Recovery of the Eastern Baltic Cod Fishery: Perspectives Revealed through Bioeconomic Modelling

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Abstract

The paper describes the situation of Polish cod fishery in the Baltic Sea and its perspectives in the future. The paper sets up a general model and exemplifies it by simple functional forms taking its offset in the problem of overcapacity in Polish fleet causing lack of profitability of the sector. The viable control approach is used in order to determine dynamic compatibility with defined constraints when making an intertemporal decision regarding the regulations affecting the stock of interest and the economy of the sector. The paper illustrates how the dynamic optimisation methodology can be used to determine the Optimal Economic Intertemporal Path and reveals potential benefits of following it.

Keywords: Atlantic cod, Bioeconomic modelling, Viable control approach, Fleet overcapacity, Decommissioning

1. Introduction

The world we are living in is becoming small. Globalization has an enormous effect on the whole population, as well as on each of us as individuals. In the global economy we eat in the middle of winter ripe banana from Ecuador, drive car using oil from the Middle East or find McDonald round every corner. Every decision and action is affecting the global market through its cumulative influence. Further, with constantly growing world population, the demand for goods and products is increasing. And in order to meet this demand, the more and more resources are required.

Some of those are renewable resources. Each year the agriculture is producing new crop, forests can be replanted and grow more wood, fish will reproduce to increase the stock base for fishery sector. Those can be maintained in infinite time, but only under a proper management scheme. Fish stock, if fished every year more than its growth rate, will be decreasing. It may even decrease to the point, when its recovery is not possible any more. Thus, the serious question arises: what can be done considering effective resource management to prevent catastrophic consequences of overusing renewable resources? How is it possible to avoid the 'tragedy of commons'?

The paper focuses on the condition of the Baltic Sea Eastern cod stock. Cod, as the most valuable fish in the Baltic Sea, is the base fishing stock for a large number of fishermen in the region. However, apart from its economic aspect, it is also an important link in the Baltic Sea food web. As a top predator, cod is performing an important structuring role in the ecosystem ensuring its stability. Therefore, the proper management regime securing the right abundance of the stock is of particular interest. For that reason, the new insight into the case is performed through applying the bioeconomic modelling methodology. The aim is to obtain the model explaining the possibility to reach optimal economic path maximising the revenues from the fishery while not putting the specie into risk of extinction considering its biological parameters.

The paper is structured as follows. The introduction is followed by section which gives the insight into the case studied, providing the explanation of further used model parameters which have a significant impact on designing a sufficient management plan. Section three contains the model developed with objective to estimate economically optimal biomass level and fleet size using viable control approach and dynamic optimization methodology. The model is applied to the case of Baltic Sea cod (Eastern stock) with focus on Polish fleet. The paper closes with conclusions regarding efficiency in fishery sector.

2. The Baltic Sea cod (Eastern stock)

Atlantic cod (*Gadus morhua*) is a demersal fish belonging to the family *Gadidae*. Its typical feature is elongated structure called 'barbell' hanging from chin. It has three dorsal fins, two anal fins and broom-shaped tail fin. It is long lived fish, possible to reach age of 20 (NOAA, 1999). It is distributed in waters of temperate climate, from shallows to deeper waters near the continental shelf (NOAA, 1999). Cod is feeding of variety of invertebrates and fish, whereas larval forms feed on krill, copepod larval, small crustaceans and fish. It reaches sexual maturity between ages two and four. Females lay between 2,5 and 9 million eggs in a single spawning which are fertilized externally. The spawning takes place annually in winter and early spring, while hatching occurs after 8 to 60 days, depending on the temperature (Hardy 1978). There are also migration patterns observed, particularly from feeding to spawning grounds (STECF, 2010).

There are two separate cod stocks in the Baltic Sea where the geographical boarder is the island of Bornholm (Figure 1). They show several differences, including meristic and morphometric characters, otolith structure, and genetic characteristic (EFIMAS, 2011). The eastern stock (*Gadus morhua callaris* L.), which focus is on, is uniquely adapted to the different environmental conditions which is the brackish water (ICES/GLOBEC, 2001) and therefore treated separately when considering in management plans (since 2004).

2.1 The role of cod in the Baltic Sea

The Baltic Sea open sea areas are dominated by three commercially important fish species: cod, herring and sprat. All those species form interacting fish community which abundance fluctuations are interconnected and affect the dynamics of those species (Heikinheimo, 2007), as well as those lower in the food web (Österblom, 2006). The main interconnections causing chain reactions in the ecosystem are explained as follows. Cod is the most important predator of both herring and sprat, whereas clupeids (family including sprat and herring) prey on the early stages of cod. The 1980s decrease in cod stock has proven the significant impact on abundance of sprat, leading to its increase. The main sprat food source, marine copepods, declined during the same period, which is likely to be partly an effect of increased predation (Österblom, 2006). Revealing the interactions, cod is the top link in trophic cascades defined as “top-down control of community structure by predators and conspicuous indirect effects two or more links distant from the primary one” (Frank et al., 2005). Thus, there are several potential ecosystem responses to the change. First of all, the transition from high- to low-trophic-level fish (regime shift) may occur (Österblom, 2006). The decrease in in the top of the food web, implying increase in prey, diminish the trophic bottom level, what to some extent may decrease each population at every single level (May et al., 1979). There is also ecological risk associated with 'fishing down the food web’ (Pauly et al., 1998). The changes across the food web may indirect result in altered nutrient cycling and primary production (Frank et al., 2005). Thus, the cod stock shortage is potentially intensifying algal blooms occurring in Baltic countries each summer, which shows the ecosystem structuring role of this big predator (MacKenzie et al., 2011).

On the other hand, cod is playing an important role in the fishing sector. This valuable fish supports the subsistence of numerous of fisherman in the region. The increasing demand for the product, which could be produced by local industry, presents potential of the sector where changes within have an important impact on the local economy and the labour market in the coastal areas.

