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North Sea cod recovery?

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Recovery of depleted marine, demersal, commercial fish stocks has proved elusive worldwide. As yet, just a few shared or highly migratory stocks have been restored. Here we review the current status of the depleted North Sea cod (*Gadus morhua*), the scientific advice to managers, and the recovery measures in place. Monitoring the progress of North Sea cod recovery is now hampered by considerable uncertainties in stock assessments associated with low stock size, variable survey indices, and inaccurate catch data. In addition, questions arise as to whether recovery targets are achievable in a changing natural environment. We show that current targets are achievable with fishing mortality rates that are compatible with international agreements even if recruitment levels remain at the current low levels. Furthermore, recent collations of data on international fishing effort have allowed estimation of the cuts in fishing mortality achieved by restrictions on North Sea effort. By the beginning of 2005, these restrictions are estimated to have reduced fishing mortality rates by about 37%. This is insufficient to ensure recovery of North Sea cod within the next decade.

Keywords: fisheries management, fishing effort, recovery plans.

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State of North Sea cod

Assessments of cod (*Gadus morhua*) in the North Sea, Skagerrak, and eastern English Channel, referred to here as North Sea cod, are undertaken annually by the International Council for the Exploration of the Sea (ICES). Trends in spawning-stock biomass (SSB), the mature component of the stock, show a decline from a peak of 250 000 t in the early 1970s to current levels of about 40 000 t (ICES, 2005; Figure 1). ICES' limit (B_{lim}) and precautionary (B_{pa}) reference levels are also shown. The stock is well below the limit level of 70 000 t, below which ICES considers productivity of the stock to be impaired. Worldwide, recovery of demersal, wide-ranging stocks has not been very successful, and most recoveries occurred where the stock was at the centre of the geographical range of the species (Caddy and Agnew, 2004); North Sea cod is near the southern limit of its eastern Atlantic temperature range (Drinkwater, 2005).

There are now significant uncertainties with the assessment of North Sea cod. These uncertainties appear particularly in estimates of the most recent annual rate of fishing mortality (F). They are less significant for estimated trends of SSB. The current assessment relies upon three sets of research surveys to calibrate the assessment: a spring international bottom trawl survey (IBTS), plus autumn Scottish and English surveys. Survey catch rates are turned into population numbers, calibrated from past years when the stock size was known by virtual population analysis (VPA). Total Allowable Catches (TACs) have been restrictive for several years, and there has been a potentially large, but unknown, level of under-reporting of landings and discards. The assessments now additionally estimate this missing catch component (ICES, 2004, 2005). Typically, values of F have been about 1.0 over the past two decades, so about 60% of the population is fished each year. The most recent results gave annual estimates of F in 2004 of between 0.7 and 1.5 (ICES, 2005, 2006). The larger value represents a significant increase and the former a modest decrease over recent levels. It will be shown later that recent increases in F are unlikely, owing to major reductions in effort, but because of the uncertainties, ICES has not given advice on TAC levels consistent with management targets.

There are some important biological characteristics and recent changes in demography that are important for management. The "North Sea" cod is really a metapopulation of sub-populations with differential rates of mixing among them (Blanchard *et al.*, 2005a; STECF, 2005a).

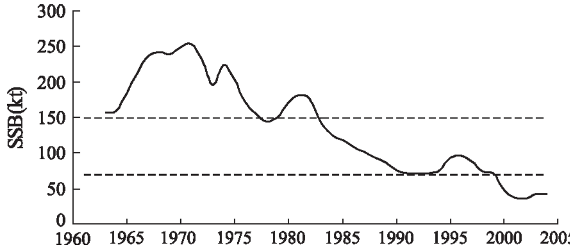

Figure 1. The spawning-stock size (SSB, '000 t) of North Sea cod. ICES limit (70 000 t) and precautionary (150 000 t) stock reference levels ($B_{\rm lim}$ and $B_{\rm pa}$) are also included.

