

The Political Economy of the European Common Fisheries Policy

Inauguraldissertation zur Erlangung des akademischen Grades
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der Wirtschafts- und Sozialwissenschaftlichen Fakultät
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vorgelegt von
Diplom-Volkswirtin Julia Hoffmann
aus Rostock

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1. GENERAL INTRODUCTION

Fisheries management has a long tradition in the European Union. The first European Common Fisheries Policy came into force in 1983. Its main intention was to secure and allocate fishing rights of member states. It also introduced conservation measures in order to protect the European fish stocks (European Council (1983), Art. 1 and 2). Over time, the Common Fisheries Policy focused more and more on the implementation of a sustainable fisheries management (European Council, 1992, 2002; European Union, 2013). The Common Fisheries Policy comprises a number of different tools to reach that aim, the most important one being the total allowable catch (TAC). It defines the amount of fish that is allowed to be taken from a specific stock in a year. While TACs have a huge potential to restrict fishing activities, the TAC management of the European Union failed (European Commission, 2001, 2009b). Over many years and for many stocks TACs were set on ineffectively high levels such that their restrictive impact was either very small or even non-existent (Khalilian et al., 2010; Froese, 2011). TACs are set by majority voting of the European Council of Ministers. Once a TAC is set it is allocated to the European member states according to the principle of relative stability. This principle ensures that each country always receives the same relative share of a TAC.

Although several reforms modified the tools and management goals of the Common Fisheries Policy, the process of TAC setting and the allocation of TACs to the European member states have always been the same (Churchill and Owen, 2010). This dissertation addresses the political economy of the Common Fisheries Policy and investigates how traditional concepts can hinder the success of the European fisheries management. The first two papers focus on the decision-making process of TAC setting. Papers three and four

examine aspects of the Common Fisheries Policy where the principle of relative stability limits the management's potential. This dissertation has been written within the project 'The Political Economy of the European Common Fisheries Policy' in the research area Ocean Governance of the Cluster of Excellence 'Future Ocean' at Kiel University. The Cluster of Excellence funded this project for three years.

The first paper 'Common Pool Politics and Inefficiency of Fisheries Management' deals with the question as to why TACs are set on too high levels. The focus here is on the institutional set-up of the decision-making process. This process is modeled as a dynamic non-cooperative game in discrete time. It is a general model which can be applied to the situation in the European Union. TACs are fixed by majority decision in a council consisting of decision-makers who are heterogeneous with respect to their discount rates. Decision-makers with a higher discount rate are assumed to be patient and prefer more restrictive TACs while decision-makers with a lower discount rate are assumed to be impatient and prefer higher, i.e. less restrictive, TACs. It is shown that due to the uncertainty in the annual TAC setting the optimal feedback strategy for the impatient decision-makers is to set inefficiently high TACs in Markov-perfect Nash equilibrium. According to this theoretical analysis, the institutional set-up of the decision-making process itself promotes inefficient TACs. A binding commitment between the two groups of decision-makers to a long-term management plan could help solving this problem and lead to a more sustainable fisheries management. This paper is joint work with my first advisor Martin Quaas. I contributed to the model analysis, calculations and the writing. The paper is published online in *Environmental and Resource Economics* (2015, DOI 10.1007/s10640-014-9842-4) (B-journal (Handelsblatt, 2015), impact factor: 1.703).

Another problem in TAC setting is that often the interests of the different stakeholders are unequally represented in the decision-making process, leading to economic interests being in a better bargaining position than conservation interests (Okey, 2003). This imbalance can also lead to ineffective TAC management. The second paper 'Bargaining over Resource Regulation: Total Allowable Catch Setting in the European Common Fisheries Policy' is

concerned with an empirical analysis of the distribution of bargaining power between different interests groups in the TAC decision-making of the European Union. For this purpose, the concept of Nash bargaining (Nash, 1953) has been modified to fit the bargaining process over TACs. The process is modeled as a cooperative game between two players with different interests regarding TACs. Nash's bargaining solution of this game is used to derive an equation to estimate the bargaining powers of the two players. Panel data of TACs for European stocks is used for the estimation. The estimation results show that the player representing interests of the fishermen and the fishing industry has the stronger bargaining position compared to the player representing conservation interests. The only exception are stocks that are fished by European Union member states but not managed by the Common Fisheries Policy (e.g. stocks in Norwegian or Icelandic waters). For those stocks, it is estimated that the player representing conservation interests has the stronger bargaining position leading to a more effective TAC management (as e.g. in Iceland (Hilborn, 2007)). The analysis also shows that scientific recommendations have a greater influence in the bargaining when the underlying data is of good quality. The conclusion is that effective TAC management requires both, a sound scientific assessment and a stronger inclusion of scientific advice. This is a single-author paper. It has not been submitted to a journal yet.

For most of the stocks TACs are set according to single-species management meaning that a management goal, e.g. a minimum level of biomass, is set without considering the effects on other species or the ecosystem. In contrast, the multi-species management approach does consider such biological and ecological interactions. If multi-species management is applied the management effects will differ depending on how the focus of the management is set. Especially if several countries fish for different species of the same ecosystem, management effects on profits will be heterogeneous between countries. The third paper 'Regional Trade-Offs from Multi-Species Maximum Sustainable Yield (MMSY) Management Options' investigates the regional trade-offs of different management options of a multi-species management in the Baltic Sea. The three species interacting are the Baltic cod (*Gadhus morhua*), her-

ring (*Clupea harengus*) and sprat (*Sprattus sprattus*) with cod preying on herring and sprat (Köster and Möllmann, 2000). An ecological-economic model of the Baltic Sea is developed simulating the stock dynamics of interacting population of the three species in order to investigate a set of different strategic management options. Profits of each option are calculated. The profits for each country participating in the Baltic fishery differ between the management options. A country's share of profits depends on its share of TAC. Because of the principle of relative stability a country's TAC share is always the same. Thus, a management option building up the cod stock and by that reducing the sprat stock leads to benefits (losses) for countries holding a TAC share for cod (sprat). The inflexibility of TAC distribution according to the principle of relative stability can therefore lead to regional inequality in future profits. A reallocation of profits is required to achieve a concordant agreement on strategic multi-species management goals. This paper is joint work with Rudi Voss, Martin Quaas and Jörn Schmidt. Rudi Voss and Jörn Schmidt are fisheries biologists working in the research group of Martin Quaas at Kiel University. I contributed data and materials, participated in the design of the analysis and co-wrote the paper. The paper is published as a featured article in Marine Ecology Progress Series (2014), Vol. 498, pp. 1–12. This journal covers all aspects of marine ecology (impact factor: 2.640).

Countries allocate their TAC share to their national vessels by country-specific distribution schemes. Each vessel receives a quota which it is allowed to fish. Usually there are several countries holding a TAC share for a specific stock. Hence, their vessels compete with each other. If now the efficiency of vessels differ between countries it could be reasonable to allow for quota trade between vessels of different countries. The more efficient vessels could buy quota from less efficient vessels. By that, the overall fleet efficiency could be increased. The fourth paper 'Input-Efficiency of Fishing Cod in the Baltic Sea – Comparing Major European Union Trawler Fleets' examines the efficiency of different segments of the Baltic trawler fleet in order to evaluate whether quota trade between vessels of different countries could improve the situation. The distance function approach (Färe and Grosskopf, 1990)

is used to derive an equation to estimate the efficiencies of different fleet segments. Data for different vessel length categories for different countries is used. The estimation reveals significant asymmetries in the efficiencies between countries. The asymmetry is bigger for small vessels because they are not as mobile and depend heavily on the circumstances surrounding them including the fishing ground quality. Bigger vessels are more mobile and tend to concentrate their fishing activity in similar areas (most productive fishing grounds). Therefore, differences in efficiencies do not mainly result from the choice of fishing ground but rather from differences in the national fleet management and the current state of the fleet segment. Allowing for quota trade in the Baltic fleet could improve the overall efficiency. Such a transnational quota trading system would enable the fleet to coordinate its fishing activities far more flexible than under the fixed allocation of TACs according to the principle of relative stability. This paper is joint work with Barbara Hutniczak (University of Maryland Chesapeake Biological Laboratory, USA), Emmi Nieminen (Department of Economics and Management, University of Helsinki, Finland) and Johanna Yletyinen (Stockholm Resilience Center, Sweden). I wrote the sections on European and national fisheries management and co-wrote the sections on results and concluding remarks. This paper is published online as a discussion paper by the University of Helsinki, Finland (2015, <http://www.helsinki.fi/taloustiede/Abs/DP68.pdf>).

This dissertation contributes to the research on how institutional set-ups and concepts in fisheries management can block the management's intentions. It also suggests alternatives to overcome that problem. However, further research regarding the functioning, implementation and implications of these alternatives for TAC setting and allocation mechanisms is required.

2. COMMON POOL POLITICS AND INEFFICIENT FISHERY MANAGEMENT

Julia Hoffmann¹ and Martin F. Quaas²

Published online in *Environmental and Resource Economics* (2015, DOI 10.1007/s10640-014-9842-4).

Abstract.

Fisheries management often fails because total allowable catches (TACs) are set at inefficiently high levels. To study why decision-makers choose such high TACs, we model the annual negotiation on TACs as a dynamic game in discrete time. TACs are fixed by majority decision in a council consisting of decision-makers who are heterogeneous with respect to their discount rates. We show that the optimal feedback strategy for the less patient decision-makers will set inefficiently high TACs in Markov-perfect Nash equilibrium. A binding commitment to a long-term management plan could help solving this problem and lead to a more sustainable fishery management.

Keywords: fisheries; fishery economics; environmental uncertainty; constant escapement; political economy; dynamic game theory

JEL-Classification: Q22; Q57; D78

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2.1 Introduction

According to the FAO's latest report on the state of world fisheries and aquaculture, the fraction of overexploited stocks among all fished stocks world-wide has continuously increased in the past decades and was roughly 30% in 2009 (FAO, 2012). In the past, overfishing has resulted from situations where individual fishermen or fishing nations are competing for fish stocks under open-access or limited-entry conditions – situations widely analyzed in resource economics (Gordon, 1954; Munro, 1979; Levhari and Mirman, 1980; Bailey et al., 2010). The establishment of exclusive economic zones in 1982 gave coastal states the exclusive use rights for the fish stocks within 200 nautical miles from their coastline (UNCLOS, 1982), thus limiting the access to these resources. Since then, most fishing nations have introduced fisheries management strategies to increase sustainability and economic efficiency. The on-going overfishing indicates, however, that these management strategies have not always been effective. In this paper we study a particular institutional set-up of the decision-making process and show that in this setting the politics of managing the common-pool resource may lead to inefficient fishery management.

The most important instrument in fisheries management is to set total allowable catches (TACs), limiting the amount of fish that can be caught legally from a certain stock in a year.³ Evidence shows that some countries have implemented a quite successful TAC management, for example Iceland and New Zealand (Hilborn, 2007), where fish stocks have increased and fisheries have become highly profitable after the implementation of the management schemes. In other countries or regions with TAC management fish stocks continue to be overfished. That is the case for example for Chile (Leal et al., 2010), the European Union (European Commission, 2009b; Khalilian et al.,

³ The TAC is then divided in form of quotas among the different members of the fisheries sector. Management systems differ in the allocation mechanisms. Under a system of individual transferable quotas (ITQs), fishing quotas belong to individual fishermen and are freely transferable. Other systems include individual vessel quotas (IVQ), or forms of non-transferable quotas. The common denominator of TAC/quota management systems is that they effectively prevent overfishing only if the TACs are set at sufficiently restrictive levels.

2010; Quaas et al., 2012) or the United States (Rosenberg et al., 2006).

Failure of fisheries management is often traced back to overly high TAC levels that fail to sufficiently restrict fishing activities. To explain this failure it is widely assumed that decision-makers (mostly politicians) act in favor of their personal short-term interests (Froese, 2011; Mardle and Pascoe, 2002). Accordingly, they would push towards high TAC levels to increase fishing benefits in the short run, at the costs of continued overfishing. For the European Common Fisheries Policy, Franchino and Rahming (2003) examine the internal structure of the European Council of Ministers for Agriculture and Fisheries and show that the ministers, despite their obligation to implement sustainable fishery, are more concerned with short-run benefits for the fishery than with environmental issues. The same holds for the Chilean fisheries management (Leal et al., 2010). Another often mentioned aspect of ineffective fisheries management is the discrepancy between scientific and political positions (Delaney and Hastie, 2007). Okey (2003) argues that commercial interests might be over-represented in the decision-making body using the United States' fisheries management councils as an example. As a consequence less sustainable regulations are adopted. Daw and Gray (2005) argue for the European Common Fisheries Policy that a lack of acceptance of fisheries science and its recommendations by the ministers contributes to the choice of high TAC levels.

However, none of these contributions gives a clear-cut explanation why in some countries the politicians fail to take into account the long-term benefits of sufficiently restrictive TACs while in other countries they do. Comparing the institutional set-up of the decision-making processes in countries with successful and failed fisheries management an important difference can be found. While in New Zealand and Iceland TACs are set by a single person, the minister of fisheries (Lock and Leslie, 2007; Arnason, 1996), TACs mostly are negotiated on a yearly basis in councils in the European Union (Churchill and Owen, 2010), Chile (Leal et al., 2010), and the United States (Okey, 2003), i.e. in groups of several decision-makers. The examples considered here suggest that TAC decisions made by a group of decision-makers on a yearly basis (as in Europe, the United States, and Chile) tend to be less

efficient than those made by single decision-makers (as in New Zealand and Iceland).⁴

In this paper we study how the political set-up of fixing the TAC for the common pool resource fish influences the efficiency of the resulting fishery management. Thereby we contribute to the small literature that is filling a gap in resource economics identified by Homans and Wilen (1997), namely that “economists have essentially ignored the fact that regulations are endogenous in modern fisheries.” We use a game-theoretic approach to model TAC setting by heterogeneous decision-makers, who differ in the discount factors they apply. We consider two institutional settings. In one setting, TAC decisions are made on an annual basis by majority voting in a council of decision-makers. Since the majority in the council can change, each group has to consider the possibility that in the next period the TAC level is set by another group. We solve this problem applying the concept of Markov-perfect Nash equilibrium in feedback strategies. In an alternative setting, we consider the case where the decision-makers decide once and for all on a management plan, implemented as a feedback harvest-control rule for the fishery.

Our analysis is related to the general economic literature on policy-making in a dynamic setting, which has shown that optimal policies are either time inconsistent or sub-optimal from the current policy-maker’s point of view (Kydlund and Prescott, 1977), and that a particular institutional set-up can help improving the outcome (Riboni, 2010). In contrast to this literature, which studies the strategic interaction between a policy-maker and individual economic agents, however, we focus on heterogeneous decision-makers which all have an interest in the long-term effects of the policy. Also, we assume that the TAC, once decided upon, will be implemented effectively at no cost. This neglects strategic incentives to limit enforcement effort for members in a coalition jointly managing a fish stock (Kronbak and Lindroos, 2006).

We show that the resulting TAC levels can be higher than those preferred

⁴ Another difference that undoubtedly has an influence on the difference in efficiency of fisheries management programs between the two sets of countries is that New Zealand and Iceland have ITQ-based catch share programs, which are less common in Europe, the United States, and Chile. We come back to this issue in the discussion in section 2.6.

by the least patient group of decision-makers. Thus, our theory provides an explanation why TACs are particularly ineffective in restricting overfishing when they are set on an annual basis by a council of heterogeneous decision-makers. Moreover, we show that the TAC set by the less patient decision-makers will *increase* with the discount factor of the more patient, i.e. when the more patient would actually prefer a more restrictive TAC. Not surprisingly, we find that a set-up where all decision-makers agree on a management plan once and for all leads to more restrictive TAC levels. This paper thus provides a rigorous theoretical foundation for the policy recommendation to change the institutional set up to allow for binding long-term management plans, especially in regions like Europe or Chile where TACs are set in an annual voting procedure.

The paper is structured as follows. The model is set up in section 2.2. We then characterize first-best fishery management (section 2.3), common pool politics with annual voting on TACs in a council (section 2.4), and the harvest-control rule on which the council would agree if it could commit to a binding plan (section 2.5). The final section discusses our findings and draws a short conclusion.

2.2 The Model: Stochastic Resource Dynamics and Management Objectives

In the following we set up the model of resource dynamics and decision-making in the council.

For the fish stock dynamics we consider the standard biomass model in discrete time (Reed, 1979; Clark, 1990). The stochastic growth dynamics of the fish stock biomass x_t from time step t to $t+1$ is described by the equation

$$x_{t+1} = z_t g(s_t), \tag{2.1}$$

where $s_t = x_t - h_t$ is escapement, i.e. the stock that remains in the sea after harvesting a quantity h_t . Uncertainty is captured by a series z_t of independent and identically distributed random variables with expected value $E(z_t) = 1$

and support $[\underline{z}, \bar{z}] \subset [0, \infty)$. In our model, the harvest h_t corresponds to the TAC level in period t . Given the stock size x_t before fishing, the optimal escapement level determines the optimal TAC as $h_t = x_t - s_t$. The biomass growth function is assumed to be increasing for sufficiently small escapement levels, with $g'(0) > 1$, and concave, $g''(s) < 0$. Furthermore, there is some \underline{s} such that all escapement levels $s_t \in (0, \underline{s})$ are ‘self-sustaining’, i.e. $x_{t+1} = z g(s_t) > s_t$ with probability one (Reed, 1979).

We assume that the decision-makers’ interest is focused on economic benefits (profits) from fishing. In the discrete time-setting, marginal profits during the harvesting season are given by the difference between the output price p of fish and marginal harvesting costs $c(x)$, which are assumed to decrease with the current stock size x , i.e. $c'(x) < 0$. This stock size decreases due to harvesting in the course of the fishing season. Profits from an entire fishing season are given by the integral over marginal profits on the interval between the stock at the beginning of the harvesting season, x_T , and at its end, which is the ‘escapement’ s_t , (details on the derivation can be found in Clark, 1990),

$$\int_{s_t}^{x_T} (p - c(x)) dx \equiv \pi(x_T) - \pi(s_t), \quad (2.2)$$

where $\pi(s)$ is defined by the condition $\pi'(s) = p - c(s)$. We impose the standard assumption that $\pi'(zg(s))zg'(s)/\pi'(s)$ is non-negative and decreasing in s (Reed, 1979).

To keep the analysis of heterogeneous decision-makers simple, we assume that there are only two types of decision-makers, and the only dimension in which they differ are their discount factors ρ .⁵ Impatient decision-makers (indicated by i) have a lower discount factor than patient decision-makers (indicated by p), $\rho_i < \rho_p$. Decision-makers with the same discount factor build a homogeneous group, i.e. have identical objective functions.

We consider two different set-ups for the decision-making process. One is annual voting and majority decision on TAC levels, analyzed in section 2.4.

⁵ Note that this refers to the discount factors of decision-makers. The discount rates of individual fishermen, in turn, may be influenced by the management system resulting from the decision-making process (Asche, 2001; Teh et al., 2013; Newell et al., 2005).

In the other one, the two groups of decision-makers decide once and for all on a binding long-term management plan. This setting is introduced and analyzed in section 2.5. As the benchmark-case we first study the optimal fishery management for either group in the next section.

2.3 Optimal Fishery Management

In this section we characterize the two Pareto-optimal fishery management scenarios where the pay-off of either group of decision-makers $j \in \{i, p\}$ is maximized. The corresponding fishery management strategy is found by assuming that group j has full control over the fishery and chooses escapement levels such as to maximize the expected present value of their pay-offs, i.e.

$$\max_{\{s_j\}} E \left[\sum_{t=1}^{\infty} \delta_j^{t-1} (\pi(x_t) - \pi(s_t)) \right] \quad \text{subject to (2.1)}. \quad (2.3)$$

We first re-state a well-known result as the following lemma.

Lemma 1. *The optimal feedback policy $s_j^*(x)$ for group $j \in \{i, p\}$ is a most rapid approach to a constant escapement level s_j^* , i.e.*

$$s_j^*(x) = \min \{x, s_j^*\}, \quad (2.4)$$

where s_j^* is implicitly given as the solution of

$$\pi'(s_j^*) = \rho_j E [z g'(s_j^*) \pi'(z g(s_j^*))]. \quad (2.5)$$

A proof for this lemma can be found in Reed (1979) or Clark (1990). The technical reason for this result is that the optimal feedback solution is independent of the current state of the fishery, because of the additive separability of the objective function in x_t and s_t , and because the next period's stock depends only on the control variable s_t .

The assumptions on $\pi(s)$ and $g(s)$ imposed above imply that s_j^* is increasing in the discount factor ρ_j (Reed, 1979), which is a very intuitive result: the higher the discount factor, the more important are the future benefits of

stock conservation for the decision-maker. Hence, the optimal escapement level for the impatient decision-makers is strictly smaller than the optimal escapement level for the patient decision-makers, $s_i^* < s_p^*$.

Here we consider the case that the group under consideration can implement their preferred TAC levels in all periods. For either group, the development of the fish stocks will be as illustrated in fig. 2.1. Here, the numbers

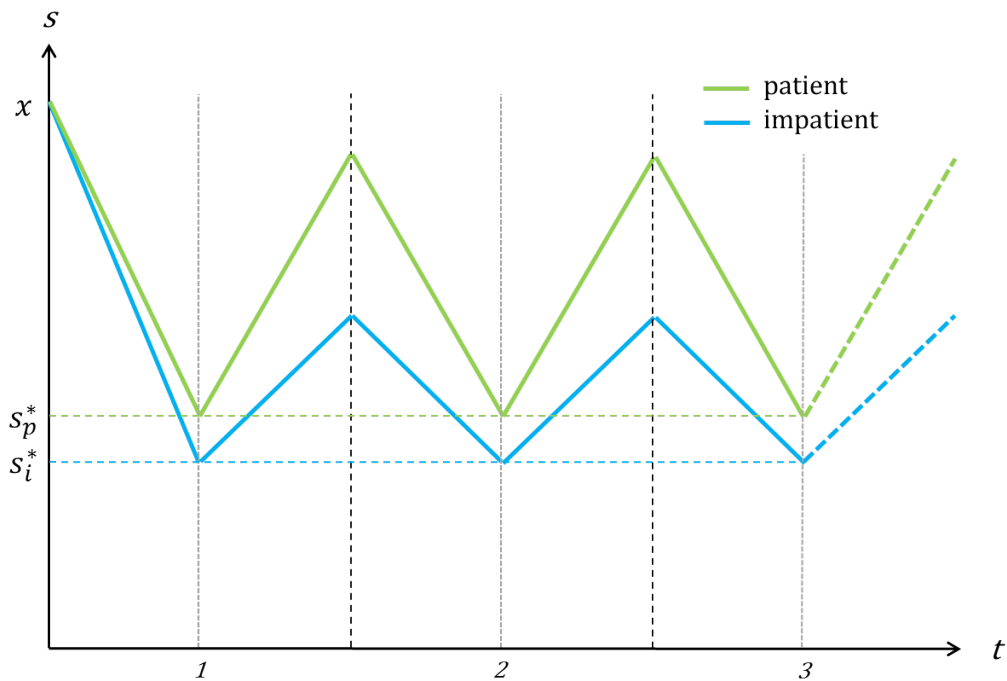


Fig. 2.1: Expected development of the stock size over time without change of majority.

$t = 1, 2, 3$ on the horizontal axis denote the end of the respective harvesting periods, when the stock has been fished down from the initial stock size x to the respective optimal escapement levels s_j^* . Then, fishing will stop and the stock grows again. The expected stock of the next period is then given by $E[x_{t+1}] = g(s_j^*)$.

2.4 Common Pool Politics: Annual TAC Voting

Now we turn to the institutional set-up we are most interested in for this paper: annual voting and decision on TAC levels by majority rule. In this setting the group that is in majority will choose an optimal harvest strategy (i.e. a feedback-control rule) that maximizes the expected present value of profits. We assume that there is no cooperation between the groups. The actual escapement level set in a particular period does not only depend on the size of the fish stock, but also on the current majority in the council. This makes the dynamic decision problem depend on two state variables, the stock size x and the majority m , which can take two values, according to the two groups of decision-makers. We denote the state of the currently ruling majority as follows:

$$m = \begin{cases} i & \text{if impatient decision-makers are in majority.} \\ p & \text{if patient decision-makers are in majority.} \end{cases} \quad (2.6)$$

Due to elections or other political processes a majority of impatient can be replaced by a majority of patient decision-makers (and vice versa) from period to period. We simplify the analysis by assuming that the exchange of decision-makers in the council is independent of the outcome of the decisions. This is a reasonable assumptions for regions or countries where fisheries policy plays only a minor role for the outcome of elections. Given this assumption, we model the change in majority as a random process, and use q to denote the probability that impatient decision-makers will rule in period $t + 1$, and $1 - q$ for the probability that patient decision-makers will rule, independently of what the current state of majority is. Another simplifying assumption here is that these probabilities are constant over time and do not depend on the timing of legislative periods or other political cycles.

We now turn to the analysis of management decisions in the council where majorities can change between periods. We model this setting as a dynamic game and derive the Markov-perfect Nash equilibrium in feedback strategies. To derive the equilibrium feedback strategies, we set up the Bellman equations and derive the profit maximizing escapement level for each group

of decision-makers taking into account the strategic interaction by including the other group's feedback policy. We formulate two Bellman equations for each group of decision-makers, depending on whether they are currently in the majority or not. For the impatient decision-makers we use $v(x, m)$ and for the patient decision-makers we use $V(x, m)$ to denote the value functions at a fish stock size x and a current majority m . We further use $\hat{s}_j(x)$ to denote the equilibrium feedback strategies that specify the escapement level chosen by group $j \in \{i, p\}$ if this group has the majority in the council.

If the impatient decision-makers are in the majority (i.e. $m = i$), they choose the escapement level such as to maximize the present value of profits, and the Bellman equation is:

$$\begin{aligned} v(x, i) &= \max_s \{ \pi(x) - \pi(s) + \rho_i E [q v(zg(s), i) + (1 - q) v(zg(s), p)] \} \\ &\equiv \pi(x) - \pi(\hat{s}_i(x)) + \rho_i E [q v(zg(\hat{s}_i(x)), i) + (1 - q) v(zg(\hat{s}_i(x)), p)], \end{aligned} \quad (2.7)$$

where $E[\cdot]$ denotes the expectation with respect to z , and $\hat{s}_i(x)$ is the feedback policy chosen by the impatient decision-makers in Nash equilibrium. The first two terms on the right-hand side describe the profits of the current period. The term in brackets gives the future profits discounted with the impatient decision-makers discount factor ρ_i , and weighted with the probabilities q for an impatient and $1 - q$ for a patient majority in the next period, enter the future values for the respective state of majority. In both cases the future stock is determined by the optimal escapement of the impatient, $\hat{s}_i(x)$ via equation (2.1). If the impatient decision-makers do not rule (i.e. $m = p$), they face the decision on escapement by the patient decision-makers, $\hat{s}_p(x)$, which is the analogously defined optimal feedback policy for the patient decision-makers. The corresponding Bellman equation is:

$$v(x, p) = \pi(x) - \pi(\hat{s}_p(x)) + \rho_i E [q v(zg(\hat{s}_p(x)), i) + (1 - q) v(zg(\hat{s}_p(x)), p)]. \quad (2.8)$$

Again, the right-hand side consists of the sum of current profit and dis-

counted future profits weighted with probabilities for the different majority scenarios. Here, the future stock depends on \hat{s}_p , because in the current period the patient decision-makers choose the escapement level. Similarly, the two Bellman equations determining the value function for the patient decision-makers are:

$$V(x, i) = \pi(x) - \pi(\hat{s}_i(x)) + \rho_p E [q V(zg(\hat{s}_i(x)), i) + (1 - q) V(zg(\hat{s}_i(x)), p)] \quad (2.9)$$

$$V(x, p) = \pi(x) - \pi(\hat{s}_p(x)) + \rho_p E [q V(zg(\hat{s}_p(x)), i) + (1 - q) V(zg(\hat{s}_p(x)), p)]. \quad (2.10)$$

The corresponding total allowable catches are then given by $TAC_i = h_i = x - \hat{s}_i(x)$ if the impatient decision-makers rule and $TAC_p = h_p = x - \hat{s}_p(x)$ if the patient decision-makers rule.

Our first result is that the management decision by the patient decision-makers is not affected by the non-cooperative setting in the council. If they have the majority, they will choose their optimal feedback policy.

Proposition 1. *In the Markov-perfect Nash equilibrium the patient decision-makers always choose their optimal feedback policy, i.e. their dominant strategy is $\hat{s}_p(x) = s_p^*(x)$.*

Proof. See Appendix 2.7.1. □

The intuitive reason for this result is that for the patient decision-makers the marginal opportunity costs of current harvest in terms of foregone future harvest are the same irrespective of which group will set TACs in the next period.

For the impatient decision-makers, this result does not hold. Our central result for the setting with annual majority decisions on TAC levels is that the impatient decision-makers would choose a lower escapement level than optimal for them individually if the discount factors are sufficiently heterogeneous.

Proposition 2. *The optimal feedback policy for impatient decision-makers is a constant escapement strategy $\hat{S}_i(x) = \min\{x, \hat{s}_i\}$.*

If and only if $s_p^* > \underline{z}g(s_i^*)$, the impatient decision-makers will choose a strictly lower escapement level than their individually optimal one, $\hat{s}_i < s_i^*$.

Proof. See Appendix 2.7.1. □

Note that the condition $s_p^* > \underline{z}g(s_i^*)$ is on the individually optimal escapement levels that either group would choose if they would remain in the majority position forever. Thus, it can be verified without knowing the solution of the game in advance.

The underlying reason why the impatient decision-makers might choose an inefficiently low escapement level is the following: for them, the marginal opportunity costs of current harvest in terms of foregone future harvest may be zero if the patient decision-makers rule in the next period and choose a TAC of zero, which they do if the initial stock size in $t + 1$ is low and their discount factor is relatively large. The following corollary relates the condition in proposition 1 to the discount factors:

Corollary 1. *There exists a threshold difference $\bar{\rho}$ in discount factors such that the impatient decision-makers' Markov-perfect escapement level is strictly below their optimal escapement level, $\hat{s}_i < s_i^*$, if $\rho_p - \rho_i > \bar{\rho}$.*

A change from an impatient to a patient majority implies stronger fishing restrictions in the next period. Because of $\rho_i < \rho_p$ the patient decision-makers' optimal escapement is larger than the impatient's. Hence, in the next period the impatient decision-makers are not able to fish as much fish as would be optimal for them, but less. The change in majority translates into harvest shortfalls in the next period for the impatient decision-makers. As long as $\rho_p - \rho_i \leq \bar{\rho}$ those losses are not big enough to have any impact on the impatient decision-makers choice of escapement. Yet, given that the difference of the discount factors is sufficiently large, i.e. $\rho_p - \rho_i > \bar{\rho}$, the optimal escapement level of the impatient s_i^* is so low that the stock size in the next period, $\underline{z}g(s_i^*)$, is below the optimal escapement of the patient decision-makers s_p^* . In that case, the patient decision-makers will enforce a fishing stop if they get the majority in the next period. This has an important implication. To compensate the risk of harvest shortfalls that will happen

due to the change in majority the impatient decision-makers will deviate from their individually optimal choice and choose an even lower escapement \hat{s}_i in the current period. This is equivalent to an increase in the harvest or TAC level.

In other words, given that the discount factors are heterogeneous enough, the uncertainty regarding the majority and its choice of escapement in the next period motivates the impatient decision-makers to choose higher current fishing income (which is safe) rather than uncertain future fishing income. This type of ‘common pool politics’ may help explaining the ongoing over-fishing in regions like Europe and Chile for fish stocks where TAC levels are set in annual voting procedures.

Fig. 2.2 illustrates this outcome. Considering a fishing stop due to a potential change in majority the impatient decision-makers deviate from their optimal escapement level s_i^* and choose the lower \hat{s}_i . After the fishing season the stock grows, but is not going to exceed the patients’ optimal escapement level s_p^* . Hence, in the next period there will be either a fishing stop if the patients get the majority with probability $1 - q$ or on-going fishing to the impatient’s escapement level with probability q .

Given that $\rho_p - \rho_i > \bar{\rho}$, the optimal escapement level for the impatient decision-makers is also influenced by the probability of a change in the state of majority, q . If the impatient decision-makers can be (relatively) sure that they will keep the majority in the next period, i.e. q is sufficiently large, the escapement level will be not as low compared to the case that a patient majority is more likely, i.e. q is rather low. We have the following result.

Proposition 3. *If $\rho_p - \rho_i > \bar{\rho}$, the optimal escapement level for the impatient decision-makers increases with the probability that there is a majority of impatient decision-makers,*

$$\frac{d\hat{s}_i}{dq} > 0. \tag{2.11}$$

Proof. See Appendix 2.7.2. □

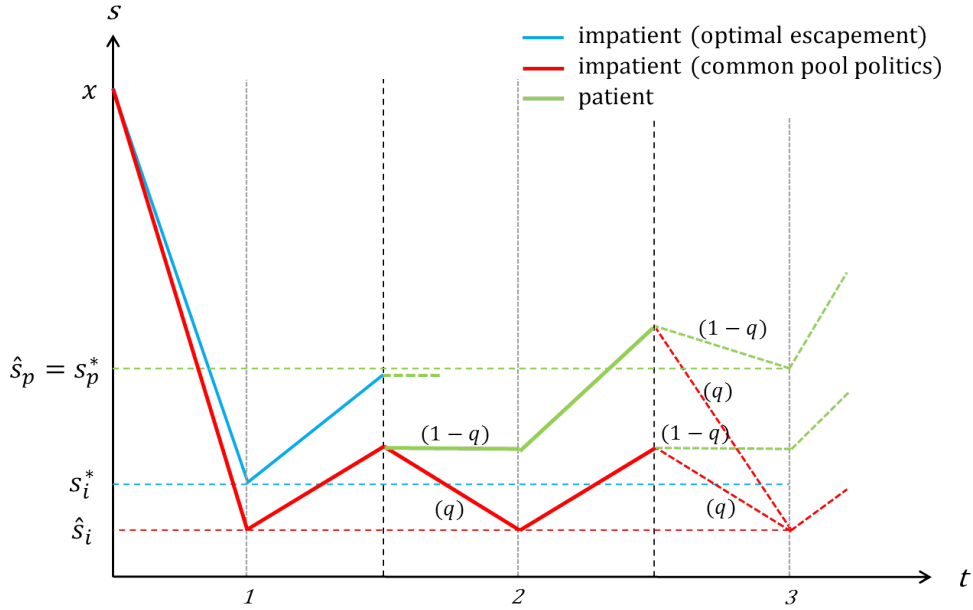


Fig. 2.2: Illustration of stock dynamics under common pool politics: development of the escapement level over time with potential change of majority in $t \geq 2$.