2.2 Threats to the Baltic Sea cod

The cod population dynamics is strongly dependent on environmental conditions (Röckmann et al., 2005). The main influence factors are salinity, oxygen concentration, temperature and eutrophication (McKenzie et al., 2004). The Eastern Baltic cod eggs are neutrally buoyant below the permanent halocline. There the salinity together with the oxygen concentration is highly dependent on inflows of water from the North Sea. As occurrence of inflows is irregular (MacKenzie et al., 2004), the cod stock abundance is fluctuating with the environmental variability. Apart from direct impact on cod recruitment (i.e., through egg and larval survival), the changes in salinity and oxygen conditions influence the availability of *Pseudocalanus acuspes*, the main food source for larval cod (Köster et al., 2005).

2.3 Status of the Baltic Sea cod

The abundance of the Baltic Sea cod stock has fluctuated a lot, particularly since 1960s (Figure 2). The peak biomass, over 1 000 000 t, was estimated in 1980s, which is attributed to high frequency of inflows from the North Sea resulting in high salinity water with high oxygen concentration in the spawning areas. This implied high survival rate of eggs and good recruitment quality. In that time, the Baltic Sea catch made up roughly 21%

of the worldwide landings of this specie (FishStat Plus, 2009). No major inflows to the Baltic Sea since 1980s led to poor condition for eggs and lower recruitment. Together with eutrophication and predation (mainly by seals) (MacKenzie et al., 2011), a significant increase of fishing pressure on stock due to improvements in technology and increase in fishing effort (Bagge et al., 1994), lead to the biomass drop below biological limit, which is assumed to be 160 000 t (Röckmann et al., 2005).

Unfavourable environmental conditions influenced also size of the spawning areas making suitable for this process only Bornholm Basin. Lack of salt water inflows avert the Gotland Basin until from 1960s from being a potentially suitable habitat for cod spawning. In addition, the increase in sprat population leaded to reduced abundance of the copepod *Pseudocalanus* sp., the main larval food of cod. Further, the pressure on cod stock is triggered, as sprat and herring are preying on the cod larvae. The 1993 water inflow improved the egg survival rate, however limited food supply inhibited stock from noticeable change.

At the beginning of new millennia, the concern about Baltic Sea cod was high. In 2006, the World Wildlife Fund stated in its “A Sustainable Future for Baltic Sea Cod and Cod Fisheries” report that “The Baltic Sea cod stocks are overexploited and risk commercial extinction.” (WWF, 2006). Though, a major inflow in 2003 substantially influenced the volume of water suitable for cod egg survival, which resulted in strong year classes in 2003, 2004 and 2006 comparing with last 20 years’ time span and resulted in stable stock increase starting from 2005.

Nevertheless, the awareness about the stock continued. The advice from the International Council for the Exploration of the Sea about the decline of the stock resulted in establishing multiannual plan for fisheries management in 2007 (EC 1098/2007) aiming to decrease the fishing mortality. The target of the management plan has been achieved but most probable reason explaining it was a good environmental condition over last few years. Further, the accession to the European Union by Poland in 2004 resulted in passing new resolutions and regulations including buyback programs addressing overcapacity. The Polish fishing fleet in years 2004-2008 decreased by almost 450 vessels (WWF & MIR, 2009), which lowered the fishing pressure on the stocks in the Baltic Sea (Polish Ministry of Agriculture and Rural Development, 2006).

3. Model of polish cod fishery in the Baltic Sea

3.1 Bioeconomic modelling

In order to ensure the safety of worldwide fish stocks, the proper management regimes have to be introduced. For this purpose, the theoretical background for decision-making is developed in the form of bioeconomic modelling. Bioeconomy is a broad field incorporating economic and biological factors. In fisheries, economic forces affect the fishery industry, while the biological dimension determines amount of supply available in the sea. Modern fishery bioeconomics provides the insight approach to deal with various issues including complexity of overcapacity and overexploitation in marine fisheries. Furthermore, it investigates management methods in order to examine profitability (Anderson and Seijo, 2010).

3.2 Bioeconomic characteristics of fishery

The paper considers single stock fishery characterised for each year t by biomass B_t and the fleet size in number of vessels K_t. The bioeconomic system dynamics is controlled by effort e_t which correspond to days at sea per vessel and per year, as well as by changes in fleet size. To represent the fish stock growth, the logistic model is used:

$$G(B_t) = rB_t\left(1 - \frac{B_t}{B_K}\right) \tag{1}$$

where B_K is carrying capacity of ecosystem and r is intrinsic growth rate of the population. The fishing fleet is assumed homogeneous and each vessel shares the same characteristics. The total harvest H_t is characterised by catch-effort relation:

$$H_t = qE_tB_t \tag{2}$$

where E_t=K_te_t and q is catchability coefficient. Following Gordon (1954), the combined resource dynamics looks:

$$B_{t+1} = B_t + G(B_t) - H_t = B_t + rB_t\left(1 - \frac{B_t}{B_K}\right) - qB_te_tK_t \tag{3}$$

The fleet economic status is characterised by profit per vessel. This depends on the resource landings L_t, which are assumed to be equal to harvest per vessel adjusted by discard rate d:

$$Lt = (1-d)h_t = (1-d)\frac{H_t}{K_t} = (1-d)qB_te_t \tag{4}$$

The yearly vessel revenue (π_t) associated with targeted specie catch is given by part α of total vessel's revenue:

$$\pi_t = \frac{p(1-d)qB_t e_t}{\alpha} - (c_f + c_v e_t) \tag{5}$$

where π_t is profit per vessel, p is exogenous ex-vessel resource price assumed constant, c_f are fixed costs per vessel and c_v are variable costs associated with fishing effort and calculated per effort unit. The fleet size is assumed to be flexible within constraints and evolving according to decision control factor ζ_t:

$$K_{t+1} = K_t + \zeta_t \tag{6}$$

The fleet size change is restricted in the way that limited number ζ_{ent} of vessels can enter the fishery in year t and the limited number ζ_{ex} of vessels can exit the fishery in year t. This result in constraint:

