ICES Journal of Marine Science, 60: 1114–1122. 2003
doi:10.1016/S1054–3139(03)00094-8



# Evaluation of the exploitation of Eastern Baltic cod (*Gadus morhua callarias* L.) stock in 1976–1997

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Radtke, K. 2003. Evaluation of the exploitation of Eastern Baltic cod (*Gadus morhua callarias* L.) stock in 1976–1997. – ICES Journal of Marine Science, 60: 1114–1122.

Big changes occurred in the Eastern Baltic cod biomass and catches in the 1976–1997 period. At present, the Eastern Baltic cod stock spawning biomass (SSB) and catches are approximately five times lower than their highest ever recorded levels observed in the middle of the 1980s. The reasons for the stock decline, namely low recruitment and high fishing mortality, are widely known and well described in the literature. Throughout the whole period, the International Council for the Exploration of the Sea (ICES) made scientific recommendations regarding the exploitation level of the cod stock. The ICES presented and analysed different management strategies based on fishing mortalities which corresponded to biological reference points (BRP) and also recommended total allowable catches (TACs) for cod, taking into account the sustainability of cod resources. In fact, in most years the TAC established by the International Baltic Sea Fisheries Commission (IBSFC) and cod catches (observed exploitation) exceeded the ICES-recommended TAC and thus their scientific advice was neither taken into account by the IBSFC nor by fishermen.

This paper evaluates: (1) the would-be state of the Eastern Baltic cod stock if it had been exploited according to ICES-recommended TAC levels, as compared with observed stock exploitation; and (2) the potential effects of management using fishing mortality rates which correspond to BRP on SSB estimates and catch levels, as compared with observed stock exploitation.

It is concluded that if ICES advice had been followed, the cumulative cod catches in the 1976–1997 period would have been the same as those observed, but the stock biomass would have been much higher and at a safe level (SSB above 240 000 t).

Furthermore, from the comparative analysis of different management strategies based on BRP and the observed strategy, it appears that other management strategies could have been applied which would have produced a higher biomass and greater cumulative catch numbers than those observed.



Keywords: biological reference points, Eastern Baltic cod, International Baltic Sea Fisheries Commission, International Council for the Exploration of the Sea, total allowable catches.

Received 15 March 2002; accepted 2 October 2002.

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## Introduction

Cod is one of the most important species in the Baltic Sea. There are two cod stocks: the Western Baltic stock, inhabiting regions west of Bornholm (ICES Sub-divisions 22–24) and the Eastern Baltic stock, inhabiting regions east of Bornholm (ICES Sub-divisions 25–32) (Figure 1). This paper focuses on the latter.

The fishery management decision process on the exploitation level of Baltic stocks is outlined below.

The International Council for the Exploration of the Sea (ICES) is a scientific organisation and its Advisory Committee on Fishery Management (ACFM) assesses the state of the stock. It makes scientific recommendations on the exploitation level (total allowable catch, TAC) and evaluates the potential consequences of accepting a specified management strategy (biological reference points, BRP). The International Baltic Sea Fisheries Commission (IBSFC) is a management body that makes the final decision regarding the exploitation level (TAC) of Baltic stocks. Establishing TACs, which the ICES has recommended for Baltic cod stocks since 1976 is one of the methods to regulate fishing mortality (ICES, 1977a; Garrod, 1978).

ICES decided that TACs should be calculated on the basis of fishing mortality which corresponds to a biological reference point equal to $F_{0.1}$ (ICES, 1977b). $F_{0.1}$ is the level of fishing mortality corresponding to the point on the yield curve at which the marginal yield is 10% of the initial catch

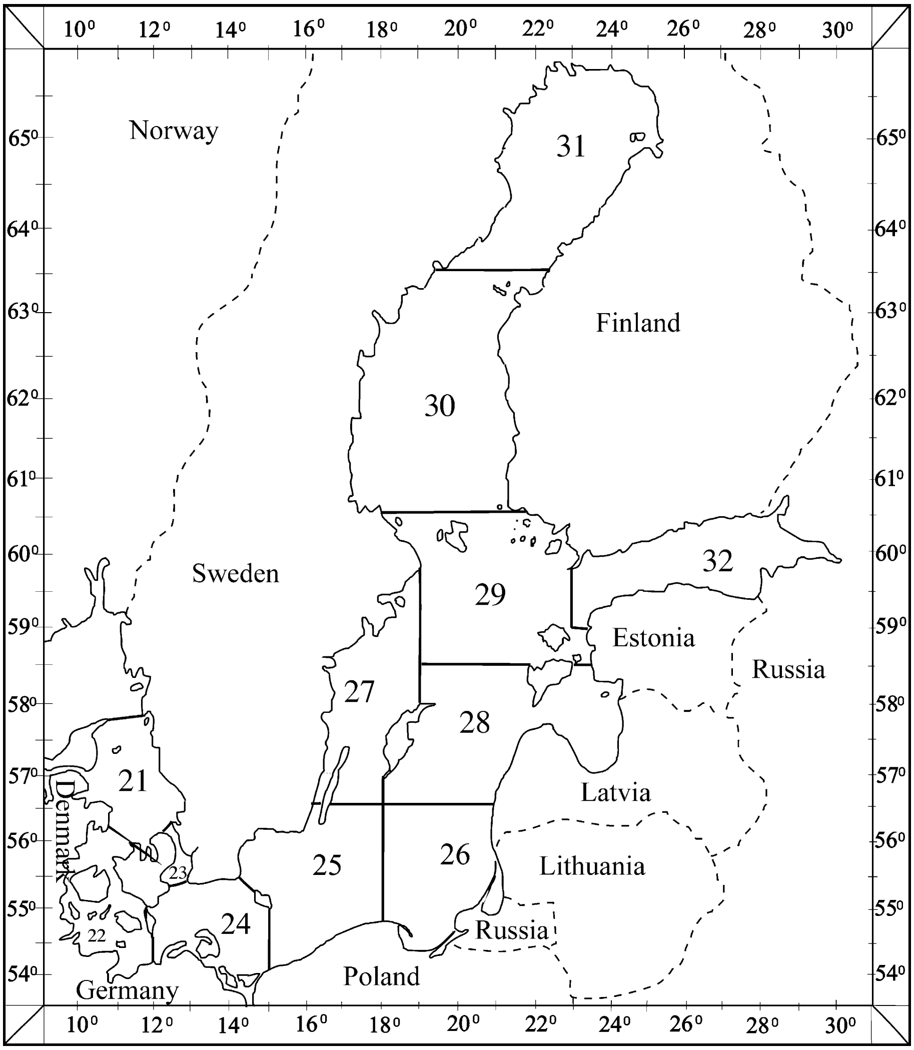


Figure 1. Statistical Sub-divisions of the Baltic Sea according to the ICES.