It is straightforward to verify that also in this setting with strategic interactions the escapement level chosen by the impatient decision-makers is increasing in their discount factor, $d\hat{s}_i/d\rho_i > 0$. A change in the discount factor of the group of patient decision-makers has the opposite effect on \hat{s}_i , as formally stated in the following proposition.

Proposition 4. *If $\rho_p - \rho_i > \bar{\rho}$, the optimal escapement level for the impatient decision-makers decreases with the discount factor of the patient decision-makers,*

$$\frac{d\hat{s}_i}{d\rho_p} < 0. \quad (2.12)$$

Proof. See Appendix 2.7.1. □

Thus, the more conservative the patient decision-makers behave, the worse the overall outcome tends to be – a result that is similar in flavor to the ‘green paradox’ in climate economics (Sinn, 2008).

We have seen that the set-up of the decision-making process upon TACs, i.e. the annual updating, leads to inefficiently high TACs if (a) the impatient decision-makers form the current majority and (b) the difference of the discount factors of the two groups of decision-makers is sufficiently large. Then, the uncertainty about future regulations decreases the escapement level and thereby increases the TAC level in order to outweigh more restrictive fishing regulations due to a possible change in majority. This problem will not only hold for the setting of TACs. The crucial point in our model is that the set-up of the decision-making fosters short-term thinking of the impatient majority. Every fishing activity limiting management tool, e.g. TACs or TAE (total allowable effort), will be set inefficiently high to offset future forgone profits. This problem could be avoided if both groups of decision-makers can commit to a binding agreement on a management plan that is decided upon once and for all, as this would reduce the uncertainty about future fishing opportunities. In the next section we examine such a setting.

2.5 Binding Long-Term Management Plan

In this section we consider an institutional setting for fisheries management where the council can commit to a binding long-term management plan. This means that the council decides upon a feedback strategy $\bar{s}(x)$, in fisheries sometimes referred to as harvest-control rule (Froese et al., 2011), that would be applied to determine all future TACs. We consider two cases how the agreement is made: one without the possibility of transfer payments; the other one with the possibility of a transfer payment between the two groups of decision-makers.

2.5.1 Agreement without Transfer Payments

We now consider a setting where decision-makers agree once and for all on a long-term management plan without having the possibility of transfer payments between the two groups. We use $\bar{V}(x)$ to denote the value function for the group of patient decision-makers and $\bar{v}(x)$ to denote the value function for the group of impatient decision-makers in this setting. Following Breton

and Keoula (2014), we assume that the harvest-control rule $\bar{s}(x)$ is chosen to maximize a weighted sum of the present values for the two groups,

$$\max_{\bar{s}(x)} E [\alpha \bar{V}(x) + (1 - \alpha) \bar{v}(x)], \quad (2.13)$$

where the parameter α measures the bargaining power of the impatient decision-makers, which we assume to be fixed. Among other aspects, this bargaining power reflects the actual majority in the council. Note that a time-consistent management plan is found only in the closed-loop solution to the optimization problem (2.13). In open-loop, the aggregation of discount factors would lead to a time inconsistent solution (Breton and Keoula, 2014).

We find that the resulting harvest-control rule is again characterized by a constant-escapement strategy, with an escapement level in between the optimal escapement levels for either group:

Proposition 5. *In the setting with agreement on a binding long-term management plan without transfer payment, the optimal harvest-control rule is characterized by a constant escapement strategy*

$$\bar{s}(x) = \max \{ \bar{s}^*, x \} \quad \text{with} \quad s_i^* \leq \bar{s}^* \leq s_p^*. \quad (2.14)$$

Proof. See Appendix 2.7.3. □

Thus, a binding management plan would circumvent the problems of ‘common pool politics’ associated with the annual voting on TAC levels in the council.

2.5.2 Agreement with Transfer Payments

Finally we briefly turn to the setting with a binding long-term management plan, but we assume that it is possible to pay transfer payments between the groups. As the two groups’ objective functions (2.3) are expressed in present values of profits, they can directly be compared to each other. Applying the envelope theorem, we find that this present value is monotonically increasing with the discount factor. It follows that the pa-

tient decision-makers attach a higher value to the fishery than the impatient decision-makers, as

$$E \left[\sum_{t=1}^{\infty} \delta_p^{t-1} (\pi(x_t) - \pi(s_p^*(x_t))) \right] > E \left[\sum_{t=1}^{\infty} \delta_i^{t-1} (\pi(x_t) - \pi(s_i^*(x_t))) \right]. \quad (2.15)$$

If the decision-makers have the opportunity to agree on a binding long-term management plan, the solution would probably be that the optimal feedback strategy of the patient decision-makers would be implemented, and that this group would compensate the impatient decision-makers. The reason is that the patient decision-makers will most likely gain more from the change to the binding agreement than the impatient decision-makers, who would implement their optimal policy at least when they are in majority (cf. Proposition 1). In a real decision context, such a compensation could take place in form of a direct transfer payment, or by means of some other kind of log-rolling.

Thus, with a binding long-term management plan and the possibility of transfer payments, the resulting harvest-control rule would likely be the most conservative one, and obviously the problem of ‘common pool politics’ could be solved.

2.6 Conclusion and Discussion

In this paper we presented a theory that explains why annual majority voting on total allowable catches (TACs) can lead to inefficiently high TACs – in particular in a setting where heterogeneous decision-makers vote on TACs on an annual basis. According to our theory the underlying reason for setting inefficiently high TACs is the uncertainty of the next period’s majority and its choice of TAC if the current majority is impatient. This shows that under the annual voting, the common pool problem on the oceans is translated in some sense into a common pool problem in the council of decision-makers. This is what we refer to as ‘common pool politics’.

We have further shown that the TAC set by the impatient decision-makers

will increase with the discount factor of the more patient decision-makers, i.e. when the latter would actually prefer a more restrictive TAC. This is a result in the same vein as the green paradox in climate economics: an environmentally friendly intention may actually lead to a result that is harmful for the environment.

We have derived these results by assuming that there are only two groups of decision-makers who differ only in their discount factors. One could generalize the model taking into account heterogeneity in other dimensions (as Munro, 1979 does in a cooperative setting). For example, if some decision-makers would attach a higher utility to the catches than another group, the first one would behave similarly as the one with the lower discount factor considered here. More generally, each decision-maker may be influenced by political pressures and the traditions of her or his national political system, which would be taken into account by changing the decision-maker's objective function. Specifically, one could include stakeholder interests that may influence the decision-makers objective functions, such as the interests of artisanal fishermen who may require redistributions in their favor. Such extensions may help explaining why fish stocks managed by ITQ systems (as in Iceland and New Zealand) tend to be less prone to overfishing (Costello et al., 2008). The management under such systems seems therefore to be more efficient. Thus, the way how TACs are distributed on national level might also influence the level of efficiency of TACs as a fishery management tool.

Finally, there may be more actors involved in the process of TAC setting than just the decision-makers. In particular, similar mechanisms as we studied for the TAC setting may play a role in group decisions as part of scientific advice giving, for example in committees of the International Council for the Exploration of the Seas (ICES), which are responsible for stock assessment and scientific advice for the TAC setting in many Atlantic fisheries.

We have studied a model set-up where constant escapement strategies are optimal. This is a consequence of assuming linear objective functions (Reed, 1979), a model set-up commonly used in resource economics. Another model set-up that allows for analytical solutions supposes iso-elastic, no-

linear objective functions and a specific class of resource growth functions, which leads to optimal harvesting policies that are linear in the stock sizes (Antoniadou et al., 2013; Kapaun and Quaas, 2013). Preliminary calculations for such a type of model indicate that our main results are robust as long as the non-linearity is not too large. A comprehensive analysis of this issue is left for future research, however.

There is evidence that long-term management plans can lead to more efficient fishery management (European Commission, 2009b). To study the TAC setting under a binding long-term management plan we have also considered the setting where the council decides once and for all on a harvest-control rule for the fishery. We have shown the resulting TAC will be set at more efficient levels. Without the possibility of transfer payments between the groups, the resulting TAC will be in between the levels preferred by the more and less patient decision-makers. With the possibility of a transfer payment between the groups, the TAC will be equal to the level preferred by the most patient decision-makers, i.e. the management will be particularly conservative. This paper thus provides a rigorous theoretical foundation for the policy recommendation to change the institutional set-up to allow for binding long-term management plans, especially in regions like Europe or Chile where TACs are set in an annual voting procedure.

2.7 Appendix

2.7.1 Proof of Propositions 1,2 and 4

Assume a finite time horizon of T periods. In the last period T , the optimal escapement levels are determined by the condition $\pi'(s_T^*) = 0$, for both types of decision-makers. In period $T - 1$, the Bellman equations thus read, using subscripts $T - 1$ for the corresponding value functions,

$$\begin{aligned}
 v_{T-1}(x, i) &= \max_{0 \leq s \leq x} [\pi(x) - \pi(s) + \rho_i E_z [\pi(z g(s)) - \pi(s_T^*)]] \\
 &= \pi(x) - \pi(S_i^*(x)) + \rho_i E_z [\pi(z g(S_i^*(x))) - \pi(s_T^*)] \\
 V_{T-1}(x, p) &= \max_{0 \leq s \leq x} \{\pi(x) - \pi(s) + \rho_p E [\pi(z g(s)) - \pi(s_T^*)]\} \\
 &= \pi(x) - \pi(S_p^*(x)) + \rho_p E_z [\pi(z g(S_p^*(x))) - \pi(s_T^*)] \\
 v_{T-1}(x, p) &= \pi(x) - \pi(S_p^*(x)) + \rho_i E_z [\pi(z g(S_p^*(x))) - \pi(s_T^*)] \\
 V_{T-1}(x, i) &= \pi(x) - \pi(S_i^*(x)) + \rho_p E [\pi(z g(S_i^*(x))) - \pi(s_T^*)]
 \end{aligned}$$

where we have used the guess (which is to be verified) that $S_j^*(x) = \min\{x, s_j^*\}$ is the optimal feedback policy for type $j \in \{i, p\}$.

In $T - 2$, and in all periods before $T - 2$, the Bellman equation for the case where type p rules reads

$$\begin{aligned}
 V_{T-2}(x, p) &= \max_{0 \leq s \leq x} \left\{ \pi(x) - \pi(s) + \rho_p E_z [q V_{T-1}(z g(s), i) \right. \\
 &\quad \left. + (1 - q) V_{T-1}(z g(s), p)] \right\} \\
 &= \max_{0 \leq s \leq x} \left\{ \pi(x) - \pi(s) + \rho_p E_z [\pi(z g(s)) + q (-\pi(S_i^*(z g(s)))) \right. \\
 &\quad \left. + \rho_p E_{z'} [\pi(z' g(S_i^*(z g(s))))] \right. \\
 &\quad \left. + (1 - q) (-\pi(S_p^*(z g(s))) + \rho_p E_{z'} [\pi(z' g(S_p^*(z g(s))))]) \right] - \rho_i \pi(s_T^*) \}
 \end{aligned}$$

Using that s_p^* is self-sustaining, i.e. that $g(s_p^*) > s_p^*$ with probability one, it follows for an interior solution for the optimization problem that $S_p^*(\hat{s}_p) = s_p^*$. Since $s_i^* < s_p^*$ this also implies $S_i^*(\hat{s}_p) = s_i^*$. Thus, the first-order condition

for the optimization problem is

$$\pi'(s) = \rho_p E_z [\pi'(z g(s)) z g'(z)],$$

which is identical to the first-order condition (2.5) for the optimal escapement level for type p . This proves proposition 1. In $T - 2$, the Bellman equation for the case where type i rules reads

$$\begin{aligned} v_{T-2}(x, i) &= \max_{0 \leq s \leq x} \left\{ \pi(x) - \pi(s) + \rho_i E_z [q v_{T-1}(z g(s), i) \right. \\ &\quad \left. + (1 - q) v_{T-1}(z g(s), p)] \right\} \\ &= \max_{0 \leq s \leq x} \left\{ \pi(x) - \pi(s) + \rho_i E_z [\pi(z g(s)) + q (-\pi(S_i^*(z g(s))) \right. \\ &\quad \left. + \rho_i E_{z'} [\pi(z' g(S_i^*(z g(s))))]] \right. \\ &\quad \left. + (1 - q) (-\pi(S_p^*(z g(s))) + \rho_i E_{z'} [\pi(z' g(S_p^*(z g(s))))]) \right\} - \rho_i \pi(s_T^*) \end{aligned}$$

We start with the guess that the solution \hat{s}_i to the optimization problem is self-sustaining, i.e. $z g(\hat{s}_i) > s_i^*$ with probability one, or equivalently $\underline{z} g(\hat{s}_i) > s_i^*$. This guess will be verified by the result that $\hat{s}_i \leq s_i^* < \underline{s}$. Further, we use that $S_p^*(z g(s)) = \max\{z g(s), s_p^*\}$. Thus, $S_p^*(z g(s)) = z g(s)$ for $z < s_p^*/g(s)$ and $S_p^*(z g(s)) = s_p^*$ else. Using these results, and using $\varphi(z)$ to denote the probability density function of z , we obtain the following Bellman equation

$$\begin{aligned} v_{T-2}(x, i) &= \max_{0 \leq s \leq x} \left\{ \pi(x) - \pi(s) + \rho_i E_z \left[\pi(z g(s)) \right. \right. \\ &\quad \left. \left. + q (-\pi(s_i^*) + \rho_i E_{z'} [\pi(z' g(s_i^*))]) \right] \right. \\ &\quad \left. + (1 - q) \int_{\underline{z}}^{s_p^*/g(s)} (-\pi(z g(s)) + \rho_i E_{z'} [\pi(z' g(z g(s))]) \varphi(z) dz \right] \\ &\quad \left. + (1 - q) \left(\int_{s_p^*/g(s)}^{\bar{z}} \varphi(z) dz \right) (-\pi(s_p^*) + \rho_i E_{z'} [\pi(z' g(s_p^*))]) \right\} - \rho_i \pi(s_T^*) \end{aligned}$$

The first-order condition for the maximization problem reads

$$\begin{aligned} \pi'(s) &= \rho_i E_z [z \pi'(z g(s)) g'(s)] \\ -(1-q) \int_{\underline{z}}^{\frac{s_p^*}{g(s)}} &(\pi'(z g(s)) - \rho_i E_{z'} [\pi'(z' g(z g(s))) z' g'(z g(s))]) z g'(s) \varphi(z) dz \end{aligned} \quad (2.16)$$

This equation is solved by some \hat{s}_i which is independent of x . Thus, the optimal policy for type i is a constant escapement policy as well.

Comparing (2.16) to the first-order condition (2.5) for the optimal escapement level for type i , we find that the right-hand side of (2.16) is smaller than the right-hand side of (2.5), as the second term is negative. The term in brackets is monotone in s (as π and g are concave). It is negative both at the lower and upper bound of integration. At the lower bound it is negative because $\underline{z} g(s) > s_i^*$, and

$$\begin{aligned} \pi'(z g(s)) - \rho_i E_{z'} [\pi'(z' g(z g(s))) z' g'(z g(s))] \\ > \pi'(s_i^*) - \rho_i E_{z'} [\pi'(z' g(s_i^*)) z' g'(s_i^*)] = 0. \end{aligned}$$

At the upper bound it is negative because

$$\pi'(s_p^*) - \rho_i E_{z'} [\pi'(z' g(s_p^*)) z' g'(s_p^*)] > \pi'(s_p^*) - \rho_p E_{z'} [\pi'(z' g(s_p^*)) z' g'(s_p^*)] = 0.$$

This holds provided the upper bound of the integral is larger than the lower bound, i.e. if $s_p^* > \underline{z} g(\hat{s}_i)$. As $\hat{s}_i \geq s_i^*$, a sufficient condition for this to hold is $s_p^* > \underline{z} g(s_i^*)$.

Proposition 4 follows directly, as the (negative) second term on the right-hand side of condition (2.16) is decreasing in s_p^* , which, in turn, is monotonically increasing in ρ_p .

2.7.2 Proof of Proposition 3

From proposition 2:

$$\begin{aligned} v(x, 1) &= \pi(x) - \pi(g(\hat{s}_i)) + \rho_i(q(\pi(g(\hat{s}_i))) + (1 - q)C_3)) \\ \pi'(\hat{s}_i) &= q \rho_i g'(\hat{s}_i) \pi'(g(\hat{s}_i)) \\ q \rho_i &= \frac{\pi'(\hat{s}_i)}{g'(\hat{s}_i) \pi'(g(\hat{s}_i))} \end{aligned}$$

The right-hand side is increasing in s (Reed, 1979). Thus, if q increases, s has to increase, too.

2.7.3 Proof of Proposition 5

The optimal feedback-control rule $\bar{s}(x)$ is characterized by the Bellman equation

$$\begin{aligned} \alpha \bar{V}(x) + (1 - \alpha) \bar{v}(x) \\ = \max_s \{ \pi(x) - \pi(s) + E [\alpha \rho_p \bar{V}(z g(x)) + (1 - \alpha) \rho_i \bar{v}(z g(s))] \} \end{aligned} \quad (2.17)$$

We guess the following value functions:

$$\bar{V}(x) = \pi(x) + \bar{C} \quad (2.18)$$

$$\bar{v}(x) = \pi(x) + \bar{c} \quad (2.19)$$

with constants \bar{C} and \bar{c} . With this guess, the first-order condition for the right-hand side of (2.17) becomes

$$\pi'(s) = (\alpha \rho_p + (1 - \alpha) \rho_i) E[\pi(z g(s)) z g'(s)] \quad (2.20)$$

This first-order condition is solved by a constant escapement level. This verifies the guess of the value function. Furthermore, the optimal escapement level that solves (2.20) is the same as the optimal escapement level for a hypothetical decision maker with discount factor $\alpha \rho_p + (1 - \alpha) \rho_i$, which is a convex mixture of the discount factors of the two groups, and hence in

between the two.

3. BARGAINING OVER RESOURCE REGULATION: TOTAL ALLOWABLE CATCH SETTING IN THE EUROPEAN COMMON FISHERIES POLICY

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Unpublished manuscript.

Abstract. A problem in TAC setting is that often the interests of the different stakeholders are unequally represented in the decision-making process putting economic interests in a better bargaining position than conservation interests. This imbalance can lead to ineffective TAC management. In order to analyze the distribution of bargaining power between different interests groups the TAC decision-making is modeled as a cooperative two-player-game with one player representing fishermen and fishing industry's interests and the other player representing conservation interests. Nash's bargaining solution of this game is used to derive an equation to estimate the bargaining powers. Panel data of TACs for European stocks are used for the estimation. The results show that the player representing interests of the fishermen and the fishing industry has the stronger bargaining position compared to the player representing conservation interests. The only exception are stocks that are fished by European Union member states but not managed by the Common Fisheries Policy. For those stocks, the player representing conservation interests has the stronger bargaining position leading to a more effective TAC management. The analysis also shows that scientific recommendations

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have a greater influence in the bargaining when the underlying data is of good quality. The conclusion is that effective TAC management requires both, a sound scientific assessment and a stronger inclusion of scientific advice.

Keywords: fisheries; fishery economics; bargaining power; political economy; cooperative game theory

JEL-Classification: Q22; Q71; D78

3.1 Introduction

Exploiting a renewable common pool resource such as fisheries in a non-cooperative way often leads to overexploitation or even distinction of the resource (Gordon, 1954; Clark, 1990). Cooperation between the groups of interests is the most promoted tool to overcome that problem (Kaitala and Lindroos, 2007; Bailey et al., 2010). The European Union uses such a cooperative management for the European fisheries. The most important instrument is the total allowable catch (TAC) which defines the amount of fish that is allowed to be caught from a specific stock in a year. TACs are set for a wide range of stocks to restrict the fishing activities by setting catch limits. However, according to past evaluations of the European Common Fisheries Policy TACs have not been used to their potential (European Commission, 2001, 2009b). They often are set at too high levels leading to the failure of the fisheries management (Khalilian et al., 2010). This is not only a problem in the European Union but also apparent in other nations' fisheries policies (see e.g. Leal et al. (2010); Okey (2003)). A TAC does not restrict fishing at all if it exceeds the landings of the corresponding period. In that case TACs are not restrictive and fisheries are effectively unregulated, i.e. de-facto open access (Quaas et al., 2012). For 57% of the stocks examined in this paper landings reach 95% or less of the TAC. On average, TACs exceed landings by roughly 60%. TACs are set at binding levels for only 16% of all cases.² So, even if the decision on TACs is made in a cooperative framework, the solution does not necessarily guarantee a sustainable use of the resource. It is often argued that during the TAC bargaining process decision-makers have a rather short-term perspective (Franchino and Rahming, 2003) or ignore scientific advice (Froese, 2011). But this does not need to hold for all decision-makers participating in the bargaining. There might also be decision-makers with a perspective on conservation that rely on the scientific recommendation. The problem then may be that the decision-makers of the second kind are under-represented what can cause ineffective management (Okey, 2003; Hilborn,

² In the remaining 26% the landings exceed the TAC by more than 5%. In these cases the enforcement of the TAC regulation has probably not been strict enough. A prominent example of overfishing the TAC is the Polish cod fishery (ORCA-EU, 2009).

2007).

This paper examines the bargaining position of different interests groups in the TAC bargaining process theoretically and in an empirical application to the European Union's TAC management. For the purpose of this analysis decision-makers, stakeholders and further interest groups are assumed to prefer a specific status quo TAC. For simplicity, I further assume that these status quo preferences can be classified into the two groups 'high TAC preference' and 'low TAC preference'. Using this kind of classification, the bargaining now takes place between two groups, i.e. two players, with opposing interests. I apply Nash's bargaining solution (Nash, 1953) on this cooperative two-player-game in order to derive an equation that allows to estimate the bargaining power for each player using data on European stocks and their TACs. The analysis considers the distribution of bargaining power between the two players for the whole data set. It is also examined if this distribution changes in different fishing areas using subsets of the data.

In the following the set-up of the decision-making process for TACs in the European Union is described (section 3.2.1) and the game-theoretic background is explained (section 3.2.2). Section 3.3 describes the data that is used. Results are presented in section 3.4. The paper closes with a discussion of the findings in section 3.5.

3.2 *Theoretical Model of Bargaining over TACs*

3.2.1 *Background: Decision-Making Process of TAC Setting in Europe*

The formal decision-making process for the TAC setting is clearly defined (Churchill and Owen, 2010). The European Commission prepares a proposal on TACs based on scientific input from research groups such as the Scientific, Technical and Economic Committee for Fisheries (STECF) and the International Council for the Exploration of the Seas (ICES). The proposal is handed to the European Council of Ministers. This Council currently consists of 28 national representatives, usually the ministers of agriculture and fisheries.³

³ The number of members changed over time depending on the number of European Union member states.

The ministers have to discuss the Commission’s proposal and decide on the TAC levels. Until the latest reform of the Common Fisheries Policy, it has not been possible for other institutions, e.g. the European Parliament, to intervene or veto the Council’s decision on TACs (e.g. European Council (2002), Art. 20). Hence, the ministers had the final say in this matter. However, since the adoption of the new Common Fisheries Policy in 2014 the European Parliament can intervene in the decision-making process of multi-annual plans where TACs are also included (European Union, 2013). The observation period of the data used in this paper ends in 2013. Therefore, intervention of the European Parliament is not considered. It is important to note that there is a deadline for the ministers to fix the TACs (e.g. mid of January for stocks in European Union- and Non-European Union waters (European Council, 2014a). Hence, the period of bargaining is limited. The ministers are obliged to find an agreement, either by unanimity or by voting with qualified majority.⁴ Given the minutes of the Council meetings discussing TACs, it seems that most of the TAC decisions are made by voting with at most three dissenting votes and/or abstentions (European Council, 2014b). According to the formal decision-making process only the ministers are participating in this bargaining process. However, there are stakeholders on national and European Union level, such as producer and consumer organisations or NGOs, that affect this procedure and the ministers in an informal way. For simplification, I assume that the actors participating directly or indirectly in the TAC setting can be classified into two groups. One group comprises those actors who favor and support the conservation of fish stocks and a sustainable fisheries management. Members are e.g. scientists or environmental NGOs, such as Greenpeace or WWF, who clearly call for restrictive TACs. The second group comprises those actors who focus on profits (and hence catches) from fishing. Fishermen, the fishing and processing industry and producer organisations belong to this group. They call for TACs that do not restrict their fishing activities. Ministers can be part of

⁴ In general, a qualified majority requires at least 255 out of 345 votes. Since 2014, a qualified majority “corresponds to at least 55% of the members, comprising at least 15 of them and representing at least 65% of the European population. A blocking minority may be formed comprising at least four members of the Council” (European Union, 2015).

either group. However, given the unsuccessful performance of the European TAC management in the past (European Commission, 2001, 2009b), and the fact that ministers had the final say regarding TACs it can be assumed that most of the ministers can be assigned to the second group. I further assume that the preferences regarding status quo TAC levels are different for each minister or stakeholder. Still, the status quo TAC preferences of actors of the same group are in the same range because members of the same group have similar interests. Hence, the preferred TAC level of each member of the first group will be lower than the preferred TAC level of each member of the second group. Assuming now that the members of each group are homogeneous, each group can be seen as a player preferring a specific status quo TAC. Then, the bargaining process simplifies to a cooperative two-player-game with one player having a lower preferred status quo TAC than the other. The interesting question then is which player dominates the bargaining process.

3.2.2 *Game Theoretic Approach*

In the cooperative two-player-game it is each player's aim to set a TAC close to her preferred TAC level. However, the two players have to bargain since their preferences differ. This kind of game can be solved by applying the concept of the Nash bargaining solution (NBS) (Nash, 1953; Binmore et al., 1986). The NBS is usually derived by maximizing the product of each player's difference in utilities of an agreement versus a disagreement, i.e. the Nash product. However, in the TAC bargaining process disagreement is not an option. Therefore, each player's aim is to minimize the deviation between their preferred option (disagreement) and the agreed-on TAC (agreement). Following the NBS notation the objective function then is:

$$\min_{TAC_t} (u_l(REF_t) - u_l(TAC_t))^\alpha (u_h(REF_t) - u_h(TAC_t))^\beta \quad (3.1)$$

with $u_l(\cdot)$ denoting the utility function of the player favoring low TACs, i.e. player l , and $u_h(\cdot)$ denoting the utility function of the player favoring high TACs, i.e. player h . The utility functions depend on the player's individual

preferred status quo TAC, which is the reference value *REF* (in the case of disagreement), and the agreed-on *TAC* (in the case of agreement). In the NBS framework the exponents α and β can be interpreted as bargaining power parameter of each player if they sum up to one. It is therefore assumed that $\alpha + \beta = 1$. Also, players may differ in their bargaining power, i.e. $\alpha \neq \beta$. The higher the bargaining power parameter the smaller the deviation between agreed-on TAC and the player's preferred TAC and the higher the assertiveness of this player in equilibrium. In addition, it is assumed that $\alpha, \beta \in (0; 1)$.

The utility functions for players l and h are assumed to be:

$$u_l = \log(H_l^{-\delta}) \text{ and } u_h = \log(H_h^\mu) \quad (3.2)$$

with H indicating the amount of harvested fish and $\delta, \mu > 0$. Player l 's utility decreases with the amount of harvested fish. The marginal utility loss is increasing the more fish has been harvested. This is because a stock's rebuilding capacity decreases if too much of the stock has been removed. Overexploitation or even extinction might be the consequence. Both have a negative impact on player l 's utility. In contrast, player h 's utility increases the higher the amount of harvested fish. However, the marginal utility is decreasing because of capacity and effort limits and decreasing fish prices.

For estimating the bargaining power of each player the following reference values, i.e. preferred status quo TACs, are assumed. The reference value of player l is the scientific advice of the current period t (ADV_t) to the decision-makers based on stock assessment and further research. The intention of the advice is to facilitate TACs that allow the recovery of a stock and - if the stock biomass is on a sufficiently high level - a sustainable use of the stock. The preferred status quo TAC of player l is therefore rather conservative. Player h orientates her reference value at the landings of the previous period (L_{t-1}). She would like to keep at least that level of landings in period t . In addition, she would like to reduce current fishing restrictions which is why she demands a TAC which exceeds the previous landings by a certain percentage $\gamma > 0$. γ is stock specific and depends on characteristics such

as growth rate or market price for a stock. The reference value of player h is therefore $(1 + \gamma)L_{t-1}$. A TAC equal to $(1 + \gamma)L_{t-1}$ ensures that fishing activities can be kept at least at the previous level. Restrictions in the future fishing activities are avoided.

Given that, equation (3.1) can be modified to:

$$\min_{TAC_t} (\log(ADV_t^{-\delta}) - \log(TAC_t^{-\delta}))^\alpha (\log(((1 + \gamma)L_{t-1})^\mu) - \log(TAC_t^\mu))^\beta. \quad (3.3)$$

The terms in brackets denote the deviation in utility.

The TAC solving (3.3) is given by:⁵

$$TAC_t = (1 + \gamma)^\alpha L_{t-1}^\alpha ADV_t^{1-\alpha}. \quad (3.4)$$

Equation (3.4) states that the final TAC in the current period t depends on the advice of the current period and the landings of the previous period. The advice captures the interests of player l while player h 's interests are represented by the landings. The exponents α and β describe the bargaining power of player h and l , respectively. The higher the parameter the more the player's interests are affecting the final TAC. The assumption $\alpha, \beta > 0$ in equation (3.4) is verified. If there have been higher landings in the previous period player h will like to keep that level which puts pressure on the decision-makers to increase the TAC or at least does not motivate a decrease. Therefore, α has to be positive. Regarding the advice, it can be assumed that decision-makers will follow a recommended increase of the TAC. However, a recommended decrease is probably not implemented as willingly. The motivation for this is as follows. Assuming that player h has the stronger bargaining position (given the too high TACs in the past (European Commission, 2001, 2009b)) the decision-makers will rather follow player h 's preferences which support an increase in TACs and disapprove a decrease in TACs. Either way, β has to be positive. Since $\alpha, \beta > 0$ and $\alpha + \beta = 1$ hold, the assumption $\alpha, \beta \in (0; 1)$ is also verified.

In order to quantify the bargaining power of the players l and h equation

⁵ See Appendix 3.6.1 for calculations.

(3.4) is estimated.

3.3 Data

I use panel data for 73 fish stocks from European and Non-European waters in the Baltic Sea (12 stocks), North Sea (20 stocks), Celtic Sea and West of Scotland (21 stocks), Bay of Biscay and Atlantic Iberian waters (6 stocks) and Norwegian, Icelandic, Greenland, Faroer and Russian waters (10 stocks) and 4 widely distributed stocks that can not be assigned to a single area. These 73 stocks represent 15 species: cod, haddock, herring, plaice, sole, whiting, anchovy, capelin, hake, horse mackerel, mackerel, megrim, Norway pout, saithe, sandeel and sprat (see Appendix 3.6.2). For each stock a TAC is set each year. The time series of observations run from 1987 to 2013.⁶ Data is available for the TAC (in tons), landings⁷ (in tons), advice⁸ (in tons) and information on the fishing area and the quality of the data underlying the assessment.⁹ The data stem from the ICES advice sheets from 2014 (ICES, 2014). If available, ICES estimates of landings are used. If these were not available official landing numbers reported by the countries are used. The advice sheets are used in the preparation of TAC proposals from the European Commission to the European Council of Ministers. Summarizing statistics of the data in total and by stock are given in section 3.6.3.

3.4 Estimation and Results

To consider the cross-sectional dimension of panel data, a one-way error component model is used for the estimation. One-way error component models assume that the error term u_{it} is composed of two parts:

$$u_{it} = \tau_i + \epsilon_{it} \tag{3.5}$$

⁶ For the majority of the stocks data is available for the whole period. However, in some cases the time series starts later, e.g. because the TAC management was not introduced for all stocks at the same time.

⁷ If not available, catch (in tons) is used. The catch includes landings and discard.

⁸ Landings (or catches) according to the TAC recommended by the ICES.

⁹ Ecoregion and more detailed area code is defined by the ICES.

where t denotes the time and i denotes the individual dimension of the data. τ_i is an unobservable, time-invariant individual-specific component and ϵ_{it} is the error term (see for example Baltagi (2005)). Depending on the specifications of τ_i different model types are appropriate. If the individuals are drawn randomly from a large population it can be assumed that τ_i is random and independent of the explaining variables. In that case, the random-effects model is appropriate. In contrast, if the individuals belong to a specific set, τ_i can be assumed to be fixed for each individual. Then, the fixed-effects model is the appropriate choice. The stocks in the data set used in this paper are not drawn randomly but are chosen according to the specific criteria that they are fished by European Union member states and managed by the European Common Fisheries Policy's TAC system. Therefore, τ_i can be assumed to be fixed for each stock which is why a fixed-effects model is used for the estimation. In addition, a performed Hausman test also suggests that the fixed-effects model is a better fit to the data than the random-effects model (Hausman, 1978).¹⁰

For the estimation, I take the logarithms of equation (3.4), and assume that the parameter γ depends on stock characteristics. The resulting fixed-effects model is:

$$\log(TAC_{it}) = c + \alpha \log(L_{i,t-1}) + \beta \log(ADV_{it}) + \sum_{i=2}^{73} \tau_i dummy_i + \epsilon_{it} \quad (3.6)$$

with $c = \alpha(1 + \gamma)$, $t = 1987, \dots, 2013$ representing the year and $i = 1, \dots, 73$ representing the stocks. There are 73 stocks from different areas fished by different countries which is why stock dummies are included. The stock dummies capture any individual-specific characteristic of the stocks that are not covered by the variables of landings and advice. Such characteristics can be the fishing area or biological and ecological specifications (e.g. stock size or reproduction behavior) that vary between stocks.¹¹ The stock-specific

¹⁰ The null hypothesis of using a random-effects model can be rejected in favor of a fixed-effects model (p-value = 0.000).

