Sustainable Management

of the Eastern Baltic Cod Fishery

Dissertation

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Für meine Mutter,

die so gerne Fisch isst!

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Abbreviations

AC	Average Cost
ACFM	Advisory Committee on Fishery Management
B_{lim}	Biomass limit reference point: if the spawning stock biomass falls below this limit, there is a serious risk of stock collapse.
BSI	Baltic Sea Index
CFP	Common Fisheries Policy
DKK	Danish krone (in Danish: *Dansk krone/ Danske kroner*) 1 € equals 7.42 to 7.48 DKK +/- 0.5%
EC	European Community
EU	European Union
GCM	General circulation model
HELCOM	Helsinki Commission (Baltic Marine Environment Protection Commission)
IBSFC	International Baltic Sea Fisheries Commission
ICES	International Council for the Exploration of the Sea
IPCC	Intergovernmental Panel on Climate Change
MAGP	Multi-Annual Guidance Programme
MBI	Major Baltic Infow
MPA	Marine Protected Area
(ad) MSVPA	(area-disaggregated) Multispecies Virtual Population Analysis
NAO	North Atlantic Oscillation
psu or PSU	Practical Salinity Units
RCM	Regional Climate Model
RV	Reproductive Volume
SD	Subdivision
SRES	Special Report on Emissions Scenarios
SSB	Spawning Stock Biomass
TAC	Total Allowable Catch
XSA	Extended Survivor Analysis

Chapter 1 - Introduction

1.1 The problem of overfishing and its global implications

Globally, fisheries are in a crisis. According to statistics from the Fisheries Department of the Food and Agriculture Organization of the United Nations, around 50% of all marine fish stocks appear to be fully exploited, and an additional 20-30% are considered overexploited, depleted, or recovering (FAO 2004; Garcia and Moreno 2001). Within the last two decades, this situation has severely impacted marine fish yields: Annual global marine catch has decreased from ca. 80 million tons in 1985 to ca. 70 million tons in 2000 (Watson and Pauly 2001). The reasons for this negative trend are manifold and related to the malfunctioning of governance, management, and institutional systems of fisheries (Buckworth 2001; Hardin 1968). The effects of population growth and technological progress in the last century have aggravated the situation (Ludwig *et al.* 1993). The difficulty to manage fisheries in a sustainable way lies partly in the interdisciplinarity of the problem, spanning ecology, economy and sociology (Policansky 2001).

Not only the ‘tragedy of the commons’ and open-access policies (Clark 1973; Gordon 1954; Hardin 1968; Ludwig *et al.* 1993), but also subsidy-driven overcapitalisation (Garcia and Newton 1997; Hardin 1968; Pauly *et al.* 2003), technological innovation (Ludwig *et al.* 1993), and the explosive increase in harvesting capacity have resulted in overexploitation and a situation in which fisheries are well on the way to undermining their supporting ecosystems. Examples can be found in numerous studies of various ecosystems and fish stocks (Garcia and Newton 1997; Jackson *et al.* 2001; Myers and Worm 2003; Myers *et al.* 1997; Pauly *et al.* 1998; Pauly *et al.* 2003; Watson and Pauly 2001).

Management regulations may be divided into input controls (e.g. spatial or temporal access limitation, boat licenses, gear restrictions) and output controls (e.g. total catch limits, fish size/age restrictions). Fisheries management has failed to stop the decline of fish stocks – worldwide (Beverton 1998; Botsford *et al.* 1997; Buckworth 2001; Worm and Myers 2004). Environmental variability and the resulting fluctuating nature of fish stocks render conventional management approaches, such as the setting of annual ‘Total Allowable Catches’ (TACs), highly uncertain. They require precise biological parameter estimates, which scientific fish stock assessment methods cannot deliver. Due to the precarious state of fish stocks worldwide and the inefficiency of former and present management strategies, there is an urgent need for research into alternative fisheries management strategies. Marine protected areas represent a potential tool within ecosystem-based management to effectively achieve sustainability (Watson and Pauly 2001).

1.2 Marine Protected Areas: Examples from empirical and theoretical studies

Recently interest has focused on the potential of marine reserves or marine protected areas[1] (MPAs) as an alternative fishery management tool (e.g. Beverton 1998; Bohnsack 2000; Buckworth 2001; Pauly *et al.* 2002; Pearce 2002; Roberts 2000; Roberts *et al.* 2001; Roberts *et al.* 2005; Sumaila *et al.* 2000; Walters 2000; Walters 2001). Several field studies have illustrated that closed areas can lead to increases in fish biomass, density and size, as well as ecosystem diversity (reviewed by Halpern 2003).

It is, however, important to acknowledge realistic limitations and expectations and not to present reserves as a general panacea (Allison *et al.* 1998; Dayton *et al.* 2000). Whether MPAs can enhance fisheries outside of their borders is still equivocal, for it depends on the setting, size and design of the reserve, on the life history of the species, on the specific characteristics of the ecosystem, and on the fishing activity surrounding the MPA (Halpern 2003; Lauck *et al.* 1998; Roberts 2000; Roberts and Sargant 2002; Roberts *et al.* 2003a; Roberts *et al.* 2003b; Sladek Nowlis and Roberts 1998; Starr 2001; Sumaila *et al.* 2000; Walters 2000; Walters 2001). When established in tropical regions with the objective of protecting reef fish of low mobility, studies have shown that MPAs enhance adjacent fisheries through larval dispersal or adult spillover and improved habitat structure (Roberts *et al.* 2001; Russ *et al.* 2003). In temperate waters, however, where species variability is lower than in the tropics and environmental conditions are much more variable, there is still a lack of empirical studies investigating fisheries benefits from MPAs – in particular, MPAs designed to protect mobile fish species. The few existing field studies that focus on mobile temperate fish species either lack adequate size and proper enforcement (Martell *et al.* 2000), or were effectively used to enhance a fishery for sedentary species, e.g. sessile scallops instead of migratory Atlantic cod and haddock (Murawski *et al.* 2000).

As long as no large reserves are implemented, we can only rely on modelling studies to evaluate the implications of MPAs for migratory fish stocks and their respective fisheries in temperate regions. Simulations of the effects of closed areas on the dynamics of migratory species have been examined by a number of authors. For example, Apostolaki *et al.* (2002) simulated the potential of partial closures as a rebuilding strategy for the Mediterranean hake fishery. Armstrong *et al.* (in prep.) examine the bio-economic effects of partial closures for North East Atlantic cod. Guenette *et al.* (2000) investigate with the help of an age- and spatially-structured model whether marine reserves could have prevented the 1992 collapse of the Canadian Northern cod stock, a highly migratory species. Walters (2000) applies an ecosystem simulation model to examine the size of an MPA required to protect migrating species. This particular ecosystem simulation model has also been applied to project biomass and catch for the next 30 years for the South China Sea (Pitcher *et al.* 2000), and to investigate the effectiveness of different approaches for managing the Faroe Island fisheries (Zeller and Reinert 2004).

Other models investigating the effects of MPAs have been published, but most of them deal with fish population dynamics and life history in a very general approach (Bohnsack 2000; Guenette and Pitcher 1999; Lauck *et al.* 1998; Mangel 2000; Rodwell and Roberts 2004; Sladek Nowlis 2000; Sladek Nowlis and Roberts 1998). Although such general approaches are easily applicable to any fishery, their value for case-specific policy advice

[1] In this thesis, I do not differentiate between the terms "marine protected area" and "marine reserve". Both terms are used interchangeably here and are abbreviated as MPA.

and management is limited: Regionally specific expertise and details on the fish stocks, their ecology and environment, as well as on the fishery, its structure and economics, are required to produce reliable model output.

The fish and fisheries science community – spanning fisheries biologists, oceanographers, fisheries economists and managers – expects that global climate change affects the marine environment, including fish stocks (e.g. Perry *et al.* 2005; Rose 2004; Worm and Myers 2004). Despite the apparent influence of climatically driven marine environmental change on fish population dynamics, few studies, which investigate effects of MPAs, incorporate environmental parameters explicitly. Rodwell and Roberts (2004) presented a theoretical study including the variability of two environmental parameters. In their study, the parameter variability affects population dynamics and is simulated stochastically: (1) stochastic variability of recruitment with underlying regime shifts; and (2) stochastic variability of natural mortality, including sporadic catastrophic events – expressed as pulses that increase natural mortality.

With regard to the Eastern Baltic cod stock, interactions between environmental variability and population dynamics have been studied intensively (e.g. Aro 2000; Bagge 1996; Bagge and Thurow 1994a; MacKenzie *et al.* 1996; MacKenzie *et al.* 2000; Wieland *et al.* 1994). This knowledge affords more detailed and precise modelling of these interactions than what is possible for other fish stocks and marine environments. This thesis develops and presents such a model in Chapters 3-5.

1.3 The Baltic Sea marine environment and Baltic Sea fisheries management

This thesis focuses on the Eastern Baltic Cod stock for three main reasons: (1) The Baltic Sea marine environment and food web is relatively simple, compared to other regional seas such as the North Sea. (2) At present, the Eastern Baltic Cod is the best understood cod stock with respect to the effects of environmental conditions on population dynamics (e.g. Köster *et al.* 2001; STORE 2002). (3) The stock has been below safe biological limits since the beginning of the 1990s and has not recovered since.

Eastern (or Central) Baltic cod (*Gadus morhua callarias L.*), along with herring (*Clupea harengus*) and sprat (*Sprattus sprattus*), constitute the major proportion of landings of the commercial fisheries in the Baltic Sea (ICES 2004). Baltic Sea fish stock assessments show a large decline of the cod biomass since the mid-1980s (ICES 2003). Recent estimates of spawning biomass being less than B_{lim} – the precautionary biomass level, below which recruitment is impaired – imply a reduced reproductive capacity of the stock (ICES 2003; ICES 2004). Hence, the stock is classified “as being outside safe biological limits”, posing concerns in the Baltic Sea management advice (IBSFC 2004).

Since January 2006, the European Community (EC) has managed the main commercial fisheries in the Baltic Sea.[2] Until December 2005, the principal fisheries management authority was the International Baltic Sea Fisheries Commission (IBSFC). Its management was mainly based on the setting of annual TACs, supplemented by technical regulatory measures, such as closed periods for fishing, minimum landing sizes, and mesh size

[2] See Chapter 2 for a detailed review of the past, present and future state of Baltic Sea fisheries management.

regulations (IBSFC 2002). A summer ban of the cod fishery has been established since 1995 in addition to the catch quotas. Due to the persistently severe situation of the stock, the IBSFC adopted in 2003 a new recovery plan for the Eastern and Western Baltic cod stocks, which focuses on meeting clearly defined stock reference points within several years (ICES 2004). Nevertheless, the principal policy instrument – setting of TACs – relies on the quality of the scientific fish stock assessments, which are carried out by the International Council for the Exploration of the Sea (ICES), the organisation that coordinates and promotes marine research in the North Atlantic, including adjacent seas such as the Baltic Sea. In general, these assessment methods are very uncertain due to the variability and uncertainty of a number of input parameters (e.g. catch-at-age data, mortality estimates, recruitment parameters, estimates of stock size and fishing mortality for the terminal years) and the difficulty in integrating multispecies interactions, ecosystem functions, and environmental parameters (Botsford *et al.* 1997; Hollowed *et al.* 2000; ICES 1998; Stefansson 2001; Walters 2001).

The establishment of an MPA represents an alternative to conventional fisheries management under uncertainty. Whether the particular design (location, time, size) of an MPA can be effective to rebuild the Eastern Baltic cod stock is not clear *a priori* due to the migratory nature of this stock and the variability of environmental conditions in the semi-enclosed, brackish Baltic Sea. Its performance can, however, be tested theoretically by application of a simulation model before practical implementation in reality, which is performed in this study.

1.4 Objectives of the PhD project and outline of the approach

The present dissertation aims to shed light on the environmental/ecological, economic, and legal sides of fisheries management in the Baltic Sea with the objective to support the recovery of the Eastern Baltic cod stock and to contribute to the sustainable management of the Eastern Baltic cod fishery. A central question motivating this research is: Can an MPA, permanent or seasonal, be effective in rebuilding the Eastern Baltic cod stock AND, at the same time, ensure future harvests to fishermen – also in light of global climate change? Several gaps towards a bio-economic evaluation of selected management policies for the Eastern Baltic cod fishery are bridged by this study, which is composed of four manuscripts[3], forming Chapters 2-5. The approach presented in this dissertation is as follows:

- First, the legal framework of fisheries management at the European level, and particularly that of the Baltic Sea, is depicted (**Chapter 2**). The subsequent modelling-based policy analysis is designed to fit into this framework and to propose new legislation or policy recommendations. Chapter 2 corresponds to the following paper:

[3] The style of chapters 2-5 is kept according to the submitted or accepted manuscripts, following the selected journal or book style. The corresponding references, and if so, appendices are presented at the end of each chapter.

Röckmann, C. (2006) *International cooperation for sustainable fisheries in the Baltic Sea*. Forthcoming in Ehlers, P. and Lagoni, R. (Eds.): International Maritime Organisations and their Contribution towards a Sustainable Marine Development.

- The core of the thesis is the development of a spatially explicit simulation model of the Eastern Baltic cod population dynamics (**Chapter 3**) and the subsequent coupling with economic calculations (**Chapters 4 and 5**). The population dynamics are externally driven by (a) management policies and (b) environmental scenarios. The simulations focus on the evaluation of an MPA as a management tool. The MPA location choice is based on environmental and biological reasoning. Focussing on an MPA approach, the developed simulation model requires a higher spatial and temporal resolution than normally applied by ICES in the standard fish stock assessment models. Chapter 3 corresponds to the following paper:

Röckmann, C., M.A. St.John, U.A. Schneider, F.W. Köster, F.W. and R.S.J. Tol (2006) *Testing the implications of a permanent or seasonal marine reserve on the population dynamics of Eastern Baltic cod under varying environmental conditions*. FNU-63-revised, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg. Submitted to Fisheries Research.

- Additionally, the model is extended to incorporate global climate change and its regional consequences in the Baltic Sea area (**Chapter 4**). The driving question is whether stock recovery is possible in the face of global warming. A preliminary economic analysis is coupled to the biological component, allowing simulations of future yield and profit development. Chapter 4 corresponds to the following paper:

Röckmann, C., U.A. Schneider, M.A. St.John, and R.S.J. Tol (forthcoming), *Rebuilding the Eastern Baltic cod stock under environmental change - a preliminary approach using stock, environmental, and management constraints*. Natural Resource Modeling; special issue, planned as Volume 20, Issue 2, in spring 2007.

- Finally, the economic model component is extended by calculating the variable costs of fishing (**Chapter 5**). Fishermen's future operating profits are estimated, and a ranking of the selected management policies in terms of economic profit is suggested. Chapter 5 corresponds to the following paper:

Röckmann, C., R.S.J. Tol, U.A. Schneider, and M.A. St.John (2006) *Rebuilding the Eastern Baltic cod stock under environmental change – Part II: The economic viability of a marine protected area.* Submitted to Natural Resource Modeling.

- **Chapter 6** concludes, and it points out areas that warrant further research.

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Chapter 2 - International cooperation for sustainable fisheries in the Baltic Sea

2.1 Introduction

The Baltic Sea is surrounded by eight Member States of the European Union (EU) – namely Denmark, Germany, Poland, Lithuania, Latvia, Estonia, Finland, and Sweden – and the Russian Federation (Figure 2.1). The entire Baltic Sea is divided in the Exclusive Economic Zones (EEZ) and the territorial seas of the surrounding countries. Due to the small size of the Baltic Sea, no EEZ reaches its maximal length of 200 nautical miles (nm). Hence, there is virtually no high seas in the Baltic Sea area (irrespective of one small area around Poland). Since the accession of the Baltic countries to the European Community[1] (EC) on 1 May 2004, the EEZs of the new EU/EC member states belong to the "European waters"; there is thus only one European Fishing Zone in the Baltic Sea, apart from a very small part (< 10%), which forms the Russian Exclusive Economic Zone. Within the 12 nm zone, the EC has reassigned the responsibility for coastal resources management to the individual coastal states[2].

Figure 2.1: Geopolitical map of the Baltic Sea.

As the Baltic Sea is a semi-enclosed ocean basin, water exchange is restricted. The Baltic Sea's marine fauna and flora is specially adapted to survive in these particular hydrographic conditions, which are characterised by moderately saline to brackish water in the South-Western and Southern parts and by very low-saline to freshwater in the North-Eastern and Northern parts. The hydrographic conditions are influenced by

1 According to Article 3, Paragraph 1 (e) of the Consolidated Version of the Treaty establishing the European Community (OJ C 325, pp.33-184 (2002)) fisheries policy forms part of the European Community's competence. Hence, the EC is being referred to here, rather than the EU.

2 "Council Regulation (EC) No 2371/2002 of 20 December 2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy", (2002) OJ L 358.

atmospheric conditions and impact on the entire food-web, fisheries resources included[3]. In certain cases these environmental impacts on fish population dynamics can be more important than the impact caused by the fishing activity.

Due to its estuarine character, species diversity in the Baltic Sea is limited compared to other marine areas[4]. Only three marine and one anadromous fish species are important for commercial exploitation, namely Baltic cod, sprat, herring, and salmon[5]. The other fish species are of minor importance to the commercial fishery. Comparable to the status of many commercially exploited fish stocks worldwide[6], Baltic Sea fish stock assessments show a large decline of the cod biomass since the mid-1980s[7] (Figure 2.2). Recent estimates of spawning biomass being less than B_{lim} – the precautionary biomass level, below which recruitment is impaired – imply a reduced reproductive capacity of the stock[8]. Hence, the stock is classified “as being outside safe biological limits”, posing concerns in the management advice for the fisheries in the Baltic Sea[9].

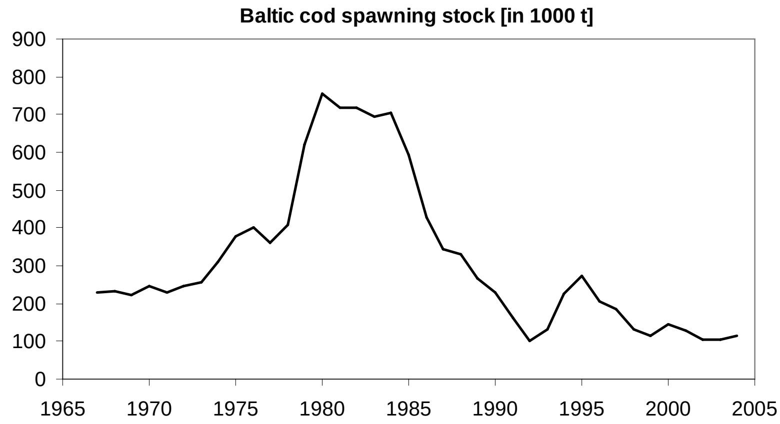

Figure 2.2: Development of the size of the Baltic cod spawning stock.

The complexity of the political and environmental/ecological situation calls for strong international cooperation in order to achieve economically and socially sustainable, environmentally safe and responsible fisheries. Management needs to be flexible to allow

3 Cf. H.-H. Hinrichsen, M. St.John*, et al.*, "Resolving the impact of short-term variations in physical processes impacting on the spawning environment of eastern Baltic cod: application of a 3-D hydrodynamic model", (2002) 32 *Journal of Marine Systems*, 281-294; Lehmann, W. Krauss*, et al.*, "Effects of remote and local atmospheric forcing on circulation and upwelling in the Baltic Sea", (2002) 54 A *Tellus*, 299-316.

4 HELCOM, "Fish", (visited 8 April 2005) *http://www.helcom.fi/environment2/biodiv/en_GB/fish/*

5 *Ibid*.

6 Cf. R.C. Buckworth, "World fisheries are in crisis? We must respond!" in: T. J. Pitcher, P. J. B. Hart and D. Pauly, *Reinventing Fisheries Management* (2001), 3-17; S.M. Garcia and C. Newton, "Current situation, trends and prospects in world capture fisheries", in: E. L. Pikitch, D. D. Huppert and M. P. Sissenwine, *Global trends: fisheries management* (1997), 3-27; J.A. Hutchings, "Collapse and recovery of marine fishes", (2000) 406 *Nature*, 882-885.

7 ICES, "Report of the Baltic Fisheries Assessment Working Group", (2003) *ICES CM 2003/ACFM:21*, 1-522.

8 *Ibid*., and ICES, "Report of the Baltic Fisheries Assessment Working Group", (2004) *ICES CM 2004/ACFM:22*, 1-522.

9 IBSFC, "Proceedings of the thirtieth session", (2004).

for direct reactions and adjustments in case of any natural or anthropogenic adverse impacts. At the same time, a minimum of income stability from the transboundary, hence internationally shared, fish resources in the Baltic Sea should be guaranteed to local fishing communities.

In this chapter, the situation and functioning of Baltic Sea fisheries management is analysed. Emphasis is put on the EC's Common Fisheries Policy (CFP), its evaluation and special implications for achieving sustainable fisheries in European waters in general and in the Baltic Sea in particular.

The text is organised as follows: In the following section, a definition of sustainable fisheries is presented. In Section 3, the historic and recent development of international cooperation for fisheries management in the Baltic Sea is depicted. Sections 2.4 and 2.5 deal with the structure, functioning, and operation of the current and future management authorities, respectively. The effectiveness of the CFP to achieve sustainability in fisheries is evaluated in Section 2.6. Section 2.7 concludes.

2.2 Sustainable fisheries

The International Baltic Sea Fisheries Commission (IBSFC), in close cooperation with the International Council for the Exploration of the Sea (ICES) and the Helsinki Commission (HELCOM), drafted a definition of sustainable fisheries for the "Sector Report on Fisheries" under the framework of the Action Programme of the "Baltic Agenda 21"[10]. Sustainability is defined, referring to the environmental, economic and social point of view: "*Sustainable, productive fisheries are achieved when appropriate management ensures a high probability of stocks being able to replenish themselves over a long period of time within a sound ecosystem, while offering stable economic and social conditions for all those involved in the fishing activity*."[11]. The environmental and ecological aspects of sustainable fisheries refer to maintaining biologically viable fish stocks, the marine and aquatic environment and associated biodiversity. Within these environmental limits, economic sustainability shall establish maximum fishing possibilities. Finally, the social aspect of sustainability concerns equity in the allocation and distribution of the direct and indirect benefits of fishery resources between local communities.

2.3 International Cooperation: History and recent development

From 1974 until the end of 2005, the responsible fisheries management authority for the Baltic Sea was the International Baltic Sea Fisheries Commission (IBSFC)[12]. The IBSFC had been founded by seven parties: the Governments of the Republic of Finland, the Kingdom of Denmark, the German Democratic Republic, the Federal Republic of Germany, the Polish People's Republic, the Kingdom of Sweden and the Union of Soviet

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10 IBSFC, "Sector Report on Fisheries - Contribution to "Baltic 21", Agenda 21 for the Baltic Sea Region", (1998) Baltic 21 Series No 4/98, 69.

11 *Ibid*.

12 Cf. <http://www.ibsfc.org> (last visited 12 April 2006).

Socialist Republics. The pattern of membership of the Commission changed over time, *inter alia* due to accession of member states to the EC.

Following the most recent enlargement of the EC on 1 May 2004, Estonia, Latvia, and Lithuania requested to withdraw from the IBSFC. Since this only took effect on 31 December 2005, there were six members in the IBSFC's plenary, namely Russia, Estonia, Latvia, Lithuania, Poland, as well as the enlarged EC. Each party had a full vote according to Rule 2 of the Rules of Procedure for the Commission Representation[13]. Consequently, there were five "European" votes versus one vote of Russia. After notification by the EC, Estonia, Latvia, and Lithuania of their withdrawal from the "Convention on Fishing and Conservation of the Living Resources in the Baltic Sea and the Belts" (Gdansk Convention), the IBSFC as an organisation ceased to function from 1 January 2006, but it still legally exists in 2006 with two Contracting Parties (Poland and the Russian Federation). Now, fisheries agreements draw on bilateral negotiations between Russia and the EC. Already since May 2004, the Common Fisheries Policy has applied to roughly 90% of the Baltic Sea territory, as only about 10% of the Baltic Sea belong to Russian waters.

2.4 The International Baltic Sea Fisheries Commission (IBSFC)

The IBSFC was established pursuant to Article V of the "Convention on Fishing and Conservation of the Living Resources in the Baltic Sea and Belt", also known as the Gdansk Convention (signed 13.9.1973, entered into force 28.7.1974).

2.4.1 The IBSFC's objectives, scope, goals, measures, principles

The scope of the IBSFC, as defined in article I of the Gdansk convention, is to cooperate closely in order to achieve sustainable fisheries. As a consequence of this commitment, the "Action Program for Sustainable Development of the Fishery" was developed in the framework of "Baltic Agenda 21"[14]. The duty of the IBSFC is to coordinate fisheries management, to coordinate scientific research, to prepare recommendations, to collaborate with the international technical and scientific organisations and the official bodies of the Contracting States (Article IX). In Article X, possible measures for fisheries management are depicted. These have been translated into "IBSFC Fishery Rules" and include the following[15]:

- regulation of fishing gear, appliances and catching methods;
- regulation of the size limits of fish;
- establishment of closed seasons;
- establishment of closed areas;
- improvement of / increase in the living marine resources, official reproduction and transplantation of fish and other organisms;
- establishment of total allowable catch or fishing effort;

13 Cf. <http://www.ibsfc.org/documentation/ibsfc_rules_of_procedure > (last visited 11 April 2005).

14 Cf. <http://www.ibsfc.org/baltic21/action_programme> (last visited 11 April 2005).

15 IBSFC, "Fishery Rules of the International Baltic Sea Fishery Commission", (2002).

- any other measures related to the conservation and rational exploitation of the living marine resources.

Moreover, the IBSFC has acknowledged to apply the *precautionary approach* to the management of living marine resources, as set out in the FAO "Code of Conduct for Responsible Fisheries"[16]. An absence of adequate scientific knowledge, which – particularly in the field of fisheries – arises due to many inherent uncertainties in fish stock assessments, should not be used as a reason for postponing or failing to take conservation management measures. The IBSFC has also approved the integration of fisheries and environmental protection, conservation and management measures by applying an *ecosystem approach*. This means that food-web interactions and ecosystem processes, functioning, productivity, and biological diversity, which are critical for maintaining an ecosystem's characteristic structure, shall be taken into account as far as scientific knowledge permits. Hence, the IBSFC aims at providing a healthy, functioning environment by minimising adverse impacts of fishing activities on species and habitats. As provided for in Article 7.5.3 of the FAO „Code of Conduct for Responsible Fisheries", the IBSFC has furthermore endorsed the establishment of stock-specific „target reference points" and „limit reference points" to allow harvesting within safe biological limits, with the objective to achieve sustainability well before 2030[17]. Being a fisheries management authority, the IBSFC aims in general at achieving a balance between the harvesting capacity of fleets and the target reference points for stocks. At the time of signature in 1973, the Gdansk Convention was very innovative. It was actually signed before the start of the Third UN Conference on the Law of the Sea. The idea of an "Exclusive Economic Zone" had just been launched in 1972 by a Declaration of the Organisation of African States[18].

2.4.2 The IBSFC's decision making process

The representatives of the contracting parties meet in plenary meetings (sessions) once a year[19]. They may take decisions by "unanimous agreement" on the transmittal of proposals or recommendations under Article X of the Gdansk Convention[20]. Texts of recommendations, agreed upon during a Session, shall be adopted before the end of a Session. Amendments must be submitted within 30 days after the end of a Session. Finally, IBSFC recommendations shall be made binding to all Contracting Parties[21].

Several international organisations are observers of the IBSFC, e.g. the International Council for the Exploration of the Sea (ICES), a scientific organisation, and the Helsinki Commission - Baltic Marine Environment Protection Commission (HELCOM), an

16 Cf. <http://www.fao.org/documents/show_cdr.asp?url_file=/DOCREP/005/v9878e/v9878e00.htm> (last visited 11 April 2005).

17 Cf. <http://www.ibsfc.org/about/about_measures> (last visited 12 April 2006).

18 Cf. <http://www.oceanlaw.net/texts/yaounde.htm> (last visited 11 April 2005).

19 IBSFC Rule of Procedure 6.

20 IBSFC Rule of Procedure 5.2.

21 Cf. <http://www.ibsfc.org/documentation/ibsfc_rules_of_procedure> (last visited 12 April 2006).

environmental organisation, established under the “Convention on the Protection of the Marine Environment of the Baltic Sea Area”[22].

2.4.3 The legal nature of the IBSFC’s regulatory framework and shortcomings

The vocabulary applied in the IBSFC Fishery Rules emphasise their binding nature. However, most rules lack a penalty statement in case of infringement, except for Fishery Rule 3, Article 4, on the handling of overfishing of permitted landings: Landings in excess of the respective quotas shall lead to deduction from the corresponding quota in the following year[23].

Additionally, the binding character of the Gdansk Convention is flawed by explicitly providing for loopholes. Apart from a ninety days objection period[24], the Contracting parties are additionally given the possibility to withdraw or not accept a regulation “after the date of entry into force of a recommendation adopted by the Commission”[25]. Here, “any Contracting State may notify the Commission of the termination of its acceptance of the recommendation and, if that notification is not withdrawn, the recommendation shall cease to be binding on that Contracting State at the end of one year from the date of notification”[26]. Moreover, a “recommendation which has ceased to be binding on a Contracting State shall cease to be binding on any other Contracting State thirty days after the date on which the latter notifies the Commission of the termination of its acceptance of the recommendation”[27].

Further criticism refers to the lack of unified action to infringements among the Contracting Parties. Article XII transfers the task of implementation, control and punishment to the national authorities: “Each Contracting State shall take […] appropriate measures to ensure the application of the provisions of this Convention and of the recommendations of the Commission which have become binding for the Contracting State and in case of their infringement shall take appropriate action”[28].

2.5 The Common Fisheries Policy (CFP) of the European Community

2.5.1 The beginnings, development, and characteristics of the CFP before 2002

According to the provisions of a Common Fisheries Policy as established under the Treaty of Rome[29], the conservation and management of sea fishery resources is the

[22] Helsinki Convention, signed 1992, entered into force 17.1.2000.

[23] Cf. IBSFC Fishery Rule 3, Article 4, § 1, 2

[24] IBSFC, Gdansk Convention, Article XI, § 2

[25] IBSFC, Gdansk Convention, Article XI, § 4a

[26] Ibid.

[27] IBSFC, Gdansk Convention, Article XI, § 4b

[28] IBSFC, Gdansk Convention, Article XII, § 1

[29] Cf. Article 3 and Articles 32-38 of the Treaty establishing the European Community (Rome, 25 March 1957).

exclusive competence of the European Community. These provisions are newly envisaged in Council Regulation (EC) 2371/2002 of 20 December 2002, establishing a Community system for the conservation and sustainable exploitation of fisheries resources under the CFP[30].

The first Community system for conservation and management of fishery resources was established in Council Regulation (EC) 170/83[31]. Four main tasks were set out, which still apply:

- manage and regulate conservation and exploitation of the resource
- Structural measures
- Common organisation of markets
- Agreements with third countries

Total allowable catches (TACs) and quotas were enacted as the principal management tool. Additionally, new measures were introduced over time, during and following the first review process of the CFP in 1992, which resulted in a new framework for the CFP, established in Council Regulation (EC) 3760/92[32]. The log-book was introduced as control instrument, obliging fishermen to report fishing location, time, amount harvested, type, species of catch, and fishing gear applied. As a reaction to the perceived decline in Community fish stocks, multi-annual guidance programmes (MAGPs) were introduced in order to limit the activity at sea and to reduce the overcapacity of the fleets[33]. Moreover, technical regulations, such as minimal mesh size, minimum landing size, closed areas and seasons, were implemented.

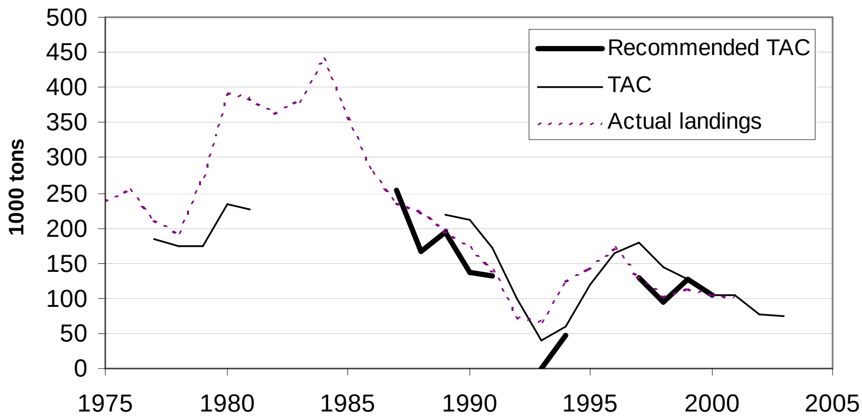

Figure 2.3: Recommended and agreed TACs for cod in the Baltic Sea and actual landings of Baltic cod[34].