per unit effort in a lightly exploited fishery (Gulland and Boerema, 1973). In addition, the recommended TACs were modified to keep the stock spawning biomass (SSB) within safe biological limits (ICES, 1977b). In the 1953–1977 period, the recommended TAC for species outside the Baltic was derived through the application of another biological reference point, $F_{max}$ (Hersoug, 1996). $F_{max}$ is the level of fishing mortality for a given size at first capture, which maximizes the average yield from each recruit entering the fishery (Beverton and Holt, 1957). Both of these BRP were widely applied in ICES recommendations in the 1970s and 1980s (Hildén, 1993).

In spite of TACs set by the ICES for Sub-divisions 25–32, cod catches exceeded the recommendations, especially up to 1985, in the range of 18–95% (Aro, 1995, 2000) (Figure 2). TACs established by IBSFC (Sub-divisions 22–32) was also exceeded from 1977 to 1981, (from 12 to 69%). Unfortunately, the TACs established by the IBSFC during 1979–1981 were not divided by country and thus provided little or no regulation control. During 1982–1988 the situation deteriorated since the IBSFC was not able to establish a TAC. This resulted in an uncontrolled fishery. Nevertheless, the IBSFC introduced regulatory measures like mesh size regulations, minimum landing size, closed seasons, and a limit on the amount of by-catch of undersized cod (IBSFC, 1993, 1994).

In 1987, ICES included new BRP, $F_{med}$ and $F_{high}$. These indicate values of fishing mortalities, where with $F_{med}$ it is probable and with $F_{high}$ it is doubtful that recruitment (per unit biomass) over longer times will be sufficient to maintain a stable stock size (ICES, 1988).

Unfortunately, the uncertainties in the catch statistics provided to the ICES Working Groups made relying exclusively on $F_{0.1}$ and $F_{max}$ an insufficient criteria for

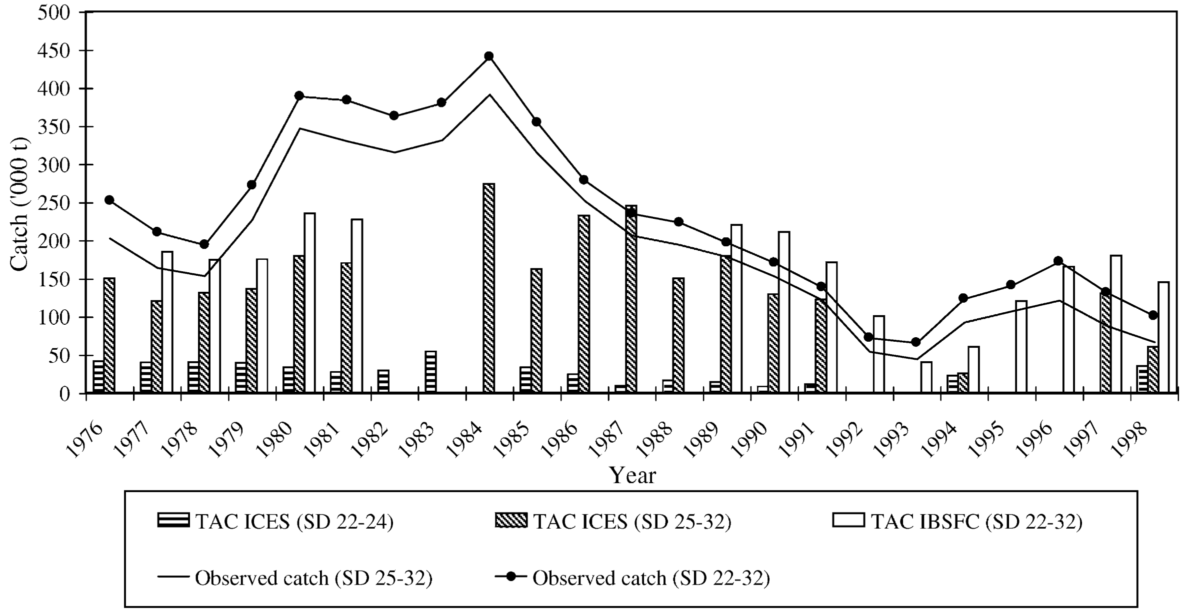


Figure 2. TAC recommended by the ICES (TAC ICES) and by the IBSFC (TAC IBSFC) in comparison to observed cod catches, 1976–1998.

rational stock exploitation. It is well known that the resources of many stocks, especially demersal ones, have declined. Under these circumstances, a new management concept, PA (precautionary approach), was developed (Garcia, 1996). Under this concept, the new BRP $F_{pa}$ and $B_{pa}$ were introduced. ICES has defined $B_{pa}$ as the biomass below which actions to safeguard the stock should be taken and $F_{pa}$ as the fishing mortality above which management action should be taken (ICES, 2000). $B_{pa}$ is the biomass below which the stock would be regarded as potentially depleted or overfished. In the years preceding the implementation of $B_{pa}$, another biological reference point, minimum biologically acceptable level (MBAL), had been applied. In the case of Eastern Baltic cod, $B_{pa}$ was assumed to be equal to MBAL at 240 000 t (Anon., 1998a). If exploitation is carried out at an intensity not exceeding the value of fishing mortality that corresponds to $F_{pa}$, then generally the stock should not decline below $B_{pa}$.

This article is organised into two subsections. The first subsection evaluates the potential effects of the stricter enforcement of TACs on SSB estimates and catch levels. The second, evaluates the potential effects of management using fishing mortality rates corresponding to BRP—$F_{0.1}$, $F_{max}$, $F_{low}$, $F_{high}$, $F_{med}$, $F_{pa}$, $F_{safe}$ — on SSB estimates and catch levels.

