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Windows of Opportunity for Sustainable Fisheries Management: The Case of Eastern Baltic Cod

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Abstract We study under which conditions a 'window of opportunity' for a change from an overfishing situation, with high fishing effort, but low stocks and catches, towards sustainable fishery management arises. Studying the Eastern Baltic cod fishery we show that at very low stock sizes (as they prevailed in the early 2000s) all interest groups involved in the fishery unanimously prefer maximum-sustainable-yield management (as prescribed by the management plan in place since 2007) over the previous overfishing situation. With increasing stock sizes, the present value of fishermen surplus would be higher when switching back to overfishing again, while other interest groups maintain their preference for sustainable fishery management.

Keywords Sustainable resource use · Fisheries economics · Resource rent · Consumer surplus · Worker surplus

JEL Classification Q22 · Q28

1 Introduction

The problem of overfishing persists in the oceans globally (FAO 2012; Pauly and Froese 2012), as well as regionally in European coastal waters and elsewhere, despite the fact that a more sustainable fisheries management is a political goal declared at the 2002 World Summit on Sustainable Development (Johannesburg), the Rio +20 conference in 2012, and in the 2030 Agenda for Sustainable Development. The specific political aim of the European Common Fisheries Policy (EU 2013) is to manage fish stocks such that they produce maximum

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sustainable yields (MSY). However, the transition from business-as-usual management, characterized by high fishing effort, but low stocks and catches, towards a management that would bring the stocks to MSY levels (called 'MSY-management' in the following), is apparently difficult to manage. The questions arise, why is sustainable fishery management so difficult to implement, and are there opportunities to overcome this difficulty?

In this paper we address these questions by studying the different interests involved in fishery policy. Implementing sustainable management is of general public interest. This general public interest is however entangled with particular private interests of the different economic groups involved in a fishery. Ideally, politics is a process of a common search for the common good—and a large part of the fisheries literature focuses on studying such an optimal fisheries management (Clark 1990). However, in political practice institutional improvements and optimal solutions are often not implemented because private interests of influential groups are affected. To reach an agreement on sustainable measures and to implement them successfully, politicians must not miss the 'right time to act' within a 'window of opportunity'. Interests may change over time and a window of opportunity for a joint interest in sustainability may open for a while when certain occasions or constellations of circumstances align private interests (Klauer et al. 2013a, b).

We study under which conditions a 'window of opportunity' for the transition towards sustainable fishery management arises. Such a window of opportunity is particularly important in a situation where social preferences are time-inconsistent, such that policy-makers would like to put in place a policy that cannot be changed easily and thus may provide a commitment device. In this kind of situation, a 'window of opportunity' can be understood as a situation where the interests of the different groups are brought in line with the change towards a binding sustainable fishery management regime (such as the long-term management plan for Baltic cod). As proxies for the interests of economic groups involved in the fishery, we employ quantifiable welfare effects on the input and output sides of the harvesting sector. On the input side, we consider the present values of surpluses of input suppliers to harvesting (workers and fishing capital owners); on the output side we consider the present values of surpluses to fish processors and final consumers (Copes 1972).

In addition, fisheries create net revenues for the owners of fishing rights, as the resource itself is scarce and thus valuable. The literature in resource economics typically compares the outcome of a fishery under open-access conditions (a situation similar to the business as usual in many fisheries, Quaas et al. 2012), to a management that maximizes the present value of net revenues from the fishery, which results in an outcome similar to MSY-management for many fisheries (Grafton et al. 2007; Wilen 2000). Thus, owners of fishing rights will unambiguously benefit from the transition towards MSY management. For other groups involved in the fishery, this is not necessarily true, however. The general finding is that the welfare effect of improving the sustainability of fisheries management on the users of fishery products and on the owners of production factors used in the fishery is ambiguous. Consumer surplus may increase or decrease under private ownership compared to open-access (Turvey 1964; Copes 1972; Anderson 1980; Stoeven and Quaas 2012). Owners of production factors employed in harvesting may prefer a situation of overfishing, because high levels of fishing effort secure them a large surplus from employment in the fishery (Samuelson 1974; Weitzman 1974; Stoeven and Quaas 2012; Baland and Bjorvatn 2013). Skill differences among heterogeneous fishermen are one explanation for infra-marginal rents (Johnson and Libecap 1982; Karpoff 1987; Grainger and Costello 2016). In addition to skill rents, Boyce (2004) argues that a regulator's instrument choice (for a given total allowable catch) may also be influenced by input suppliers' infra-marginal rents (Grainger and Parker 2013; Costello and Grainger 2015). For Baltic fisheries managed by the European Union, Voss et al. (2014) show that distributional issues across countries may influence how total allowable catches are set in an international multi-species fishery.

Studying the different surpluses a fishery generates, we abstract from such multi-species considerations and consider just one decision-maker and just one policy instrument, namely the determination of the annual total allowable catch (TAC). To be able to focus on just one policy instrument, we assume that the total allowable catch is in some way allocated to individual harvesters, thus preventing the problem of rent dissipation through a race for a given total allowable catch (Homans and Wilen 1997). By assuming just one regulator, we abstract from coordination problems among multiple decision-makers. This problem is at the core of the game-theoretical literature on international fisheries (Bailey et al. 2010; Hannesson 2011 and Pintassilgo et al. 2015 review this literature; Hoffmann and Quaas 2016 and Liu et al. 2016 are recent contributions on resource management by majority voting, and forming coalitions to manage range-contracting fish stocks, respectively). While the game-theoretical literature analyses the interplay of multiple decision-makers pursuing one form of surplus (resource rent), the present paper contributes to the literature by combining the different surpluses a fishery generates in one consistent dynamic model. Motivating each interest group by a group-specific form of surplus, we offer quantifiable welfare measures for the social aspects of fishery management (Péreau et al. 2012) that also allow for the calculation of net present values to compare different harvest trajectories. We quantify these welfare measures for a relevant case, the Eastern Baltic cod fishery.

The Eastern Baltic cod fishery is historically one of largest and most productive cod stocks in the North Atlantic (Dickson and Brander 1993) and is the economically most important fishery in the Baltic. It is jointly managed by the European Union and Russia, which has a small Exclusive Economic Zone (EEZ) in the Baltic Sea as well. For most European fish stocks, total allowable catches (TACs) are negotiated annually in the council of fishery (or agricultural) ministers of the EU member states. For a few important fish stocks long-term management plans are in place that set the TACs according to harvest-control rules. Such a long-term management plan was set in place for the Eastern Baltic cod fishery in 2007 and is in force since 2008 (EC 2007). Experience with long-term management plans in European fisheries policy indicates that fishery management is committed to follow these plans.