30 "Council Regulation (EC) No 2371/2002 of 20 December 2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy", (2002) OJ L 358.

31 "Council Regulation (EEC) No 170/83 of 25 January 1983 establishing a Community system for the conservation and management of fishery resources", (1983).

32 "Council Regulation (EEC) No 3760/92 of 20 December 1992 establishing a Community system for fisheries and aquaculture", (1992).

33 D. Symes, "The European Community's common fisheries policy", (1997) 35 *Ocean & Coastal Management*, 137-155, p.149.

34 Source: L.G. Kronbak, "The Dynamics of an Open Access: The case of the Baltic Sea Cod Fishery - A Strategic Approach", (2002) IME working paper No. 31/02.

Nonetheless, a downward trend of many fisheries due to management fallacies and a clear unbalance between fishing fleets and available fisheries resources have become apparent. This has led to biological overfishing of many commercial fish stocks of the Community and an under-utilisation of fishing capacity of the Member States' fleets. The CFP has thus been judged a failure[35]. The biggest problem of the system is its dependence on accurate fish stock assessments for setting TACs and the subsequent political bargaining on TACs higher than recommended during the decision making process at the Council of Ministers. The agreed TACs were often out of line with scientific recommendations and the need to reduce catches. The mismatch between the scientific TAC recommendations, the politically adopted TACs, and the actually landed quantity of fish is illustrated exemplarily in Figure 2.3 for Baltic cod. Consequently, the TACs did not promote stock recovery and even resulted in a decline of the stock size. Another problem with TACs is the single-species nature: Single-species TACs are unable to work effectively in the mixed fisheries that characterise much of the Community's common pond[36].

Furthermore, the Community's system of control and enforcement was very ineffective, not able to counteract discarding and landing of blackfish. Enforcement, prosecution, and sanction was the Member States' duty, but there was no unified approach among the Member States until the reform of the CFP in 2002.

2.5.2 The new CFP under Council Regulation (EC) 2371/2002 of 20 December 2002[37]

The CFP was reviewed again in 2002. This review resulted in a reform of the CFP's framework[38].

The principal objective of the new CFP is to bring the fleet size in balance with the size of the resource. For that purpose, new management tools focus on reducing the size of the European fishing fleet, namely long-term management and recovery plans, decommissioning, a Community fleet register, entry-exit programmes, and emergency measures. The new Council Regulation (EC) 2731/2002 is subdivided into seven chapters, which will be discussed here.

Chapter I:

The scope of the new CFP is to provide for measures concerning:

- Conservation, management, and exploitation
- Limitation of environmental impact of fishing
- Conditions of access to waters and resources
- Structural policy and management of fleet capacity
- Control and enforcement
- Aquaculture
- Common organisation of markets
- International relations

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35 See *supra*, p.15 (D. Symes, 1997).

36 *Ibid*., p.147.

37 "Council Regulation (EC) No 2371/2002 of 20 December 2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy", (2002) OJ L 358.

The policy's basic principles are still non-discrimination and equal access, as modified by the concept of relative stability. The objective is to protect and conserve available and accessible living marine aquatic resources, to protect the marine environment, to provide for rational and responsible exploitation on a sustainable basis, while ensuring appropriate economic and social conditions for the sector, taking into account implications for the marine ecosystem, and in particular taking into account the needs of both producers and consumers. Finally, the aim is to provide good quality food to consumers. Chapter I moreover envisages the precautionary approach and – if scientific knowledge is sufficient – an ecosystem-based approach. Fisheries management decisions shall be based on sound scientific advice. Emphasis is also put on the involvement of stakeholders. According to these formulations in Chapter I, the focus of the new CFP stresses the importance of achieving environmental sustainability of the fishery resource.

Chapter II:

In Chapter II, measures to achieve conservation and sustainability are presented, i.e., long-term management and recovery plans, and emergency measures. Multi-annual management plans shall be implemented for stocks whose biomass is above B_{lim}, whereas stocks whose biomass is below B_{lim} shall be managed by multi-annual recovery plans (Art.6, IVd and 5, IVd). Management and recovery plans may include:

- setting of harvesting rules, which consist of a predetermined set of biological parameters to govern catch limits
- measures based on biological limit & target reference points (targets for every species to be reached within several years)
- the consideration of biological characteristics (e.g. multi-species interactions, ecosystem effects, spawning period)
- the possibility to reduce capacity in the framework of recovery plans
- emergency measures (Art. 7, Art. 8)
- TACs, fishing licences, technical measures.

Chapter II elucidates existing and additional new measures, focusing on stock conservation. Due to the abrogation of the MAGPs, there is no direct effort limitation scheme available anymore in the legal framework of the CFP. Indirectly, however, recovery plans allow for the reduction of fishing effort via restrictions of days at sea. This provision introduces flexibility to the management system. Nonetheless, the main management tool is still the setting of TACs, and its inherent problem of high susceptibility to uncertainty and poor quality of scientific advice remains. In spite of this disadvantage, the system has improved thanks to the implementation of long-term management plans. This tool will reduce the extent of political bargaining at the minister level in the European Council, because the TACs have to remain within a certain range to achieve the long-term management targets.

Chapter III:

Fleet policy and structural policy are grouped collectively in Chapter III. This indirectly serves as an economic approach to fleet management, as the use of public aid for capacity adjustment is of essential importance[38]. The chapter presents guidelines and rules for the necessary adjustment of the fishing fleet capacity in order to achieve a balance between fleet size and size of the resource. These are explicitly related to the withdrawal of aid for capacity renewal and the enhancement of aid for capacity reduction, for example, using decommissioning in cases where impacts of fishing effort reductions are severe. From an economic perspective, this adapted framework is of fundamental importance in relation to the adjustment of fleet capacity[39].

The new management system does not define specific capacity objectives. In contrast, the adjustment of capacity occurs indirectly via limitations on fishing effort defined under the long-term management and recovery plans. The main instrument to control fleet capacity is via a reference level for the capacity of the individual Member State, which is based on the objectives of the abrogated MAGP[40].

A new regime for fleet entry and exit is regulated in relation to the Community fleet register and to the reference levels of the fleet. If a Member State applies for financial aid for fleet modernisation, it has to withdraw an equal or even greater amount of capacity. Additionally, public aid for fleet renewal will only be granted, if the Member State's overall capacity is reduced (Art. 13.2).

Chapter IV:

The policy's principle of equal access to waters and resources in all Community waters is readopted in Chapter IV (Art. 17.1). Additionally, jurisdiction and sovereignty over the 12 nm zone is reassigned to the coastal state (Art. 17.2). The principle of "relative stability" in the allocation of fishing opportunities to each Member State is reaffirmed (Art. 20.1). The method of allocating a Member State's national quota to its fishermen is determined by the Member State itself (Art. 20.3).

Chapter V:

Chapter V establishes a community system to control and enforce the CFP in order to harmonise control and enforcement methods between the Member States. According to the subsidiary principle, the responsibility for control, inspection, and enforcement is reassigned to the Member States (Art. 23), whereas the Commission holds the right to control the enforcement activities and compliance of the Member States. The Member States' compliance is peer-reviewed by a compliance scoreboard.

The Council of the European Communities defined types of behaviour, which represent serious infringements of the rules of the CFP[41]. With respect to the follow-up of such infringements, Member States "shall ensure that appropriate measures are taken, including […] criminal proceedings […] where the rules of the Common Fisheries Policy have not been respected" (Art. 25.1). A catalogue prescribing concrete sanctions shall be established (Art. 25.4). Inspections shall follow a specific monitoring programme decided

38 E. Lindebo, H. Frost*, et al.*, "Common Fisheries Policy reform - A new fleet capacity policy", (2002), Fodevareokonomisk Institut, Kopenhavn, Report No. 141, p.12.

39 *Ibid*., p.12.

40 *Ibid*., p.13.

41 "Council Regulation (EC) No 1447/1999 of 24 June 1999 establishing a list of types of behaviour which seriously infringe the rules of the common fisheries policy" (1999), OJ L 167, p.5.

under Article 34c of Regulation (EEC) No 2847/93[42]. In order to facilitate control, Community fishing vessels shall install the satellite vessel monitoring system (Art. 22.1b). The joint Commission inspection structure also includes a Community Fisheries Control Agency (CFCA), to be established in Spain[43].

Chapter VI:

In Chapter VI, the decision-making procedure as well as possibilities of consultation are exposed. A new element concerning consultation is the establishment of Regional Advisory Councils (RACs). Their main purpose is to involve all stakeholders and interest groups in the preparatory process on matters of fisheries management and to advise the Commission. The group of different stakeholders comprises Ministries responsible for fisheries, scientists, fishermen associations, industry, labour unions, consumer organisations, NGOs, etc.

In general, the decision-making process in the EC follows a strict scheme, which is illustrated in Figure 4. Recommendations by the European Commission are transformed into community law by regulations adopted by the Council of Ministers on a proposal from the European Commission. The regulations are binding and directly applicable in all Member States[44]. In case of infringement of fishery regulations, Article 31 of Council Regulation (EEC) No 2847/93 includes measures to be taken in the case of non-compliance with the rules in force[45]. The formal EC position is established following co-ordination within the framework of the entire Community (Fig. 2.4).

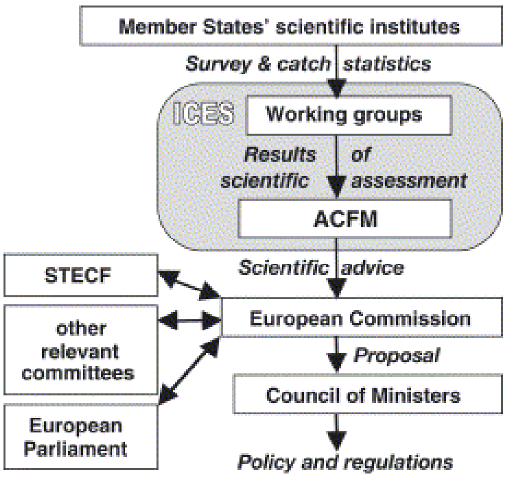

Figure 2.4. Route for the implementation of scientific research into fisheries policy within the European Community.

42 "Council Regulation (EEC) No 2847/93 of 12 October 1993 establishing a control system applicable to the common fisheries policy" (1993), OJ L 261.

43 E. Mastracchio, "The role of a Community Fishery Control Agency", (2004) *International Fisheries Compliance Conference*.

44 Cf. Article 249 of the Treaty establishing the European Community (consolidated text) of 24 December 2002, OJ C 325 24.12.2002, p. 33

45 "Council Regulation (EC) No 1447/1999 of 24 June 1999 establishing a list of types of behaviour which seriously infringe the rules of the common fisheries policy " (1999), OJ L 167.

Chapter VII:

Final provisions are given in Chapter VII.

2.6 Evaluation of the new CFP with respect to achieving sustainable fisheries in the Baltic Sea

The latest reform of the CFP, envisaged in Council Regulation (EC) 2371/2002, has opened new doors for more effective and sustainable management of European fisheries. In contrast to the IBSFC rules and recommendations, the EC regulations are of a binding nature and do entail sanctions in case of infringement of the law. Regulation (EC) 2371/2002 has to be regarded as a framework regulation, providing wide, new opportunities to further develop and define new, specific rules concerning sustainable fisheries management. Therefore, many issues and aspects therein are not treated in detail, but the text rather calls for negotiations between the Commission and the Member States to prepare more specific and elaborate regulations. One of the issues remaining to be tackled in the future is, for instance, the development of a catalogue of specific sanctions. Nonetheless, examples exist of specific sanctions, which have already been implemented in Community law, e.g. the regulation and suspension of fishing activities, if a Member State has overfished its allocated quota[46].

An important and explicitly stated aspect that reveals improvement of the new CFP is the attempt to unify and harmonise the system of control and enforcement in the EC. Since the Community's fishery resources are transboundary and exploited by several Member States at the same time, equity in control, enforcement, and prosecution is very important, for it can prevent cheating and contribute to better compliance.

Furthermore, a new opportunity and a major step forward is the introduction of Regional Advisory Councils. Although they will initially serve as advisory bodies to the European Commission only, a future expansion of their responsibilities towards regional management bodies is imaginable and possible. Corten[47] recommended such a delegation of administrative responsibility from Brussels to "regional units" as one possibility to increase the chances of successful management. Otherwise, due to the large geographical expansion of EC waters following past enlargements of the Union, the final result of centralised decision-making is often "a large number of complicated regulations which are not really suitable for any given situation"[48]. RACs present an opportunity to change this situation, which has been governed by centralised administration and management, decreasing the distance between managers and the national fisheries in each countries. By opening the management and decision-making process to all stakeholders in a regional advisory body, the EC may finally gain support of its regulations by fishermen and fishing industries.

Another overriding problem of the first two decades of the CFP, which – according to Corten – has produced "disappointing results" is the "fish stock management through

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46 Article 21 of "Council Regulation (EEC) No 2847/93 of 12 October 1993 establishing a control system applicable to the common fisheries policy" (1993), OJ L 261, Art. 21.

47 Corten, "The widening gap between fisheries biology and fisheries management in the European Union", (1996) 27 *Fisheries Research*, 1-15, p.15.

48 *Ibid*., p.10.

quota regulations"[49]. Under the new CFP framework, quota management can be extended by effort limitation schemes via the establishment of long-term management and recovery plans. At present, no management plan has been established yet. Several recovery plans, however, have already been proposed by the European Commission, which explicitly limit days at sea for individual fisheries in addition to the TAC and quota regulations, e.g. for cod, hake, sole, and Norway lobster stocks[50]. The IBSFC has already agreed to establish a recovery plan for Baltic cod in 2001[51]. Once EC administration will fully be in place for the Baltic Sea fisheries, a recovery plan for Baltic cod is likely to be implemented quickly by modification and expansion of the IBSFC's preparatory work. Bilateral agreements with Russia should not hamper management efficiency, for this has already been proven successful with other partners, e.g. with Norway concerning fisheries in the Barents Sea[52]. The long-term nature of the management and recovery plans presents an additional advantage: The extent of political bargaining during the Council Meeting of Ministers every year in December to decide on TACs and quotas is limited, as quotas have to remain within the framework defined in the long-term plans.

Flexibility in management to spontaneously react to unforeseen environmental or anthropogenic impacts is explicitly taken account of in the new CFP by means of emergency measures. Furthermore, the CFP stresses the inherent necessity to conserve and protect not only the fisheries resources but also the ecosystems they dwell in. With special regard to the Baltic Sea environment, this emphasis is of crucial importance for Baltic Sea fisheries management due to the special hydrographic and environmental conditions in the Baltic Sea, the influence of climate variability on hydrographic conditions in light of global climate change, and the permanent threat to flora, fauna and the ecosystem posed by shipping.

Caveat

The optimism concerning improvement in fisheries management due to the establishment of the new CFP should be accompanied by a caveat. There are, of course, critical voices, who challenge that the new CFP represents an improvement towards sustainability[53]. These originate on one side from environmental activists and NGOs; on the other side, sympathisers of the fishing industry express their concerns, as well. The advantages and benefits of the CFP, as described in the previous paragraphs, can only be achieved if the European Commission and the Member States, acting via the Council and the Parliament, take the necessary actions in the right direction. As pointed out above, the CFP presents a rather general binding regulatory framework, whereas the extent to which improvement is achieved depends on the European Commission's initiative and willingness to take progressive action, transforming the general legal

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49 *Ibid*., p.4.

50 Commission of the European Communities: COM(2003) 237 final; COM(2003) 374 final; Com(2003) 818 final; COM(2003) 819 final.

51 IBSFC Resolution XVII on Recovery Plan for the Baltic Cod.

52 Cf. <http://odin.dep.no/fkd/engelsk/p10001957/pressem/008041-070202/dok-bn.html> (last visited 12 April 2005).

53 Cf. T. Gray and J. Hatchard, "The 2002 reform of the Common Fisheries Policy's system of governance--rhetoric or reality?" (2003) 27 *Marine Policy*, 545-554; T. Daw and T. Gray, "Fisheries science and sustainability in international policy: a study of failure in the European Union's Common Fisheries Policy", (2005) 29 *Marine Policy*, 189-197.

framework into specific regulations. Only if the Commission and the Member States are willing to take courageous steps, the CFP may lead to decentralisation and liberalisation of the system and a separation of powers among national and regional administrations, i.e., the application of the subsidiarity principle. Moreover, the stakeholders have to be willing to communicate and get involved with the administrators and managers.

2.7 Conclusions for management of the Baltic Sea fisheries

Future management of the Baltic Sea fisheries resources is likely to benefit from a switch away from IBSFC management to CFP-based EC management, if all, let alone some, of the opportunities for improvement, which the new CFP regulation as of December 2002 has envisaged, are realised. First of all, the commercial fish stocks in the Baltic Sea may benefit from a stronger emphasis on conservation and recovery. Secondly, the decommissioning scheme can help to reduce any overcapacity present in Baltic Sea fishing fleets. Additionally, old and ineffective vessels, which sometimes even pose threats to their crew, can be either scrapped or modernised, since the structural policy within the new CFP framework offers aid directed towards these purposes. Such money is not available in the IBSFC framework.

An evaluation of the effects of the CFP on fish stocks and on fisheries, however, depends on the point of view. Can one of the three pillars of sustainable fisheries be considered to be most important, and if yes, which one? In my view, the only basis for sustainable fisheries is a viable fish stock, because we cannot provide neither for sustainable resource exploitation nor for the allocation of the profits in a socially sustainable manner without the existence of viable fish stocks. Therefore, the conservation of stocks is of prime importance. The new CFP aims to achieve this objective by introducing long-term management and recovery plans, emphasising the necessity of a healthy marine ecosystem, and allowing for flexible management tools.

The empowerment of the Community, mainly through control by the European Commission should be seen as positive, since fish stocks as well as the fishing activities in Community waters are transboundary. Hence, unification and harmonisation in control and enforcement is a prerequisite to the equality principle and is likely to result in better compliance of the Member States and also of the individual fishermen.

Chapter 3 - Testing the implications of a permanent or seasonal marine reserve on the population dynamics of Eastern Baltic cod

3.1 Introduction

Baltic Sea fish stock assessments found a large decline of the cod biomass since the mid-1980s (ICES, 2003). Recent estimates of spawning biomass fall below B_{lim} (the precautionary biomass level, below which recruitment is impaired), implying a reduced reproductive capacity of the stock (ICES, 2003; 2004b). Hence, the stock is classified "as being outside safe biological limits", posing concerns for Baltic Sea fisheries management (IBSFC, 2004).

The principal policy instrument for managing the Baltic Sea Fisheries is annual 'Total Allowable Catches' (TACs), supplemented by technical regulatory measures, such as minimum landing sizes, mesh size regulations, and closed periods for fishing (IBSFC, 2002). Due to the persistently severe situation of the stock, the International Baltic Sea Fisheries Commission (IBSFC) adopted in 2002 a new recovery plan for the Eastern and Western Baltic cod stock, which focuses on meeting clearly defined stock reference points within several years (ICES, 2004b). Also, in addition to the catch quotas, a spawning closure has been established since 1995, prohibiting the cod fishery every year between 16 June and 15 August. Furthermore, the IBSFC implemented a seasonal area closure on all fishing in the Bornholm Deep. This 'summer ban' was extended by several weeks in 2005, lasting now from 15 May till 31 August 2005. Moreover, the IBSFC established additional spawning area closures in the Gdansk Deep and the Gotland Deep. Nonetheless, TACs are still in place and thus remain the main policy instrument. Their effectiveness, however, relies heavily on the quality of scientific fish stock assessments, which are highly susceptible to the variability and uncertainty of a number of input parameters (e.g. catch-at-age and weigth-at-age data, mortality estimates for the terminal years, environmental parameters) and the difficulty in integrating complex processes, such as multispecies interactions and ecosystem functions (e.g. Botsford *et al.*, 1997; ICES, 1998; Walters, 2001). Furthermore, illegal landings falsify the empirical data basis of the assessments.

Recently, interest has focused on the potential of marine reserves or marine protected areas (MPAs) as an alternative fishery management tool (e.g. Pauly *et al.*, 2002; PROTECT, 2005; Roberts *et al.*, 2001, 2005; Walters, 2001). Several field studies have illustrated that closed areas can lead to increases in fish biomass, density, and size, and ecosystem diversity (reviewed by Halpern, 2003). It is, however, important to recognise realistic limitations and expectations of the MPA approach and not to present reserves as a general panacea (Allison *et al.*, 1998; Dayton *et al.*, 2000; Kaiser, 2005): Whether MPAs can enhance the fisheries outside of their borders is still in question, as success depends on the setting, size and design of the reserve, on the life history and migratory behaviour of the species, on the specific characteristics of the ecosystem, and on the fishing activity surrounding the MPA. In contrast to the tropics, species variability is lower in temperate waters, but environmental conditions are much more variable, rendering the implementation of MPAs as fisheries management tool more complicated. Only very few empirical studies have investigated the effects of MPAs on mobile temperate fish and their related fisheries. MPAs in such studies either lack adequate size and proper enforcement (Martell *et al.*, 2000) or were effectively used to enhance a fishery for sedentary species, e.g. sessile scallops instead of migratory Atlantic cod and haddock (Murawski *et al.*, 2000). Since large reserves have as yet not been implemented, we can only rely on modelling studies to evaluate the implications of MPAs for migratory fish stocks and their respective fisheries in temperate regions.

Here, we present a spatially disaggregated, discrete time, age-structured model of the population dynamics of the Eastern Baltic cod (*Gadus morhua callarias L.*) to investigate the biological consequences of the establishment of a permanent or a seasonal marine reserve in a biologically highly productive area in the Baltic Sea. Our approach to the assessment of the implications of an MPA-based management policy and its potential importance on stock dynamics follows and extends the approach presented in Apostolaki *et al.* (2002), who simulated the potential of partial closures as rebuilding strategy for the Mediterranean hake fishery. Our model is a single-species, but is fed with output from an area-disaggregated Multispecies Virtual Population Analysis (adMSVPA). Here, we decided not to implement the adMSVPA, but rather a simplified model, which compares favourably with the complex behaviour of the cod stock and the outputs of the adMSVPA. The advantage of this approach relative to the adMSVPA is its transparent structure and the ability to readily couple it to complex bio-economic models and thereby scenario test the implications of management options and environmental conditions on stock dynamics.

Since, at present, there are no quantitative data on Baltic cod migration available and qualitative descriptions vary widely, here we decided to investigate the situation as if there were three independent substocks of the Eastern Baltic cod in three particular subdivisions. Although unrealistic, we believe, that such a simplified investigation serves as basis for future bio-economic modelling.

We apply our model to simulate stock development of the Eastern Baltic cod over 50 years under various environmental conditions using different management policies. Our management scenarios investigate the biological effects of the establishment of an MPA in subdivision (SD) 25 (Figure 3.1), which encompasses the Bornholm Basin, as opposed to policies based on the overall reduction of fishing mortality in the Eastern Baltic Sea. Marine biologists and conservationists have already recommended the establishment of an MPA in SD 25 (MacKenzie *et al.*, 1996), as the Bornholm Basin has been the most important spawning ground of Baltic cod during the last decades due to favourable hydrographic conditions (Nissling and Westlin, 1991; Nissling *et al.*, 1994; Plikshs *et al.*, 1993).

Baltic cod eggs, which are neutrally buoyant, need a minimum salinity ($S \geq 11$ psu) and a minimum concentration of dissolved oxygen ($c[O_2] \geq 2$ ml/l) to develop (e.g. Nissling *et al.*, 1994). The volume of water having these characteristics has been termed the "reproductive volume" (RV) for this species (e.g. MacKenzie *et al.*, 2000; Plikshs *et al.*, 1993) and been employed in the development of stock and recruitment models of Baltic cod (e.g. Köster *et al.*, 2001b, 2003; STORE, 2002). In the Eastern part of the Baltic Sea, a reproductive volume usually only occurs below 50 m depth in the deep basins of the Baltic Sea, namely the Bornholm Basin, the Gdansk Deep, and the Gotland Deep, located in SD 25, 26 and 28, respectively (Figure 3.1) (Bagge *et al.*, 1994). The bottom water in the deep basins regularly becomes anoxic due to the bacterial breakdown of organic material below the halocline combined with reduced replenishment due to bottom topography resulting in restricted horizontal and vertical circulation in the Baltic deep water (Matthäus and Lass, 1995).

The reproductive volume is replenished when inflows from the North Sea transport saline and oxygen rich water into the Baltic basins, termed "Major Baltic Inflows" (MBI) (e.g. Matthäus and Frank, 1992; Schinke and Matthäus, 1998). Its size mainly depends on the frequency and strength of such North Sea inflow events as opposed to the length of stagnation periods (e.g. MacKenzie *et al.*, 2000; Oeberst and Bleil, 2000). A large reproductive volume, with hydrographic conditions favourable for successful cod egg development, occurs less frequently in the Gotland Deep and the Gdansk Basin than in the Bornholm Basin. Their location farther East/Northeast and hence more distant from the North Sea leads to stagnation periods which are much more pronounced and prevail much longer than farther West in the Baltic Sea (Köster *et al.*, 2001a; Plikshs, 1993, 1996). Therefore, the Gotland Deep in SD 28 and the Gdansk Basin in SD 26 have become less important for cod spawning since 1986. These facts support our hypothesis that a closure of ICES subdivision 25 can result in a significant biological benefit to the Baltic cod stock recovery.

We focus on a comparison of a permanent versus a seasonal marine reserve, as temporary openings of an MPA to fishing might be the only opportunity for fishermen to accrue catches of the protected part of the fish stock, in particular in cases where the fish do not frequently migrate out of the protected area.

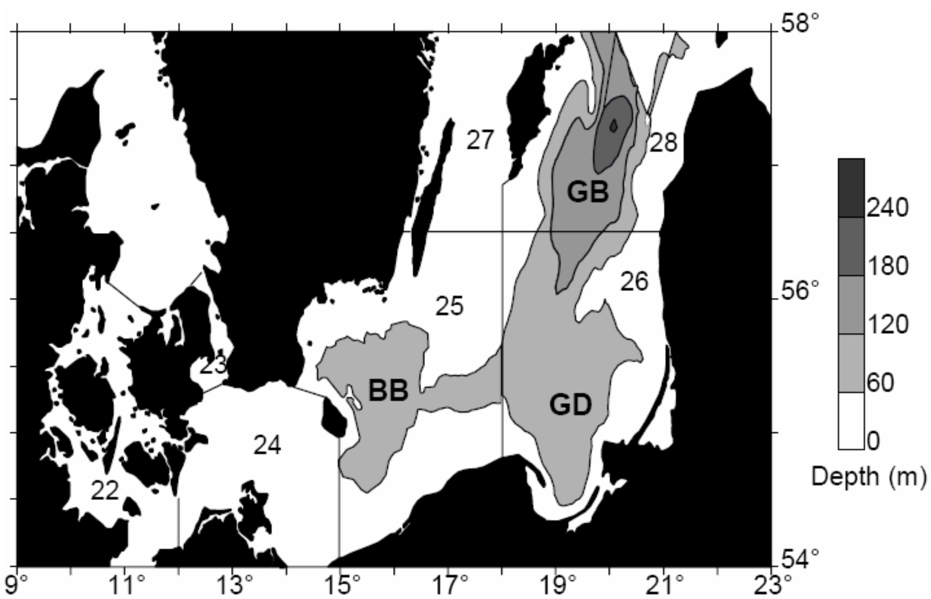

Figure 3.1. Map of the Baltic Sea with deep basins of the Central Baltic in greyscale (BB - Bornholm Basin; GD - Gdansk Deep; GB - Gotland Basin; numbers - ICES Subdivisions). Source: Möllmann, 2001).

3.2 Methods

3.2.1 Model construction

The Eastern Baltic cod stock is distributed over ICES subdivisions (SD) 25-32 (Aro, 1989), however, the majority of cod is found in the three ICES subdivisions 25, 26, and 28 (Fig.1), which our study is confined to (Sparholt *et al.*, 1991). The cod in subdivisions 25, 26, and 28 are assumed to be a stock unit composed of age-groups 0-8 with the oldest age-group not handled as plus group. Based on maturity estimates from maturity ogives, we assume that cod of age 2 and older are mature and thus able to spawn (ICES, 2002; STORE, 2002). The age of entry into the exploitable fishery is also assumed to be age 2.

We use quarterly data on stock size, natural, predation and fishing mortality of cod for the ICES subdivisions (SD) 25, 26, and 28 from adMSVPA, covering the time period 1974 to 1999 (ICES, 1999, 2001b; Köster *et al.*, 2001a, 2001b). Basin-specific data on reproductive volume for the time period 1976 to 1996 are specified based on estimates from MacKenzie *et al.* (2000) and Köster *et al.* (2001b), with estimates for the most recent years taken from ICES (2004a).

A discrete time, age-structured model is applied to calculate cod stock size (N) for each age-group (a) and for each subdivision (r), accounting for recruitment (R) and mortality due to fishing (F), predation (P) and natural mortality (M), using an extension of the standard equation of population dynamics (Beverton and Holt, 1954). It is an exponential decay model, in which stock size at one time is calculated as a function of stock size in the previous time step, multiplied by the exponential mortality coefficients (M,P,F). There are three separate equations needed to incorporate changes in age (a) and year (y), from one quarter (q) to the next (Equations 3.1, 3.2) and add recruitment (R) once a year in quarter 3 (Eq. 3.3). For definition of symbols, refer to Table 3.1.

(3.1) $$N_{a+1,r,q=q1,y+1} = N_{a,r,"q4",y} \cdot e^{-M\ -P_{a,r,"q4",y}-F_{a,r,"q4",y}}$$

(3.2) $$N_{a,r,q=q2\vee q4,y} = N_{a,r,"q1\vee q3",y} \cdot e^{-M\ -P_{a,r,"q1\vee q3",y}-F_{a,r,"q1\vee q3",y}}$$

(3.3) $$N_{a,r,q=q3,y} = N_{a,r,"q2",y} \cdot e^{-M\ -P_{a,r,"q2",y}-F_{a,r,"q2",y}} + R_{r,y}\ |_{a="a0"}$$

Table 3.1. Variables, parameters, and indices used in our model.

variables and parameters			indices
$N_{a, r, q, y}$	Eastern Baltic cod stock size in number of fish [million]	r	region (i.e., subdivision: SD 25, SD 26, SD 28)
$R_{r, y}$	Recruitment [million]	a	age-group (ag0 – ag8)
M	Natural Mortality	q	quarter (qu1 – qu4)
$P_{a, r, q, y}$	Predation Mortality	y	year (y1976 – y2050)
$F_{a, r, q, y}$	Fishing Mortality		
$ssN_{r, q, y}$	Spawning stock size in number of fish		
$RV_{r, y}$	Reproductive Volume		

The endogenous variables in our model are stock size (N), recruitment (R), and cannibalism (P). For parameterisation of the two sub-models calculating recruitment and cannibalism, we performed multiple linear regression analyses.

Cannibalism (Predation mortality P)

Predation mortality refers to cannibalism by mature cod on the early and juvenile life stages of cod (ages 0, 1, and 2). In accordance with Köster *et al.* (2001b), predation mortality is linearly related to the cod spawning stock size (ssN), i.e., the sum of mature population numbers at ages 2-8, in the corresponding subdivision: $P_{a,r,y} = d_{a,r} \cdot ssN_{r,"q1",y} + e_{a,r}$. Table A3-1 in the Appendix (Section 3.7) shows the parameters and statistical outputs of our regression analyses, performed to describe predation mortality of the early life-stages of cod (age-groups 0, 1, and 2) in the three subdivisions as a function of the size of the spawning stock. In this exercise, the independent variable (ssN) explains 70-88% of the variance of predation mortality, depending on the age-group and subdivision.

Recruitment (R)

In our approach, recruitment refers to 0-group cod. Here, young of the year enter the model in the third quarter every year (cf. Eq. 3.3), if a spawning stock exists. Thereafter, these early life stages are subject to cannibalism and to natural mortality. Köster *et al.* (2001b) have shown that cod recruitment in the Baltic Sea cannot suitably be described by a simple stock-recruit relationship such as the Ricker (1958) or Beverton & Holt (1954) curves, because environmental conditions in the deep basins play a crucial role for the recruitment success of Baltic cod (cf. Section 3.1). Here, we calculate recruitment in each of the three subdivisions as a function of the basin-specific spawning stock size (ssN) and the size of the basin-specific reproductive volume (RV). In Tables A3-2 and A3-3 in the Appendix, we show functional forms and statistics of eight different possibilities (cf. equations #1 – #8) of combining the two explanatory variables ssN and RV. The tested functional forms explain 35-64% of the variance of recruitment in SD 25 and 0-85% in SD 26 and 28. In SD 25, the inclusion of RV as second explanatory variable increases the explained variance of functional forms # 2, #3, and #4 as opposed to #1, as well as for the Ricker-type functional forms #6 and #7 as opposed to #5.