## Materials and methods

The SSB simulations in subsection 1 and 2 were performed on the same data that were used by the ICES Working Group in 1998 for the assessment of cod stock size (Anon., 1998b). In addition, the ICES data on observed recruitment and observed SSB were used. The range of the ICES data used referred to the 1976–1997 period.

The SSB level which resulted from the simulation is called the simulated biomass (simSSB), and the SSB calculated by the Working Group is called observed biomass (obsSSB). The starting point of the simulation was the stock at age in numbers as estimated by the ICES for 1976 (Anon., 1998b).

### Potential effects of the stricter enforcement of TACs on SSB estimates and catch levels

This simulation was performed to compare the state and results of observed cod stock exploitation in the 1976–1997 period with the probable state of the stock if it had been exploited according to the recommendations of ICES. To perform this simulation, the recommended TAC and the predicted SSB that corresponds to the recommended TAC were used (ICES, 1977a, 1978–1997). The predicted SSB for 1977–1981 were not presented in the ICES Co-operative Research Reports. Therefore for 1977–1981 the relevant SSBs were taken from WG Reports (Anon., 1978–1980).

The observed catches of cod were substituted with the recommended TAC. The proportions of the percentages of age groups in the recommended TAC were assumed to be the same as those in the observed catches. To simulate the stock in numbers at age, Pope's equation was used (Pope, 1972):

$$N_{t+1} = (N_t e^{-M/2} - C_t)e^{-M/2} \quad (1)$$

where $N_{t+1}$ is the stock size in numbers at age t+1, $N_t$ the stock size in numbers at age t, $C_t$ the catch in numbers at age t, and M is the natural mortality.

The first year of this simulation was 1976. If the catches in a given year had been the same as the recommended TACs, then the biomass would have been different than that observed, and consequently, the TAC recommended in the following years would have been different. Therefore, the TAC recommended by ICES was modified by the proportion of the amount of the simSSB to biomass, on the basis of which, the ICES recommended the TAC. Therefore, in Equation (1) the catches were modified:

$$C_{t,y}^{sim} = C_{t,y}^{ICES} \frac{B_y^{sim}}{B_y^{ICES}} \quad (2)$$

where $C_{t,y}^{sim}$ is the simulated catches at age t in year y, $C_{t,y}^{ICES}$ the catches at age t in year y, resulting from ICES recommendations, $B_y^{sim}$ the simSSB in year y, and $B_y^{ICES}$ is the biomass in year y, on the basis of which ICES recommended the amount of the catch in year y.

The observed recruitment (1976–1978) for the SSB simulation for 1976–1978 was used. However, if simulated SSB is different from observed SSB (ICES advice is followed), one could expect changes in recruitment. So, for 1979–1997, the observed recruitment was modified based on the proportion of recruitment resulting from the stock–recruitment relationship at the simSSB to recruitment resulting from the stock–recruitment relationship at the obsSSB. The stock–recruitment relationship was modelled by the Beverton–Holt equation (1957). Thus, the simulated recruitment entering the fishery was described by the following equation:

$$R_y^{sim} = R_y^{obs} \frac{R_{model}(SSB_{y-2}^{sim})}{R_{model}(SSB_{y-2}^{obs})} \quad (3)$$

where $R_y^{sim}$ is the simulated recruitment in year y, $R_y^{obs}$ the observed recruitment in year y, $R_{model}$ the recruitment resulting from Beverton–Holt model, $SSB_{y-2}^{sim}$ the simulated spawning-stock biomass in year y−2, and $SSB_{y-2}^{obs}$ is the observed spawning-stock biomass in year y−2. The modelled value of recruitment was constrained to the highest observed recruitment value in the 1966–1997 period.

The SSB was calculated as a sum of the following products: stock size in numbers at age; weight in stock at age; and maturity proportion at the beginning of the year.

### Potential effects of management using fishing mortality rates corresponding to BRP—$F_{0.1}$, $F_{max}$, $F_{low}$, $F_{high}$, $F_{med}$, $F_{pa}$, $F_{safe}$—on SSB estimates and catch levels

For the SSB simulations, values of fishing mortality which correspond to the BRP $F_{med} = 0.97$, $F_{high} = 1.85$, $F_{low} = 0.39$, $F_{pa} = 0.6$ were taken from Anon. (1999) and $F_{safe} = 0.32$ was taken from Horbowy (1992). $F_{safe}$ is the level of fishing mortality leading to an increase of stock biomass at any level of recruitment. If recruitment is zero, then the stock biomass is constant in two consecutive years. $F_{0.1}$ and $F_{max}$ at the age of first capture equal to 3 and 4 were calculated from the yield per recruit equation (Beverton and Holt, 1957).

Growth parameters of cod $W_\infty = 11$ kg, $K = 0.14$ and $t_0 = 0.15$ necessary for yield per recruit equation were taken from Kosior (1977).

The simulations were started in 1976 and, in principle, they were performed in a similar way as in the previous subsection using the following equation instead of Equation (1):

$$N_{t+1} = N_t e^{-(F_t+M)} \quad (4)$$

where $N_{t+1}$ is the stock size in numbers at age t+1, $N_t$ the stock size in numbers at age t, $F_t$ the fishing mortality at age t, and M is the natural mortality.

Using Equation (4), stock in numbers in succeeding years was calculated substituting F in Equation (4) with one of the values of fishing mortality that corresponds to one of the management strategies according to the BRP. The recruitment was simulated in the same way as in the previous subsection. The values of fishing mortality for age groups 2 and 3 which are not fully exploited by the fishery were modified by selection values calculated from the separable VPA (Pope and Shepherd, 1982).

The SSB was calculated in the same way as in the previous subsection.

The catch in numbers was calculated using Baranov's (1918) catch equation:

$$C_t = N_t \frac{F_t}{F_t + M}(1 - e^{-F_t - M}) \quad (5)$$

where $C_t$ is the catch in numbers at age t, $N_t$ the stock size in numbers at age t, and F and M are the fishing and natural mortality, respectively.

The cumulative catch and average biomass per year was calculated for every management strategy.