¹¹ A t-test testing the null hypothesis of all stock dummies being jointly equal to 0 suggests to include stock dummies (Prob > F = 0.0000).

characteristics are time invariant. To avoid perfect multicollinearity, the dummy for Anchovy from the Bay of Biscay (stock id: 1) is removed. That means Anchovy from Bay of Biscay is the reference stock against which all other stock dummies are compared. Equation (3.6) has been estimated with the constraint that $\alpha + \beta = 1$. This is required by the Nash Bargaining Solution framework. It is assumed that observations are independent between the groups, however, it is controlled for intra-group correlation.¹²

The results for α, β and c of estimating equation (3.6) are presented in table 3.1 (for the whole estimation output including dummy coefficients see Appendix 3.6.4).

		coefficient	SE	p-value	95% conf. interval	
$\log L_{t-1}$	α	0.5605	0.0735	0.000	0.4163	0.7047
$\log ADV_t$	β	0.4395	0.0735	0.000	0.2953	0.5837
	c	0.2431	0.0054	0.000	0.2326	0.2536
No. of obs. = 1190		Prob. > F = 0.000		Root MSE = 0.1376		

Tab. 3.1: Estimation results of equation (3.6) for the whole data set under the constraint $\alpha + \beta = 1$. The reference stock is Anchovy in Bay of Biscay (stock id: 1).

Both coefficients, α and β , have a positive influence on the TAC level as expected. If the advice increases by 1% the TAC increases by 0.4395%. The landings' impact is higher. A 1% increase of landings leads to a 0.5605% increase of TAC. This implies that player h seems to have more bargaining power than player l . The results suggest that the interests of fishermen and the fishing industry have a stronger impact on the TACs than the interests of scientists and supporters of conservation. Most of the stock dummy coefficients have significant values indicating that there are stock-specific effects that have to be taken into account (see Appendix 3.6.4). The constant c here is the intercept referring to the reference stock Anchovy in Bay of Biscay (the stock that is left out in the dummies). The intercepts of the other stocks can be calculated relative to the Anchovy in Bay of Biscay using the estimated

¹² The calculations are done with STATA using the command `cnsreg`.

stock effects (i.e. dummy coefficients in table 3.6.4). For example, the stock effect of the Western Baltic Cod (stock id: 5) is 0.1181 leading to an intercept of 0.3612. So, relative to Anchovy in the Bay of Biscay the Western Baltic Cod has a higher TAC level if the effect of landings and advice are not considered. In contrast, Capelin in Icelandic and Greenland waters (stock id: 4) has an intercept of 0.0387 indicating a lower TAC level compared to the Anchovy in the Bay of Biscay if the effects of landings and advice are not considered. Based on the individual intercepts the mark-up parameters γ_i with $i = 1, \dots, 73$ can also be determined for each stock. Using the examples from above, player h calls for an increase in TAC of 171% from year to year for Anchovy in Bay of Biscay. For the Western Baltic Cod and the Capelin in Icelandic and Greenland waters the demanded increase in TAC is 341% and 17%, respectively. For some stocks the intercept is negative which indicates a strong downward deviation in the predicted TAC levels compared to Anchovy in Bay of Biscay. A negative intercept also translates into a negative γ implying that player h is willing to accept a TAC that is below the previous level of landings.

The estimation results may be influenced by the quality of the scientific advice available. Although player h does not rely directly on the scientific advice, it can be assumed that she considers recommendations for TACs for orientation, e.g. for choosing the γ to set her preferred TAC value. The extent to which player h relies on the scientific advice might depend on the quality of the underlying data. A sound scientific assessment of a stock's situation allows to derive reliable advised TAC based on the assessment. The assessment of a stock for which only poor data is available is likely to be highly uncertain, which also implies that TAC advices based on the uncertain assessment might not be very reliable. As a consequence, the relevance of the scientific advice for stocks with poor data is decreasing which would weaken player l 's bargaining position since her reference value equals the advised TAC. That in turn, would strengthen player h 's bargaining position.

In each ICES advice sheet it is indicated whether the data is sufficient for an assessment or not. If the data is not sufficient, the ICES uses an approach for data-limited stocks for the assessment. To determine the influence of data

quality, I classified the stocks according to the quality of data used for their assessment indicated in the ICES advice sheets of 2014 into the two groups ‘good data’ if data has been at least sufficient for the assessment and ‘poor data’ if the data-limited approach has been used. Then, I estimated equation (3.6) for both groups. Results regarding α, β and c are given in table 3.2 (for the whole estimation output including stock effects see Appendix 3.6.5).

		coefficient	SE	p-value	95% conf. interval	
Group ‘Good Data’						
$\log L_{t-1}$	α	0.5392	0.0826	0.000	0.3771	0.7014
$\log ADV_t$	β	0.4608	0.0826	0.000	0.2986	0.6229
	c	0.2446	0.0060	0.000	0.2328	0.2565
	No. of obs. = 1033	Prob. > F = 0.000		Root MSE = 0.1342		
Group ‘Poor Data’						
$\log L_{t-1}$	α	0.7099	0.0908	0.000	0.5304	0.8894
$\log ADV_t$	β	0.2901	0.0908	0.002	0.1106	0.4696
	c	0.1259	0.01169	0.000	0.1029	0.1491
	No. of obs. = 157	Prob. > F = 0.000		Root MSE = 0.1549		

Tab. 3.2: Estimation results of equation (3.6) for the subsets according to data quality under the constraint $\alpha + \beta = 1$. The reference stock for group ‘Good Data’ is Anchovy of Bay of Biscay (stock id: 1) and for group ‘Poor Data’ Eastern Baltic Cod (stock id: 6).

Player h has the better bargaining position in both subsets. However, in the subset of poor data her position is much stronger relative to player l ’s than in the subset of good data. Note that the coefficients are significantly different between the two groups. Thus, the quality of data matters in the bargaining process. If TACs for a stock with poor data for assessment are negotiated, player l ’s position is relatively weak, which might result in too high TACs since there is no sound scientific argument against it. On the other hand, if the data is good the scientific advice seems to have more influence in the decision-making.

3.4.1 Analysis by Fishing Area

In the previous section the whole data set was examined in order to get information on how the bargaining power in the TAC setting is distributed between player l favoring low TACs and player h favoring high TACs. This section examines to what extent the bargaining power of the two players differs between fishing areas. The motivation is as follows. Due to the regulation of fishing opportunities the countries are only allowed to fish for stocks for which they have a TAC (e.g. European Council (2002); European Union (2013)). Since most of the stocks can be assigned to a spatially limited habitat the fishing activities of countries is also spatially limited to specific fishing areas. In the TAC setting, all countries have a say even if they decide on TACs that are not relevant for them. Hence, the composition of actors (representing the interests of their home country) preferring a low status quo TAC or a high status quo TAC is likely to differ between fishing areas depending on whether the actors have an interest in stocks of this specific fishing area or not. That implies that the bargaining positions of players l and h also differ between fishing areas.

For the estimation by fishing area each stock is assigned to one of the following fishing areas:¹³ Baltic Sea, North Sea, Celtic Sea and West of Scotland (in the following Celtic Sea), Bay of Biscay and Atlantic Iberian Waters (in the following Bay of Biscay), and the rest including Barent Sea, Icelandic Sea, Norwegian Sea, and East Greenland Sea (in the following Non-EU waters). Most of the stocks can be assigned to a single fishing area. Widely distributed and migratory stocks are assigned to all areas in which they are present. Then, equation (3.6) is estimated for each area over the whole time period from 1987 to 2013.

Area			coef.	SE	p-value	95% conf. interval	
Baltic Sea	$\log L_{t-1}$	α	0.6399	0.0986	0.000	0.4455	0.8343
	$\log ADV_t$	β	0.3601	0.0986	0.000	0.1657	0.5545
		c	0.3583	0.0036	0.000	0.3513	0.3654
No. of obs. = 210			Prob. > F = 0.000		Root MSE = 0.1954		
North Sea	$\log L_{t-1}$	α	0.6248	0.0826	0.000	0.4624	0.7872

¹³ The corresponding fishing area for each stock is taken from the ICES advice sheets.

	$\log ADV_t$	β	0.3752	0.0826	0.000	0.2128	0.5375
		c	-0.0166	0.0032	0.000	-0.0229	-0.0103
No. of obs. = 393			Prob. > F = 0.000			Root MSE = 0.1232	
	$\log L_{t-1}$	α	0.5092	0.0932	0.000	0.3259	0.6925
Celtic Sea	$\log ADV_t$	β	0.4908	0.0932	0.000	0.3075	0.6740
		c	0.2558	0.0172	0.000	0.2219	0.2897
No. of obs. = 366			Prob. > F = 0.000			Root MSE = 0.1325	
	$\log L_{t-1}$	α	0.6408	0.1059	0.000	0.4310	0.8505
Bay of Biscay	$\log ADV_t$	β	0.3592	0.1059	0.001	0.1495	0.5689
		c	0.2372	0.0077	0.000	0.2219	0.2525
No. of obs. = 136			Prob. > F = 0.000			Root MSE = 0.1358	
	$\log L_{t-1}$	α	0.1474	0.1099	0.181	-0.0693	0.3641
Non-EU	$\log ADV_t$	β	0.8526	0.1099	0.000	0.6359	1.0693
		c	0.0556	0.0327	0.091	-0.0089	0.1199
No. of obs. = 250			Prob. > F = 0.1814			Root MSE = 0.1297	

Tab. 3.3: Estimation results by area according to equation (3.6) under the constraint $\alpha + \beta = 1$. The reference stocks are for the Baltic Sea Western Baltic Cod (stock id: 5), for the North Sea Cod in areas IIIa, IV, VIId (stock id: 7), for Celtic Sea Cod in areas VIIe-k (stock id: 10), for Bay of Biscay Anchovy in Bay of Biscay (stock id: 1) and for Non-EU waters Capelin in Barent Sea (stock id: 3).

The results regarding α, β and c are given in table 3.3 (for the whole estimation output see Appendix 3.6.6). Landings and advice have positive coefficients throughout all fishing areas. In all European areas player h has the higher share of bargaining power ($\alpha > \beta$). The Bay of Biscay shows the biggest imbalance of the players' bargaining powers followed by the Baltic Sea and the North Sea. Here, scientific recommendation does not seem to be important in the TAC setting. Interests in profits from catches seem to dominate the discussion. For the Celtic Sea bargaining powers are more evenly distributed. That could indicate that the representation of different interests is more balanced. In the Non-EU waters the opposite picture can be found. Player l has a very strong bargaining position relative to player h ($\alpha < \beta$). The estimated bargaining power of player h is even insignificant. Thus, player h does not seem to have an impact on the TAC negotiations. The stocks in these waters are mainly managed by Non-EU countries. From their agreed-on TAC a specific share is going to the European Union. The

European Common Fishery Policy itself is not affecting the management in these waters as much as in EU waters. The high coefficient β might indicate that in the Non-EU countries scientific recommendations and conservation of stocks are more taken into account. This may lead to a more effective TAC management, as it is the case for Iceland (Hilborn, 2007).

The differences in the bargaining power distribution in the TAC setting process in the different fishing areas might lead to differences in the performance of TAC management. A measure for the effectiveness or bindingness of TACs is the ratio of landings and TACs. I assume that a ratio between 0.95 and 1.05 indicates binding TACs.¹⁴ A ratio below 0.95 implies that TACs have not been fully fished. Therefore they are too high and do not restrict the fishing activity as intended. A ratio greater than 1.05 implies that landings exceed the TAC. In that case, the TAC is at a restrictive level but not enforced properly.

Area	Baltic Sea	North Sea	Celtic Sea	Bay of Biscay	Non-EU
Mean Ratio	0.68	1.01	0.85	0.86	1.09
SD	(0.40)	(0.53)	(0.69)	(0.40)	(0.51)

Tab. 3.4: Mean ratio of landings and TACs by area from 1987 to 2013 (SD = standard deviation).

The mean ratio of the Baltic Sea is relatively low (0.68) indicating that TACs are set on too high and hence ineffective levels (table 3.4). This could be a consequence of the strong bargaining position of player h . TACs in the Celtic Sea and the Bay of Biscay seem to be more effective. For the Celtic Sea, this could be caused by the relatively stronger bargaining position of player l . In the North Sea the ratio is close to 1 which indicates effective TACs. For Non-EU waters the TACs are at effective levels, too. However, the ratio exceeds 1.05 which means that landings exceed the TACs by more than 5%. TACs could have been an efficient tool in this area. However, they have not been successfully enforced.

¹⁴ Ideally, the ratio should equal 1. Then the TAC is perfectly binding. However, to account for uncertainties and inaccuracies a ratio $\in (0.95; 1.05)$ is also considered to indicate binding TACs.

3.5 Discussion and Conclusion

This paper conceptualizes the political TAC setting process as a kind of Nash bargaining. It quantifies the bargaining power of the two players l and h representing the participating actors preferring low and high TACs, respectively, in order to examine how interests are represented in the decision-making process. The analysis has been done for the whole set of observations and for subsets according to fishing areas in order to capture different distributions of interests.

For the whole data set, player h (favoring high TACs) has a stronger position in the bargaining process than player l (favoring low TACs). The weak performance of the European TAC management therefore could be a result of the strong influence of fishermen, the industry, producer organisations and ministers who focus on profits from fishing, captured by player h . Scientific recommendations and interests in conservation of fish stocks, captured by player l , are less important. This is supported by the analysis by fishing area. In all EU areas, player h has a stronger bargaining position compared to player l leading to ineffective TAC levels. In contrast, in the Non-EU waters player l clearly dominates the bargaining process which could be one reason why the TAC management in these waters is more successful. The analysis also shows that a sound stock assessment based on good data improves the bargaining position of player l . In cases where only poor data has been available for the stock assessment player h 's bargaining position is much stronger. If a reliable assessment is available the scientific recommendation for TACs is taken more into account. It is therefore very important to strengthen the position of the scientific input in the TAC bargaining process and to improve the data base underlying the scientific advice. Otherwise, it might be difficult to improve the TAC management's performance. Recognizing that, the Commission addressed this problem in the recent reform of the European Common Fisheries Policy (European Union, 2013; European Commission, 2009b).

The estimations performed in this paper have been done under the constraint that the bargaining power parameters add up to one, i.e. $\alpha + \beta = 1$,

to fit the assumptions of Nash's bargaining solution. The results of an unconstrained regression are given in Appendix 3.6.7, 3.6.8 and 3.6.9. In this setting, player h also has the stronger bargaining position – in the whole data set as well as for the EU fishing area subsets. In the Non-EU fishing area player l has the much stronger bargaining position. However, the coefficients of player h and l do not add up to one in any of these estimations (this option is not even included in the confidence intervals, except for Bay of Biscay and the Non-EU waters). Hence, it can be argued that the cooperative two-player-approach might not be sufficient to capture all aspects of this bargaining process. Another approach could be to account for more differentiated interests groups and allow for three or more players. Then, the TAC bargaining could be modeled as a cooperative coalition game (Lindroos et al., 2007). Even if cooperation is possible between the players it can still be difficult to reach a cooperative solution. Munro (1979) considered side payments to overcome these difficulties. On the other hand, the contradiction to Nash's assumption could also suggest that a cooperative approach is not appropriate to model the TAC bargaining process – no matter how many players are involved. Hoffmann and Quaas (2015) argue that, assuming a non-cooperative setting, the institutional set-up of the TAC setting process in the European Union promotes short-term thinking and therefore leads to high TACs. They propose that binding long-term agreements including transfer payments solve that problem.

3.6 Appendix

3.6.1 Nash Bargaining Solution

The Nash Bargaining Solution (NBS) can be derived by solving the minimization problem

$$\min_{TAC_t} (\log(ADV_t^{-\delta}) - \log(TAC_t^{-\delta}))^\alpha (\log(((1 + \gamma)L_{t-1})^\mu) - \log(TAC_t^\mu))^\beta \quad (3.7)$$

The first order condition (FOC) is given by:

$$\begin{aligned} & \alpha(\log(ADV_t^{-\delta}) - \log(TAC_t^{-\delta}))^{\alpha-1} \frac{\delta}{TAC_t} \\ & \quad \cdot (\log(((1 + \gamma)L_{t-1})^\mu) - \log(TAC_t^\mu))^\beta \\ & + \beta(\log(((1 + \gamma)L_{t-1})^\mu) - \log(TAC_t^\mu))^{\beta-1} \frac{-\mu}{TAC_t} \\ & \quad \cdot (\log(ADV_t^{-\delta}) - \log(TAC_t^{-\delta}))^\alpha = 0 \end{aligned} \quad (3.8)$$

Rearranging yields:

$$\begin{aligned} 0 & = \delta\alpha(\log(TAC_t^\mu) - \log(((1 + \gamma)L_{t-1})^\mu)) - \mu\beta(\log(TAC_t^{-\delta}) \\ & \quad - \log(ADV_t^{-\delta})) \\ 0 & = \delta\alpha\mu \log\left(\frac{TAC_t}{(1 + \gamma)L_{t-1}}\right) - \delta\beta\mu \log\left(\frac{TAC_t}{ADV_t}\right) \\ 0 & = \alpha \log\left(\frac{(1 + \gamma)L_{t-1}}{TAC_t}\right) + \beta \log\left(\frac{ADV_t}{TAC_t}\right) \end{aligned} \quad (3.9)$$

Solving for TAC_t gives the NBS:

$$TAC_t = (1 + \gamma)^\alpha L_{t-1}^\alpha ADV_t^{1-\alpha} \quad (3.10)$$

For equation (3.10) to be the minimum the second order condition (SOC)

derived from (3.9) has to be positive.

$$\min_{TAC_t} \alpha \log \left(\frac{(1 + \gamma)L_{t-1}}{TAC_t} \right) + \beta \log \left(\frac{ADV_t}{TAC_t} \right) \\ 0 \leq (\alpha + \beta) \frac{1}{TAC_t} \quad (3.11)$$

Since $\alpha + \beta = 1$ the SOC is positive. Hence, equation (3.10) minimizes equation (3.7).

3.6.2 List of Fish Stocks in Data Set

Tab. 3.5: List of fish stocks in the data set including ID and fishing area.

ID	Fish species	Fishing Area (ICES Division)
1	Anchovy	VIII (Bay of Biscay)
2	Anchovy	IXa (Portuguese Waters)
3	Capelin	I, II (Barent Sea)
4	Capelin	V, XIV, IIa (Iceland-East Greenland-Jan Mayen Area)
5	Cod	22-24 (Baltic Sea)
6	Cod	25-32 (Baltic Sea)
7	Cod	IIIa, IV, VIId (Skagerrak, North Sea, Eastern Channel)
8	Cod	IIIa (Skagerrak)
9	Cod	IV (North Sea)
10	Cod	VIIe-k (Celtic Sea)
11	Cod	I, II (Barent Sea, Norwegian Sea)
12	Cod	Norwegian Waters
13	Cod	Va (Icelandic Waters)
14	Cod	VIIa (Irish Sea)
15	Cod	VIa (Celtic Sea and West of Scotland)
16	Haddock	IIIa, IV (Skagerrak, North Sea)
17	Haddock	IIIa (Skagerrak)
18	Haddock	IV (North Sea)
19	Haddock	VIa (West of Scotland)
20	Haddock	VIIb-k (Celtic Sea and West of Scotland)
21	Haddock	Arctic waters
22	Haddock	Va (Icelandic Waters)
23	Haddock	VIIa (Irish Sea)
24	Haddock	VIb (Rockall)

25	Herring	25 - 29, 32 (Baltic Sea excluding Gulf of Riga)
26	Herring	30 (Baltic Sea, Bothnian Sea)
27	Herring	31 (Baltic Sea, Bothnian Bay)
28	Herring	IIIa, 22 - 24 (Western Baltic Sea)
29	Herring	IIIa, IV, VIIId (Skagerrak, Kattegat, North Sea, Eastern Channel)
30	Herring	VIIa, VIIg,h,j,k (Celtic Sea and South of Ireland)
31	Herring	VIa, VIIb,c (West of Scotland, Rockall)
32	Herring	VIIa (Irish Sea)
33	Herring	I, II, V, IVa, XIV (Norwegian Waters)
34	Herring	28.1 (Baltic Sea, Gulf of Riga)
35	Herring	Va (Icelandic Waters)
36	Herring	VIa (West of Scotland)
37	Hake	IIIa, IV, VI, VII, VIIIa,b (Skagerrak, Kattegat, North Sea, Irish and Celtic Sea, Channel, Bay of Biscay)
38	Hake	VIIIc, IXa, (Bay of Biscay, Portuguese Waters)
39	Horse Mackerel	IXa (Portuguese Waters)
40	Horse Mackerel	IIa, IVa, Vb, VIa, VII a-c, e-k, VIII (Norwegian waters, North Sea, Icelandic waters, West of Scotland, Irish Sea, Bay of Biscay)
41	Mackerel	North-east Atlantic
42	Megrim	IVa, VIa (North Sea, West of Scotland)
43	Megrim	VIIb (Rockall)
44	Megrim	VIIIc, IXa (Bay of Biscay, Portuguese Waters)
45	Norway Pout	IV, IIIa (Skagerrak, Kattegat, North Sea)
46	Plaice	21 - 23 (Kattegat, Belts, Sounds, Baltic Sea)
47	Plaice	VIIh-k (South-west of Ireland)
48	Plaice	VIIIf,g (Celtic Sea)
49	Plaice	VIIId,e (Eastern and Western Channel)
50	Plaice	VIIa (Irish Sea)
51	Plaice	IV (North Sea)
52	Plaice	20 (Skagerrak, Baltic Sea)
53	Saithe	IIIa, IV, VI (Skagerrak, North Sea, West of Scotland and Rockall)
54	Saithe	IIIa, IV (Skagerrak, Kattegat, North Sea)
55	Saithe	VI (West of Scotland)
56	Saithe	I, II (North-east Arctic)
57	Sandeel	IIIa, IV (Kattegat, Skagerrak, North Sea)
58	Sole	VIIh-k (South-west of Ireland)
59	Sole	VIIIa, b (Bay of Biscay)
60	Sole	VIIIf,g (Celtic Sea)
61	Sole	VIIId (Eastern Channel)

62	Sole	VIIe (Western Channel)
63	Sole	VIIa (Irish Sea)
64	Sole	IIIa, 22 - 24 (Baltic Sea, Skagerrak, Kattegat, Belts)
65	Sole	IV (North Sea)
66	Sprat	22 - 32 (Baltic Sea)
67	Sprat	IIIa (Skagerrak, Kattegat)
68	Blue Whiting	I-IX, XII, XIV (North-east Atlantic)
69	Whiting	IV, VIIId (North Sea, Eastern Channel)
70	Whiting	IV (North Sea)
71	Whiting	VIIId (Eastern Channel)
72	Whiting	VIIe-k (South-west of Ireland)
73	Whiting	VIa (West of Scotland)

3.6.3 Data Summary

Tab. 3.6: Statistical summary by stock including fishing area.

ID	Fish species	Fishing Area	Var.	Mean	SD	No. of Obs.
1	Anchovy	Bay of Biscay	TAC	30440	3721.47	10
			Landings	18000	11402.1	10
			Advice	19080	12974.66	10
2	Anchovy	Bay of Biscay	TAC	8750	1544.79	12
			Landings	5341.67	2232.59	12
			Advice	4750	100	12
3	Capelin	Non-EU waters	TAC	457083.3	266189.1	12
			Landings	432333.3	272404.9	12
			Advice	432333.3	211504.7	12
4	Capelin	Non-EU waters	TAC	1007500	368266.2	16
			Landings	932625	338773.8	16
			Advice	740375	207496.8	16
5	Cod	Baltic Sea	TAC	79573.7	68624.4	19
			Landings	23763.2	8337.5	19
			Advice	24847.4	11433.25	19
6	Cod	Baltic Sea	TAC	110665.3	60861.4	15
			Landings	84809.8	40407.7	15
			Advice	73693.33	47751.63	15
7	Cod	North Sea	TAC	98500	61419.83	10
			Landings	89180	57740.5	10
			Advice	104604.1	60344.3	10
8	Cod	North Sea	TAC	16685.7	6836.3	7

			Landings	13428.6	5858.3	7
			Advice	18871.4	4354.9	7
9	Cod	North Sea	TAC	112133.3	40371.5	9
			Landings	96466.7	39007.2	9
			Advice	115555.6	41437	9
10	Cod	Celtic Sea	TAC	13130.1	5892.2	16
			Landings	8218.8	3186.9	16
			Advice	6037.5	2689.7	16
11	Cod	Non-EU waters	TAC	520115.4	193850.9	26
			Landings	564956.8	165974.3	26
			Advice	464480.8	236078.2	26
12	Cod	Non-EU waters	TAC	40000	0	3
			Landings	35333.3	5507.6	3
			Advice	14333.3	7094.6	3
13	Cod	Non-EU waters	TAC	203440	47716.3	25
			Landings	221560	52807.9	25
			Advice	192960	44941.2	25
14	Cod	Celtic Sea	TAC	9441.7	3872.6	12
			Landings	7309.2	3117.7	12
			Advice	7916.7	3801.2	12
15	Cod	Celtic Sea	TAC	13846.7	4448.1	6
			Landings	10450	7276.7	6
			Advice	11733.3	4752.9	6
16	Haddock	North Sea	TAC	88429.1	44778.1	19
			Landings	108300	50481.1	19
			Advice	67946.6	47731.5	19
17	Haddock	North Sea	TAC	4912.5	1296.6	8
			Landings	3962.5	2640.3	8
			Advice	3375	1164.7	8
18	Haddock	North Sea	TAC	70352.6	38217.7	16
			Landings	83562.5	44589.9	16
			Advice	67924.1	37047.8	16
19	Haddock	North Sea	TAC	15410.4	10496.7	15
			Landings	12906.7	7171.6	15
			Advice	11813.3	6077.6	15
20	Haddock	Celtic Sea	TAC	10544.3	3170.3	3
			Landings	9300	3651.1	3
			Advice	8233.3	1167.6	3
21	Haddock	Non-EU waters	TAC	148291.7	73064.3	24

			Landings	148208.3	69413.1	24
			Advice	141083.3	83032.7	24
22	Haddock	Non-EU waters	TAC	61384.6	22003.8	26
			Landings	61923.1	20715.1	26
			Advice	59923.1	25768.1	26
23	Haddock	Celtic Sea	TAC	4965.4	6778.1	7
			Landings	2200	1710.8	7
			Advice	2541.4	2135.9	7
24	Haddock	Celtic Sea	TAC	5765.5	1627.1	2
			Landings	3750	636.4	2
			Advice	8855	2467.8	2
25	Herring	Baltic Sea	TAC	296739.1	177979.1	23
			Landings	158067.5	53739.5	23
			Advice	185347.8	115961.4	23
26	Herring	Baltic Sea	TAC	90714.3	20158.9	21
			Landings	62280.9	19028.5	21
			Advice	67061.9	25437.5	21
27	Herring	Baltic Sea	TAC	89133.3	17482.9	15
			Landings	4320	1517.1	15
			Advice	5980	5402.5	15
28	Herring	Baltic Sea	TAC	120633.3	66277.1	21
			Landings	57666.7	37914.8	21
			Advice	112678.6	57484.6	21
29	Herring	North Sea	TAC	362923.1	126830.9	13
			Landings	434538.5	172415	13
			Advice	344230.8	118709.1	13
30	Herring	Celtic Sea	TAC	18147.5	4121.1	20
			Landings	17440	5135.4	20
			Advice	17297.5	6224.5	20
31	Herring	Celtic Sea	TAC	21336.8	6669.6	19
			Landings	27105.3	9134.2	19
			Advice	21289.5	7733.9	19
32	Herring	Celtic Sea	TAC	6074.7	1492.9	24
			Landings	4683.3	1591.5	24
			Advice	5339.6	1269.9	24
33	Herring	Non-EU waters	TAC	856950	480780.2	20
			Landings	853450	474349.2	20
			Advice	837450	506228.6	20
34	Herring	Baltic Sea	TAC	36100	3586.4	11

			Landings	32281.8	4314.8	11
			Advice	33254.6	5622.3	11
35	Herring	Non-EU waters	TAC	100403.8	27152.9	26
			Landings	98646.2	29640.1	26
			Advice	95538.5	22693.1	26
36	Herring	Celtic Sea	TAC	46316	20607.8	19
			Landings	26760	7327.3	19
			Advice	38077.1	15802.3	19
37	Hake	North Sea,	TAC	55822.7	8673.5	22
		Celtic Sea and	Landings	55113.6	13101.4	22
		Bay of Biscay	Advice	45836.4	12508.9	22
38	Hake	Bay of Biscay	TAC	13221.1	5166.4	16
			Landings	11840	3528.9	16
			Advice	9106.3	4471.9	16
39	Horse Mackerel	Bay of Biscay	TAC	58468.9	15230	23
			Landings	27739.1	8935.2	23
			Advice	43578.3	16604.2	23
40	Horse Mackerel	Non-EU waters, North Sea and Celtic Sea	TAC	179015	67882.1	20
			Landings	210700	79355.4	20
			Advice	161100	39960.4	20
41	Mackerel	all areas except Baltic Sea	TAC	643687.5	180155	16
			Landings	701133.3	130687.1	15
			Advice	529218.8	96153	16
42	Megrim	Celtic Sea	TAC	5893.7	1518.1	12
			Landings	2681.5	676.5	12
			Advice	3420	1410.9	12
43	Megrim	Celtic Sea	TAC	3647.3	855.9	12
			Landings	511	280	11
			Advice	3041.7	1628.5	12
44	Megrim	Bay of Biscay	TAC	2590.6	1888.9	16
			Landings	1229.4	185.4	16
			Advice	1220	281.5	16
45	Norway Pout	North Sea	TAC	138250	100268.5	6
			Landings	55666.7	42935.6	6
			Advice	217166.7	184946.9	6
46	Plaice	Baltic Sea	TAC	2554.7	853.2	13
			Landings	2753.8	919.8	13
			Advice	10453.9	2645.6	13
47	Plaice	Celtic Sea	TAC	368.4	138.9	8

			Landings	166.8	37.1	8
			Advice	242	107.5	8
48	Plaice	Celtic Sea	TAC	840.5	472.5	19
			Landings	785.8	450.9	19
			Advice	714.2	498.9	19
49	Plaice	North Sea	TAC	7019.2	2157.7	24
			Landings	7147.8	2458.6	24
			Advice	5813.3	2686.1	24
50	Plaice	Celtic Sea	TAC	2676.8	1293.9	23
			Landings	1810.9	1218.8	23
			Advice	3209.6	1600.9	23
51	Plaice	North Sea	TAC	99152.2	45701.7	23
			Landings	87391.3	36230	23
			Advice	90260	45892.7	23
52	Plaice	Baltic Sea	TAC	9176.9	1544.9	13
			Landings	7315.4	1104.4	13
			Advice	10453.9	2645.6	13
53	Saithe	North Sea	TAC	135847.4	33920.1	25
			Landings	110319.6	13914.3	25
			Advice	131333.3	38912.1	25
54	Saithe	North Sea	TAC	120488.8	28783.2	25
			Landings	99593.2	12157.7	25
			Advice	119141.6	33097.6	25
55	Saithe	North Sea	TAC	15543.8	7510.7	22
			Landings	10643.6	7432.7	22
			Advice	13854.3	7281.5	22
56	Saithe	Non-EU waters	TAC	159841	39552.2	25
			Landings	155160	27417.6	25
			Advice	157960	50649.5	25
57	Sandeel	North Sea	TAC	233666.7	153350.4	3
			Landings	261000	168721.7	3
			Advice	240686.7	176608.3	3
58	Sole	Celtic Sea	TAC	541.9	126.8	8
			Landings	315.9	111.9	8
			Advice	311.5	55.1	8
59	Sole	Bay of Biscay	TAC	4989.5	910.4	21
			Landings	5119.1	893.7	21
			Advice	4581.9	1134.6	21
60	Sole	Celtic Sea	TAC	1043.5	106.9	23

			Landings	1053.9	158.7	23
			Advice	965.2	144.1	23
61	Sole	North Sea	TAC	4735.4	982.4	25
			Landings	4332	497.3	25
			Advice	4553.6	1132.9	25
62	Sole	North Sea	TAC	814.8	167.8	23
			Landings	974.3	187.7	23
			Advice	661.3	273.7	23
63	Sole	Celtic Sea	TAC	1124.5	326.5	20
			Landings	1086.3	402.1	20
			Advice	1009	313.7	20
64	Sole	Baltic Sea	TAC	842.6	328.4	19
			Landings	732.6	221.9	19
			Advice	727.3	194.9	19
65	Sole	North Sea	TAC	19652.8	5739.1	25
			Landings	20936	7363.6	25
			Advice	18156	6031.6	25
66	Sprat	Baltic Sea	TAC	370295.5	128583	22
			Landings	312045.5	115675	22
			Advice	297181.8	135078.3	22
67	Sprat	Baltic Sea	TAC	57800	17183.7	7
			Landings	28000	34837.7	7
			Advice	320212.4	393073.5	7
68	Blue Whiting	all areas	TAC	902909.1	628151	11
		except	Landings	799909.1	564580.1	11
		Bay of Biscay	Advice	632500	360400.3	11
69	Whiting	Celtic Sea	TAC	47282.5	17005	13
			Landings	19887.5	4212.9	13
			Advice	31200	14193.9	13
70	Whiting	North Sea	TAC	33137.1	29410	14
			Landings	37012.4	34021.2	14
			Advice	31407.1	32194.1	14
71	Whiting	North Sea	TAC	21321.1	4905	12
			Landings	4812.8	1071.8	12
			Advice	7991.7	5258.1	12
72	Whiting	Celtic Sea	TAC	24906.7	3608.6	15
			Landings	15680	4237.3	15
			Advice	12540	5663.6	15
73	Whiting	Celtic Sea	TAC	7410	5601.5	10

Landings	4190	3378.2	10
Advice	6400	4867.6	10

3.6.4 Constrained Regression of the whole Data Set

Tab. 3.7: Results of constrained estimation of equation (3.6) for the whole data set controlling for intra-group correlation and including stock effects. The reference stock is Anchovy in the Bay of Biscay (stock id: 1).

