Marine Policy 35 (2011) 266–270

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Historical ecology provides new insights for ecosystem management: eastern Baltic cod case study

Brian R. MacKenzie [a,b,c,]*, Henn Ojaveer [d], Margit Eero [a]

[a] National Institute for Aquatic Resources, Technical University of Denmark (DTU-Aqua), Jægersborg Allé 1, Charlottenlund Castle, DK-2920 Charlottenlund, Denmark
[b] Department of Marine Ecology, University of Aarhus, c/o DTU-Aqua, Jægersborg Allé 1, Charlottenlund Castle, DK-2920 Charlottenlund, Denmark
[c] Center for Macroecology, Evolution and Climate, Department of Biology, University of Copenhagen, Universitetsparken 15, DK-2100 Copenhagen, Denmark
[d] Estonian Marine Institute, University of Tartu, Lootsi 2a, 80012 Pärnu, Estonia

ARTICLE INFO

Article history:
Received 5 July 2010
Received in revised form
10 October 2010
Accepted 11 October 2010

Keywords:
Marine historical ecology
Baltic Sea
Cod
Fisheries
Ecosystem
Management

ABSTRACT

A recent historical marine ecological case study (cod in the eastern Baltic Sea) is used to show how long-term data and knowledge of fluctuations can contribute to revisions of fishery management policy. The case study first developed new longer analytical time series of spawner biomass and recruitment back to the 1920s, which extended knowledge of population dynamics into a time period when ecosystem state was characterized by temporally varying combinations of exploitation, climate-hydrographic conditions, marine mammal predation and eutrophication. Recovery of spatially resolved historical catch data from the late 1500s to early 1600s also contributed new perspectives to cod population dynamics under alternative ecosystem forcings. These new perspectives have contributed, and will likely continue to contribute to new management policies (e.g., revision of fishery management reference points), which should lead to higher sustainability of the population and fishery yields, and improved overall ecosystem health. These perspectives will likely continue to provide baseline information as ICES and the EU develop new policies based on maximum sustainable yield concepts.

1. Introduction

Marine fish populations and ecosystems around the world change over time due to both human impacts and natural environmental variations [1–3]. Some of these changes may be abrupt (e.g., within 1–3 years) whereas others, such as those due to eutrophication or the impact of a gradual decline of a top predator species on foodweb structure and functioning, occur more gradually (decadal-centennial scale). As a result, the ecosystem can be transferred into a new regime characterized by major structural–functional reorganisation [4,5].

The major management challenge is to ensure that these changes do not jeopardize how populations and ecosystems can continue to provide goods and services to human society on a sustainable basis. This challenge requires an understanding of how humans have impacted life in the sea both during the last few decades and further back in time. Indeed, sometimes ecological change is so slow that it is imperceptible within human lifetimes, and it is only over longer periods of time that such changes are detectable [6–8]. Without a long-term perspective, managers and society may run the risk of using the present or recent past (e.g., during a few decades) as the quality standard for ecological status even though ecological conditions may have changed for the worse long before scientific investigations have begun (“shifting baseline syndrome”) [9,10].

Monitoring of stock status over time is therefore a pre-requisite for sustainable management, but how can longer observational records than those which are typically available to fishery scientists and managers (ca. 20–40 years) be acquired? A relatively recently developed new field of science – historical (marine) ecology (i.e., recovery and analysis of historical information from a variety of sources, including those from socio-economic and archaeological literatures, and interpretation of the results in the context of contemporary marine and fisheries science) – provides new opportunities and challenges for improving the current understanding of historical performance of fish stocks under different ecosystem regimes (Fig. 1) [1,7,11–13]. Historical time series and reference points can for example provide new targets for biodiversity and the distribution and biomass of species and increase our understanding of long-term variability. Results from such an approach can potentially contribute to ecological actions such as those envisaged by recent and developing EC policies (e.g., a new Common Fishery Policy; CFP) and directives [14–18].

Integrating knowledge of past developments into management advice and the decision-making process is also globally increasingly recognized as essential for defining meaningful targets for management, restoration and recovery of fish populations and marine

* Corresponding author at: National Institute for Aquatic Resources, Technical University of Denmark (DTU-Aqua), Jægersborg Allé 1, Charlottenlund Castle, DK-2920 Charlottenlund, Denmark. Tel.: +45 3588 3445; fax: +45 3588 3333.
E-mail address: brm@aqua.dtu.dk (B.R. MacKenzie).

