Comparison of two periods of North Sea herring stock management: success, failure, and monetary value

E. John Simmonds

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At two points in the past (1970 and 1995), North Sea herring (*Clupea harengus*) abundance and catches have been in a similar situation: the stock had declined from an earlier high and reached a depleted state with a spawning-stock biomass of around 400 000 t, well below the agreed biomass limit reference point of 800 000 t. Catches were also similar at 600 000 t annually, and too high to be sustainable. A comparison of the scientific advice, the management actions, and their effects on population trends over the periods following these two critical years provides insight into important management issues. The benefits to the industry of the value of the cumulative catch resulting from successful management of this large stock have been proven to outweigh by far the costs of obtaining good management advice. The conclusion is that sound scientific information plays an important role when difficult management issues have to be confronted. However, there are other critical issues, such as the stakeholders' wish to preserve the stock at all costs and a management organization that has authority to take decisions.

Keywords: cost-benefit analysis, North Sea herring, stock management.

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E. J. Simmonds: FRS Marine Laboratory, PO Box 101, Victoria Road, Aberdeen, Scotland AB11 9DB, UK. tel: +44 1224 295366; fax: +44 1224 295511; e-mail: j.simmonds@marlab.ac.uk.

Introduction

For hundreds of years, herring (*Clupea harengus*) have been an important source of food and economic wealth in Europe, with the Baltic and North Sea resources contributing to the development of the Hanseatic League during the 14th–16th centuries, and conflicting interests in the North Sea herring fishery being one of the causes of the war between UK and the Netherlands in the 16th century (Tracy, 1993). Historical detail for the period 1600–1860 is provided by Poulsen (2006), who concludes that, although the fisheries met periods of hardship, they have had a negligible impact on the stock. By the 1950s, however, the North Sea herring fisheries had expanded to a level at which they were bound to have a major impact on the stock. Between 1960 and 2003, the stock experienced two periods of severe exploitation. After reviewing management actions from 1964 to 1978, Saville and Bailey (1980) concluded that the fisheries had been the major cause of extreme stock depletion. Bjoerndal and Conrad (1987) went even further and suggested that the stock would have become extinct if the fishery had not been closed in 1978. The second period of major decline was in the mid-1990s, and again high fishing mortality (F) was the major cause. During both periods, the stock declined to well below the minimum spawning-stock biomass (SSB) required to ensure average recruitment (Figure 1). This reference level was described in the 1980s and 1990s as the minimum biologically acceptable level (Mbal: set at approximately one-third of the unexploited biomass), and more recently as $B_{\rm lim}$ (the SSB level below which empirical evidence indicates that recruitment will be reduced).

During the first period of excess fishing, no management action and a plummeting stock resulted in 1978 in total collapse and a closure of the entire fishery, followed by a slow recovery. The second resulted in an EU/Norway agreement on management actions introduced in 1997, and by 2003 the stock had recovered without requiring temporal closures. Using information on estimated catches and recommended and agreed total allowable catches (TACs) from assessment Working Group reports, and drawing on the ICES Advice and on the implementation of management decisions, I contrast these two periods and compare the cumulative monetary value of the catches and the costs of science to demonstrate the benefits of improved management. I conclude with a discussion of those aspects that were critical for management to succeed in pursuing its objectives.

General description

In 1970, the stock and the catch were similar to those observed in 1995 that triggered the major management change in 1996 (Figure 1; ICES, 2004). Figure 2 contrasts the stock development in terms of recruitment (R), SSB, catch, and F through both 8-y periods leading up to these years and the 8-y periods thereafter. During the pre-1970 and pre-1995 periods, mean R differed by just 1%. This similarity provides no evidence of a major change in recruitment patterns, although annual values vary because of environmental effects. These environmental effects are difficult to disentangle. Nash and Dickey-Collas (2005) found no clear relationship between survival of juvenile herring and the abundance of *Calanus finmarchicus* (an important food source), but they did find a negative relationship between year-class strength and bottom temperature (lower temperatures being associated with higher abundance of *Calanus*). Their analysis shows that year-class strength is largely determined between the larval and the