$$-\zeta_{ex} \le \zeta_t \le \zeta_{ent} \tag{7}$$

The effort technical constraint put on vessel in terms of days per sea is defined as:

$$0 \le e_t \le e_{\max} \tag{8}$$

3.3 Viability constraints

The fishery, in order to be viable, has to satisfy several constraints (Martinet et al., 2007). The renewable resource stock preservation requires certain minimum biomass size:

$$B_t \ge B_{viab} \tag{9}$$

For economic units to be viable, the vessel's profit has to meet constraint:

$$\pi_t \ge \pi_{\min} \tag{10}$$

The number of vessels, due to social concerns, is also required to be at least at threshold level:

$$K_t \ge K_{viab} \tag{11}$$

3.4 Induced constraints

The profitability constraint (10) combined with equation (5) gives:

$$\frac{p}{\alpha}(1-d)qB_t e_t - (c_f + c_v e_t) \ge \pi_{\min} \tag{12}$$

Hence, the minimum effort is equal:

$$e_{\min}(B_t) = \frac{\pi_{\min} + c_f}{\frac{p}{\alpha}(1-d)qB_t - c_v} \tag{13}$$

With the minimum effort increase, the stock decreases as noticeable in equation (13). The minimum effort cannot however exceed maximum effort. Thus the minimum biomass is equal:

$$B_{\min} = \frac{\pi_{\min} + (c_f + c_v e_{\max})}{\frac{p}{\alpha}(1-d)qe_{\max}} \tag{14}$$

3.5 Parameters

The model is applied to Polish cod fishery in the Baltic Sea. It follows empirical modelling approach in order to avoid analytical and computational difficulties. It is calibrated according to 2004-2007 data for Polish fishing fleet (average values for four years). The parameters are listed in Table 1.

The price is the average ex-vessel cod price per tonne (live weight) over calibration period. The fixed costs include crew payments, reparation, capitalization and other costs not depending on extent of vessel use. The variable costs include fuel and other variable costs depending on vessel's effort days. The minimum profit is an amount assumed to remunerate capital and labour per vessel in Polish fleet.

The cod intrinsic growth rate r is taken from literature (Agnarsson et al., 2008). The value is calculated for Denmark, but it is assumed correct as both fleets share the same stock. The catchability coefficient is calculated from relation $q=F_t/B_t$ where F_t is fishing mortality. It is calculated as the average for the whole Baltic Sea due to data availability. The Baltic Sea carrying capacity for cod B_K is assumed the highest biomass estimate available, which reached around million tonnes in 1980s. Due to focusing on Polish fleet only, this value is adjusted to 20% according to Polish share in cod harvest. The maximum effort per vessel e_{max} is assumed the average effort adjusted by not used cod quotas. This gives the maximum effort indicating regulated open access where each vessel can fish freely until using all the TAC. The discard rate (d) is the Baltic average discard as a part of total catch. The discard coefficient only includes years 2006-2007, as that was the time when Community Fisheries

Control Agency was brought into force. The previous estimates are claimed to be highly underestimated because of lack of efficient control (WWF & MIR, 2009). The revenue share associated with cod catch λ is given by value of Polish cod landings divided by total value of Polish landings. The minimum biomass B_{viab} is given in literature and accounts for 160 000 t (Röckmann et al., 2005), which is again adjusted to 20%. The viable fleet size K_{viab} is arbitrary number assumed to keep the Polish fishing sector working. Following Martinet et al. (2007), the restrictions regarding pace of fleet change ζ_{ent} and ζ_{ex} are caused by technical and regulatory constraints when it comes to enter and by social and political constraints when comes to exit. Those values are arbitrary set at level of 50 vessels per year considering yearly average of change in peak periods.

3.6 Steady states

The steady states are characterised by no changes in biomass and fleet size, so $B_{t+1}=B_t$ and $K_{t+1}=K_t$. This imply $\zeta_t=0$ and growth equal to harvest $G(B_t)=H_t$. Those relationships give opportunity to write:

$$K_t = \frac{H_t}{qB_t e_t} = \frac{rB_t\left(1-\frac{B_t}{B_K}\right)}{qB_t e_t} \tag{15}$$

Holding constraints, the linear relationship between the fleet size and the stock size is found. It depends on the effort level, which two extreme cases correspond to relation:

$$\frac{r}{qe_{\max}(B)}\left(1-\frac{B_t}{B_K}\right) \le K \le \frac{r}{qe_{\min}}\left(1-\frac{B_t}{B_K}\right) \tag{16}$$

for every stock size larger than B_{min}. Two lines in Figure 3 marked K_{min} and K_{max} represent those boundaries and the area between correspond to states satisfying all constraints (9-11).

On the Figure 3, within steady states intersection, there are marked points of particular interest. The regulated Open Access Equilibrium (OAE) is the state which fishery reaches under open access with free possibility to enter/leave fishery and choose its effort level as a response to the profit within the quota limitation. Whenever profit is positive, the fishery is extending its fleet which result in biomass decrease. This continues to the point, when B_{min} is reached, which is proven to be a minimum biomass allowing profit constraint held. The Maximum Sustainable Yield (MSY) is the set of steady states where the stock regeneration G (B_{MSY}) is maximised. The various states are possible depending on the effort and fleet size. The Maximum Economic Yield (MEY) corresponds to maximum of Sustainable Economic Rent function. Here, the total fleet profit is maximized.

