic activity, e.g. the β-parameter, is of greater importance. For a large importance of this fishing sector, e.g. β- parameter close to 1, the stock level is higher. The differences between the stock levels for different β-values become smaller with higher pollution level. Furthermore, when there is more pollution, the stock gets closer to the threshold, where it is reaching carrying capacity ($x^* = 1 = K$) and is no longer harvested. The calculated threshold value for assumed coefficients is p=0.874. The threshold is illustrated with the dotted line in Figure 1. Thus, high pollution implies closure of the fishing sector.

Investigating the harvest rate in steady-state for different pollution levels (Fig. 2), the initial slight increase is noticeable. This is associated with increasing stock size. However, the subsequent rise of contamination reduces the harvest due to the fall in the catch value, making harvest less profitable. To prove this, the profit was calculated for different β levels according to pollution level (Fig. 3). Profits from the fishery sector demonstrate a falling trend with pollution increase. The significant differences in harvest rates and consequential profits between different β levels are connected with the degree of polluting sector importance. Its bigger share implies a lower incentive to preserve the stock as the potential future benefits are decreasing and it is economically more viable to harvest at faster pace.

Values of pollution, where profit reaches 0.001, which is equal to the fishing cost, are presented in table 2. Below it, there is no positive revenue from fishery sector.

β	0.25	0.5	0.75	1
P	0.930	0.940	0.944	0.947

Table 2: Pollution levels for different fishery sector share where profit $\pi = 0.001 = c$.

The exact shape of the figure is dependent on the chosen parameter values. Changing coefficients creates differences in model results, of which the most interesting ones are described. Increasing the cost of fishing (c) causes an increase in fish stock, and carrying capacity is reached within lower level of pollution, thus the pollution threshold becomes lower. Increase in the catchability coefficient (q) makes stock level lower. Further, this lack of efficiency in the sector will imply straightforward impact of pollution, as the increase in stock effect would not make significant impact in general. Increase in intrinsic growth rate (r) decrease stock level and changes of r to around 0.1 provides the set of numbers not reaching carrying capacity. It also implies lower profits from the sector. Furthermore, rise of discount factor (δ) causes an increase of the profits from fishing sector for each β level.

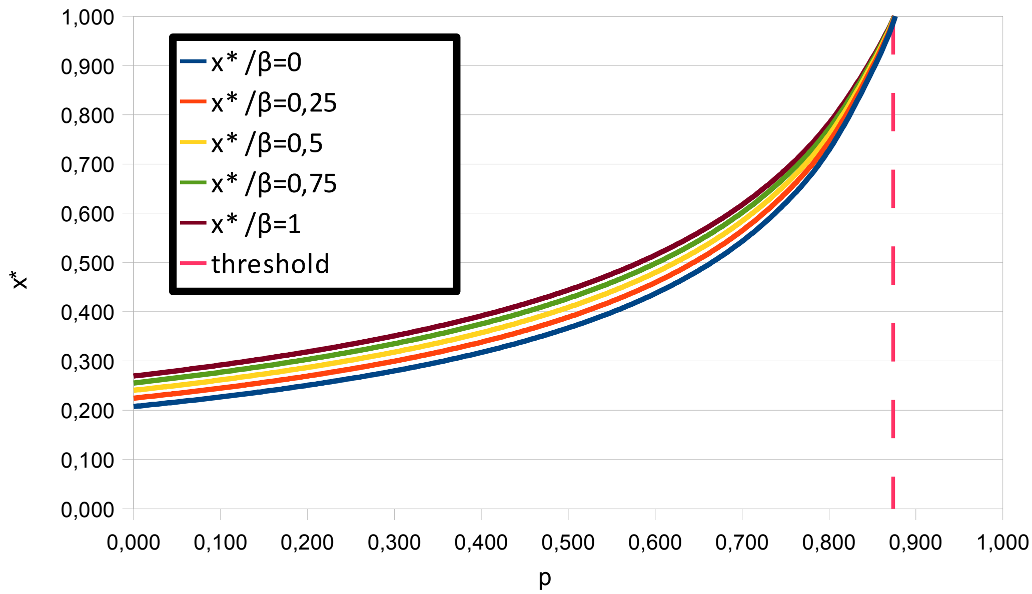

Figure 1: Steady state stock rate in function of pollution for different β levels.