Equation #2 has the highest predictive power in SD 28, explaining 85% of the variance of recruitment, whereas equation #6 explains 64% and 85% in SD 25 and 26, respectively. Equation #6, however, is not sensitive to the size of the spawning stock in SD 25 and SD 26 (p(t-stat.) > 0.6, cf. Tables A2&A3); hence, it is not used in this study. Since equation # 2 explains 57%, 83%, and 85% of the variance of recruitment in SD 25, 26, and 28, respectively, here we chose this linear combination of ssN and RV for calculating recruitment in our scenario analysis: $R_{r,y} = a_r \cdot ssN_{r,"q1",y} + b_r \cdot RV_{r,y} + c_r$. The regression parameters of the selected model #2, are significant at the 1% level of significance in SD 25 and 26 (cf. Tables A3-2 and A3-3 in the Appendix). In SD 28, the level of significance of the explanatory variable RV is 24%. As a matter of simplicity, we decided to apply the same functional form to calculate recruitment in all three subdivisions (instead of applying equation #1 in SD 28), and hence, we also chose equation #2 in SD 28.

The lack of density dependence in this linear model does not pose a problem in the case of the Eastern Baltic cod, as the stock is currently at a very low stock level. At such low level, the stock is limited neither by competition for food nor by cannibalism and predation. Historic stock records reveal that the Baltic cod spawning stock has not exceeded a quantity of 0.7

billion. We point out that the first part of the Ricker curve, with spawning stock number between 0 and 0.7 billion, can be approximated by a linear function.

Fishing mortality (F)

As our prime aim is an analysis of selected management policies, which constrain fishing mortality (F), here, F is an external forcing parameter, treated as exogenous variable. F differs between the investigated management scenarios, but is held constant during a management scenario. For the period 1976-1999 we apply the quarterly fishing mortalities derived by adMSVPA. During the simulation period, 2000-2050, the average fishing mortalities are modified according to the management policies, as described below.

Natural mortality (M)

Natural mortality was assumed to be 0.2/year, equally distributed over quarters, corresponding to standard MSVPA runs in the Baltic Sea (Sparholt, 1991).

3.2.2 Statistics and model validation

We tested the data for autocorrelation (Durbin-Watson test), checked the significance of variables (t-test) and the quality of the multiple regression between modelled and observed stock sizes. We omitted years 1976, 1979, and 1996 in our regression analyses for recruitment due to data inconsistencies and tuning problems of the adMSVPA during these years (Köster *et al.*, 2001a, 2001b).

To assess the overall accuracy of our model, combined over subdivisions 25, 26, and 28, the projected stock sizes were summed over all ages and all three subdivisions, and the resulting total stock size was compared to corresponding estimates from the standard ICES stock assessment for the Central Baltic for the time series 1976-1999 (ICES, 2002).

3.2.3 Scenario analysis

(A) Management Scenarios

Our analyses focus on the establishment of a marine reserve in SD 25. Here, we compare the development of the stock size of Eastern Baltic cod under five selected management policies:

1. FasU — Fishing mortality ‘as usual’, applying the average fishing mortality of 1990-1995 over the 50-year simulation period.
2. RoF70 — overall reduction of fishing mortality by 70% in all three subdivisions (corresponds to ACFM advice for, 2003).
3. C25q1q2 — seasonal closure of SD 25 in quarters 1 and 2; quarters 3 and 4 are open to reduced fishing (fishing mortality in quarters 3&4 is reduced by 50%).
4. C25 — permanent closure of SD 25.
5. TC — total closure, i.e., fishing mortality is zero in all three subdivisions (corresponds to ACFM advice for 2005).

Model runs are performed covering the years 1976-2050 with the different management scenarios initiated in year 2000. Quarterly estimates of fishing mortalities are available from adMSVPA until 1999 (Köster *et al.*, 2001a). The management scenarios we have chosen can be implemented in our model by the following equation:

(3.4) $$F^{MR}{}_{a,r,q,y} = \alpha_{r,q} \cdot F_{a,r,q,y} + \beta \cdot F_{a,r,'SD25',y}$$

Fishing mortality in the individual subdivisions after marine reserve implementation ($F^{MR}{}_{a,r,q,y}$) is derived from the pre-reserve fishing mortality ($F_{a,r,q,y}$), which defines the FasU scenario, and the degree of fishing effort redistribution from SD 25 into SD 26 or 28. As pre-reserve fishing mortality, we take the average fishing mortality of the years 1990-1995 and apply it to the simulation period 2000-2050. We tested the effect of using other constant fishing mortalities for the simulation period, e.g. averages of the years 1986-1995 and 1974-1999. However, results of these simulations showed little variation from those using the average fishing mortality from 1990-1995.

Here, we assume that fishermen will only redistribute their effort if there are spillover fish from the reserve to follow. Since we neglect fish migration, we therefore do not study effects of effort redistribution, and hence, β is zero in the five presented management policies. Values for the coefficient α according to the corresponding scenarios are given in Table 3.2.

Table 3.2. Coefficient $\alpha_{r,q}$, defining management scenarios 1-5.

Management Scenario		*SD 25*	*SD 26*	*SD 28*
1. FasU		1	1	1
2. RoF70		0.3	0.3	0.3
3. C25q1q2	q1,q2:	0	1	1
	q3,q4:	0.5	1	1
4. C25		0	1	1
5. TC		0	0	0

(B) Environmental Scenarios

Data on reproductive volume are available until 1999. To perform simulations of the Baltic cod population dynamics, we also need to specify future environmental conditions. The size of the reproductive volume in the three spawning basins depends on the frequency and strength of major Baltic inflows from the North Sea, which are triggered by large scale and local atmospheric forcing conditions, such as the North Atlantic Oscillation (Hinrichsen *et al.*, 2002; Schinke and Matthäus, 1998). There are, however, no climate models as yet available that project future atmospheric conditions for the Baltic Sea region. In the present study, we do not attempt to predict reproductive volume; instead, we look at trends of cod stock development based on the reoccurrence of historic environmental conditions. Thus, for the simulation period (2000-2050) we base our environmental scenarios on the observed reproductive volume as it was estimated for the years 1974-1999. Under environmental conditions 1, we apply the historic data set starting in 1974, when reproductive volume was high in all three subdivisions. Under environmental conditions 2, we assume that unfavourable conditions prevail in the first years of the simulation period; therefore, we start the simulation with the reproductive volume data of year 1981 and then repeat the historic data sequence from 1981 through 1999 followed by 1974 to 1980. We also investigate two extreme cases of having very large or very small reproductive volumes for a cycle of several years. The four environmental conditions can be characterised as follows:

- Environmental conditions 1 (“HighLow”):
  varying reproductive volume; the data sequence from 1974-1999 is applied repeatedly for the simulation period 2000-2050.
- Environmental conditions 2 (“LowHigh”):
  varying reproductive volume; the data sequence from 1981-1999 followed by 1974-1980 is applied repeatedly.
- Environmental conditions 3 (“HighHigh”):
  constantly high reproductive volume; data from year 1977.
- Environmental conditions 4 (“LowLow”): six year cycle of low reproductive volume; the data sequence from 1985-1990 is repeatedly applied.

3.3 Results

3.3.1 Model validation

A comparison of the development of the cod spawning stock size derived by our model #2 in contrast to the spawning stock size derived by extended survivor analysis (XSA), i.e., the ICES standard stock assessment technique, reveals that our model underestimates the spawning stock size in the first part of the validation period 1976-1999 whereas it overestimates values towards the end of the validation period. This problem can be attributed to flaws in the recruitment equation in SD 25, which does not accurately reproduce the observed recruitment, showing the same trends of under- and overestimation in the late 1970s/early 1980s, and in the early 1990s, respectively. Nevertheless, our combined model, applying recruitment equation #2, explains 72% of the variance of ICES standard stock assessment estimates (2002) (Figure 3.2).

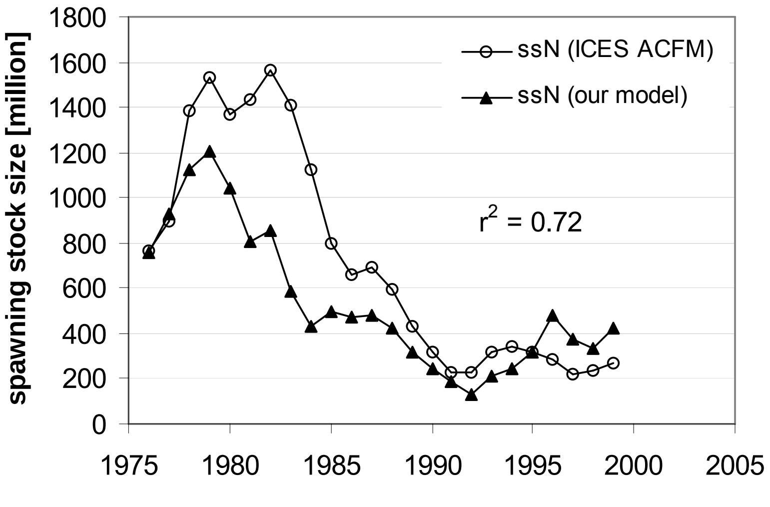

Figure 3.2. Linear regression of the spawning stock size, derived by our model (applying functional form #2 for calculating recruitment) with spawning stock estimates derived by ICES standard stock assessment; time series: 1976-1999.

This correlation is based on the number of fish in millions. If we base the correlation on fish biomass instead of stock size in numbers by multiplying the number of fish in each age-group with the average weight-at-age of each age-group, the quality of the correlations diminishes (r^2 = 66%): Errors with age-readings in Baltic cod, regional differences in the quality of the individual fish, as well as the standardised ICES procedure of determining mean weight-at-age data at the beginning of a year, derived from the 12 months average (thus neglecting fish growth) cause additional uncertainty, and hence a loss in precision (ICES, 2001; Reeves, 2001). For that reason, in the following we present results of the spawning stock in numbers instead of in biomass.

3.3.2 Scenario analysis

The 50-year-simulations are initiated in the year 2000, when the size of the Eastern Baltic cod stock was very low and the fishery considered to be overexploited. The curves in Figures 3.3-3.6 depict the trend of the development of the cod spawning stock in millions of fish, summed over SD 25, 26, and 28, for alternative environmental conditions that we will present separately.

Environmental conditions 1 ("HighLow")

The simulation period under environmental conditions 1 starts with several years of large reproductive volume in the three subdivisions (large black, white, and grey bars in Fig.3). This leads to an erratic increase in the spawning stock size in 2004 under all five management scenarios (Figure 3.3). The reproductive volume decreases within four years after the major Baltic inflow event in 2002 and remains low for about 10 years from 2007 onwards. With a lag period of two years, the spawning stock size decreases gradually under all five management scenarios while reproductive volume remains low. The decrease in stock size is most evident for management scenario 1 (FasU) with fluctuations in stock size around a higher stock size dampened in scenario 5 (TC). Under management scenarios 2, 3, and 4, the spawning stock size increases by 80, 100, and 120%, respectively during the first seven years of the simulation period. Scenario 4 (C25) results in an initial increase in the cod spawning stock size to > 1 billion, a level similar to the spawning stock size at the end of the 1970s, beginning of the 1980s. Under management scenario 5 (TC), the spawning stock size increases by 160% to unprecedented high values. Under management scenario 1 (FasU), the spawning stock size initially increases by 50% to approx. 700 million cod within four years. While reproductive volume is low, spawning stock size then decreases to less than 200 million spawners. This situation resembles the extremely low level of the spawning stock in 1992 (ICES, 2003, 2004b). The stock does not go extinct under environmental conditions 1, because the reoccurrence of inflows after about 15 years leads to the replenishment of reproductive volumes and thus to stock recovery.

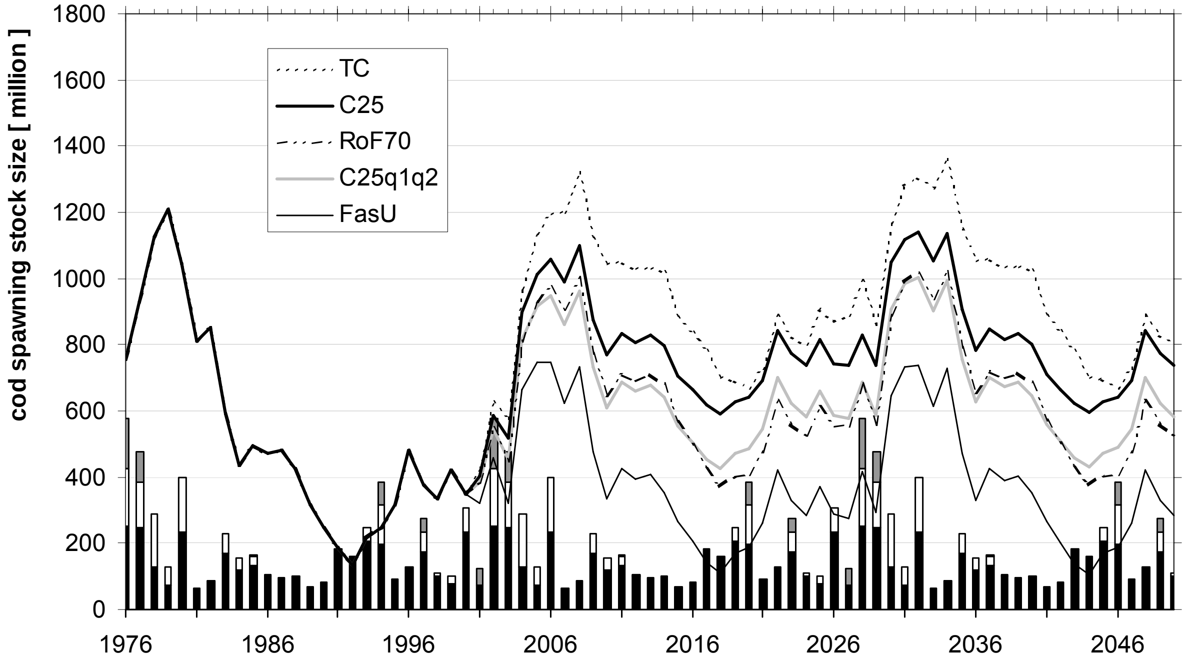

Figure 3.3. Simulations based on environmental conditions 1 ("HighLow"): data sequence from 1974-1999 is applied repeatedly for the simulation period 2000-2050. Management scenarios: (FasU) Fishing "as Usual"; (C25q1q2) closure of SD 25 in quarters 1 and 2, quarters 3 and 4 are open to fishing reduced by 50%; (RoF70) 70% reduction of fishing mortality; (C25) 100% closure of SD 25; (TC) Total Closure = zero fishing. Bars: reproductive volume [km^3] in SD 25 (black), in SD 26 (white), in SD 28 (grey).

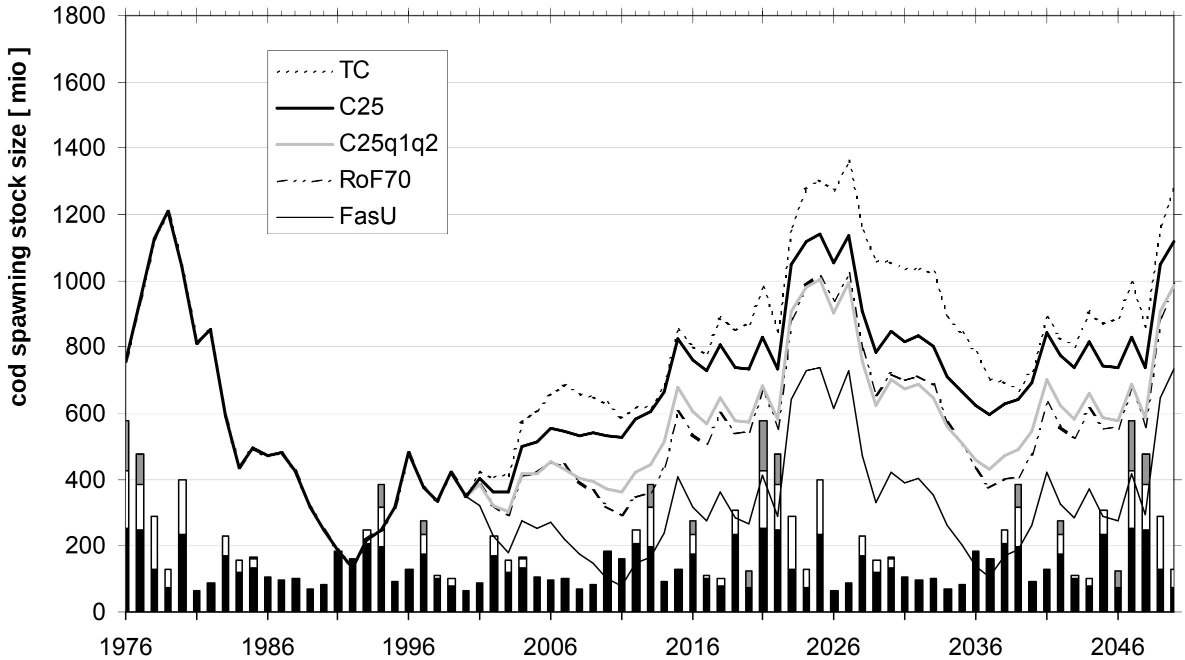

Figure 3.4. Simulations based on environmental conditions 2 ("LowHigh"): data sequence from 1981-1999 followed by 1974-1980 is applied repeatedly. See Figure 3.3 legend for explanation of the graphs.

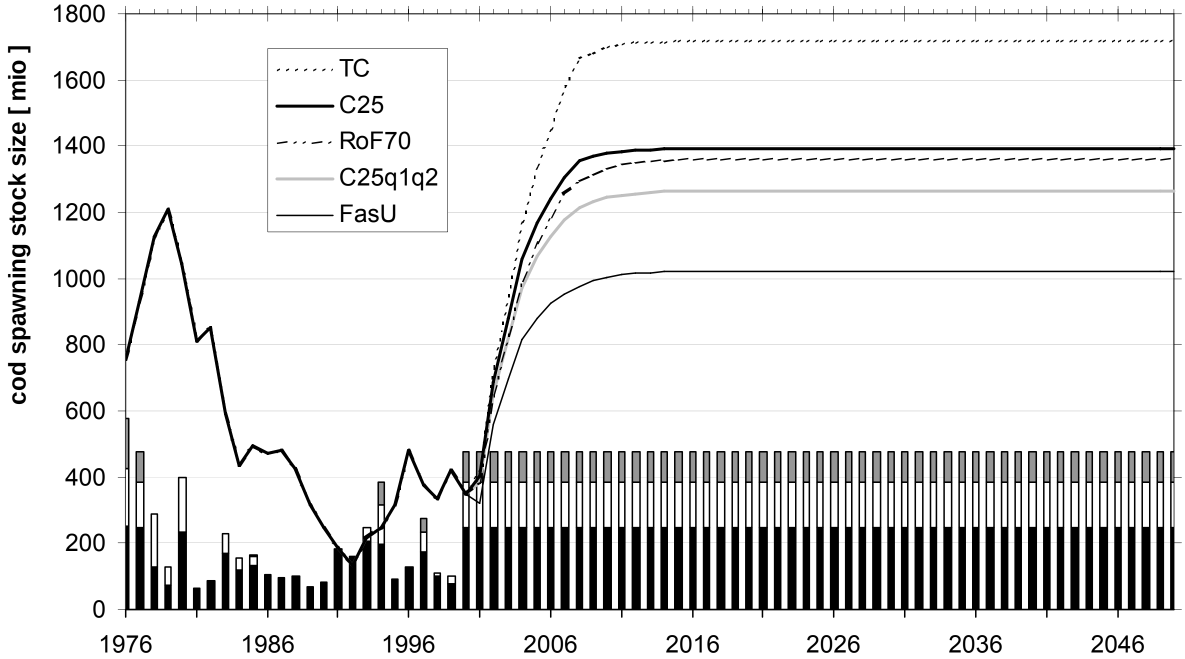

Figure 3.5. Simulations based on environmental conditions 3 (“HighHigh”): constantly high reproductive volume; data from year 1977. See Figure 3.3 legend for explanation of the graphs.

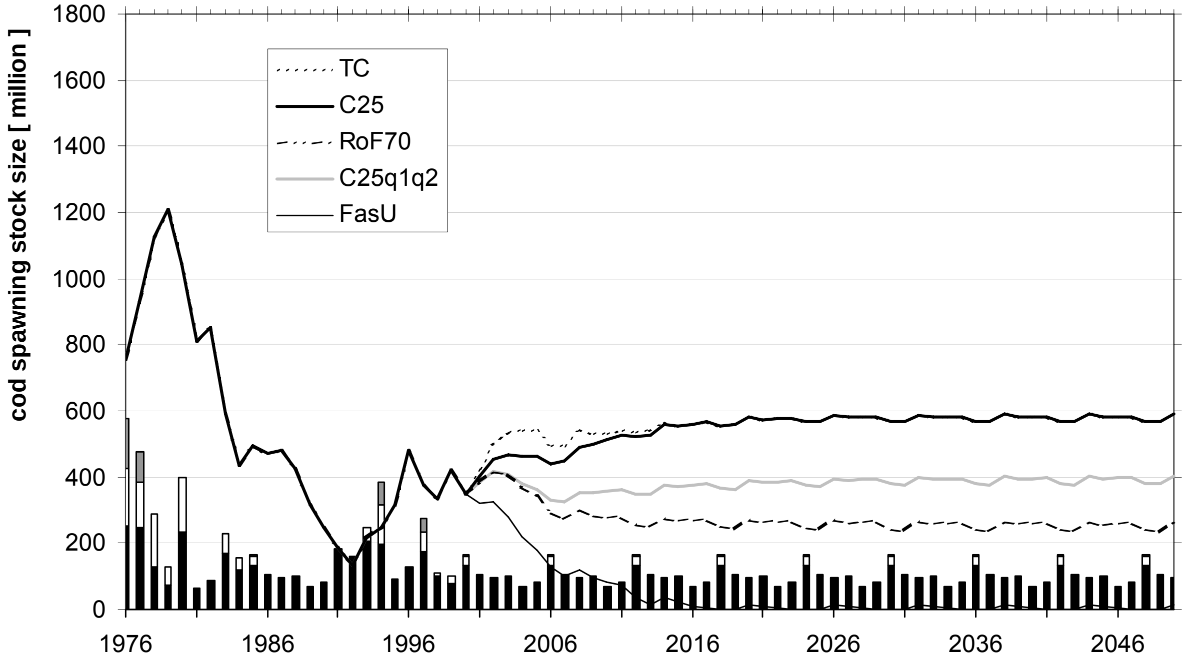

Figure 3.6. Simulations based on environmental conditions 4 (“LowLow”): six year cycle of low reproductive volume; the data sequence from 1985-1990 is repeatedly applied. See Figure 3.3 legend for explanation of the graphs.

Figure 3.7 shows the age structure of the stock in 2050 under environmental conditions 1 for the five selected management scenarios. Under the FasU scenario, hardly any cod grows older than 4 years. In contrast, under the total closure and the permanent MPA scenario, the stock's age structure improves greatly, supporting around 30% of 5- to 8-year old cod. Under the seasonal MPA scenario, this fraction of older fish contributes around 20% to the stock size. If overall fishing mortality is reduced by 70%, the stock is composed of approx. 10% of fish of age 5 and older. The presented trend in age structure for environmental conditions 1 also holds for environmental conditions 2, 3, and 4.

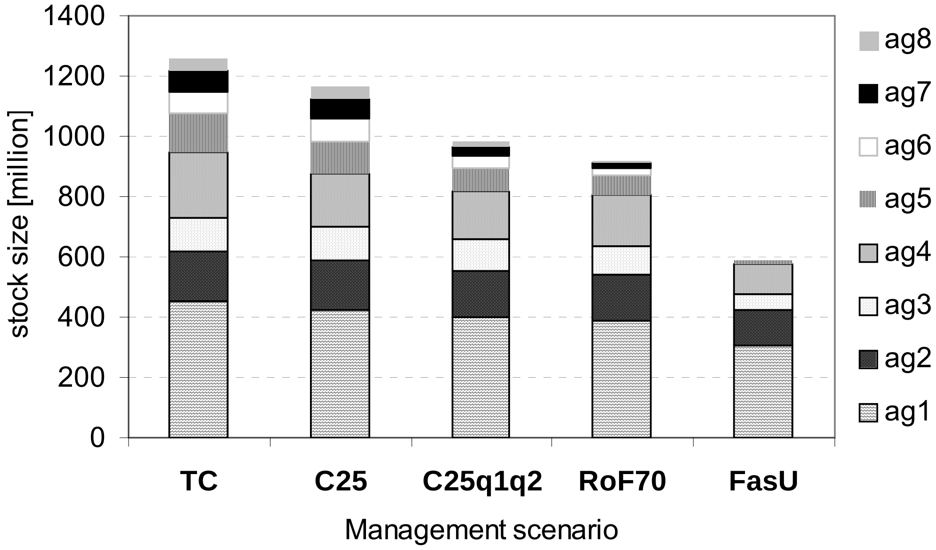

Figure 3.7. Age structure of the cod stock in year 2050 for the five different management scenarios under environmental conditions 1 ("HighLow").

Figure 3.3 illustrates that, in general, the spawning stock size under the five management policies differs by a greater extent during periods of stagnation (low RVs) than during and shortly after major Baltic inflows (high RVs). The lines in figure 3, representing the five management policies, lie closer together in years directly after major inflow events. Moreover, the C25q1q2 line is lower than the RoF70 line during years of high RV, but after a stagnation period of approx. 10 years, the two lines intersect, and spawning stock size under C25q1q2 exceeds the spawning stock under RoF70. Considering the development of the spawning stock size towards the end of such a stagnation period, the ranking of management policies from highest to lowest spawning stock size is as follows:

1. TC, 2. C25, 3. C25q1q2, 4. RoF70, 5. FasU.

Environmental conditions 2 ("LowHigh")

The simulation period under environmental conditions 2 starts with 12 years of low reproductive volume. This leads to a decrease in the spawning stock size under management scenario 1 (FasU) until 2011 (Figure 3.4). Spawning stock size under scenarios 2 (Rof70) and 3 (C25q1q2) fluctuates around 400 million. Again, the C25q1q2 line and the RoF70 line intersect: after several years of low RV, spawning stock size under C25q1q2 exceeds the spawning stock under RoF70, whereas after the replenishment of RVs, spawning stock size under RoF70 exceeds ssN under C25q1q2.

Under scenarios 4 (C25) and 5 (TC), spawning stock size increases by 100% during the first 12 years of low RV. Afterwards, when RV is replenished by inflow events in 2013, 2016, 2021 and 2022, stock size increases even further.

In this "LowHigh" scenario, the spawning stock reaches levels similar to those reached under environmental conditions 1 ("HighLow"), however, it takes about two decades longer to achieve these levels. Likewise, the spawning stock shows similar dynamics to those under environmental conditions 1, i.e. the slope of the decrease in stock size is steepest for management scenario 1 (FasU) and weakest for scenario 5 (TC). Also, the ranking of management policies from highest to lowest spawning stock size is the same as stated above. Similar to environmental conditions 1, the stock does not go extinct under environmental conditions 2, because the reoccurrence of inflows after about 12-15 years leads to the replenishment of reproductive volumes and thus to stock recovery.

Environmental conditions 3 ("HighHigh")

Albeit unrealistic, stock development under environmental conditions 3 (constant high reproductive volumes) is useful as a potential upper boundary of stock development. The spawning stock size increases under all five management scenarios (Figure 3.5). Equilibrium is reached after about ten years under all five management scenarios.

Under scenario 1 (FasU), the spawning stock size increases by more than 100% to approximately one billion cod, which is lower than historic stock sizes at the end of the 1970s. The stock benefits much more under management scenarios 2, 3, and 4, where spawning stock sizes increase by 140, 160, and 180% , respectively. Under management scenario 5 (TC), the spawning stock increases by 260% to an unprecedented high level of > 1.7 billion spawners. The ranking of management policies from highest to lowest spawning stock size under these permanently favourable environmental conditions of high RV is as follows:

1. TC, 2. C25, 3.RoF70, 4. C25q1q2, 5. FasU.

In comparison to the ranking under environmental conditions 1 and 2, positions 3 and 4 are interchanged.

Environmental conditions 4 ("LowLow")

Figure 3.6 depicts spawning stock development under the worst case of environmental conditions 4, i.e. no inflows for all five management scenarios. Except for a weak inflow event which reoccurs every six years to replenish a small reproductive volume in SD 25 and 26, only a small volume in SD 25 can permanently provide appropriate spawning conditions for successful cod egg development (cf. black bars in Fig. 3.6). Such unfavourable hydrological conditions combined with high fishing pressure (FasU) lead to the extinction of the cod stock after 18-20 years. If overall fishing pressure is reduced by 70% (RoF70), the spawning stock size falls below 300 million. The cod spawning stock can slightly recover and stabilise around a level of approximately 400 million spawners when temporarily closing SD 25 for fishing during the first and second quarter of the year (C25q1q2). Management scenarios 4 (C25) and 5 (TC) show that a slight stock recovery is possible despite unfavourable environmental conditions: The spawning stock increases by 50% within 20 years to 600 million. These two scenarios differ during the first 13 years, with stock size under a total closure exceeding stock size under the C25 scenario. Afterwards, both management scenarios result in the same spawning stock size.

3.4 Discussion

3.4.1 Model validation

As can be interpreted from Figure 3.2, our model is able to reproduce the historic stock assessment estimates reasonably well: The correlations of our model results with the ICES standard stock assessment estimates (ICES, 2002) yield an explanatory power of 72%. Nevertheless, there is the problem of underestimating the size of the spawning stock in the first part of the historic time series and overestimating in the most recent part of the time series. One explanation for this is the comparatively poor coefficient of determination (R^2 = 0.57) for calculating recruitment in SD 25 as opposed to an R^2 > 0.8 in SD 26 and 28. The reproductive volume is probably not the only environmental factor, which influences spawning behaviour and recruitment, particularly in SD 25. Other processes have been proposed including predation of cod eggs by clupeids, transport to or retention in optimal habits, and larval feeding environment (Hinrichsen and Möllmann, 2002; Hinrichsen *et al.*, 2003). These factors have the potential to be included in extensions of our model. Furthermore, the inherent uncertainty of standard fish stock assessment is equally present at the basis of our model exercises, since the underlying area-disaggregated data for recruitment, spawning stock size, and mortalities can be afflicted with an error of +/- 50% (Chen, 2003; Walters, 2001).

3.4.2 Scenario analysis

Our management scenarios 2-5 essentially represent policies that reduce fishing mortality, pursuing different approaches. The results of our simulations clearly show that the reduction of fishing mortality via the establishment of a marine reserve in SD 25 is beneficial for the cod stock under both favourable and unfavourable environmental conditions (Figures 3-6). Even in the case of prevailing unfavourable environmental conditions (“LowLow”), the stock stabilises around 400 million under the seasonal marine reserve scenario (C25q1q2) and recovers under the permanent marine reserve scenario (C25) and the total closure (TC) scenario (Figure 3.6). It also becomes obvious, that the cod stock can go virtually extinct, if unfavourable environmental conditions in the future prevail for a longer period of time while fishing continues as usual (Figure 3.6). Total stock size under management scenario 5 (TC) converges towards the total stock size under scenario 4 (C25) within 15 years (Figure 3.6). What is happening? The subpopulations in SD 26 and 28 quickly go extinct under prevailing unfavourable environmental conditions. Since this has not occurred in the past, this result gives additional support to our conclusion that migration of cod in the Baltic Sea is of very high importance and needs to be incorporated into future models of the Baltic cod fishery. Without migration (as was assumed here), there would not be any cod left in the areas to the east and northeast of SD 25.

Management scenario 5 (TC) is probably the most unrealistic scenario from a management point of view; it corresponds, however, to the recent ICES (2004b) management advice given to the IBSFC by the ICES Advisory Committee on Fishery Management (ACFM). Due to the high uncertainties in the Baltic fish stock assessments, the ACFM was reluctant to present a catch forecast in any form, and its management advice was “no catch in 2005” (ICES, 2004b). Moreover, the total closure scenario (TC) can be interpreted as representing the environmental carrying capacity of cod in the Eastern Baltic Sea. According to our results, the carrying capacity ranges from approximately 600 million under unfavourable reproductive conditions ("LowLow") to 1.7 billion under the best case of reproductive conditions ("HighHigh"). Supposing that historic environmental conditions reoccur in the future, the carrying capacity varies between 1 and 1.4 billion, depending on the actual future reproductive conditions.