0308-597X/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.marpol.2010.10.004

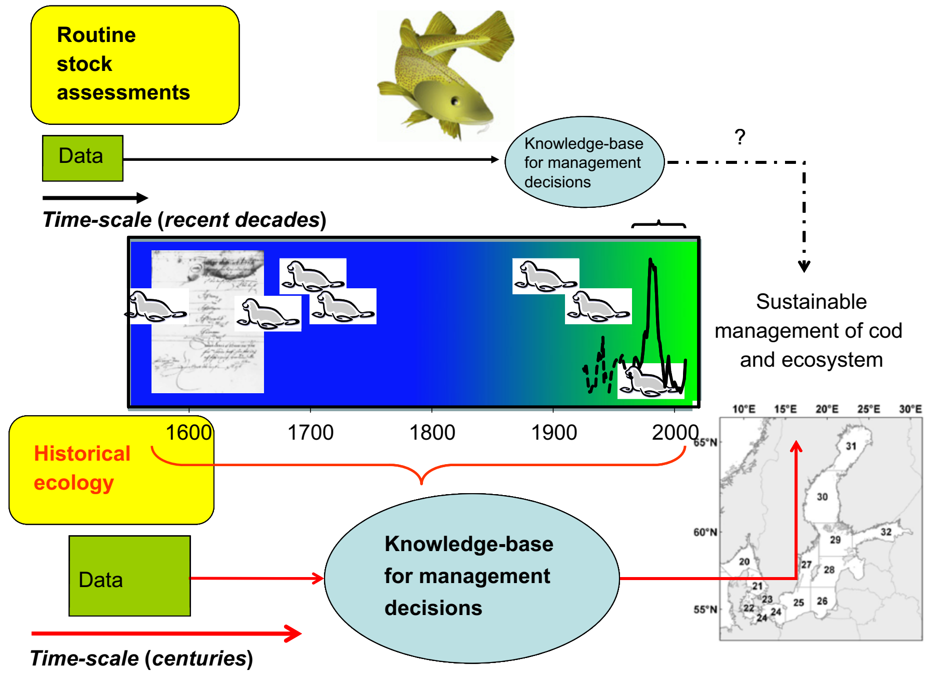

Fig. 1. Overall concepts discussed in this report in relation to the contribution of long datasets and historical marine ecological knowledge to advice and policy formulation. Inset documents: a handwritten Danish tax record from 1602 documenting that 4800 cod were paid in tax by households in the village of Snogebæk, Bornholm (Baltic Sea) to the Danish king (courtesy of M. Bager, Amager Museum, Denmark [48]); the time series (gray lines) illustrates the long-term fluctuations in cod biomass as estimated from standard stock assessments (solid line [51]) and historical ecological investigations (dashed line [45,46,52–54]). The background shading gradient of the time series panel shows the increase in eutrophication of the Baltic Sea, and seal images represent changes in seal abundance [12,31]. Map of Baltic Sea with ICES subdivisions in lower right corner.

ecosystems [1,2,11,19]. However, the relevant management policies should be developed and implemented at regional sea scales [8,17,20], but such implementation and subsequent governance is a complex process involving stakeholders with different backgrounds and interests [21]. As a result there are still relatively few examples how to achieve an implementation [22,23] of historical marine ecological knowledge in new restorative and sustainability policies. This paper briefly summarizes research results from a recently undertaken historical marine ecological case study of the cod population in the eastern Baltic Sea. It then describes how the results have expanded perceptions of human impacts on this population, and more generally the Baltic Sea foodweb, and discusses the added value of the results for the advisory process leading to fishery and ecosystem management. The results were obtained from the long-term (2000–2010) Baltic Sea regional case study within the inter-disciplinary History of Marine Animal Populations sub-project of the global Census of Marine Life program. The overall goals of HMAP were to improve understanding of long-term changes in abundance of marine organisms, the ecological impact of large-scale harvesting and the role of marine resources in historical development of human societies [24,25].