The Eastern Baltic cod stock has been subject to serious overfishing in the two decades before 2008, being fished under conditions close to open access (Kronbak 2004; Quaas et al. 2012). The management plan introduced in 2007 aims at reaching the maximum sustainable yield (MSY). This is done by setting the TAC such that the 'fishing mortality' F, which measures the exploitation rate, is kept at a level $F = 0.3$. This level is close to the fishing mortality F_{MSY} that would lead to the maximum sustainable yield in the long run for this stock (Froese and Proelß 2010; Froese and Quaas 2011; Quaas et al. 2012).

This paper is motivated by the question why the politicians in the council of ministers were able to agree on a more sustainable management of the Eastern Baltic Cod stock in 2007, whereas overfishing of the Eastern Baltic cod stock was an issue long before 2007. To answer this question, and to characterize a potential 'window of opportunity' for the transition towards a long-term sustainable fishery management plan, we set up a dynamic bioeconomic model in discrete time, which we quantify based on literature data and stock assessment date for the Eastern Baltic cod fishery.

The stock advice (ICES 2012) as well as the management plan for Eastern Baltic Cod (EC 2007) use an age-structured model.[1] To focus on the economic aspects, we use a standard

[1] Nieminen et al. (2016) use game theory to study shared multispecies management with an age-structured Eastern Baltic Cod stock.

surplus-production model, which we quantify for the Baltic cod fishery on the basis of an age-structured fish population model (Tahvonen 2009; Tahvonen et al. 2013) parameterized according to stock assessment data (ICES 2012).

We compare the welfare effects for different interest groups involved in the Eastern Baltic cod fishery under two scenarios of fishery management: a business-as-usual (BAU) scenario where fishing would go on at the high exploitation rates that prevailed in the early 2000s, and a scenario with MSY-management that sets harvest rates such that the fishing mortality is equal to F_{MSY}, as prescribed in the management plan in place since 2007.

We find that at very low, overfished stock sizes, welfare for all functional interest groups in a single-species fishery—workers and capital owners; the processing industry and consumers—is higher under the total allowable catches set according to MSY management than in the BAU overfishing scenario. Such very low stock sizes prevailed in the 2000s, thus providing an explanation why it was possible to implement the long-term management plan a little later. We also find, however, that with increased stock sizes, fishermen would again prefer BAU to MSY management. This is because their surplus tends to decrease with the stock size, as less effort is demanded to fish the same quantity at higher stock sizes. We thus conclude that low stock sizes provide a 'window of opportunity' for the adoption of a long-term sustainable fishery management regime, as all interest groups unanimously prefer this regime to preserving the overfishing situation. We also find that other functional interest groups, in particular the owners of fishing rights, would maintain their interest in more sustainable mangement. Yet, we conclude that the institutional set-up of this kind of management plan should be such that it actually becomes a binding commitment device.

The paper is structured as follows. Section 2 introduces the Eastern Baltic cod fishery, the biological model and the simulations of the different fishing scenarios. In Sect. 3, we derive the welfare measures and some results on their properties. In Sect. 4, we apply the model to the Eastern Baltic cod fishery and we present our results in Sect. 5. The final Sect. 6 concludes and discusses the policy implications.

2 Population Dynamics and Fishing Scenarios for Eastern Baltic Cod

We derive the fish population dynamics from an age-structured population model based on the framework of Tahvonen (2009) and Tahvonen et al. (2013), which we quantify using stock assessment data from the International Council for the Exploration of the Seas (ICES 2012). Details on the age-structured population model can be found in the Appendix. As we are not interested in the details of the age-structured population in this paper, we simplify the analysis by fitting a standard surplus-production biomass model to the age-structured model.[2] The surplus-production model describes the development of cod biomass B_t according to

$$B_{t+1} = B_t + g(B_t) - H_t = B_t \left(1 + \frac{r}{\alpha}\left(1 - \left(\frac{B_t}{K}\right)^{\alpha}\right) - F_t\right) \tag{1}$$

where $g(B_t)$ denotes the natural growth function, $H_t = F_t\, B_t$ is harvest, with F_t being fishing mortality. In the Appendix we derive the parameters of the growth function (as in Blenckner et al. 2015) from the age-structured population model, which gives the estimates $r = 0.736$,

[2] We also ignore environmental stochasticity. For the case of Eastern Baltic Cod, Kapaun and Quaas (2013) show that environmental variability has a small effect on optimal catch quantities. On these grounds, we feel that the distributive effects of alternative fishery management scenarios can be well understood in a deterministic setting.

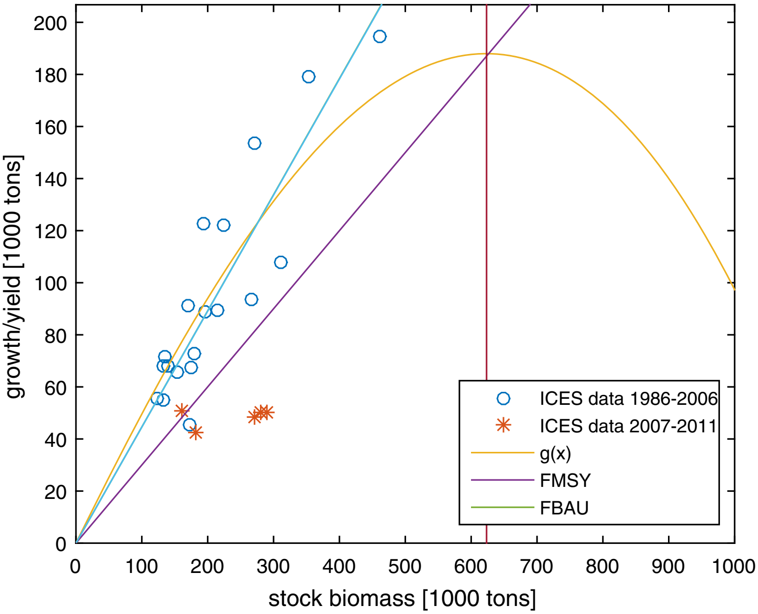

Fig. 1 Catches and biomass for Eastern Baltic cod from ICES (2012). The *solid red curve* is the graph of the surplus production model derived from a full-fledged age-structured population model for Eastern Baltic cod. The *lower straight line* has a slope equal to $F_{\text{MSY}} = 0.3$, which approximates the MSY from the model considered here very well. The *upper straight line* has a slope $F_{\text{BAU}} = 0.446$ that is obtained by a fit to the catch/stock biomass data for the 'business as usual' (BAU) period 1986–2006. (Color figure online)

$K = 1158$ thousand tons, and $\alpha = 1.441$. The graph of the resulting surplus-production function is shown in Fig. 1.

In the following we first investigate the two alternative scenarios with fixed fishing mortality. In one scenario, we fix fishing mortality at F_{MSY}, i.e., we compute the model keeping F_t fixed at the level $F_{\text{MSY}} = 0.3$. In the other scenario, we similarly keep fishing mortality fixed, but at the average level of the period 1986–2006 before the introduction of the management plan, which gives the 'business as usual' scenario with fishing mortality fixed at the level $F_{\text{BAU}} = 0.446$.