When comparing stock dynamics under management scenarios 3 and 4, the intersecting lines under environmental conditions 1 and 2 lead to the conclusion that a seasonal marine reserve policy (C25q1q2) is more effective in protecting the spawning stock under unfavourable hydrographic conditions than an overall reduction of fishing mortality by 70% (RoF70). The different ranking of management policies 3 and 4 of the "HighHigh" and the "LowLow" environmental scenarios further supports this conclusion. Again, this result supports our initial hypothesis that a protection of the spawning stock in SD 25 can be sufficient to rebuild the Eastern Baltic cod stock. This is due to the fact that a reproductive volume will generally be present in the Bornholm Basin, despite unfavourable conditions, i.e., despite the lack of very strong inflow events from the North Sea, which could replenish the deep basins in SD 26 and 28.

Our simulations support the hypothesis that MPAs, both permanent and seasonal, can improve the age-structure of initially overexploited fish stocks (e.g. Apostolaki, 2001; Roberts *et al.*, 2001), serving as positive feedback, in particular in the case of the Eastern Baltic cod (Figure 3.7). Here, the advantage of having more older fish in the stock results from the following: Older females lay many more eggs and they spawn over a longer time period than young females (Nissling *et al.*, 1994, Vallin and Nissling, 2000). Moreover, the time period, when the eggs are at best quality to be fertilised, is longer for eggs of older females than for those of younger females. Note that the model in this paper does not account for greater reproduction with age (cf. Eq.3.2).

In addition, our simulations support claims raised by several fisheries scientists that the size and location of the marine reserve is a crucial factor for evaluating its impacts (Beattie *et al.*, 2002; Martell *et al.*, 2000; Sumaila, 2002; Walters, 2000). In the Baltic Sea environmental conditions strongly drive the population dynamics of Baltic cod. Therefore, closing an area is useless, if unfavourable hydrographic conditions do not allow for successful cod egg development and, in turn, do not increase potential recruitment. Closures, not based on a sound biological basis, can even be counterproductive, as each negative example of marine reserve establishment can cause fishermen to become more reluctant to this type of management tool in the future. Furthermore, as Baltic cod is a migratory species with pronounced feeding and spawning migration, a small reserve size, such as the spawning ground closure, established by the IBSFC since 1995, may very well dissipate any beneficial result for mobile species because of dispersal losses or effort concentration around the borders of MPAs (Walters, 2000).

As has already been stressed, our results have to be interpreted with caution due to our assumptions, which were described in the method section. For example, although commonly applied, the concept of constant natural mortality is very unrealistic. This may be improved by incorporating more environmental variables, which impact on natural mortality rates, in particular of the early life stages (e.g. Köster *et al.*, 2001b; MacKenzie *et al.*, 1996). Furthermore, the management scenarios are derived from the assumption of a constant fishing mortality, the average of the years 1990-1995. For more realistic simulations, fishing mortality should be transformed into an endogenous variable that can reflect reactions to management measures. Including dynamic variation in fishing mortality requires an understanding of fishermen's behaviour and a complete analysis of the dynamics of the Baltic cod fishery (Kronbak, 2004). Hence, in the future, this biological model should be coupled to an economic model of the Baltic Sea cod fishery. The combined bio-economic model can then be used to evaluate the potential impacts of an area closure on the biology of the fish stocks on the one side and on the Baltic cod fishery on the other side. It needs to be emphasized that adding movement dynamics and exploring the model sensitivity to movement rates is vital to a bio-economic approach. Including migration of cod between subdivisions might reduce the biological benefits of closing SD 25 while at the same time sustain economic benefits. However, depending on the timing and direction of migration, it could also lead to increased biological effects in SD 25, but no spillover to the adjacent areas and thus no economic benefits.

Similar to the conclusions drawn by Brander and Mohn (2004), our simulations reveal that stock development depends strongly on future environmental conditions, in particular hydrological conditions, which are triggered by inter-annual climate variability. There is a clear need to improve climate, meteorological, and hydrographic models which will allow to make better fish stock projections and provide scientifically sound advice to fishery managers and decision makers.

A major future goal in research has to be the integration of larval dispersal, adult cod migration, and movement rates. Quantifying larval dispersal requires larval fish surveys during and after the spawning periods as well as analytical techniques such as genetic or otolith analyses. Last but not least, tagging experiments are urgently needed to get quantitative information about adult cod migration.

3.5 Conclusion

In summary, our results suggest that the Eastern Baltic cod stock can significantly benefit from the implementation of an MPA that focuses on the protection of the spawning stock in SD 25. Under unfavourable environmental conditions, hydrographic conditions in the basins East/Northeast of SD 25 do not allow for successful cod egg development anymore, and hence, it is particularly important, to protect the viable component of the spawning stock in SD 25. Then, the stock benefits more from a seasonal marine reserve policy, focussing on the protection of the spawning stock in SD 25, than from an overall reduction of fishing mortality in the Eastern Baltic Sea.

However, in contrast to the investigated seasonal marine reserve scenario, the seasonal closure that has been established in the Bornholm Basin is spatially too small and temporally too short to effectively reduce fishing mortality on the spawning stock. Furthermore, the additional closures in the Gdansk Deep and the Gotland Basin may only be effective sporadically, in the rare case of strong MBIs. During stagnation periods, these closures cannot lead to enhanced recruitment from SD 26 and 28.

According to our findings, a total moratorium on fishing in the entire Baltic Sea could be avoided by an MPA approach focussing on SD 25 to rebuild the Eastern Baltic cod stock. We conclude that MPAs as a policy instrument can and should be applied in areas, where the location of the stock's spawning concentration is known.

3.6 References

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3.7 Appendix to Chapter 3

Appendix Table A3-1. Results and statistics of regression analyses of age-specific predation mortality for cod age 0, 1, and 2 in SD 25, 26, and 28 ($P_{a,r,y} = d_{a,r} \cdot ssN_{r,"q1",y} + e_{a,r}$): parameter estimate, standard error, significance level of t-statistics, Durbin Watson statistics (indicating serial correlation in residuals if DW < 2), and r^2 values (indicating the proportion of the total variance accounted for by the linear influence of the explanatory variable ssN).

subdivision	prey age	Parameter	Std. Error	p(t-stat.)	DW	r^2
SD 25	age 0	d = 0.00082	0.00011	0.000	2.28	0.75
		e = 0.00293	0.04261	0.946		
SD 25	age 1	d = 0.00051	0.00006	0.000	1.79	0.80
		e = -0.00575	0.02308	0.806		
SD 25	age 2	d = 0.00005	0.00001	0.000	1.64	0.70
		e = -0.00026	0.00299	0.933		
SD 26	age 0	d = 0.00133	0.00015	0.000	2.66	0.83
		e = 0.02484	0.05253	0.642		
SD 26	age 1	d = 0.00089	0.00008	0.000	1.22	0.87
		e = -0.00048	0.03023	0.988		
SD 26	age 2	d = 0.00012	0.00002	0.000	1.08	0.70
		e = 0.00472	0.00698	0.508		
SD 28	age 0	d = 0.00285	0.00034	0.000	1.70	0.80
		e = -0.01466	0.05657	0.799		
SD 28	age 1	d = 0.00205	0.00018	0.000	1.12	0.88
		e = -0.01159	0.02975	0.702		
SD 28	age 2	d = 0.00023	0.00003	0.000	1.34	0.81
		e = -0.00003	0.00448	0.995		

Appendix Table A3-2: Results of regression analyses of stock-recruit relationships in SD 25: functional form of recruitment equation, parameter estimate, standard error, significance level of t-statistics, Durbin Watson statistics, and r^2 values.

Recruitment Equation [linearised form in brackets]		Parameter value	s.e.	p(t-stat.)	DW	r^2 (*)
SD 25						
#1 R = a*ssN + c	a =	0.69481	0.23906	0.01	0.90	0.35
	c =	56.9188	86.7356	0.52		
#2 R = a*ssN + b*RV + c	a =	0.77217	0.20207	0.00	1.03	
	b =	1.44479	0.51662	0.01		
	c =	-166.740	108.030	0.14		
#2, corrected for autoregression	a =	0.769131	0.237	0.01	1.97	0.57
R = a*ssN+b*RV+c +ar1+ar2	b =	1.372792	0.325873	0.00		
	c =	-163.2885	98.777	0.13		
	ar1	0.762269	0.241	0.01		
	ar2	-0.629696	0.263	0.04		
#3 R = a*ssN*RV + c	a =	0.00493	0.00108	0.00	1.16	0.57
	c =	68.9399	55.5463	0.23		
#4 R = RV*(a*ssN + c)	a =	0.00736	0.00213	0.00	2.08	0.49
[R/RV = a*ssN + c]	c =	-0.11076	0.77430	0.89		
#5 R = ssN*exp(a*ssN + c)	a =	-0.00052	0.00072	0.48	1.00	0.37
[ln(R/ssN) = a*ssN + c]	c =	-0.03224	0.26038	0.90		
#6 R = ssN*exp(a*ssN + b*RV + c)	a =	-0.000278	0.000592	0.65	1.46	0.64
[ln[R/ssN] = a*ssN + b*RV + c]	b =	0.004525	0.001515	0.01		
	c =	-0.73276	0.316729	0.04		
#7 R = ssN*RV*exp(a*ssN + c)	a =	-0.00006	0.00065	0.93	1.73	0.57
[ln(R/(ssN*RV)) = a*ssN + c]	c =	-5.02174	0.23634	0.00		
#8 R = $ssN^a * RV^b$ * exp(c)	a =	0.92336	0.20127	0.00	1.34	0.57
[ln(R) = a*ln(ssN) + b*ln(RV) + c]	b =	0.59092	0.21329	0.01		
	c =	-2.62516	1.67092	0.14		

(*) When referring to the linear recruitment equations (#1-#3), the square of the Pearson correlation coefficient (r^2) is equal to the coefficient of multiple determination R^2.

Appendix Table A3-3: Results of regression analyses of stock-recruit relationships in SD 26 and 28. For further explanations refer to Table A3-2.

Recruitment Equation [linearised form in brackets]		Parameter value	s.e.	p(t-stat.)	DW	r^2 (*)
SD 26						
#1 R = a*ssN + c	a =	1.295053	0.21899	0.00	1.32	0.69
	c =	-73.88097	73.79343	0.33		
#2 R = a*ssN + b*RV + c	a =	0.974694	0.192394	0.00	1.67	0.83
	b =	2.119031	0.612369	0.00		
	c =	-72.00417	56.83591	0.22		
#3 R = a*ssN*RV + c	a =	0.008195	0.001381	0.00	1.16	0.69
	c =	151.6722	46.7975	0.01		
#4 R = RV*(a*ssN + c)	a =	3.346399	2.00575	0.11	1.61	0.15
[R/RV = a*ssN + c]	c =	-104.0102	675.8954	0.88		
#5 R = ssN*exp(a*ssN + c)	a =	0.000746	0.000809	0.37	0.94	0.71
[ln(R/ssN) = a*ssN + c]	c =	-0.416527	0.272634	0.15		
#6 R = ssN*exp(a*ssN + b*RV + c)	a =	-9.98E-05	0.000838	0.91	0.96	0.85
[ln[R/ssN] = a*ssN + b*RV + c]	b =	0.005591	0.002668	0.05		
	c =	-0.411575	0.247667	0.12		
#7 R = ssN*RV*exp(a*ssN + c)	a =	-5.93E-03	0.003775	0.14	1.25	0.15
[ln(R/(ssN*RV)) = a*ssN + c]	c =	0.57968	1.271986	0.65		
#8 R = ssN^a * RV^b * exp(c)	a =	0.868428	0.211268	0.00	0.67	0.76
[ln(R) = a*ln(ssN) + b*ln(RV) + c]	b =	0.103038	0.047658	0.05		
	c =	0.411377	1.128871	0.72		
SD 28						
#1 R = a*ssN + c	a =	1.388394	0.15375	0.00	1.74	0.84
	c =	-34.87475	23.71123	0.16		
#2 R = a*ssN + b*RV + c	a =	1.396162	0.151571	0.00	1.73	0.85
	b =	0.718526	0.588287	0.24		
	c =	-42.42439	24.15914	0.10		
#3 R = a*ssN*RV + c	a =	0.009536	0.009861	0.35	0.30	0.06
	c =	120.2287	37.7014	0.01		
#4 R = RV*(a*ssN + c)	a =	128.7795	20.40592	0.00	1.04	0.07
[R/RV = a*ssN + c]	c =	-4526.896	3147.047	0.17		
#5 R = ssN*exp(a*ssN + c)	a =	0.006479	0.001469	0.00	1.76	0.78
[ln(R/ssN) = a*ssN + c]	c =	-1.368814	0.226543	0.00		
#6 R = ssN*exp(a*ssN + b*RV + c)	a =	6.59E-03	0.001346	0.00	1.33	0.82
[ln[R/ssN] = a*ssN + b*RV + c]	b =	0.010576	0.005223	0.06		
	c =	-1.479937	0.21448	0.00		
#7 R = ssN*RV*exp(a*ssN + c)	a =	8.10E-03	0.00717	0.28	1.69	0.06
[ln(R/(ssN*RV)) = a*ssN + c]	c =	1.693038	1.105708	0.15		
#8 R = ssN^a * RV^b * exp(c)	a =	1.458096	0.121747	0.00	0.88	0.82
[ln(R) = a*ln(ssN) + b*ln(RV) + c]	b =	0.083543	0.050107	0.12		
	c =	-2.243144	0.552074	0.00		

(*) When referring to the linear recruitment equations (#1-#3), the square of the Pearson correlation coefficient (r^2) is equal to the coefficient of multiple determination R^2.

Chapter 4 - Rebuilding the Eastern Baltic cod stock under environmental change - a preliminary approach using stock, environmental, and management constraints

4.1. Introduction

The population dynamics of the Eastern Baltic cod (*Gadus morhua callarias L.*) depends strongly on environmental conditions (e.g. Bagge and Thurow 1994a; MacKenzie *et al.* 2002). As a result of the Baltic Sea's environmental variability, Baltic cod stock abundance has fluctuated widely over time and particularly since the mid-1960s: Spawning stock biomass peaked around 700,000 t in the early 1980s; during the past decade, however, biomass has dropped below the biological limit (B_{lim}) of 160,000 t, representing the level below which recruitment is impaired (ICES 2004a). Concomitant to these fluctuations in biomass, landings increased from less than 10,000 t in the early 20th century to approximately 400,000 t during the 1980s (Sparholt 1994), due in part to increases in fishing effort and improved technology (Bagge *et al.* 1994b). In 1992, landings dropped below 100,000 t, and they have remained low since. The sharp decline in stock size since the mid-1980s has been attributed to an interplay between overfishing (high fishing mortality) and unfavourable environmental conditions (MacKenzie *et al.* 2002).[1]

MacKenzie *et al.* (2002, p.184) suggest that "the most important environmental factors for the biota of the Baltic Sea are salinity, oxygen concentration, temperature, and eutrophication". Unlike other cod populations, cod eggs in the Eastern Baltic are neutrally buoyant in deep water below the permanent halocline[2]. Salinity and oxygen concentrations below the halocline vary relative to major Baltic inflows from the North Sea. They have a direct impact on the development of the Baltic cod eggs, which need a minimum salinity ($S \geq 11$ psu) and a minimum oxygen concentration ($c[O_2] \geq 2$ ml/l) to develop (Nissling *et al.* 1994; Wieland *et al.* 1994). The volume of water having these characteristics has been termed the "reproductive volume" (RV) for Baltic cod (e.g. MacKenzie *et al.* 2000; Plikshs *et al.* 1993); it has been applied in the development of Baltic cod stock and recruitment models (Köster *et al.* 2001a, 2001b; Röckmann *et al.* 2005; STORE 2002). Climatic variables directly and indirectly influence the Baltic Sea hydrography, e.g. via precipitation. The reproductive volume and in turn cod population dynamics are thus susceptible to the regional consequences of global climate change (cf. Section 4.2).

In this study, we extend an existing model of the population dynamics of the Eastern Baltic cod (Chapter 3; Röckmann *et al.* 2006) to test whether a set of policy options could prevent the stock from collapsing because of climate change. We analyse future stock and yield development, and effects on fishermen's revenues for three environmental scenarios, which are based on simulation results of a coupled ocean-atmosphere regional climate

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[1] For a detailed description of the reconstructed historic biomass and landings of Baltic cod before the 1960s, the reader is referred to MacKenzie *et al.* (2002) and Thurow (1999).

[2] The halocline are layers of water where the water's salinity changes rapidly with depth.

model (RCM) (Meier forthcoming). Meier's results project an overall decrease in salinity in the Baltic Sea due to global climate change. As a preliminary approach, we develop linear relationships between average salinity in the Baltic Sea and the area-specific size of the reproductive volume in the three subdivisions, serving as the link between climate change and fish population dynamics.

The model of Baltic cod population dynamics is age structured and calculates stock size on a time step of three months explicitly for three subdivisions in the Eastern Baltic Sea. The model includes the migration of mature cod between sub-areas based on theoretical, process-oriented assumptions.

The investigated management policies focus on rebuilding the cod stock via the establishment of a marine reserve (permanent or temporal) in and around a major spawning ground of the Eastern Baltic cod stock. Field studies have illustrated that closed areas can lead to increases in fish biomass, density, and size, and in ecosystem diversity (reviewed by Halpern 2003). Furthermore, marine reserves as a fisheries management tool do not rely on accurate fish stock assessments and are therefore less susceptible to the fallacies of conventional management approaches (e.g. Botsford *et al.* 1997; Walters 2001).[3]

In the next section, we present how climatically driven environmental factors, such as salinity and oxygen, influence Baltic Sea hydrography, and how climate and atmospheric constellations drive these factors. Section 4.3 provides an outline of the population dynamics model for the Eastern Baltic cod stock combined with the fishery, and describes the environmental scenarios and the selected management policies. The simulation results for the different scenarios are presented and discussed in Section 4.4. Estimates of stock development, yield development, and the net present value of revenues are shown for the different scenarios. Finally, in Section 4.5 we conclude the work and point out caveats representing areas where future research is warranted.

4.2. Baltic Sea hydrography and climate change

Dissolved oxygen concentration in the Baltic Sea is influenced abiotically, partly by wind-induced mixing of the surface water layer, partly by sporadic Major Baltic inflows (MBI) through the Belt Sea, which replenish the deep water layers of the Baltic Sea with saline and well oxygenated North Sea water (e.g. Matthäus and Frank 1992; Schinke and Matthäus 1998). Furthermore, strong cooling at the sea surface results in higher oxygen solubility (Hinrichsen *et al.* 2002b). Additionally, biotic factors alter the dissolved oxygen concentration in the Baltic Sea, as e.g. bacterial degradation and decomposition consume oxygen.

Eutrophication and temperature indirectly impact on the year class strength of Baltic cod. Thurow (1997) assumed "that eutrophication has caused the increase in the Baltic fish stocks since about 1950", which, when coupled with the high fishing mortality exerted on the cod stock, has resulted in increased predation pressure by sprat and herring on the early life stages of Baltic cod (e.g. Köster and Möllmann 2000). Furthermore, increased primary production as a result of eutrophication leads to an increase in particulate organic matter, which in turn fuels oxygen-consuming demineralisation of organic material during sedimentation. Hence, eutrophication has an indirect effect on the oxygen concentration and the occurrence of hypoxia and anoxia in the bottom water layers.

[3] For a discussion of the pros and cons of marine reserves, see Kaiser (2005) and Chapter 3, Section 3.1.

Similar to eutrophication, an increase in water temperature generally has a stimulating effect on primary production and on metabolic activity of higher organisms. Oxygen concentrations are more likely to decrease in warmer than in colder waters, not only due to increased oxygen-consuming demineralisation of organic material, but also because increasing water temperature reduces oxygen solubility. In a multispecies context, an increase in water temperature favours the reproductive capacity of sprat (MacKenzie and Köster 2004), i.e., sprat reproductive success increases, which may be unfavourable for cod due to a potential increase in predation pressure by adult sprat on the early life stages of cod (Köster and Möllmann 2000). Additionally, the survival of larval cod may become food limited, as the abundance of the zooplankton *Pseudocalanus elongatus*, the main food of cod larvae, decreases with decreasing salinity (Hinrichsen *et al.* 2003).

Salinity conditions in the Baltic Sea are driven by several meteorological and climatic variables, such as temperature, sea ice cover, precipitation, river runoff, atmospheric circulation patterns influencing the occurrence of Major Baltic inflows (MBI) from the North Sea, and by radiation (Hänninen *et al.* 2000; Lehmann *et al.* 2002; Matthäus and Schinke 1999; Omstedt and Nohr 2004; Winsor *et al.* 2001). Regional climate models (RCM) predict that global climate change results in higher air temperatures and an increase in precipitation and freshwater-runoff over the Baltic Sea drainage area (Döscher and Meier 2004; Omstedt *et al.* 2004; Rutgersson *et al.* 2002). An indirect effect of increased precipitation is the reduction of the impact of major inflows of North Sea water on salinities in the deep layers of the Baltic Sea. The sporadic occurrence of such inflows is triggered by the combination of specific wind speeds and directions (Matthäus and Frank 1992; Schinke and Matthäus 1998). Lehmann *et al.* (2004) investigated effects of remote and local atmospheric forcing on circulation and upwelling in the Baltic Sea. They related the local wind field over the Baltic Sea to the large-scale atmospheric circulation over the North Atlantic, the North Atlantic Oscillation (NAO), by defining a Baltic Sea Index (BSI). Nonetheless, a predictive understanding of the effect of changes in atmospheric circulation on inflow dynamics and the resulting hydrographic conditions in the Baltic Sea is as yet unavailable.

By developing relationships between the seasonal variability of the reproductive volume and environmental factors, MacKenzie *et al.* (1996b) showed that the seasonal decrease in the size of the RV is temperature dependent. Also, existing knowledge concerning the implications of climate change on the Baltic Sea suggest that salinity and oxygen conditions are likely to deteriorate with increasing water temperatures, as we presented above. In summary, the combined effect of climate change and its regional consequences for the Baltic Sea area points at a decrease of the size of the reproductive volume in the future, and hence a deterioration of environmental conditions for Baltic cod recruitment, which has been suggested by MacKenzie *et al.* (1996b).

4.3. Modelling approach and scenario development

4.3.1 Study area and spatial resolution

The area modelled, located in ICES area IIId, is composed of the three ICES subdivisions (SD) 25, 26, and 28 (Figure 4.1). It is the principal habitat of the Eastern Baltic cod stock (Sparholt *et al.* 1991) and the origin of more than 90 % of the international catch of

Eastern Baltic cod (ICES 2000, 2001b, 2002, 2003, 2004a). We neglect the remaining subdivisions, as they do not at this time comprise an important spawning ground for Baltic cod, and cod fishing in subdivisions 27 and 29 to 32 is of minor importance to the commercial fishery.

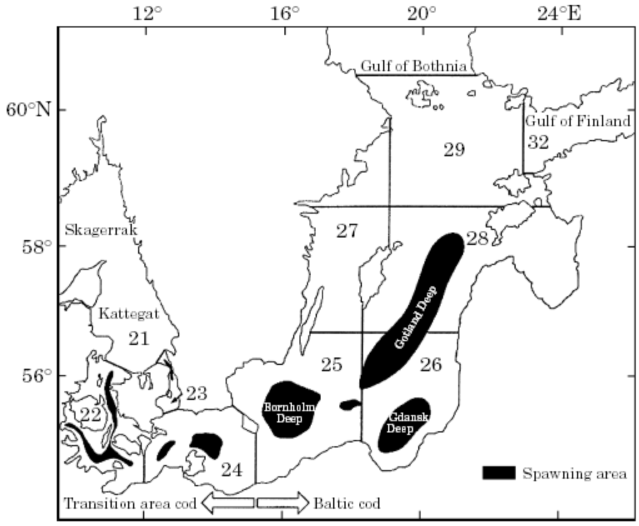


Figure 4.1. Chart of the Baltic Sea, showing ICES subdivisions and important spawning grounds of Baltic cod. Source: after Bagge *et al.* (1994b).

4.3.2 Data

Quarterly data on stock size, natural, predation and fishing mortality of cod for the ICES subdivisions 25, 26, and 28 are employed from an area-disaggregated Multispecies Virtual Population Analysis (MSVPA), covering the time period 1974 to 1999 (ICES 2001a; Köster *et al.* 2001a). Basin-specific data on reproductive volume for the time period 1976 to 1996 are available from MacKenzie *et al.* (2000). Additional data for the years 1997-1999 are taken from ICES (ICES 2005a).

Data for cod weight-at-age in the catch is highly uncertain and of poor quality, partly because of age-reading problems of the otoliths of Baltic cod (ICES 2001c; Reeves 2001), but also because of differences between individual fish, depending on location, food availability, and the time of capture. In general, fish of a similar age from SD 25 are heavier and in a better shape than their cohorts in SD 26 and 28 (H.-H.Hinrichsen, pers. communication). Estimates of average weight-at-age in the stock and in the catch published by STORE (2002) differ by several kg from those published by ICES (2003). In this study, we utilise estimates from the ICES data base, as, within the scope of the standard stock assessments, they provide a long time series of yearly estimates. For the simulation time period 2005 to 2055, we apply the average weight-at-age for the years 2000-2002 (ICES 2003, pp.186-187).

With respect to the Eastern Baltic cod fishery, Polish, Swedish, and Danish fishermen together harvest roughly 70% of the total catch of the Eastern Baltic cod (ICES 2004a). The remainder is shared by Latvia, Russia, Lithuania, Germany, Finland, and Estonia, in decreasing order of catch quantity. In general, ex-vessel prices per kilogram of cod vary by nation as well as over the course of a year and a month. In Denmark, for example, the prices are usually low at the beginning of a month, when each vessel has its full fishing quota and can supply high landings. Towards the end of the month, many vessels have taken their individual vessel quotas, resulting in low landings – hence, prices increase. Price development over the course of a year also reflects accessibility to the resource: In the Baltic Sea, cod fishing has been banned from June to August by the International Baltic Sea Fisheries Commission (IBSFC). Therefore, the monthly average prices of cod increase during the summer months, when supply is restricted, consisting mostly of North Sea or Atlantic cod. In autumn and winter prices decrease again, as continued harvesting in the Baltic Sea delivers additional cod supply (Figure 4.2; Fiskeridirektoratet 2003).

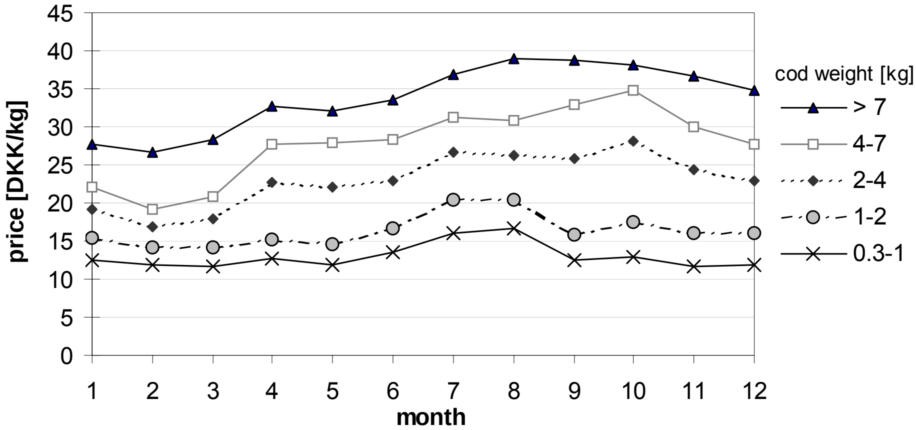


Figure 4.2. Monthly variability of ex-vessel prices for 5 size categories (1-5) of cod in Denmark; 3-year (2001-2003) averages. For details on the size categories, see Table 4.1.

The above descriptions suggest the existence of a local market for Baltic cod where the price is sensitive to local supply. The relationship between price and quantity has, however, not yet been analysed, which would be an interesting extension of our study. In the absence of such an analysis, we use a constant price as a simplification; here, we settle for the 2005 minimum prices of the Danish Fishermen's Producers Organisation (DFPO): Offering a "safety net" for Danish fishermen, the DFPO guarantees minimum payments for cod of quality category E and A, if the affiliated fishermen cannot sell their fish at a certain minimum price (cf. Table 4.1).[4] The minimum prices, which we apply, have been confirmed by employees at the Danish fish auctions in Hirtshals and Hanstholm (pers. communication).[5]

The data reveal that prices depend on the quality and size of the landed fish. For cod, there are six different weight categories and three different quality categories (Table 4.1). Average prices of cod seem to be determined by external factors; but there is a fairly robust difference in price between small and large specimens. Note that our model deals with separate age groups.

There are substantial differences between the DFPO minimum prices and the three-year average prices: The average prices are recorded on a monthly basis, whereas the minimum prices remain constant over a year. Furthermore, monthly average prices in 2001-2003 were more than 200% higher than the 2005 minimum prices. The minimum prices can therefore be considered a robust minimum estimate. In reality, prices probably do not fall below this target.

[4] About 70% of the total Danish fishing capacity is affiliated to the DFPO.

[5] We apply prices and calculate revenues in "Danish krone" (DKK) for two reasons: (1) The best available economic data on the Baltic cod fishery is collected by the Danish fisheries directorate (e.g. Fiskeridirektoratet 2003). (2) The existing economic studies and working papers on the Baltic cod fishery are mostly from Denmark (e.g. Kronbak 2003, Andersen 2002, Jørgensen 1988).

Table 4.1. Quality categories, weight categories and respective age-groups, DFPO minimum prices for 2005, and average Danish ex-vessel prices for cod in 2001-2003.

Quality E =	New fish, first quality			
Quality A =	Ordinary fish			
Quality B =	Bad quality			
Sorting category	**Weight classes (kg)**	**Corresponding age-group**	**Danish PO Minimum price for quality categories E and A [DKK/kg]**	**3-year average ex-vessel price for cod in Denmark [DKK/kg]**
0	> 10		9.25	
1	7 – 10		9.25	33.65
2	4 – 7	Age 8 and older	9.25	26.46
3	2 – 4	Age 6, 7	8.73	21.88
4	1 – 2	Age 5	6.94	15.55
5	0.3 – 1	Age 2, 3, 4	4.88	12.41

Based on information from http://www.dfpo.dk/danish_fishermens_po.htm (visited June 8, 2005) and from the Yearbooks of Fishery Statistics 2001-2003, Ministry of Food, Agriculture and Fisheries, Danish Directorate for Fisheries (Fiskeridirektoratet 2003).

4.3.3 The model of population dynamics

The model of population dynamics for the Eastern Baltic cod (cf. Chapter 3) consists of an age-structured, area-disaggregated, discrete time model of the Beverton and Holt type. Here, recruitment refers to 0-group cod and occurs at discrete time intervals. Recruits join the parent population two years after spawning at age 2. A similar approach has been used in several applied studies, e.g. for the East Atlantic Bluefin Tuna (Bjørndal and Brasao forthcoming). The model of population dynamics is presented in Chapter 3 (Röckmann *et al.* 2006). Variables and parameters in model notation are defined in Table 4.2.

Table 4.2. Variables, parameters, and indices used in our model.

variables and parameters		indices/ subscripts	
N	Eastern Baltic cod stock size in number of fish	r	region (r25, r26, r28)
ssN	spawning stock size in number of fish	a	age-group (a0 – a8)
R	recruitment	q	quarter (q1 – q4)
M	natural mortality	y	year (1976-2055)
P	predation mortality		
F	fishing mortality		
Z	total mortality		
RV	reproductive volume		
S	spawning migration		
D	feeding migration		
w	Eastern Baltic cod weight-at-age in the catch		
p	price of Baltic cod per kg, in Danish Kroner (DKK)		
C	catch		
Y	yield		
I	gross revenue (income)		
r	discount rate		
PV	net present value of yield (revenues)		

Since Baltic cod is known to have an extended spawning season and feeding migrations (Aro 1989, 2000, 2002), we extended the existing model by accounting for migration of mature Baltic cod between the three subdivisions. We considered two processes:

(a) spawning migration (S) in spring, with a net migration from the North/Northeast to the South/Southwest

(b) feeding migration (D) in autumn after spawning, directed mainly from the South/Southwest to the North/Northeast, depending on spatial density differences.