2. The Baltic Sea ecosystem and cod population dynamics

The Baltic Sea is a large brackish ecosystem which has undergone substantial human impacts particularly during the 20th century, such as near-depletion of marine mammals, large reductions and some local extinctions of the most valuable commercial fish species (sturgeon *Acipenser sturio*, salmon *Salmo salar*, cod *Gadus morhua*, etc.), eutrophication and bioinvasions [26]. In addition, the system has recently experienced a comparatively rapid rate of warming [27], which has been exceeding that in nearly all other large marine ecosystems in the world [28]. The warm temperatures have probably had detrimental effects on the cod population via foodweb effects [5,5,29].

Cod is the most important marine piscivorous fish in the Baltic Sea and has important structuring roles in the system [5]. The species is managed as two distinct stocks, distributed east and west of the island of Bornholm [30]. This study focusses on the eastern stock.

During much of the 20th century, cod spawner biomass fluctuated between 100 and 300 kt before reaching peak biomass in the early 1980s, after which a major (ca. 10-fold) decline occurred (Fig. 1). Four main factors have recently been identified to explain these variations: exploitation, climate–hydrographic variability, eutrophication and predation (e.g., by seals) [31]. These impacts varied in intensity, timing and direction (e.g., eutrophication having initially positive but then negative effects) during the 20th century. In particular, the decline during the 1980s and 1990s was due to a combination of high fishing pressure and deteriorating (natural) environmental conditions reinforced by eutrophication [20,31]. However, only through careful recovery and interpretation of historical materials has it been possible to begin to understand the relative contributions of these forcings over longer time scales (e.g., entire 20th century), and how they sometimes coincided to accelerate or decelerate increases or declines in stock biomass. The details of these interactions and dynamics are explained elsewhere [12,31], and here the focus is mainly on how these findings have influenced the cod fishery management advice in recent years and how they could do so in future.

3. Fishery management policy frameworks in the Baltic Sea

The historical development of fishery management in the Baltic Sea is described elsewhere [32] and will not be repeated here. Instead, attention is given to the most recent developments, particularly in relation to the cod management and recovery plans developed in the last 5–10 years. Until the early-mid-2000s, both biomass and exploitation (F) reference points were used to formulate management advice and develop management policy for Baltic cod [33]. However, given the historical evidence that fish stock productivities change [31,34], and in particular, that environmental variations affect spawner biomass–recruitment relationships in ways which change over time, especially for the eastern Baltic cod stock [31,33], the ICES and the EU have changed the way it utilises reference points within advice formulation.

The two biggest changes are that *spawner biomass* reference points no longer are used in ICES advice for this stock and exploitation limits have been replaced by exploitation targets. Part of the motivation to de-emphasize use of spawner biomass as a reference point is because spawner biomass can decline (even if $F=0$) due to reduced productivity under certain environmental situations [34,35]; moreover, and more generally, because of changes in productivity, recovery actions might not achieve rebuilding of fish stocks to reference levels defined under alternative productivity regimes [34]. As a consequence, the fishery management advice for Baltic cod is now based on a target *exploitation* level (i.e., the level of fishing which is believed to be consistent with precautionary approach objectives; [33,35–37]). This target level ($F=0.3$) has been shown via simulation modelling to be robust to the low productivity and recruitment regimes observed during much of the late 1980s–early 2000s, and thus is expected to allow recovery even if such a situation continues for the next 2–3 decades [33,38].

The management and advisory frameworks are however continuing to evolve. Recent initiatives include developments of indicators of good environmental status (GES) for fish stocks, biodiversity and foodwebs with the context of the EU's Marine Strategy Framework Directive (MSFD) [18,37,39,40] and a transition to maximum sustainable yield (MSY) based approaches, either for single stocks, entire ecosystems, or for maximum sustainable economic yield from stocks or ecosystems [41–43]. In addition, the Baltic Sea Action Plan (BSAP) developed by the regional environmental management authority (Helsinki Commission for the Protection of the Baltic Marine Environment; HELCOM) has defined management goals for the Baltic Sea, which largely correspond to the pre-industrial level situation that occurred before the 1950s [44]. Thus, knowledge of historically observed effects of respective drivers and their interactions with each other is and will be important for developing and implementing ecological policies such as the new MSY-based approaches, GES within the MSFD [18], a new CFP and the BSAP itself.