## Results

### Potential effects of the stricter enforcement of TACs on SSB estimates and catch levels

The simSSB exceeded the obsSSB within the range of 60 000–237 000 t in all years covered by the simulation (Figure 3). The calculated average simSSB per year equalled 496 000 t while the average obsSSB was lower by 124 000 t at 372 000 t. The simSSB dropped below $B_{pa}$ only in 1992 (195 000 t).

The calculated cumulative catch resulting from the simulation (1976–1997) was only 5000 t (0.1%) lower than the observed cumulative catch for the same period. The results of the catch simulation are presented in Figure 4.

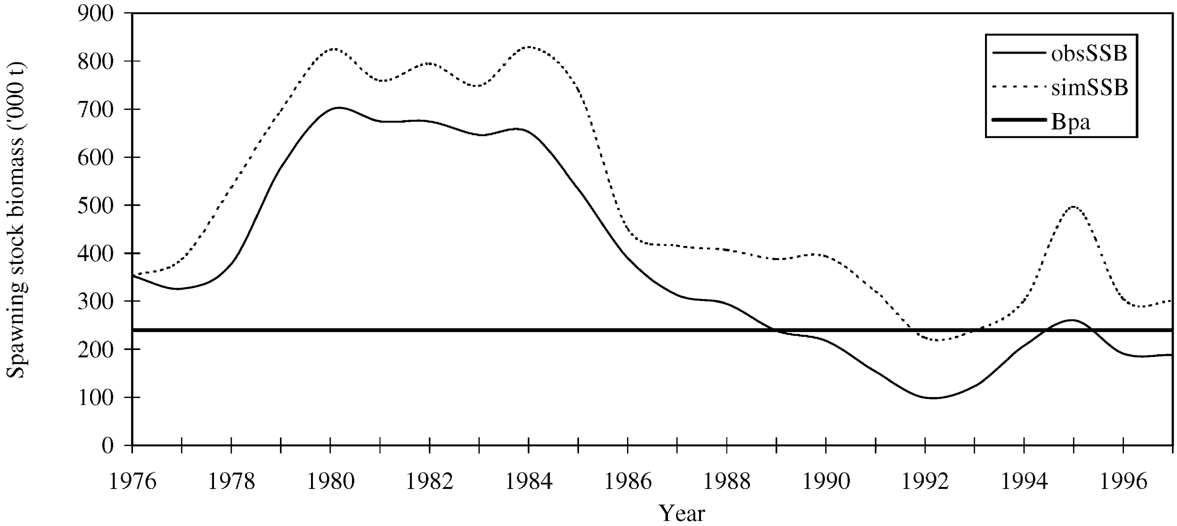


Figure 3. Observed (obsSSB) and simulated (simSBB) cod spawning-stock biomass in Sub-divisions 25–32, 1976–1997, in comparison to $B_{pa}$.

## Potential effects of management using fishing mortality rates corresponding to BRP—$F_{0.1}$, $F_{max}$, $F_{low}$, $F_{high}$, $F_{med}$, $F_{pa}$, $F_{safe}$—on SSB estimates and catch levels

The calculated values of fishing mortality which corresponded to BRP $F_{0.1}$ and $F_{max}$ for an age at first capture of $t_c = 3$ years equalled 0.15 and 0.25, respectively, and for an age at first capture of 4 years it equalled 0.17 and 0.34, respectively. The selection values for age groups 2 and 3, assuming a reference age of 4 (selection = 1), equalled 0.1 and 0.42, respectively.

The management strategies which correspond to BRP $F_{max}$ $t_c = 3$ years, $F_{max}$ $t_c = 4$ years, $F_{safe}$, $F_{pa}$ and $F_{low}$ produced higher cumulative catches (exceeding the catches which correspond to the observed strategy within the range of 14 000–523 000 t). The results of cumulative catches are presented in Figure 5.

The average biomasses per year which correspond to $F_{pa}$, $F_{low}$, $F_{safe}$, $F_{max}$ $t_c = 3$ years, $F_{max}$ $t_c = 4$ years, $F_{0.1}$ $t_c = 4$ years and $F_{0.1}$ $t_c = 3$ years exceeded the average obsSSB within the range of 115 000–823 000 t (Figure 6).

The cumulative catches of management strategies which correspond to BRP $F_{med}$, $F_{0.1}$ $t_c = 4$ years, $F_{0.1}$ $t_c = 3$ years and $F_{high}$ produced lower cod catches than the observed strategy within the range of 498 000–1 898 000 t. The average simSSB that corresponded to $F_{med}$ and $F_{high}$ was

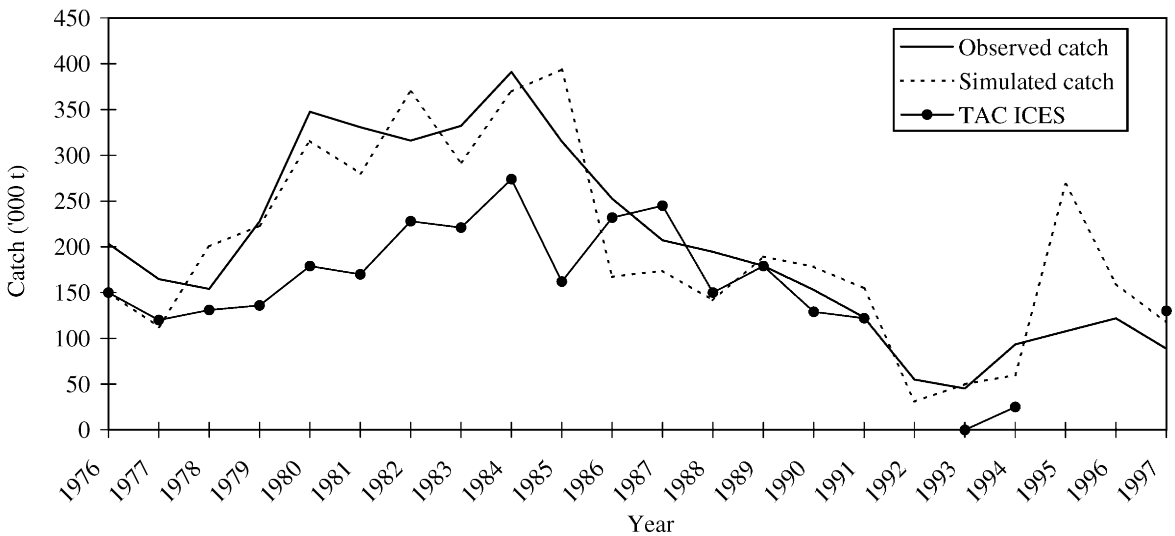


Figure 4. TAC recommended by ICES, observed and simulated cod catches in Sub-divisions 25–32, 1976–1997, assuming that ICES advice had been followed.