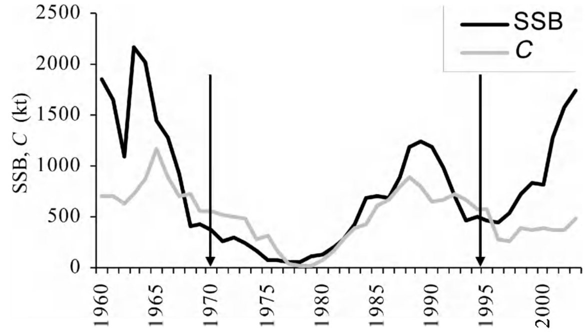

Figure 1. SSB and estimated catch (C) according to the 2004 assessment of North Sea herring, 1960–2003 (ICES, 2004). The arrows identify 1970 and 1995 as the critical years for management action, when stock conditions were similar.

juvenile stages. Although the cause is uncertain, the reduction of average R at low SSB is well established.

The two periods exhibit similarly high rates of exploitation of catch, increases in F to >0.6, and a reduction in SSB to well below 800 000 t (Mbal/B_{lim}). Highlights of the information from assessments and scientific advice and associated management action by year are contrasted for the two periods in Table 1, which also lists the sources.

The periods running up to 1970 and 1995 (which, in hindsight, appear to have been critical for management action) show considerable similarity, but some features differ. The 1960s were characterized by 4 y of high exploitation, followed by 5 y of increasing concern as the geographic centre of the fishery moved north. The scientific advice was disputed, and several requests and proposals were made for better science, which served only to delay decision-making. Management considerations were primarily related to area or seasonal closures, without any insight into the utility of such measures. In the end, no substantive management action was taken to reduce the fishery, despite sufficient evidence to indicate that F was too high for yields to be sustainable (total mortality being close to $Z = 1$), and $F = 0.4$ being suggested as a more rational target. Similarly in the late 1980s and early 1990s, scientists reported a moderate to large stock size, and fishing exceeded agreed TACs by estimated factors of 1.35. Some uncertainty in the assessment was noted, and advice was given that a target F of 0.3 would be sustainable in the long term. However, the recommended TACs did not particularly reflect the long-term advice. Even when the decline in the stock had become clear by 1994, the tone and the content of the advice remained the same: no alarm bell rang.

For the period 1987–2003, an indication of the degree of correspondence between the recommended and agreed TACs and the estimated catch can be derived from Figure 3. The recommended TAC has generally been accepted by the Council of Ministers after consultation with Norway. The catches have always been larger than the agreed TAC by 20% on average. Excess catches were mainly estimated from evidence of area misreporting, catches from the North Sea being reported from almost all surrounding areas. However, even the data currently available may be incomplete, and additional non-reported catches may have been taken.

Equivalent detail on the relationship between advice and estimated catch is absent for the period 1962–1977, because, at that time, the fishery remained effectively unregulated (no catch limits were set, and effort regulations were restricted to small seasonal closures, which cannot be translated into explicit estimates of catch reduction).

Seen in retrospect, the herring stock had reached a critical stage in both 1970 and 1995: SSB had declined to a level at which there was a high probability of reduced recruitment (Figure 2). However, in 1970 there was no firm evidence yet of a stock-recruitment relationship, and the advice contained warnings rather than pointers to imminent danger. Because of constitutional constraints, the responsible management agency was not in a position to set catch limits, fishing continued, and the stock collapsed. In contrast, and following a much more explicit