Notably during the last 10–15 years when new reference points were being developed and revised, parallel work, both within the ICES and several research projects, was improving the input data for stock assessments and the process-based knowledge of environmental impacts on the stock and ecosystem. As a result, it was possible to derive new, longer time series of spawner biomass and F (from 1966 back to 1947 [45] and then to the mid-1920s [46]), which accommodated variations in biological parameters (e.g., growth, maturity, etc.; [33]) during longer parts of the time series. The development of new datasets has been therefore crucial to detection of multi-annual changes in productivity (including recruitment), which subsequently contributed to the basis for revising much of the fishery management philosophy (e.g., elimination of spawner biomass as a basis for advice) for this stock. These developments, and a lower target exploitation level, if fully implemented by the fishing industry, should reduce the likelihood of fishery-induced stock collapses and could result in stabler yields and economic returns [38].

The new time series therefore provide new contexts for the development of fishery- and ecosystem-management policies. For example, the early 1980s peak in cod biomass was unique for the entire 20th century, and the mid-late 1990s biomass estimate was a record being the lowest for most of the entire century (Fig. 1). In particular, the increase in biomass could be attributed to a combination of reduced exploitation and good hydrographic conditions for reproduction, rather than reduced seal predation or nutrient inputs [31]. Based on the new information, one can ask whether it is realistic to expect a return to such high levels, and under what conditions could such a return be plausible? Some of the conditions which are necessary to achieve such a biomass are now evident from the historical ecological investigations, namely low-moderate exploitation, good hydrographic conditions, moderate eutrophication and low seal predation [31]. Extending the temporal perspective farther back into the late 1500s–early 1600s showed that cod were widespread in the Baltic Sea (i.e., near Stockholm and SW Finnish archipelagos), as was the case when biomass was at its 20th century peak in the late 1970s–early 1980 [47], and thus also likely very abundant, even though the Baltic was oligotrophic and had relatively more seal predators of cod in the historical period than 400 years later [48]. Even though seal abundance is currently increasing [49], this perspective suggests that cod could become more abundant again, provided that exploitation is maintained at low-moderate levels, hydrographic conditions are suitable for reproductive success and a moderate eutrophication level is achieved.

Our case study also illustrates how multiple forcings (e.g., fishing, hydrographic conditions, etc.) acting in the same direction (e.g., negative) affect cod productivity [31,50] and erode or promote resilience of exploited populations to collapse. Neglecting such effects when developing management policies can lead to unexpectedly rapid declines in biomass or to overly optimistic expectations of future sustainable yields when ecosystem conditions deteriorate again. Such knowledge should be applied in developing new MSY- and GES-based fishery and ecosystem advice and emphasizes the need for similar data-mining exercises and application of modelling approaches to be conducted for other economically valuable and ecologically important fish stocks as well as marine ecosystems.

These historical ecological perspectives suggest that a sustainable management of the Baltic Sea cod population will likely be most successful if it includes elements and actions which reduce the risk that simultaneous negative impacts on cod productivity co-occur, and which increases the likelihood that positive impacts on stock development coincide (i.e., maintain low F under good hydrographic conditions to promote rapid recovery). Recent actions within ICES and the EU appear to be going in these directions [33,35,38]: adoption and implementation of policies with lower exploitation levels have occurred in recent years, and recent estimates of F suggest a downward trend [35]. Despite a continuing high eutrophication level, improved hydrographic conditions in the mid-2000s together with declining F has allowed cod spawner biomass to increase from $\sim$66,000 to $\sim$220,000*t* during 2005–2009 [35]. Consequently, some positive developments have recently been taking place, and the efforts to implement and maintain these actions by all stakeholders should be acknowledged, recognized and encouraged. Such efforts provide encouragement for implementation of similar policies in other jurisdictions for other stocks and ecosystems and could enable declining trends of large marine animal populations [1] to be reversed.

4. Conclusions

The recent historical ecological studies have provided important new insights to the dynamics of the cod population and its response to various natural and anthropogenic forcings over different ecosystem regimes. Sustainable management for Baltic cod can best be achieved if the various forcings are considered in a joint manner. However, identification of the magnitudes, frequencies and interactions of these forcings does require a view into the past and continued monitoring of the fish stock and the ecosystem status into the future. Such a retrospective view has become somewhat sharper, at least for the cod and the Baltic Sea, due to recent marine historical ecological investigations. Incorporation of this knowledge into fishery and ecosystem management advice will likely increase sustainability and thereby have many ecological and societal benefits.