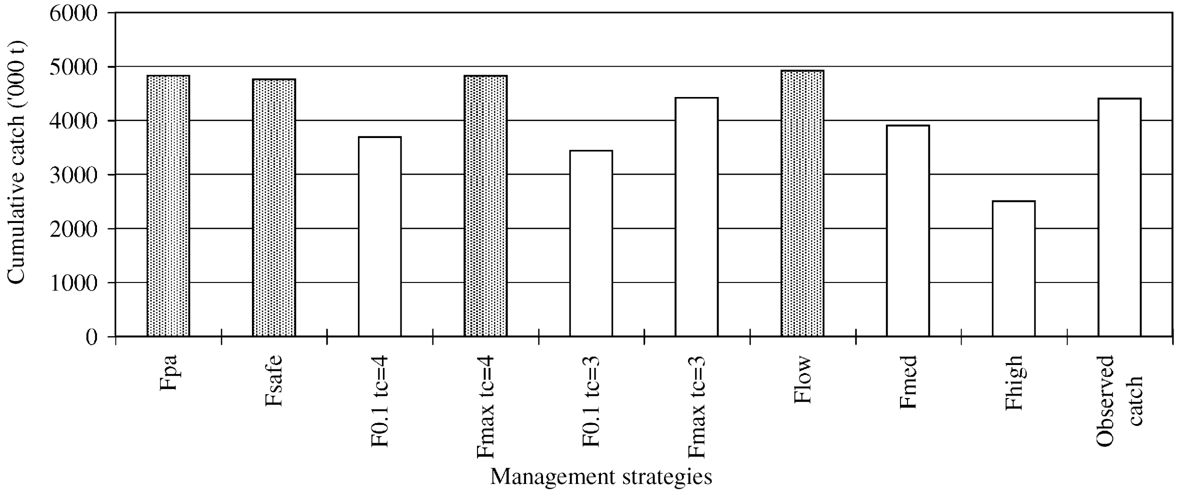


Figure 5. Cumulative observed catch and cumulative cod catches in Sub-divisions 25–32 which resulted from the application of different management strategies, 1976–1997. (Management strategies considered as optimal are designated by dotted bars).

lower than the observed values and ranged from 100 000 to 256 000 t, respectively.

# Discussion

## Potential effects of the stricter enforcement of TACs on SSB estimates and catch levels

The SSB simulation indicates that the implementation of recommended ICES TACs could have prevented the decrease of SSB to the extreme low level. The application of the recommended ICES TACs, however, did not halt the stock decline in the second half of the 1980s (Figure 3). Decreasing recruitment caused by unfavourable hydrological conditions appears to have been the main reason for stock decline (Kosior and Netzel, 1989; Lablaika *et al.*, 1989; Westin and Nissling, 1991; Plikshs *et al.*, 1993). According to these authors, decreasing recruitment was determined mainly by unfavourable conditions. The second reason for the stock decline was overfishing (Horbowy and Netzel, 1992). The observed catch and SSB figures suggest that cod was caught in large amounts. Horbowy and Netzel (1992) used the CAGEAN model (Deriso *et al.*, 1985) to demonstrate that catches from 1982 had exceeded surplus production. Prolonged exploitation that exceeds surplus production will lead to stock decline (King, 1996).

The fishery was totally uncontrolled between 1982 and 1988 and occurred despite decreasing recruitment in the

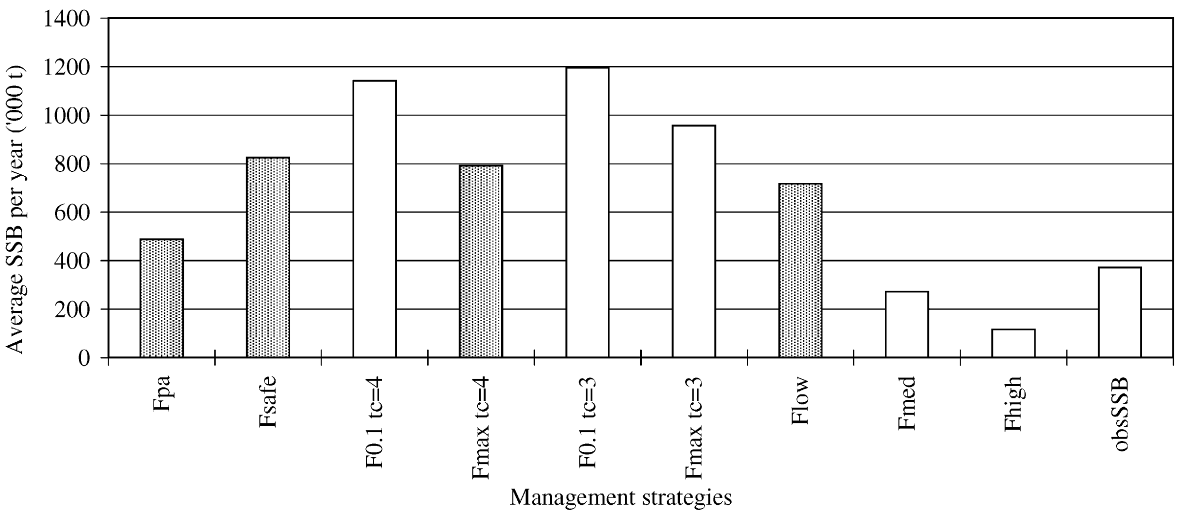


Figure 6. Average observed SSB (obsSSB) per year and average simulated SSBs of cod in Sub-divisions 25–32 which resulted from the application of different management strategies, 1976–1997. (Management strategies considered as optimal are designated by dotted bars).

second half of the 1980s. To counteract the declining recruitment, ICES acted by decreasing the recommended TAC although the biomass was still at a very high level at that time (Figure 2). Standard procedure in setting TAC takes recruitment into account as one of the important factors (Brander, 1987). The role of management bodies has been emphasised by ICES (ICES, 1982), and they have suggested many times that TACs for the western and eastern cod stocks should be set separately by the IBSFC since this is the only way to effectively manage these stocks (ICES, 1988–1990). However, the IBSFC has failed to do this.