3.7 Viability kernel

The viable control approach is used to determine dynamic compatibility with defined constraints. The result is the viability kernel - the whole range of bioeconomic states from which there is at least one set of intertemporal decision choices which trajectory will respect all constraints indefinitely. It is defined, following Martinet et al. (2007), by:

$$Viab = \left\{ (B_0, K_0) \left| \begin{array}{l} \exists(e(\cdot), \zeta(\cdot)) \textit{and } (B(\cdot), K(\cdot)), \textit{starting} \quad \textit{from } (B_0, K_0) \\ \textit{satisfying} \ : \\ B_{t+1} = B_t + G(B_t) - H_t \\ K_{t+1} = K_t + \zeta_t \\ -\zeta_{ex} \le \zeta_t \le \zeta_{ent} \\ B_t \ge B_{viab} \\ K_t \ge K_{viab} \\ \pi_t \ge \pi_{\min} \end{array} \right. \right\} \tag{17}$$

The viability kernel in Figure 3 is the area below the dotted line and bounded by B_{viab}, K_{viab} and B_K. The historical path based on the data available for years 2000-2009 is also displayed. Notice the marked point for 2008 year. It is the first point of the trajectory appearing in the viability kernel meaning that from this point the steady state can be reached without violating any constraint.

3.8 The scenarios

This section presents two different management scenarios: regulated Open Access and Optimal Economic Intertemporal Path and compares them with historical paths. The regulated Open Access scenario represents the situation, where vessels can freely enter or exit the fishery (subject to constraint (7) and choose own effort within the quota limits. To establish the correct effort level, the profit equation (5) derivation with respect to the effort e_t is defined:

$$\frac{\partial \pi}{\partial e} = \frac{p}{\alpha}(1-d)qB_t - c_v \tag{18}$$

This leads to the resource stock threshold B_χ. Following the 'bang-bang' or 'most rapid approach' theorem, the individual instantaneous profit will be maximised if effort used is maximum for $B_t \geq B_\chi$ and zero for $B_t < B_\chi$:

$$e_t^{OA} = \begin{Bmatrix} e_{\max} \Leftrightarrow B_t \geq B_\chi \\ 0 \Leftrightarrow B_t < B_\chi \end{Bmatrix} \tag{19}$$

Further, the change in the fleet size depends on the profit per vessel. If the profit is higher than $\pi_{\min}$, then more vessels enter the fishery. If the profit is not high enough to cover the opportunity costs, then vessels leave the fishery. This dynamics is summarised by:

$$\zeta_t^{OA} = \begin{Bmatrix} \zeta_{ent} \Leftrightarrow \pi_t \geq \pi_{\min} \\ -\zeta_{ex} \Leftrightarrow \pi_t < \pi_{\min} \end{Bmatrix} \tag{20}$$

The second scenario, the Optimal Economic Intertemporal Path, is defined by maximised sum of discounted fleet profits with respect to applied effort and changes in fleet size:

$$\max_{e(\cdot),\zeta(\cdot)} \sum_{t=0}^{T} \rho^t \, \Pi(B_t H_t) \tag{21}$$

where:

$$\Pi(B_t, H_t) = p_t q B_t E_t - E_t c_v - K_t c_f = p_t H_t - E_t\left(c_v - \frac{c_f}{e_t}\right) = p_t H_t - EC_t \tag{22}$$

subject to:

$$B_{t+1} = B_t + G(B_t) - H_t \tag{23}$$

$$B_0 \ given \tag{24}$$

where C_t is unified cost combining fixed and variable costs ($c_v + c_f/e_t$). In order to solve the dynamic optimisation problem, the optimal control theory is used (Perman, 2003). The objective is to maximise the present value of net benefits, subject to resource dynamics and the initial condition B_0. The problem is solved using the method of Lagrange multipliers (Conrad, 1999). The Lagrangian expression takes the form:

$$L = \sum_{t=0}^{T} \rho^t \{\Pi(B_t, H_t) + \rho\lambda_{t+1}[B_t + G(B_t) - H_t - B_{t+1}]\} \tag{25}$$

The costate variable λ is a shadow price indicating the marginal value of an incremental increase in B_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. The equation (25), when all the variables are reaching constant value ensuring the steady-state optimum, leads to 'fundamental equation of renewable resources' known also as a 'golden rule':

$$G'(B) + \frac{\partial \pi(\bullet)/\partial B}{\partial \pi(\bullet)/\partial H} = \delta \tag{26}$$

From equation (26), using catch-effort relation and substituting harvest with growth function, it is possible to identify optimal level of stock B*.

$$B^* = \frac{B_K}{4}\left[\left(\frac{c_v + \frac{c_f}{e_{\max}}}{pqB_K} + 1 - \frac{\delta}{r}\right) + \sqrt{\left(\frac{c_v + \frac{c_f}{e_{\max}}}{pqB_K} + 1 - \frac{\delta}{r}\right)^2 + \frac{8\left(c_v + \frac{c_f}{e_{\max}}\right)\delta}{pqB_K r}}\right] \tag{27}$$

Note that the effort in steady state is set at the maximum level, as it is the most efficient solution in the long run. The optimum stock size accounts for B*=116 433 t and fleet size for K* = 330 vessels. The optimal way to reach this optimal steady state is to follow 'bang-bang' strategy (Clark, 2010), which is however restricted here by constraints. In order to show the optimal paths with no constraint violation, the starting point for optimal economic path is the year 2008, which is the first one inside of the viability kernel.

3.9 The trajectories

The trajectories in Figures 4-7 presents biomass size, fleet size, effort per vessel and profit per vessel in two different management scenarios compared with historical path. The Figure 4 shows, that regarding biomass, the regulated Open Access scheme may be highly threatening Baltic Sea ecosystem, even with effort limited to e_{max}. The stock is much lower compared to the historical path, which proves the lack of binding restrictions imposed by quota system on the fishery. However, the regulations aiming to reach optimal economic path would bring positive impact, especially in the long run. Further, both historical and regulated Open Access paths lead the stock below the biological viability level. Starting from year 2008, when the fishery reached the viability kernel area, the optimal economic path with no constraint violation is available where the recovery to the optimum level (B*) is possible. The all fleet size paths shows the reduction at the maximum available pace. This highlights problem of overcapitalization of Polish fishing fleet which size in 2000 was roughly four times higher than optimal level (K*). The effort level in Open Access regime is fluctuating between zero and e_{max}, which depends on current biomass level. The historical path shows systematic decrease in effort, which seem to possibly reach the recommended optimal economic path. The effort based on attempt to keep the social optimum is firstly decreasing to allow stock recovery, and then increasing to the maximum level when the stock and fleet reaches the optimum levels. The profit, both from historical path and the regulated Open Access is below the minimum. This means no capital and labour remuneration at their opportunity costs for a long period. The optimum economic path from 2008 ensures the minimum profit to the fishery. The guarantee of minimum profit, recalling proof (14), sets the initial significant constraint on minimum effort. However, applying minimum effort for an initial period of time leads to increase of the stock and gives the possibility to increase effort to maximum gradually. The recovery of the stock accompanied with the fleet reduction will lead to income increase until optimum level.