Acknowledgements

We thank the Census of Marine Life—History of Marine Animal Populations, EU projects (UNCOVER, RECLAIM) and Networks of Excellence (MarBEF, Eur-oceans) and the Danish National Research Foundation's Center for Macroecology, Evolution and Climate for support and assistance and acknowledge the efforts of the ICES Baltic Fisheries Assessment Working Group over the past 10–15 years. The contribution of Henn Ojaveer was partly financed by a fundamental research grant from the Estonian Ministry of Education and Research (grant SF0180005s10). We thank Poul Holm, Doris Schiedek and Morten Vinther for their discussions.

References

[1] Lotze HK, Worm B. Historical baselines for large marine animals. Trends in Ecology & Evolution 2009;24:254–62.
[2] Erlandson JM, Rick TC. Archaeology meets marine ecology: the antiquity of maritime cultures and human impacts on marine fisheries and ecosystems. Annual Review of Marine Science 2010;2:231–51.
[3] Finney BP, Alheit J, Emeis KC, Field DB, Gutiθrrez D, Struck U. Paleoecological studies on variability in marine fish populations: a long-term perspective on the impacts of climatic change on marine ecosystems. Journal of Marine Systems 2010;79:316–26.
[4] deYoung B, Barange M, Beaugrand G, Harris R, Perry RI, Scheffer M, et al. Regime shifts in marine ecosystems: detection, prediction and management. Trends in Ecology & Evolution 2008;23:402–9.
[5] Casini M, Hjelm J, Molinero JC, Lövgren J, Cardinale M, Bartolino V, et al. Trophic cascades promote threshold-like shifts in pelagic marine ecosystems. Proceedings of the National Academy of Sciences of the USA 2009;106: 197–202.
[6] Huntsman AG. Movements and decline of large Quoddy herring. Journal of the Fisheries Research Board of Canada 1953;10:1–50.
[7] Roberts CM. The unnatural history of the sea. Island Press; 2007.
[8] Horwood J. Marine ecosystem management: fish abundance and size under exploitation. Marine Policy 2010;34:1203–6.
[9] Pauly D. Anecdotes and shifting baseline syndrome of fisheries. Trends in Ecology and Evolution 1995;10:430.
[10] Pinnegar JK, Engelhard GH. The 'shifting baseline' phenomenon: a global perspective. Reviews in Fish Biology and Fisheries 2008;18:1–16.
[11] Pitcher TJ. Fisheries managed to rebuild ecosystems? Reconstructing the past to salvage the future Ecological Applications 2001;11:601–17.
[12] MacKenzie BR, Alheit J, Conley DJ, Holm P, Kinze CC. Ecological hypotheses for a historical reconstruction of upper trophic level biomass in the Baltic Sea and Skagerrak. Canadian Journal of Fisheries and Aquatic Sciences 2002;59: 173–90.
[13] Ojaveer H, MacKenzie BR. Historical development of fisheries in northern Europe—reconstructing chronology of interactions between nature and man. Fisheries Research 2007;87:102–5.
[14] EC. Directive 2008/56/EC of the European Parliament and the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). OJEC L 164:40 pp. Brussels: European Commission; 2008.
[15] EC. The Common Fisheries Policy—A User's Guide. Luxembourg: Office for Official Publications of the European Communities; 2009.
[16] EC. Green paper: Reform of the Common Fisheries Policy. COM(2009) 163 (final): 27 pp. Brussels: Commission of the European Communities; 2009.
[17] EC. Communication from the Commission: Consultation on fishing opportunities for 2011, Brussels, 17.5.2010. COM (2011) 241 (final): 19 pp. Brussels: European Commission; 2010.
[18] Cardoso AC, Cochrane SKJ, Doerner H, Ferreira JG, Galgani F, Hagebro C et al.. Scientific support to the European Commission on the Marine Strategy Strategy Framework Directivet: management group report. In: JRC Scientific and Technical Reports Piha H. Luxembourg (editor). Office for Official Publications of the European Communities (available at: 〈http://www.ices.dk/projects/MSFD/Management%20Group%20Report_Final_vII.pdf〉); 2010.
[19] Jackson JBC, Kirby MX, Berger WH, Bjorndal KA, Botsford LW, Bourque BJ, et al. Historical overfishing and the recent collapse of coastal ecosystems. Science 2001;293:629–38.
[20] Österblom H, Gårdmark A, Bergström L, Müller-Karulis B, Folke C, Lindegren M, et al. Making the ecosystem approach operational—can regime shifts in ecological- and governance systems facilitate the transition?Marine Policy 2010;34:1290–9.
[21] Pitcher TJ, ME Lam. Fishful thinking: rhetoric, reality, and the Sea before us. Ecology and Society 2010;15:1–27. 〈http://www.ecologyandsociety.org/vol15/iss2/art12/〉.
[22] ICES. Report of the workshop on historical data on fish and fisheries (WKHIST). International Council for the Exploration of the Sea CM 2008/RMC: 04 2008; 1–54.
[23] Smith TD, Pike DG. The enigmatic whale: the North Atlantic humpback. North Atlantic Marine Mammal Commission Scientific Publications 2009;7:161–78.
[24] Holm P. History of marine animal populations: a global research program of the Census of marine life. Oceanologica Acta 2002;25:207–11.