As no quantitative data on cod migration are available at present, the migration patterns used are a stylised representation of those believed to exist, based on the qualitative descriptions by Aro (1989, 2000, 2002). The mathematical functions used to describe these two migration processes (cf. Eq. 4.3 and 4.4 below) are different, meaning that fish that migrate from region k to region j to feed, do not necessarily return to region k to spawn. This assumption is in line with the fact that there is no evidence of homing behaviour of the Eastern Baltic cod stock, “and thus cod may use different spawning grounds in successive years in its distribution area” (ICES 2001b). Egg and larval drift is currently not taken into account in our model, as it is beyond the scope of the present study, requiring for example coupling to a meteorological model which generates spatially and temporally resolved wind fields. Here, we assume that cod of ages 1-8 show the same migration pattern, independent of age.

Spawning migration (S) is calculated in the second quarter as a directional movement from SD 28 into SD 26 and 25, and from SD 26 into SD 25, depending on the size of the reproductive volume in SD 28 and 26, respectively. We are not aware of any study that has investigated migration behaviour of a demersal species, like Baltic cod, in relation to environmental factors. Therefore, we tested three different functional forms – linear (lin), exponential (ex), and logistic (log) (Equations 4.1-4.3). With respect to the sigmoid form, we set RV^{max} at 500 km^3 in all subdivisions, which corresponds to the highest values in the available time series, observed at the beginning of the 1950s (MacKenzie *et al.* 2000).

(4.1) $$S^{lin}{}_{a,y,j->k} = \alpha \cdot N_{a,j,"q2",y} \cdot \left(1 - \beta^{lin} \cdot R_{rj,y}\right)$$

(4.2) $$S^{ex}{}_{a,y,j->k} = \alpha \cdot N_{a,j,"q2",y} \cdot \mathrm{e}^{-\beta^{ex} \cdot RV_{j,y}}$$

(4.3) $$S^{log}{}_{a,y,j->k} = \alpha \cdot N_{a,j,"q2",y} \cdot \left(1 - \frac{1}{1 + RV_j^{\max} \cdot e^{-\beta^{log} \cdot RV_{j,y}}}\right)$$

with j = SD 28 or 26, k = SD 26 or 25.

Our results are not very sensitive to the three different mathematical approaches. Here, we chose the logistic approach (Equation 4.3). For appropriate parameter choices, this S-shaped curve resembles a step function, which Huse *et al.* (2002) have successfully applied in schooling species, such as herring, to model migration according to the ‘adopted-migrant hypothesis’ (McQuinn 1997). The logistic function is smooth, however.

The coefficient α is a scaling parameter, accounting for the assumption that a small percentage of cod does not emigrate despite unfavourable hydrographic conditions. This phenomenon of intrapopulation variation in movement is known as partial migration, and there are documented instances of partial migration in a wide array of taxa from insects to fish to birds (Dingle 1996). Here, we arbitrarily set the maximum percentage of mature cod migrants from SD 26 and SD 28 to 70% and 90%, respectively (Table 4.3).

The coefficient β is chosen such that spawning emigration from SD j into SD k is zero, if the reproductive volume in SD j is close to 200 km^3, which we assume to be sufficient to allow for successful spawning in SD 26 and 28 (Table 4.3). Several ecological studies describe comparable inverse relationships between the level of a particular environmental factor, such as soil moisture, precipitation, or temperature, and the frequency and proportion of migrants of a species (Dingle *et al.* 2000, and references herein).

Table 4.3. Coefficient estimates applied in equations 3-6, describing spawning and feeding migration.

Spawning Migration from SD j → into SD k	**26 → 25**	**28 → 25**	**28 → 26**
Coefficient α	0.7	0.5	0.4
Coefficient β_{lin}	0.005	0.006	0.006
Coefficient β_{ex}	0.01	0.01	0.01
Coefficient β_{log}	0.1	0.1	0.1
Feeding Migration from SD j → into SD k	**25 → 26**	**25 → 28**	**26 → 28**
Coefficient γ	0.2	0.1	0.1

The feeding migration (D) after spawning is incorporated as a density-dependent random diffusion process in the fourth quarter (Equation 4.4).

(4.4) $$D_{a,y,rk->j} = \gamma \cdot \left(N_{a,rk,"q4",y} - N_{a,rj,"q4",y} \right) ,$$

with j = SD 28 or 26, k = SD 26 or 25.

Similar to our assumption on spawning migration, we also expect feeding migration to occur only partially. We tested different values for γ. If γ is larger than 0.25, the modelled stock sizes and yields are higher than the historically observed values, i.e., if $\gamma > 0.25$, the model does not reproduce the historic data during the validation period 1976-1999 correctly anymore. Here, we choose $\gamma = 0.2$ for feeding migration between SD 25 and 26, and $\gamma = 0.1$ for feeding migration between SD 25 and 28 and SD 26 and 28. These values take account of the spatial differentiation of the three subdivisions, i.e., SD 25 is currently more important as spawning ground but less important as feeding ground than SD 26 and 28.

4.3.4 The economic component

The fish caught during one quarter ($C_{a,y,q,r}$) is calculated for each age-group and for each subdivision according to the Baranov Catch Equation (Equation 4.5), with $Z_{a,y,q,r}$ being the total mortality, i.e., the sum of natural, predation, and fishing mortality (Z = M + P + F).

(4.5) $$C_{a,y,q,r} = \frac{F_{a,y,q,r}}{Z_{a,y,q,r}} \cdot \left(N_{a,y,q,r} - N_{a,y,q+1,r} \right)$$

The corresponding yield ($Y_{a,y,q,r}$), accumulated during one time step (q), is computed by multiplying the age-specific catch with the age- and area-specific estimates of weight-at-age in the catch ($w_{a,r}$) (Equation 4.6).

(4.6) $$Y_{a,y,q,r} = C_{a,y,q,r} \cdot w_{a,r}$$

The fishermen's yearly total gross revenue (income I_y) is calculated by multiplying the age-specific yield with the age-specific minimum price per kg (p_a/kg) according to Table 4.1 and then summing over quarter, subdivision, and age (Equation 4.7).

(4.7) $$I_y = \sum_{r=1}^{3} \sum_{q=1}^{4} \sum_{a=2}^{8} Y_{a,y,q,r} \cdot \frac{p_a}{kg}$$

Ideally, a cost analysis should be included at this stage to facilitate estimation of profits and present values. However, this would be beyond the scope of this research. Moreover, cost data are not readily available and for this reason it has not yet been investigated how unit costs depend on the quantity harvested and/or on stock size. When referring to a demersal fishery, it is usually assumed – following Schaefer (1957) – that variable unit costs are inversely proportional to stock size, implying a stock elasticity of –1. Recently, however, an elaborate empirical study by Sandberg (in press) showed that variable unit costs are only moderately sensitive to stock size, with stock elasticities being significantly less than –1 for five Norwegian vessel groups fishing Northeast Arctic cod. Additionally, Sandberg found that unit costs for these five cod fisheries decrease if output, i.e., the quantity harvested, increases. A detailed cost analysis, as part of a bioeconomic analysis, shall be a subject of future research. Here, we limit our analysis to the calculation of revenues and net present value of revenues (i.e., harvests).

The net present value (PV) of the cumulative gross revenues earned over the 50 year simulation period is calculated by summing the discounted yearly total revenues over years (Equation 4.8). To address the uncertainty of future discount rates (r), we compare PVs using a basic 4% discounting with PVs from alternative discount rates employing a wide range between 0 and 40%. We tested such a wide range of discount rates because the computational costs are close to zero and we wanted to be sure to include all possible values. Note, however, that we do not expect discount rates for fisheries to be above 10%.

(4.8) $$PV = \sum_{y=2005}^{2055} \frac{I_y}{(1+r)^{y-2004}}$$

4.3.5 Scenario Development

The objective of our study is an analysis of the biological and economic effects of implementing selected management policies under potential environmental change scenarios. Hence, we need to specify the exogenous variables fishing mortality (F) and reproductive volume (RV) over the 50 year simulation horizon.

(A) Management Policies

We investigate the development of the cod stock size, yield and revenues from the Eastern Baltic cod fishery under the following six different management policies:

1. FasU — Fishing mortality 'as usual', applying the average fishing mortality of 1990-1995.
2. C25qu12 — seasonal closure of SD 25 in quarter 1 and 2; quarter 3 and 4 are open to reduced fishing (fishing mortality is reduced by 50%).
3. C25er — permanent closure of SD 25 with fishing effort redistribution from SD 25 into SD 26 or SD 28, i.e., the fishing effort that had previously been applied in SD 25 is fully redistributed into SD 26 or SD 28.
4. C25 — permanent closure of SD 25, no fishing effort redistribution.
5. RoF70 — reduction of fishing mortality F by 70% in the Eastern Baltic Sea (corresponding to ACFM advice for 2003).
6. TC — total closure, i.e. fishing mortality is zero in all three subdivisions (corresponds to current ACFM advice for 2005)[6].

Our scenarios focus particularly on SD 25 with respect to reductions in fishing mortality, because SD 25 comprises the Bornholm Basin, the primary existing spawning ground. Due to regularly returning favourable hydrographic conditions, the Bornholm Basin has turned into the most important spawning ground of Baltic cod during the last decades (e.g. Nissling *et al.* 1994; Plikshs *et al.* 1993). In contrast, the Gotland Deep in SD 28 and the Gdansk Basin in SD 26 have become less important for cod spawning since 1986. Their location farther East/Northeast makes them less likely to be influenced by inflows and, hence, leads to stagnation periods which are much more pronounced and prevail much longer than farther West in the Baltic Sea (e.g. Plikshs *et al.* 1993).

Model runs are performed covering the years 1976-2055 with the different management scenarios initiated in year 2005. Quarterly estimates of fishing mortalities are available from area-disaggregated MSVPA until 1999 (Köster *et al.* 2001a). After 1999, we apply the average fishing mortality of the years 1990-1995 ($F^{average}_{a,r,q,y}$). We also tested the effect of using other constant fishing mortalities for the simulation period, e.g. averages of the years 1986-1995 and 1974-1999. However, results of these simulations showed only little variation from those using the average fishing mortality of the years 1990-1995. The management scenarios we have chosen are initiated in year 2005 and implemented in our model by the following equation:

$$F_{a,r,q,y} = \alpha_r * F^{average}_{a,r,q,y} + \beta_r * F^{average}_{a,\text{“}r25\text{“},q,y} \qquad (4.9)$$

The coefficient α_r determines fishing mortality as a fraction of the original 5 year average quarterly fishing mortality in the three subdivisions (r); β_r accounts for the possibility of redistributing fishing mortality from SD 25 into SD 26 or 28. Values for the coefficients α_r and β_r according to the corresponding selected management policies are given in Table 4.4.

[6] ACFM advice for 2006: A TAC of less than 14 900 tonnes is suggested, but from a biological point of view, a complete closure of the fishery is seen as the best option.

Table 4. Coefficients α_r and β_r, defining management scenarios 1-6 via Equation 11.

Management Scenario	$\alpha_{SD\ 25}$	$\alpha_{SD\ 26}$	$\alpha_{SD\ 28}$	$\beta_{SD\ 25}$	$\beta_{SD\ 26}$	$\beta_{SD\ 28}$
"FasU"	1	1	1	0	0	0
"C25qu12"	quarter 1&2: 0 quarter 3&4: 0.5	1	1	0	0	0
"C25er"	0	1	1	0	1	0
"C25"	0	1	1	0	0	0
"RoF70"	0.3	0.3	0.3	0	0	0
"TC"	0	0	0	0	0	0

(B) Environmental change scenarios

We have depicted that the important exogenous parameter in our model, which is related to climate change and which controls cod recruitment (R) and spawning migration (S), is the reproductive volume (RV). Here, we attempt to project a potential future decrease of the exogenous variable RV based on recent model simulation results, which project average salinity in the Baltic Sea to decrease by 7-47% in the period 2071-2100, relative to the reference time slice 1961-1990 (Meier forthcoming).

Meier obtained these results by performing a set of four scenarios with a fully coupled atmosphere-ocean RCM for the Baltic Sea area[7] using two global general circulation models (GCM)[8] and two IPCC forcing scenarios. The two IPCC emission scenarios analysed are the SRES A2 and B2, representing a high and a low scenario of future CO_2 emissions, respectively, which are driven by different societal change (Nakicenovic and Swart 2000). The wide range of the projected decrease in salinity is not very sensitive to the emission scenario, but is, in fact, caused by differences in the two GCMs, which produce the external forcing to the RCM. The lower estimates are obtained when applying the Hadley Centre's GCM HadAM3H; the higher estimates are obtained when the RCM is coupled to the ECHAM4/OPYC3. Despite the divergence of the model results, there is agreement on the sign of the change in salinity. It will be negative. Furthermore, Meier argues that the future decrease in salinity will be more pronounced in the deep water layers (Meier forthcoming).

Quantitative relationships projecting future sizes of the RV have not been published to date due to the complexity of interactions between the size of the RV and determinant environmental factors (cf. Section 4.2). Research into potential correlations between meteorological variables, major Baltic inflows, and reproductive success of Baltic cod is ongoing, and results allowing us to properly investigate and describe the atmosphere-hydrosphere-biosphere interactions are therefore not yet available. Here, we perform simple linear regression analyses using the average salinity in the second quarter in the Bornholm Basin to explain the variability of the size of the RV in the three subdivisions. With respect to RV in SD 26, and 28, we average salinity over the total depth of the water column. In SD 25, we take the average salinity between 55 and 65 m depth, which improves the correlation. We have checked that average salinity at 55-65m depth is highly correlated to overall average

[7] The Rossby Centre Atmosphere Ocean model

[8] HadAM3H and ECHAM4/OPYC3

salinity. Also, salinity in the Gotland and Gdansk basin is correlated with salinity in the Bornholm Basin. Regression results are shown in Table 4.5.

The developed regression relationships for RV in the three subdivisions with salinity in the Bornholm Basin being the explanatory variable explain 66%, 59%, and 46%, of the variance in RV in SD 25, 26, and 28, respectively. All coefficients are highly significant. The constants of all three regressions are negative, and their absolute values are large. This implies that theoretically the reproductive volume gets negative, if salinity drops below 10 or 9 psu. In our model, we set all computed negative RV estimates to zero. The frequent absence of a reproductive volume in SD 26 and 28 (i.e. RV = 0) accounts partly for the unexplained variance of the regressions, which is particularly high in SD 26 and 28. Additionally, we attribute the unexplained variance to the lack of incorporation of the other environmental variables and artefacts, such as insufficient sampling, different data processing methods, and processes, which have not been identified yet, e.g. patchiness, unusual mixing regimes.

Table 4.5. Results of linear regression analyses, using salinity in the Bornholm Basin in the second quarter as explanatory variable for explaining the variance of the reproductive volume (RV). For RV in SD 25, we apply the mean salinity from 55-65m depth. For the RV in SD 26 and 28, we apply the salinity averaged over the whole water column. Table presents parameter estimates, standard error, significance level of parameter estimates, Durbin Watson statistics, and R^2 values.

dependent variable	explanatory variable	Coefficient	Std. Error	Prob. (t-stat)	DW	R^2
RV (SD25)	$S_{55\text{-}65m}$	56.5794	6.3261	0.000	1.84	0.66
	constant	-503.9241	74.1344	0.000		
	AR(1)	0.5364	0.1572	0.002		
RV (SD26)	$S_{average}$	105.2018	16.6747	0.000	2.08	0.59
	constant	-1028.6720	172.1346	0.000		
	AR(1)	0.2898	0.1443	0.054		
RV (SD28)	$S_{average}$	53.5814	11.3237	0.000	1.95	0.46
	constant	-533.1376	116.5172	0.000		
	AR(1)	0.2576	0.1726	0.147		
	AR(2)	-0.3737	0.1727	0.039		

As salinity and the size of the reproductive volume have a high interannual variability, we apply a normally distributed random variable to produce future realisations of salinity. Mean and variance of this random variable are derived from the salinity data of 1966-1999, which we tested for normality. To account for different climate change projections, we test three scenarios, where the mean salinity is assumed to decrease linearly over the 50 year simulation period according to the following three scenarios:

- low change — 7% decrease in mean salinity (S) over a period of 100 years, i.e., 3.5% decrease of S over 50 years
- medium change — 25% decrease in mean S over a period of 100 years, i.e., 12.5% decrease of S over 50 years
- high change — 47% decrease in mean S over a period of 100 years, i.e., 23.5% decrease of S over 50 years.

For simplicity and due to lack of information, we assume that the variance does not change over time (cf. Meier forthcoming).

As already explained, salinity is not the only factor influencing the size of the reproductive volume. Oxygen also has a direct impact on the RV, and additionally, a number of other environmental factors indirectly affect the Baltic Sea's hydrographic conditions (cf. Section 4.2). In this study we do not incorporate the dynamics of oxygen in the deep basins, since a predictive understanding of the spatial and temporal dynamics of oxygen renewal and utilisation is as yet unavailable. Hence, our approach, albeit novel, is simplistic. Resolving the effect of changes in atmospheric forcing on inflow dynamics is critical to projecting the reproductive success of Baltic cod in the future. Hence, future research is planned to develop new relationships including the hitherto omitted variables. This will strengthen the reliability of our output. Despite these shortcomings, we believe that including additional factors would not significantly influence our results and conclusions. Rather, the Baltic Sea's hydrographic conditions are expected to become more unfavourable for successful hatching of cod eggs in the future not only due to the expected decrease in salinity, but also due to the continuous deterioration of oxygen concentrations, since eutrophication is still a serious problem in the Baltic Sea (HELCOM 2004).

4.4 Results and Discussion

In the first subsection, we show the development of the external forcing of stock development, namely salinity, which, in turn, the reproductive volume depends on. We then present and discuss the results of stock and yield development in the second and third subsection, respectively. In the last subsection, we illustrate results of the net present value of revenues, summed over the 50 year simulation period.

For purpose of illustration, the figures plotting RV, stock and yield development are based on only one random choice of salinities. In the tables and when generalising, we present average values and standard errors, derived from 50 random model realisations.

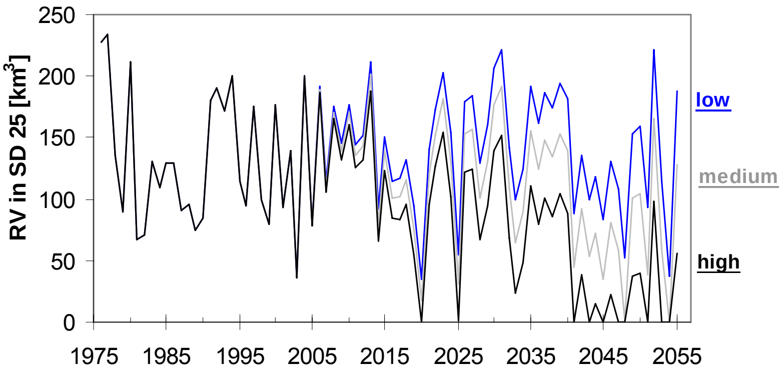


Figure 4.3. Reproductive volume (RV): data until 1999; from 2000 on: estimates derived from salinity as a normally distributed random variable (1 random run out of 50 performed runs), with its mean decreasing linearly over the 50 year simulation horizon by 7%, 25% and 45%, representing a low, a medium, and a high climate change scenario, respectively.

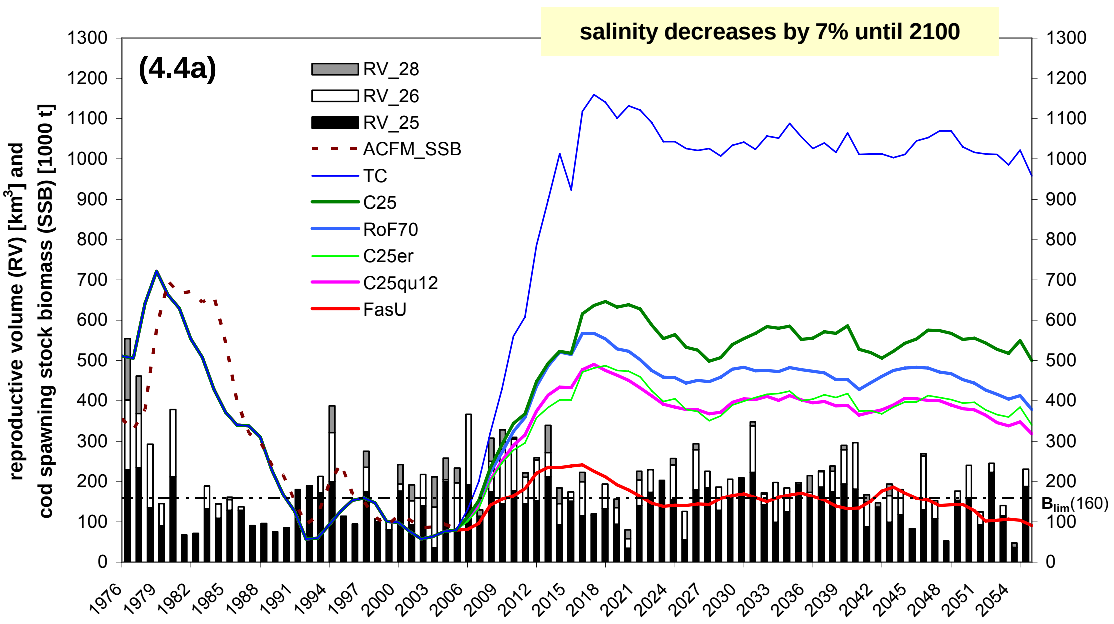
4.4.1 External forcing – Variation and Change in reproductive volume

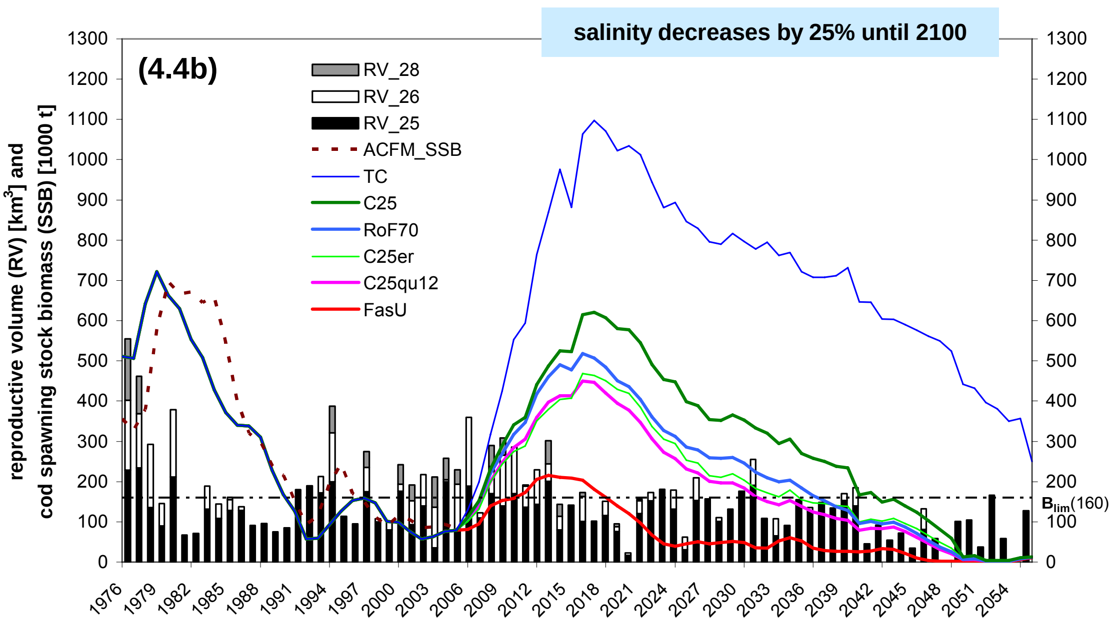
The reproductive volume in SD 25, derived from salinity of one random model run for the three environmental scenarios, is plotted in Figure 4.3. The variability in reproductive volume for the three climate change scenarios is similar. The absolute values for the low, medium, and high climate change scenario, however, are different, as we assume the 34-year historic mean of salinity to decrease by 7%, 25% and 47% until 2100, respectively. Correspondingly, the decreasing trend over the 50 year simulation period can be observed for the size of the reproductive volume.

4.4.2 Change in spawning stock biomass (SSB)

Figure 4.4 a-c illustrates the simulated development of the sum of the cod spawning stock biomass (SSB) in subdivisions 25, 26, 28 under the low, medium, and high environmental change scenario. The black, white, and grey bars in the parts a to c show the size of the reproductive volume in SD 25, 26, and 28, respectively. Each line in the figures depicts one of the six different fisheries management policies. The restrictive management scenarios involving overall reductions in fishing mortality (RoF70, TC) or partial reductions via spatial and temporal closures of SD 25 (C25, C25er, C25qu12) yield the upper lines of SSB development, while the fishing as usual scenario (FasU) forms the bottom line.

The period 1976-1999 serves as validation period: The dotted line (ACFM_SSB) shows the total spawning stock biomass of the Eastern Baltic cod, i.e., summed over subdivisions 25-32, as estimated by the ICES standard stock assessments. Our model is able to reproduce the historic stock fluctuations satisfactorily, with an explanatory power of 0.80. The broken line shows the biological limit biomass B_{lim} of 160,000 t, representing the level below which recruitment is impaired.





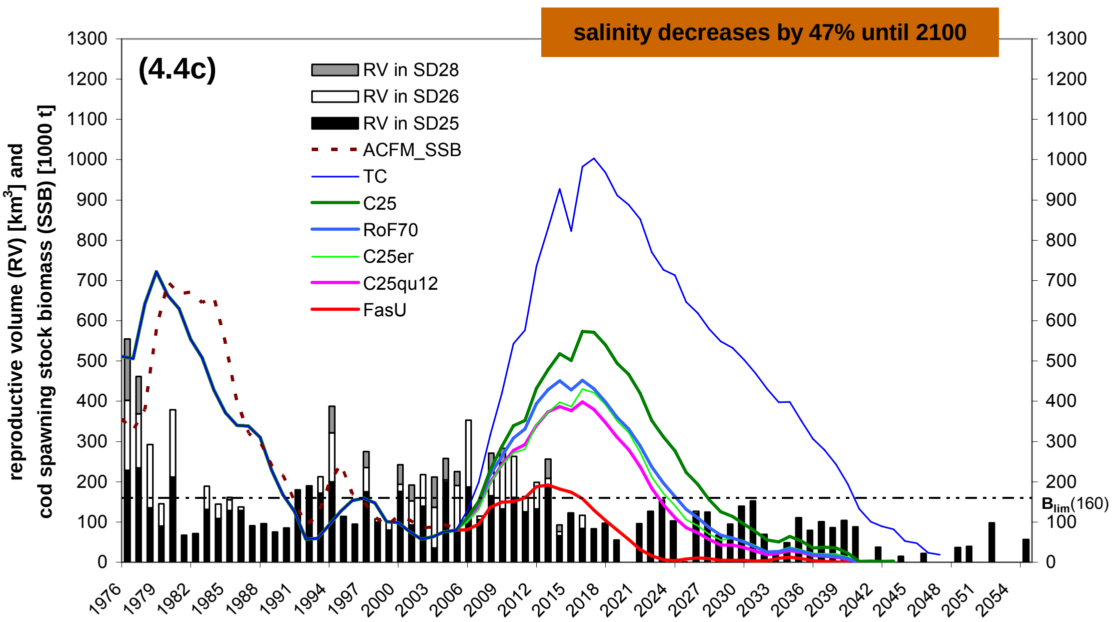


Figure 4.4a-c. Simulated development of SSB (in 1000 t) under the (a) low, (b) medium, and (c) high environmental change scenarios for the six different management policies. Bars: reproductive volume [km^3] in SD 25 (black), in SD 26 (white), in SD 28 (grey). Lines represent six different management policies: "FasU" = Fishing mortality as usual; "C25qu12" = temporal closure of SD 25 in quarter 1 and 2; quarter 3 and 4 are open to reduced fishing; "C25er" = permanent closure of SD 25 with fishing effort redistribution from SD 25 into SD 26; "RoF70" = reduction of fishing mortality F by 70% in the Eastern Baltic Sea; "C25" = permanent closure of SD 25 without fishing effort redistribution; "TC"= total closure. "ACFM_SSB" shows standard stock assessment estimates from 1976-1999 for model validation. See text for further explanation.

Low environmental change

Under the fishing as usual policy (FasU), the cod stock experiences a slight recovery during the initial ten years of the simulation period due to a period of large reproductive volumes in all three subdivisions (i.e., large black, white, and grey bars). Spawning stock biomass (SSB) increases from less than 100,000 t to approximately 240,000 t. After 2016, following a period of lower reproductive volumes, SSB decreases again to around 160,000 t (Blim) and fluctuates around Blim for the rest of the simulation period. It can be concluded that in the long run the cod stock cannot recover under the 'fishing as usual' management scenario.

On the contrary, under the presented five restrictive management policies an enduring stock recovery to SSB levels around and above 400,000 t is possible. Under the total closure scenario, SSB even increases by approximately 100% within the first ten years of the simulation period, yielding a spawning stock size of around 1,000,000 t. Such a high SSB has not been precedented in history and can be regarded as a possible maximum environmental carrying capacity of the Eastern Baltic cod stock, given the environmental conditions of our low climate change scenario. This result, however, should be regarded with caution, because our simulations do not include food-web interactions, such as predation of cod eggs by sprat and herring.

In contrast to achieving an overall reduction of fishing mortality (RoF70), the establishment of a permanent marine reserve in SD 25 (C25) focuses on the protection of a large component of the cod spawning stock to ensure spawning in SD 25 and thus provide for successful recruitment. Our simulation results suggest that the latter policy is indeed more effective in rebuilding the stock, because a permanent closure of SD 25 without fishing effort redistribution leads to an SSB which is roughly 10% higher than under an overall reduction of fishing mortality by 70%. Apart from a higher stability with respect to recruitment, additional stock benefits result from the circumstance that a part of the stock's habitat is permanently protected. At least a small, less migratory, fraction of the stock is thus allowed to grow older than without this habitat protection (Figure 4.5). At the end of the simulation period in year 2055, there are 5-15 million more cod of age 4, 5, 6, 7, and 8 under policy C25 than under policy RoF70.

Stock recovery is also achieved with management policies C25qu12, based on a temporal closure of SD 25 before and during the spawning period, and C25er, the permanent closure of SD 25 allowing for full effort redistribution. Both policies yield very similar results in terms of simulated SSB, which is approximately 20% lower than that achieved under C25 and approximately 10% lower than under RoF70.

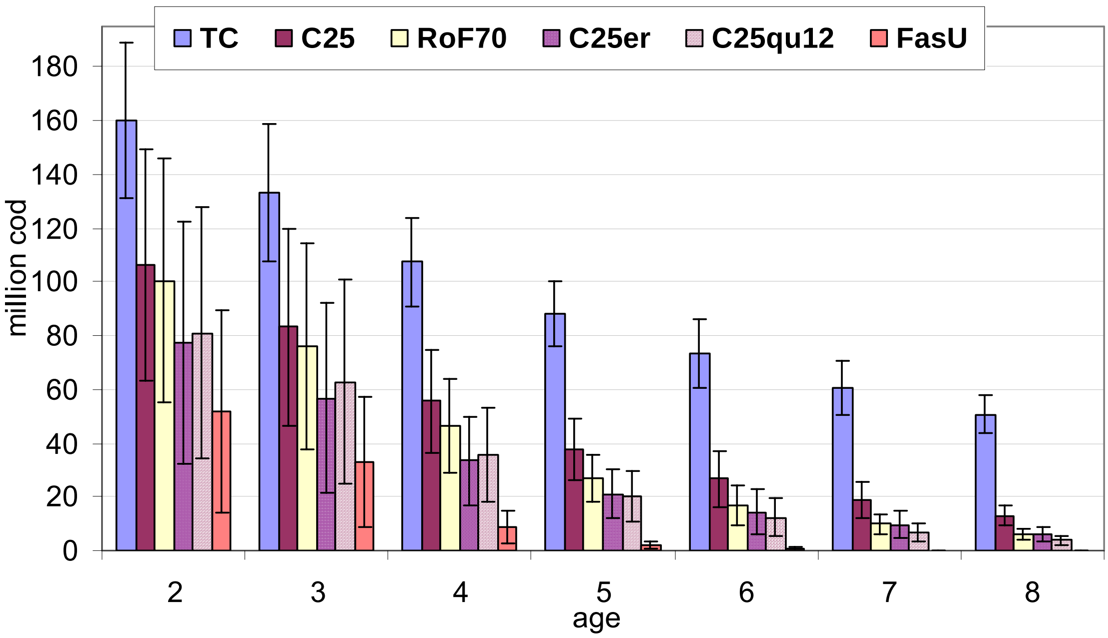


Figure 4.5. Age structure of the spawning stock in year 2055 under the low environmental change scenarios for the six different management policies (average of 50 model runs and standard deviation).