The sub-population in the Southern Bight is relatively discrete from that in the northern North Sea, which lives in deeper water north of the Flamborough front. There is a limited influx of young cod from the eastern English Channel into the southern North Sea. Cod in the German Bight show some limited mixing with cod in the Southern Bight. There are also coastal populations off Flamborough and in the Moray Firth.

The distribution of cod within the North Sea complex has changed. The centre of distribution has moved north (Hedger *et al.*, 2004; Perry *et al.*, 2005). This has been attributed to effects of seawater warming on the North Sea cod as an entity. However, the changes may also be associated with the different sub-population responses to both warming and differing spatial fishing pressures. Although cod remain widely dispersed, survey data have also revealed a contraction of distribution within the range (Figure 2). The great majority of young cod are now found in just 40–50% of the North Sea, as sampled by research vessels, compared with 90% when cod were most abundant (Blanchard *et al.*, 2005b).

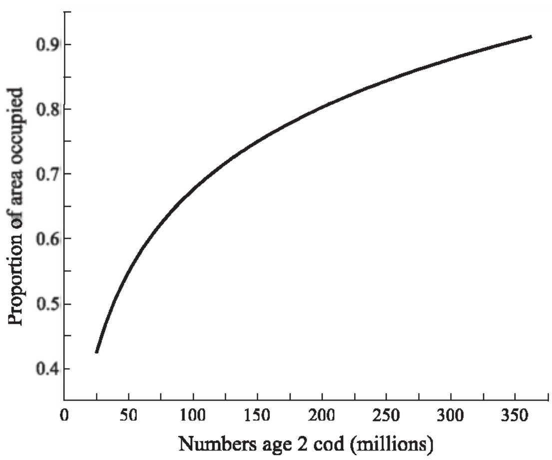

Figure 2. Proportion of the area occupied by 95% of age-2 North Sea cod in research surveys, 1975–2002, plotted against the abundance of age-2 cod in the survey year (after Blanchard *et al.*, 2005b).

There appears to have been a particular reduction in the spawning intensity in the Southern Bight, but other spawning locations have remained unchanged (Fox *et al.*, 2005).

Recruitment of young cod depends upon an adequate parent stock and the correct environmental conditions for larvae and young fish to survive. The period 1965–1985 was one of exceptionally good recruitment, termed the "gadoid outburst". It was associated with cooler water, and an abundance of *Calanus finmarchicus* as food. Since then, there has been warming of the North Sea and changes in the type, abundance, and timing of plankton (Beaugrand *et al.*, 2003).

Figure 3 is a plot of anomalies, from the means, of sea surface temperature (Smith and Reynolds, 2004) and cod recruitment (ICES, 2003). The earlier, cooler period of more favourable recruitment is clear, as is the change to warmer water and poorer recruitment. It is notable that the better 1996 year class was associated with a cooler year. However, parental stock size is very low, and it might be expected that few adults will generate few offspring. On an SSB-per-recruit basis, fishing at $F = 1.0\ {\rm y}^{-1}$ would reduce the SSB to 2% of a theoretical virgin stock. Using stock-recruit relationships, it has been shown that recent, historically high levels of fishing mortality are unsustainable (Cook *et al.*, 1997). There have been various statistical exercises relating recruit abundance to temperature and/or stock size (Planque and Frédou, 1999; O'Brien *et al.*,