3.10 Model conclusions

The viability kernel represents the bioeconomic states and decision possibilities which will satisfy constraints dynamically. Any path leaving this area is certain to violate the constraints in finite time and face the crisis situation. The historical path based on the available Polish fleet data shows signs of recovery and entering the area defined as a viable for further progress in fishery performance. This study shows the possibility to use the opportunity of reaching the area of viability kernel in the latest past to continue the fishery following the Optimal Economic Intertemporal Path. Thus, well performed management plan may result in profitability of the sector, as well as stock increase when reaching the goal of the Maximum Economic Yield point. The main issue here is however the overcapitalization of the fleet. To show the lack of efficiency of present quota system, the scenario of regulated Open Access is investigated, where poor long term advantages are revealed.

There are however few issues important to highlight before applying this framework to the real life case. The foregoing model gives the illustrative image of stock regeneration under certain management configurations, but there are several limitations to address before. The more realistic and detailed model should consider stock age structure, environmental uncertainty affecting recruitment including climate change, pollution impact and ecosystem interactions between different species. In case of cod, the evident shortcoming is not including the internal food web interactions (cod - sprat - zooplankton - phytoplankton) mentioned above. It is often claimed, that single species fishery models results do not apply for multispecies communities (May et al., 1979; Hannesson, 1983).

Further, the model concentrates only on Polish fleet sharing the part of the whole stock. To make it more comprehensive, the data from all Baltic countries involved in cod fishery should be integrated and modelled for the whole stock. Lack of longer time series of available data may also influence the correctness. All those concerns should be taken into account when designing model for strategic use in policy formulation. The general conclusions of the model are, however, very illustrative and could be used to other fisheries worldwide to examine the extent of the fleet overcapacity and highlight the importance of reaching the Optimal Economic Intertemporal Path. The straightforward message arising from the model gives easy to understand call for system improvement and, promoted to the larger public, incentive to support management initiatives.

4. Efficient fishery considerations - conclusions

The command and control approach is the most common way of regulating the fisheries (Perman et al., 2003). In case of Baltic cod, the current method is Total Allowable Catch system. The final quotas, despite the advices, however were consistently higher than recommendations for a prolonged time period (ICES, 2010). This was mainly happening because fleet capacity is over-exceeding actual stock reproduction potential (Döring and Egelkraut, 2008). Overcapitalization, caused by previous high EU subsidies for investment in larger vessels and modern technologies, requires large landings in order to prevent financial collapse. Trying to keep fishermen in business resulted in short-term perspective of management policies. The high uncertainty about future regulation discouraged investments in living stock as there was no guarantee for benefits from conservation efforts. Thus, member countries stood for various exceptions regarding quotas, which were often accepted (Edwards et al., 2004).

All the mentioned reasons, put together, result in management failure. The managers, addressing political and social causes and influenced by stakeholders, were forced to ignore the scientific advice instead ignoring public interest and invest in long-term health of fish populations. The contracting parties maximising the economic return, attempt to allocate this greater value to themselves considering scientific-based recommendations just 'the starting point for talking up quotas' (Aps et al., 2007). Those decision-makers allowed TAC to deviate from advices believing that socioeconomic arguments justify higher level of harvest, while risk of irreversible harm to the stocks is low (Aps et al., 2007). Further, with no efficient control instruments, the secure, sustainable use of resource is at risk.

The improvement in control instruments in 2008 gives the opportunity to efficiently enforce the agreed Total Allowable Catches. Therefore, the partial solution for sustainable fishery lay within EU Council of Ministers competences when making a decision about quota. Then, the successful decommissioning programme is required to solve the overcapacity problem.

The model proves that investment in natural capital would lead to greater harvest and would be economically viable. Therefore effort into reasonable management would be beneficial, both for fish stock and fishermen. However, there are several concerns regarding pursing successful decommissioning programme. First of all, decision makers should influence fishermen incentive to form capital assuring the security of sustainable fishery in the long run. The decommissioning schemes set permanently are believed to accelerate the investment in the sector. It is associated with reduced risk connected with investment in new vessel (Clark et al., 2005), as the input can be recovered in case of failure (Jensen, 2002). Therefore, the best perspective gives the overcapacity reduction scheme combined with effective control of new investments (Jensen, 2002).

The biggest concern regarding decrease of the Polish fleet are substantial losses of working places in the coastal zone. This leads to necessity of finding new job in other area by fishermen to which most is not prepared, increased of unemployment in coastal municipalities resulting in additional expenditures to local authorities through obligation to provide unemployment benefits and damage to local culture based for ages on fishing activities.

Concluding, there is a possibility to manage Eastern Baltic cod stock in economically viable way. This would result in stock increase and the profitability of the sector. Despite the previous management far form recommended, the recent cod stock size is promising. This is most likely attributed to external factors with the biggest share of favorable hydrologic conditions. Though, it would be recommended to use the opportunity of advantageous situation to continue the exploitation according to Optimal Economic Intertemporal Path.

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References

Agnarsson S., Arnason R., Johannsdottir K., Ravn-Jonsen L., Sandal L.K., Steinshamn S.I., & Vestergaard N. (2008). *Comparative Evaluation of the Fisheries Policies in Denmark, Iceland and Norway: Multispecies and Stochastic issues.* Nordic Council of Ministers, Copenhagen 2008.