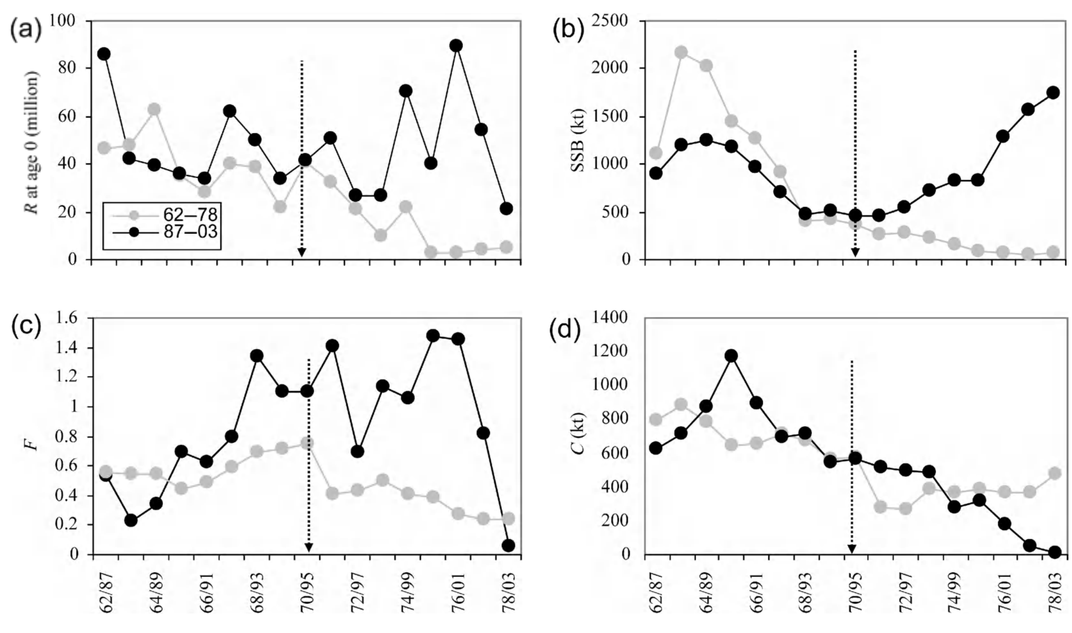

Figure 2. Comparison of two periods of 17 y (1962–1978 and 1987–2003) of population parameters according to the 2004 assessment of North Sea herring (ICES, 2004): (a) recruitment (R); (b) SSB; (c) fishing mortality rate (F); and (d) estimated catch (C).

Table 1. Comparison of scientific information and advice for North Sea herring in the periods 1962–1978 (left column) and 1987–2003 (right column) (information from reports listed below the Table).