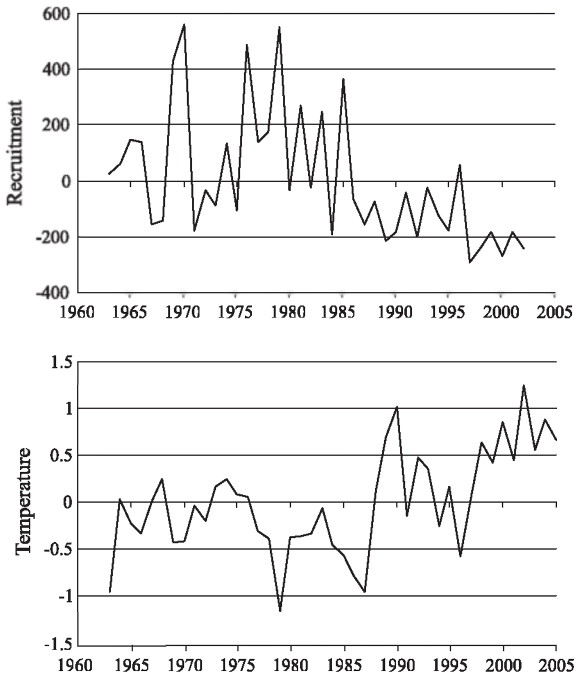

Figure 3. Post-1963 North Sea sea surface temperature anomalies in °C (bottom panel) and cod recruitment anomalies in millions (top panel) showing the earlier colder period of larger recruitment and the later warmer period of smaller recruitment.

2000; Kell *et al.*, 2005). They all suggest that for North Sea cod any correlation is negative: higher temperatures – lower recruitments. The precise form of any recruit-stock-temperature relationship is highly model-dependent and, for example, statistical modelling has considered continuous functional changes rather than stepped regimes. Nevertheless, it appears that two strong pressures are acting together to depress recruitment (O'Brien *et al.*, 2000). Separating these two effects is scientifically challenging, with no definitive solution at this time. Of concern is the run of poor recruitment post-1997.

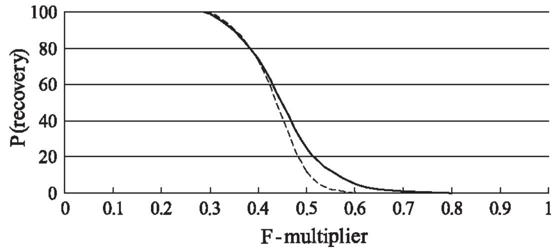

Figure 4. Percentage probability of cod recovery, within a decade, against cuts in *status quo* fishing mortality (modelled at $F_{sq} = 1.1$), based on two different stock-recruitment scenarios. There is a narrow window of F between recovery and eventual collapse.

The scientific advice

Bannister (2004) reviewed the recent history of ICES advice. From 1990 ICES advised cuts in fishing mortality on cod. In 1992, ICES advised that if it were not for the fact that cod were caught as part of a mixed-species fishery, it would have advised a zero TAC. Because of the nature of the mixed roundfish fisheries, ICES has consistently advised that TACs alone could not protect the cod stock, and that cuts in direct effort were needed. This is because vessels fishing for other species would still catch and discard cod even if there was a low TAC for cod. The good 1996 year class gave some respite, but it was soon fished down.

Subsequently, ICES introduced more formal processes for providing advice within a Precautionary Approach framework, which was required under, *inter alia*, the UN Fish Stocks Agreement (UN, 1995), and by ICES' own client for advice, the European Commission. In late 2002, ICES advised closure of the fisheries. The rationale was that the stock was so far below B_{lim} that only zero fishing mortality could restore the stocks to above such a safe level in the fastest possible time. ICES also reviewed the Recovery Plans for cod (EC, 2004), described below, and implicitly regarded them as not "precautionary", because they would not restore the stock to above B_{lim} in the fastest possible time. ICES continued to advise no fishing (ICES, 2005).

In 2002, EU and Norwegian scientists met to model cod-recovery scenarios (STECF, 2002). Simulations showed that cutting F to its precautionary reference level (F_{pa}) of 0.65 y^{-1} gave low probability of recovery to B_{pa} within a decade, and a reduction to 80% of F_{pa} gave poor probability of such a recovery. However, reduction to 60% of F_{pa} gave a high probability of recovery within ten years, which at the time was thought to be equivalent to cutting F by 53%. Recruitment was determined by stock-recruitment relationships. The results of the projections were sensitive to starting conditions, and the work was repeated in 2003 (O'Brien, 2003). It was concluded that cuts in fishing mortality of some 60–70% were needed to ensure recovery within a decade (Figure 4). Figure 4 also shows the sharp divide between potential recovery and no recovery.