We start the simulations at 2005, the year with the minimum spawning stock biomass in the record. Figure 2 shows the historical development of the stock biomass and the simulated development from 2005 onwards under the two scenarios.

Under the BAU scenario, the stock increases slightly towards a steady-state stock size of 276,000 tons. Under the MSY scenario, by contrast, the stock steadily increases from 2006 onwards, reaching a steady state at 626,000 tons within two decades. This level is within the range of historical observations. For the period 2006–2011, when the management plan was in place, the stock biomasses have been close to those under the MSY scenario (ICES 2012).

3 Harvesting and Surpluses

We define the different functional interest groups according to the harvesting process in the fishery (Fig. 3). We think of fishing as an economic process that uses inputs such as labor (working hours of fishermen), and capital (fishing vessels and gear), to produce an

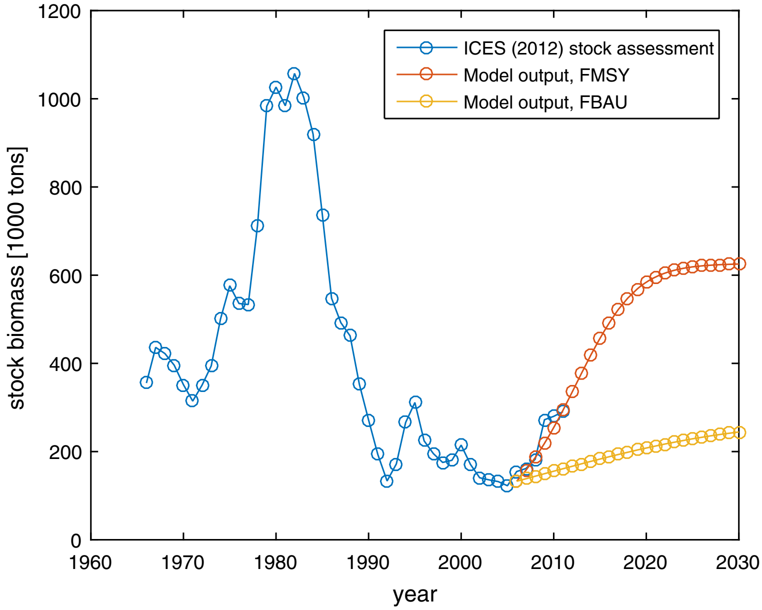

Fig. 2 Development of Eastern Baltic cod spawning stock biomass. Historical data from ICES (2012); model output for F_{MSY} (*upper curve*) and F_{BAU} (*lower curve*). (Color figure online)

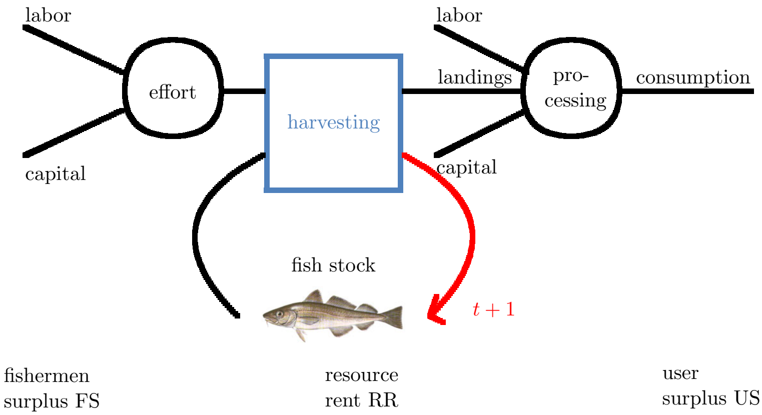

Fig. 3 Sketch of harvesting model and economic surpluses on the input and output side of the fishery

intermediate input into harvesting, ‘fishing effort’. We group all economic surpluses derived from owning factor inputs used in the production of ‘fishing effort’ and refer to them as ‘fishermen surplus’.

Effort and the stock in combination then generate the catch. Landed catch again is an intermediate product; to produce fish consumption goods, landings have to be processed, using other production factors (labor and capital).

All economic surpluses derived from using the catch, be it in the processing industry or in the final consumption of processed fish goods, are grouped together and referred to as ‘user surplus’. Finally, there may be a surplus that accrues to the second input into the harvesting process, the fish stock, which is commonly referred to as ‘resource rent’. If there is no market for fishing quotas and no harvesting tax, resource rent equals the profits from producing landed catch.

4 User Surplus from Fish Processing and Consumption

In the following we describe our model of the economic processes that make use of the landed fish. Harvest H is processed to produce fish consumption goods (quantity Y) by using as inputs harvest H and a vector $z = \left(z_1, z_2, \ldots, z_I\right)$ of I inputs, including processing-specific labor and capital goods. The processing technology is described by the production function

$$Y = f\left(H, z\right). \tag{2}$$

We assume that this production function exhibits constant returns to scale with positive and decreasing marginal products for all inputs. This production function captures that fish input may be substituted by labor or other inputs in the production of fish products. For example, using more labor input may increase the quantity of fillet obtained per fish. Also, using more labor input may increase processing speed and thus decrease the quantity of fish that is spoiled while processing.

Using P to denote the price of fish harvest, $p = \left(p_1, p_2, \ldots, p_I\right)$ to denote the vector of other input prices, where p_i is the price of input z_i in fish processing, and π to denote the price for the fish consumption good, competitive firms in the processing maximize profits

$$\max_{H,\{z_i\}} \left\{\pi f\left(H, z\right) - PH - \sum_{i=1}^{I} p_i z_i\right\}. \tag{3}$$

The first-order conditions read (using subscripts to denote partial derivatives)

$$\begin{aligned} \pi f_H\left(H, z\right) &= P \\ \pi f_{z_i}\left(H, z\right) &= p_i, \quad i = 1, \ldots, I \end{aligned} \tag{4}$$

These conditions determine the inverse supply for the fish consumption product and inverse demand for inputs $z_i^*\left(p, P, \pi\right)$. Departing from the standard approach in fishery economics, we allow the supply of production inputs to be imperfectly elastic. Neglecting income effects and general-equilibrium feedbacks between the different factor markets (thus adopting a partial equilibrium approach), the inverse supply for input z_i is given by $\omega_i\left(z_i\right)$, where $\omega_i'\left(\cdot\right) \equiv 0$ would correspond to perfectly elastic supply at a constant price, while here we allow for $\omega_i'\left(z_i\right) > 0$. Similarly, we allow the inverse demand for fish products, $\pi\left(Y\right)$ to be downward sloping, i.e. $\pi'\left(Y\right) \leq 0$. The conditions for equilibrium on fish and input markets are

$$\begin{aligned} \pi\left(f\left(H, z\right)\right) f_H\left(H, z\right) &= P \\ \pi\left(f\left(H, z\right)\right) f_{z_i}\left(H, z\right) &= p_i\left(z_i\right), \quad i = 1, \ldots, I. \end{aligned} \tag{5}$$