Medium and high environmental change

The simulated SSB results of the six management policies for the medium and high environmental change scenarios follow the same order as those under low environmental change. SSB is lowest under the fishing as usual scenario (FasU), which exerts the highest fishing mortality on the stock. With a fishing moratorium in the entire Eastern Baltic Sea (TC), SSB for both medium and high environmental change increases to unprecedented high levels. The maximum SSB, reached during the initial 8-10 year recovery phase of high reproductive volumes, is, however, approximately 20% lower for the high environmental change scenario than for the low environmental change scenario.

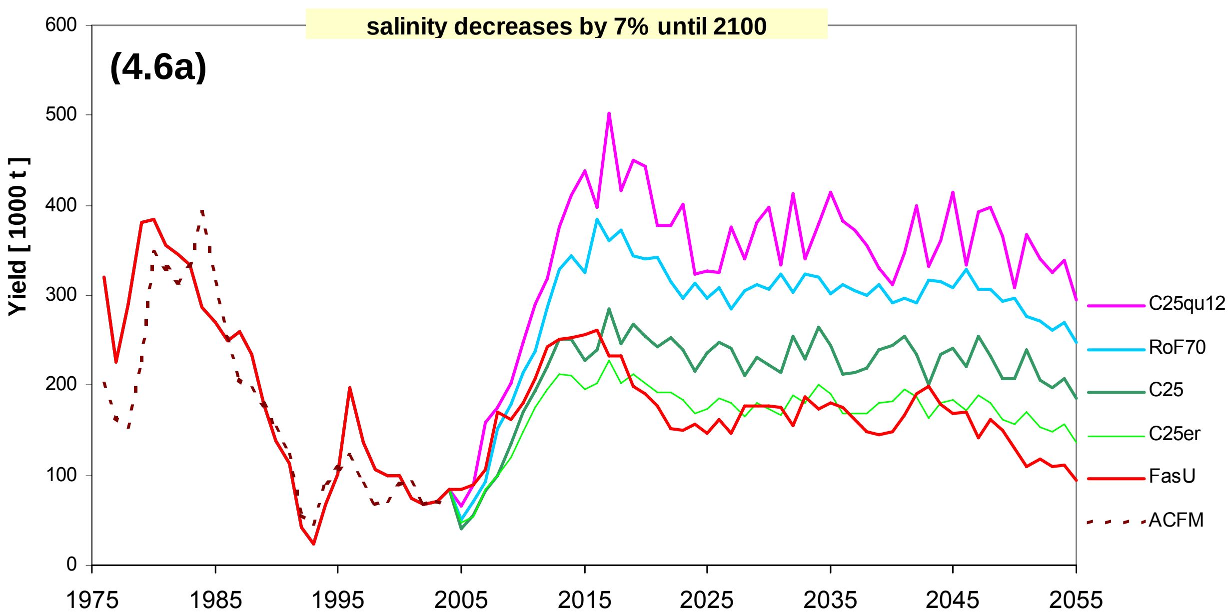
The main difference between simulated SSBs for the three environmental scenarios is the long-term development, i.e., the trend after the initial decade of stock recovery. For medium and high environmental change, a gradual decrease in SSB starts around 2020 under the five restrictive management policies. The decrease starts already around 2016 under the fishing as usual policy.

For high environmental change, simulated SSBs decrease steadily and steeply, resulting in the extinction of the spawning stock around 2026 under fishing as usual, around 2040 for the marine reserve scenarios, and around 2050 under the total closure scenario. The steadiness of the decrease results from our simplifying assumption to calculate the reproductive volume via salinity estimates only - thus neglecting any future sporadic Major Baltic Inflows which would increase the reproductive volume. According to the model calculations for the high environmental change scenario, the reproductive volumes in SD 26 and 28 disappear completely after 2026 (cf. white and grey bars in Figure 4.4c, respectively). In reality, however, North Sea inflow events sporadically replenish the Baltic Sea deep water and hence contribute to a sporadic increase in salinity and the re-occurrence of reproductive volumes, despite the general tendency of decreasing salinity due to climate change. Despite these shortcomings, we believe that future reproductive volumes will be smaller and less frequently present. Our model simulations for the medium and high environmental change scenarios both show clearly that the cod stock is threatened by extinction if current fishing effort prevails (FasU). Under medium environmental change, extinction may set in within the coming 20 years, as SSB remains below 50,000 t from 2026 onwards.

4.4.3 Development of yield

The curves in Figure 4.6 a-c illustrate the simulated development of the expected annual yield from the Eastern Baltic cod fishery under the low, medium, and high environmental change scenario. Again, the period 1976-1999 serves as validation period: The dotted line (ACFM) shows the total landings of the Eastern Baltic cod, i.e., summed over subdivisions 25-32, as estimated by the ICES standard stock assessments. Our model reproduces the historic yield fluctuations reasonably well, with an explanatory power of 0.78.

During the initial decade of the simulation period, which is characterised by favourable hydrographic conditions leading to stock recovery (cf. Figures 4.4a-c), the yield curves follow the stock development, i.e., yields increase together with increasing SSB. During these first ten years, the different yield curves follow a similar behaviour under all three environmental change scenarios. Yields increase within the first ten years from less than 100 kt to 190, 200, and 210 kt (minimum) or to 410, 460, and 520 kt (maximum) under the high, medium, and low environmental change scenarios, respectively.



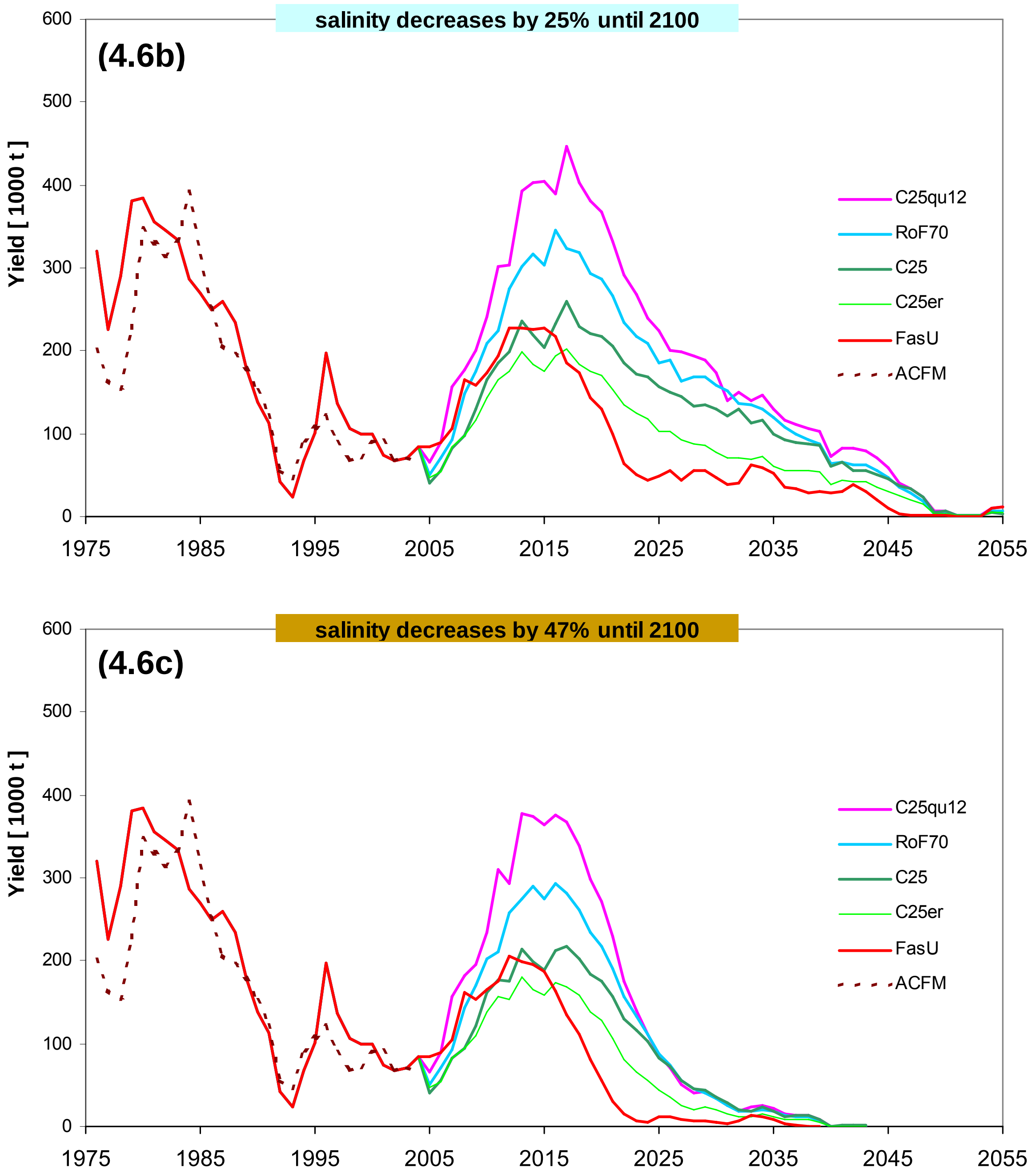


Figure 4.6 a-c. Simulated development of yield in 1000 t under (a) low, (b) medium, and (c) high environmental change scenarios for five different management policies: “FasU” = Fishing mortality as usual; “C25qu12” = temporal closure of SD 25 in quarter 1 and 2; quarter 3 and 4 are open to reduced fishing; “C25er” = permanent closure of SD 25 with fishing effort redistribution from SD 25 into SD 26; “RoF70” = reduction of fishing mortality F by 70% in the Eastern Baltic Sea; “C25” = permanent closure of SD 25 without fishing effort redistribution. Broken line “ACFM” shows actual ACFM landing estimates from ICES for comparison.

In the first two years of the simulation period, the fishing as usual policy (FasU) produces the highest annual yields of all presented management policies. In contrast, losses in yield in the first two years characterise the two permanent marine reserve policies (C25, C25er) and the policy with overall reduction of fishing mortality by 70% (RoF70). Yet, already in 2007, i.e., year three of the simulations, yield under the temporal marine reserve policy (C25qu12) exceeds yield under fishing as usual, and in year 2009, also yield under RoF70 exceeds yield under FasU. Even yield under the permanent marine reserve scenario (C25) increases gradually until it exceeds yield under fishing as usual in 2017. There is a turning point in the development around 2015 (a little earlier under high environmental change, a little later under low environmental change), when yields start to decrease. Only with low environmental change, yields under C25 and C25er remain more or less stable around 250,000 and 180,000 t.

Yields decrease steadily under the medium and high environmental change scenarios parallel to the gradual decrease in spawning stock size, starting between 2015-2020. Yields drop to zero around 2050 under the medium environmental change scenario. Under the high environmental change scenario, this happens already between 2025 and 2040, depending on the management policy.

The order of management policies from lowest to highest yield in year 2025 (representing a long term estimate) for the three environmental change scenarios is presented in Table 4.6.

Table 4.6. Yield in 1000 tons in year 2025 under the low, medium, and high environmental change scenario. Values are averages ± the standard deviation of 50 random model runs, which differ in the external forcing by salinity. This translates into differences in reproductive volume and finally in different population dynamics of the 50 model runs.

Yield in 2025	**FasU**	**C25er**	**C25**	**RoF70**	**C25qu12**
Low	124 ± 48	154 ± 29	203 ± 33	265 ± 46	316 ± 64
Medium	47 ± 33	84 ± 34	127 ± 40	154 ± 57	175 ± 75
High	15 ± 16	33 ± 22	56 ± 34	59 ± 41	65 ± 47

This arrangement clearly shows that annual yield under the first four management policies exceeds yield obtained under “fishing as usual”. This occurs as the reduction in fishing mortality fosters stock recovery. A reduced fishing mortality exerted on a large stock size results in higher yield than a high fishing mortality exerted on a small stock size. Furthermore, this arrangement elucidates that the permanent marine reserve policy allowing for effort redistribution (C25er), does not reduce fishing mortality effectively. Instead, fishing mortality is shifted from SD 25 into SD 26, increasing fishing mortality in SD 26. The overall effect on total fishing mortality reduction is thus only weak. Therefore, we do not consider this management policy very effective in sustaining long-term yields.

According to our simulations, the most effective policy for achieving highest long-term yields is the seasonal marine reserve policy (C25qu12). The permanent, thus more restrictive marine reserve policy (C25), results in lower yields, while the SSB is higher than under C25qu12.

4.4.4 Gross revenues

Due to our assumption of a constant price, the order of management policies from highest to lowest revenues is the same as for annual yield. We note that, as prices decrease with increasing supply and vice versa, fishing strategies which increase the quantity of landings would become less attractive than under the assumption of constant prices.

When calculating the net present value of revenues, the ranking of the management policies persists for discount rates between 0-10%. The attractiveness of the two permanent marine reserve scenarios C25 and C25er, however, decreases relative to the fishing as usual (FasU) scenario, when discount rates greater than 10% are applied. Critical discount rates which would reverse the order of these three least attractive policies (C25, C25er and FasU) are 10/ 13/ 14% and 22/ 23/ 24% under the low/ medium/ high climate change scenario. The FasU policy is shifted up one position, overtaking C25er in the ranking, when applying discount rates of 10-22/ 13-23/ 14-24% under the low/ medium/ high climate change scenario. When discount rates above 22/ 23/ 24% are applied, net present value of gross revenues from FasU also exceeds the C25 policy.

As an example, we have presented average net present values of 50 random model realisations, applying a discount rate of 4% in Table 4.7. Under the three environmental change scenarios, the temporal marine reserve policy with reduced fishing in quarters three and four (C25qu12) yields the highest net present value of revenues over the 50 year simulation period. Table 4.7 elucidates that for all three environmental change scenarios the net present value of revenues under this seasonal marine reserve policy is more than twice as high as under the fishing as usual policy.

Table 4.7. Net present value of revenues in Billion Danish Krone [DKK] under the low, medium, and high environmental change scenario, discounted over the 50 year simulation period (2005-2055) applying a discount rate of 0.04. Values are averages ± the standard deviation of 50 random model runs.

Climate change	**FasU**	**C25er**	**C25**	**RoF70**	**C25qu12**
Low	14 ± 3.2	18 ± 3.1	24 ± 3.6	31 ± 5.1	37 ± 6.2
Medium	9 ± 2.7	11 ± 3.2	15 ± 4.2	19 ± 5.6	23 ± 6.6
High	6 ± 2.1	8 ± 2.7	11 ± 3.7	13 ± 4.7	17 ± 5.5

We have not included costs into our analysis because of insufficient data availability. The ranking of our results might be altered, once operating costs of fishing are included in the analysis, which then allows the calculation of net present value of profits rather than revenues. An investigation of costs of the Eastern Baltic cod fishery therefore warrants further research. Cost data could be obtained from the administrating national fisheries directorates. Alternatively, a cost analysis could start with applying cost function parameters from other cod fisheries, such as the Northeast Arctic cod fisheries investigated by Sandberg (2006).

In our study, one can hypothesise that harvesting costs per kilogram will be lower than under the fishing as usual policy, if fishing mortality and hence fishing effort is reduced, while at the same time stock size increases. This is the case under policies C25qu12, RoF70, and

C25. As, however, the policy C25qu12, which yields highest gross present value in our analysis, does not maintain the highest stock size (cf. Figures 4.4a-c), policies C25 and RoF70 might be advantageous in terms of economic outcome, once operating costs are included in the analysis.

4.5 Conclusion and outlook

We can derive some general conclusions from our simulations as to potential impacts of environmental and climate change on the Baltic cod fishery. The implications in the form of a decrease in recruitment, resulting in a decrease in the spawning stock biomass and finally in decreased yield and revenues, will be more severe, the more rapidly climate changes. The results of our simulations under different environmental scenarios show that a future decrease in the size of the reproductive volume caused by a climatically induced decrease in salinity results in extinction of the Eastern Baltic cod stock. Nonetheless, our simulations of stock and yield development under different management policies also elucidate that fisheries management can dampen the negative consequences of climate change for at least 20 years. Such policies should focus on the protection of the spawning stock in SD 25 for at least the six months before and during the extended spawning period of the Eastern Baltic cod. However, stock collapse cannot be prevented but only postponed with such measures.

In line with advice by the Ad hoc Group on Long-term Management to the European Directorate General for Fisheries (ICES 2005b, p.31), a significant reduction in fishing of the Eastern Baltic cod stock would preserve the stock, unless environmental conditions will become very detrimental. A permanent closure of SD 25 would be even better for the fish. Our simulation results demonstrate that maintaining the spawning stock biomass above B_{lim} is a prerequisite to achieve high yields in the long term. In terms of stock recovery and conservation, establishing a permanent marine reserve in the Eastern Baltic Sea in SD 25 is more efficient than an overall reduction of fishing effort and establishing a temporal/seasonal marine reserve. From the economic point of view, the results are slightly twisted: The establishment of a seasonal marine reserve in SD 25 leads to highest yields and revenues. The second best policy in terms of yields and revenues is the overall reduction of fishing effort, whereas the establishment of a permanent marine reserve ranks third. Closing subdivision 25, at least temporarily for at least six months every year during the cod spawning period, would allow the mature fish to spawn before being caught. Cod reproduction can therefore be ensured to occur at least in SD 25, whereas successful reproduction in SD 26 and 28 cannot be relied on due to the climatically induced deterioration of hydrographic conditions particularly in regions farther East/ Northeast in the Baltic Sea, which will be more unfavourable for cod reproduction in the future.

An improvement of the stock's age-structure by allowing more fish to grow older is most effectively achieved by permanently closing SD 25. Nonetheless, we conclude from Figure 4.5 that the crucial factor for improving the stock's age-structure is the reduction of fishing, be it an overall reduction or spatially differentiated by the establishment of marine reserves. In summary, it can be concluded that the establishment of a temporal but also a permanent marine reserve in SD 25 resembles a "win-win" situation for the stock as well as for the fishery. Since larger, older females produce many more and more viable eggs, reproductive success tends to be better if the stock comprises a larger portion of older fish (e.g. Hutchings

2004). As a consequence year classes can get stronger, thus providing a larger harvestable fish stock to the fishery.

The International Baltic Sea Fisheries Commission has already established a closure of the Bornholm Basin spawning ground and a temporal summer ban for the cod fishery since 1995 in addition to the annual TACs and supplementary technical regulatory measures, such as minimum landing sizes and mesh size regulations (IBSFC 2002). These spatial closures are, however, too small and too short to effectively reduce fishing mortality on the spawning stock in SD 25. Poor enforcement of management policies moreover aggravates the uncertainty of fish stock assessments and consequently the susceptibility to unbalanced management by TACs, especially if a significant amount of the catch is landed illegally or not reported. In the Baltic Sea, poor management enforcement is a severe problem (ICES 2005a, 2005b) and can render management plans useless, if they assume precise estimates of present stock parameters. Due to these problems, the ACFM was reluctant to give management advice for the Baltic cod fishery in 2005, just recommending “No catch in 2005” (ICES 2004a).

We now point out caveats resulting from critical assumptions, simplifications, or unknown hence omitted processes in our model specifications. All of these aspects represent areas that warrant future research.

As our model is narrowed down to three subdivisions and does not take into account multi-species interactions and density-dependent growth and maturity, the results should only be taken as indicative of the direction of change. To incorporate multispecies and food-web interactions, our model could be coupled to a similar model of sprat and herring population dynamics. This would then account for effects such as the potential increase in predation mortality on juvenile cod by mature sprat due to the projected future increase in water temperature in the Baltic Sea.

As regards the biological part of the model, the following model specifications could be improved: The underlying data from area-disaggregated MSVPA is highly uncertain and could be updated, as it is currently only available until 1999. The calculation of migration estimates should be derived from field data. Such data will become available within the next couple of years, because an extensive tagging project of Baltic cod is ongoing (R&D project CODYSSEY). Movement of cod between subdivisions should also include passive wind-induced egg and larval drift. Hydrodynamic models are already available (Hinrichsen and Möllmann 2002; Hinrichsen *et al.* 2002b), but research is needed on meteorological coupling parameters and on the impact of climate change on their future course.

As stressed already, salinity is not the only factor impacting on cod reproductive success. Oxygen is at least of equal importance and is strongly affected by inflow events from the North Sea. Correlations between regional climate change, air and water circulation, and dissolved oxygen should be established and incorporated into the model.

Furthermore, it would be worthwhile to explore potential correlations between the reproductive volume and eutrophication measures, e.g. nutrient concentration. If in the future eutrophication prevailed, hydrographic conditions were expected to aggravate. On the other side, if eutrophication decreased, then this could improve oxygen conditions, which, to some degree, could counteract or dampen the reproductive disadvantage of a decrease in salinity.

With respect to the economic calculations in our model, future research should focus on including costs in the calculations. As pointed out above, the economic evaluation of our simulation results might be altered, once operating costs of fishing are included in the analysis, because the policy C25qu12, which yields highest gross present value in this study, does not maintain the highest stock size. Therefore, policies C25 and RoF70, which sustain a higher spawning stock biomass, might be advantageous in terms of economic outcome, once operating costs are included in the analysis. It is hence desirable to present results of net revenues and net present value of profits in a follow-up study. Finally, the currently static parameter fishing effort should be transferred into a dynamic variable, so that dynamic harvesting policies and an optimal approach can be found.

To summarise, we emphasise that under the presented simulations of future climate change a significant reduction in fishing mortality is necessary to achieve high yields from the Eastern Baltic cod fishery in the long term.

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Chapter 5 - Rebuilding the Eastern Baltic cod stock under environmental change - Part II: The economic viability of a marine protected area

5.1 Introduction

Recent studies suggest that global climate change affects the marine environment (e.g. Barnett *et al.* 2005; Ottersen *et al.* 2001), including fish stocks (Perry *et al.* 2005; Rose 2004; Worm and Myers 2004)[1]. As a consequence, fishermen and the fishing industry are also affected and may, for instance, benefit from rising profits from an expansion of favourable fish habitat and a resulting increase in stock size (Lorentzen and Hannesson 2005). In contrast, regional climate change may lead to stock extinction, hence, triggering income losses (Röckmann *et al.* forthcoming). However, the outcomes are case-specific and one cannot generalise.

Here, we focus on the Eastern Baltic cod fishery, which is expected to suffer from global warming (MacKenzie *et al.* 2002; Röckmann *et al.* forthcoming). The projected future decrease in Baltic Sea salinity and dissolved oxygen concentration due to increasing temperatures (Meier *et al.* 2004) means a loss in environmentally favourable spawning habitat of Eastern Baltic cod, possibly resulting in increased recruitment failure. A declining stock size will ultimately lead to declining yields and loss in gross revenues, if fishing continues as usual (Röckmann *et al.* forthcoming).

Can fishermen and fisheries managers counteract or mitigate negative consequences of climate change? Röckmann *et al.* (forthcoming) find that a marine protected area (MPA) (either permanent or seasonal) can reduce the negative consequences of climate change in the Eastern Baltic cod fishery. Such a policy should focus on the protection of the spawning stock in ICES subdivision 25, where environmental conditions are favourable for successful Baltic cod egg development most frequently, thus increasing biological productivity in this subdivision. From a biological point of view, the Eastern Baltic cod stock can be rebuilt by reducing fishing mortality on the spawning stock, allowing part of the stock to spawn successfully and to grow older. Adequately designed seasonal marine reserves are not only a tool to rebuild fish stocks; they also benefit fishermen, who are allowed to target a stock that had temporarily been protected and allowed to grow older and larger. Provided that some fish emigrate from the protected area into the adjacent open areas, such policies may also contribute to sustainable fisheries management in economic terms. With regard to the

[1] See also articles in Volume 62 of the ICES Journal of Marine Science, October 2005.

Eastern Baltic cod fishery, revenues increase not only due to higher catches but also due to the improved age-structure of the stock, with older specimen reaping a higher price per kilogram.

Röckmann *et al.*'s (forthcoming) findings are based on gross revenue; they neglected the costs of fishing, which is equivalent to assuming that harvesting costs are constant. Here, we add a cost analysis to the previous study. We investigate how the incorporation of variable costs influences the ranking of different management policies with regard to maximum operating profits in the Eastern Baltic cod fishery. We additionally perform a sensitivity analysis testing different values of stock and output elasticities of variable costs.

The chapter is structured as follows. In section 2, we briefly describe the problem of assessing costs in a fishery. In section 3, the Eastern Baltic cod fishery is depicted and rough estimates of variable costs for the Danish Eastern Baltic cod fishery are calculated and extrapolated to the international Eastern Baltic cod fishery. Section 4 introduces the employed cost function and the concept of cost elasticity parameters. Results of model simulations and sensitivity analyses, testing a range of cost elasticities, are presented and discussed in Section 5. The final section concludes and it points out areas that warrant further research.

5.2 Assessing the costs of fishing

Empirically, it is difficult to determine the costs of fishing for a particular fish species. First, cost data on the vessel level are usually confidential, and the accessible data collected by national administrations often only allow for aggregate analyses. Second, in general vessels target more than just one fish species, but apply the same input factors – at least partly – to produce several outputs. Such multi-species fisheries, where firms use the same input factors to harvest several species, are called a multi-output production and characterised as "joint in inputs" (Squires and Kirkley 1991). At least part of the vessel operating and maintenance costs then have to be considered joint in production of other species; hence, one cannot readily disentangle variable costs and attribute them to one species only. Third, available data differ across regions.

In general, fixed costs (e.g. vessel costs such as depreciation and financial costs) occur as a consequence of all the fisheries which the vessel participates in. They can therefore be considered as "joint in [production] inputs" (Squires and Kirkley 1991). In contrast, variable costs (i.e., cost items necessary to operate the vessel in the short term, such as fuel, lubrication oil, special social fees, bait, ice, salt, packing, social expenses, food, crew wages/shares) can be species-specific. It depends on the form of the production technology whether variable costs in a multi-species fishery are species-specific or occur equally in each specific fishery (Squires and Kirkley 1991).

In the following, we neglect fixed costs, which are joint in production of other fish species, since most vessels/ fleets temporarily change their rigging to target other species, e.g. at times, when the Eastern Baltic cod fishery is closed. As we only look at variable costs, we shorten the 50-year simulation period of the previous study to approximately 30 years.

5.3 The Eastern Baltic cod fishery

The Eastern Baltic cod fishery is very heterogeneous due to its internationality and the multitude of possible cod harvesting technologies employed (static gears, such as trap; active gears such as trawl, purse seine, gillnet) (Anonymous 2003). The main fisheries for cod in the Eastern Baltic use demersal trawls, pelagic trawls and gillnets (ICES 2005). However, with the change in stock age composition towards younger ages since the late 1990s, the share of the total catch of cod taken by gillnets has decreased while that of demersal trawl increased (ICES 2005). Estimated recent landings of Eastern Baltic cod range between 50 and 100 thousand tonnes, although recent estimates are uncertain due to unreported landings: The ICES Advisory Committee on Fishery Management (ACFM) estimates that recent catches have been around 35-45% higher than the officially reported figures. Discarding, especially of age 1 to age 3 cod, is also a severe problem in the Eastern Baltic cod fishery. The amount of discard which has been estimated by use of extrapolation in 2004 is 63% for gillnet and 40% for trawl (ICES 2005).

Eastern Baltic cod have traditionally been taken in a targeted fishery, with limited by-catch of other target species but only some by-catch of flatfish, primarily flounder (ICES 2005). Catches of Eastern Baltic cod as by-catch in pelagic fisheries have been very limited. Hence, variable costs in the Eastern Baltic cod fishery can be considered as non-joint to the production of other species.

The heterogeneity of the fleet calls for a cost analysis with a high level of disaggregation. On the other hand, uncertainty as well as the lack of accessibility to high-resolution economic fisheries statistics compel simplification. To get a rough numerical idea of variable costs in the Eastern Baltic cod fishery, we looked at Danish fisheries statistics (FOI 2006) and extrapolated these to get an estimate of the aggregated variable costs in the international Eastern Baltic cod fishery. Our estimates are based on Danish regionally-specific fisheries statistics for the years 2000-2004. Since 97% of the Danish Eastern Baltic cod catch originates from SD 25 (ICES 2002), the data referring to the Bornholm region can be taken as representative for the Danish Eastern Baltic cod fleet. Furthermore, we assume that variable costs of the Danish Bornholm vessels are representative for the whole international Eastern Baltic cod fleet. For illustration, we show data and rough extrapolation figures for three recent years in Table 5.1.

According to ICES catch statistics, the Danish share of the total Eastern Baltic cod catch (C) was 11-12% during 2001-2003. We apply this share to extrapolate from the Danish estimate of variable costs per firm in the Bornholm region (E) to get an estimate of the total international Eastern Baltic cod fishery (G).

We calculated total variable costs in the Danish Eastern Baltic cod fishery (F) by multiplying the variable costs (excluding depreciation) per vessel in the Bornholm region (E) with the number of vessels fishing in the Bornholm region (D). Dividing by the Danish share on the international Eastern Baltic cod yield (C) gives an estimate of the international Eastern Baltic cod total variable costs (G). The unit[2] variable costs in the international Eastern Baltic

[2] Following Sandberg (2006), we use unit cost as a synonym for average cost of fishing one unit [here: kg] of fish.

cod fishery (H) are calculated as the quotient of the international Eastern Baltic cod total variable costs (G) and the total international Eastern Baltic cod yield (B). In 2001-2003, the estimated unit variable costs are around 10 *Danske kroner* (DKK) per kilogram (kg). This estimation seems reasonable as unit variable costs lie in the same range dimensionally as the unit price of Eastern Baltic cod, which, depending on fish length, varies between 12 and 34 DKK/kg (Fiskeridirektoratet 2003). Estimates of average variable costs in the Swedish bottom trawl fishery range from approx. 9-16 DKK/kg[3] (Eggert and Tveterås 2004). Eggert & Tveterås (2004) estimated unit costs as a function of labour, capital, and fuel consumption, assuming constant marginal cost of effort (or linear total costs). They found large possibilities to reduce unit costs in the Swedish bottom trawl fishery when annual landings are below 400 tons per vessel. Landings above 400 tons do not enjoy scale economies to any extent. For landings above 880 tons, scale diseconomies occur. Eggert & Tveterås (2004) thus described an L-shaped average cost (AC) curve, with large returns to scale in the lower interval and then a flat AC curve.

Table 5.1: International (A, G, H) and Danish (C-F) fisheries statistics, referring to the Eastern Baltic cod fishery, and rough calculations of annual international unit and total variable costs in *Danske kroner* (DKK).

		2001	**2002**	**2003**	**Source**
A	Eastern Baltic cod Yield (Denmark) ['000 t]	10	8	8	ICES 2002, 2004
B	Eastern Baltic cod Yield (international) ['000 t]	91	68	71	ICES 2005
C	**Danish share of international Eastern Baltic cod yield**	**0.11**	**0.12**	**0.11**	**A/B**
D	# Danish vessels (Bornholm region)	141	128	124	FOI 2006
E	Total variable cost per vessel (Bornholm) ['000 DKK / firm]	717	678	663	FOI 2006
F	**Eastern Baltic cod total variable costs (Danish) [million DKK]**	**101.1**	**86.8**	**82.2**	**E*D/1000**
G	**Eastern Baltic cod total variable costs (international) [million DKK]**	**920**	**738**	**730**	**F/C**
H	**Eastern Baltic cod unit variable costs (international) [DKK/kg]**	**10.11**	**10.85**	**10.28**	**G/B**

5.4 Cost function and cost elasticities

The variable costs (C) of fishing depend on the costs of the different production factors. It is well known that the fish stock is an important factor of production in the fishery (Clark and Munro 1975; Gordon 1954). Contrary to other input factors, the size of the fish stock is beyond control of the single firm. Hence, the fish stock can be considered an external factor. Apart from the stock size (B), the cost of production of a fishery also depends on the output

[3] Original result: 12-20 SEK/kg (exchange rate fluctuated between 0.78-0.83 DKK = 1 SEK over the past years)

quantity (Y), market prices of variable input factors (W) such as fuel, ice, labour, and various other factors (O) (e.g. age/experience and skill of the skipper, vessel characteristics): $C = f(B,Y,W,O)$. Here, we reduce this function to $C = f(B,Y)$, based on two assumptions:

Real prices in the input markets are constant, i.e., W = constant.

Unobserved effects of other factors could be neutralised by the fixed effect method, which is equivalent, for instance, to assigning dummies for different vessel types (Sandberg 2006). Here, we assume that a single vessel from Bornholm is representative for the total international fleet targeting Eastern Baltic cod, following Kronbak (2004). Thus, O is assumed to be constant as well.