1962 *C* and *B* increasing	**1987** *B* increasing. TAC and *C* similar at 610 and 625 kt, respectively
1963 *C* increasing, *B* at its peak	**1988** *B* increasing. TAC and *C* diverge at 515 and 698 kt, respectively ($C = 1.35$TAC)
1964 *C* increasing, *B* declining	**1989** *B* at peak. Advice to aim for target *B* of 1.5–2.0 million tonnes. Concern at extent of fishery on juveniles TAC and *C* divergent at 515 and 700 kt, respectively ($C = 1.35$TAC)
1965 *C* increasing. Information on *C* of juveniles suggests no benefit in reducing them. Concerns expressed about declining *C* in southern North Sea; overall reduction in fishing effort would enhance future *C* Intention to set up joint Working Group to provide advice	**1990** *B* at peak. Advice for target *B* maintained and concerns about fishery on juveniles maintained. Concerns expressed that the fishery is not adhering to TAC TAC and *C* divergent at 403 and 553 kt, respectively ($C = 1.35$TAC)
1966 Working Group meets at ICES: fishery in the south collapsing, in the north expanding and developing faster than biological data could be collected. Further investigations needed before advice could be given on measures to protect southern North Sea. Usefulness of one-month fishing bans should be investigated *C*: 896 kt	**1991** *B* thought to be in or just below target range of 1.5–2.0 million tonnes Concerns about fishery on juveniles maintained TAC and *C* divergent at 423 and 566 kt, respectively ($C = 1.33$TAC)
1967 Fishery in the south now failing. Advice on one-month closures rejected by some countries. Economic considerations should be given more weight. Equality of sacrifices required before measures could be accepted Advice on proposed closures disputed. One area closed for two months providing partial (~25%) spawning ground protection for Downs herring. More research plans proposed *C*: 696 kt	**1992** *B* fluctuating but thought to be well above Mbal. Concerns about fishery on juveniles maintained. Major discussion on long-term management objectives TAC_{rec} and *C* divergent at 406 and 549 kt, respectively ($C = 1.34$TAC)
1968 Fisheries in the south much reduced and no signs of recovery in this area. Central North Sea fishery failing. Northern North Sea now rapidly declining after substantial growth from 1963 to 1966 Major Bløden tagging experiment proposed, but awaiting international financial backing to be started Expert Working Group set up at ICES to meet in January 1969 *C*: 718 kt	**1993** *B* fluctuating, but thought to be well above Mbal recommended $F = 0.3$. Considerable uncertainty as three main tuning indices give rather different results (0.7–4.3 million tonnes) TAC and estimated *C* divergent at 340 and 524 kt, respectively ($C = 1.53$TAC)
1969 More experiments proposed, including herring larvae and young herring surveys. Liaison Committee unable to provide additional advice, but stressing inadequacy of *C* statistics; rather tentative conclusions about average sustainable yield (not exceeding 850 million tonnes). To restore both fisheries and *B* to more satisfactory and less dangerous state, *F* to be reduced well below level experienced since 1964. No advice on fisheries on juveniles pending Bløden tagging experiments (not yet under way—results not expected before 1972) First mention by Liaison Committee of possible stock-recruitment relationship *C*: 547 kt (mostly from the north)	**1994** *B* declining below Mbal in 1993, but changes in mean weight and maturity give estimate above Mbal. No strong concerns expressed that *B* had apparently declined to 50% of 1990 level, only that fishery on juveniles was removing potential yield from fishery on adults No change in advice: recommended $F = 0.3$ TAC and *C* divergent at 346 and 468 kt, respectively ($C = 1.35$TAC)
1970 Total mortality estimated at $Z = 1.0$; available information does not change the view that *F* needs to be reduced; *C* limit of 500 kt suggested Working Group expressed fears for unfavourable consequences of current exploitation level. Stock-dependent recruitment considered possible SG recommends implementation of TACs. However, constitutional constraints within NEAFC prevent early imposition of TACs. Delegates concerned about equitability in setting TACs. Complaints against any measure that would have a major impact. Two closures (May and 20 August–30 September) agreed for 1971 *C*: 563 kt	**1995** Advice: *B* declining below Mbal; significant reduction in exploitation required to rebuild SSB: F_{1996} should be 50% of F_{1994}. Long-term gains at lower *F* such as $F = 0.3$ No change in basis of TAC Working Group expressed range of concerns regarding successive downward revisions of stock and major area misreporting, and unexplained reductions in *F* leading to worries of overestimating *B* TAC and *C* divergent at 429 and 534 kt, respectively ($C = 1.35$TAC)
1971 Bløden tagging experiments under way (55 000 herring tagged). Preparations for analysis by the end of the year	**1996** Advice: 50% reduction in *F* from 1994 level Initial TAC of 235 kt, revised to 159 kt during the year (based on new