Solving the I latter equations for z_i yields demand for capital and labor inputs as a function of harvest, $z_i = z_i^*\left(H\right)$. Plugging these expressions into the first of the above equations yields the inverse demand for fish,

$$P\left(H\right) = \pi\left(f\left(H, z_1^*(H), \ldots, z_I^*\left(H\right)\right)\right) f_H\left(H, z_1^*(H), \ldots, z_I^*\left(H\right)\right). \tag{6}$$

The given assumptions on the inverse demand for the fish consumption product and the production function guarantee $P'\left(H\right) \leq 0$ with $P'\left(H\right) < 0$ if $\pi'\left(Y\right) < 0$ or $\omega_i'\left(z_i\right) > 0$

for any input z_i. Thus, the equilibrium inverse demand function $P(H)$ is decreasing in H if supply of any of the inputs is imperfectly elastic or if demand for the consumption product is imperfectly elastic as stated in the following result:

Result 1 *If for some inputs into fish processing the supply is imperfectly elastic, or if demand for fish consumption products is not perfectly elastic, harvest generates a user surplus* US (H) *that is increasing in the quantity of harvest, and independent of inputs into fishing, i.e. independent of effort, and not directly depending on stock size.*

Note that the user surplus captures the entire consumer and producer welfare from buying the landings up to final consumption of the fish product. For the quantitative application to the Baltic cod fishery, we assume that the inverse demand for harvest is iso-elastic, $P(H) = \overline{P} H^{\mu}$, such that user surplus for the processing industry and consumers of fish products is given by[3]

$$\mathrm{US}(H) = \int_0^H P(h)\, dh - P(H)\, H = \frac{\mu}{1-\mu}\, \bar{P}\, H^{1-\mu}. \tag{7}$$

Note that no input prices occur in (7), as we are considering equilibrium on input markets where these prices endogenously depend on harvest quantity.

To determine the user surplus of the fishery, we only have to quantify the inverse demand function for landings. Obviously, one would need more sophisticated data to derive separate expressions for the surpluses that accrue to the processing industry and to consumers of processed fish products. Such a separation of different surpluses on the output side of the fishery is beyond the scope of this paper.

4.1 Fishermen Surplus

As a next step, we derive an expression for fishermen surplus, i.e. the welfare that workers and capital owners in fish harvesting derive from the fishery. Again, we focus on the aggregate surplus on the input side of the fishery and leave a further disentangling of surpluses for future research.

Harvesting is described by the generalized Gordon-Schaefer production function

$$H_t = q(B_t)\; E_t, \tag{8}$$

where the 'catchability' $q(B_t)$ depends on fishable biomass B_t, which generalizes the Gordon-Schaefer specification $q(B_t) = \bar{q}\, B_t$, and E_t is aggregate fishing effort. As outlined above, we interpret this as an intermediate product that in turn is produced by means of labor and capital inputs (Hannesson 1983).[4] Assuming that there are J such inputs and using a_j to denote the quantity of input $j = 1, \ldots, J$, we write the effort production function as

$$E = e(a_1, \ldots, a_J). \tag{9}$$

We assume constant returns to scale for the effort production function, hence there are no profits of effort production. Labor and capital inputs are supplied on local markets at factor

[3] As for consumers, we are considering Marshallian consumer surplus. For a quasi-linear utility function, a change in Marshallian consumer surplus is equivalent to the Hicksian measures of compensating or equivalent variation (Just et al. 2004). As we do not have information on consumption of goods other than fish, and as expenditures for fish are only a small fraction of income for the consumers of Baltic cod, we use Marshallian consumer surplus as the welfare measure for users of fish.

[4] In the Gordon-Schaefer specification, fishing effort is proportional to the exploitation rate F_t.

prices r_j and we allow for upward-sloping inverse supply functions. For capital, this captures the common effect that fishing capital is malleable only to a limited extent. Thus, if there is little demand for fishing capital, the supply price will be low (or even zero in the case where fishing capital is not malleable at all), but it might be increasing steeply when demand for fishing capital increases. For simplicity, we consider an upward-sloping inverse supply function for renting fishing capital instead of explicitly modeling investment decisions (Clark et al. 1979).

Similarly, considering an upward-sloping inverse supply function for workers is reasonable if employment alternatives outside the harvesting sector are not the same for all (potential) workers in fishing industry. This will be the case, for example, if fishermen differ with respect to fishing skills. A simplifying assumption here is that the labor markets for fishermen and workers in fish processing are detached, such that the inverse supply for labor in fish processing does not depend on labor input in the fishery and vice versa. This assumption greatly simplifies the analysis. While it should be kept in mind that for some fisheries this might be a somewhat simplistic description of the actual labor market, it is beyond the scope of this paper to study the implications of a more integrated labor market.

The cost minimization problem of the representative fishing firm reads

$$\min_{\{a_j\}} \left\{ \sum_{j=1}^{J} r_j a_j \right\} \quad \text{s.t. } E \geq e(a_1, \ldots, a_J). \tag{10}$$

Using the Lagrangian $L = \sum_{j=1}^{n} r_j a_j + \lambda\,(E - e(a_1, \ldots, a_J))$, the first-order conditions lead to $r_j = \lambda\, e_{a_j}(a_1, \ldots, a_J)$ and $E = e(a_1, \ldots, a_J)$. By constant returns to scale, we thus have $\lambda = \left(\sum_i r_i a_i\right)/E$. From the first-order conditions for cost minimization we can derive the inverse input demand functions $r_j^*\,(a_1, \ldots, a_n, E)$. Using $\rho_j\left(a_j\right)$ to denote the inverse supply function for input a_j the market equilibrium conditions are $\rho_j\left(a_j\right) = r_j^*\,(a_1, \ldots, a_n, E)$. Solving these conditions gives the input quantities $a_j^*(E)$ in market equilibrium, which are increasing in effort. Plugging $a_j^*(E)$ into the cost function at equilibrium prices yields $\hat{C}\,(E) = \sum_{j=1}^{n} \rho_j(a_j^*(E))a_j^*(E)$, i.e. the effort cost in equilibrium on input markets as a function of effort E. If the inverse supply function is increasing for at least one input j, the (market equilibrium) cost function is convex in effort, $\hat{C}'(E) > 0$. Using $E_t = H_t/q\,(B_t)$ from the harvest function, we then obtain the equilibrium cost as a function of harvest and biomass, $C(H_t, B_t)$. If the equilibrium cost function $\hat{C}(E_t)$ is increasing and convex in effort, the cost function $C(H_t, B_t)$ is increasing and convex in harvest, because of the linear relationship between harvest and effort. As effort—for a given harvest level—is decreasing with biomass (provided $q'\,(B) > 0$), the equilibrium cost function is decreasing in biomass B_t.