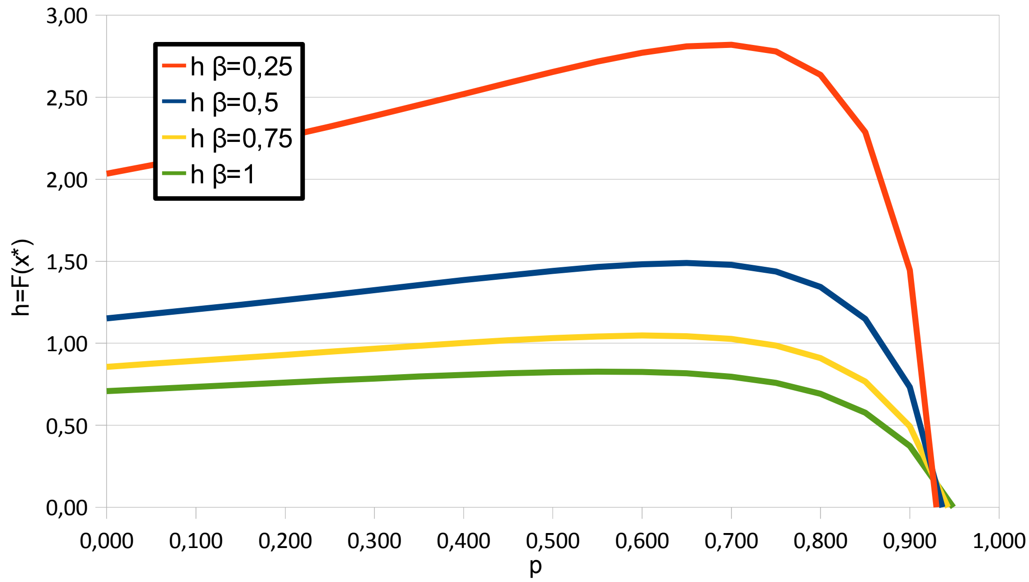

Figure 2: Steady-state harvest rate as a function of pollution.

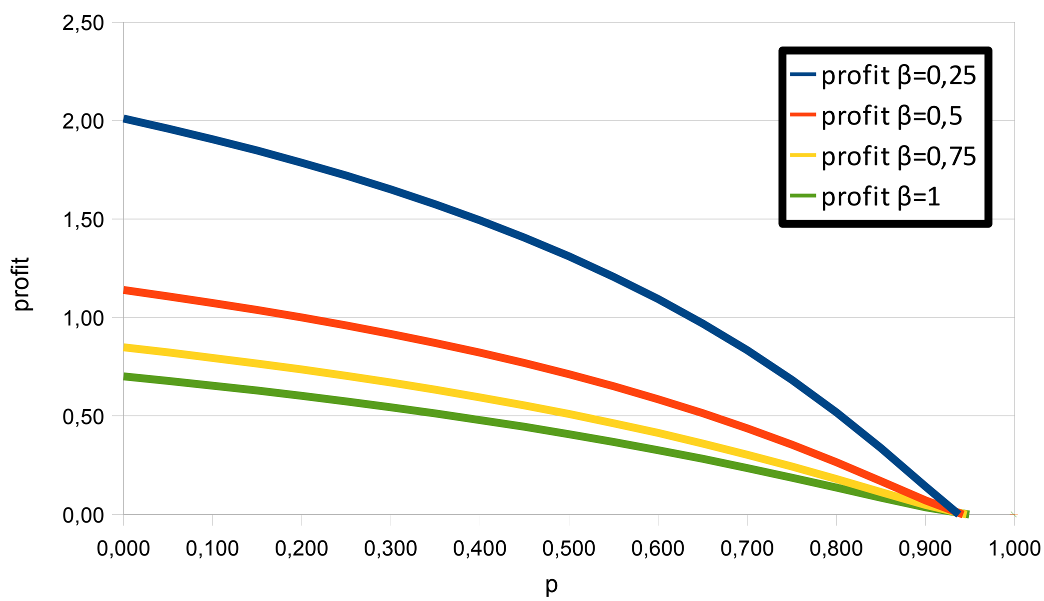

Figure 3: Profit from fishery for different pollution level and fishery sector share.

5. Conclusion

This study aims to highlight the importance of combined models for pollution and fisheries. Dioxins, as persistent substances, once released into the water affect the environment for a prolonged period of time. The underlined consequences for the fishery sector show high complexity concerning the stock level and its value, with the possibility of reaching the state where it is not worth fishing. The model shows that the value decrease may reach the state where it is lower than fishing costs.

Undoubtedly, progress in other industry sectors is necessary as well, and development must continue. However, development must be conducted in a sustainable fashion. In order to sustain the fishery, it must be managed so that current and future needs are balanced. The optimal rate of emission would have to be kept on a level where the benefit from marginal discharge is equal to forgone benefits from the fishery sector.

Furthermore, in a competitive market where sector switches are possible, it would be expected that contamination and falling fishery value would lead to a noticeable transition between sectors. A bigger share of other economic activities could cause an even faster pace of pollution, a self-triggering process leading to environmental degradation and preventing environmental self-cleaning adequate to maintain the health of the ecosystem. Therefore, it becomes probable that the pollution threshold causing total closure of the fishery sector may be reached.

Identification and mapping of the dioxin in the Baltic Sea has been conducted (Jensen, 2003), but the work covered a geographical, chemical and biological approach. The economic angle, including the challenge of fisheries regulation, is a new area for research (Lindebo, 2004) which adds a significant contribution to the literature.

The analysis has important policy implications and suggests some critical directions for future research. It shows that no intervention may lead to degradation of the environment and that proper action should be taken. However, there are also some areas in the research to be extended. This paper only seeks to find the social planner optimum. The analysis is also constrained in several areas. There are numerous simplifying assumptions made to allow the model to serve its purpose. The social planner findings are based on the steady state analysis only. The paths forward, and therefore the time lag implications, are omitted. Also, there is a big assumption concerning the chosen coefficients, whose values may vary greatly from reality. In the future, it might be necessary to look for consequences in different management regimes (suboptimal outcomes), comparing competition or open access among the exploiters of the fish resource, competition among different countries in polluting economic activities or perhaps linking fisheries to a broader ecosystem management approach.

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