Variable	Coef.	SE	P>|t|	95% Conf. Interval
$\log L_{t-1}$	.5605129	.073486	0.000	.4163267 .7046991
$\log ADV_t$	.4394871	.073486	0.000	.2953009 .5836733
c	.2430826	.0053645	0.000	.232557 .2536082
id				
2	-.0175466	.0009553	0.000	-.0194211 -.0156722
3	-.0646633	.0272266	0.018	-.1180843 -.0112423
4	-.2043688	.0034079	0.000	-.2110554 -.1976822
5	.1181409	.0026958	0.000	.1128515 .1234302
6	-.0978685	.0040907	0.000	-.1058949 -.0898422
7	-.2622226	.0082304	0.000	-.2783715 -.2460737
8	-.2568855	.0172272	0.000	-.2906868 -.2230841
9	-.2417379	.0069975	0.000	-.2554676 -.2280082
10	.0032226	.0082304	0.695	-.0129263 .0193714
11	-.2294181	.0030299	0.000	-.235363 -.2234732
12	-.0045067	.0267244	0.866	-.0569425 .047929
13	-.2587185	.0002205	0.000	-.259151 -.2582859
14	-.1645583	.0040785	0.000	-.1725606 -.156556
15	-.144473	.0067117	0.000	-.157642 -.131304
16	-.2071198	.0180737	0.000	-.242582 -.1716576
17	-.074237	.0047215	0.000	-.083501 -.0649731
18	-.2963195	.0034998	0.000	-.3031863 -.2894526
19	-.2092569	.0005144	0.000	-.2102662 -.2082476
20	-.1949937	.0010043	0.000	-.1969642 -.1930231
21	-.2165195	.0024557	0.000	-.2213377 -.2117013
22	-.2400964	.003386	0.000	-.24674 -.2334527
23	-.0650115	.0073591	0.000	-.0794507 -.0505723
24	-.1780492	.0388006	0.000	-.2541796 -.1019189
25	-.05303	.0054284	0.000	-.063681 -.042379
26	-.0654391	.0088638	0.000	-.0828307 -.0480475
27	1.065983	.0090878	0.000	1.048152 1.083815
28	-.0569062	.0279002	0.042	-.1116489 -.0021635
29	-.2918826	.0034538	0.000	-.2986594 -.2851059
30	-.2183533	.0038213	0.000	-.2258509 -.2108556
31	-.3068108	.0039566	0.000	-.3145741 -.2990475
32	-.1525835	.0100186	0.000	-.1722408 -.1329261
33	-.2296718	.0040417	0.000	-.237602 -.2217416
34	-.2074486	.0050304	0.000	-.2173188 -.1975783
35	-.2332565	.0046861	0.000	-.2424512 -.2240619
36	-.0939	.0143298	0.000	-.1220163 -.0657837

37	-.1883087	.000982	0.000	-.1902356	-.1863818
38	-.1427129	.0097461	0.000	-.1618356	-.1235902
39	-.0129658	.0171222	0.449	-.0465612	.0206296
40	-.2903377	.0025353	0.000	-.2953121	-.2853633
41	-.2304675	.0032242	0.000	-.2367937	-.2241414
42	.0559145	.0097124	0.000	.0368578	.0749711
43	.3313094	.0567434	0.000	.2199736	.4426452
44	-.0047864	.0048133	0.320	-.0142306	.0046578
45	.1037244	.0541102	0.056	-.0024447	.2098935
46	-.5374021	.0477602	0.000	-.631112	-.4436921
47	-.005837	.0118864	0.623	-.0291591	.0174851
48	-.1950574	.0031058	0.000	-.2011512	-.1889637
49	-.1959413	.0054441	0.000	-.2066231	-.1852595
50	-.1772274	.0219787	0.000	-.2203517	-.1341032
51	-.197508	.0042143	0.000	-.2057768	-.1892392
52	-.2120237	.0159917	0.000	-.2434009	-.1806466
53	-.1977779	.0088918	0.000	-.2152244	-.1803313
54	-.2032939	.0094797	0.000	-.2218939	-.1846939
55	-.1208471	.0130471	0.000	-.1464467	-.0952475
56	-.2310699	.0048942	0.000	-.2406727	-.2214671
57	-.3089218	.0098226	0.000	-.3281947	-.289649
58	-.0356544	.0022413	0.000	-.0400521	-.0312567
59	-.2334377	.0008853	0.000	-.2351748	-.2317006
60	-.2312799	.0020097	0.000	-.2352231	-.2273367
61	-.2144048	.0061875	0.000	-.2265453	-.2022644
62	-.2362514	.0100995	0.000	-.2560676	-.2164351
63	-.2276369	.0004409	0.000	-.228502	-.2267718
64	-.1960326	.0049777	0.000	-.2057993	-.1862659
65	-.2365859	.0008671	0.000	-.2382873	-.2348845
66	-.1386936	.0037945	0.000	-.1461388	-.1312484
67	.0695219	.0510308	0.173	-.0306052	.1696489
68	-.2248373	.0011825	0.000	-.2271574	-.2225173
69	.037452	.0158221	0.018	.0064076	.0684964
70	-.2513269	.005081	0.000	-.2612963	-.2413574
71	.3425602	.0162649	0.000	.310647	.3744734
72	.0198172	.0032579	0.000	.0134249	.0262094
73	-.141439	.0116108	0.000	-.1642204	-.1186576
No. of obs.	1190				
F(1,1116)	58.18				
Prob > F	0.0000				
Root MSE	0.1376				

3.6.5 Constrained Regression of Data Subsets according to Data Quality

Tab. 3.8: Results of constrained estimation of equation (3.6) for the data subset ‘poor data’ controlling for intra-group correlation and including stock effects. The reference stock is Eastern Baltic Cod (stock id: 6).

Variable	Coef.	SE	P>|t|	95% Conf.	Interval
$\log L_{t-1}$	.709936	.0908189	0.000	.5304362	.8894359
$\log ADV_t$	.290064	.0908189	0.002	.1105641	.4695638
c	.1259883	.0116853	0.000	.1028927	.1490839
id					
23	.0561386	.0141504	0.000	.0281708	.0841063
27	1.190649	.0162868	0.000	1.158458	1.222839
43	.5528754	.0751829	0.000	.4042794	.7014713
46	-.3341022	.0640809	0.000	-.4607554	-.2074489
47	.1245186	.0197455	0.000	.0854923	.1635448
48	-.0951861	.0012173	0.000	-.097592	-.0927802
49	-.1008247	.0016726	0.000	-.1041305	-.0975189
50	-.0263505	.0322183	0.415	-.0900287	.0373276
52	-.0733206	.0248192	0.004	-.1223746	-.0242665
58	.0750894	.0078255	0.000	.0596225	.0905563
No. of obs.	157				
F(1,186)	61.11				
Prob > F	0.0000				
Root MSE	0.1549				

Tab. 3.9: Results of constrained estimation of equation (3.6) for the data subsets ‘good data’ controlling for intra-group correlation and including stock effects. The reference stock is Anchovy in Bay of Biscay (stock id: 1).

Variable	Coef.	SE	P>|t|	95% Conf.	Interval
$\log L_{t-1}$	.5392302	.0826339	0.000	.3770684	.7013919
$\log ADV_t$	.4607698	.0826339	0.000	.2986081	.6229316
c	.2446362	.0060323	0.000	.2327984	.256474
id					
2	-.0178233	.0010742	0.000	-.0199314	-.0157152
3	-.0725485	.0306159	0.018	-.1326295	-.0124676
4	-.2033818	.0038321	0.000	-.2109021	-.1958616
5	.1173601	.0030313	0.000	.1114114	.1233089
7	-.2646063	.009255	0.000	-.2827684	-.2464442
8	-.2618748	.0193717	0.000	-.2998901	-.2238594
9	-.2437645	.0078686	0.000	-.2592059	-.2283231
10	.0056063	.009255	0.545	-.0125559	.0237684
11	-.2285406	.0034071	0.000	-.2352266	-.2218545
12	.0032331	.0300512	0.914	-.0557397	.0622059
13	-.2587823	.0002479	0.000	-.2592688	-.2582958
14	-.1657395	.0045862	0.000	-.1747395	-.1567395
15	-.1464169	.0075472	0.000	-.1612276	-.1316061
16	-.2018854	.0203236	0.000	-.2417686	-.1620021
17	-.0756044	.0053092	0.000	-.0860233	-.0651855
18	-.2953059	.0039354	0.000	-.3030288	-.2875829
19	-.209108	.0005784	0.000	-.2102431	-.2079728
20	-.1947028	.0011293	0.000	-.196919	-.1924866
21	-.2172307	.0027614	0.000	-.2226496	-.2118118

22	-.241077	.0038075	0.000	-.2485489	-.2336051
24	-.1892865	.0436307	0.000	-.2749079	-.1036651
25	-.0546022	.0061041	0.000	-.066581	-.0426233
26	-.0680062	.0099672	0.000	-.087566	-.0484464
28	-.0649865	.0313733	0.039	-.1265539	-.0034191
29	-.2908823	.0038838	0.000	-.2985039	-.2832607
30	-.21946	.004297	0.000	-.2278924	-.2110276
31	-.3056649	.0044492	0.000	-.314396	-.2969338
32	-.155485	.0112657	0.000	-.1775931	-.133377
33	-.2308424	.0045449	0.000	-.2397613	-.2219235
34	-.2089055	.0056567	0.000	-.2200062	-.1978047
35	-.2346137	.0052695	0.000	-.2449546	-.2242728
36	-.0980502	.0161136	0.000	-.1296717	-.0664286
37	-.1880243	.0011043	0.000	-.1901914	-.1858572
38	-.1398903	.0109593	0.000	-.161397	-.1183836
39	-.0179246	.0192537	0.352	-.0557083	.019859
40	-.2896035	.0028509	0.000	-.295198	-.2840089
41	-.2295338	.0036256	0.000	-.2366486	-.2224189
42	.0531016	.0109214	0.000	.0316692	.074534
44	-.0061804	.0054125	0.254	-.016802	.0044412
45	.0880532	.0608461	0.148	-.0313519	.2074584
51	-.1987285	.0047389	0.000	-.2080281	-.1894289
53	-.2003531	.0099987	0.000	-.2199747	-.1807315
54	-.2060394	.0106598	0.000	-.2269582	-.1851205
55	-.1246258	.0146713	0.000	-.1534169	-.0958347
56	-.2324873	.0055034	0.000	-.2432873	-.2216873
57	-.306077	.0110454	0.000	-.3277527	-.2844014
59	-.2336941	.0009955	0.000	-.2356477	-.2317404
60	-.2318619	.0022599	0.000	-.2362967	-.2274272
61	-.2161968	.0069578	0.000	-.2298509	-.2025428
62	-.2333264	.0113568	0.000	-.255613	-.2110397
63	-.2277646	.0004958	0.000	-.2287376	-.2267916
64	-.1974742	.0055974	0.000	-.2084586	-.1864899
65	-.236837	.0009751	0.000	-.2387505	-.2349235
66	-.1397926	.0042669	0.000	-.148166	-.1314191
67	.0547425	.0573833	0.340	-.0578673	.1673523
68	-.2244949	.0013297	0.000	-.2271042	-.2218856
69	.0328696	.0177917	0.065	-.0020451	.0677843
70	-.2498553	.0057135	0.000	-.2610676	-.238643
71	.3378497	.0182896	0.000	.3019579	.3737415
72	.0207607	.0036634	0.000	.0135715	.0279499
73	-.1448016	.0130561	0.000	-.1704232	-.1191801
No. of obs.	1033				
F(1,186)	42.58				
Prob > F	0.0000				
Root MSE	0.1342				

3.6.6 Constrained Regression by Fishing Area

Tab. 3.10: Results of constrained estimation of equation (3.6) for the Baltic Sea. The reference stock is Western Baltic Cod (stock id: 5).

Variable	Coef.	SE	P>|t|	95% Conf. Interval	
$\log L_{t-1}$	.6399144	.0985885	0.000	.445484	.8343448
$\log ADV_t$	.3600856	.0985885	0.000	.1656552	.554516
c	.3583399	.0035803	0.000	.351279	.3654008
id					
6	-.2233422	.0091047	0.000	-.241298	-.2053864
25	-.1682183	.0036661	0.000	-.1754483	-.1609883
26	-.1769154	.008275	0.000	-.1932349	-.1605959
27	.9547491	.0085755	0.000	.9378371	.9716612
28	-.1478137	.0338141	0.000	-.2145	-.0811275
34	-.3230668	.0031322	0.000	-.329244	-.3168897
46	-.6068509	.0604583	0.000	-.7260832	-.4876186
52	-.3157984	.0178377	0.000	-.3509769	-.2806198
64	-.3117079	.0030614	0.000	-.3177455	-.3056703
66	-.2556473	.0014741	0.000	-.2585544	-.2527401
67	.0036069	.064846	0.956	-.1242786	.1314924
68	-.3471686	.005203	0.000	-.3574297	-.3369076
No. of obs.	210				
F(1,196)	42.13				
Prob > F	0.0000				
Root MSE	0.1954				

Tab. 3.11: Results of constrained estimation of equation (3.6) for the North Sea. The reference stock is Cod in areas IIIa, IV, VIIId (stock id: 7).

Variable	Coef.	SE	P>|t|	95% Conf. Interval	
$\log L_{t-1}$	.6248115	.0825614	0.000	.4624601	.7871628
$\log ADV_t$	.3751885	.0825614	0.000	.2128372	.5375399
c	-.0166324	.0032199	0.000	-.0229641	-.0103007
id					
8	.0132091	.0101079	0.192	-.0066673	.0330856
9	.0194059	.0013852	0.000	.016682	.0221298
16	.0320873	.0295526	0.278	-.0260259	.0902005
17	.1849153	.0039423	0.000	.1771631	.1926676
18	-.0443605	.0131789	0.001	-.0702758	-.0184452
19	.0453141	.0098248	0.000	.0259943	.0646339
29	-.0398835	.0131273	0.003	-.0656973	-.0140696
37	.0658532	.0103502	0.000	.0455002	.0862062
40	-.0375348	.0120952	0.002	-.0613193	-.0137504
41	.0217325	.0128693	0.092	-.003574	.047039
45	.4060908	.0515458	0.000	.3047294	.5074521
49	.0543164	.0153633	0.000	.0241055	.0845273
51	.0612006	.0045122	0.000	.0523277	.0700734
53	.0650234	.0007431	0.000	.0635622	.0664846
54	.0600218	.0014035	0.000	.0572618	.0627817

55	.14559	.0054115	0.000	.1349486	.1562314
57	-.0624952	.0202826	0.002	-.1023795	-.022611
61	.0460303	.0022952	0.000	.0415169	.0505436
62	.0099329	.0205937	0.630	-.0305631	.050429
65	.019194	.0082727	0.021	.0029264	.0354616
68	.0291492	.0105754	0.006	.0083535	.0499449
70	-.0007515	.0149554	0.960	-.0301603	.0286573
71	.6118128	.0090267	0.000	.5940624	.6295632
No. of obs.	393				
F(1,368)	57.27				
Prob > F	0.0000				
Root MSE	0.1232				

Tab. 3.12: Results of constrained estimation of equation (3.6) for the Celtic Sea and West of Scotland. The reference stock is Cod in areas VIIe-k (stock id: 10).

Variable	Coef.	SE	P>|t|	95% Conf.	Interval
$\log L_{t-1}$	.5092272	.0931563	0.000	.325992	.6924624
$\log ADV_t$	.4907728	.0931563	0.000	.3075376	.674008
c	.255793	.0172339	0.000	.2218945	.2896915
id					
14	-.1763712	.0156037	0.000	-.2070631	-.1456793
15	-.1581237	.0189418	0.000	-.1953815	-.1208659
20	-.2032593	.0091604	0.000	-.2212774	-.1852412
23	-.079114	.0197624	0.000	-.117986	-.0402419
24	-.2140947	.05962	0.000	-.3313652	-.0968241
30	-.2299867	.0152776	0.000	-.2600373	-.1999361
31	-.3130161	.0054178	0.000	-.3236726	-.3023595
32	-.168542	.0231338	0.000	-.2140454	-.1230386
36	-.1128673	.028599	0.000	-.1691205	-.0566141
37	-.1965899	.0091886	0.000	-.2146635	-.1785163
40	-.2975349	.0072196	0.000	-.3117357	-.2833342
41	-.237184	.0063463	0.000	-.2496668	-.2247011
42	.0401696	.0227457	0.078	-.0045703	.0849095
43	.2827417	.0823657	0.001	.1207313	.4447522
47	-.0230991	.0255015	0.366	-.0732597	.0270616
48	-.2018565	.0064964	0.000	-.2146348	-.1890783
50	-.2015329	.0382953	0.000	-.2768585	-.1262073
58	-.0461852	.0132748	0.001	-.0722962	-.0200742
60	-.241649	.0129811	0.000	-.2671825	-.2161156
63	-.2369112	.0109924	0.000	-.258533	-.2152895
68	-.2329787	.0089345	0.000	-.2505526	-.2154048
69	.0174432	.0304908	0.568	-.0425311	.0774175
72	.0131243	.0063036	0.038	.0007254	.0255232
73	-.1585087	.0251522	0.000	-.2079822	-.1090352
No. of obs.	366				
F(1,340)	29.88				
Prob > F	0.0000				
Root MSE	0.1325				

Tab. 3.13: Results of constrained estimation of equation (3.6) for the Bay of Biscay and Atlantic Iberian Waters. The reference stock is Anchovy in Bay of Biscay (stock id: 1).

Variable	Coef.	SE	P>|t|	95% Conf.	Interval
$\log L_{t-1}$	.6407773	.1059947	0.000	.4310329	.8505216
$\log ADV_t$	.3592227	.1059947	0.001	.1494784	.5689671
c	.2372233	.0077376	0.000	.2219119	.2525346
id					
2	-.0165032	.0013779	0.000	-.0192299	-.0137765
37	-.1893813	.0014165	0.000	-.1921843	-.1865784
38	-.153358	.0140575	0.000	-.1811754	-.1255407
39	.0057358	.0246968	0.817	-.0431346	.0546063
41	-.2339891	.0046505	0.000	-.2431917	-.2247866
44	.0004709	.0069427	0.946	-.0132674	.0142092
59	-.2324707	.001277	0.000	-.2349976	-.2299437
No. of obs.	136				
F(1,127)	36.55				
Prob > F	0.0000				
Root MSE	0.1358				

Tab. 3.14: Results of constrained estimation of equation (3.6) for the Non-EU waters (Barent Sea, Icelandic Sea, Norwegian Sea and East Greenland Sea). The reference stock is Capelin in Barent Sea (stock id: 3).

Variable	Coef.	SE	P>|t|	95% Conf.	Interval
$\log L_{t-1}$	.1474187	.1099904	0.181	-.0692698	.3641072
$\log ADV_t$	.8525813	.1099904	0.000	.6358928	1.06927
c	.0555237	.0327222	0.091	-.0089411	.1199886
id					
4	.0325031	.0458523	0.479	-.0578289	.1228352
11	.0053288	.0452865	0.906	-.0838885	.0945462
12	.3634365	.0807513	0.000	.204351	.5225221
13	-.042243	.0404215	0.297	-.1218761	.03739
21	-.0126091	.037076	0.734	-.0856512	.060433
22	-.0414158	.0356834	0.247	-.1117146	.028883
33	-.0346773	.034702	0.319	-.1030425	.033688
35	-.0418845	.0337375	0.216	-.1083496	.0245805
40	-.0583713	.0445461	0.191	-.1461301	.0293876
41	.0053717	.0455773	0.906	-.0844186	.095162
56	-.0408672	.0334261	0.223	-.1067189	.0249845
68	-.0004756	.0425213	0.991	-.0842454	.0832943
No. of obs.	250				
F(1,236)	1.80				
Prob > F	0.1814				

3.6.7 Unconstrained Regression of the whole Data Set

Tab. 3.15: Results of unconstrained estimation of equation (3.6) for the whole data set controlling for intra-group correlation and including stock effects. The reference stock is Anchovy in the Bay of Biscay (stock id: 1)

Variable	Coef.	SE	P>|t|	95% Conf.	Interval
$\log L_{t-1}$	.4120475	.0681766	0.000	.2761399	.5479552
$\log ADV_t$	.3448198	.0528853	0.000	.2393948	.4502448
c	1.274592	.2292952	0.000	.8174998	1.731683
id					
2	-.1466351	.0287426	0.000	-.2039324	-.0893377
3	.2147188	.0608406	0.001	.0934352	.3360023
4	.2044754	.0910978	0.028	.0228752	.3860755
5	.1493948	.0067832	0.000	.1358728	.1629168
6	.0480091	.0330591	0.151	-.0178929	.1139112
7	-.1011207	.0349094	0.005	-.1707113	-.0315301
8	-.2759211	.0139789	0.000	-.3037875	-.2480547
9	-.0579111	.0399496	0.152	-.1375491	.021727
10	-.0971265	.0217592	0.000	-.1405026	-.0537504
11	.1194455	.077754	0.129	-.0355543	.2744453
12	.0297104	.0222123	0.185	-.0145691	.0739899
13	.0024469	.0578057	0.966	-.1127866	.1176804
14	-.2565978	.0212042	0.000	-.2988676	-.2143281
15	-.1992844	.0139947	0.000	-.2271823	-.1713865
16	-.0513677	.0393889	0.196	-.1298882	.0271527
17	-.2528747	.040422	0.000	-.3334546	-.1722949
18	-.1457701	.0339668	0.000	-.2134817	-.0780585
19	-.2536024	.0097492	0.000	-.2730371	-.2341678
20	-.2621764	.0147423	0.000	-.2915646	-.2327882
21	-.0085573	.0457142	0.852	-.0996868	.0825722
22	-.1145047	.0274016	0.000	-.1691287	-.0598807
23	-.298907	.0531801	0.000	-.4049196	-.1928944
24	-.3191672	.0462161	0.000	-.4112974	-.227037
25	.1780362	.0504897	0.001	.0773868	.2786856
26	.0620928	.0276104	0.028	.0070525	.1171332
27	.9171421	.0349487	0.000	.8474731	.986811
28	.0785929	.0324383	0.018	.0139283	.1432575
29	.0335242	.0726355	0.646	-.111272	.1783205
30	-.2236421	.003223	0.000	-.2300671	-.2172171
31	-.2733778	.008484	0.000	-.2902903	-.2564652
32	-.2894469	.032621	0.000	-.3544757	-.224418
33	.1482573	.0831297	0.079	-.0174588	.3139733
34	-.1402071	.0145642	0.000	-.1692402	-.111174
35	-.0563348	.0386084	0.149	-.1332992	.0206296
36	-.0391159	.0141986	0.007	-.0674203	-.0108114
37	-.0794126	.0242768	0.002	-.1278075	-.0310177

38	-.2010987	.0133574	0.000	-.2277261	-.1744713
39	.0518725	.0168694	0.003	.018244	.085501
40	-.0430555	.0551812	0.438	-.1530572	.0669462
41	.1453345	.0837512	0.087	-.0216204	.3122894
42	-.135643	.0444422	0.003	-.224237	-.047049
43	.0149503	.088377	0.866	-.1612261	.1911268
44	-.2873969	.0634157	0.000	-.4138139	-.1609799
45	.2076318	.0410165	0.000	.1258668	.2893967
46	-.6801632	.0515356	0.000	-.7828975	-.5774289
47	-.4800722	.107174	0.000	-.6937198	-.2664247
48	-.5398152	.0759091	0.000	-.6911373	-.3884932
49	-.3063265	.0239263	0.000	-.3540228	-.2586302
50	-.404129	.0558193	0.000	-.5154027	-.2928553
51	-.0347088	.0355355	0.332	-.1055476	.03613
52	-.2906021	.0228442	0.000	-.3361412	-.2450629
53	.003758	.0437289	0.932	-.0834139	.0909299
54	-.0123793	.041379	0.766	-.0948668	.0701082
55	-.1744594	.016658	0.000	-.2076665	-.1412524
56	-.0032712	.0498219	0.948	-.1025894	.096047
57	-.0414058	.0611431	0.500	-.1632924	.0804808
58	-.4557571	.0933944	0.000	-.6419355	-.2695788
59	-.3692735	.0302248	0.000	-.4295255	-.3090214
60	-.5317928	.0668756	0.000	-.6651069	-.3984787
61	-.3614066	.0337863	0.000	-.4287585	-.2940548
62	-.5612434	.0707923	0.000	-.7023652	-.4201217
63	-.5261221	.0661724	0.000	-.6580343	-.3942099
64	-.5351117	.0759369	0.000	-.6864892	-.3837342
65	-.2287097	.0017245	0.000	-.2321475	-.225272
66	.1508588	.0636026	0.020	.0240694	.2776483
67	.1079265	.0361047	0.004	.0359531	.1798998
68	.1529042	.0838417	0.072	-.0142312	.3200397
69	.0671297	.0119382	0.000	.0433313	.0909281
70	-.2034107	.0119421	0.000	-.2272169	-.1796045
71	.2169853	.0324078	0.000	.1523816	.281589
72	-.0065048	.0058082	0.266	-.0180832	.0050736
73	-.2898667	.0356066	0.000	-.3608471	-.2188862
No. of obs.	1190				
R^2	0.9784				
Root MSE	0.12954				

3.6.8 Unconstrained Regression of Data Subsets according to Data Quality

Tab. 3.16: Results of unconstrained estimation of equation (3.6) for the data subset ‘poor data’ controlling for intra-group correlation and including stock effects. The reference stock is Eastern Baltic Cod (stock id: 6).

Variable	Coef.	SE	$P > |t|$	95% Conf. Interval
$\log L_{t-1}$	.4023689	.0913958	0.001	.1987265 .6060114
$\log ADV_t$	.1993705	.0819901	0.035	.016685 .3820559

<i>c</i>	2.062875	.5183187	0.003	.9079894	3.217761
id					
23	-.5759747	.1670137	0.006	-.9481044	-.203845
27	.6963428	.1296742	0.000	.4074108	.9852749
43	-.2575779	.2079068	0.244	-.7208231	.2056673
46	-.8523259	.1331111	0.000	-1.148916	-.5557358
47	-.9052462	.2727175	0.008	-1.512899	-.2975937
48	-.8997285	.2161333	0.002	-1.381304	-.4181535
49	-.5194074	.1130019	0.001	-.7711913	-.2676235
50	-.6598144	.1645257	0.002	-1.0264	-.2932284
52	-.4585806	.0994886	0.001	-.6802551	-.2369062
58	-.857555	.2490907	0.006	-1.412564	-.3025464
No. of obs.	157				
R^2	0.9731				
Root MSE	0.12956				

Tab. 3.17: Results of unconstrained estimation of equation (3.6) for the data subset ‘good data’ controlling for intra-group correlation and including stock effects. The reference stock is Anchovy in Bay of Biscay (stock id: 1).

Variable	Coef.	SE	P>|t|	95% Conf. Interval
$\log L_{t-1}$	.4169367	.0793367	0.000	.2582931 .5755803
$\log ADV_t$	.374944	.0615399	0.000	.2518874 .4980006
<i>c</i>	1.127249	.2554543	0.000	.6164362 1.638061
id				
2	-.1282595	.032029	0.000	-.1923054 -.0642136
3	.1683752	.0674873	0.015	.0334261 .3033243
4	.1463628	.1015236	0.155	-.0566461 .3493717
5	.144289	.0075227	0.000	.1292464 .1593315
7	-.1261679	.0387341	0.002	-.2036216 -.0487142
8	-.2770458	.0163786	0.000	-.3097969 -.2442947
9	-.0859542	.0443534	0.057	-.1746443 .0027359
10	-.0808283	.0241307	0.001	-.1290805 -.032576
11	.0698859	.0866558	0.423	-.1033932 .2431649
12	.0307801	.025995	0.241	-.0212 .0827603
13	-.0352128	.0643617	0.586	-.163912 .0934864
14	-.2442586	.0237312	0.000	-.291712 -.1968052
15	-.1928973	.0158288	0.000	-.2245488 -.1612457
16	-.0697415	.0445126	0.122	-.15875 .019267
17	-.2282088	.0451395	0.000	-.3184708 -.1379468
18	-.1666652	.0379168	0.000	-.2424845 -.090846
19	-.2471008	.0108442	0.000	-.2687852 -.2254165
20	-.2522761	.0163935	0.000	-.2850569 -.2194952
21	-.0390569	.0508479	0.445	-.1407335 .0626198
22	-.133351	.0304431	0.000	-.1942256 -.0724763
24	-.3075522	.0531535	0.000	-.4138392 -.2012653
25	.1435423	.0561077	0.013	.031348 .2557366
26	.0417379	.0306212	0.178	-.019493 .1029688
28	.0528186	.036301	0.151	-.0197698 .125407

29	-.0125623	.0809679	0.877	-.1744676	.149343
30	-.223738	.0037691	0.000	-.2312748	-.2162012
31	-.2773045	.0095906	0.000	-.2964821	-.2581269
32	-.2719856	.0366489	0.000	-.3452696	-.1987016
33	.092925	.0924741	0.319	-.0919884	.2778384
34	-.1510194	.0161515	0.000	-.1833163	-.1187224
35	-.0828648	.0428952	0.058	-.1686391	.0029094
36	-.0502211	.0159979	0.003	-.082211	-.0182312
37	-.0948743	.0270571	0.001	-.1489783	-.0407702
38	-.1905035	.0148843	0.000	-.2202664	-.1607406
39	.0386927	.019013	0.046	.0006738	.0767116
40	-.0780975	.0615089	0.209	-.2010922	.0448973
41	.0919391	.0933386	0.329	-.0947029	.2785811
42	-.1102366	.0497797	0.031	-.2097772	-.010696
44	-.2477786	.0707401	0.001	-.3892322	-.106325
45	.1805251	.0472984	0.000	.085946	.2751042
51	-.0590991	.0394828	0.140	-.1380499	.0198517
53	-.0272605	.0485343	0.576	-.1243108	.0697898
54	-.0420001	.0459151	0.364	-.1338131	.0498129
55	-.1696667	.0191054	0.000	-.2078704	-.131463
56	-.0371746	.0553738	0.505	-.1479014	.0735522
57	-.0777263	.0683642	0.260	-.214429	.0589765
59	-.3499105	.0336775	0.000	-.4172529	-.2825682
60	-.4889672	.0745165	0.000	-.6379721	-.3399623
61	-.3416256	.0378021	0.000	-.4172155	-.2660356
62	-.5121751	.0786286	0.000	-.6694027	-.3549475
63	-.4832364	.073694	0.000	-.6305967	-.3358762
64	-.4873982	.0846854	0.000	-.6567371	-.3180593
65	-.2300386	.0019137	0.000	-.2338653	-.2262118
66	.1083091	.0707374	0.131	-.0331391	.2497572
67	.0909439	.0422706	0.035	.0064186	.1754692
68	.0987713	.0933872	0.294	-.0879679	.2855105
69	.0593051	.0137757	0.000	.0317589	.0868514
70	-.2091708	.0134772	0.000	-.2361202	-.1822214
71	.2314192	.0366895	0.000	.1580539	.3047845
72	-.0019831	.0064499	0.760	-.0148804	.0109142
73	-.2710973	.0400305	0.000	-.3511433	-.1910513
No. of obs.	1033				
R^2	0.9760				
Root MSE	0.12847				

3.6.9 Unconstrained Regression by Fishing Area

Tab. 3.18: Unconstrained estimation of equation (3.6) for the Baltic Sea. The reference stock is Western Baltic Cod (stock id: 5).

Variable	Coef.	SE	P>|t|	95% Conf. Interval	
$\log L_{t-1}$	.4556672	.1022309	0.001	.2329252	.6784092
$\log ADV_t$	.297289	.0961721	0.009	.087748	.50683
c	1.439412	.5401503	0.021	.262525	2.616298
id					
6	-.1037906	.0579208	0.098	-.2299892	.0224079
25	.0335665	.1019823	0.748	-.1886338	.2557668
26	-.0818915	.0501257	0.128	-.1911059	.0273229
27	.7688521	.0910694	0.000	.5704289	.9672752
28	-.0533451	.062021	0.407	-.1884772	.0817871
34	-.2875613	.0187439	0.000	-.3284006	-.2467219
46	-.8041434	.0957157	0.000	-1.01269	-.5955969
52	-.4334394	.0560413	0.000	-.5555429	-.3113359
64	-.6890351	.1880727	0.003	-1.09881	-.2792599
66	.0063071	.1314935	0.963	-.2801927	.2928068
67	-.0110918	.0518341	0.834	-.1240287	.101845
68	.0066551	.1757869	0.970	-.3763517	.3896619
No. of obs.	210				
R^2	0.9525				
Root MSE	0.1899				

Tab. 3.19: Unconstrained estimation of equation (3.6) for the North Sea. The reference stock is Cod in areas IIIa, IV, VIId (stock id: 7).

Variable	Coef.	SE	P>|t|	95% Conf. Interval	
$\log L_{t-1}$	.5295963	.0699665	0.000	.3848595	.6743332
$\log ADV_t$	.3244541	.0845533	0.001	.1495422	.499366
c	.6990396	.250393	0.010	.1810622	1.217017
id					
8	-.0956712	.035304	0.012	-.1687031	-.0226393
9	.0331497	.0044415	0.000	.0239618	.0423375
16	.0310569	.0273566	0.268	-.0255345	.0876484
17	-.0187352	.0724208	0.798	-.168549	.1310786
18	-.0497224	.0129844	0.001	-.0765828	-.0228621
19	-.0772883	.0469948	0.114	-.1745045	.0199279
29	.0597156	.031922	0.074	-.0063201	.1257513
37	.0352786	.016854	0.048	.0004134	.0701438
40	.0150908	.0172981	0.392	-.020693	.0508746
41	.1515642	.0419844	0.001	.0647128	.2384156
45	.3679534	.0439685	0.000	.2769977	.4589091
49	-.1075201	.0632732	0.103	-.2384108	.0233706
51	.0625525	.0039933	0.000	.0542918	.0708131
53	.0892406	.0087249	0.000	.0711918	.1072894
54	.0778144	.0068089	0.000	.0637292	.0918996
55	.0163003	.0433032	0.710	-.0732792	.1058798
57	.0028808	.0230746	0.902	-.0448526	.0506141
61	-.1387512	.0652053	0.044	-.2736387	-.0038637
62	-.2803435	.109934	0.018	-.5077593	-.0529276
65	-.072175	.0355118	0.054	-.1456367	.0012867
68	.1599758	.0426737	0.001	.0716985	.2482531
70	-.0675917	.0313636	0.042	-.1324723	-.0027112
71	.4390581	.0573965	0.000	.3203244	.5577917
No. of obs.	393				
R^2	0.9754				
Root MSE	0.1206				

Tab. 3.20: Unconstrained estimation of equation (3.6) for the Celtic Sea and West of Scotland. The reference stock is Cod in areas VIIe-k (stock id: 10).