We thus have the following result:

Result 2 *Assume a harvesting function of the generalized Gordon-Schaefer form* (8)*, and a constant-returns-to-scale effort production function* (9)*. If supply for at least one of the inputs in effort production is imperfectly elastic, fishermen surplus FS, which consists of the worker and capital owner surpluses, is positive and increasing in harvest H*

$$FS(H, B) = C_H(H,\ B)\, H - C(H,\ B) > 0. \tag{11}$$

If the 'catchability' is increasing in fish biomass, $q'\,(B) > 0$, fishermen surplus FS decreases with biomass B.

For the quantitative application to the Baltic cod fishery, we assume the following functional form for the equilibrium cost function

$$C\,(H, B) = c_0\, B^{-\chi} H^{\varepsilon} \tag{12}$$

with $c_0 > 0$, $\chi > 0$ and $\varepsilon > 1$.

4.2 Fishing Profit and Resource Rent

Fish is a valuable resource. Utilizing this resource thus generates a social resource rent, or welfare (W) which is given by the difference of the use value of fish and the direct harvesting cost, i.e. the cost needed to make the fish available for use,

$$W = \int_0^H P(h)dh - C(H, B). \tag{13}$$

For the same reason, fishing rights have economic value, which is typically referred to as resource rent (RR) in the fishery economics literature. Resource rent, if there is any, is thus given by the difference between revenues and costs. As fishing firms have to pay the market prices for inputs, their marginal fishing costs are constant and given by $c \equiv C_H(H, B)$. Using $P \equiv P(H)$to denote the market price of landed fish, private resource rent is

$$\mathrm{RR}(H_t, B_t) = P\,H - c\,H. \tag{14}$$

Resource rent depends on both harvest and stock size, as in equilibrium the marginal harvesting cost depend on stock size, and both price and marginal harvesting cost depend on the level of harvest. The next result follows immediately from (13), (14), and Results 1 and 2.

Result 3 *Welfare is the sum of user surplus, fishermen surplus and resource rent*

$$W_t = US_t + FS_t + RR_t \tag{15}$$

The marginal *changes of welfare and resource rent with H_t are the* same*,*

$$\frac{dW_t}{dH_t} = \frac{dRR_t}{dH_t} = P(H_t) - C_{H_t}\,(H_t, B_t)\,. \tag{16}$$

When changing fisheries management (harvesting $\hat{H}_t$ instead of $\underline{H}_t$, the non-marginal *change in welfare will in general be* different *from the* non-marginal *change in resource rent*

$$W_t(\hat{H}_t, B_t) - W_t(\underline{H}_t, B_t) \neq RR_t(\hat{H}_t, B_t) - RR_t(\underline{H}_t, B_t). \tag{17}$$

In particular, fisheries create welfare even if no private resource rents accrue to anyone. In this case, welfare is simply the sum of user surplus and fishermen surplus. More generally, when switching from the BAU overfishing scenario to sustainable fishery management, the present values of both welfare and resource rent will typically increase. However, the increase in present value of resource rent may be larger or smaller than the increase in present value of welfare. There even may be cases where both the present value of user and fishermen surplus decrease as a consequence of the change in management.

To quantify the model parameters for the Eastern Baltic cod fishery, we make use of the fact that total allowable catches often have not been binding before the introduction of the management plan in 2007, i.e. the fishery has been de facto open access in the past (Kronbak 2004; Quaas et al. 2012). For this purpose, we derive an equation that describes the relationship between harvest and stock size under open-access conditions. In such a situation, fishermen only take into account private harvesting costs and increase catches until a further increase in harvest is not profitable, $P(H) = C_H(H, B)$. Because of increasing marginal costs in market equilibrium, there will be a positive fishermen surplus. Assuming market equilibrium on output and factor markets, and using $P(H) = \overline{P}H^{\mu}$ and (12) in the open-access condition, we find

$$H_t^{oa}(B_t) = \left(\frac{\bar{P}}{\varepsilon c}\right)^{\frac{1}{\varepsilon+\mu-1}} B_t^{\frac{\chi}{\varepsilon+\mu-1}}. \tag{18}$$

5 Quantitative Application: Eastern Baltic Cod Fishery

We quantify the elasticities for the cost and inverse demand functions in the Eastern Baltic cod fishery based on literature data and a calibration to the fishing patterns observed in the 'business as usual' period 1986–2006. For the stock-elasticity of the cost function (12), we use the estimate $\chi = 0.644$ from Kronbak (2004). For the elasticity of the inverse demand function, we use the estimate $\mu = 0.23$ from Nielsen (2006).

To calibrate the open-access harvesting function (18) to the constant fishing mortality in the BAU scenario, we assume $\frac{\chi}{\varepsilon-1+\mu} = 1$. Using the literature estimates $\chi = 0.644$ and $\mu = 0.23$ we thus obtain $\varepsilon = 1.414$. Using the average catch in the period 2002–2005 $H_{BAU} = 65.6$ thousand tons, and the average price $P_{BAU} = 1.95$ EUR/kg for that period from Danish fishery accounts (Statistics Denmark 2016), converted into Euros, gives $\bar{P} = P_{BAU}H_{BAU}^{\mu} = 5.10$. Using this estimate, we obtain from the open-access harvesting function (18) $c_0 = \frac{\bar{P}}{\varepsilon}F_{BAU}^{-(\varepsilon-1+\mu)} = 6.07$.

As we are interested in the present values of user surplus (US) and fishermen surplus (FS) under the two different scenarios, the discount rate plays an important role. The appropriate discount rate to be used here is the interest rate on assets available to the respective interest group. To obtain a realistic description of the actual behavior, we use estimates for discount rates of individual subjects obtained by experimental studies rather than values for some 'market interest rate' or social discount rate, as commonly used in bioeconomic studies. Experimental evidence shows that individuals discount consumption at rates that are higher than those typically assumed for social discount rates. Here we use the estimate $\delta = 0.101$ with a standard error of 0.008 from Andersen et al. (2008, Table III). Andersen et al. (2008) elicit risk and time preferences in lab experiments using subjects from the adult Danish population. The estimate used here is the one obtained when correcting for risk aversion. In the simulations, we vary the discount rate in the 95% confidence interval [0.0853, 0.1167] as listed in Andersen et al. (2008, Table III).

6 Results: Windows of Opportunity for Sustainable Fishery Management

Figure 4 shows the time paths of resource rent RR, as given in Eq. (14), user surplus US, as given in Eq. (7), and fishermen surplus FS, as given in Eq. (11) for the two scenarios of BAU and MSY management. The surpluses for users of fish landings (user surplus US) and capital owners and workers employed in the fishery (fishermen surplus FS) as well as resource rent are, by coincidence, similar in absolute value in the BAU scenario.[5] Switching

[5] Under open-access conditions, US is proportional to FS. This can be verified by plugging (16) into (6) to derive US and into (9) with (10) to derive FS. Hence, it is obvious that the two curves should move parallel in the BAU scenario.