The results of simulated catches have indicated that compliance with the TACs recommended by ICES would have led to cumulative catches of almost the same magnitude (5000 t lower = 0.1%) as the observed catches, while sustaining the SSB at a higher, safer level than that of the observed SSB. The SSB and catch simulations indicate that it was indeed possible to reconcile the interests of fishermen with rational stock management. In this context it is necessary to emphasise that although the ICES recommendations have only biological foundations, they should not be considered separately from economic considerations (ICES, 1984). This premise is confirmed by the results of the biomass and catch simulations presented above. The higher biomass could have produced a higher catch per unit of effort (CPUE), which is important for fishery economics.

Previous evaluations of SSB development of cod stocks in Sub-divisions 22–24 and in Sub-divisions 25–32 which resulted from ICES recommendations have been presented by Weber (1989). In this analysis, the fishing mortalities recommended by ICES were applied instead of TACs, but neither the influence of differences between the simulated stock biomass and the observed one on ICES recommendations nor the influence on observed recruitment were modelled (simulated). Weber's results were somewhat peculiar; the simSSB was lower than the observed one in 1978–1984 and higher than the observed one in 1985–1987. In the present paper, the simSSB was always higher than the obsSSB.

## Potential effects of management using fishing mortality rates corresponding to BRP—$F_{0.1}$, $F_{max}$, $F_{low}$, $F_{high}$, $F_{med}$, $F_{pa}$, $F_{safe}$—on SSB estimates and catch levels

Figures 5 and 6 indicate that more reasonable cod management strategies than the implemented ones could have been used. The basis of the biological advice provided by ACFM (ICES, 1984) is as follows: "The ACFM still considers that the biological advice provided should not be seen in isolation from economic considerations and would welcome a continuing dialogue with other parties in the management process, in order to tailor the biological advice to best suit the needs of the subsequent stages in the process of creating viable management". This dialogue could yield a criterion of an optimal management strategy, in which on one hand, the biological foundations of the ACFM advice are met—safe stock size level is ensured (SSB long-term average above $B_{pa}$ – 240 000 t)—and on the other hand, economic considerations are not isolated—relatively high catches are achieved (comparing long-term cumulative catches of different management strategies). In this paper, the strategies that correspond to $F_{pa}$, $F_{safe}$, $F_{max}$ $t_c = 4$ years and $F_{low}$ can be regarded as optimal in that sense (Figures 5 and 6). The cumulative catch obtained from the above-mentioned strategies exceeded the observed one and was the highest (exceeding 4.5 million t) among other strategies that provided a simultaneously relatively high average biomass (exceeding $B_{pa}$) which is safe for the stock's sustainability. Sustaining a high SSB level is profitable for fisheries since it allows a higher rate of CPUE to be achieved.

The application of the $F_{pa}$ strategy resulted in simSSB (496 000 t) nearest to the simSSB resulting from the application of the recommended TACs (487 000 t).

The other management strategies studied in this subsection were not classified as optimal due to the reasons described below.

The strategies on the basis of $F_{0.1}$ were rejected since the resulting catches were relatively low and the SSBs high. Such a high biomass is not necessary for stock safety nor would the catches satisfy fishermen. The average biomass resulting from the $F_{0.1}$ strategy exceeded the observed one by more than threefold. It is likely that such a high simSSB could have not been supported by the environment. Probably, in an earlier stage of biomass development, density dependent factors would decrease the growth rate of fish and increase the natural mortality and this would reduce the SSB (Gulland, 1991). A strategy based on $F_{0.1}$ is often suggested as an alternative to $F_{max}$ giving similar values of catches without a radical reduction of SSB as is the case with $F_{max}$ (Sissenwine and Shepherd, 1987).

The strategy that corresponds to $F_{max}$ $t_c = 3$ years also produced a very high biomass level and the summarised catches were almost similar to observed ones, therefore this strategy was also not considered as optimal.

On the contrary to the above-presented strategies, the application of the $F_{high}$ led to biomass lower than $B_{pa}$ and $F_{med}$ to those which were very close to $B_{pa}$. Both biomasses were below obsSSB. Sustaining this high level in subsequent years leads to stock reduction and decreasing catches (Shepherd, 1992). The results of the $F_{high}$ strategy in simulations that correspond to a definition of the reference point given by ICES (1984) indicate that it is not probable that the stock can sustain exploitation with $F_{high}$ for a prolonged length of time. The course of changes of simSSB indicated that in this case $F_{med}$ should be regarded as a limit reference point as it was originally considered by ICES (Caddy and Mahon, 1995), and not as a target reference point according to which exploitation should be carried out. The exploitation of stocks with fishing mortalities lower than the fishing mortality that corresponds to $F_{med}$ is often considered as safe (Cook, 1998). In recent years the exploitation of Eastern Baltic cod stocks has well exceeded $F_{med}$ (Anon., 1999).

The results of cumulative catches of management strategies considered as optimal indicate that by reducing fishing mortality rates long-term catch levels could be increased substantially as compared with the observed strategy. Reduction of fishing mortality rates in a present and foreseeable environmental conditions is the only way to rebuild and maintain the SSB at the level of 550 000 t, if the goal of management is maximizing the yield (Sparholt, 1995; Kuikka *et al.*, 1999).

The inspection of fishing mortality and values of BRP carried out by Horbowy (1995) indicate that fishing mortality was high in the last two decades, and it considerably exceeded $F_{max}$ and $F_{med}$ in most of the years. A fishing mortality that exceeded $F_{max}$ led to growth overfishing and one that exceeded $F_{med}$ led to recruitment overfishing.

## Conclusions

SSB simulations show that the cod exploitation by TACs proposed by ICES could have led to very similar catches and higher SSB values than obsSSB, and consequently to higher CPUE values. Unfortunately, the decline in SSB and catch could not have been avoided due to the decrease in recruitment.