Continued

Table 1. *Continued*

Continued decline in *C* matter for concern. Agreement that TACs would provide a solution, but no agreement reached C: 520 kt	advice) together with reduction in bycatch limits in fisheries for juveniles Actual *C* reduced to 275 kt *F* reduced from 0.74 to 0.35 based on 2004 assessment, above the aim of $F = 0.2$
1972 Further closed areas agreed only for 1972, with increased flexibility and derogations for ten countries. Proposed closures for 1973 disputed. Concerns that agreed measures would only meet half the reductions required Proposals to implement TACs by 1974, but no agreement reached C: 498 kt	**1997** Advice for reduced *C* maintained; implementation incomplete *F* perceived to be reduced to 0.29, but now estimated to have been constant around 0.45, far above the 0.2 requested SSB rises slightly
1973 Advice: MSY could be achieved at $F = 0.4$ if fisheries on juveniles were closed. Current fishery mostly on juveniles; warning that a succession of poor year classes would lead to collapse. Proposal put forward to close North Sea (with national exemptions to effectively set a TAC). Area closures continued, more draconian regulations voted down by almost all countries except those proposing the regulation Proposal for quota circulated, but not supported by enough countries for implementation (although accepted by a majority) C: 484 kt	**1998** Advice for reduced *C* relaxed slightly; implementation incomplete *F* constant around 0.45, but above 0.2 as requested SSB continues to rise slowly At the time, Working Group imagines a lower *F* and higher SSB than is actually the case
1974 NEAFC proposal for TAC_{1975} matched *C*-levels in earlier years (494 kt); agreement finally reached on the basis that shares would not be used for future allocations. Norwegian objections (because of belief it would have no regulatory effect) withdrawn in the end to allow an agreement to be reached C: 275 kt	**1999** Advice for reduced *C* maintained; TAC held constant, implementation incomplete *F* constant around 0.45, but above 0.2 as requested SSB rises above B_{lim} of 800 kt At the time, Working Group imagines *F* was lower and of SSB higher than is actually the case
1975 NEAFC President opened discussions by stressing this was perhaps NEAFC's last chance to prevent a total collapse. TAC set for six months for the first half of 1976 at 87 kt Current *B* estimated at 10% of *B* between 1953 and 1960 that had provided *C* of 700 kt C: 313 kt	**2000** Advice for reduced *C* maintained; TAC held constant; implementation incomplete *F* slightly reduced to 0.40, but above the 0.2 required Large 1998 year class recruiting to fishery on juveniles
1976 For the first time, restrictive TAC in force; *C* in the first nine months match 75% of TAC. Discussions focused on zero TAC for directed herring fisheries, as recommended C: 175 kt	**2001** Advice for reduced *C* maintained; TAC is held constant; implementation incomplete *F* reduced to 0.28, but above the 0.2 requested 1998 year class contributes more to *C*
1977 Fishery closed, subject to limited bycatch allowances in other fisheries C: 46 kt	**2002** SSB above B_{pa} and stock declared inside safe biological limits. Advice for reduced *C* maintained; TAC held constant, implementation incomplete $F = 0.25$, above the 0.2 requested 1998 and 2000 year classes contribute even more to *C*
1978 Fishery closed, subject to limited bycatch allowances in other fisheries. C: 11 kt (The fishery remained closed until 1983)	**2003** Stock inside safe biological limits. Advice for reduced *C* relaxed; TAC allowed to rise from 265 to 400 kt *F* reaches 0.25, as requested SSB continues to rise Projections suggest sustainable medium-term *C* of 400 kt

Sources: Report of the Herring Assessment Group on the North Sea Herring and its Exploitation: ICES Document CM 1964/Herring Committee No. 3.
Report of the Assessment Group on Herring and Herring Fisheries in the North Eastern Atlantic. ICES Document CM 1965/Herring Committee No. 1.
Reports of the North Sea Herring Assessment Working Group: ICES Document CM 1969/H: 4; ICES Document CM 1970/H: 6; ICES Document CM 1971/H: 28; ICES Document CM 1972/H: 13; ICES Document CM 1973/H: 27; ICES Document CM 1974/H: 4; ICES Document CM 1975/H: 2; ICES Document CM 1976/H: 2; ICES Document CM 1977/H: 3; ICES Dcoument CM 1978/H: 67.
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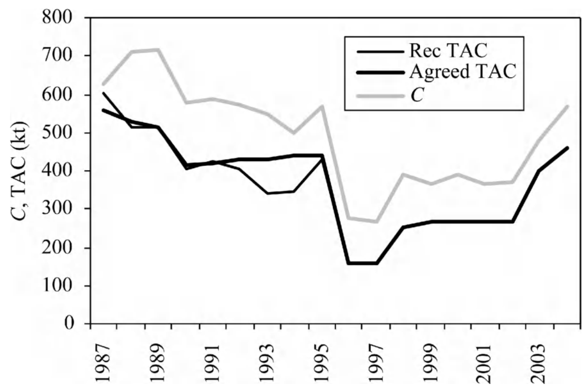

Figure 3. Comparison of recommended catch option (Rec TAC), agreed TAC, and estimated catch (C) for North Sea herring, 1987–2003.

statement from ICES about the seriousness of the situation, action was taken to reduce catches in 1996, and the TAC was halved in-year. In 1997, a harvest control rule (HCR) was agreed (Patterson *et al.*, 1997). This approach had been suggested earlier by Kunzlik and Bailey (1986), but its adoption by managers was a *novum* for European fisheries at the time (Buhl-Mortensen and Toresen, 2001). Its implementation led first to a reduction in *F*, then the stock started to rebuild while recruitment remained largely unaffected.