Anderson L.G., & Seijo J.C. (2010). *Bioeconomics of Fisheries Management*. Ames: Wiley-Blackwell.

Aps R., Kell L.T., & Lassen, Liiv I. (2007). Short Communication Negotiation framework for Baltic fisheries management: striking the balance of interest. *ICES Journal of Marine Science*, 64, 858–861. http://dx.doi.org/10.1093/icesjms/fsl038

Bagge O., Thurow F., Steffensen E., & Bay J. (1994). The Baltic cod., *Dana*, 10, 1-28.

Clark C.W. (2010). *Mathematical Bioeconomics; The Mathematics of Conservation*. New Jersey: John Wiley & Sons.

Clark C.W., Munro G.R., & Sumaila U.R. (2005). Subsidies, buybacks, and sustainable fisheries. *Journal of Environmental Economics and Management*, 50, 47-58. http://dx.doi.org/10.1016/j.jeem.2004.11.002

Conrad J.M. (1999). *Resource Economics.* New York: Cambridge University Press.

Döring R., & Egelkraut T.M. (2008). Investing in natural capital as management strategy in fisheries: The case of the Baltic Sea cod fishery. *Ecological Economics,* 64, 634 – 642. http://dx.doi.org/10.1016/j.ecolecon.2007.04.008

Edwards S.F., Link J.S., & Rountree B.P. (2004). Portfolio management of wild fish stocks. *Ecological Economics,* 49, 317–329. http://dx.doi.org/10.1016/j.ecolecon.2004.04.002

EFIMAS (2011). Operational Evaluation Tools for Fisheries Management Options. [Online] Available: http://www.efimas.org/ (February 1, 2012).

FishStat Plus (2009). FishStat Plus - Universal software for fishery statistical time series. [Online] Available: http://www.fao.org/fishery/statistics/software/fishstat/en (February 1, 2012).

Frank K.T., Petrie B., Choi J.S., & Leggett W.C. (2005). Trophic Cascades in a Formerly Cod-Dominated Ecosystem. *Science,* 308, 1621-1623. http://dx.doi.org/10.1126/science.1113075

Gordon H.S. (1954). The economic theory of a common property resource: the fishery. *Journal of Political Economy,* 62, 124-142. http://dx.doi.org/10.1086/257497

Hannesson R. (1983). Optimal Harvesting of Ecologically Independent Fish Species. *Journal of Environmental Economics and Management,* 10, 329-345. http://dx.doi.org/10.1016/0095-0696(83)90003-7

Hardy J.D.Jr. (1978). *Development of fishes of the Mid-Atlantic Bight: An atlas of egg, larval and juvenile stages.* Vol. 2: Anguillidae through Syngnathidae. U.S. Fish and Wildlife Service.

Heikinheimo O. (2007). Interactions between cod, herring and sprat in the Baltic Sea, simulated with a robust dynamic model. Finnish Game and Fisheries Research Institute.

ICES (2010). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* 15 - 22 April 2010, Copenhagen.

Jensen C.L. (2002). Reduction of the fishing capacity in "common pool" fisheries. *Marine Policy,* 26 (3), 155-158. http://dx.doi.org/10.1016/S0308-597X(01)00037-9

Köster F.W., Möllmann C., Hinrichsen H.-H., Tomkiewicz J., Wieland,K., Kraus G., Voss R., MacKenzie B.R., Schnack D., Makarchouk A., & Plikshs M., Beyer J.E. (2005). Baltic cod recruitment – the impact of climate variability on key processes. *ICES Journey of Marine Science,* 62, 1408-1425. http://dx.doi.org/10.1016/j.icesjms.2005.05.004

MacKenzie B., Almesjö L., & Hansson S. (2004). Fish, Fishing and pollutant Reduction in the Baltic Sea. *Environmental Science and Technology,* 38, 1970-1976. http://dx.doi.org/10.1021/es034297n

MacKenzie B.R., Ojaveer H., & Eero M. (2011). Historical ecology provides new insights for ecosystem management: eastern Baltic cod case study. *Marine Policy,* 35, 266-270. http://dx.doi.org/10.1016/j.marpol.2010.10.004

Martinet V., Thébaud O., & Doyen L. (2007). Defining viable recovery paths toward sustainable fisheries. *Ecological Economics,* 64, 411-422. http://dx.doi.org/10.1016/j.ecolecon.2007.02.036

May R.M., Beddington J.R., Clark C.W., Holt S.J., & Laws R.M. (1979). Management of Multispecies Fisheries. *Science,* 205 (4403), 267-277. http://dx.doi.org/10.1126/science.205.4403.267

Österblom H. (2006). Complexity and Change in a Simple Food Web - Studies in the Baltic Sea (FAO Area 27.IIId). Stockholm University.

Pauly D., Christensen V., Dalsgaard J., Froese R., & Torres Jr. F.C. (1998). Fishing down marine food webs. *Science,* 279, 860-863. http://dx.doi.org/10.1126/science.279.5352.860

Perman R., Ma Y., Common M., Maddison D., & McGilvaray (2003). *Natural Resource and Environmental Economics.* Essex: Pearson Education

Polish Ministry of Agriculture and Rural Development (2006). Program Operacyjny Zrównoważony rozwój sektora rybołówstwa i nadbrzeżnych obszarów rybackich na lata 2007-2013, Ministerstwo Rolnictwa i Rozwoju Wsi, Warszawa [in Polish] [Online] Available: http://www.funduszestrukturalne.gov.pl/informator/npr2/po/rybki.pdf (February 1, 2012).

Röckmann Ch., Schneider U.A., St. John M.A., & Tol R.S.J. (2005). Rebuilding the Eastern Baltic cod stock under environmental change - a preliminary approach using stock, environmental, and management constraints.