[25] Reid C. Conference Report: Twelfth Conference of the North Atlantic Fisheries History Association, Old Dominion University, Nor-folk, Virginia, 19–22 August 2009. Marine Policy 2010;34:737–38.
[26] Helcom. HELCOM thematic assessment on biodiversity and nature conservation. Helsinki: Helsinki Commission for the Protection of the Baltic Marine Environment. 〈http://www.helcom.fi〉; 2009.
[27] MacKenzie BR, Schiedek D. Daily ocean monitoring since the 1860s shows unprecedented warming of northern European seas. Global Change Biology 2007;13:1335-1347 10.1111/j.1365-2486.2007.01360.x.
[28] Belkin IM. Rapid warming of large marine ecosystems. Progress in Oceanography 2009;81:207–13.
[29] MacKenzie BR, Gislason H, Möllmann C, Köster FW. Impact of 21st century climate change on the Baltic Sea fish community and fisheries. Global Change Biology 2007;13:1348–67, doi:10.1111/j.1365-2486.2007.01369.x.
[30] Bagge O, Thurow F, Steffensen E, Bay J. The Baltic cod. Dana 1994;10:1–28.
[31] Eero M, MacKenzie BR, Köster FW, Gislason H. Multi-decadal responses of a cod (*Gadus morhua*) population to human-induced trophic changes, exploitation and climate variability. Ecological Applications. 〈http://www.esajournals.org/doi/pdf/10.1890/09-1879.1〉; in press.
[32] Hammer C, von Dorien C, Ernst P, Gröhsler T, Köster FW, MacKenzie BR, et al. Fish stock development under hydrographic and hydrochemical aspects, the history of Baltic Sea fisheries and its management. In: Feistel R, Nausch G, Wasmund N, editors. State and evolution of the Baltic Sea, 1952–2005. John Riley & Sons, Inc.; 2008. p. 543–81.
[33] Köster FW, Vinther M, MacKenzie BR, Eero M, Plikshs M. Environmental effects on recruitment and implications for biological reference points of eastern Baltic cod (*Gadus morhua*). Journal of Northwest Atlantic Fisheries Science 2009;41:205–20.
[34] ICES. Report of the workshop on the integration of environmental information into fisheries management strategies and advice (WKEFA). International Council for the Exploration of the Sea CM 2007/ACFM 2007;25:1–182.
[35] ICES. ICES Advice—Baltic Sea ecoregion, cod in subdivisions 25–32. International Council for the Exploration of the Sea Advice Book 8 2010.
[36] EC. Council regulation (EC) no. 1098/2007 establishing a multi-annual plan for the cod stocks in the Baltic Sea and the fisheries exploiting those stocks, amending Regulation (ECC) no. 2847/93 and repealing Regulation (EC) no. 779/97; 2007.
[37] Piet GJ, Albella AJ, Aro E, Farrugio H, Lleonart J, Lordan C et al. Marine strategy framework directive Task Group 3 report: commercially exploited fish and shellfish. JRC Scientific and Technical Reports 3:87 pp. In: Doerner H, Scott R, editors. Luxembourg: Office for Official Publications of the European Communities (available at 〈http://www.ices.dk/projects/MSFD/TG3%20FINAL%20REPORT.pdf〉); 2010.
[38] Bastardie F, Vinther M, Nielsen JR, Ulrich C, Paulsen MS. Stock-based vs. fleet-based evaluation of the multi-annual management plan for the cod stocks in the Baltic Sea. Fisheries Research 2010;101:188–202.
[39] Cochrane SKJ, Connor DW, Nilsson P, Mitchell I, Reker J, Franco J et al. Marine strategy framework directive Task Group 1 report: biological diversity. JRC Scientific and Technical Reports 1:120 pp. In: Zampoukas N., editor. Luxembourg: Office for Official Publications of the European Communities (available at 〈http://www.ices.dk/projects/MSFD/TG1final.pdf〉); 2010.
[40] Rogers S, Casini M, Cury P, Heath M, Irigoien X, Kuosa H et al. Marine strategy framework directive Task Group 4 report: food webs. JRC Scientific and Technical Reports 4:63 pp. In: Piha H, editor. Luxembourg: Office for Official Publications of the European Communities (available at 〈http://www.ices.dk/projects/MSFD/TG4%20report_Final_vII.pdf〉); 2010.
[41] ICES. Chair's report of the workshop on the form of advice (WKFORM). International Council for the Exploration of the Sea CM 2009/ACOM 2009:53;1–11.
[42] ICES. Report of the workshop on implementing the ICES Fmsy framework. International Council for the Exploration of the Sea CM 2010/ACOM2010: 54;1–79.
[43] Mesnil B, Rochet MJ. A continuous hockey stick stock-recruit model for estimating MSY reference points. International Council for the Exploration of the Sea J Mar Sci. Journal of Marine Science 2010;67:1780–4.
[44] Helcom. HELCOM Baltic Sea Action Plan:102 pp. Helsinki: Helsinki Commission for the Protection of the Baltic Marine Environment 〈http://www.helcom.fi〉; 2007.
[45] Eero M, Köster FW, Plikshs M, Thurow F. Eastern Baltic cod (*Gadus morhua callarias*) stock dynamics: extending the analytical assessment back to the mid-1940s. International Council for the Exploration of the Sea Journal of Marine Science 2007;64:1257–71.
[46] Eero M, Köster FW, MacKenzie BR. Reconstructing historical stock development of the eastern Baltic cod (*Gadus morhua*) before the beginning of intensive exploitation. Canadian Journal of Fisheries and Aquatic Sciences 2008;65: 2728–41.