During the 1970s, the Northeast Atlantic Fisheries Commission (NEAFC) had attempted to reach agreement on a TAC, but was unable to do so because initially it had no constitutional remit to implement such a measure. Earlier attempts to adopt this management tool did not receive sufficient support from national delegates. Only when the stock had already dropped too low was the constitution finally amended, and a formal TAC could be imposed, provided enough delegates agreed. In practice, however, a TAC would only be agreed if it was unrestrictive. The NEAFC reports show the President's desperation as he tried to persuade delegates of the need for action (Table 1). In response, some delegates cited the short-term economic losses of reducing catches as the main reason that restrictions were unacceptable, without considering the longer term biological and economic consequences, and this tendency exists even today (Christensen and Lassen, 2004). When reviewing the 1970s, it is clear that the flexibility of management to consider economic and social trade-offs diminished to zero as the stock declined and the fishery had to be closed in 1978, creating a medium-term loss that outweighed any of the short-term losses that would have been suffered earlier if appropriate action had been taken. In contrast, medium-term economic benefit was obtained from restrictions in the short term in the late 1990s, when action was indeed taken.

The scientific advice in the late 1990s was not perfect. The true *F* was underestimated and the assessment failed to track accurately the changes in stock and fishery following the change in management. Although *F* did not reach its recommended level until 2002, the substantial reduction (Figure 2) was enough to halt the decline in SSB and to keep *R* around the average level, so allowing the fishery to continue. The scientific basis of the advice had improved considerably compared with the 1970s, when the absence of scientific information on the effect of the industrial fishery was used as an excuse to delay action and to await the results of proposed tagging studies, although the estimates of total mortality indicated that exploitation was far too high. Improved science coupled with