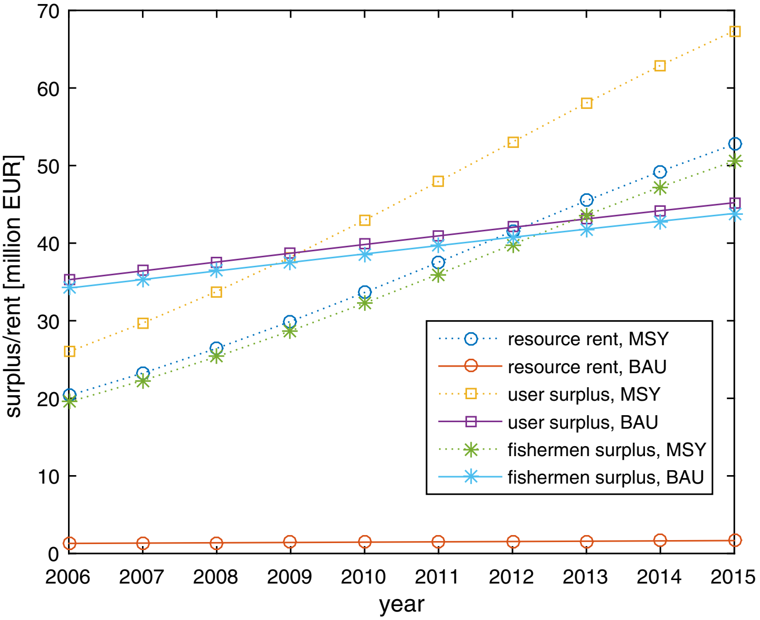

Fig. 4 Time paths of resource rent (RR, *circles*), user surplus (US, *squares*), and fishermen surplus (FS, *stars*) under the maximum-sustainable-yield management (MSY, *solid lines*) and under business-as-usual management (BAU, *dotted lines*). (Color figure online)

from BAU management to MSY management decreases harvests at the beginning of the rebuilding phase. This increases output prices and decreases input prices in the harvesting process, which generates rents for fishing firms at the expense of capital owners and workers on the one hand, and users of landed fish, on the other hand. In the course of time, profits in the MSY scenario further increase, reaching a steady-state level of 160 million Euros per year.

Both user surplus and fishermen surplus are initially higher in the BAU scenario than in the MSY scenario. As catches increase in the MSY scenario, both user and fishermen surplus increase over time. Fishermen surplus increases to a lesser extent than user surplus, as increasing stock sizes tend to decrease fishermen surplus (11). After 2 (4) years, the current user surplus (fishermen surplus) under the MSY scenario exceeds the user surplus (fishermen surplus) under the BAU scenario.

The main question of this paper is how the present values of user surplus and fishermen surplus are affected by the change from BAU to MSY management. For this sake, we study the net present values of switching from BAU to MSY management, i.e. the difference in present values of US and FS under the two different harvesting and stock trajectories, both starting at the same initial stock sizes. Using $\hat{H}_t$ and $\hat{B}_t$ to denote harvest and stock biomass under MSY management and $\underline{H}_t$ and $\underline{B}_t$ to denote harvest and stock biomass in the BAU scenario, the net present value of user surplus is

$$\mathrm{NPVUS} = \sum_{t=t_0}^{\infty} (1+\delta)^{t_0-t} \, \frac{\mu}{1-\mu} \, \bar{P} \, \left(\hat{H}_t^{1-\mu} - \underline{H}_t^{1-\mu} \right). \tag{19}$$

Similarly, the net present value of fishermen surplus is

$$\mathrm{NPVFS} = \sum_{t=t_0}^{\infty} (1+\delta)^{t_0-t} \, (\varepsilon-1) \, c_0 \, \left(\hat{H}_t^{\varepsilon} \, \hat{B}_t^{-\chi} - \underline{H}_t^{\varepsilon} \, \underline{B}_t^{-\chi} \right). \tag{20}$$

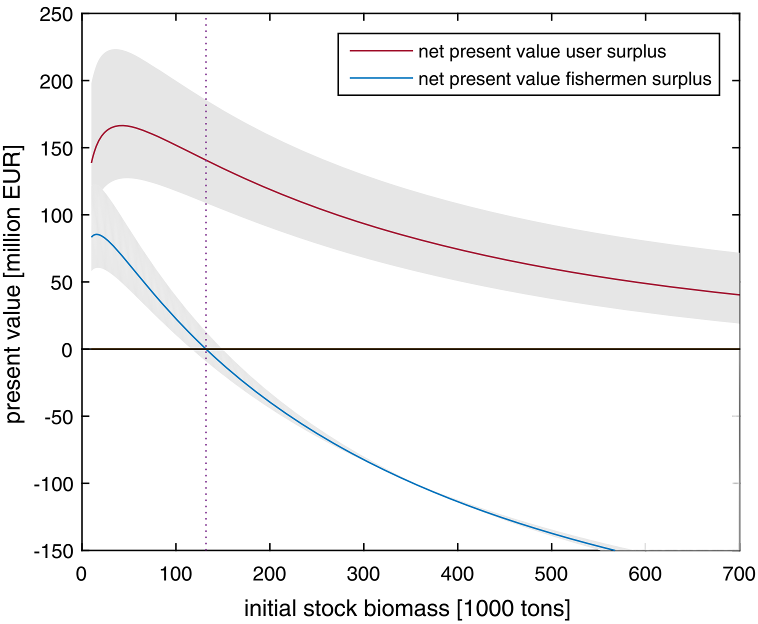

Fig. 5 Differences in present values of user surplus (*red line*) and fishermen surplus (*blue line*) between MSY and BAU management with given FMSY and FBAU, for varying initial stock biomasses. The *solid curves* show the results for the point estimate of the discount rate, $\delta = 0.101$; the *shaded areas* give the results discount rates in the lower and upper bounds of the 95% confidence interval of from Andersen et al. (2008). (Color figure online)

And finally, the present value of resource rent is

$$\text{NPVRR} = \sum_{t=t_0}^{\infty}(1+\delta)^{t_0-t}\left(\bar{P}\hat{H}_t^{-\mu} - c_0\hat{H}_t^{\varepsilon}\,\hat{B}_t^{-\chi} - \left(\bar{P}\underline{H}_t^{\mu} - c_0\underline{H}_t^{\varepsilon}\,\underline{B}_t^{-\chi}\right)\right). \tag{21}$$

To study how these net present values depend on the initial situation, we consider a range of initial stock sizes from 0 to 700,000 tons, which is slightly above the MSY steady-state stock size of 626,000 tons.

The results of these calculations are shown in Fig. 5. The figure shows the net present values of user surplus (blue curve) and fishermen surplus (green curve) as a function of the initial stock biomass. Users prefer stock rebuilding under MSY management over switching back to the BAU scenario along the whole rebuilding trajectory. The curve describing the fishermen-specific advantage of adopting MSY-management as a function of initial biomass is downward sloping, however. The net present value of fishermen surplus assumes negative values at initial stock sizes of 132,000 tons or larger. The reason is that fishermen surplus decreases with the stock size (at a given harvest quantity; cf. Result 2), while user surplus depends only on the harvested quantity (Result 1).