Variable	Coef.	SE	P>|t|	95% Conf. Interval	
$\log L_{t-1}$	.3874752	.0650176	0.000	.2532854	.521665
$\log ADV_t$	.3927595	.1069183	0.001	.1720909	.6134281
c	1.095157	.2962246	0.001	.4837797	1.706535
id					
14	-.1667759	.0160073	0.000	-.1998133	-.1337384
15	-.1144322	.0290851	0.001	-.174461	-.0544035
20	-.1720569	.0174092	0.000	-.2079877	-.136126
23	-.1971853	.0352336	0.000	-.269904	-.1244667
24	-.2429808	.0465471	0.000	-.3390493	-.1469123
30	-.1420218	.0414645	0.002	-.2276002	-.0564433
31	-.1913679	.0472448	0.000	-.2888764	-.0938594
32	-.1984566	.0161557	0.000	-.2318003	-.1651129
36	.0311766	.0703997	0.662	-.1141213	.1764745
37	-.0062277	.074348	0.934	-.1596744	.147219
40	.0176501	.1185099	0.883	-.2269423	.2622425
41	.1940523	.1601874	0.238	-.1365583	.5246629
42	-.0392343	.0230811	0.102	-.0868713	.0084027
43	.0984953	.0618598	0.124	-.0291771	.2261676
47	-.3576445	.1095345	0.003	-.5837125	-.1315765
48	-.4219074	.0766799	0.000	-.5801668	-.2636479
50	-.3108067	.0329663	0.000	-.3788459	-.2427676
58	-.3334341	.0978162	0.002	-.5353169	-.1315513
60	-.4208411	.0589506	0.000	-.5425092	-.299173
63	-.4145361	.0592354	0.000	-.536792	-.2922802
68	.2003564	.1623812	0.229	-.134782	.5354948
69	.1390463	.0639936	0.040	.0069701	.2711226
72	.0808787	.0283145	0.009	.0224404	.139317
73	-.1986065	.0175434	0.000	-.2348142	-.1623988
No. of obs.	366				
R^2	0.9801				
Root MSE	0.1266				

Tab. 3.21: Unconstrained estimation of equation (3.6) for the Bay of Biscay and Atlantic Iberian Waters. The reference stock is Anchovy in Bay of Biscay (stock id: 1).

Variable	Coef.	SE	P>|t|	95% Conf. Interval	
$\log L_{t-1}$	.313134	.1171604	0.032	.0360937	.5901743
$\log ADV_t$	.232833	.0888848	0.034	.0226537	.4430122
c	2.167172	.5921628	0.008	.7669294	3.567414
id					
2	-.2582218	.0741306	0.010	-.4335128	-.0829308
37	.0146479	.0625506	0.822	-.1332607	.1625565
38	-.2557057	.0342182	0.000	-.336619	-.1747924
39	.1150747	.0398738	0.023	.0207883	.2093612
41	.4700056	.2158481	0.066	-.040394	.9804052
44	-.530585	.1625536	0.014	-.9149632	-.1462069
59	-.4867415	.077995	0.000	-.6711703	-.3023127
No. of obs.	136				
R^2	0.9724				
Root MSE	0.1259				

Tab. 3.22: Unconstrained estimation of equation (3.6) for the Non-EU waters (Barent Sea, Icelandic Sea, Norwegian Sea and East Greenland Sea). The reference stock is Capelin in Barent Sea (stock id: 3).

Variable	Coef.	SE	P>|t|	95% Conf. Interval	
$\log L_{t-1}$	.1287805	.0817207	0.141	-.0492736	.3068347
$\log ADV_t$	.7563169	.1230159	0.000	.4882883	1.024345
c	.6903693	.3755472	0.091	-.1278778	1.508617
id					
4	.0722063	.0318008	0.042	.0029182	.1414943
11	.0169507	.0328392	0.615	-.0545998	.0885012
12	.2097453	.1310206	0.135	-.075724	.4952146
13	-.0697877	.0417644	0.121	-.1607845	.021209
21	-.0637299	.0503154	0.229	-.1733578	.0458981
22	-.130812	.0692038	0.083	-.2815942	.0199702
33	-.004361	.0240922	0.859	-.0568533	.0481313
35	-.1061109	.0547475	0.076	-.2253954	.0131735
40	-.0944092	.0485018	0.075	-.2000856	.0112672
41	.0295882	.031435	0.365	-.0389027	.098079
56	-.0809037	.0424165	0.081	-.1733213	.011514
68	.0260891	.0291463	0.388	-.0374152	.0895934
No. of obs.	250				
R^2	0.9197				
Root MSE	0.1277				

4. REGIONAL TRADE-OFFS FROM MULTI-SPECIES MAXIMUM SUSTAINABLE YIELD (MMSY) MANAGEMENT OPTIONS

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Abstract. The maximum sustainable yield (MSY) is, theoretically, the largest yield that can be taken from a single species' stock over an indefinite period. Formulation of strategic MSY management goals is, however, complicated by the need to move beyond biological single-species considerations. Interactions among species necessitate multi-species (MMSY) definitions, incorporating ecological, economic and social considerations. We developed an ecological-economic model of the Baltic Sea, simulating stock dynamics of interacting populations of cod (*Gadus morhua*), herring (*Clupea harengus*) and sprat (*Sprattus sprattus*). We investigated a set of different strategic management options. These likely, yet non-formalized experiments evaluate and illuminate alternative regional trade-offs. We computed multi-species maximum economic yield (MMEY) under certain ecological constraints, with profits as

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a performance indicator. An unconstrained profit-maximizing management strategy would lead to a highly profitable cod fishery in a cod-dominated ecosystem. Concurrent sprat stock size (and profits) would be low, falling below ecological precautionary reference points. Consideration of ecological constraints on minimum stock sizes leaves a range of strategies, including the change from a cod-dominated to a more clupeid-dominated system. The regional distribution of profits depends on the management. Therefore, adjustment payments or other forms of compensation might be needed to achieve a concordant agreement on strategic multi-species management goals.

Keywords: equity; Baltic Sea; distribution; relative stability; profits; economic optimization; bio-economic model

JEL-Classification: Q22; Q57; D78

4.1 Introduction

Establishing successful and commonly accepted fisheries management rules is a key issue for the future sustainable use of the world ocean's living resources. Worldwide approximately 500 million people are directly dependent on fisheries for earning their livelihood (FAO, 2012). A growing world population in combination with an increasing population concentration at the coasts is likely to further exacerbate problems linked to poor management of marine resources. Regulations are missing or are limping behind; partly because basic ecological and economic conditions for the relevant fishery are not understood. Even in Europe, as a highly developed region, fisheries management is still mainly single-species management, based on natural sciences, but ignoring any species interactions or any social and economic considerations. Consequently, in its latest evaluation of the European Common Fisheries Policy (CFP) the Commission concluded that the CFP had failed and needed a substantial revision (European Commission, 2009b). In the 2009 Green Paper on the reform of the CFP the maximum sustainable yield (MSY) concept was included as a principle, accounting for the global imperative to manage fish stocks sustainably. Achieving this goal is complicated by the lack of a common interpretation of 'sustainability' and 'yield' and by the fact that achieving a theoretic long term 'maximized' yield for one stock may detrimentally affect other stocks and harm broader ecosystem, economic or social aspects. Especially in systems with strong predator-prey links, either top down or bottom up, management decisions taken for one stock will inevitably have influence on the other stock(s), too. Rebuilding stocks of large predators like cod might take its toll on future profits from the corresponding prey-fish fishery, as the prey stocks will be depleted by the abundant predator. Different interpretations or prioritizations of 'yield' will therefore result in different long-term management goals, e.g. steering a system towards maximum yield in terms of biomass (usually prioritizing forage fish) is adverse to maximum yield in terms of profit (usually prioritizing predatory large fish). Unconstrained optimization for any given target might result in unacceptable situations, harm legally binding ecosystem indicators, e.g.

the Good Environmental Status (GES) within the European Union’s Marine Strategy Framework Directive (MSFD), or stock levels falling below precautionary biomass levels. Therefore, the feasible ‘space of possible solutions’ might be narrower than originally perceived. However, even in a reduced decision space, decisions on trade-offs have to be explicitly made. Currently the reform of the CFP is under way, including a range of new management measures, more regional structures and a more participatory and open process. However, some principles still seem to be carved in stone. One principle which is not subject to the discussion is the ‘principle of relative stability’. According to this principle, the Baltic countries hold fixed shares of cod, herring and sprat quota. Therefore, the absolute catch amounts may differ between years depending on the stock status, but the percentage distribution of TACs to countries does not. In this paper we perform an exploration of opportunities for strategic management goals in a multi-species set-up and investigate their regional distributional effects. We use the example of the Baltic Sea to show that inflexibility in the distribution of catch shares to countries, as constrained by the principle of relative stability, can lead to regional inequity of the distribution of future profits. The central Baltic Sea fish community is dominated by three species only, namely cod (*Gadus morhua*), herring (*Clupea harengus*) and sprat (*Sprattus sprattus*). The fishery mainly consists of single-species fisheries. However, the fish stocks are closely connected by strong ecological interconnections between the species (Köster and Möllmann, 2000), as cod is preying on both herring and sprat (Lewy and Vinther, 2004). Thus, fluctuations in the size of the cod stock relate to considerable changes in natural mortality rates of sprat and juvenile herring. Under optimal management the cod fishery would be the most profitable fishery by far (Nieminen et al., 2012; Quaas et al., 2013). The combination of high fishing pressure and environment-driven low recruitment success led to a decrease of the cod spawning stock biomass (SSB) from almost 700,000 to 100,000 tons from 1983 to 1992, increasing shortly after, but reaching a record low level in 2005 (ICES, 2012). This strong decrease in the cod stock and a concurrent increase in the sprat stock resulted in a change from a cod-dominated system to a sprat-dominated system. In recent years the Eastern

Baltic cod has recovered, like a number of other North-east Atlantic stocks (Fernandes and Cook, 2013), to a SSB $> 200,000$ tons in 2011 (ICES, 2012).

The recovery is due to a combination of improved recruitment and better management, i.e. agreement by all relevant stakeholders on a cod long-term management plan in 2006 (European Council, 2007). The cod long-term management plan aimed at rebuilding the full reproductive capacity of the stock and resulted in a better compliance and substantially reduced fishing mortality ($F = 0.3$). A major difference to the previous management strategy is that inter-annual changes in the TAC, both in terms of reductions and increases, are limited to a maximum of 15%.

In June 2011, the Commission and member states agreed that the Baltic cod plan should be replaced by a Baltic multi-species management plan which would take account of major species interactions. The Baltic Regional Advisory Council (RAC) also expressed support for such an approach. Accordingly, a number of expert groups were initiated, dealing e.g. with defining the methods of multi-species stock assessment (see Rindorf et al. (2013) for overview). The scientific basis is formed by earlier multi-species works (Gislason, 1999) showing that single- and multi-species reference points are different, and that it is impossible to define a ‘safe’ level of biomass without taking changes in species interaction into account. Including first-order interactions is needed for medium-term management purposes (Collie and Gislason, 2001). In the case of the Baltic Sea this addresses predation mortality induced by the cod stock. Socio-economic considerations are often not part of the terms of reference, but are treated in sub-sequent analysis. We believe that this needs to be changed, as useful management targets can only be achieved including more detailed socio-economic analysis of the involved fisheries (Gislason, 1999).

Using 2006 as our base year (i.e. the year of adoption of the cod management plan), we undertake model experiments to investigate four hypothetical long-term management goals and their outcome in terms of ecology (stock sizes), economy (total profits) and social aspects (regional distribution of profits): (1) an unconstrained economic optimization (maximizing profits) of the three-species system, (2) optimization of the present value of the cod fish-

ery’s present value, while respecting a precautionary biomass level of sprat, (3) optimization of the sprat fishery, while paying regard to a precautionary biomass level of cod, and (4) a simulation of the current cod management plan. We show that a change back to a cod-dominated system is economically highly profitable on aggregate, but not all countries would actually benefit from this change in an equal way. Therefore, compensation might be needed to avoid inequity.

We developed and applied a combined three-species, age-structured ecological-economic model, which takes cod predation on two clupeid species into account. We used four scenarios (table 4.1) to investigate the distribution of country-specific future profits.

4.2 Material and Methods

4.2.1 Ecological-Economic Modeling

Our model is an extension of the single-species age-structured fishery model of Tahvonen (2009) and Tahvonen et al. (2013), similar in scope to that of Nieminen et al. (2012).

Scenario	Objective
1	Unconstrained economic optimization
2	Optimization for profits from cod fishery, while respecting a precautionary SSB (B_{pa}) of 570,000 tons of sprat (ICES, 2013)
3	Optimization for profits from sprat fishery, while respecting a cod B_{pa} of 88,000 tons (ICES, 2013)
4	Simulation of the agreed long-term management plan for cod and subsequent optimization for clupeids

Tab. 4.1: Management scenarios 1 to 4, using different sets of input or optimized fishing mortalities (F). SSB = spawning stock biomass.

We use the subscript $i \in \{C, S, H\}$ for the cod (C), sprat (S), and herring

(*H*) fisheries. The fishing profit for the cod fishery in year t is:

$$\pi_C = \sum_{s=1}^8 p_C(s)w_C(s)(1 - \exp(-F_C(t)))q_C(s)x_C(s,t) - c_C F_C(t). \quad (4.1)$$

Here we use $x_C(s,t)$ to denote stock numbers of age s in year t , $p_C(s)$ for age-specific prices, $w_C(s)$ for age-specific weights, and $q_C(s)$ for age-specific relative catchabilities. Instantaneous fishing mortality is $F_C(t)$, and the cost function is of the Spence type (Spence, 1974), where c_C is a cost parameter (as in Quaas et al. (2012)). Sprat and herring, $i = \{S, H\}$, are modeled as schooling fisheries (Tahvonen et al., 2013), with profits:

$$\pi_i = (p_i - c_i) \sum_{s=1}^8 w_i(s)(1 - \exp(-F_i(t)))q_i(s)x_i(s,t) \quad (4.2)$$

where p_i is the market price (which is assumed to be independent of age) and c_i is the constant marginal cost of harvest. For each fishery $i = \{C, S, H\}$ we consider a representative fisherman's intertemporal utility from fishing income,

$$V_i = \sum_{t=0}^{\infty} \rho^t \frac{\pi_i^{1-\eta}}{1-\eta} \quad (4.3)$$

where ρ is the discount factor and η is the representative fisherman's aversion against inter-annual income fluctuations. The higher η is, the more a constant income stream over time is preferred. Such a desire for relative constancy is reflected in several management plans for European fish stocks (e.g. Baltic cod; European Council (2007)), which have been agreed upon by a broad range of stakeholders, including fishermen. It is expressed, for example, as a requirement that TACs shall not change by more than a certain percentage between two subsequent years (15% in the case of Baltic cod). The objective is to maximize a weighted sum of the intertemporal utilities ($E(t)$) of the representative fishermen of all three fisheries:

$$\max_{E_C(t), E_S(t), E_H(t)} \{\lambda_C V_C + \lambda_S V_S + \lambda_H V_H\}. \quad (4.4)$$

This model set-up allows changing the weights $\lambda_i > 0$ to model different strategic management goals or constraints. In the case of unconstrained economic optimization we take $\lambda_C = \lambda_H = \lambda_S = 1$, which means that all three fisheries have equal weight in the management optimization. Fishing mortalities may not be negative, i.e. $F_i(t) \geq 0$ in all cases. The age-structured multi-species population dynamics are described as follows. SSB of species i in year t is given by:

$$ssb_i(t) = \sum_{s=1}^8 w_i(s)\gamma_i(s)x_i(s, t) \quad (4.5)$$

where $\gamma_i(s)$ is used to denote age-specific maturities. Population dynamics of the stock of species i are given by

$$x_i(s = 1, t + 1) = \varphi_i ssb_i(t) \exp(-\beta_i ssb_i(t)) \quad (4.6)$$

$$x_i(s, t + 1) = \alpha_i(s - 1)(1 - q_i(s)(1 - \exp(-F_i(t))))x_i(s - 1, t) \quad (4.7)$$

for $s = 2, \dots, 7$

$$x_i(s = 8, t + 1) = \alpha_i(7)(1 - q_i(s)(1 - \exp(-F_i(t))))x_i(7, t) \\ + \alpha_i(8)(1 - q_i(8)(1 - \exp(-F_i(t))))x_i(8, t). \quad (4.8)$$

This formulation implies that fishing and natural mortality are sequential, and was chosen as it is standard in resource dynamics literature (Tahvonen, 2009). Changing the model to address fishing and natural mortality as competitive causes of death would slightly affect cost and catch, but not population dynamics. For cod and herring we assume stock-recruitment functions of the Ricker type (Ricker, 1954), for sprat we assume a Beverton-Holt type (Beverton and Holt, 1957). Age-specific survival rates are

$$\alpha_C(s) = \exp(-M_C(s)) \quad \text{for cod} \quad (4.9)$$

$$\alpha_S(s, t) = \exp(-M_{S1}(s) - M_{S2}(s)ssb_C) \quad \text{for sprat} \quad (4.10)$$

$$\alpha_H(s, t) = \exp(-M_{H1}(s) - M_{H2}(s)ssb_C) \quad \text{for herring} \quad (4.11)$$

which are constant for cod. Residual (M_{i1}) and predation (M_{i2}) mortal-

ity estimates for the different age classes of herring and sprat are based on regression analysis, using stochastic multi-species (SMS) (Lewy and Vinther, 2004) output on mortality for different stock sizes of cod. Predation mortality is almost linearly dependent on the cod stock biomass for a wide range of stock states (Tahvonen et al., 2013). This shortcut in calculation of M_{i2} values was used to reduce model complexity and implies a dependency of predation mortality on both, predator and prey abundance.

4.2.2 Data and Estimation of Model Parameters

Age-specific weights $w_i(s)$ and maturities $\gamma_i(s)$ are taken from the ICES (2012) assessment reports for the three stocks, using the mean values from 2002 to 2006. Age-specific catchabilities were estimated based on mean age-specific fishing mortalities for the years 2002 to 2006 as reported in ICES (2012) with $q_A = 1$ for the age class with highest mortality by normalization. In case of reaching $q_A = 1$ for an age class < 8 , it was kept constant for the older age classes, as it is meant to reflect mesh-size selection (table 4.2).

Age class	Numbers 2006 (millions)			Maturity			Weight (g)			Catchability		
	C	H	S	C	H	S	C	H	S	C	H	S
1	196.555	11597	60816	0	0	0.17	80	11	52	0	0.28	0.27
2	131.041	5123	23884	0.13	0.7	0.93	179	20	84	0.11	0.44	0.49
3	122.411	5519	60692	0.36	0.9	1	511	25	96	0.42	0.66	0.79
4	52.298	5919	19240	0.83	1	1	838	31	105	0.81	0.82	0.85
5	15.187	1713	3179	0.94	1	1	1204	37	111	1	0.97	1
6	3.546	1105	1519	0.96	1	1	1796	43	113	1	0.96	1
7	0.714	830	1510	0.96	1	1	2596	48	111	1	1	1
8	0.383	789	1959	0.98	1	1	4068	53	113	1	1	1

Tab. 4.2: Cod (C), Herring (H), Sprat (S). Parameters used in the economic-ecologic model. Values for maturity, weight and catchability are taken from (ICES, 2012) standard assessment, using mean values 2002 to 2006; numbers at age (corrected for spawning time) are taken from (ICES, 2012) for 2006.

Natural mortalities for the herring and sprat age classes are calculated dependent on the size of the cod stock. Estimates are based on a stochastic

multi-species model (Lewy and Vinther (2004)) and reported in table 4.3.

Age class	Mortality 'no interaction'			Residual Mortality M1			Predation Mortality (M2)		
	C	H	S	C	H	S	C	H	S
1	0	0.2	0.2	0	0.1702	0.1318	-	3.324×10^{-4}	8.740×10^{-4}
2	0.2	0.2	0.2	0.2	0.1728	0.1367	-	2.312×10^{-4}	7.076×10^{-4}
3	0.2	0.2	0.2	0.2	0.1778	0.1318	-	0.448×10^{-4}	6.737×10^{-4}
4	0.2	0.2	0.2	0.2	0.1878	0.1318	-	0.448×10^{-4}	6.737×10^{-4}
5	0.2	0.2	0.2	0.2	0.1878	0.1318	-	0.448×10^{-4}	6.737×10^{-4}
6	0.2	0.2	0.2	0.2	0.1878	0.1318	-	0.448×10^{-4}	6.737×10^{-4}
7	0.2	0.2	0.2	0.2	0.1878	0.1318	-	0.448×10^{-4}	6.737×10^{-4}
8	0.2	0.2	0.2	0.2	0.1878	0.1318	-	0.448×10^{-4}	6.737×10^{-4}

Tab. 4.3: Cod (*C*), Herring (*H*), Sprat (*S*). Natural mortality estimates used in the ecological-economic modeling. Residual and predation mortality estimates in the multi-species (interaction) case are based on regression analysis, using stochastic multi-species (SMS) output on mortality for different stock sizes of cod.

The parameters for the stock-recruitment functions are given in table 4.4.

	ψ_i	β_i
Cod (Ricker)	1.7	0.00182
Herring (Ricker)	30.33	0.000469
Sprat (Beverton-Holt)	104.2	0.5032

Tab. 4.4: Parameters of the stock-recruitment functions, obtained by either fitting a model to data from 1974 to 2011 as provided by ICES (2012) for herring, or functions by Quaas et al. (2012) for cod and Tahvonen et al. (2013) for sprat. Functions noted in parentheses.

For cod we use age-specific European reference prices, which are the lowest prices at which imports of cod of specific weight classes, sprat or herring into the European Union are allowed (European Council, 1999; European Commission, 2009a), table 4.5.

Age class	1	2	3	4	5	6	7	8
Price €/kg	0	0.35	0.35	0.35	0.477	0.477	0.636	0.731

Tab. 4.5: Age-specific European reference prices for cod (European Council, 1999; European Commission, 2009a).

The cost parameter for cod is $c_C = 55.2$ million € (Quaas et al., 2012). To estimate prices and cost parameters for sprat, we use price data and data on variable fishing cost for the Swedish (years 2002 to 2008) and Polish (years 2005 to 2008) pelagic trawler and seiner fleets from STECF (2011), which leads to $p_S = 0.144 \frac{\text{€}}{\text{kg}}$ for the price and $c_S = 0.106 \frac{\text{€}}{\text{kg}}$ for the cost parameter. Similarly, for herring, we use STECF (2011) data for the Danish, Estonian, Finnish, Polish and Swedish trawl and seiner fleets (years 2002 to 2008), which saves estimates $p_H = 0.251 \frac{\text{€}}{\text{kg}}$ for the price and $c_H = 0.151 \frac{\text{€}}{\text{kg}}$ for the cost parameter. For the representative fisherman’s aversion against inter-annual income fluctuations we assume $\eta = 0.25$. The discount rate is set at 0% and 5%, respectively.

4.2.3 Numerical Optimization

To determine the optimal management, while paying regard to any given constraints in the management scenarios, we solved the optimization problem numerically. For this, the dynamic optimization was performed using the interior-point algorithm of the Knitro (version 8.1) optimization software with Matlab (R2012b), and AMPL.

4.2.4 Transition Dynamics

The transition path (i.e. short-term effects) towards the long-term management goal might be crucial for acceptance. Even if the long-term goal is accepted, the transition dynamics (e.g. fishing restrictions) might confront the fisheries with severe problems due to anticipated short-term income losses. In addition to the long-term steady state, we investigate the short-term (2006 to 2012) transition dynamics under each scenario. Yearly fishery-specific and total profits are calculated.

4.2.5 Regional Distribution of Profits

The distributional effects of the four management scenarios were calculated by simulating the interacting stock dynamics, associated species-specific catch and cost data and finally country-specific future profits. Country-specific quota allocation followed the relative stability principle. Overall annual profits were calculated as the sum of profits of all three fisheries. To illustrate the long-term distributional effect we chose the reference year 2030, i.e. we chose a year after initial transition dynamics would have stabilized.

4.3 Results

4.3.1 Stock Development Scenarios

Historic stock development shows a switch from a system dominated by cod in the early 1980s to a clupeid-dominated system beginning in the early 1990s (Möllmann et al. (2009) ; fig. 4.1 a). Up to the year 2006 no signs of a cod recovery could be observed.

In scenario 1, we applied an unconstrained economic optimization of the multi-species fishery (fig. 4.1 b). This resulted in a fast rebuilding of the cod stock to ca. 700,000 tons of SSB. The herring stock increases in parallel to > 1 million tons of SSB, while the sprat stock is reduced to 212,000 tons of SSB, due to the strong predatory impact of the large cod stock. The level of sprat SSB is well below the recently defined precautionary biomass limit for impaired recruitment (570,000 tons; ICES (2013)).

In scenario 2, the precautionary biomass level for sprat (B_{pa}) was used as a constraint. Keeping a minimum of 570,000 tons of sprat SSB reduces the optimal cod SSB to 329,000 tons. Optimal herring stock size reached almost 1.4 million tons (fig. 4.1 c). Optimal fishing mortality is considerably higher for all three species than in scenario 1 (table 4.6).

Setting a precautionary cod SSB (cod B_{pa}) of 88,000 tons (ICES, 2013) as constraint, while otherwise optimizing profits from the clupeid fishery (scenario 3), increasingly emphasizes the role of herring and sprat (fig. 4.1 d). The precautionary stock size of cod could be maintained at fishing mortality

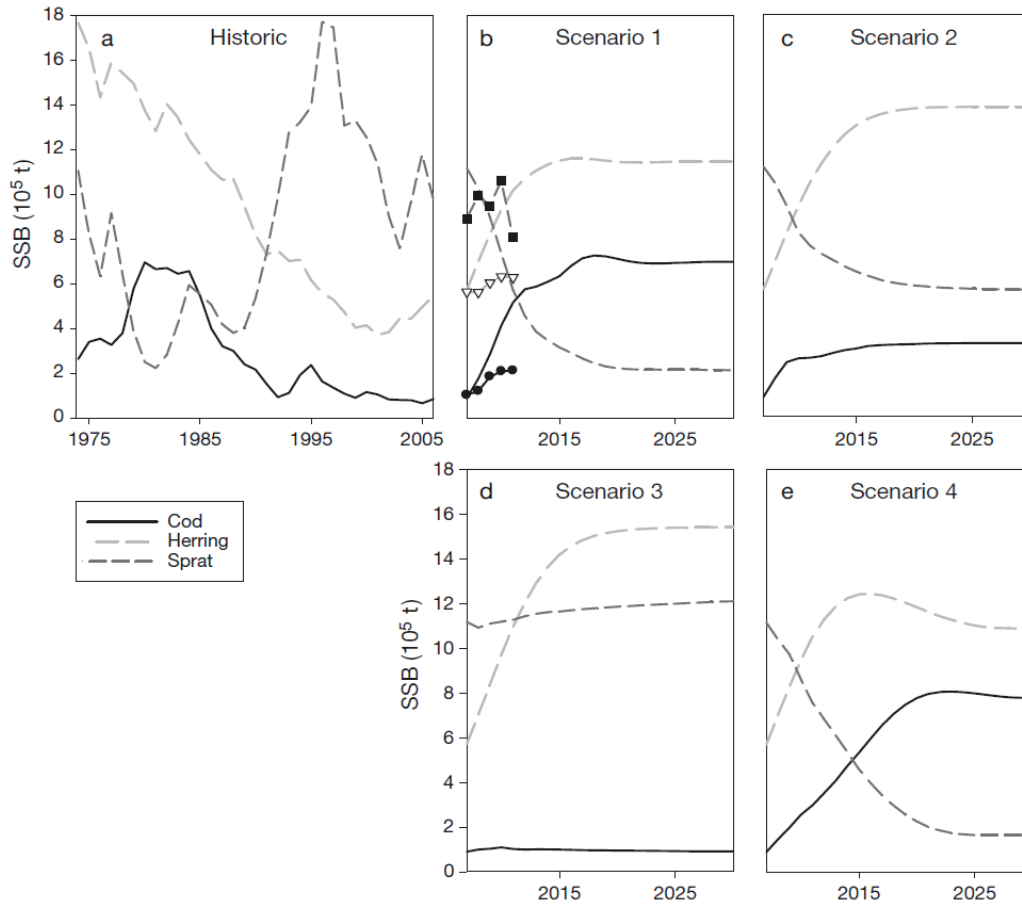


Fig. 4.1: Stock development of Baltic cod, herring and sprat: historic stock trends and management scenarios (table 4.1). Panel (b) includes the actual stock development from 2006 to 2011 under the cod management plan (lines with symbols).

as high as $F = 0.9$; the cod fishery, however, would be unprofitable (table 4.6). SSB of herring and sprat peak at 1.5 million tons and 1.2 million tons, respectively. This illustrates the broad range of strategic management options, while still accounting for ecological constraints.

The equilibrium stock sizes when simulating the cod management plan (scenario 4) resemble the solution for the economically optimal solution (fig. 4.1 e). The cod stock increases slightly with corresponding smaller clupeid stock sizes as a result of intensified cod predation (table 4.6). The target fishing mortality under the cod management plan ($F = 0.3$) is slightly lower

	Scenario	1	2	3	4
Profit	Cod	97.5 (96.3)	43.8 (27)	0 (0)	99.8 (99.8)
	Herring	17.7 (17.1)	26.1 (26.9)	32.4 (31.5)	15.7 (15.3)
	Sprat	2.6 (2.9)	8.2 (9.6)	15.4 (15)	1.8 (1.8)
	Sum	117.8 (116.3)	78.1 (63.5)	47.8 (46.5)	117.3 (116.9)
SSB	Cod	698 (689)	329 (264)	89 (89)	777 (777)
	Herring	1146 (878)	1386 (1164)	1540 (1280)	1088 (805)
	Sprat	212 (195)	568 (565)	1209 (965)	164 (130)
F	Cod	0.35 (0.36)	0.67 (0.76)	0.9 (0.9)	0.3 (0.3)
	Herring	0.18 (0.23)	0.23 (0.29)	0.26 (0.31)	0.17 (0.23)
	Sprat	0.45 (0.58)	0.59 (0.74)	0.49 (0.66)	0.4 (0.51)

Tab. 4.6: Projected profits (million €/year), spawning stock biomass (SSB; '000 tons), and fishing mortality F for the year 2030, for the four selected long-term management goals (scenarios 1 to 4, table 4.1). Values refer to 0% (5%) interest rate.

than the steady-state fishing mortality under economically optimal management ($F = 0.35$).

The combined profits from all three fisheries are by far the highest if the cod stock is rebuilt (table 4.6; scenarios 1 and 4). The economically optimal management is only slightly better in terms of combined profits as compared to the simulated cod management plan. (The difference in present value terms is a bit larger because of the faster transition to the optimal steady state under optimal management.) According to our model, the cod fishery would not be profitable (zero profits) in scenario 3, i.e. if the fishing mortality of cod is not reduced considerably below the 2002 to 2006 level ($F_{2002-2006} = 0.93$). A reduced cod stock would, however, result in higher profits for the herring and, especially, sprat fishery.

Setting the interest rate to 5% instead of 0% as in our reference case reduces steady-state biomasses as well as profits by maximal values of 24% (biomass) and 19% (profits). Fishing mortality is generally slightly higher. The results are, however, not qualitatively changed.

4.3.2 Transition Dynamics

According to the economically optimal management (scenario 1), the cod fishery would have been closed for almost three years ($F = 0.04$ in third year). Afterwards a gradual increase to the steady-state value of $F = 0.35$, with a concurrent strong increase in profits, would have been allowed (see fig. 4.2). Cod stock rebuilding under the cod management plan (scenario 4) takes a few years longer, as fishing is kept up at the reduced rate of $F = 0.3$. Scenarios 2 and 3 allow for continued cod fishing at moderate (scenario 2: sprat B_{pa}) or high levels (scenario 3: cod B_{pa}). In scenario 3 the cod fishery stays, however, unprofitable. Due to the bad stock status and the unprofitability of the cod fishery in 2006, all scenarios offer monotonically increasing total profits, even when the cod fishery is closed in the beginning.

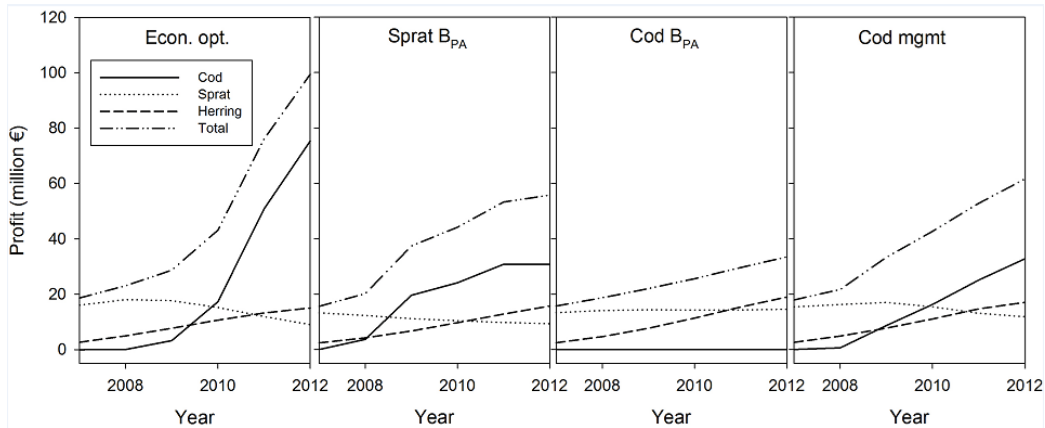


Fig. 4.2: Transition dynamics: path of fishery-specific as well as total profits (used as a performance indicator) from 2006 to 2012 for the four management scenarios: (1) unconstrained economic optimization, (2) optimization for profits of the cod fishery, while respecting a precautionary sprat SSB (sprat B_{pa}) of 570,000 tons, (3) optimization for profits of the sprat fishery, while respecting a precautionary cod SSB (cod B_{pa}) of 88,000 tons, (4) simulation of the cod management plan.

4.3.3 Regional Distribution of Profits

In 2006, the regional distribution of profits mirrored the country-specific catch shares of herring and sprat, as the cod fishery was unprofitable, due to the severely overfished state of the cod stock in that year. The highest profits were gained in Poland and Sweden (fig. 4.3 a). Under economically optimal management (scenario 1) all countries would benefit (fig. 4.3 b, Appendix 4.7). However, the amount of increase in benefits is very different regionally. Countries in the East, with a small share of the cod quota, e.g. Finland and Estonia, only gain little, while countries in the West, e.g. Denmark and Germany, realize the highest relative increases in profits. Currently quotas cannot be traded internationally. If such an international quota trade was introduced, these results would remain the same, as the market value of quotas corresponds to the (potential) profits that can be gained in the respective fishery.

The scenarios 2 and 3 respect ecological precautionary points and can be seen to set the boundaries of feasible management options (fig. 4.3 c,d). Within these constraints most countries realize the highest profits under the sprat B_{pa} scenario (scenario 2); some other countries, however, would benefit more from a cod B_{pa} scenario (scenario 3) (i.e. Estonia and Finland). The different management options do not only cause an uneven regional profit increase, but they also imply social consequences within a certain country, as a re-distribution of profits between the different fisheries occurs (Appendix 4.7), e.g. scenario 1 (economically optimal management) and 4 (cod management plan) create high total profits, the sprat fishery, however, loses substantially.