There are different possibilities to describe a fisheries production function and the resulting variable costs. Translog functions have been used, e.g. by Weninger (1998), Bjørndal and Gordon (2001). Here, we follow Sandberg (2006) and employ a generalised Cobb-Douglas-type cost function with two explanatory variables, assuming that stock size and output affect unit variable costs (c) multiplicatively (Equation 5.1). [4]

(5.1) $$c_y = \alpha \cdot B_y^{\beta} \cdot Y_y^{\gamma}$$

Subscript y denotes the time step, which is a year. α is a calibration factor. Here, it is tuned such that unit variable costs of the international Eastern Baltic cod fishery during 2001-2003 reach a value of 10 DKK/kg. The parameters β and γ are stock and output elasticities of unit costs, respectively. We expect both elasticities to be negative.

Yearly total variable costs (C_y) are calculated as:

(5.2) $$C_y = Y_y \cdot c_y$$ (Y in kg).

Yearly operating profit (π_y) is calculated as:

(5.3) $$\pi_y = \mathrm{I}_y - C_y$$ where $\mathrm{I}_y = Y_y \cdot p$ (cf. Röckmann *et al.* forthcoming).

5.4.1 Stock elasticity of unit variable costs

In standard fisheries economics, it is assumed that the total cost of fishing is directly proportional to the amount of fishing effort (Gordon 1954). The cost per unit of effort is assumed constant. Furthermore, stock size under equilibrium conditions[5] is a linear function of fishing effort (Schaefer 1957). Consequently, the cost of fishing one unit of fish is linearly related to stock size. Generally speaking, unit variable costs rise with decreasing stock size. Assuming that the fish stock is distributed homogeneously, the Schaefer function, which is linear in both effort and stock size, implies a stock elasticity of output of one. For schooling species, however, it has been recognised that the stock elasticity is significantly less than one (Bjørndal 1987; Bjørndal 1988). Accordingly, for a given effort level, harvest and

[4] Sandberg (2006) was the first to investigate empirically the dependence of unit variable costs on both stock size and output.

[5] I.e., when the catch is exactly equal to the rate of natural increase in population size.

consequently unit costs are not very sensitive to changes in stock size, as still fish schools of small stock size can be detected and harvested very efficiently. Recently, Sandberg (2006) reported that even for demersal species such as the Northeast Arctic cod, stock elasticities of unit costs were in the range -0.2 to -0.6, thus different from –1.0. These findings confirm once more that unit costs do not fall linearly with increasing biomass. Previous studies, where a Cobb-Douglas production function was applied, had also reported stock elasticities of output less than 1 (Eide *et al.* 2003; Flaaten 1983; Hannesson 1983).

5.4.2 Output elasticity of unit variable costs

With respect to the output elasticity of unit costs, economies of scale have been reported to exist, as long as firms produce below their maximum production capacity. Hence, unit variable costs fall with increasing output (e.g. Bjørndal 1987; Bjørndal 1988; Bjørndal and Gordon 2001; Eggert and Tveterås 2004; Eide *et al.* 2003; Sandberg 2006). Sandberg (2006) reported output elasticities in the Northeast Arctic cod fisheries in the range -0.2 to -0.5. In the following cost analysis of the international Eastern Baltic cod fishery, we also assume a negative cost-output elasticity, i.e., unit variable costs decrease when output (yield) increases. Since output in the Eastern Baltic cod fishery is limited by total allowable catch (TAC) quotas, the harvested yield can be assumed to be below the vessels' maximum harvesting capacity. Furthermore, the Baltic Sea fisheries are characterised by overcapacity (Eggert and Tveterås 2004; Lindebo *et al.* 2005), and therefore, production capacity should not be a production constraint.

In general, a negative output elasticity may represent an incentive to highgrade[6]. However, as the cod stock is currently at a very low level, the incentive to highgrade is low. Once the Eastern Baltic cod stock size increases again, the incentive to highgrade might then also increase.

5.4.3 Sensitivity analysis of cost simulations

Since no studies exist so far which have empirically investigated cost elasticities in the Eastern Baltic cod fishery, we started out our analysis by assuming that both, stock and output elasticity of unit costs are -0.2 ("base case"). Then we ran sensitivity analyses, testing stock elasticities in the range –0.1 to –0.8 and output elasticities in the range –0.1 to –0.5. Values for the investigated parameter combinations of α, β, and γ, are shown in Table A5-1 in the Appendix to Chapter 5 (Section 5.7).

[6] Discarding of lower valued fish is known as "highgrading". It is a practice to ensure that only the highest-priced portion of the catch is landed and counted against quota.

5.5 Discussion of simulation results and sensitivity analysis

5.5.1 Model and scenario assumptions.

The following simulations are based on population dynamics of the Eastern Baltic cod, modelled by means of an age-structured, area-disaggregated, discrete time model of the Beverton and Holt type (see Chapters 3 and 4 for complete model description). Here, we show results based on the “medium climate change” scenario, which is characterised by a decrease in mean salinity by 25% over the next century (see Chapter 4 or Röckmann *et al.* forthcoming).

To provide clarity in the figures, we limit the illustration of policy simulations to three, namely the no-policy option FasU (**F**ishing mortality ‘**as u**sual’), the seasonal marine reserve policy C25qu12 (seasonal **c**losure of SD **25** in **qu**arter **1** and **2**; quarter 3 and 4 are open to reduced fishing), and the permanent marine reserve policy C25 (permanent **c**losure in SD **25**). The simulations cover a time period of roughly 30 years, starting in year 2005.

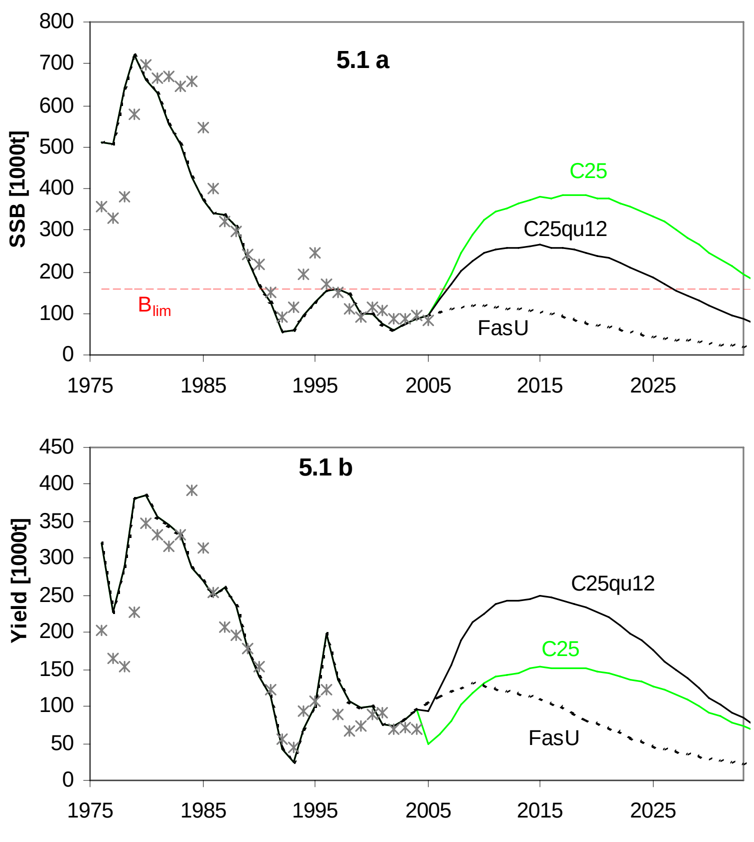


Figure 5.1: Simulated development of (a) SSB [1000 t] and (b) yield [1000 t] under the medium environmental change scenario for three different management policies: C25 = permanent closure of SD 25, no fishing effort redistribution; C25qu12 = seasonal closure of SD 25 in quarter 1 and 2; quarter 3 and 4 are open to reduced fishing; FasU = Fishing mortality as usual. Stars show historic ACFM data of SSB and yield.

“Base case” simulations

Figures 5.1a and 5.1b show the development of the Eastern Baltic cod spawning stock biomass (SSB) and yield, respectively, under the medium climate change scenario, averaged over 50 model simulations with random parameter realisations. Stars represent corresponding estimates of standard ICES stock assessment which illustrate that our model can well reproduce historic SSB and yield estimates (ICES 2005). While the permanent marine reserve policy (C25) yields the largest stock size in the simulation period, yield is highest under a temporal marine reserve policy (C25qu12). The fishing as usual policy (FasU) leads to inferior outcomes, both from the biological as well as from the economic point of view.

As there is no historic time series of revenue and cost data available, which would allow a validation of our model calculations, Figures 5.2a and 5.2b as well as all figures hereafter focus on the approximately 30-year simulation period only.

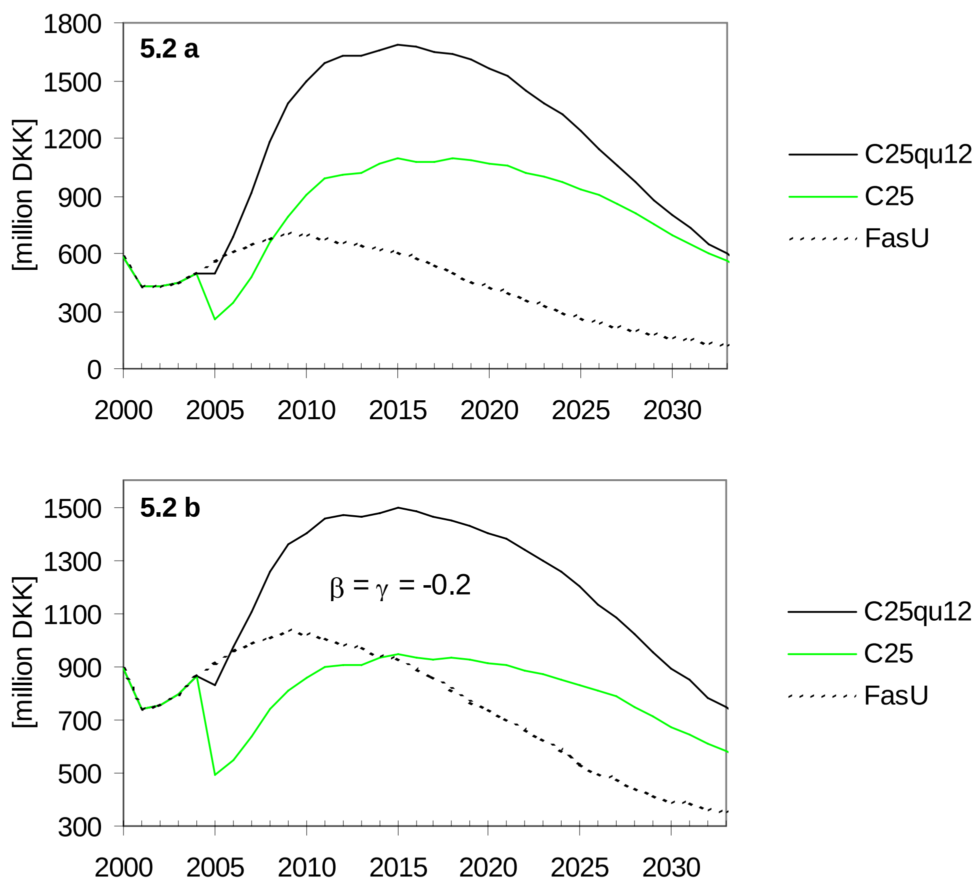


Figure 5.2: Simulated development of (a) gross revenues, and (b) “base case” total variable costs in million *Danske Kroner* (DKK) under the medium environmental change scenario for three different mangagement policies (see text for further explanation)

Gross revenues (Figure 5.2a) and total variable costs (Figure 5.2b) show similar dynamics to yield in the simulation period. Recall that both variables are a function of yield. In the initial year of the simulations, revenues and costs are highest under the FasU policy. But as the stock recovers over time under the marine reserve policies, the reduced fishing mortality under these policies leads to higher yields and revenues than does a higher fishing mortality of the FasU policy on a smaller stock. Gross revenues (Figure 5.2a) are influenced by the stock's age-structure, because larger, and thus older, fish reap a higher price per kilogram. We point out that our revenue estimates represent lower boundaries only, for they are computed applying minimum prices (cf. Röckmann *et al.* forthcoming).

The total variable cost simulations shown in Figure 5.2b are based on the "base case" ($\beta=\gamma=-0.2$). Cost elasticities around –0.2 were found in several Norwegian cod fisheries (Sandberg 2006). The values of β and γ in the Eastern Baltic cod fishery are unknown, though, and therefore, the cost estimates are hypothetical. This uncertainty is naturally passed on to the calculation of operating profit. Hence, instead of showing simulations of operating profit employing the "base case" cost elasticities here, we first perform a sensitivity analysis to illustrate the effect of employing a range of cost-stock and cost-output elasticities on variable cost, total cost, and operating profit (Figure 5.3 a-c).

5.5.2 Sensitivity analyses

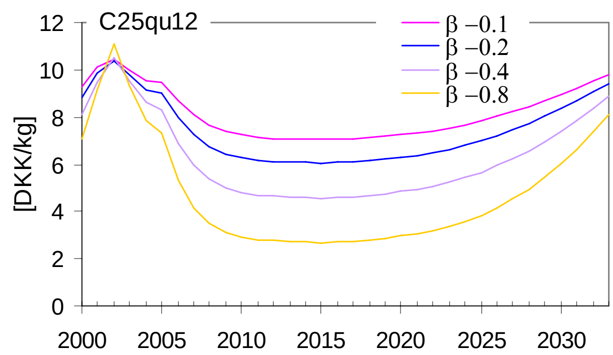
Figure 5.3a-c show simulated unit variable cost, total variable cost, and operating profit, respectively, under the seasonal marine reserve policy (C25qu12) for a range of cost-stock elasticities (β). Parameter values referring to the analyses' names are defined in Table A1 in the Annex. Since the sensitivity analysis of different cost-output elasticity values (γ) shows comparable dynamics to those presented in Figures 5.3a-c, we do not show additional figures here.

High negative values (close to –1) of the two cost elasticities β and γ produce the largest amplitudes in the unit variable cost figure (Figure 5.3a). When assuming a high cost-stock elasticity (β is close to –1), unit costs are very sensitive to stock size and therefore fall/rise strongly when stock size increases/decreases. On the other side, if cost-stock elasticity is assumed to be low (β is close to 0), one cannot expect a big gain/loss from an increase/decrease in stock size, as unit costs fall/rise only little. The same dynamics of cost-stock elasticities can be observed for different assumptions of cost-output elasticities in terms of sensitivity of variable costs to output quantity.

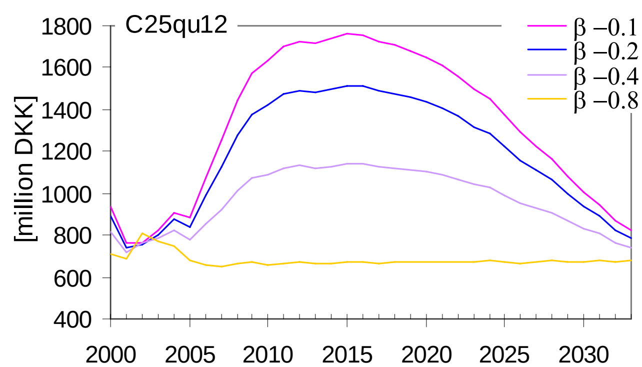
Note that the absolute values of total variable cost and operating profit have a large variability depending on the chosen cost elasticity values. Total variable costs as well as operating profits may differ by 1 billion DKK (Figures 5.3b&c). The absolute values thus have to be considered as very uncertain. For our purpose, the relative results, i.e., the ranking of the different management policies, are important, though. Under most of the analysed combinations of stock and output elasticities, the seasonal marine reserve policy C25qu12 produces highest operating profits during the first 20-25 years (Figures 5.4a-c). This ranking is robust for all elasticity combinations, except for very low negative values of β and γ (Figure 5.4d). In the latter case, unit variable costs are hardly sensitive to neither stock size nor yield.

Thus, total costs are lower under the permanent marine reserve policy than under the seasonal reserve policy, because lower yield causes lower total costs.

5.3a)



5.3b)



5.3c)

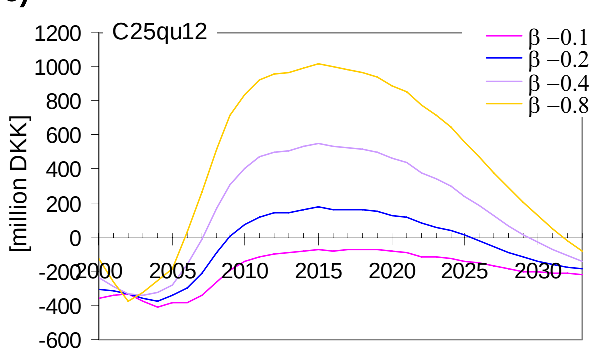


Figure 5.3: Sensitivity of (a) unit variable costs, (b) total variable costs, and (c) operating profit [million DKK] to different cost-stock elasticities under the seasonal marine reserve policy C25qu12.

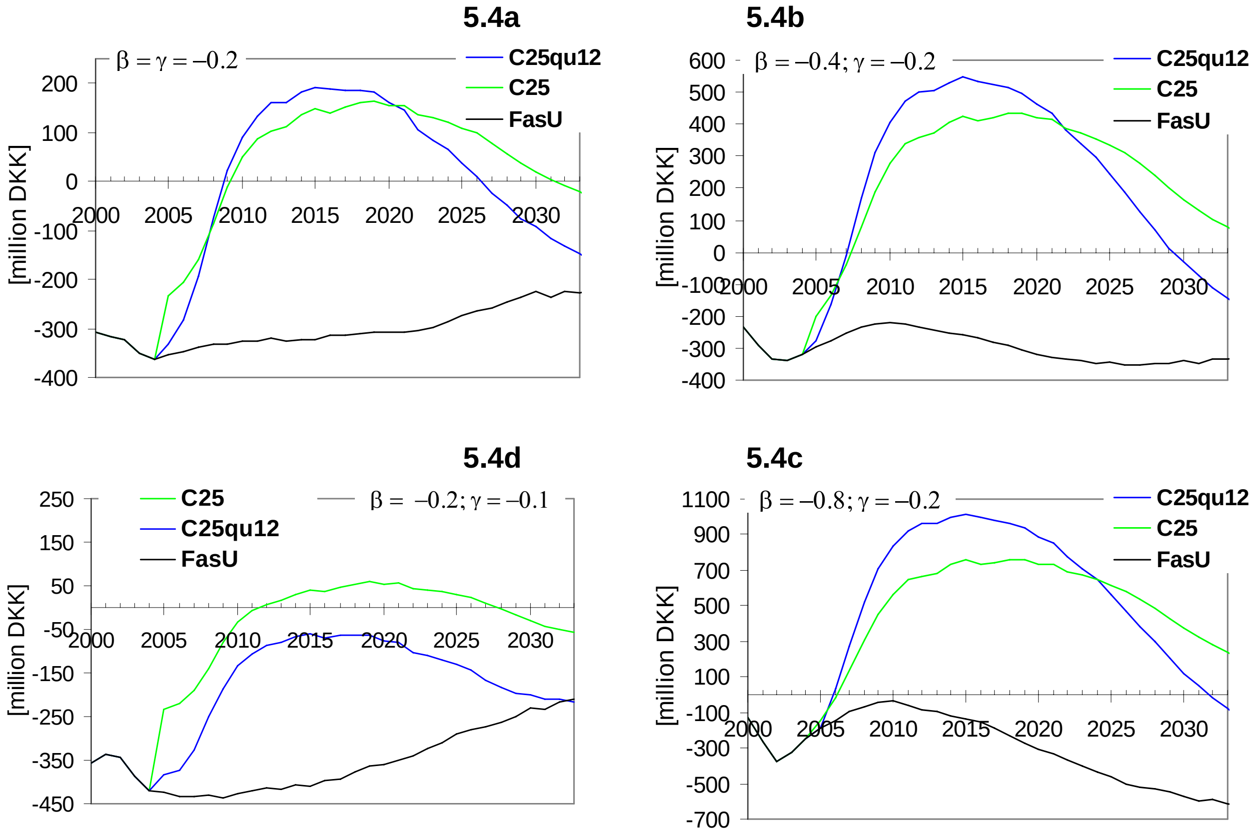


Figure 5.4: Sensitivity of operating profit [million DKK] to different cost elasticities (a) "base case" and (b-d) alternative cases of cost elasticities β and γ for the three selected management policies (see text for further explanation).

We also tested the sensitivity of our results to different assumptions of Eastern Baltic cod migration between subdivisions. Röckmann *et al.*'s (forthcoming) calculations of how many fish migrate between subdivisions are uncertain because quantitative data of cod migration are still not available. Figures 5.5a-c illustrate that the "base-case" operating profit under the permanent marine reserve policy decreases more than proportionately if migration is 20% (Figure 5.5b) or 50% (Figure 5.5c) less than originally calculated (Figure 5.5a). Therefore, the seasonal marine reserve policy is more favourable from the economic point of view than the permanent reserve policy. Operating profit under C25 crucially depends on fish migration out of the protected area into the adjacent regions which are open to fishing, whereas C25qu12 allows fishermen to target the stock in the protected area during a limited time of the year, which is more efficient in terms of operating profit. In summary, this analysis shows that the absolute values of our simulation results are sensitive to the underlying migration estimates, but our conclusion concerning the usefulness of a seasonal marine reserve policy is robust. Additionally, we can state that a permanent reserve policy is more favourable in terms of increasing operating profits the higher the cod migration out of the protected area.

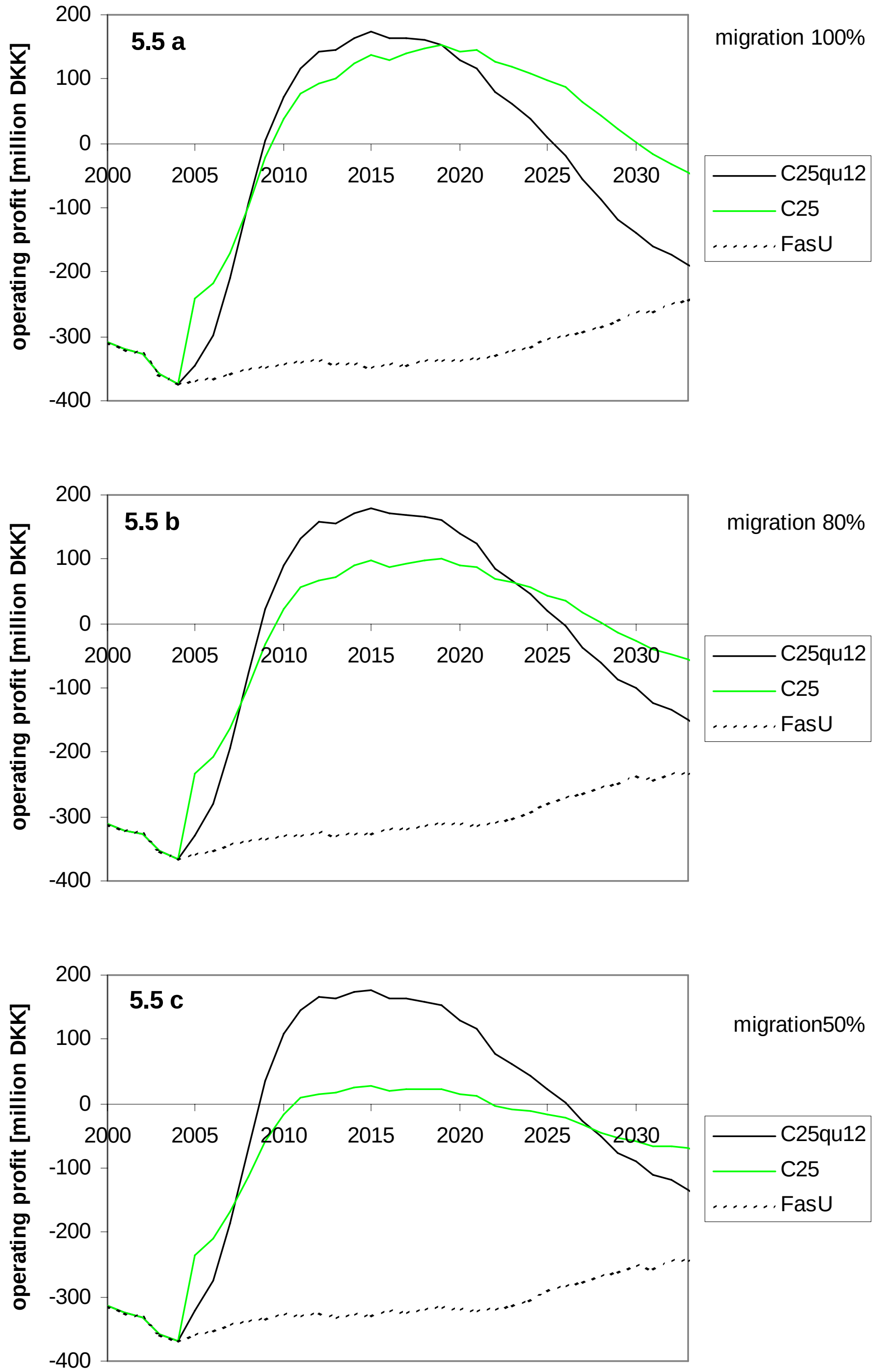


Figure 5.5: Sensitivity of operating profit [million DKK] to reduced migration rates for the three selected management policies (see text for further explanation): (a) original calculation according to Röckmann *et al.* (forthcoming); (b) reduction of the originally calculated migration by 20%; and (c) reduction of the original by 50%.

Our model simulations are strongly driven by future environmental conditions, which are unknown, generated randomly in our model realisations (cf. Röckmann *et al.* forthcoming). In order to test whether policies do indeed generate different results in each of the n random model runs, we calculated the differences in outcomes between two contrasting policies, namely C25qu12 and FasU, for 50 individual simulations. We calculated the average and the standard deviation of the 50 differences (graphical results are given in Figures A5-1 to A5-4 in the Appendix). All means including standard deviations are different from zero. Therefore we conclude that despite the uncertainties regarding environmental variability in the model realisation, a seasonal marine reserve policy leads to better economic results than continuing fishing as usual.

Caveats

We only looked at variable costs here. Ideally, one should also include fixed costs, for fishermen can adjust their fleet size to an increased or decreased stock size over the longer term. As fishermen can sell their vessels, this also represents an opportunity cost. Overcapacity has been reported to exist in the Baltic Sea (Eggert and Tveterås 2004; Lindebo 2001). The majority of the Baltic Sea fishing vessels are old, though. It is likely that a number of vessels will be decommissioned or scrapped in the near future, which will result in a reduction of the total fleet size, if no additional new vessels are bought. Subsidies for building new ships or the renewal of engines have been banned since the reform of the European Common Fisheries Policy in December 2002 (EC 2002). A transition period of two years allowed that “public aid for the renewal of fishing vessels […] [could still be] granted until 31 December 2004” (EC 1999, Article 9). Since 1 January 2005, however, there have been no more subsidies at all for fleet or engine renewal and modernisation. Hence, it is likely that the total fleet size in the international Baltic cod fishery will decrease. Therefore, unit costs may even decrease further, as the remaining smaller fleet can fish more efficiently.

Our analysis is based on the assumption that fishermen perfectly obey the management policies, thus lacking possible dynamics/responses between stock size and fishing effort and yield. Incorporating assumptions on fishermen behaviour (e.g. maximisation of net present value of operating profit) should be the next step in this research.

The cost analysis is simplified, because we implicitly assume that all vessels are identical and have the same cost and revenue structure. A typical vessel for the Danish cod fishery in the Eastern Baltic Sea was depicted by Kronbak (2002; 2004). This “Bornholm vessel” has a tonnage of 49.34 BRT, which is a medium to large vessel in the Baltic Sea. The vessel is a trawler, which is the most common type of vessel catching cod in the Baltic Sea (Frost and Andersen 2001). Sandberg (2006) showed that responsiveness of unit variable costs to output and stock size differs between different vessel types. Hence, optimal stock and fleet management differs between vessel groups. It was outside the scope of this study to look at individual firms and optimal fleet size. However, this represents an area where future research is warranted. The international fleet fishing in the Baltic Sea is very heterogeneous. Our estimates are derived based on rough calculations from Danish statistics. As the majority of the total international vessels may be smaller than the average Danish vessels, the financial results of smaller vessels are likely to be affected differently by management policies to counteract climate change.

Smaller vessels may benefit more from increasing harvests, as, for example, fuel costs decrease if harvest and revenues are higher. On the other hand, if additional small boats start fishing, unit variable costs will increase with increasing harvest.

Finally, we also expect differences in stock-output elasticity depending on the gear type (trawl versus gillnet). As a consequence, the relative profitability of gear types changes when the stock biomass rises or falls.

5.6 Summary and Outlook

This study adds a cost analysis of the Eastern Baltic cod fishery to an existing study by Röckmann *et al.* (forthcoming), who simulated the population dynamics of Eastern Baltic cod, yield, gross revenues, and net present values of gross revenues in the Eastern Baltic cod fishery. As cost data specifically on this international fishery do not exist, we made a first attempt to get rough cost estimates. Additionally, we simulated unit and total variable costs and tested the sensitivity of our simulations to a set of different cost-stock and cost-output elasticities. The following conclusions can be drawn:

This study confirms previous findings by Röckmann *et al.* (forthcoming) that a seasonal marine reserve policy, which focuses on protecting the Eastern Baltic cod spawning stock in ICES subdivision 25, is a valuable fisheries management tool to (a) rebuild the overexploited Eastern Baltic cod stock and (b) increase operating profits, thus avoiding the negative effects of overfishing. The negative effects of climate change can be postponed for at least 20 years – depending on the assumed rate of future climate change. Including variable costs in the economic analysis does not influence the ranking of management policies, which Röckmann *et al.* (forthcoming) proposed in their preliminary approach, where they neglected costs.

The performed sensitivity study, analysing the effects of applying different cost-stock and cost-output elasticities on simulated variable costs and operating profit, confirms expectations: Under high negative values of elasticities, there is a strong response between stock size and unit costs and between output and unit costs. The lower the cost elasticity, the less sensitive are costs to stock size. Therefore, under very low negative values of cost-output and cost-stock elasticities (close to 0), a permanent marine reserve policy, which restricts fishing mortality more strongly and thus reaps lower yields than a seasonal reserve policy, turns out better than a seasonal one. Assuming high elasticities, a seasonal marine reserve policy is better than a permanent one for a time period of about 20-25 years.

We have already mentioned and discussed some assumptions which might be too simple. In the future, various aspects of our analysis should be improved and new data should be collected to allow for more sophisticated analyses. These aspects are as follows:

- The spatial and the temporal resolution of the cost function should be increased. Variable costs should vary over subdivision and quarter, taking account of the Eastern Baltic cod's spawning concentrations and heterogeneous feeding migrations. Seasonality and intra-annual variation in catchability, as reported by Eide *et al.* (2003) for the Norwegian bottom trawl cod fisheries, may very likely occur in the Eastern Baltic cod fishery as well.

- Due to the heterogeneity of the fishing fleet, cost-stock as well as cost-output elasticities are likely to vary not only over season and region, but also depending on vessel type and fishing gear.
- Although the sensitivity analysis regarding migration estimates supports our general conclusion that a seasonal marine reserve policy is effective in both rebuilding the cod stock as well as ensuring future harvests and operating profits to fishermen, the uncertainty in the applied migration functions and parameters call for empirical studies to investigate the Eastern Baltic cod's migration patterns *in situ*. Such field studies might also give insight into differences in catchability depending on time and region.

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5.8 Appendix

Table A5-1: Parameter values for calculation of unit variable costs, according to: $c_y = \alpha \cdot B_y^{\beta} \cdot Y_y^{\gamma}$ **[B and Y in kg].**

Sensitivity analysis name	α	β	γ
β -0.1	2340	-0.1	-0.2
β -0.2	14000	-0.2	-0.2
β -0.3	84500	-0.3	-0.2
β -0.4	510000	-0.4	-0.2
β -0.5	3100000	-0.5	-0.2
β -0.6	19000000	-0.6	-0.2
β -0.8	700000000	-0.8	-0.2
γ -0.1	2340	-0.2	-0.1
γ -0.3	85000	-0.2	-0.3
γ -0.4	520000	-0.2	-0.4
γ -0.5	3200000	-0.2	-0.5

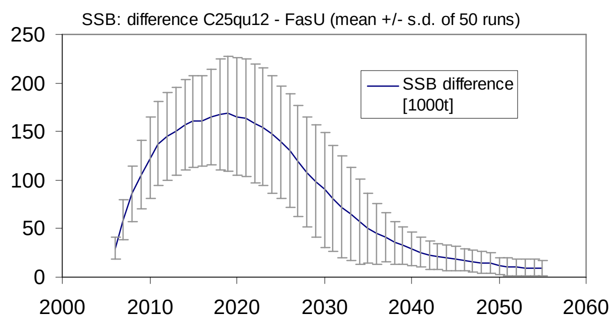

Figure A5-1: Mean and standard deviation of difference between SSB under C25qu12 and FasU of 50 random model runs.