This result shows the following: For the very low stock size that prevailed in 2005, the net present values of switching from BAU to MSY management are positive for both interest groups. This means that in a situation of severely depleted stocks we can assume that all interest groups—owners of production factors used in the fishery, users of fish landings, and owners of harvesting rights—are in favor of stock rebuilding, as a switch from a BAU management to a more sustainable MSY management increases the present values of all respective surpluses. We consider this to be a 'window of opportunity' for sustainable fisheries management.

This result also indicates that the decision to switch from BAU to MSY management is not time consistent for all interest groups: As the stock increases under MSY management, at some point in time the stock size will be reached where fishermen would prefer BAU over MSY management. The quantitative results for the Eastern Baltic cod fishery show that the stock size at which fishermen start to prefer a switch back to BAU may be reached quite soon. We investigate this potential disagreement in the following.

By offering only one alternative to end the BAU deadlock, policy-makers could make use of a 'window of opportunity' for sustainable fishery management where the different stakeholder groups could agree to the compromise to accept the MSY policy. The MSY management seems to be a focal point, since it was declared a political goal at the international level. The actual scope for more sustainable fishery management may be much richer, though. To explore this in more detail, we study which is the range of fishing mortalities F on which both users and fishermen could agree if they compare the present values of their individual surpluses under management with fishing mortality F and BAU management. To determine the set of 'agreeable' values of a fixed fishing mortality, given some initial stock size B_0, we determine the level of fishing mortality F that maximizes the present value of user surplus under the constraint that the present value of fishermen surplus is at least as high as in the BAU alternative,

$$\max_F \sum_{t=t_0}^{\infty} (1+\delta)^{t_0-t} \, \frac{\mu}{1-\mu} \, \bar{P} \, \tilde{H}_t^{1-\mu}$$

$$\text{subject to} \sum_{t=t_0}^{\infty} (1+\delta)^{t_0-t} \, (\varepsilon-1) \, c_0 \left(\tilde{H}_t^{\varepsilon} \, \tilde{B}_t^{-\chi} - \underline{H}_t^{\varepsilon} \, \underline{B}_t^{-\chi} \right) \geq 0 \qquad (22)$$

Here, $\tilde{H}_t$ and $\tilde{B}_t$ to denote the trajectories of harvest and stock biomass when fishing mortality is fixed at some level F (chosen such as to solve the optimization problem), and $\underline{H}_t$ and $\underline{B}_t$ to denote harvest and stock biomass in the BAU scenario, all with the same initial stock size B_0. The shaded area in Fig. 6 shows the results.

The range of 'agreeable' fishing mortality levels is largest at small stock sizes, and decreases with increasing initial stock size. For stock sizes larger than about 100,000 tons, the restriction that the present value of fishermen surplus should not fall below the BAU reference level becomes binding. As we have seen already in Fig. 5, both users and fishermen would agree to a fishing mortality $F = F_{\text{MSY}} = 0.3$, compared to BAU, if the initial stock size is smaller than 132,000 tons. This is close to the average stock size in the period 2002–2006 before the introduction of the management plan. This may give some indication why the management plan is based on this value of fishing mortality. For a stock size of 573.500 tons or larger, there is no level of fishing mortality below $F_{\text{BAU}} = 0.466$ that fishermen would prefer over BAU.

Thus, our general conclusion that a 'window of opportunity' for the transition towards a fishery management regime that is more sustainable than BAU is open at low stock sizes, and closes as the stock size decreases.

This does not mean that fishery management must switch back to BAU management when the stock has grown to a larger size, though. While all functional interest groups prefer a management at a constant fishing mortality F_{MSY} over F_{BAU} management at a low stock size, the interests differ at higher stock sizes. For stock sizes up to 700,000 tons, as shown in Fig. 5, users would still prefer F_{MSY} over F_{BAU}, and so would owners of fishing rights. Only

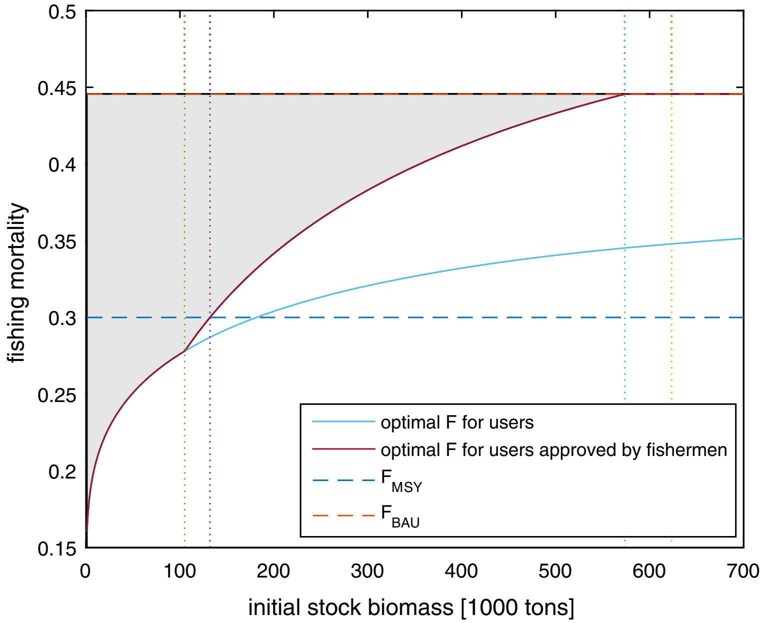

Fig. 6 Fishing mortalities that optimize the present value of user surplus if fishing mortality is constrained to be constant over time. The *blue solid curve* depicts the optimal fishing mortality for users. The *red solid curve* shows the optimal fishing mortality for users under the constraint that the present value of fishermen surplus is at least the value obtained under F_{BAU}. The *shaded area* indicates the range of 'agreeable' fishing mortalities that maximize, given the initial stock biomass, the present value of user surplus under the constraint that the present value of fishermen surplus does not fall below the BAU reference case. (Color figure online)

fishermen prefer the higher fishing mortality. Thus, there is no agreement for switching back to BAU management.

7 Conclusion

This paper contributes to the general discussion of the circumstances under which a sustainable public policy might become adoptable. Focusing on the particular case of the Eastern Baltic cod fishery, we have studied the conflicts of interests a policy-maker might face when trying to implement sustainable fisheries management. Assuming that a policy-maker is likely to pay attention to employment opportunities in the fishery and in the fish processing industry, our approach was to quantify surpluses for the different interest groups involved in the fishery. For each of these interest groups, we compared the present values of welfare measures for two different scenarios: a business-as-usual scenario with ongoing overfishing and a management scenario that leads to the maximum sustainable yield in the long run.