Working Papers FNU-106, Research unit Sustainability and Global Change, Hamburg University.

STECF. (2009) The 2009 Annual Economic Report on the European Fishing Fleet Report EUR 24069. [Online] Available: https://energyefficiency-fisheries.jrc.ec.europa.eu/c/document_library/get_file?uuid=e912ddce-9932-4c56-8eff-334d9ba71318&groupId=12762 (February 1, 2012).

STECF. (2010). Report of the Sub Group on Management Objectives and Strategies (SGMOS 10-06). Part e) Evaluation of multi-annual plan for Baltic cod, Report EUR 24628, 18-22 October 2010, Vigo. [Online] Available: https://stecf.jrc.ec.europa.eu/c/document_library/get_file?p_l_id=53314&folderId=44893&name=DLFE-5503.pdf (February 1, 2012).

WWF, & MIR. (2009). Mniej statków-więcej ryb? Społeczno-ekonomiczne skutki redukcji floty rybackiej na Morzu Bałtyckim. WWF Poland, Warszawa [in Polish].

WWF. (2006). *A Sustainable Future for Baltic Sea Cod and Cod Fisheries.* WWF Denmark, October 2006.

Table 1. Parameters for Polish Baltic Sea cod fishery model

r	0,603
q	0,0000069*
B_K	200 000 [t]*
p	1188 [EUR/t]**
c_f	20 486 [EUR]**
c_v	169 [EUR/effort day]**
e_{max}	111,5 [effort days]**
d	0,17*
α	0,38**
B_{viab}	32 000 [t]
K_{viab}	200 [vessels]
π_{min}	26 916 [EUR/vessel]
$\zeta_{ent}/\ \zeta_{ex}$	50
δ	0,05

Sources: * ICES, 2010; **STECF, 2009

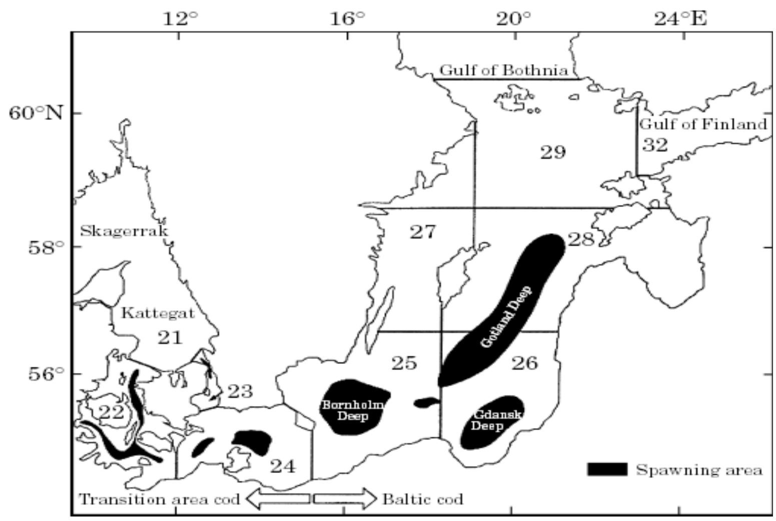

Figure 1. Baltic Sea with marked ICES subdivisions, important cod spawning areas and division between Eastern and Western cod stock (Bagge et al., 1994)

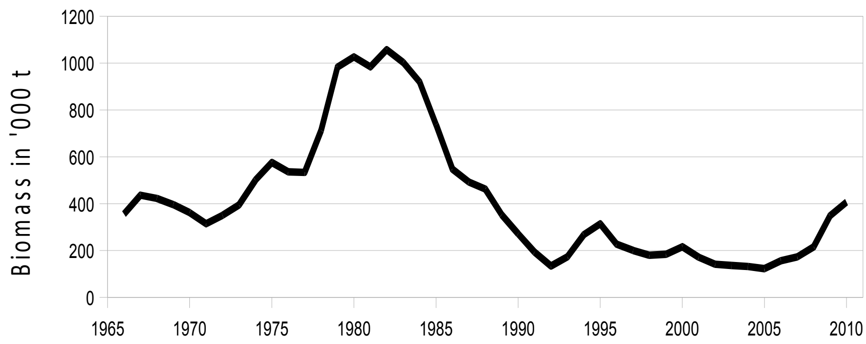

Figure 2. Fluctuation of biomass of Eastern Baltic cod (1966-2010) (ICES, 2010)

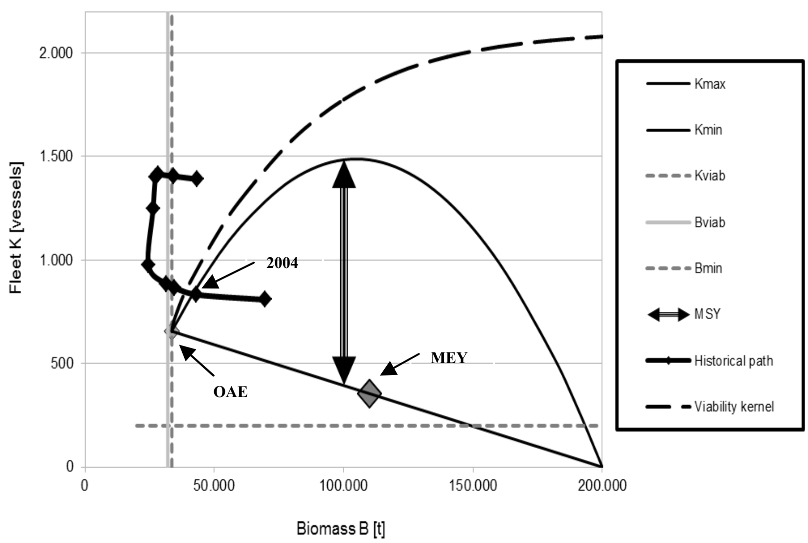

Figure 3. Steady states, viability kernel and historical path as a Biomass/Fleet relation