4.4 Discussion

We have shown that, in a multi-species set-up, different strategic management goals will result in regionally unequal distribution of future profits. Rebuilding a large predator (cod) stock will penalize countries holding a larger share of forage fish fishing rights. Unconstrained economic optimization would lead to a sprat stock size below commonly accepted ecological

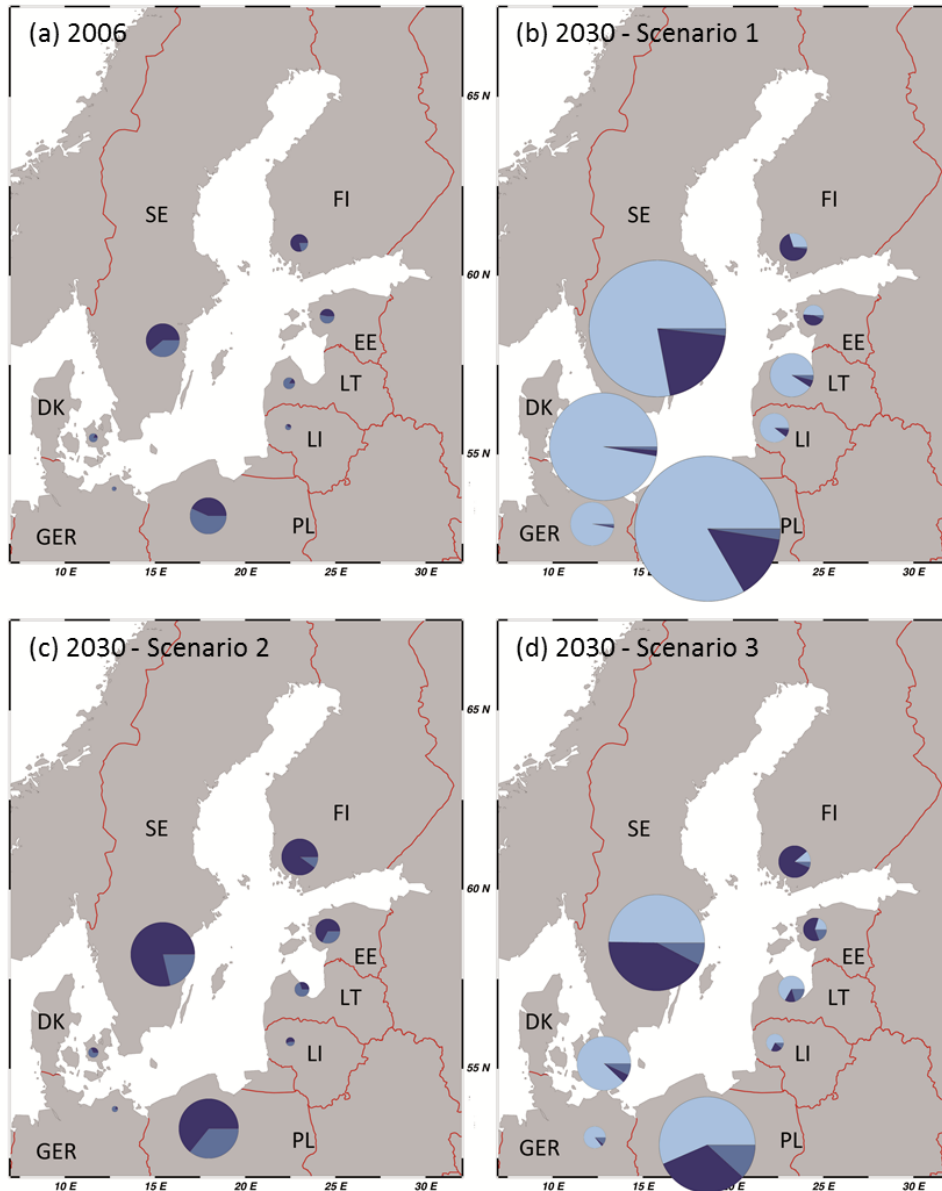


Fig. 4.3: Regional, country-specific distribution of profits from the cod (light shading), herring (dark shading) and sprat (medium shading) fishery; top left: situation at the beginning; remaining panels: distribution of the profits in the year 2030 according to scenarios. Actual values are given in Appendix 4.7.

reference levels. Even when paying regards to precautionary stock size limits, there are many strategic management goals from which to choose. The inflexible system of distribution of catches according to the principle of relative stability in combination with species interaction might require new measures of compensation, to secure future acceptance and compliance by all states – no matter which strategic goal is chosen.

According to the relative stability principle, the Baltic countries hold fixed shares of cod, herring and sprat quota. Therefore, the absolute catch amounts may differ between years depending on the stock status, but not the percentage distribution of TACs to countries. All Baltic countries are involved in all three fisheries, however, with highly variable distributional shares to species. Poland holds the largest share of the cod (26.5%) as well as the sprat quota (29.4%). Sweden owns the largest share of the herring quota (33.4%). The sum of allowable catches over all three species in 2006 (the start of our simulation) differed between $\sim 164,000$ tons (Poland) and $\sim 27,000$ tons (Lithuania). The composition of each country's catch portfolio should determine its interest in (or opposition to) the future multi-species management goals, in particular to change from a clupeid-dominated system back to a cod-dominated system (Möllmann et al., 2009).

Stock assessment in the Baltic Sea is regularly performed by the Baltic Fisheries Assessment Working Group. Its work is currently somewhere between single-species and multi-species assessment, as natural mortality of the clupeid stocks is calculated depending on the size of the cod stock, but the group does not explicitly provide multi-species advice (ICES, 2012). In early 2013, a real multi-species assessment was provided for the first time by the Benchmark Workshop on Baltic Multi-species Assessment (WKBALT) (ICES, 2013), highlighting the ecological management trade-off. Species interaction, i.e. cod predation on clupeid species, is generally of high importance in stock forecast scenarios (Kellner et al., 2011). In such an environment, single-species projections (e.g. Froese and Proelß (2010)) might be too optimistic, or even misleading. Even in the multi-species literature, economic aspects of management, especially regional distribution of profits, are rarely considered and were not explicitly addressed in the work of WKBALT, as

they were not part of the terms of reference. As shown here, such economic considerations might be as critical as ecological constraints, as they will ultimately have influence on agreements and compliance to future management decisions.

Stock rebuilding plans can produce trade-offs due to species interactions (Gröger et al., 2007), which have to be communicated to stakeholders. Standard management trade-offs include trade-offs between harvest and spawner abundance (Collie et al., 2012), stock biomass and net financial returns (Little et al., 2011), or species conservation and size of marine protected areas (McClanahan, 2011). From a more integrated point of view, trade-offs between restoration goals might be of interest (North et al., 2010), with the aim to predict benefits and quantify the associated costs. One of the few existing studies that take into account the economic impact of species interaction is on Pacific sardine *Sardinops sagax* (Chen et al., 2009). Contrary to our study, Chen et al. (2009) do not use an age-structured framework, and therefore their results cannot directly be translated to ICES stock assessment. In the Baltic Sea, management that prioritizes profits will result in relative winners (cod fishery) but also relative losers (sprat fishery). The system's dynamics are mainly driven by the cod stock: The range of optimal fishing mortality F for herring, sprat and cod is relatively narrow between scenarios (herring: 0.17 to 0.26; sprat: 0.4 to 0.59), but for cod optimal F ranges from 0.3 to 0.9 in steady state. In the model, the economically profitable cod stock is rapidly built up to a SSB of $\sim 700,000$ tons. In reality, stock rebuilding is largely dependent on recruitment success. Under unfavorable environmental conditions stock rebuilding might take longer. A high cod stock causes increased predation on sprat and herring, thus leaving less scope for improved catches from the clupeid fisheries. Cod stock recovery in the optimization model is faster than has been observed in reality after adoption of the management plan, i.e. from 2006 to 2011. This is due to a sharp reduction in catches from the cod fishery for three years in the economically optimal solution, which was not conducted in reality. Instead, the management plan aims at smoothing variations by including maximum year-to-year variations of 15% (European Council, 2007). The steady state biomass of cod is lower in the

economically optimal solution than in the simulation of the cod management plan. Accordingly, a consequent realization of the long-term management plan for cod might lead to sprat stock sizes falling below ecological reference points, and might therefore need to be revised under a multi-species- or even ecosystem-based (Pikitch et al., 2004) management.

Our model framework has room for improvements, in particular regarding environmental influences on recruitment (Köster et al., 2009), density-dependent growth (Casini et al., 2011; Gårdmark et al., 2013) and processes accounting for changes in the spatio-temporal overlap of cod and sprat (Eero et al., 2012). Nevertheless, we are confident in the range of simulated outcomes. Although future developments will most certainly increase the quantitative precision of simulations, the qualitative implications for management will likely remain robust. The Baltic Sea represents a suitable case study for demonstrating the principles of trade-off evaluation in multi-species fisheries. We are confident that our approach is readily transferable to more complex systems, since reliable coupled ecological-economic models are increasingly becoming available.

Including ecosystem considerations other than commercially exploited species and quantifying the potential economic impacts might require valuing of e.g. endangered species (Wallmo and Lew, 2011). Taking all ecosystem and economic feedbacks into account, might also reveal unforeseen trade-offs and externalities, like in the case of French Guiana, where the (economically sub-optimal) oversized trawl fishery for shrimps positively impacts the endangered Frigate birds *Fregata* spp. (Martinet and Blanchard, 2009). In the case of the Baltic Sea, we envisage a broadening of the scope to future work to an ecosystem level. This can be achieved by coupling to ecosystem models, in the sense of ensemble modeling as recently advocated by the Working Group on Integrated Assessments in the Baltic (Gårdmark et al., 2013).

Successful management in the future will require stakeholders to explicitly define commonly accepted fishery objectives against which trade-offs can be evaluated (Pilling et al., 2008). If quotas for the three species are not equally distributed among countries (like in the Baltic), new compensation schemes may be required to find international agreements – ultimately the principle

of relative stability might need to be abandoned. Additional pressure to revise the relative stability principle might also arise from the interaction of economic dynamics of fishing fleets and the European Community's legal framework, e.g. the right of establishment or free movement of workers (Morin, 2000).

When performing model runs over periods of decades, it might become important to include climate change aspects, as reproductive success of all species has been shown to strongly depend on environmental conditions (cod: Köster et al. (2005), herring: Cardinale et al. (2009), sprat: Voss et al. (2006)). Our model framework offers the possibility to simulate climate change scenarios for the most important environmental factors, and significantly different results may be obtained when comparing climate change to non-climate change scenarios (Voss et al., 2011). Besides the modeling of biological interaction and variability in physical forcing factors, assumptions on economic variables like cost functions, interest rates and prize elasticity also have a strong impact on the results (Voss et al., 2011; Tahvonen et al., 2013). Therefore, our data emphasize the need to proceed to interdisciplinary multi-species management.

4.5 Appendix

4.5.1 Country- and Fishery-specific Profits

Tab. 4.7: Country- and fishery specific profits (million €/year) in the year 2006 (base year) as well as in year 2030 for the four selected long term management goals. Values refer to 0% interest rate. FI = Finland, SE = Sweden, DK = Denmark, GER = Germany, PL = Poland, EE = Estonia, LT = Latvia, LI = Lithuania.

Scenario		FI	SE	DK	GER	PL	EE	LT	LI
2006	Cod	0	0	0	0	0	0	0	0
	Herring	2.9	4.4	0.3	0.1	3.3	1.5	0.4	0.4
	Sprat	0.8	2.8	1.5	0.9	4.3	1.7	2	0.7
	Total	3.7	7.2	1.7	1	7.6	3.2	2.4	1.1
1	Cod	1.7	22.7	22.4	8.9	25.8	2.2	8.3	5.5
	Herring	3.9	5.9	0.4	0.1	4.4	2	0.5	0.5
	Sprat	0.1	0.5	0.3	0.2	0.8	0.3	0.4	0.1
	Total	5.7	29.1	23	9.2	31	4.5	9.2	6.1
	Change	1.5	4	13.5	9.2	4.1	1.4	3.8	5.6
2	Cod	0.8	10.2	10.1	4	11.6	1	3.7	2.5
	Herring	5.7	8.7	0.6	0.2	6.5	2.9	0.7	0.8
	Sprat	0.4	1.6	0.8	0.5	2.4	0.9	1.1	0.4
	Total	6.9	20.5	11.4	4.7	20.5	4.9	5.6	3.6
	Change	1.9	2.8	6.7	4.7	2.7	1.5	2.3	3.3
3	Cod	0	0	0	0	0	0	0	0
	Herring	7.1	10.8	0.7	0.2	8.1	3.6	0.9	0.9
	Sprat	0.8	2.9	1.5	1	4.5	1.8	2.1	0.8
	Total	7.9	13.8	2.2	1.1	12.6	5.4	3	1.7
	Change	2.1	1.9	1.3	1.1	1.7	1.7	1.3	1.5
4	Cod	1.7	23.2	22.9	9.1	26.4	2.2	8.5	5.6
	Herring	3.4	5.3	0.3	0.1	3.9	1.8	0.4	0.5
	Sprat	0.1	0.4	0.2	0.1	0.5	0.2	0.3	0.1
	Total	5.3	28.8	23.5	9.3	30.9	4.2	9.2	6.2
	Change	1.4	4	13.8	9.3	4.1	1.3	3.8	5.6

5. INPUT-EFFICIENCY OF FISHING COD IN THE BALTIC SEA – COMPARING MAJOR EU TRAWLER FLEETS

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Abstract.

Total allowable catches are distributed between countries according to the principle of relative stability. Each country then allocates quotas to its vessels. The trade of these quotas between vessels of different countries is currently not allowed. However, if fleet segments of one country are more efficient than fleet segments of other countries due to location advantages or better fleet management it could be beneficial to allow the transfer of quotas on vessel level. This paper examines whether international quota trade between vessels could improve the overall efficiency of a fleet. The distance function approach is used to derive an equation to estimate the efficiencies of different segments of the Baltic demersal trawlers and seiners fleet. The

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analysis reveals significant asymmetries in the efficiencies of fleet segments between countries. The asymmetry is bigger for small vessels because they are not as mobile and depend heavily on the circumstances surrounding them including the fishing ground quality. Bigger vessels are more mobile and tend to concentrate their fishing activity in similar areas (most productive fishing grounds). Therefore, differences in efficiencies do not mainly result from the choice of fishing ground but rather from differences in the national fleet management and the current state of the fleet segment. The asymmetries in efficiencies combined with evaluated location advantages set incentives for international quota trade. The introduction of such a system could improve overall efficiency of the Baltic fleet.

Keywords: Baltic Cod (*Gadhus morhua*); Baltic Sea; European Union fishing fleets; input-efficiency

JEL-Classification: Q22

5.1 Introduction

The concept of the European Union is an integrated Europe with common laws and regulations. This is in particular applicable to common pool resources such as fisheries. In case of fish stocks which inhabit and migrate between Exclusive Economic Zones (EEZ) of multiple countries, common regulations allow management based on cooperative decisions instead of a regular ‘race-to-fish’ situation. In this way, more effective management safeguarding the stocks’ good biological state can be implemented. However, there are downsides of common regulations giving equal rights to all countries using the common pool resource. This is due to asymmetries between the countries that translate into direct advantages in resource extraction that cannot be utilized. These include development and restructuring of the fleets over past years resulting in current states that vary, and spatial relation to the most productive fishing grounds.

The paper compares the efficiency of major Baltic Sea demersal trawling fleet segments of Denmark, Germany, Poland and Sweden. The focus of this article is on the Eastern (ICES zones IIID: 25 to 32) and Western (ICES zones IIID: 22 to 24) Baltic cod stocks, shared by all aforementioned countries.⁵ It is preliminary research regarding the potential flow of individual cod quotas between countries in case the quota market would be open for free trade. Currently international trade is only available at the national level and contributes to the final Total Allowable Catch (TAC) amount. The national TAC is then distributed between individual vessels according to local regulations, in case of cod mostly in form of individual quotas.

Each vessel given a Baltic cod quota is permitted to harvest it with no restrictions regarding location, in particular it is allowed to fish in all Baltic Sea EEZs (except the 12 nautical miles coastal zone, unless otherwise individually agreed).⁶ Thus, the best fishing grounds are shared by all member countries with limits only with respect to landings amount. In such a sit-

⁵ However, as the sector is characterized by multi-product production, it is accounted for the harvest of other species.

⁶ With the exception of certain grounds during the spawning season, applicable to all Baltic Sea fleets.

uation, the harvest of a given quota is conducted mostly in the same areas as long as it is found profitable.^{7,8} However, each vessel is harvesting the quota with its own individual efficiency that is expected to vary between vessels. Those asymmetries could contribute to increased efficiency in the case of more flexibility in quota flow.⁹ The efficiency depends also on the decision regarding location choice implying specific distance from the country of origin. Thus, it is expected that some countries may enjoy the advantage of being situated closer to the most productive fishing ground and benefit from this fact when considering the trade-off between better catch per unit of effort and the distance to the specific area. This research is a starting point for efficiency comparison and looks into differences between aggregated fleet segments. Proven differences between segments indicate significant asymmetries and imply that detailed analysis on individual vessel level would result in the possibility to derive an optimal allocation of quotas in the region.

The paper is structured as follows. The introduction is followed by the presentation of the case where the current situation of the Baltic cod demersal trawler fleets is explained in the context of restructuring processes and regulations in place. The section also explains the importance of cod in the region giving arguments for validity of this study. The article proceeds with the methodology used to evaluate the asymmetries between investigated fleets, presents data and reveals the results. The model outputs are evaluated from three different perspectives, that is as a comparison of on-site efficiency, efficiency changes over time and efficiency in context of distance to the fishing grounds. The article concludes with remarks regarding differences in efficiency of harvesting cod in the Baltic Sea by the major fleets involved in this fishery and possible reasons behind it.

⁷ Small vessels have less mobility and smaller fishing grounds range. Thus, they often stay in the closer proximity of the home ports.

⁸ This includes subsidies.

⁹ Increased efficiency within the same gear and length category is expected to be directly translating into lower fuel use implying lower environmental impact and potentially lower costs. However, the possibility to lower the costs highly depends on cost differences. The cost efficiency is a closely related topic that is possible to evaluate with techniques similar to those presented later in this paper. However due to data limitations, the topic is not further investigated.

5.2 The Case Background

5.2.1 The Importance of the Baltic Cod

The Baltic cod (*Gadus morhua*) is an important species in the Baltic Sea: it plays an essential ecological role in the ecosystem and it is the commercially most valuable fish species in the Baltic Sea (ICES 2013). Thus, the cod stock variations impact both humans through the productivity of the stock utilized by commercial and recreational fishing, and environment through overall fish productivity and food web dynamics.

In the Baltic Sea, cod has traditionally been divided into two stocks: the Eastern stock east of Bornholm island and the Western stock from west of Bornholm to the Sound and Danish Belts (Bagge et al., 1994). The Eastern and Western stocks differ in morphometric characteristics and genetics (Bagge et al., 1994; Hüseyin et al., 1997; Nielsen et al., 2003). Thus, they are assessed and managed separately. The Eastern stock is larger in size and distribution, and contributes more to the total EU harvest (ICES 2013). The two stocks overlap near Bornholm where some mixing occurs (ICES 2013). The spawning grounds, where cod migrates after maturation, are located in the deeper basins of the Baltic Sea (Köster et al., 2001).

Due to its semi-enclosed nature, the Baltic Sea ecosystem is heavily influenced by environmental conditions. Variations in temperature, salinity, oxygen and nutrient levels make the Baltic Sea fisheries management difficult as sustainable exploitation levels vary in response to environmental conditions (FAO, 2011). Particularly cod has been affected by ecological stress.

The Eastern cod stock has adapted to the low salinity of the sea by producing eggs that are buoyant at the halocline and therefore its reproductive success depends on environmental variables, namely suitable hydrographic conditions in the spawning areas (Wieland et al., 1994; Nissling and Westin, 1997; MacKenzie et al., 2000; Köster et al., 2005). Salinity and oxygen concentration in the Baltic Sea are fluctuating with irregular salt- and oxygen-rich water inflows from the North Sea (Matthäus and Franck, 1992). Anoxic conditions and low salinity adversely affect fertilization and cause se-

vere mortality to the cod eggs in the deep-water layers (Wieland et al., 1994; MacKenzie et al., 2000). Unfavorable hydrographic conditions also decrease the final survival rate by prey limitation for the larvae and juvenile stages (Hüssy et al., 1997; Hinrichsen et al., 2002; Köster et al., 2005), enhanced cannibalism (Sparholt, 1994; Neuenfeldt and Köster, 2000) and vertical overlap between the eggs and clupeids (herring and sprat), the main predators (Köster and Möllmann, 2000; Köster et al., 2005).

Changes in recruitment conditions together with anthropogenic factors have caused the Eastern cod stock to fluctuate significantly over the past decades (fig. 5.1). The cod stock increased to outstanding levels in the late 1970s when the fishing pressure was relatively low and hydrological conditions advantageous for reproduction (ICES, 2013; Eero et al., 2011). The stock reached its peak in the 1980s (ICES, 2013; Eero et al., 2011), which was attributed to the high frequency of inflows from the North Sea resulting in good recruitment years. The rapid decline of the population began in the mid 1980s. The salinity and oxygen conditions for recruitment deteriorated and fishing effort remained high, partly due to improvements in harvest technology (ICES, 2013; MacKenzie et al., 2002; Eero et al., 2011). Degraded environmental conditions made the cod stock more vulnerable to fishing, and vice versa (Köster et al., 2005). The decline continued and the stock decreased to extremely low levels in the beginning of the 1990s. The major reasons were continuing fishing pressure, lack of major inflows from the North Sea, eutrophication (hypoxia) and increasing seal predation (ICES, 2013; Eero et al., 2011). A major water inflow in 2003 substantially influenced the volume of water suitable for cod recruitment, resulting in a slight increase in stock size since 2005 (ICES, 2013). However, the recent cod stock trend is still under study.

The Western cod stock fluctuations (fig. 5.1), reported by (ICES, 2013), show similarities with the Eastern stock. The Western stock was at high levels in the early 1980s from when it started to decline to the lowest recorded levels in early 1990s. Only the mid 1990s brought slight improvement and partial recovery. The high fishing effort has been in decline from year 2000, and recently recorded levels are below targets set by the management plan.

Although the Western stock biomass has been increasing since the early 2000s, the recruitment has been close to the lowest recorded levels, with no noticeable fluctuations in recruitment success. The recent abundance of the adult Western stock is likely caused by spill-over effects from the Eastern stock which is expanding its distribution.

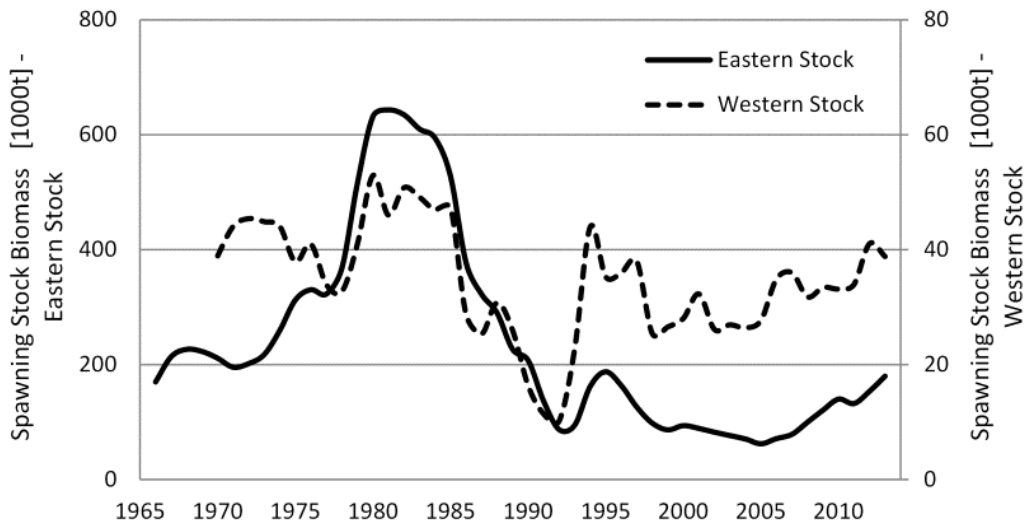


Fig. 5.1: Fluctuation of Spawning Stock Biomass (SSB) of the Baltic cod: Eastern Stock (1966 to 2013) and Western Stock (197 to 2013) (ICES, 2013).

Cod has an important ecological role as a top predator balancing the food web (Casini et al., 2008), and thus maintaining the ecosystem functionality. The Baltic food web is relatively simple and the fish community is dominated by three species: cod, sprat and herring. During the last decades, major fluctuations in the cod abundance have been part of the large-scale Baltic Sea ecosystem changes related to climate, fisheries and eutrophication (Österblom et al., 2007; Casini et al., 2008; Möllmann et al., 2009). The major period of ecological stress and anthropogenic impacts such as overfishing of cod (1987 to 1993) pushed the biotic part of the central Baltic Sea into an altered state of reduced cod productivity. This, in turn, impacted the whole ecosystem due to the role of cod as the main predator of sprat and herring (Österblom et al., 2007; Casini et al., 2008; Möllmann et al., 2009). As the

cod stock decreased, sprat stocks increased its abundance due to reduced predation supported by favorable environmental conditions at the time; a shift from a cod-dominated to a sprat-dominated regime took place. Then, the predator-prey feedback loop stabilized the system, as a high sprat stock formed an increased predation pressure on cod eggs and juveniles (Möllmann and Köster, 1999; Köster and Möllmann, 2000; Österblom et al., 2007). A trophic cascade took place as the shift from cod to clupeids occurred in combination with climate-driven changes in zooplankton composition and altered regulation of phytoplankton (Möllmann and Köster, 1999; Österblom et al., 2007; Casini et al., 2008). Changes in zooplankton composition influenced prey availability for both cod and sprat, and promoted algal blooms on the Baltic Sea (Möllmann and Köster, 1999; Österblom et al., 2007; Casini et al., 2008). Economically, the shift from a cod-dominated to a clupeid-dominated state in the late 1980s decreased the value of the catch due to the relative composition of the fish species. It has been estimated that increasing the cod stock and reducing sprat abundance would be economically more profitable than the clupeid-dominated state (Döring and Egelkraut, 2008; Nieminen et al., 2012; Waldo et al., 2013). The future major threats to cod stock sustainability and reproduction potential include pollution and climate change (MacKenzie et al., 2007; Niiranen et al., 2013; Lindegren et al., 2010).

The Western stock is mainly fished by Denmark, Germany and Sweden, whereas the Eastern stock is fished by Denmark, Sweden and Poland (ICES, 2013). The profitability depends on the gear segment, as well as the vulnerability to the condition of the main target species (Blenckner et al., 2011). The secondary economic and social impacts include employment, retail, jobs and income at the dockyards, and work for local craftsmen (Blenckner et al., 2011). In many Baltic countries, fishermen have long fishing traditions and few job alternatives, so management actions are constructed to avoid the loss of jobs (Blenckner et al., 2011).

The latest Annual Economic Report of the EU Fishing Fleet reports the 2012 value of landings generated by the EU Baltic Sea fleet in the amount of approximately 237 million €, of which Poland (56 million €), Sweden (51 million €), and Denmark (43 million €) collectively accounted for around

60%.¹⁰ Cod generated the highest value of landings (77 million €) followed by herring (63 million €) and sprat (45 million €), although the total volume of cod accounted for only 62,000 tons (compared to 220,000 tons of herring and 177,000 tons of sprat). The total volume landed in 2012 was 510,000 tons (2% decrease from 2011) (STECF, 2013).

The above-described complex links between different parts of the ecosystem show the value of cod to the Baltic Sea. It is an economically valuable fish and it contributes to the Baltic Sea ecosystem functioning. Cod forms a link between the social and ecological systems of the Baltic region both through ecosystem services and anthropogenic stressors.

5.2.2 *European Fisheries Management of the Baltic Cod*

In order to coordinate the interests of countries participating in the Baltic fisheries the International Baltic Sea Fisheries Commission (IBSFC) was established in 1973 as a result of the Gdansk Convention on Fishing and Conservation of the Living Resources in the Baltic Sea and the Belts in 1973 (Gdansk Convention, 1973). The signing countries were Denmark, Germany, Sweden, Finland, Poland and Russia, Estonia, Lithuania and Latvia as part of the USSR. The IBSFC was dissolved in 2005 when all countries except Russia had successively joined the European Union. From then on the management of the Baltic fishery has fallen under the Common Fisheries Policy (CFP) of the European Union for all member states. In 2006 the European Union called for a bilateral agreement concerning fishing activities with Russia (European Commission, 2006) which came into force in 2009 (European Council, 2009). Prior to this, there have been bilateral agreements between Russia and the individual member states (Churchill and Owen, 2010).

By the equal access principle defined in 1970 (European Economic Union (1970), modified in European Council (2002)) all European Union member states have the same right to fish in all Community waters, including all shared EEZs, except for the 12nm zone. Those terms are then manifested in bilateral agreements between member countries. In this setting all Baltic

¹⁰ Estonia is excluded from the analysis due to failed performance data for 2011. Total landings weight excludes the German pelagic trawler segment.

countries are able to choose the most profitable fishing grounds. Fig. 5.2 shows that for the Baltic cod stock these fishing grounds are located in the South of the Baltic leading to a high concentration of fishing activity in that area (maps for the demersal trawlers and seiners sector; 8m to 40m length, averages over 2004 to 2012).

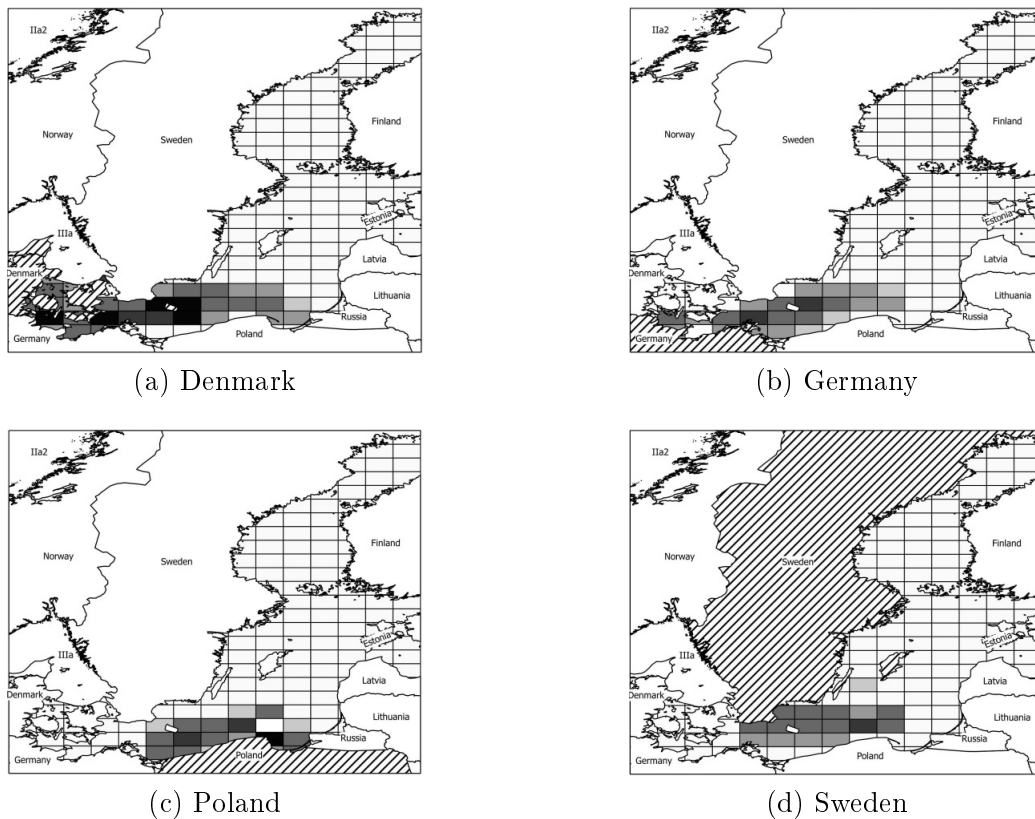


Fig. 5.2: Distribution of cod harvest by demersal trawlers and seiners sector (8m to 40m length) from Denmark, Germany, Poland, and Sweden (averages from 2004 to 2012).

The IBSFC and the CFP base their management decisions on the scientific input of the International Council for the Exploration of the Sea (ICES) and the Scientific, Technical and Economic Council of Fisheries (STECF) of the European Union. Since 2006, stakeholders are actively involved in the decision-making by the Regional Advisory Council for the Baltic Sea (European Council, 2004). In order to take the interests of individual states more

into account, the CFP encourages the cooperation of member countries with respect to fisheries management on a regional level (European Union, 2013).

The main instrument in fisheries management used by the IBSFC and the CFP is the TAC, which defines the amount of fish that is allowed to be caught from a specific stock in a year. TACs are usually set on an annual basis. The allocation of TACs between countries is based on the principle of relative stability which states that each country receives a fixed share of the TAC (European Council, 2002; Churchill and Owen, 2010). For defining those shares three criteria are taken into account: (i) historical catch records, (ii) specific needs of areas particularly dependent on fishing and its dependent industries (Resolutions of The Hague) and (iii) the loss of fishing potential in the waters of third countries (European Council, 1983, 2002; Churchill and Owen, 2010).¹¹ The TACs can be exchanged between member states (EC 2371/2002), but only on national level. Since 1976 the ICES has given recommendations for Baltic cod TACs. These have been exceeded regularly by the TACs set by the IBSFC (Radtke, 2003). From 1982 to 1988 the IBSFC was even unable to set any TACs such that in this period the conditions resembled an open access fishery (Kronbak, 2005).¹² From 1989 on, catches exceeded TACs to a lesser extent. However, substantial illegal, unregulated and unreported (IUU) fishing was a problem in the Baltic cod fishery until 2007 (OCEANA, 2012). From 1993 to 1996 and from 2000 to 2007, the level of unreported landings has been between 35% and 40% (ICES, 2013). Poland was to a large extent responsible for that fact which led to a penalty by the European Union for the Polish cod fishery (ORCA-EU, 2009). As a consequence, the effort in monitoring and controlling has been increased. In recent years the level of misreporting has decreased to 6% to 7%. However, the problem of IUU remains (OCEANA, 2012). Since 2004 there is a separate assessment including separate TACs for the Eastern and the Western cod stock (ICES, 2013). Additional management instruments are technical specifications regarding effort and gear regulations (i.e. mesh size, minimum

¹¹ With (i) and (ii) being in particular relevant for the Baltic Sea.