The comparative analysis of different management strategies based on BRP and the implemented strategy indicated that the exploitation of the cod stock with fishing mortalities that corresponded to $F_{pa}$, $F_{safe}$, $F_{max}$ $t_c = 4$ years and $F_{low}$ would have resulted in higher cumulative catches than those observed and a higher average biomass per year than the obsSSB.

Management strategies $F_{pa}$, $F_{safe}$, $F_{max}$ $t_c = 4$ and $F_{low}$ can be regarded as near optimal since they ensured both a high average biomass and produced a higher than observed cumulative catch.

The management strategy $F_{pa}$ regarded by ICES as the maximum admissible fishing mortality, produced a cumulative catch that was only 2% lower than the highest obtained from the simulations while sustaining a simultaneously relatively low, although safe, biomass level.

## Acknowledgements

I would particularly like to thank Dr Jan Horbowy, from Sea Fisheries Institute (Gdynia, Poland) for suggestions and, an especially thorough review. I am also indebted to Dr Murdoch McAllister, from the Imperial College of Science, Technology and Medicine (RRAG, London, UK) for helpful comments on earlier drafts of the manuscript. I thank the ICES General Secretary for the permission to cite the Reports of the ICES Working and Study Groups. Thanks are also due to two anonymous reviewers for their valuable comments. This work was carried out as part of a Research Project No. 5 P06 E 011 financed by the State Committee for Scientific Research, Poland.

## References

Anon. 1978. Report of the Working Group on Assessment of Demersal Stocks in the Baltic. ICES CM 1978/J: 3. 24 pp.

Anon. 1979. Report of the Working Group on Assessment of Demersal Stocks in the Baltic. ICES CM 1979/J: 4. 36 pp.

Anon. 1980. Report of the Working Group on Assessment of Demersal Stocks in the Baltic. ICES CM 1980/J: 3. 40 pp.

Anon. 1998a. Report of the Study Group on Management Strategies for Baltic Fish Stocks. ICES CM 1998/ACFM: 11, Ref. H. 36 pp.

Anon. 1998b. Report of the Baltic Fisheries Assessment Working Group. ICES CM 1998/ACFM: 16. 391 pp.

Anon. 1999. Report of the Baltic Fisheries Assessment Working Group. ICES CM 1999/ACFM: 15. 555 pp.

Aro, E. 1995. The degree of utilisation of the fish stocks managed by IBSFC. *In* Baltic Fisheries. An Integrated View. Proceedings of the Conference on Baltic Fisheries, pp. 1–24. Warnemünde, Germany, 14–16 November 1994. Publication of the European Communities, Luxembourg. 430 pp.

Aro, E. 2000. The Spatial and Temporal Distribution Patterns of Cod (*Gadus morhua callarias* L.) in the Baltic Sea and their Dependence on Environmental Variability—Implications for Fishery Management. Academic dissertation, Finnish Game and Fisheries Research Institute, Helsinki. 75 pp.

Baranov, F. 1918. On the question of the biological basis of fisheries. Izvestia Otdela Rybovodstva Nauczno-Promyslovych Issledovanij, I: 81–128 (in Russian).

Beverton, R. J. H., and Holt, S. 1957. On the dynamics of exploited fish populations. *In* Fisheries Investigations, Series 2, Vol 19. HMSO, London. 533 pp.

Brander, K. 1987. How well do working groups predict catches? Journal du Conseil pour l'Exploration de la Mer, 43: 245–252.

Caddy, J. F., and Mahon, R. 1995. Reference points for fisheries management. FAO Fisheries Technical Paper: 347. 83 pp.

Cook, R. M. 1998. A sustainability criterion for the exploitation of North Sea cod. ICES Journal of Marine Science, 55: 1061–1070.

Deriso, R. B., Quinn, T. J., II., and Neal, P. R. 1985. Catch-age analysis with auxiliary information. Canadian Journal of Fisheries and Aquatic Sciences, 42: 815–824.

Garcia, S. M. 1996. The precautionary approach to fisheries and its implications for fishery research, technology and management: an updated review. *In* Precautionary Approach to Fisheries, Part 2: Scientific Papers, pp. 1–75. FAO Fisheries Technical Paper, 350(2): 210 pp.

Garrod, D. J. 1978. The North Atlantic cod. *In* Fish Population Dynamics, pp. 216–239. Ed. by J. A. Gulland. Wiley, Chichester.

Gulland, J. A. 1991. Fish stock assessment. A manual of basic methods. FAO/Wiley Series on Food and Agriculture, 1: 223.

Gulland, J. A., and Boerema, L. K. 1973. Scientific advice on catch levels. Fishery Bulletin, 71: 325–335.

Hersoug, B. 1996. Social considerations in fisheries planning and management—real objectives or a defence of the *status quo*? *In* Fisheries Management in Crisis, pp. 19–24. Ed. by K. Crean, and D. Symes. Fishing News Books, Oxford. 222 pp.

Hildén, M. 1993. Reference points for fisheries management: the ICES experience. *In* Risk Evaluation and Biological Reference Points for Fisheries Management, pp. 59–66. Ed. by S. J. Smith, J. J. Hunt, and D. Rivard. Canadian Special Publication on Fisheries and Aquatic Sciences 120: 442 pp.