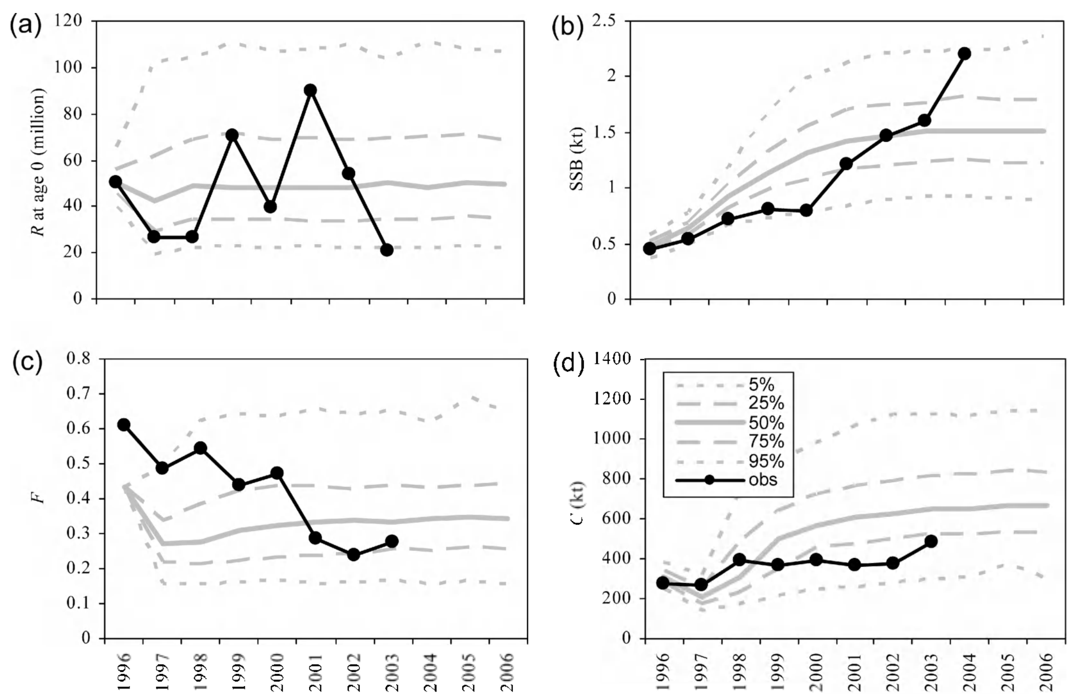

Figure 4. Comparison of stochastic medium-term predictions using data available in 1996 (supplemented with 10% assessment bias and 20% implementation bias), and the actual trajectory of population parameters of North Sea herring, 1996–2004, according to the 2004 assessment (ICES, 2004): (a) recruitment (*R*); (b) SSB; (c) fishing mortality rate (*F*); and (d) catch (*C*).

more effective management helped to deliver a recovered stock in 2003, in sharp contrast to the outcome of a depleted stock and closure of the fishery in 1978 (Table 1).

Comparison of stock projection in 1996 and actual development

An important question is whether the scientific advice in the recent period is accurate enough to make reliable medium-term predictions of the state of the stock. Figure 4 compares a medium-term stochastic prediction using the program STPR3 (Skagen, 2004), based on the 1996 assessment and the agreed HCR with the actual trajectories of R, catch, SSB, and F. The trajectories are those estimated from the 2004 assessment (assuming +10% assessment error in the final year tapering to 0% back to 1996), and they may be subject to further revision. All input data were those available in 1996, but implementation bias in the fishery (20%) and assessment bias (10%) have been estimated from the subsequent period. Although the implementation error was approximately the same for the period up to 1995, the assessment bias was unknown then because the method was relatively new and untested. From 1996, observed R was relatively low during the first 2 y, but overall, the eight R-values fall within the projected range and the mean value corresponds quite closely to the historical average (4% difference). F remained higher than the agreed target during the early years, but declined from 1998 to 2002, when catch was held constant while SSB increased. Part of the higher F resulted from underestimates in the assessment (overestimates of SSB), which reduced the effectiveness of the HCR applied in controlling F. This bias was corrected in subsequent assessments (ICES, 2004). SSB followed a trajectory well away from the median line, in part, because of the same assessment bias, but mostly because recruitment was initially below average. Despite these deviations, the reconstruction shows that the predicted effects of the agreed policy have corresponded quite well to the recovery realized.

Costs and benefits of good management

The total catches from 1970 to 1978 inclusive (2.98 million tonnes) and from 1996 to 2003 inclusive (4.4 million tonnes) show that the stock had already yielded some 1.4 million tonnes more during the latter (and 1-y shorter) period. The state of the stock is now relatively healthy, implying that yields are likely to remain moderate for at least the next few years. The current gains in yield amount to about €470 million over the 9-y period. This value should be compared with some €3.5 million spent annually on science (including research vessel surveys, and market and discard sampling, but excluding the capital costs of vessels; Anon., 2007). Therefore, the scientific advisory costs are at about 8% of the accrued additional benefit of good management and at 2.5% of the total value of landings at first sale. If the combination of science and management can maintain the stock in such a healthy state, these gains in yield should be sustainable as long as recruitment remains at an average level.

Conclusions

Scientific knowledge of the North Sea herring stock has been sufficient to provide reasonable management advice from the mid-1990s to the present. Management through TACs has always had substantial implementation error, but not to the extent that it impeded any recovery of the stock. In retrospect, the HCR has performed within the expected range, indicating that the assessment and the advice was consistent. The earlier failure to manage the stock resulted in a considerable reduction in yield and revenue to the fishery. At 2.5% of the landed value, the cost of the science and scientific advice has been only a small part of the added value through better management. The main message to fisheries management is that successful recovery in 6 y came from: (i) sufficiently believable science; (ii) a management system capable of taking consistent decisions; (iii) willingness of management and industry to take action, possibly aided by collective memory of the earlier collapse; and (iv) sustained reasonable recruitment. The key conclusion is that paying for sufficiently good science is a prerequisite to taking effective management decisions. Conversely, poor science allows for prevarication that can lead to bad management.

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