¹² Some technical measures were present, e.g. regulations regarding mesh size, minimum landing size, closed season.

landing size, type of nets, size of vessel, days at sea) (Churchill and Owen, 2010). Such specifications for the fisheries in the Baltic Sea are given in EC Regulation 2187/2005 (European Council, 2005).

As a reaction to the poor state of the Baltic cod stock in the beginning of the 1990s the IBSFC put a lot of effort into the recovery of the stocks in addition to the TAC management. A new tool was the seasonal fishing ban from June to August introduced in 1995 (European Council, 1994) which has been modified to a minimum duration of two months in 2007 (Kraus et al., 2009). In 1997 a marine protected area (MPA) to protect spawning fish stocks has been implemented east of Bornholm (Suuronen et al., 2010). This MPA has been increased several times and now covers most of Bornholm Deep. On top of this, in 2005 MPAs in the Gdansk Deep and in the Gotland Basin were implemented. There have also been a number of long term initiatives to support the recovery of the cod stock. In 1999 the IBSFC implemented a long-term strategy for the Eastern and the Western cod stocks in the Baltic Sea which had the aims to maintain a minimum spawning stock biomass (SSB) (greater than 160,000 tons for the Eastern and greater than 9,000 tons for the Western stock) and to implement a long-term management plan with TACs reflecting a precautionary fishing mortality rate (Aps and Lassen, 2010). In 2001, a Recovery Plan for the Eastern Baltic cod was adopted, calling for a management that would reduce the fishing mortality rate. This plan also included area closures and seasonal fishing bans. However, the success of these initiatives was limited because of too high TACs, lacking control and unwillingness of the IBSFC members (Aps and Lassen, 2010). Since 2005 each vessel greater than 8m fishing for cod has had to hold a special fishing permit for cod (European Council, 2005). The cod permit is given if the vessel has been active in cod fishing the previous year and new vessels can only get a cod permit if another vessel with the same capacity is going to be inactive in exchange. In addition, special permits are necessary for fishing in the Gulf of Riga (European Council, 2005). In 2007 the European Union implemented a multi-annual recovery plan for both cod stocks (European Council, 2007). The goals of this plan are the recovery of the stocks (in terms of biomass) and a reduction of the fishing mortality rate

by the implementation of a sustainable fishery based on maximum sustainable yield (MSY) criteria (target fishing mortality rate is 0.6 and 0.3 for the Western and the Eastern Baltic cod stock respectively; European Council (2007)). The instruments used are limited variation of the TAC (maximum 15% deviation from the previous year's TAC) and a 10% reduction in days at seas as long as the fishing mortality rate is above the target value. Further limitations are the prohibition of drift-nets in the cod fishery and exclusion of vessels below 8m. The plan also includes the temporary closure of fishing areas (mainly Bornholm deep) and seasonal bans (West of Bornholm 1st to 30th April, East of Bornholm 1st to 31st August). Currently both Baltic cod stocks are managed according to these plans and they are considered to be quite successful (Bastardie et al., 2010).

The guidelines regarding fisheries of the IBSFC and the CFP respectively apply to all member countries in the same way. However, there are some differences in the national allocation mechanisms of TACs. The main approach of the member states is an individual quota (IQ) system (Blenckner et al., 2011) where a governmental institution allocates shares of the TAC (quota) to either fishermen or vessels. In the following section the focus is on the national fisheries management of the major trawling fleets for the Baltic cod, including Denmark, Germany, Poland and Sweden (ICES, 2013).

5.2.3 *National Management of the Baltic Cod*

Denmark introduced a vessel quota share (VQS) system for demersal species, including cod, in 2007. The system allows trading of quotas on national markets. VQS are given and bound to vessels with more than 30,000 € gross earnings per year. The actual quota share is based on the landings of the reference period 2003 to 2005. Initially, the VQS could only be transferred with the vessel, but that regulation was abolished in 2009 (Andersen, 2012). VQS vessels can join the coastal fleet if they are less than 17m and at least 80% of their fishing trips are less than three days long (Andersen et al., 2010). Then, they have to stay in the coastal fleet for at least three years (Bonzon et al., 2013). Coastal vessels can buy quota from vessels larger than 17m

but not the other way round. Small-scale fisheries vessels (less than 30,000 € gross earning per year) are managed by a ration system with a fixed share of the national quota of 10% (Bonzon et al., 2010). In so called fish pools (voluntary cooperatives) fishermen can swap and lease VQS between vessels. Inactive vessels can lease their shares within these pools for the current year (Andersen, 2012). Highgrading is not allowed. The Danish system allows fleet adaptation by VQS transfers even on a daily basis.

Germany, Poland and Sweden use an individual vessel quota (IVQ) system where the quotas are non-tradable. In Sweden IVQs are given to vessels greater than 8m holding a special permit to fish for cod (Swedish Agency for Marine and Water Management, personal communication with Hannes Rasper). The cod permit is given to fishermen who have been active in cod fishery during 2005 to 2007. The cod permit allows for fishing in ICES zones 22 to 24 (25 to 28) for 147 (146) days and maximum 147 days in ICES zones 22 to 28. The quota share depends on the length and gross tonnage of the fishing vessel. However, currently the quota shares for Swedish vessels are unlimited, because it is not anticipated that the national TAC is going to be fully fished.

In Germany IVQs are allocated to the vessel owner. A license for fishing is only given to vessels that were active already in the fishing season 1986/1987 (German Federal Ministry of Justice, 1984). IVQs are allocated based on previous year's quota. In addition, the relevant vessel has to be active for the past three years; otherwise it is not entitled to its IVQs (German Federal Ministry of Justice, 2014). For the Baltic cod stock, individual licenses assign a specific amount of fish to each participating vessel depending on its historic catch.

In Poland the quota allocation between vessels with cod harvest permit (as in 2005) is based on vessel length (Polish Ministry of Agriculture and Rural Development, 2008). Until 2008, IVQs were given to vessels greater or equal to 10m, whereas units between 8m and 10m were subject to block quota. Vessels below 8m, according to special European Union exemption, were allowed unlimited harvest (Polish Ministry of Agriculture and Rural Development, 2008). Starting with 2009, the group of vessels between 8m

and 10m joined the IVQ regulated fleet, whereas units below 8m became subject to block quotas (Polish Ministry of Agriculture and Rural Development, 2011). The IVQs are not transferable. Additionally, from 2009 to 2011 the Polish fleet was subject to a temporarily imposed regulation allowing only about one third of the vessels with cod harvest permits to receive quotas. The special three year management plan was a result of overfishing the TAC in 2007, which resulted in this penalty imposed by the European Union. Each year's group of vessels was selected according to the lottery with the possibility to win only once (Polish Ministry of Agriculture and Rural Development, 2008). In order to reduce the overcapacity in the Baltic fleet, a new fleet policy was introduced after the reform of the CFP in 2002 (European Council, 2002). This issue is examined in more detail in the following section.

5.2.4 Overcapitalization Tendencies and Reasons Behind

The past regulations regarding Baltic cod resulted in increasing capacity. Fleet capacity consists of the number, size and type of the vessel and gear, technical efficiency of the vessel for finding, handling and storing the fish on-board, the potential fishing time of each vessel, which is dependent on the distance to the fishing grounds, and the fishers' ability to catch fish (Smith and Hanna, 1990). The fleet becomes overcapitalized if the number of vessels or capacity in a fleet exceeds the use potential of the fish stock (Blenckner et al., 2011). Overcapacity does not only have an adverse impact on the fish stocks but it also affects negatively the economic outcome of fishermen, thus it is important to balance the fishing effort and the existing resource in order for the fishery to be economically and biologically sustainable in the long-term.

In the Baltic cod fishery the main reason for the overcapitalization is the past management system that gave fishermen incentives to invest in larger vessels and new technologies. The European Union introduced subsidies in the 1970s in order to help the economic situation of the fishing companies and to keep fish prices at a consumer-friendly level (Kirkley and Squires, 1999; Blenckner et al., 2011). Subsidies reduce the costs of fishing and there-

fore encourage investments that would not occur without subsidies (Arnason et al., 2009). Once the fleets were highly capitalized, TACs were intentionally set higher than the scientific recommendation due to the political pressure by fishing industries that were troubled by overcapacity (Aps and Lassen, 2010). The decision-makers wanted to guarantee the social and economic welfare and keep the fishermen employed, but the management was driven by short-term perspective with conventional discounting which practically ignored the longer-run conservation goals (Edwards et al., 2004; Sumaila and Walters, 2005; Aps and Lassen, 2010). The decision-makers believed the socio-economic benefits were so high compared to the risk of negative effects on stocks that they justified exceeding the quotas (Aps et al., 2007). On top of this, due to technological progress, even stricter capacity reductions were needed to ensure sustainable harvest (European Commission, 2008).

Since the revision of the CFP in 2002 the member states are responsible for keeping a balance between their fishing capacity and the existing fish stocks. This continues in the most recent revision of the CFP that came into force in 2014. The members are obligated to keep their capacity (both in tonnage and power) under the fixed maximum levels, whereas failing to achieve the targeted reduction may result in suspension of the financial support from the European Maritime and Fisheries Fund.¹³ The latest analysis shows that all member states achieved the initial goal with the help of the long-term management plan introduced in 2007 by the European Union, which included effort limitations in addition to quotas. Failing to achieve the balance requires construction of an additional action plan including adjustment targets and tools for retrieving the balance (European Commission, 2014). The most commonly used tool for capacity reduction has been vessel scrapping financed by the European Fisheries Fund.¹⁴ Between 2007 to 2013 the fund allocated 1.3 billion € for permanent or temporary cessation in order to reduce the fishing capacity in European waters (European Commission, 2013). Danish fishing fleet was reduced between 2000 and 2009 by 12% with

¹³ This is the fund for the European Union's maritime and fisheries policies from 2014 to 2020 (European Union, 2014).

¹⁴ This has been the fund for the European Union's fisheries policies from 2007 to 2013 (European Council, 2006).

the use of scrapping programs. Additional 24% reduction was attributed to the ITQ system applied in 2007. Reduction programs between 2004 and 2008 succeeded in decreasing the Polish fishery by 45% in tonnage. Sweden implemented two national scrapping campaigns in 2008 and 2009 aimed at demersal cod trawlers, which contributed to a 26% reduction in tonnage (European Commission, 2013). Germany’s fleet has been reduced in number due to the European Union scrapping program by 33% between 1995 and 2010 (European Commission, 2013). However, a major problem has been encountered throughout the adopted programs, e.g. a lack of clear rules regarding what happens to the fishing rights after the scrapping. Overall, some progress towards increasing balance between the fishing capacity and the fish stocks can be noticed (European Commission, 2014). The regulations aiming at harvest control and capacity reduction had an important influence on the transitions of the fleet targeting cod over past years, including the major cod fleet, namely the demersal trawlers and seiners.

5.2.5 Demersal Trawlers and Seiners Sector

The demersal trawlers and seiners sector (DTS) accounts for the majority of the cod catches in the four Baltic Sea national fleets assessed in this study (table 5.1). Additionally, there has been a growing trend over the years strengthening its importance in the region.

Country	2008	2009	2010	2011	2012
Denmark	62.0	65.8	67.3	67.3	69.2
Germany	83.8	91.2	88.5	89.3	89.3
Poland	51.9	49.2	51.7	64.8	64.5
Sweden	60.7	67.1	76.3	79.7	80.9

Tab. 5.1: Demersal trawlers’ and seiners’ share of the live weight of the total national cod catches (%) (STECF, 2013).

The DTS sector accounted for the majority of the income in the Baltic Sea region in 2011 (101 million €), and the sector’s economic performance in the longer vessel groups (12m to 18m, 18m to 24m, and 24m to 40m) have been

improving. However, the smaller vessels are still facing problems to generate economically positive returns in the fishery. A key factor influencing profits has been the increased productivity of the fleets, whereas rising fuel prices are slowing down the development (STECF, 2013). The number of vessels is the highest in the length group 12m to 18 m, while the length category 24m to 40m accounts for the biggest share of the catch. The Danish fleet is the biggest within the sector. However, not all the Danish vessels, nor the German ones, harvest only in the Baltic Sea; a large share is operating also in the North Sea and North Atlantic. The second biggest fleet within the sector is owned by Sweden (STECF, 2013). The capacity in number of vessels has been showing mostly a negative trend in the DTS sector (table 5.2). The number of Danish demersal vessels was decreasing over past years while the sector was increasing its profits. This confirms that although the capacity decreased, the remaining vessels have sufficient technology to obtain higher catches, and thus, attain higher profits. Also, the German fleet capacity has been decreasing. In Poland, the excess capacity has been reduced especially among the bigger vessels. In 2012, a part of the Polish demersal fleet returned to the fishery after a three-year temporary suspension of cod fishing rights from 2009 to 2011, which shows in the number of smaller vessels. In Sweden the capacity in vessel number has been decreasing in all but smaller vessels (STECF, 2013).

The potential overcapacity of the DTS sector is assessed by comparing vessel utilization ratios provided by STECF (2014) (table 5.3). This technical indicator illustrates a ratio of the average fishing time spent at sea to the maximum fishing time at sea in each fleet segment.¹⁵ A value below 0.7 indicates under-utilization of the fleet which may be caused by a structural overcapacity. The values between 0.7 and 1 indicate that the fleet may be considered in balance with the available resource. The values suggest that the majority of the DTS sector struggles with overcapacity. The optimal situation is observed only among bigger vessels, over 18m, in Germany and Denmark, and among vessels over 24m in Sweden. A recent positive trend is

¹⁵ Here 240 days, used to reflect the average working days in most economic sectors (365 days less weekends and holidays). The ratio includes potential fishing in other waters.

	Length	2004	2005	2006	2007	2008	2009	2010	2011	2012
Denmark	0-10m	37	34	12	12	12	10	12	14	-
	10-12m	-	-	-	-	10	13	8	8	-
	12-18m	317	286	271	217	184	177	168	156	-
	18-24m	-	-	-	-	79	77	68	70	-
	24-40m	-	-	-	-	51	46	42	39	-
Germany	0-10m	21	14	14	14	2	2	1	1	-
	10-12m	-	-	-	-	14	13	15	15	10
	12-18m	75	76	77	78	41	39	37	33	27
	18-24m	-	-	-	-	31	28	30	29	20
	24-40m	24	27	26	26	12	17	16	13	10
Poland	0-10m	13	-	-	-	-	5	3	1	1
	10-12m	-	-	-	-	-	7	12	15	15
	12-18m	141	124	91	93	59	45	46	55	58
	18-24m	-	-	-	-	34	22	20	16	34
	24-40m	74	48	44	32	25	10	10	4	5
Sweden	0-10m	64	65	71	63	10	9	15	21	22
	10-12m	-	-	-	-	50	53	48	48	49
	12-18m	160	149	158	160	105	100	89	80	74
	18-24m	-	-	-	-	55	58	49	43	46
	24-40m	30	30	27	33	32	31	31	31	28

Tab. 5.2: Trends in the DTS sector fishing capacity (2004 to 2012) (number of vessels) (STECF, 2013). - not available.

shown by Denmark and mid-sized vessels from Poland and Sweden, indicating a capacity reduction (STECF, 2014).

5.3 Methodology

5.3.1 General Context

The fishing industry can be considered a set of firms (vessels) clustered in fleet segments depending on main gear, vessel size, country of origin and fishing region (STECF, 2013). These homogeneous sub-divisions are often referred to as *métiers* (ICES, 2013).¹⁶ In each segment, the input-based

¹⁶ There is, of course, some degree of heterogeneity within the sector. However, for the purpose of this research, the differences within sector defined in this way are not

	Length	2008	2009	2010	2011	2012
Denmark	10-12m	0.36	0.34	0.48	-	0.45
	12-18m	0.47	0.49	0.50	0.50	0.59
	18-24m	0.60	0.64	0.69	0.64	0.69
	24-40m	0.88	0.97	0.91	0.88	0.90
Germany	10-12m	0.44	0.42	0.36	0.37	0.30
	12-18m	0.40	0.40	0.40	0.39	0.45
	18-24m	0.63	0.58	0.56	0.54	0.68
	24-40m	0.86	0.72	0.68	0.68	0.84
Poland	10-12m	-	-	0.23	-	-
	12-18m	0.26	0.36	0.34	0.45	0.57
	18-24m	0.30	0.32	0.34	0.39	0.38
	24-40m	0.36	0.40	0.23	-	-
Sweden	10-12m	0.26	0.27	0.24	0.24	0.26
	12-18m	0.38	0.37	0.34	0.37	0.41
	18-24m	0.47	0.44	0.49	0.60	0.64
	24-40m	0.75	0.70	0.65	0.73	0.67

Tab. 5.3: Vessel utilization ratios for DTS sector from 2008 to 2012 (STECF, 2014). - not available.

technical efficiency (TE, referring to the full input based technical efficiency specification from herein) is dependent on the production of outputs, i.e. harvested species, using inputs in form of fishing effort. The TE value gives information to what extent the production in a segment differs from the best practice in the industry, i.e. how far it is from the established frontier. Deviation indicates that the accessible technology is not used to its full potential. The effort required for a certain level of harvest depends on the long-term strategy and short-term decision of the fishermen. The long-term strategy is associated mostly with capital investments, its type, size, etc. The short-term decision is on which species to target, whether to change gear or not, whether to fish on a given day, and where to fish (Eales and Wilen, 1986).

considered.

The choice of fishing ground is an important aspect of fishing (Pascoe et al., 2007). Following modern biological studies, the fish population structure often exhibits properties like patchiness and heterogeneity, and this effect should not be disregarded in fisheries modeling (Holland et al., 2004; Smith et al., 2009). Patch, following Sanchirico and Wilen (1999), is a ‘location in space that contains or has the potential to contain an aggregation of biomass.’ A productive patch, abounding in a target species, in general implies higher catchability, lower on-site costs and higher rents.¹⁷ Effort should be increased in such areas. In contrast, effort should be driven away from less productive patches (Sanchirico and Wilen, 1999). TEs are considered to differ with the productivity of different fishing grounds. Thus, the spatial dimension and explicit choice of fishing grounds adds new insight into comparing efficiency between métiers.

The distance between port and fishing ground is an important constraint in this context. The fisherman will not choose the most productive fishing ground if the traveling effort is too high. Thus, the fisherman faces the trade-off between TE on-site and travel distance. The fisherman’s choice of fishing ground is subject to uncertainties in the stock dynamics, stock migration and locations of stock abundance (Mangel and Clark, 1983; Schnier and Anderson, 2006). Searching behavior provides reduction of such uncertainty. However, searching for information about stock abundance implies an opportunity cost equal to forgone pay-offs which could have been realized by fishing (Marcoul and Weninger, 2008). Many fisheries require substantial effort to gather enough information about where to set the net or start the trawl (Mangel and Clark, 1983; Wilen and Botsford, 2004). Rent dissipation may occur as a consequence of excess effort involved in search itself, as well as through inefficient targeting (Eales and Wilen, 1986). Thus, the fishing behavior can be thought of as a combination of searching activity, location choice and harvest, or a trade-off between exploration and exploitation, in addition to required travel distance.

¹⁷ This consideration is of particular relevance for species whose harvest is density dependent. It may be not particularly applicable to schooling fish types whose aggregations can be targeted using modern technologies, including acoustic equipment.

5.3.2 *Modeling Approach*

Throughout this article, the TE in the fishing industry is evaluated as input based on-site TE subject to travel distance trade-offs. The on-site TE, once the investment in capital is made, corresponds to the deviation from the minimum possible input given the output combination. The output is a composition of multiple fish species that are landed after returning to the port, and it generates revenue. The input is effective effort, measured as trawling time.

It is impossible to distinguish between effort involved in search and actual harvest. However, the trawling time in relation to the harvest indicates how efficiently the total on-site effort is utilized, i.e. how well effort is divided into search and harvest compared to the best practice. It is assumed that the amount of effort required to harvest a certain fish composition depends on multiple factors describing the available technology. The affiliation to a particular fleet segment indicating main gear and size and the specification of long-term strategy is considered a major one. The TE is also dependent on national factors that include regulations, fleet structural changes, etc.

The role of technical progress in the fishing industry is acknowledged by accounting for time specific changes common to all observations (Squires and Vestergaard, 2013). In this manner, it is assumed that general advancement in technology is widely available, but fleet segments do not necessarily have to take an advantage of it, which is reflected in time-specific efficiency levels.

The on-site TEs are also considered to be specific for particular fishing grounds as those vary in fish density. However, the harvest location is associated with particular requirement with regard to travel time, here derived as distance to home country. Therefore, the fishing units face, each time, a spatial decision which implies certain on-site efficiency, but also a distance to cover. Moreover, the final productivity is only realized on-site, thus, adaptation and learning capacity when making the choice matters. Multiple empirical studies suggest that decisions regarding time and location of fishing are flexible, and can be adjusted relatively quickly (Wilén and Botsford, 2004). Often, it can be considered a discrete choice made on a daily basis (Smith,

2000). The efficiency of harvest activity depends on experience and skills (Kirkley et al., 1998). There is also a great deal of heterogeneous responses to signals and varying learning patterns associated with the search outcomes. Thus, the spatial decisions, in particular trade-offs between on-site efficiency and distance, are evaluated with respect to their rationality in the second stage analysis.

The TE is also influenced by stochastic factors which include any random processes affecting the final outcome, e.g., luck (Kirkley et al., 1995). The relation between elements determining the TE is depicted in fig. 5.3. The TE in a short-run decision process can be estimated using a stochastic frontier analysis for the multi-product distance function.

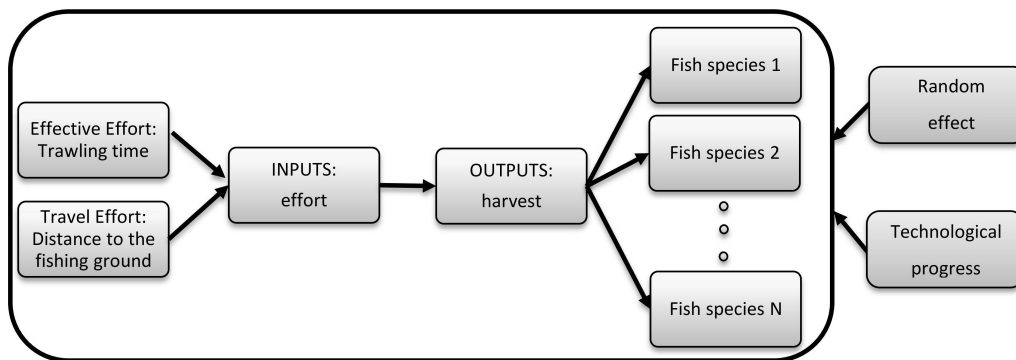


Fig. 5.3: Elements of on-site technical efficiency in short-run decision process.

5.3.3 Multi-Product Distance Function

The majority of econometric studies model multiple-output technologies by either aggregating all outputs into a single index (e.g. Paasche, Laspeyres, Fisher or Tornqvist) or using dual cost and profit functions (Coelli and Perelman, 2000). However, it is rarely the case that the whole set of prices required for creating an index is available. On the other hand, dual functions require strict assumptions regarding either cost minimization or profit maximization that are often not met due to sectors under investigation being highly regulated or strongly influenced by tradition. The example of such industry is

the European Union fishery. The remaining approaches include the factor requirement function (Diewert, 1974) and the distance function. However, because the focus of the article is on the efficiency of the European fleets, the distance function approach seems most compelling (Färe and Grosskopf, 1990).

The production technology $P(\mathbf{Y})$ represents all input vectors \mathbf{X} that can produce output vector \mathbf{Y} . As the fishing industry is considered to have better control over inputs rather than outputs, the multi-product distance function with input oriented specification is considered more appropriate (Coelli and Perelman, 2000) and can be defined as (Shepard, 1970):

$$D(X, Y)^I = \max \{ \theta : (X/\theta) \in P(Y) \} \quad (5.1)$$

where $D(X, Y)^I$ is the distance from the inner boundary of the input set with following properties: it is non-decreasing, positively linear homogeneous and concave in \mathbf{X} , and decreasing in \mathbf{Y} . The frontier is where the lowest amount of input \mathbf{X} is used to produce given output \mathbf{Y} , whereas θ indicates the level of efficiency. The maximum efficiency is realized at the frontier, which requires $D(X, Y)^I = \theta = 1$ and therefore the function $D(X, Y)^I$ can only take values ≥ 1 . Conversely, when $D(X, Y)^I$ is approaching infinity, the infinite amount of input is needed to produce a given output.

A full logarithmic specification for i outputs ($i \in I$) and j inputs ($j \in J$) for métier n at time t is given as:

$$\begin{aligned} \ln D_{n,t} = & \alpha_0 + \sum_{i \in I} \alpha_i \ln(y_{i,n,t}) + \sum_{j \in J} \alpha_j \ln(x_{j,n,t}) \\ & + \sum_{i \in I} \sum_{i' \in I} \alpha_{ii'} \ln(y_{i,n,t}) \ln(y_{i',n,t}) + \sum_{i \in I} \sum_{j \in J} \alpha_{ij} \ln(y_{i,n,t}) \ln(x_{j,n,t}) \\ & + \sum_{j \in J} \sum_{j' \in J} \alpha_{jj'} \ln(x_{j,n,t}) \ln(x_{j',n,t}). \end{aligned} \quad (5.2)$$

The choice of logarithmic form is dictated by its flexibility with respect to determining the structure of the technology (Kirkley et al., 1995). Imposing homogeneity of degree one in inputs requires: $\sum_{j \in J} \alpha_j = 1$, $\sum_{j \in J} \alpha_{jj'} =$

$0 \forall j' \in J, \sum_{j \in J} \alpha_{ij} = 0 \forall i \in I$, whereas symmetry requires $\alpha_{ii'} = \alpha_{i'i}$ and $\alpha_{jj'} = \alpha_{j'j}$. That, for the case of single input x , implies:¹⁸

$$\begin{aligned} \ln\left(\frac{D_{n,t}}{x_{n,t}}\right) &= \alpha_0 + \sum_{i \in I} \alpha_i \ln(y_{i,n,t}) + \sum_{i \in I} \sum_{i' \in I} \alpha_{ii'} \ln(y_{i,n,t}) \ln(y_{i',n,t}) \\ \text{or} \\ \ln(x_{n,t}) &= -(\alpha_0 + \sum_{i \in I} \alpha_i \ln(y_{i,n,t}) + \sum_{i \in I} \sum_{i' \in I} \alpha_{ii'} \ln(y_{i,n,t}) \ln(y_{i',n,t})) \\ &\quad + \ln(D_{n,t}). \end{aligned} \tag{5.3}$$

There are multiple concerns regarding the use of effort as a single input variable (Squires and Vestergaard, 2012). However, it is a traditionally important measure (Cunningham and Whitmarsh, 1980) which offers a convenient framework to examine TE. Moreover, the comprehensive data needs to be available, which is not the case for e.g. fuel use. This is a crucial issue with respect to the attempt to compare multiple countries.

5.3.4 Empirical Model

Extending the analysis by a spatial component requires redefining the panels in equation (5.3) as segment-, location- and time-specific. Introducing r as a notation for location and including a linear time trend t indicating technical progress, the final model takes the form of:

$$\begin{aligned} \ln(x_{n,r,t}) &= -(\alpha_0 + \sum_{i \in I} \alpha_i \ln(y_{i,n,r,t})) \\ &\quad + \sum_{i \in I} \sum_{i' \in I} \alpha_{ii'} \ln(y_{i,n,r,t} \ln(y_{i',n,r,t})) + \alpha_t t) + u_{n,r,t} + v_{n,r,t}. \end{aligned} \tag{5.4}$$

Fishing sensitivity to random factors is captured in the term $\ln(D_{n,t})$

¹⁸ For the multi-input case, the following restrictions imply (Coelli and Perelman, 2000): $\ln\left(\frac{D_{n,t}}{x_{1,n,t}}\right) = \alpha_0 + \sum_{i \in I} \alpha_i \ln(y_{i,n,t}) + \sum_{j \in J \neq 1} \alpha_j \ln\left(\frac{x_{j,n,t}}{x_{1,n,t}}\right) + \sum_{i \in I} \sum_{i' \in I} \alpha_{ii'} \ln(y_{i,n,t}) \ln(y_{i',n,t}) + \sum_{i \in I} \sum_{j \in J \neq 1} \alpha_{ij} \ln(y_{i,n,t}) \ln\left(\frac{x_{j,n,t}}{x_{1,n,t}}\right) + \sum_{j \in J \neq 1} \sum_{j' \in J \neq 1} \alpha_{jj'} \ln\left(\frac{x_{j,n,t}}{x_{1,n,t}}\right) \ln\left(\frac{x_{j',n,t}}{x_{1,n,t}}\right)$.

(equation (5.3)) that can be redefined to the composed error ($\epsilon_{n,t}$) containing the normally distributed stochastic variable $v_{n,t}$ (statistical noise) and the strictly non-negative inefficiency $u_{n,t}$.¹⁹ After transformation, the $u_{n,t}$ term can be interpreted as efficiency (Jondrow et al., 1982):

$$TE_{n,t} = \exp(-E(u_{n,t}|\epsilon_{n,t})). \quad (5.5)$$

In this paper we consider the Battese and Coelli (1995) methodology designed for panel data, in which the inefficiency term $u_{n,r,t}$ is obtained by truncation at zero of the normal distribution with mean δ , which is an unknown parameter to be estimated.²⁰ This allows comparability of the TE scores between observations, whereas it shows no attempt to evaluate numerically the influence of other factors; rather it gives consistent scores for further analysis. The advantage of the method is also that the unbalanced character of the data does not pose an estimation problem (Battese and Coelli, 1995). The estimates of the multi-product distance function give the specific on-site TE of each country at a given time and in a defined location. This efficiency, combined with information on location distance for each segment, presents a unique base for comparing overall efficiency of multiple fleet segments and the incurred trade-offs.

5.4 Data

The analysis is based on data on harvest (landings) and effective effort given by administrative rectangles for specific year, gear, country and length category, originating from supplementary material for the Annual Economic Report on the European Union Fishing Fleet (STECF, 2013).^{21,22} Effective

¹⁹ With formally stated properties as follows (Stevenson, 1980): $v_{n,t} \sim N[0, \sigma_v^2]$ and $u_{n,t} \sim N[\delta, \sigma_u^2] \perp v_{n,t}$.

²⁰ The 'sfpanel' package for STATA developed by Belotti, F., Daidone, S., Atella, V. and Ilardi, G. is used.

²¹ The exact location of each ICES statistical rectangle can be viewed as interactive map available through ICES Spatial Facility under http://geo.ices.dk/viewer.php?add_layers=ices_ref:ices_rectangles.

²² The data is available online under <http://stecf.jrc.ec.europa.eu/data-reports>.

effort is measured as the number of hours trawling. Harvest is divided into three groups reflecting the Baltic Sea species composition and includes: cod (c), pelagic species (p) with herring and sprat, and group of other species (o). The groups are formed by linear aggregation of tons of fresh weight. The data set used is limited to major European fleets fishing in the area of the Baltic Sea using demersal gear over the period 2004 to 2012. The study considers DTS sector fleets from Denmark, Germany, Poland and Sweden. These countries account for over 80% of total cod harvest during the period under investigation and therefore are the most important ones for the analysis, and the DTS sector is most important for harvesting cod in the Baltic Sea. Each demersal fleet is described by country of origin and length range. The dataset is restricted to five vessel length categories: (1) 8m to 10m, (2) 10m to 12m, (3) 12m to 18m, (4) 18m to 24m and (5) 24m to 40m. Smaller vessels are excluded as they are less mobile units and highly restricted to coastal areas neighbouring the home port. Big trawlers of length over 40m were excluded as very mobile and performing their fishing activity often outside of the Baltic Sea which is our area of focus. The data for length category 1 for 2004 in Germany was not available. Year 2004 was chosen as a starting period, as since then, all countries under investigation are members of the European Union and subject to the principle of relative stability in the context of setting TACs. The spatial distribution of cod harvest, the main target species of the DTS sector, summed over the investigated length categories is presented in fig. 5.2 (as the average of harvest over the investigated period 2004 to 2012). The observations with exceptionally low reported effort (less than 12h per year) were excluded as of low importance for the analysis. During the period under investigation, the data was recorded for 102 rectangles with fishing activity of minimum 12h during the year. In total there are 2705 observations with a summary given in table 5.4.

The distances to the fishing grounds are calculated as the length of a straight line from the middle of the rectangle's offshore area (polygon's centroid) to the nearest feature of the country of origin mainland or island with road connection (bridge). The results are derived in nautical miles with a use of GIS software (QGIS). Within this research framework the possibility

of landing the harvest on the islands with only a water-based connection was excluded. However, it is acknowledged that some of the landing occurs on Bornholm and Gotland.

Whereas Swedish Gotland is situated outside of the major cod fishing areas, fish landed on Danish Bornholm, located in the most productive cod fishing areas, may influence the results. However, the Danish landing statistics (Ministry of Food, Agriculture and Fisheries of Denmark, 2014) suggest decreasing importance of Bornholm ports. The difference in distance is also expected to be reflected in prices, as Bornholm is not the primary place of the final demand and thus most of the processed product has to be transported to the mainland.