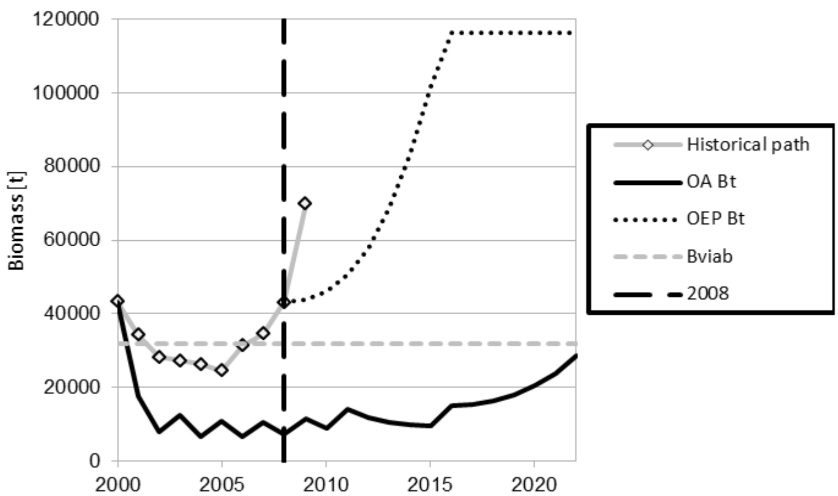

Figure 4. Trajectories of biomass size in different management schemes

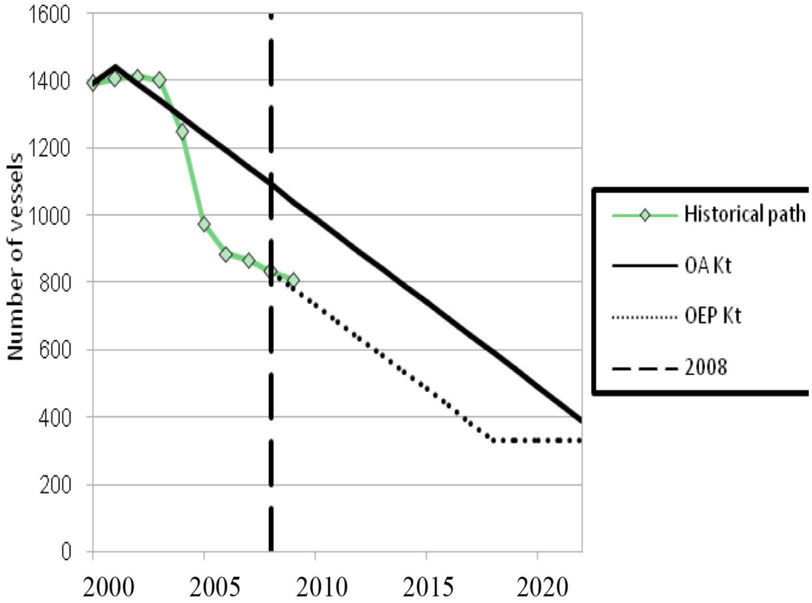

Figure 5. Trajectories of fleet size in different management schemes

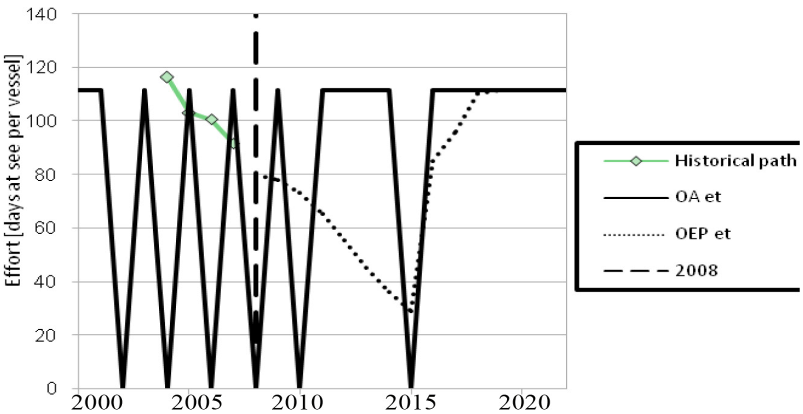

Figure 6. Trajectories of effort per vessel input in different management schemes

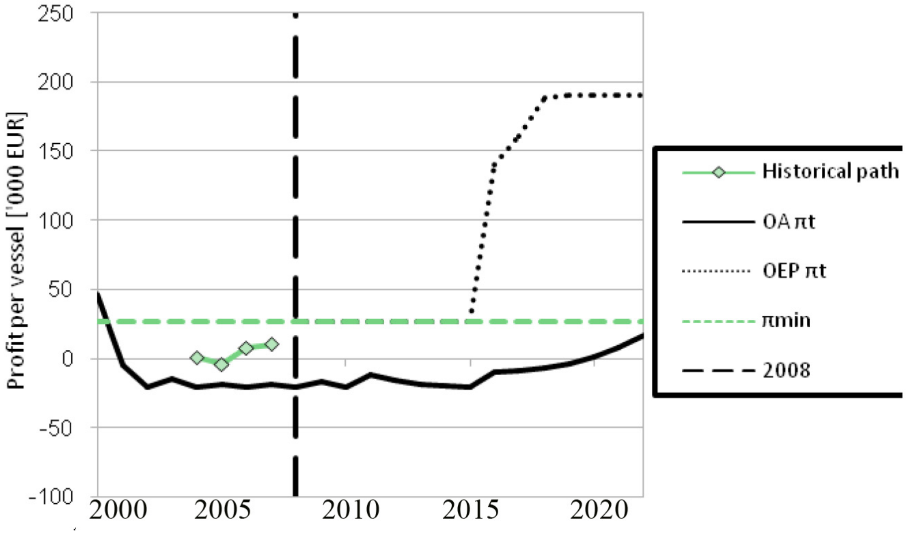

Figure 7. Trajectories of profit per vessel ['000 EUR] in different management schemes