[47] Aro E, Sjöblom V. Fishing effort and catch per unit of effort of cod in Finnish waters in 1977–82. International Council for the Exploration of the Sea CM 1984/J:24; 1984.
[48] MacKenzie BR, Bager M, Ojaveer H, Awebro K, Heino U, Holm P, et al. ;Multi-decadal scale variability in the eastern Baltic cod fishery 1550–1860: evidence and causes. Fisheries Research 2007;87:106–19, doi:10.1016/j.fishres.2007.07.003.
[49] ICES. Report of the working group on marine mammal ecology. International Council for the Exploration of the Sea CM 2010/ACOM:24; 2010.
[50] Köster FW, Möllmann C, Hinrichsen H-H, Tomkiewicz J, Wieland K, Kraus G, et al. Baltic cod recruitment—the impact of climate variability on key processes. International Council for the Exploration of the Sea Journal of Marine Science 2005;62:1408–25.
[51] ICES. Report of the Baltic fisheries assessment working group (WGBFAS). International Council for the Exploration of the Sea CM 2010/ACOM:10; 2010.
[52] Bager M, Søndergaard M, MacKenzie BR. The development of fisheries at Bornholm, Denmark (Baltic Sea) fisheries during 1880–1914. Fisheries Research 2007;87:146–54.
[53] Eero M, MacKenzie BR, Karlsdottir HM, Gaumiga R. Development of international fisheries for the eastern Baltic cod (*Gadus morhua*) during 1888–1938. Fisheries Research 2007;87:155-166 10.1016/j.fishres.2007.02.015.
[54] Ojaveer H, Awebro K, Karlsdottir HM, MacKenzie BR. Swedish Baltic Sea fisheries during c. 1870–1913: spatio-temporal dynamics of catch and fishing effort. Fisheries Research 2007;87:137–45.