Horbowy, J. 1992. The differential alternative to the Deriso difference production model. ICES Journal of Marine Science, 49: 167–174.
Horbowy, J. 1995. The state of the eastern Baltic cod stock in relation to biological reference points: review of published results. *In* Scientific Papers Presented at the Polish–Swedish Symposium on Baltic Cod, Gdynia, Poland, March 21–22, 1995. pp. 40–48. Ed. by J. Thulin, and K. Frohlund. Meddelande Från Havsfiskelaboratoriet, No. 327, Lysekil. 139 pp.
Horbowy, J., and Netzel, J. 1992. Use of the CAGEAN model to assess the biomass of the Baltic cod stock in Subdivisions 25–32. Bulletin of the Sea Fisheries Institute Gdynia, 3: 29–33.
IBSFC. 1993. Proceedings of the 19th Session. International Baltic Sea Fishery Commission, Warsaw, Poland, 3–17 September 1993. 293 pp.
IBSFC. 1994. Proceedings of the 20th Session. International Baltic Sea Fishery Commission, Gdynia, Poland, 12–16 September 1994. 338 pp.
ICES. 1977a. Reports of the Liaison Committee of ICES to the North-East Atlantic Fisheries Commission and to the International Baltic Sea Fisheries Commission, November 1975 to September 1976. ICES Co-operative Research Report, 56. 117 pp.
ICES. 1977b. Report of the ad hoc Meeting on the Provision of Advice on the Biological Basis for Fisheries Management. ICES Co-operative Research Report, 62. 16 pp.
ICES. 1978. Reports of the Liaison Committee of ICES, November 1976 to October 1977. ICES Co-operative Research Report, 73. 171 pp.
ICES. 1979. Reports of the ICES Advisory Committee on Fishery Management, 1978. ICES Co-operative Research Report, 85. 157 pp.
ICES. 1980. Reports of the ICES Advisory Committee on Fishery Management, 1979. ICES Co-operative Research Report, 93. 216 pp.
ICES. 1981. Reports of the ICES Advisory Committee on Fishery Management, 1980. ICES Co-operative Research Report, 102. 234 pp.
ICES. 1982. Reports of the ICES Advisory Committee on Fishery Management, 1981. ICES Co-operative Research Report, 114. 280 pp.
ICES. 1983. Reports of the ICES Advisory Committee on Fishery Management, 1982. ICES Co-operative Research Report, 119. 473 pp.
ICES. 1984. Reports of the ICES Advisory Committee on Fishery Management, 1983. ICES Co-operative Research Report, 128. 294 pp.
ICES. 1985. Reports of the ICES Advisory Committee on Fishery Management, 1984. ICES Co-operative Research Report, 131. 336 pp.
ICES. 1986. Reports of the ICES Advisory Committee on Fishery Management, 1984. ICES Co-operative Research Report, 137. 422 pp.
ICES. 1987. Reports of the ICES Advisory Committee on Fishery Management, 1986. ICES Co-operative Research Report, 146. 388 pp.
ICES. 1988. Reports of the ICES Advisory Committee on Fishery Management, 1987. ICES Co-operative Research Report, 153. 415 pp.
ICES. 1989. Reports of the ICES Advisory Committee on Fishery Management, 1988. ICES Co-operative Research Report, 161. 417 pp.
ICES. 1990. Reports of the ICES Advisory Committee on Fishery Management, 1989. ICES Co-operative Research Report, 168, Part 2. 91 pp.
ICES. 1991. Reports of the ICES Advisory Committee on Fishery Management, 1990. ICES Co-operative Research Report, 173, Part 2. 130 pp.
ICES. 1992. Reports of the ICES Advisory Committee on Fishery Management, 1991. ICES Co-operative Research Report, 179, Part 2. 72 pp.
ICES. 1993. Reports of the ICES Advisory Committee on Fishery Management, 1992. ICES Co-operative Research Report, 193, Part 2. 79 pp.
ICES. 1994. Report of the ICES Advisory Committee on Fishery Management, 1993. ICES Co-operative Research Report, 196, Part 2. 102 pp.
ICES. 1995. Report of the ICES Advisory Committee on Fishery Management, 1994. ICES Co-operative Research Report, 210, Part 2. 222 pp.
ICES. 1996. Report of the ICES Advisory Committee on Fishery Management, 1995. ICES Co-operative Research Report, 214, Part 2. 355 pp.
ICES. 1997. Report of the ICES Advisory Committee on Fishery Management, 1996. ICES Co-operative Research Report, 221, Part 2. 324 pp.
ICES. 2000. Report of the ICES Advisory Committee on Fishery Management, 1999. ICES Co-operative Research Report, 236, Part 1. 416 pp.
King, M. 1996. Fisheries biology, assessment and management. Fishing News Books, Oxford. 341 pp.
Kosior, M. 1977. Changes of the southern Baltic cod stock from 1945 to 1974. Studia i Materialy. Sea Fisheries Institute, Gdynia, Series B, 39. 77 pp. (in Polish).
Kosior, M., and Netzel, J. 1989. Eastern Baltic cod stocks and environmental conditions. Rapports et Procés-Verbaux des Réunions du Conseil International pour l'Exploration de la Mer, 190: 159–162.
Kuikka, S., Hildén, M., Gislason, H., Hansson, S., Sparholt, H., and Varis, O. 1999. Modeling environmentally driven uncertainties in Baltic cod (*Gadus morhua*) management by Bayesian influence diagrams. Canadian Journal of Fisheries and Aquatic Sciences, 56: 629–641.
Lablaika, I. A., Hoziosky, S. A., and Kalejs, M. 1989. Abundance dynamics of Eastern Baltic cod stocks and related factors. Rapports et Procés-Verbaux des Réunions du Conseil International pour l'Exploration de la Mer, 190: 163–165.
Plikshs, M., Kalejs, M., and Grauman, G. 1993. The influence of environmental conditions and spawning stock size on the year–class strength of the eastern Baltic cod. ICES CM 1993/J: 22.
Pope, J. G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. ICNAF Research Bulletin, 9: 65–74.
Pope, J. G., and Shepherd, J. G. 1982. A simple method for consistent interpretation of catch-at-age data. Journal du Conseil pour l'Exploration de la Mer, 40: 176–184.
Shepherd, J. G. 1992. Aide memoire on scientific advice on fisheries management. Laboratory Leaflet. MAFF Directorate of Fisheries Research, Lowestoft. 70: 18 pp.
Sissenwine, M. P., and Shepherd, J. G. 1987. An alternative perspective on recruitment overfishing and biological reference points. Canadian Journal of Fisheries and Aquatic Sciences, 44: 913–918.
Sparholt, H. 1995. Using MSVPA/MSFOR model to estimate the right-hand side of the Ricker curve for Baltic cod. ICES Journal of Marine Science, 52: 819–826.
Weber, W. 1989. A review of stock assessment of cod in the Baltic. Rapports et Procés-Verbaux des Réunions du Conseil International pour l'Exploration de la Mer, 190: 224–234.
Westin, L., and Nissling, A. 1991. Effects of salinity on spermatozoa motility, percentage of fertilized eggs and egg development of Baltic cod (*Gadus morhua*), and implications or cod stock fluctuations in the Baltic. Marine Biology, 108: 5–9.