Our main concern was the interplay of stock rebuilding dynamics and discounting in order to identify 'windows of opportunity' in which the different stakeholder interests align and jointly support the transition to a binding sustainable management regime. We find that at very low, overfished stock sizes, the present values of welfare for all interest groups considered—fishermen, workers in the processing industry and consumers—are higher under maximum-sustainable-yield (MSY) management than in the business-as-usual (BAU) overfishing scenario. For higher stock sizes, however, this situation changes: the net present value of fishermen surplus for continuing MSY management instead of switching back to BAU management becomes negative. This is because fishermen surplus tends to decrease with the stock size, as less effort is needed to fish the same quantity at higher stock sizes, and also because long-run surpluses derived from the fishery are discounted, making a short-run disinvestment phase towards the BAU stock the more attractive the higher the current fish stock is.

We have seen that the quantitative results are sensitive to the discount rate. This is naturally the case, as in essence the window of opportunity arises as a consequence of the relative dynamics of different stock variables. The fish stock is important in this respect, but the strong influence of the discount rate shows that the other assets available to the interest groups are of equal importance. The discount rate, i.e. the interest rate on these alternative assets, may be taken as a proxy for the internal dynamics of these stocks (Faber et al. 2005). The higher this discount rate is, i.e. the faster these assets develop, the smaller is the window of opportunity for sustainable fishery management.

Our results further indicate that interests may start to conflict as soon as the stock has rebuilt to moderate levels. To reach a sustainable fishery, adequate institutions are needed that make sustainable fishery management more resistant against the temptations to increase catches to satisfy short-run desires of particular interest groups. The establishment of the current long term management plan for Eastern Baltic cod may be a first step in this direction. Along the path of a more sustainable management with reduced fishing effort, less workers and less capital are be employed in the fishery, and with this development, the relative importance of these interest groups on fisheries policy may decrease as well. Thus, making use of the 'window of opportunity' may actually lead to a transition towards a long-term sustainable fishery management for the Baltic cod and elsewhere.

Appendix

Conversion of an Age-Structured Model into a Biomass Model

To set up the age-structured model, we use a similar approach and notation as Tahvonen (2009) and Tahvonen et al. (2013). We use x_{st} to denote the number of fish in age group $s = 1, \ldots, S$ at the beginning of period $t = 0, 1, \ldots$, where S is the oldest age group considered in the model. Age-specific survival rates $\alpha_s > 0$, age-specific proportions of mature individuals $\gamma_s > 0$, and mean weights of fish (in kilograms) w_s, in age groups $s = 1, \ldots, S$, all are assumed to be constant as in the standard biological stock assessments, such as ICES (2012) for the Eastern Baltic cod.

Harvesting takes place at the beginning of each period but after recruitment. The fisheries literature typically uses the instantaneous fishing mortality f_t. Assuming that the instantaneous fishing mortality f_t is constant throughout the fishing season, we can use the Baranov catch equation that gives the fraction of the stock harvested during the entire season, i.e. the exploitation rate, as $1 - \exp(-f_t)$. Note that the instantaneous fishing mortality, i.e. the instantaneous exploitation rate, can be above one. Only in the limit $f_t \to \infty$ the number of fish harvested over the entire fishing season would equal the stock size. The age-structured population model with harvesting activity is described by the following equations

$$x_{0t} = \sum_{s=1}^{S} \gamma_s \, w_s \, x_{st}$$

$$x_{1,\,t+1} = \varphi(x_{0t})$$

Table 1 Parameter values for age-structured fish population model from ICES (2012)

Parameter		Age group							
		1	2	3	4	5	6	7	8
Maturities	γ_s	0	0.13	0.36	0.83	0.94	0.96	0.96	0.98
Survival rates	α_s	1	0.82	0.82	0.82	0.82	0.82	0.82	0.82
Weights (kg)	w_s	0	0.144	0.373	0.652	1.16	1.907	2.123	3.064
Catchabilities	q_s	0	0.103	0.409	0.792	1.000	0.963	0.975	0.975

$$\begin{aligned} x_{s+1,\,t+1} &= \alpha_s\,\left(x_{st} - (1-\exp(-q_s f_t))\,x_{st}\right) \quad \text{for } s = 1, \ldots, \; S-2 \\ x_{S,\,t+1} &= \alpha_{S-1}\,\left(x_{S-1,\,t} - (1-\exp(-q_{S-1} f_t))\,x_{S-1,\,t}\right) \\ &\quad + \alpha_S\,\left(x_{St} - (1-\exp(-q_S f_t))\,x_{St}\right). \end{aligned} \tag{23}$$

The spawning stock biomass x_{0t} is given by the sum of biomasses (age-specific weight w_s times number of fish in that age group, x_{st}) of the fraction of fish that is mature in the respective age classes, γ_s. The number of recruits, x_{1t}, is given by the stock-recruitment function $\varphi(x_{0t})$. Of all fish of age group s that remain in the sea after fishing, a fraction α_s survives natural mortality (second last of the above equations). The equation describing the dynamics for the last age group differs from the equations for the younger age groups, as x_{St}captures all individuals that are of age S and older in year t.

For the Eastern Baltic cod stock, we consider eight age classes ($S = 8$), as in the standard stock assessment by the International Council for the Exploration of the Sea (ICES 2012). We parameterize the age-structured fish population using data from the ICES (2012) assessment report. For age-specific weights in stock w_s we use the values for 2011; also age-specific maturities γ_s are directly taken from the assessment report. The survival rates $\alpha_s$are computed from natural mortalities. To account for age-dependent vulnerability to fishing gear, we multiply the fishing mortality rate with a catchability factor for each age class. For the Eastern Baltic Cod stock, these catchability factors are computed from the age-specific fishing mortalities averaged over the 5 years from 2002 to 2006. The age-specific parameter values are summarized in Table 1.

We assume a stock-recruitment function of the Ricker (1954) type,

$$\phi(x_0) = \beta_1\, x_0\, e^{-x_0/\beta_2}. \tag{24}$$

This stock-recruitment function has a peak at $x_0 = \beta_2$, and is decreasing for spawning stocks larger than β_2. Such a type of stock-recruitment relationship is an appropriate description of recruitment biology of Baltic cod, capturing in particular the cannibalism of older cod on juveniles. For the parameters of the stock-recruitment function, we use the estimates $\beta_1 = 1.70$ and $\beta_2 = 1/0.00182 = 549,000$ tons from Voss et al. (2014).

In order to transform the eight-dimensional population model into a biomass model, we compute the steady-state stock biomass and harvest biomass for different fishing mortality rates. We then use the equilibrium harvest and biomass from the age-structured population model to fit the surplus production function (Blenckner et al. 2015)

$$g(B_t) = \frac{r}{\alpha} B_t \left(1 - \left(\frac{B_t}{K}\right)^{\alpha}\right)$$

We obtain estimates $r = 0.736$, $K = 1158$ thousand tons, and $\alpha = 1.441$. The graph of the resulting surplus-production function is shown in Fig. 1.

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