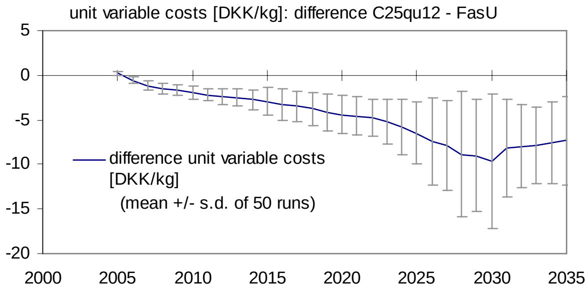

Figure A5-2: Mean and standard deviation of difference between unit variable costs under C25qu12 and FasU of 50 random model runs.

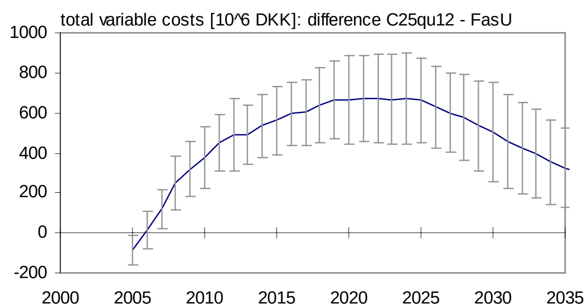

Figure A5-3: Mean and standard deviation of difference between total variable costs under C25qu12 and FasU of 50 random model runs.

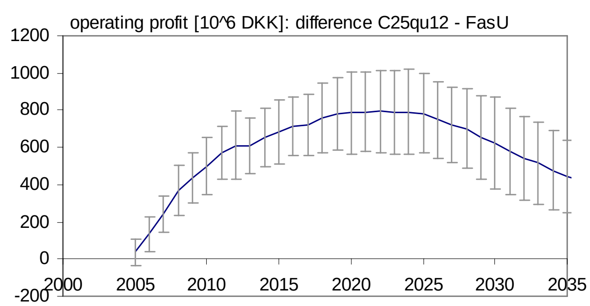

Figure A5-4: Mean and standard deviation of difference between operating profit under C25qu12 and FasU of 50 random model runs.

Chapter 6 - Conclusion and outlook

This thesis investigates the environmental, economic, and legal situation of the Eastern Baltic cod fishery. A simulation model is developed and applied to test various management options for policy advice. Selected policies are tested on their performance and effectiveness regarding stock recovery on the one hand and economic sustainability on the other hand.

The realisation of objectives of this thesis, which are set out in the first chapter, is summarised in Section 6.1. Section 6.2 draws general conclusions and presents recommendations for fisheries management and policy making. An outlook to areas which warrant further research concludes this thesis (Section 6.3).

6.1 Realisation of objectives

The legal perspective

The legal framework of fisheries management on the European Community level is reviewed with special focus on the Baltic Sea fisheries.

Future management of Baltic Sea fisheries resources is likely to benefit from a switch away from IBSFC management to EC management, if the opportunities for improvement, which the reformed European Common Fisheries Policy envisages, are realised. The new CFP regulation as of December 2002 prioritises the urgent need for stock recovery, ecosystem conservation, and long-term management. The introduction of long-term management and recovery plans terminates the myopic nature of conventional fisheries management approaches by limiting the extent of political bargaining on TACs and quotas. Furthermore, emergency measures enable higher flexibility in management to quickly react to unforeseen environmental or anthropogenic impacts. This emphasis is crucial for Baltic Sea fisheries management due to the special hydrographic and environmental conditions in the Baltic Sea, the influence of climate variability on hydrographic conditions in light of global climate change, and the permanent threat to flora, fauna, and the ecosystem posed by shipping and cargo. The use of MPAs as a tool to achieve sustainable fisheries management is explicitly mentioned within the legal framework, focussing on long-term management under the precautionary approach.

The model development – environmental and economic perspectives

A spatially explicit simulation model of the Eastern Baltic cod population dynamics is developed. The model is able to reproduce the historic stock fluctuations satisfactorily, with an explanatory power of 0.80. The model has continually been improved within the course of this thesis. A prerequisite for evaluating the effectiveness of an MPA as a fisheries management tool is a higher spatial and temporal model resolution than that which is commonly used in standard stock assessment models. The current model covers three ICES subdivisions and applies a time step of three months.

The first model version treats the cod in the individual subdivisions as three independent sub-stocks, which do not interact. The focus lies on a proper simulation of the stock's population dynamics. Since Baltic cod recruitment success depends strongly on oxygen and salinity conditions in the deep basins of the Baltic Sea, an environmental variable is incorporated into the recruitment function to account for this dependency. This variable is termed the "reproductive volume", representing the volume of water where favourable oxygen and salinity conditions make successful cod egg development possible. Extensive multiple regression analyses are performed in order to find a suitable functional form to calculate recruitment as a function of the spawning stock biomass and the reproductive volume. Natural death as well as cannibalism and fishing constitute the decay processes counteracting natural growth and recruitment, which keep the model in realistic boundaries. The model is stable, but – as it describes a variable, natural system – does naturally not lead to equilibrium.

In the second step, migration of cod between the subdivisions is incorporated to combine the three sub-models. Due to a lack of quantitative data from field observations, migration estimates are calculated based on process-oriented assumptions (spawning and feeding migration), which are derived from qualitative descriptions. This improves the initial simulations of stock size and yield, and affords economic calculations to be coupled to population dynamics.

Environmental scenarios are needed to specify future values of the exogenous environmental variable "reproductive volume". The size of the reproductive volume in the three spawning basins depends on the frequency and strength of major Baltic inflows from the North Sea, which are triggered by large scale and local atmospheric forcing conditions. There are, however, no climate models available yet that project future inflow strength and frequency. In this thesis, two different approaches are investigated with the following assumptions:

a) the reoccurrence of historic sizes of the reproductive volume;
b) the projection of potential future decrease of the reproductive volume. This assumption is based on recent model simulation results, which project average salinity in the Baltic Sea to decrease by 7-47% in the period 2071-2100, relative to the reference time slice 1961-1990.

Finally, economic calculations are coupled to the model of population dynamics, enabling the estimation of revenues, costs, and operating profits of the international Eastern Baltic cod fishery. Due to the lack of reliable data, the economic calculations are derived from accessible Danish data. Therefore, the extrapolations from Denmark to the whole international Eastern Baltic cod fishery are rather simplistic. Moreover, the performed rough extrapolations render the absolute values of the economic outcomes uncertain. However, in order to compare the performance of different management policies, it is the qualitative nature of the results that is of importance here! The absolute values of revenues and costs are likely to be uncertain, but the relative results in terms of ranking of different policies are robust to changes in assumptions and can therefore be taken as indicative. A sensitivity study, analysing the effects of applying different cost-stock and cost-output elasticities on simulated total variable costs and operating profits reveals that a seasonal MPA policy leads to better economic results than a permanent one for all selected elasticities, although this is not the case when costs are almost inelastic to output.

6.2 Conclusions and recommendations for management

The present investigation confirms our initial hypothesis: An MPA approach focussing on the protection of the spawning stock in SD 25 is sufficient to rebuild the Eastern Baltic cod stock. Hence, a total moratorium on fishing in the entire Baltic Sea, as was recommended by the ICES Advisory Committee on Fishery Management, could probably be avoided. In terms of stock recovery and conservation, establishing a permanent MPA in SD 25 is more efficient than an overall reduction of fishing effort and the establishment of a seasonal MPA. From the economic point of view, the results are different: The establishment of a seasonal MPA in SD 25 leads to the highest yields and the highest revenues. The next best policy in terms of yields and revenues is the overall reduction of fishing effort, whereas the establishment of a permanent MPA ranks third. Temporary openings of an MPA to fishing might be the only opportunity for fishermen to accrue catches of the protected part of the fish stock, in particular, if the fish do not frequently migrate out of a protected area.

Poor enforcement of management policies is a severe problem in the Baltic Sea: A significant amount of the catch is landed illegally or not reported, causing high uncertainties in the scientific fish stock assessment. Conventional TAC-based management, however, relies on the assumption that estimates of present stock parameters are precise. The susceptibility of the conventional management plans to uncertainty poses an additional reason for a shift to alternative, MPA-based management.

Size and location of the MPA are crucial factors for evaluating its impacts, especially, since environmental conditions strongly drive the population dynamics of Baltic cod. Closing an area is useless, if unfavourable hydrographic conditions do not allow for successful cod egg development and, in turn, do not increase potential recruitment. Closures, not based on a sound biological basis, can even be counterproductive, because each negative example of an MPA establishment can cause fishermen to become more reluctant to this type of management tool in the future. Negative examples do already exist, though. In contrast to the investigated MPA scenarios, the summer ban as well as the spawning ground closure in the Bornholm Basin, established by the IBSFC in 1995, are spatially too small and/or temporally too short to effectively reduce fishing mortality on the spawning stock. As Baltic cod exhibits pronounced feeding and spawning migration, benefits are easily dissipated because of dispersal losses and effort concentration around the borders of the closure. Furthermore, the additional closures in the Gdansk Deep and the Gotland Basin may only be effective sporadically, in the rare case of strong inflows from the North Sea which can replenish the deep basins in SD 26 and 28. During stagnation periods, these closures cannot lead to enhanced recruitment from SD 26 and 28. Under unfavourable environmental conditions, hydrographic conditions in the basins East/Northeast of SD 25 do not allow for successful cod egg development anymore. Hence, it is particularly important, to protect the viable component of the spawning stock in SD 25, since a reproductive volume will generally be present in the Bornholm Basin, even despite that lack of very strong inflow events from the North Sea.

Concerning the potential impacts of global climate change on the Baltic cod fishery, our simulations under different environmental scenarios illustrate that a future decrease in the size of the reproductive volume due to global warming can result in the extinction of the Eastern Baltic cod stock. Nonetheless, the simulations of stock and yield development under different management policies also show that appropriate fisheries management can dampen the negative consequences of climate change for at least 20 years – depending on the assumed rate of future climate change. Again, such policies should focus on the protection of the spawning stock in SD 25 for at least the six months before and during the extended spawning period of the Eastern Baltic cod. Stock collapse, however, cannot be prevented by such measures; it can only be postponed.

It can be concluded that the establishment of an MPA in SD 25, either permanent or seasonal, resembles a “win-win” situation for the stock as well as for the fishery:

a) An MPA policy results in an improved age-structure of the currently overexploited Eastern Baltic cod stock: Since larger, older females produce many more and more viable eggs, reproductive success tends to be better if the stock comprises a larger portion of older fish. As a consequence year classes can get stronger, thus providing a larger harvestable fish stock to the fishery.
b) Larger fish reap a higher price per kilogram, which – additionally to the larger number of fish in the stock – leads to an extra increase in revenues to the fishermen.

In summary, a seasonal marine reserve policy which focuses on protecting the spawning component of the Eastern Baltic cod in ICES subdivision 25, is a valuable fisheries management tool to (i) rebuild the overexploited stock and (ii) increase operating profits, thus avoiding the negative effects of overfishing. Closing subdivision 25, at least temporarily for at least six months every year during the cod spawning period, would allow the mature fish to spawn before being caught. Cod reproduction can therefore be ensured to occur at least in SD 25. In contrast, successful reproduction in SD 26 and 28 cannot be relied on due to the climatically induced deterioration of hydrographic conditions particularly in regions that are farther East/Northeast in the Baltic Sea, which will become more unfavourable for cod reproduction in the future. A significant reduction in fishing mortality is necessary to achieve high yields from the Eastern Baltic cod fishery in the long term, particularly in the light of future climate change.

6.3 Outlook

The Baltic Sea environment provides a good venue to test further hypotheses about ecosystem processes as well as interdisciplinary and international interactions. As in other areas, fisheries in the Baltic Sea have both direct and indirect impacts on components of marine ecosystems beyond the targeted species. Examples include discard/ by-catch mortality, alteration of seafloor habitats, changes to the relative species composition of fish and benthic communities.

It would be worthwhile to explore potential correlations between the reproductive volume and eutrophication measures, e.g. nutrient concentration. If in the future eutrophication prevails, hydrographic conditions are expected to be aggravated. On the other side, if eutrophication decreases, then this would improve oxygen conditions, which, to some degree, could counteract or dampen the reproductive disadvantage of a decrease in salinity.

An interesting extension of this study would be a comparison of the MPA policies to other management instruments, such as mesh size regulations and quotas/ TACs. An analysis of different minimum mesh sizes can easily be incorporated into the model by specifying the age-specific fishing mortality. One has to establish the relationship between minimum mesh size and minimum length-at-age in the catch. This information should be known and available from institutes focussing on fisheries technology.

Whether the present study can be replicated for other case studies and in other regional seas crucially depends on availability of area-disaggregated stock assessment data. Furthermore, a good understanding of the biology and life history of the fish stock(s)/ communities in question and any possible environmental interactions is required.

Concerning the model itself, various technical aspects can be improved. New data should be collected to allow for a more sophisticated analysis. Apart from the simplified model assumptions, a number of processes are still unknown and, hence, omitted in our analysis. All of these aspects represent areas that warrant future research.

As regards the biological compartment of the model, the following model specifications should be improved and expanded:

- The calculation of migration estimates should be derived from field data. This data will become available within the next couple of years, because an extensive tagging project of Baltic cod is ongoing (R&D project CODYSSEY). Such field studies might also give insight into differences in catchability depending on time and region.
- Movement of cod between subdivisions should also include passive wind-induced egg and larval drift. Hydrodynamic models are already available (Hinrichsen and Möllmann 2002; Hinrichsen *et al.* 2002), but research is needed on meteorological coupling parameters and on the impact of climate change on their future course.
- In order to incorporate multispecies and food-web interactions, similar models should be developed for the clupeids sprat and herring and coupled to the presented cod model. Effects such as the potential increase in predation mortality on juvenile cod by mature sprat due to the projected future increase in water temperature in the Baltic Sea could then be taken into account.
- Salinity is not the only factor impacting on cod reproductive success. Oxygen is at least of equal importance and is strongly affected by inflow events from the North Sea. Correlations between regional climate change, air and water circulation, and dissolved oxygen should be established and incorporated into the model.

So far, the model's emphasis is put on the biological side, since physical and environmental factors frame the natural limits to fish population growth. Expanding the economic component would be an important future step. In this regard, the following model specifications should be improved in the future:

- Explicit economic behaviour should be included, e.g. assuming that fishermen aim to maximise their profits. A prerequisite for such an economic analysis is the transformation of the exogenous variable fishing mortality into an endogenous one. The model can then find the optimal policy, depending on the objective function, and suggest paths to achieve the objective over time.
- An analysis of the Eastern Baltic cod international fleet structure is necessary to permit meaningful conclusions regarding the optimal number and type of vessels. Vessel- and gear-specific information on catchability is necessary to translate the variable fishing mortality into fishing effort.
- Market responses of demand for and supply of cod should be taken into consideration. Studying the relationship between landings and prices should lead to the development of a price-supply function.
- In the long run, all costs are variable, as vessels can be decommissioned, scrapped, or new ones can be built. There is thus a need for accessible and reliable cost data in order to include depreciation, as well as financial and investment costs in the cost analysis.
- The spatial and the temporal resolution of the cost function should be increased, as variable costs are likely to vary over region and time. Seasonality and intra-annual variation in catchability, as reported by Eide *et al.* (2003) for the Norwegian bottom trawl cod fisheries, probably occur in the Eastern Baltic cod fishery, too. Moreover, due to the heterogeneity of the fishing fleet, cost-stock as well as cost-output elasticities are likely to vary not only over season and region, but also over vessel type and fishing gear.

Reflecting on a larger time and spatial scale, the problems of Baltic Sea fisheries management should be placed in the global perspective and address current and future problems, in particular, the crisis of global fisheries, feeding a growing world population with fish protein, coping with or adapting to global climate change. Various factors and parameters that can be important for modelling are likely to change in the future, for example:

- Changing demand for Baltic cod of fast food chains in the Baltic countries and in Russia can influence the harvesting pattern (in these countries, fish sticks are made of Baltic cod).
- Aquaculture is on the rise, even with species such as cod. This trend offers hope to wild fish stocks, as fishing pressure will decrease, if fishermen earn enough by shifting to the aquaculture sector.
- Shortage of fossil fuels has triggered fuel prices to increase, thus rendering fishing activities unprofitable, especially those with heavy trawling gear.

Fisheries management should be open to new ideas. Feasibility is crucial as well as keeping management costs low and avoiding incentives to cheat. Rethinking of fisheries management has already been proposed by a large community of fisheries scientists (cf. Pitcher *et al.* 2001). The oceans could, for example, be treated as closed to fishing with limited fishing areas and times as small exceptions (Walters 2001).

Finally, one should always be aware that fishery science is about fish as well as people. Fishermen should be included in the discussion and the decision-making process. Participatory methods could also be used to expand the presented model to include socio-economic reactions. The model itself could be used in the decision-making process. Regional advisory councils represent a ground to inform fishermen about scientific results and conclusions. This could contribute to a better mutual understanding of all stakeholders' problems, thus foster trust and action out of conviction instead of legal forcing.

6.4 References

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- **Extended summary**

- **Zusammenfassung**

- **Acknowledgements**

Extended summary

This thesis investigates the environmental, economic, and legal situation of the Eastern Baltic cod fishery. The complexity of the political and ecological situation in the Baltic Sea area calls for strong international cooperation in order to achieve economically and socially sustainable and environmentally safe fisheries. Management needs to be flexible to allow for direct reactions and adjustments in case of any natural or anthropogenic adverse impacts. At the same time, income stability from the transboundary fish resources in the Baltic Sea, which are thus shared internationally, should be guaranteed to local fishing communities.

Chapter 2 investigates the legal aspects of fisheries management in the Baltic Sea in the past, present, and future. Emphasis is put on the functioning of the European Community's Common Fisheries Policy (CFP). In order to achieve sustainable fisheries, the conservation of stocks is of prime importance. The new CFP, as of December 2002, aims to achieve this objective by introducing long-term management and recovery plans, emphasising the necessity of a healthy marine ecosystem, and allowing for flexible management tools. It is therefore concluded that the Baltic Sea fishery is likely to benefit, if the opportunities for improvement, which the new CFP regulation envisages, are realised.

Chapters 3-5 form the core of this thesis.

In order to test the implications of the establishment of a marine reserve in the Baltic Sea, an age-structured model for the Eastern Baltic cod (*Gadus morhua callarias L.*) stock is constructed in Chapter 3. The model is resolved spatially on the level of ICES subdivisions and temporally with a time step of three months. Functional relationships for recruitment and predation mortality are developed by multiple regression analyses. The resultant model output compares well with stock assessment data from 1975-1999 of the Eastern Baltic cod fishery. The model is then applied to simulate stock development over a 50 year time period using different management policies and various environmental conditions. The management policies investigated impact on fishing mortality and range from a moratorium of the Eastern Baltic cod fishery via the establishment of a marine reserve in ICES subdivision 25 to a fishing as usual scenario. The influence of environmental conditions on Baltic cod population dynamics is incorporated via the variable "reproductive volume" (RV), i.e., the volume of water where oxygen and salinity conditions are favourable for successful cod egg development. The future size of the RV is specified in environmental scenarios. These comprise a best case and a worst case of reproductive conditions, and two more realistic scenarios, where it is assumed that a historic series of RV-sizes reoccurs over the simulation horizon. The results illustrate and emphasise the strong dependence of stock dynamics on the environmental conditions. Under prevailing low RV, our model projects stock extinction by the year 2020, if fishing continues as usual. Under all marine reserve scenarios, the stock benefits from an increase in stock size and an improved age-structure. A closure of SD 25 as opposed to a closure of the entire Baltic Sea appears to be sufficient to prevent the Eastern Baltic cod stock from falling below safe biological limits.

Chapter 4 focuses on global climate change and its potential implications for the Eastern Baltic cod stock on the one hand and the fishermen on the other hand. The model of population dynamics of the Eastern Baltic cod, that is developed and presented

in Chapter 3, is applied in 50 year simulation analyses of stock, yield, and revenue development under various management policies and environmental scenarios. The policy analysis, focusing on different regulations of fishing mortality, is embedded into three environmental scenarios, assuming a low, medium, or high rate of climate, and thus, environmental change. The environmental assumptions are based on simulation results from a coupled atmosphere-ocean regional climate model, which project salinity in the Baltic Sea to decrease by 7-47% in the period 2071-2100 relative to the reference period 1961-1990. Our simulation results show that a significant reduction in fishing mortality is necessary for achieving high long-term economic yields. Moreover, under the presented environmental scenarios, a stock collapse cannot be prevented. It can, however, be postponed by the establishment of a marine reserve in ICES subdivision 25.

Chapter 5 adds a cost analysis of the Eastern Baltic cod fishery to the existing model presented in Chapters 3 and 4. As cost data on this international fishery do not exist, available data from Denmark are extrapolated to the whole international fishery. Additionally, unit and total variable costs are simulated and the sensitivity to a set of different cost-stock and cost-output elasticities is tested. The following conclusions can be drawn: A temporary marine reserve policy, which focuses on protecting the Eastern Baltic cod spawning stock in ICES subdivision 25, is a valuable fisheries management tool to (a) rebuild the overexploited Eastern Baltic cod stock and (b) increase operating profits, thus avoiding the negative effects of overfishing. The negative effects of climate change can be postponed for at least 20 years – depending on the assumed rate of future climate change. Including costs in the economic analysis does not influence the ranking of management policies as proposed in the preliminary study where costs are neglected.

Zusammenfassung

Die vorliegende Dissertation untersucht die umwelt-naturwissenschaftlichen, ökonomischen und rechtlichen Aspekte der Dorschfischerei in der östlichen Ostsee. Die Komplexität der politischen und ökologischen Situation in der Ostsee erfordert eine starke internationale Zusammenarbeit, um eine nachhaltige Fischereiwirtschaft zu erreichen. Daher sollte das Fischereimanagement möglichst flexibel sein, damit man kurzfristig, spontan und direkt auf sich verändernde Umweltbedingungen und/oder anthropogene Einwirkungen reagieren kann. Gleichzeitig sollten die Erträge aus den internationalen Fischereiressourcen den Fischern Einkommensstabilität gewähren.

Das zweite Kapitel dieser Dissertation untersucht die rechtlichen Rahmenbedingungen des Fischereimanagements in der Ostsee. Besondere Bedeutung wird der neuen Europäischen Gemeinsamen Fischereipolitik (GFP) von Dezember 2002 eingeräumt, deren Ziele, Funktionen, Aufgaben und Strategien vorgestellt werden. Der Schutz der Fischbestände und des Meeresökosystems ist laut GFP eine wichtige Voraussetzung für Nachhaltigkeit und daher erstrebenswert. Die Einführung von Bewirtschaftungsplänen, Wiederauffüllungsplänen und Sofortmaßnahmen, in denen auch Meeresschutzgebiete vorgesehen sind, stellen mögliche flexible Management-Werkzeuge dar. Beide, Fische und Fischerei in der Ostsee, werden in Zukunft profitieren können, wenn die von der neuen GFP angebotenen Möglichkeiten und Maßnahmen von der Europäischen Kommission und von den EU-Mitgliedsstaaten realisiert werden.

In den anschließenden drei Kapiteln wird ein Modell der Populationsdynamik des Dorsches in der östlichen Ostsee (*Gadus morhua callarias L.*) entwickelt und zur Szenarienanalyse in Simulationen angewandt. Ziel ist es, die potentielle Entwicklung des Dorschbestandes sowie der Fänge, Erträge, Einnahmen und Kosten der Fischer unter verschiedenen Managementansätzen und Umweltszenarien zu simulieren. Schwerpunkt der Simulationen liegt auf der Untersuchung der bio-ökonomischen Auswirkungen der Einrichtung eines Meeresschutzgebietes in ICES-Gebiet (subdivision, SD) 25. Seit mehreren Jahren beherbergt dieses Gebiet das wichtigste Laichgebiet des Dorsches überhaupt, da dort das brackige Ostseewasser häufig durch frisches Nordseewasser erneuert wird, während die tiefen Becken weiter nördlich und nordöstlich nur selten von Nordsee-Einstromereignissen erreicht werden.

Salzgehalt und gelöster Sauerstoff beeinflussen die Entwicklung von Dorscheiern und -larven in der Ostsee. Unterhalb eines Salzgehaltes von 11 PSU (Promille) und einer Sauerstoffkonzentration von 2 ml/l können sich die Dorscheier nicht erfolgreich entwickeln. Aufgrund des speziellen Charakters der Ostsee als Brackwassermeer mit sehr tiefen Becken einerseits und sehr flachen Schwellen andererseits sind diese besonderen hydrographischen Bedingungen für die Rekrutierung des Dorsches in der Ostsee limitierend. Das Wasservolumen, in dem sowohl Salzgehalt als auch Sauerstoff hoch genug sind, wird „Reproduktionsvolumen" (RV) genannt. Es wurde beobachtet, dass es nach mehreren Stagnationsjahren gar kein Reproduktionsvolumen gibt, wenn aufgrund ausbleibender Einströme von salzhaltigem und sauerstoffreichem Nordseewasser Salzgehalt und Sauerstoff stark abnehmen.

Das biologische Modell der Populationsdynamik des Dorsches in der Östlichen Ostsee ist altersstrukturiert (neun Altersgruppen: 0- bis 8-jährige) und räumlich in ICES Gebiete und zeitlich in Quartale (3 Monate) aufgelöst. Betrachtet werden drei ICES-

Gebiete, welche die drei wichtigen Laichgebiete des Dorsches in den tiefen Becken enthalten, nämlich das Bornholm Becken in SD 25, das Danziger Becken in SD 26 und das Gotland Tief in SD 28. Für diese drei Gebiete stehen Bestandsdaten von einer räumlich aufgelösten Multispezies Virtuellen Populationsanalyse (ad MSVPA) zur Verfügung.

Die Bestandsgröße (in Millionen Dorsche) wird zu jedem Zeitschritt, für jedes Alter und für jedes Gebiet nach dem Modell der exponentiellen Sterblichkeit berechnet. Endogene (vom Modell selbst berechnete) Variablen sind, abgesehen von der Bestandsgröße, die Rekrutierung, d.h. der Nachwuchs an 0-jährigen, und die Predationssterblichkeit durch Kannibalismus. Exogene Variablen sind die natürliche Sterblichkeit, die fischereiliche Sterblichkeit (F) und das Reproduktionsvolumen (RV). Mittels Multipler Regressionsanalyse werden verschiedene funktionale Beziehungen zur Beschreibung von Rekrutierung und Predationssterblichkeit getestet. Die Rekrutierung wird im Modell als eine lineare Funktion der Laicherbiomasse und des Reproduktionsvolumens beschrieben.

Aufgrund der räumlichen Auflösung des biologischen Modells muss berücksichtigt werden, dass die Fische zwischen den drei betrachteten Gebieten wandern. Noch gibt es keine quantitativen Daten darüber, wie viele Fische wann wohin schwimmen. Allerdings beschreiben existierende qualitative Studien zwei dominierende Wanderungsprozesse:

1. Die Laich-Wanderung führt im Frühling vom Nord/Nordosten in die wichtigen Laichgebiete im Süd/Südwesten in SD 25 und 26. Im Modell wird dieser Prozess als logistische Funktion beschrieben: Die Auswanderung aus den Gebieten 26 und 28 nach 25 und 26 ist umso höher, je kleiner das Reproduktionsvolumen in den Gebieten 28 und 26 ist.

2. Die Nahrungswanderung führt im Herbst nach dem Laichen aus den tiefen Becken hinaus. Im Modell wird dieser Prozess als dichteabhängiger Diffusionsprozess beschrieben. Er ist demnach nicht gerichtet, sondern kann in jede Richtung verlaufen, je nach Unterschied der Bestandsgröße zwischen den drei Gebieten.

Das biologische Modell berechnet die Anzahl an Fischen unter bestimmten Management-Szenarien und Umweltbedingungen. Die ökonomische Komponente berechnet darüber hinaus die mit den Bestandssimulationen korrespondierenden Fänge, Erträge, Einnahmen und Kosten für die Fischer. Fang wird als die Fraktion des adulten (älter als 1 Jahr) Fischbestandes berechnet, die durch Fischerei stirbt. Der Ertrag errechnet sich aus dem Fang, der mit dem durchschnittlichen altersspezifischen Gewicht multipliziert wird. Durch Multiplizieren des Ertrags mit dem alters- bzw. gewichtsspezifischen Preis/kg erhält man die Einnahmen aus diesen Fängen. Da keine Daten über Kosten der gesamten internationalen Dorschfischerei in der östlichen Ostsee existieren, werden Kostendaten von Dänemark auf die internationale Situation extrapoliert. Außerdem werden die variablen Kosten simuliert und eine Sensitivitätsanalyse bezüglich verschiedener Kosten-Elastizitäten durchgeführt.

Die simulierten Modellergebnisse stimmen gut mit ICES-Daten von Bestandsgröße, Fängen und Erträgen der Dorschfischerei aus den Jahren 1975-1999 überein. In den Zukunfts-Modellsimulationen wird in Szenarien getestet, wie sich (a) verschiedene Management-Strategien und (b) verschiedene zukünftige Umweltbedingungen auf die Bestandsentwicklung und die ökonomische Entwicklung der Fischerei auswirken.

Die Management-Strategien beschränken die fischereiliche Sterblichkeit F und umfassen verschieden limitierende Szenarien, z.B. ein komplettes Fangverbot für Dorsch in der östlichen Ostsee, die Einrichtung eines permanenten oder saisonalen Meeresschutzgebietes in SD 25, ein „fishing as usual"-Szenario, in dem angenommen wird, dass so weiter gefischt wird wie bisher.

In den Umweltszenarien werden verschiedene Größen des Reproduktionsvolumens im Simulationszeitraum spezifiziert. Ein Schwerpunkt der Analyse liegt auf möglichen Auswirkungen des globalen Klimawandels auf den Dorsch und die Dorschfischerei in der östlichen Ostsee. Nach Projektionen von regionalen Klimamodellen führt der globale Klimawandel zu einer Zunahme des Netto-Niederschlags im Ostseeraum im Zeitraum 2071-2100. Dies bedeutet eine erhöhte Frischwasserzufuhr in die Ostsee, was zu einer Abnahme des Salzgehaltes führt. Außerdem nimmt bei erhöhter Temperatur die Primärproduktion zu: Es wird mehr organisches Material gebildet, stirbt ab, sinkt auf den Grund und führt dort zu einer erhöhten Sauerstoffzehrung aufgrund erhöhten mikrobiellen Abbaus. Dies hat eine Abnahme der Sauerstoffkonzentration im Wasser zur Folge. Beide Effekte (Abnahme des Salzgehaltes und Abnahme der Sauerstoffkonzentration) führen zu einer Abnahme des Reproduktionsvolumens. (Die Bedeutung der Nordsee-Einstromereignisse für die Erneuerung des Ostseewassers mit salzhaltigem und sauerstoffreichem Nordseewasser wird hier vernachlässigt.) Ein einfacher linearer Zusammenhang zwischen Salzgehalt und Reproduktionsvolumen wird aufgestellt (erklärte Varianz: 50-70% in den drei Gebieten). Da es noch keine wissenschaftlichen Aussagen zur zukünftigen Variabilität dieser Umweltvariablen gibt, wird als vereinfachende Annahme im Modell der Salzgehalt als normalverteilte Variable mit Mittelwert μ und Varianz s der historischen Daten betrachtet. Drei Szenarien werden untersucht, in denen der Mittelwert des Salzgehaltes in den kommenden 100 Jahren aufgrund des globalen Klimawandels um (1) 7% (low change Szenario) (2) 25% (medium change Szenario) oder um (3) 47% (high change Szenario) abnimmt.

Die Simulationsergebnisse zeigen, dass nachhaltiges Fischereimanagement die negativen Folgen des Klimawandels abschwächen und über mehrere Jahrzehnte hinaus verschieben kann. Dafür ist der saisonale Schutz des Laichbestandes in SD 25 vor und während der Laichperiode notwendig. Bei sehr starkem und schnellem Klimawandel kann der östliche Dorschbestand nicht überleben. Fänge und Einnahmen für die Fischer sind bei einer niedrigen fischereilichen Sterblichkeit höher als bei einer hohen. Außerdem entspricht die Verbesserung der Altersstruktur im Bestand durch die Reduzierung der fischereilichen Sterblichkeit einer "win-win"-Situation sowohl für den Bestand als auch für die Fischwirtschaft. Durch die Einrichtung eines Meeresschutzgebietes in SD 25 können die negativen Folgen des Klimawandels über mindestens 20 Jahre aufgehalten werden – abhängig von der angenommenen Rate über den zukünftigen Klimawandel.

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