	Length	Obs.	Rect. fished	Mean Effort (days)	Mean Harvest (tons)		
					cod	pelagics	other
Denmark	8-10m	77	17	377.88 (508.41)	7.90 (17.07)	0.00 (0.00)	6.74 (12.15)
	10-12m	160	27	1339.96 (1475.21)	46.52 (80.86)	0.15 (1.84)	16.25 (22.88)
	12-18m	277	43	4379.39 (6366.04)	235.29 (422.26)	256.70 (649.99)	78.06 (144.87)
	18-24m	238	42	1611.53 (2399.03)	130.64 (183.39)	42.07 (181.59)	28.99 (72.17)
	24-40m	201	51	419.30 (595.17)	69.96 (142.99)	86.89 (160.88)	8.83 (27.63)
Germany	8-10m	25	7	335.80 (238.01)	9.99 (9.09)	0.13 (0.45)	3.51 (3.63)
	10-12m	112	19	735.46 (828.09)	35.69 (39.07)	60.77 (128.77)	28.38 (39.40)
	12-18m	136	25	1588.05 (2362.02)	111.43 (181.62)	148.82 (246.11)	76.60 (133.20)
	18-24m	163	27	991.26 (1665.71)	110.85 (183.70)	85.91 (201.23)	45.48 (85.68)
	24-40m	162	44	435.16 (725.19)	68.38 (102.30)	117.17 (312.58)	11.50 (25.29)
Poland	8-10m	45	9	1474.47 (3280.58)	5.91 (10.73)	30.11 (74.69)	14.66 (24.51)
	10-12m	70	16	667.94 (850.09)	25.62 (45.51)	10.52 (33.37)	40.02 (61.49)
	12-18m	159	23	3538.07 (491.19)	138.05 (109.56)	40.62 (489.28)	162.80 (3.19)
	18-24m	152	22	2193.49 (3605.90)	95.04 (161.10)	37.45 (105.76)	66.96 (102.28)
	24-40m	159	31	2639.49 (5280.47)	110.41 (183.69)	42.55 (101.02)	121.93 (250.34)
	8-10m	21	3	187.48 (106.27)	0.00 (0.00)	4.36 (4.82)	0.01 (0.02)
	10-12m	79	18	403.70	0.80	33.55	0.09

				(445.83)	(3.58)	(49.04)	(0.25)
Sweden	12-18m	188	46	345.81	32.87	233.44	0.83
				(491.19)	(109.56)	(489.28)	(3.19)
	18-24m	167	40	462.16	101.70	329.32	1.43
				(616.46)	(249.97)	(554.70)	(4.24)
	24-40m	114	36	277.11	69.08	271.91	0.67
				(338.19)	(149.99)	(412.77)	(1.99)

Tab. 5.4: Summary statistics for the data used. Standard deviations in parentheses.

5.5 Results

5.5.1 Distance Function Estimates

The estimation is performed over panels with observations for the DTS sector specified by country, administrative rectangle and time, separately for each length category. Due to lack of more detailed data on capital, there is no possibility to compare directly métiers of different sizes. Therefore the comparison will be relevant only within each length category and the production technology that is common for such a group is estimated (Vestergaard et al., 2002). For the purpose of estimation, data have been scaled through dividing each parameter by sample mean prior to estimation (Coelli and Perelman, 2000). The results of the distance function estimation, together with robust standard errors adjusted for clusters on country and area, are presented in table 5.5.

The majority of coefficients is statistically significant indicating good fit of the proposed model for each length category. Additionally, an alternative structure of the model in the form of the Cobb-Douglas function was tested and rejected for each length category. All first-order terms have expected negative signs. The first-order output coefficients, with exception of the category including the biggest vessels, sum to an absolute value smaller than one, indicating increasing returns to scale. The opposite, decreasing returns to scale, are found for vessels between 24m and 40m. The coefficient α_t in each length category is significant and indicates a common positive time trend. In general, it shows increasing production at the same level of input over time. The ratio of σ_u to σ_v exceeded a value of one and was statistically different

from zero at 1% level of significance for each length category. This suggests the existence of a stochastic frontier function and that the deviations from the frontier are dominated by input inefficiencies. The model inefficiency levels suggest a higher degree of heterogeneity between small vessels.

Length	8-10m	10-12m	12-18m	18-24m	24-40m
α_c	-0.327*** (0.108)	-0.358*** (0.097)	-0.405*** (0.087)	-0.441*** (0.054)	-0.515*** (0.077)
α_p	-0.245** (0.115)	-0.004 (0.069)	-0.196*** (0.072)	-0.185*** (0.043)	-0.259*** (0.053)
α_o	-0.197 (0.170)	-0.281*** (0.063)	-0.299*** (0.071)	-0.198*** (0.037)	-0.353*** (0.044)
α_{cc}	-0.120*** (0.029)	-0.124*** (0.024)	-0.114*** (0.024)	-0.095*** (0.014)	-0.096*** (0.015)
α_{cp}	0.016 (0.012)	0.022* (0.012)	0.015 (0.011)	0.022 (0.006)	0.016** (0.007)
α_{co}	0.045** (0.022)	0.048*** (0.018)	0.052*** (0.018)	0.047*** (0.007)	0.029*** (0.009)
α_{pp}	-0.035 (0.027)	0.007 (0.021)	-0.051** (0.023)	-0.045*** (0.013)	-0.057*** (0.015)
α_{po}	0.030 (0.022)	0.026*** (0.010)	0.028** (0.012)	0.024*** (0.004)	0.006 (0.007)
α_{oo}	-0.061** (0.027)	-0.076*** (0.030)	-0.072*** (0.016)	-0.069*** (0.009)	-0.076*** (0.011)
α_t	0.049** (0.023)	0.045*** (0.016)	0.069*** (0.014)	0.092*** (0.012)	0.082*** (0.014)
α_0	-0.029 (0.268)	0.455 (0.336)	-0.112 (0.146)	-0.372* (0.138)	-0.305* (0.158)
σ_u	5.180*** (1.994)	1.053** (0.466)	4.257* (2.023)	2.576*** (4.115)	3.493*** (0.677)
σ_v	0.467*** (0.098)	0.497*** (0.141)	0.686*** (0.135)	0.566*** (0.046)	0.585*** (0.047)
Estimated inefficiencies $\hat{u}_{n,r,t}$					
Mean	0.573	0.915	0.489	0.343	0.404
SD	0.495	0.550	0.326	0.193	0.259
Min	0.119	0.147	0.105	0.097	0.093
Max	3.186	3.081	2.647	1.517	2.461
Log-Likelihood	-178.14	-512.99	-939.72	-717.59	-1175.37

Tab. 5.5: Estimated parameters of the distance functions. Standard error in parentheses. Significance levels: *** 1%, ** 5% and * 10%.

5.5.2 Efficiency On-Site Comparison

The TE estimates in form of mean and standard deviation are reported at national level for each length category in table 5.6. The overall TE for a

given fleet segment is formed by weighting site specific values with associated effort. Thus, the final TE measure incorporates the effect of fishing ground choice.

Among analyzed countries, Germany is the most efficient, except being closely behind Poland in length category 2. The least efficient fleet belongs to Sweden looking at units below 18m, and to Poland considering the fleet consisting of larger vessels. The biggest differences are observed among small vessels (length category 2), where the best score, for Poland, is over 60% higher compared to Sweden, the last in the group. The differences between TEs fade away with increasing size of the vessel. The smallest efficiency asymmetries are observed among the largest vessel group where the most efficient, Germany, is only about 20% ahead of Poland which is closing the group. The biggest vessels are also characterized by the smallest variation of efficiency within the group, again suggesting that the small vessels are considerably more heterogeneous.

Length	8-10m			10-12m			12-18m			18-24m			24-40m		
	M	SD	EW	M	SD	EW	M	SD	EW	M	SD	EW	M	SD	EW
Denmark	0.60	0.15	0.53	0.34	0.15	0.32	0.62	0.11	0.62	0.70	0.12	0.67	0.67	0.14	0.63
Germany	0.65	0.10	0.62	0.56	0.11	0.50	0.72	0.07	0.71	0.78	0.06	0.77	0.75	0.08	0.71
Poland	0.65	0.23	0.47	0.60	0.15	0.52	0.64	0.11	0.60	0.67	0.13	0.56	0.63	0.14	0.57
Sweden	0.53	0.25	0.44	0.40	0.24	0.19	0.61	0.21	0.53	0.75	0.10	0.75	0.70	0.12	0.65

Tab. 5.6: Efficiency estimates: Mean (M), Standard Deviation (SD) and Efficiency Weighted (EW). EW using effort as weighting factor.

5.5.3 Changes over Time

The model results suggest a negative time trend for effort requirement in the investigated part of the European fishing industry. The most probable explanation is the combination of technological progress in European fisheries, less competition in the sector, decreasing size of the European Union fleets and improving cod stock condition (from 2005). The biggest increase in efficiency is observed among vessels over 18m.

Disregarding the common time trend and looking at individual country

changes over time (fig. 5.4, specific values in Appendix 5.8), the fleet below 10m presents considerably more variation over years compared to bigger vessels. The simple explanation may be that the small scale fleet lacks capacity for fast adaptation to variation of external factors. This is in line with conclusions of other authors, who have found that mobile fleets adjust faster to catch per unit of effort compared to small-scale, sedentary fleets fishing in close proximity to the home port (Hilborn and Ledbetter, 1979).

The biggest differences between nations can be observed in length category 2, in which, in contrast to length category 1, the technical efficiencies stay at similar levels over years. Regarding length category 3 to 5, one interesting feature is a substantial drop of efficiency in 2012 within Danish vessels, which is a big contributor to lower overall efficiency of this country. One probable reason behind is the decrease of total landings in 2012 compared to 2011 by 31% along with an effort drop of only 3%. The major factor causing it was a decrease by about 80% in the sandeel quota which is an important species for the Danish industrial fisheries, as well as a significant drop in the harvest of other pelagic species, sprat (64% drop) and herring (20% drop) (STECF, 2013; ICES, 2013). The harvest of demersal and pelagic species is interconnected, as they are often targeted by the same vessels, i.e. vessels in the DTS sector have the option to allocate some of their effort to pelagic harvest through flexible gear changes (Hutniczak, 2014). It is expected that this fact contributed to demersal segment performance whereas the available data is not sufficient to predict the future trend with respect to this fleet. One can also notice a temporary peak for Polish vessels in length category 3 to 5 during the period 2009 to 2011. That could be explained by higher on average individual vessel quotas and less competition due to restricting access to the fishery as a consequence of the European Union's punishment for overfishing cod in earlier years (European Council, 2008). Furthermore, the landing volumes for earlier years are probably underestimated due to problems with illegal landings and misreporting (ICES, 2013). Moreover, the visible increasing trend in the efficiency of Polish vessels above 12m can be a result of the major fleet restructuring process that is outrunning other countries.

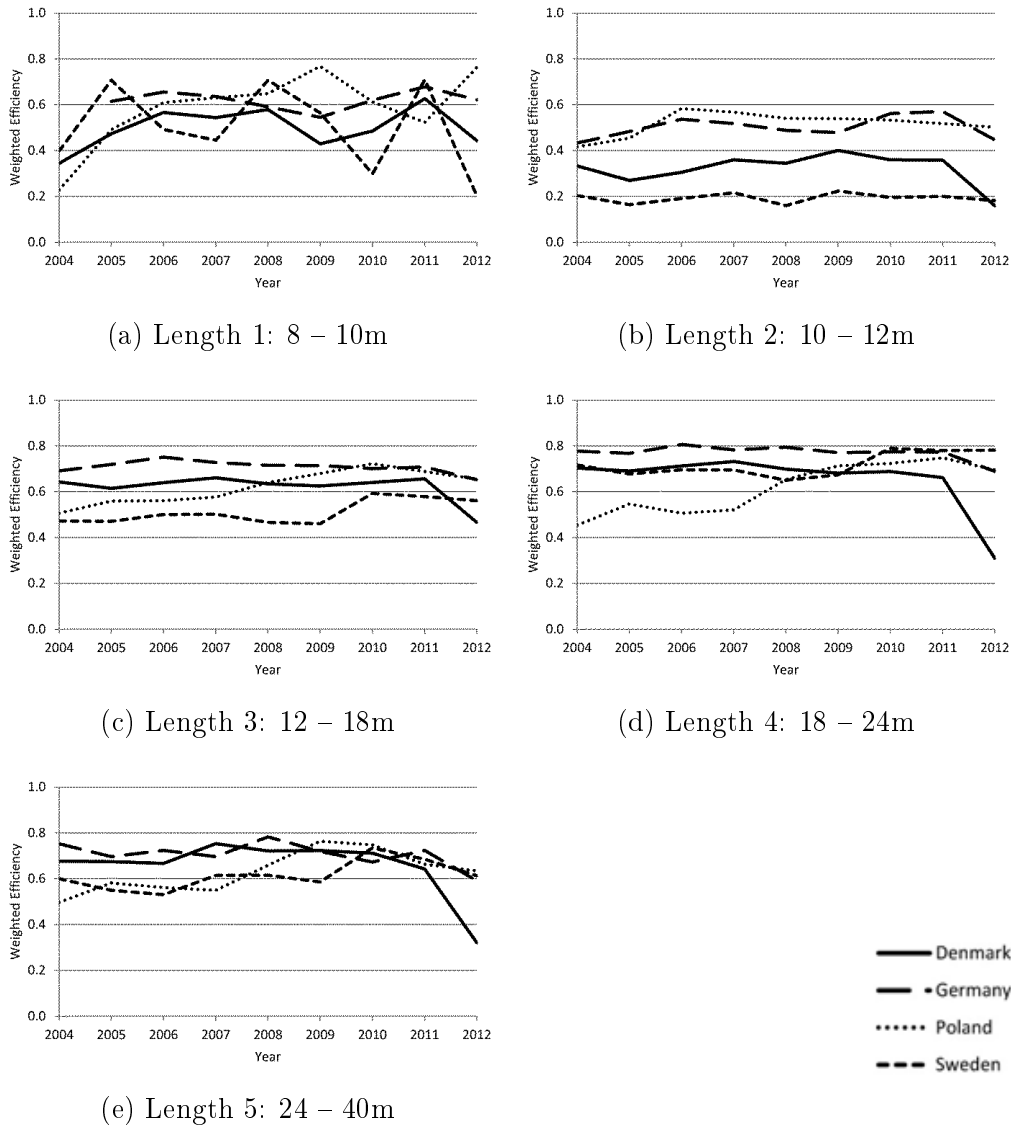


Fig. 5.4: Efficiency estimates by year, weighted by effort.

5.5.4 Spatial Consideration

The model presents significant differences in on-site TE depending on the choice of fishing ground. The specific results compiled with distances for the most important cod fishing grounds are presented in the Appendix 5.9. The efficiencies were calculated as weighted with effort average over the period

2004 to 2012.²³

There is a big overlap between countries with respect to fishing ground choice for the bigger vessels. Considering top rectangles, bigger vessels (over 12m) from all countries share the most productive fishing grounds. In particular, the largest vessels are observed to be fishing the same few rectangles. In the case of length category 5, 88% of cod is harvested in merely 12 rectangles. Harvest by small vessels is much more spread, showing the limitations in location choice. This fact is most visible in length category 1, but also noticeable for length category 2. This conclusion is in line with findings by other authors that suggest vessel size significantly influences trip choice behavior (Pradhan and Leung, 2004).

The trade-offs between on-site efficiency and distance to the fishing ground is evaluated by comparing weighted TE and distances for the whole fishing activity with the equivalent parameters for the most efficiently utilized effort and the area with the most effort applied. The results for 2011 are presented in table 5.7. Year 2011 was chosen as the most recent after eliminating 2012 due to results for Denmark outside of general trend.²⁴ The table shows that in many cases the trade-offs are well established and the majority of effort is often utilized in the areas of closer proximity to home country, even despite the lower on-site efficiency. Potential for TE improvement by better location choice can be observed in the column denoted by 'Top 10%'. Here the results are derived for the 10% of effort utilized at the highest efficiency level. Although in a few cases it would require a significant increase of distances, there are many instances in which the potential for improvement, both from the perspective of on-site TE and distance, is noticeable. In relation to weighted distance, that includes: Denmark in category 1; whole category 2; Denmark and Germany in category 3; Poland in category 4; and category 5 with exclusion of Germany. Thus, better management, defined here as more optimal site choice, gives a potential for higher input efficiency.

²³ No significant differences over years when it comes to choice of harvest grounds by each length category were observed, whereas the time trend was excluded.

²⁴ Despite the arguments explaining the low efficiency scores for Denmark in 2012, due to insufficient data it cannot be established whether the situation has a temporary or permanent character. On contrary, the data for 2011 fits into consistent trend.

	Weighted Average		Max Effort		Top 10%	
	TE	Distance	TE	Distance	TE	Distance
Length category 1: 8-10 m						
Denmark	0.63	40.6	0.67	98.5(1)	0.77	11.2
Germany	0.68	4.7	0.67	2.2	0.71	12.4
Poland	0.52	3.2	0.65	1.3	0.70	3.6
Sweden	0.71	6.9	0.71	6.9	0.71	6.9
Length category 2: 10-12 m						
Denmark	0.36	45.7	0.46	98.5(2)	0.53	6.1
Germany	0.57	13	0.59	5.7	0.67	12.9
Poland	0.52	17.3	0.29	1.3	0.71	14.7
Sweden	0.20	8.6	0.11	7	0.50	2.9
Length category 3: 12-18 m						
Denmark	0.66	47.8	0.70	98.5(3)	0.70	35.6
Germany	0.71	16.4	0.71	9.6	0.76	16.1
Poland	0.69	19.4	0.70	9.9	0.76	24.1
Sweden	0.58	18.5	0.66	13.3	0.89	91
Length category 4: 18-24 m						
Denmark	0.66	84.5	0.55	103.3(4)	0.77	103.8
Germany	0.77	27.3	0.76	9.6	0.81	60.6
Poland	0.75	18.5	0.74	3.6	0.81	15.1
Sweden	0.78	34	0.76	13.3	0.82	76
Length category 5: 24-40 m						
Denmark	0.64	131.1	0.61	132.1(5)	0.76	73
Germany	0.72	53.5	0.72	5.7	0.79	102.6
Poland	0.66	27.4	0.70	28.6	0.77	21.6
Sweden	0.68	41.7	0.72	13.3	0.76	39.9

Tab. 5.7: Technical efficiency and distance trade-offs in 2011. Note: Distance in nautical miles. Max Effort indicates score for the area where the most effort was applied. Top 10% indicates 10% share of effort utilized at the highest levels of efficiency. (1) - (4): These are the distances for the Bornholm rectangle. The scores for the next in line that is not in the area of Bornholm are as follows: (1) TE=0.66, Distance=2.2, (2) TE=0.53, Distance=6.1, (3) TE=0.67, Distance=6.1, (4) TE=0.66, Distance=12.8. (5): The sector is almost exclusively fishing in the distant to the mainland waters.

5.6 Concluding Remarks

The article addresses a potential shortcoming of the vast literature on fishery resource exploitation, namely the assumption about the uniformly distributed effort (Smith and Wilen, 2003). The modeling system takes ad-

vantage of a richer data set and incorporates spatial and intertemporal dimensions. These exhibited features build into general efficiency that can be compared between countries. The study moves away from the obsolete views that treat fish populations as spatially uniform or the state of technology over time as constant (Smith et al., 2009). The paper compares multiple fleet segments taking into account different accessibility of the most productive fishing grounds, the state of current technological progress, efforts undertaken in the fleet restructuring process, and advantages created by applied management systems.

The major argument for different levels of technical efficiency that comes to mind is uneven access to the most productive fishing grounds. However, the equal access principle in the European Union gives all member states the same right to fish in the whole Baltic Sea.²⁵ Hence, there is no legal discrimination of vessels regarding access to fishing grounds. The article shows that vessels of length over 12m (and partially vessels of length 10m to 12 m) take full advantage of this fact and conduct their activity in the same areas. The lack of technical limitations (capital feasibility) cause strong spatial overlap of fishing grounds. The advantages of fishing in particular areas are shown by derived area-specific TEs that present considerable asymmetries. On the other hand, for smaller vessels it is more risky, costly or even unfeasible, to go all the way to the main cod fishing areas and thus the harvest activity is more localized. Thus, trade-offs between on-site efficiency and traveled distance, especially in the case of bigger vessels, are necessary to be considered when comparing efficiencies of European fleets' with respect to utilization of national TACs.

The paper investigates the traveled distances to the fishing grounds in comparison with on-site efficiencies specified for given area per length category. These can be considered second order frontiers of the industry with two inputs, effective effort and travel effort. The smallest vessels (length category 1) travel mostly up to 20nm (on average five to ten nm, depending

²⁵ Except for the 12 nautical mile zone. In these zones bilateral agreements define access rights.

on country) and are not able to reach the most productive fishing grounds.²⁶ The landings of this length category are also not substantially contributing to the total Baltic Sea production of cod. Considering TE, the results for the smallest vessels show high variability which means vulnerability to local variations of fishing conditions, i.e. changes in the distribution of fish. Thus, it is difficult to draw specific conclusions besides the high sensitivity of this fleet sector to surrounding circumstances. Considering quota exchanges within this group, the high responsiveness to surrounding conditions suggests that short-term quota leases might be efficiency improving. They would allow the more flexible participants to take an advantage of favorable conditions.

Certainly a different situation occurs in the case of bigger vessels (length category 2 only partially). These can travel longer distances (more than 100nm up to 200nm) and are more flexible in their choice of fishing site. Their fishing activities overlap and are concentrated in the most productive south part of the Baltic Sea, around the island of Bornholm. Given that those vessels fish in the same area, the differences in TE are expected to be more likely resulting from differences in the structure and the utilization of the national fleets.²⁷ Fisheries management is also an important factor in this context as national implementation of CFP varies between countries. This holds especially for the way in which the TAC is allocated between resource users.

The differences between estimated TEs among bigger vessels are more visible and allow comparison as the levels are rather stable. Based on the model results the following conclusion can be made. The stage of the fleet restructuring process seems to have the highest impact on the on-site catch efficiencies of the single fleet segments. If the restructuring process is in an advanced stage (as e.g. in Germany or Denmark) and the capacity utilization is high, the catch efficiencies are higher. On the other hand, a country still undergoing major structural changes and struggling with overcapacity

²⁶ The exceptionally high distances for Denmark within length category 1 account for the harvest located in rectangles directly bordering the island of Bornholm. This part of harvest is most probably locally landed in Bornholm.

²⁷ E.g. the effects of restructuring process, here meaning the adjustment of the fleets to requirements of the European Union.

is reflected in a low level of catch efficiency (as e.g. in Poland), which does however give the potential of faster improvement. The outstanding result for Poland (vessels over 12m, especially length category 4) showing faster improvement than other countries suggests an increase in performance over the last years. That can be explained again by the big restructuring process in the Polish fleet – between 2004 and 2011 almost 500 vessels were removed.

The use of tradable quotas seems to improve efficiency although it is expected that its main contribution is in supporting the restructuring process. A flexible quota system that allows quota swapping (i.e. ITQs) is expected to have a positive impact on the catch efficiency through incentives given to less efficient vessels to leave the market by selling their quota shares and thus increasing the catch efficiency of the sector. These effects have been shown by Andersen et al. (2010) for Denmark and its introduction of ITQs for pelagic and demersal fleets. According to Andersen et al. (2010), the ITQ system motivated smaller vessels (up to 18m) to sell their catch shares to bigger vessels and drop out of the market. That increased the overall resource rent of the remaining fleet. However, the differences in TE have faded away in recent years, implying that the fleets in the DTS sector in the Baltic Sea are becoming more competitive.

Moreover, the article findings suggest that efficiency can be improved by the optimal choice of fishing grounds. The results show significant differences in TE between harvest areas which are often not well utilized. In many instances the overall efficiency would increase by changing effort allocation patterns, not necessarily at the cost of further distances. Moreover, being situated closer to the productive grounds is shown to be beneficial. Countries like Poland and Germany take advantage of it. This fact is expected to influence the potential direction of international quota flow.

Concluding, the asymmetries in on-site efficiencies combined with evaluated location advantages are expected to be crucial when evaluating the benefits of the potential international flow of quotas. Allowing quota trade between the countries could diminish the discrepancies in efficiency and simultaneously increase the overall efficiency. Following economic principles, such a system would set incentives for the less efficient vessels to sell their

shares while the more efficient vessels enlarge their harvest by buying additional quotas, and contribute to overall efficiency by moving it closer to the established technological frontier. Better spatial management and benefits associated with optimal fishing ground choice in the context of the advantage of being located closer to generally more productive grounds could be utilized as well. Such a system would show in practice the true distance versus on-site capital utilization trade-off. This kind of trans-border management is also in line with the current CFP, whose latest reform promotes the idea of regionalization of the fishing management (European Union, 2013). The aim is to reallocate responsibility from the European Union level and allow the member states to freely coordinate their activities as long as the overall goals of the CFP are taken into account.

Nevertheless, the social concerns associated with applying pure economic principle (Kjærsgaard, 2010), e.g. lack of fairly distributed benefits from common pool resource, may be hard to overcome. Such a state also may not be desirable to individual countries. Thus, the impact of other factors influencing national levels of efficiency is highlighted here, which can be considered as guidance for best practices to improve efficiency.

5.7 Appendix

5.7.1 Efficiency Estimates

Tab. 5.8: Efficiency estimates by year, weighted by effort. - indicates missing data.

	2004	2005	2006	2007	2008	2009	2010	2011	2012
Length category 1: 8-10m									
Denmark	0.345	0.473	0.567	0.543	0.579	0.429	0.485	0.627	0.443
Germany	-	0.614	0.655	0.636	0.591	0.545	0.620	0.678	0.622
Poland	0.228	0.491	0.609	0.631	0.648	0.768	0.612	0.523	0.763
Sweden	0.399	0.707	0.492	0.445	0.707	0.564	0.298	0.709	0.203
Length category 2: 10-12m									
Denmark	0.333	0.270	0.306	0.360	0.344	0.400	0.360	0.358	0.159
Germany	0.433	0.483	0.537	0.518	0.488	0.478	0.562	0.571	0.447
Poland	0.416	0.454	0.584	0.568	0.541	0.540	0.533	0.518	0.502
Sweden	0.204	0.163	0.191	0.216	0.160	0.224	0.195	0.200	0.182
Length category 3: 12-18m									
Denmark	0.643	0.614	0.640	0.661	0.634	0.625	0.641	0.656	0.466
Germany	0.691	0.719	0.751	0.727	0.715	0.715	0.701	0.708	0.653
Poland	0.506	0.560	0.561	0.576	0.640	0.680	0.722	0.688	0.655
Sweden	0.473	0.471	0.501	0.502	0.466	0.461	0.592	0.579	0.561
Length category 4: 18-24m									
Denmark	0.703	0.690	0.712	0.732	0.698	0.681	0.688	0.662	0.310
Germany	0.777	0.767	0.806	0.782	0.794	0.770	0.774	0.774	0.689
Poland	0.454	0.546	0.506	0.521	0.653	0.713	0.724	0.747	0.695
Sweden	0.716	0.677	0.695	0.694	0.650	0.674	0.790	0.779	0.781
Length category 5: 24-40m									
Denmark	0.677	0.675	0.667	0.753	0.722	0.723	0.711	0.643	0.321
Germany	0.752	0.696	0.723	0.696	0.783	0.719	0.673	0.723	0.592
Poland	0.497	0.581	0.561	0.549	0.658	0.763	0.748	0.663	0.635
Sweden	0.599	0.550	0.530	0.615	0.615	0.586	0.734	0.685	0.613

5.7.2 Efficiency Scores and Distances

Tab. 5.9: Efficiency scores and distances for the Baltic Sea rectangles with high cod harvest. Note: Rect.: rectangle, harvest: sum of cod harvest in tons, share: share of harvest within length category, Dist: distance. The rectangles with high cod harvest are defined as administrative areas where cod harvest was over 1,000 tons within length category and minimum 100 tons for length category 1 over the investigated period. - indicate no harvest activity in given rectangle within the length category. (1): rectangles that are not top cod harvest locations (less than 10,000 tons in total for all length categories over the investigated period). (2): rectangles surrounding the island of Bornholm.

Rect.	harvest	share	Denmark		Germany		Poland		Sweden	
			TE	Dist.	TE	Dist.	TE	Dist.	TE	Dist.
Length category 1: 8-10m										
39G5(2)	182	0.16	0.70	98.5	-	-	0.66	55.7	-	-
38G0	145	0.13	0.56	6.1	0.86	16.2	-	-	-	-
37G2(1)	125	0.11	-	-	0.62	2.2	-	-	-	-
37G1	119	0.11	-	-	0.63	9.6	-	-	-	-
37G5(1)	102	0.09	-	-	-	-	0.80	9.9	-	-
Length category 2: 10-12m										
39G5(2)	2827	0.21	0.41	98.5	0.58	75.4	0.70	55.7	-	-
38G5(2)	1591	0.12	0.25	103.3	0.60	64.4	0.69	33.0	-	-
39G4(2)	1505	0.11	0.48	66.5	0.55	49.9	0.49	70.8	0.61	14.3
38G4(2)	1193	0.09	0.30	69.1	0.61	30.7	0.63	44.0	-	-
38G3	1148	0.09	0.22	35.4	0.40	5.7	0.56	56.3	-	-
38G0	1046	0.08	0.36	6.1	0.53	16.2	-	-	-	-
Length category 3: 12-18m										
39G5(2)	17029	0.16	0.68	98.5	0.75	75.4	0.68	55.7	0.65	42.4
38G5(2)	13349	0.12	0.60	103.3	0.69	64.4	0.70	33.0	0.65	59.0
39G4(2)	9915	0.09	0.69	66.5	0.66	49.9	0.62	70.8	0.72	14.3
38G0	9767	0.09	0.64	6.1	0.77	16.2	-	-	-	-
38G2	6091	0.06	0.6	12.8	0.73	14.9	-	-	-	-
37G1	5872	0.05	0.66	19.7	0.70	.6	-	-	-	-
38G4(2)	5762	0.05	0.63	69.1	0.69	30.7	0.69	44.0	0.75	39.6
38G3	4817	0.04	0.65	35.4	0.72	5.7	0.66	56.3	0.70	34.7
38G8(1)	4277	0.04	-	-	-	-	0.46	3.6	-	-
39G7	4267	0.04	0.51	166.0	-	-	0.65	28.6	0.74	68.0
40G4(1)	3065	0.03	0.67	67.0	-	-	-	-	0.68	13.3
39G0(1)	2239	0.02	0.58	5.2	0.71	35.4	-	-	-	-
37G5(1)	2232	0.02	0.70	108.2	0.60	49.8	0.66	9.9	0.80	76.8
41G2(1)	2085	0.02	0.61	10.7	-	-	-	-	-	-
39G8	1999	0.02	0.64	199.9	-	-	0.48	25.7	0.70	90.6
39G2(1)	1789	0.02	0.65	6.0	-	-	-	-	-	-
39G3(1)	1787	0.02	0.62	35.9	0.74	30.9	0.73	80.2	0.74	10.1
39G6	1345	0.01	0.55	132.1	0.64	106.1	0.54	39.8	0.74	55.0
38G1(1)	1242	0.01	0.65	5.1	0.80	15.6	-	-	-	-

40G5(1)	1181	0.01	0.64	96.2	0.84	95.0	-	-	0.66	22.8
38G9(1)	1060	0.01	0.72	239.2	0.77	191.0	0.47	18.5	-	-
Length category 4: 18-24m										
39G5(2)	9963	0.12	0.70	98.5	0.79	75.4	0.67	55.7	0.81	42.4
39G7	8160	0.10	0.62	166.0	0.73	138.6	0.63	28.6	0.82	68.0
37G1	6954	0.09	0.71	19.7	0.77	9.6	-	-	-	-
39G8	6507	0.08	0.71	199.9	0.77	169.0	0.42	25.7	0.81	90.6
38G5(2)	5816	0.07	0.62	103.3	0.80	64.4	0.71	33.0	0.81	59.0
38G2	4909	0.06	0.60	12.8	0.79	14.9	-	-	-	-
39G6	4696	0.06	0.64	132.1	0.80	106.1	0.61	39.8	0.81	55.0
38G3	4638	0.06	0.69	35.4	0.77	5.7	-	-	0.82	34.7
38G4(2)	3706	0.05	0.68	69.1	0.74	30.7	0.74	44.0	0.78	39.6
39G4(2)	3595	0.04	0.71	66.5	0.75	49.9	0.62	70.8	0.79	14.3
38G8(1)	3009	0.04	0.72	209.6	-	-	0.55	3.6	-	-
40G5(1)	2489	0.03	0.74	96.2	0.82	95.0	-	-	0.78	22.8
38G0	2256	0.03	0.67	6.1	0.79	16.2	-	-	-	-
41G2(1)	1926	0.02	0.72	10.7	-	-	-	-	0.84	2.8
39G3(1)	1825	0.02	0.73	35.9	0.78	30.9	0.79	80.2	0.78	10.1
40G6(1)	1489	0.02	0.65	130.0	0.77	120.5	-	-	0.76	27.0
37G2(1)	1307	0.02	0.62	17.2	0.79	2.2	-	-	-	-
40G8(1)	1225	0.02	0.73	197.8	0.81	180.6	0.41	55.4	0.82	74.2
40G4(1)	1188	0.01	0.83	67.0	0.83	76.4	-	-	0.76	13.3
Length category 5: 24-40m										
39G8	8675	0.17	0.67	199.9	0.78	169.0	0.43	25.7	0.73	90.6
39G5(2)	6185	0.12	0.62	98.5	0.71	75.4	0.64	55.7	0.73	42.4
39G6	6094	0.12	0.58	132.1	0.76	106.1	0.65	39.8	0.73	55.0
39G7	6024	0.12	0.57	166.0	0.77	138.6	0.65	28.6	0.73	68.0
38G5(2)	3953	0.08	0.48	103.3	0.74	64.4	0.75	33.0	0.76	59.0
38G4(2)	3612	0.07	0.69	69.1	0.63	30.7	0.72	44.0	0.69	39.6
38G3	2483	0.05	0.71	35.4	0.74	5.7	0.72	56.3	0.76	34.7
38G8(1)	1963	0.04	0.72	209.6	-	-	0.50	3.6	0.85	113.2
40G6(1)	1760	0.03	0.68	130.0	0.72	120.5	0.70	66.5	0.77	27.0
40G8(1)	1646	0.03	0.57	197.8	0.70	180.6	0.30	55.4	0.79	74.2
39G4(2)	1446	0.03	0.71	66.5	0.76	49.9	0.46	70.8	0.73	14.3
39G3(1)	1099	0.02	0.71	35.9	0.75	30.9	0.52	80.2	0.73	10.1

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Eidesstattliche Erklärung

Ich erkläre hiermit, an Eides statt, dass ich meine Doktorarbeit ‘Political Economy of European Fisheries Management’ selbstständig und ohne fremde Hilfe angefertigt habe und dass ich alle von anderen Autoren wörtlich übernommenen Stellen, wie auch die sich an die Gedanken anderer Autoren eng anlehrenden Ausführungen meiner Arbeit, besonders gekennzeichnet und die Quellen nach den mir angegebenen Richtlinien zitiert habe.

Kiel, Oktober 2015

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Publications

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- J. Hoffmann, M.F. Quaas, 2014, "Common Pool Politics and Inefficient Fisheries Management", Journal of Environmental and Resource Economics, doi:10.1007/s10640-014-9842-4, <http://link.springer.com/article/10.1007/s10640-014-9842-4>.
- B. Hutniczak, E. Nieminen, J. Hoffmann, J. Yletyinen, 2015, "Input-Efficiency of Fishing Cod in the Baltic Sea – Comparing Major EU Trawler Fleets", Working Paper, <http://www.helsinki.fi/taloustiede/Abs/DP68.pdf>.

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