An EU–Norway expert group reviewed a range of technical measures including mesh size and closed areas. A 30 mm increase in minimum mesh size would be equivalent to a 30% reduction in fishing mortality (ICES, 2001). However, any such increase would be implemented in the 100/120 mm fleets of the northern North Sea, and other fleets also catch cod. The total effect of increasing the mesh size in only these fleets would then be proportionally reduced. Unfortunately, cod are large fish that mature late, so giving cod all the protection it needs would require mesh sizes of about 150 mm, and such mesh sizes would retain few, if any, haddock (*Melanogrammus aeglifinus*) or whiting (*Merlangius merlangus*). There has been further work on more selective gear, but with little uptake by the North Sea fisheries (Revill *et al.*, in press).

Extensive studies have been undertaken on the use of closed areas to conserve cod. Although cod are now more aggregated (Blanchard *et al.*, 2005b), their generally widespread nature, at the scale of ICES rectangles, and lack of high density concentrations mean that movement of effort from one closed area to another open one would save few cod, if any. The work has been constrained by poor availability of spatial data on catch rate, but it is possible that closed areas could have a role to play if better data were to become available (STECF, 2003; Darby *et al.*, 2006). Even so, for cod, such areas are likely to be large.

From the above, the science, subject to its inherent assumptions, shows that cod recovery needs cuts of at least 60% in the total rate of fishing mortality, from the high levels experienced in 2000 of $F = 1.0–1.2\ y^{-1}$. Technical measures have a role to play, but their potential in reducing F is modest. The key to recovery over a period of about a decade, short of complete closure of the North Sea, must be restrictive effort measures.

Management measures

North Sea cod are managed under joint agreements, and management plans, between the EU Council of Ministers and Norway. The agreement of December 2005 (EC, 2005) seeks to rebuild the cod to above B_{pa}, and when achieved to set a management target of a fishing mortality rate of $F = 0.4\ y^{-1}$.

Since 2000 the EU has set highly restrictive cod TACs. For 2001 only, it implemented a 10-week closed area for part of the North Sea (EC, 2001); this was predictably ineffective. However, following the ICES advice for a cessation of all directed fishing on cod, the Council of Ministers agreed further measures to achieve cod recovery, but which also maintained access to fish stocks that were healthy, such as the abundant North Sea haddock. For 2003, a cod TAC was agreed that was consistent with a 65% reduction in fishing mortality. This was underpinned by effort restrictions in the EU zone of the North Sea (EC, 2002).

The Recovery Plan was finalized in 2004 for cod stocks in the North Sea, Kattegat, west of Scotland, and the Irish Sea (EC, 2004). For North Sea cod, it aimed to move the stock to above B_{pa} by setting TACs consistent with 30% annual increases in SSB. Importantly, it allowed measures that restricted fishing effort.

For 2003, vessels using gear with minimum mesh size >100 mm were restricted to 9 days at sea per month, netters to 16 days, beam trawlers to 15 days, and the 70–99 mm sector to 25 days. If it is taken that 25 days represents a month's full activity, then the large-mesh sector was restricted in line with the reduced TAC. The >100 mm sector targets primarily roundfish. However, the implication of the measure was that they were previously fishing for 300 days per year, which many were not, and that the other fleet sectors were of little concern, which they were and are. We examine the actual effect of these restrictions below.

Mesh sizes were also increased. In 2002, minimum codend mesh size in the whitefish trawl fleet was increased from 100 mm to 120 mm, with an interim measure in 2003. This should have almost halved the mortality on age-1 cod by the sector. However, mesh sizes in the other trawl fleets were unaffected, and at present, we see no dramatic improvement in selectivity of the large-mesh sector (ICES, 2006).

Progress to recovery?

Here we consider the interaction between the Recovery Plans and the stock assessments, the validity of the management targets, and the effects of the cuts in effort to date.

It is proving increasingly difficult to monitor the recovery, if any, of cod. No quantitative assessment for North Sea cod was agreed by ICES in 2005, because of the uncertainty in estimated large "missing" catches included in the assessments which were impossible to verify, along with the different fishing mortality rates found by calibrating to different surveys. Survey vessel data alone indicated trends in stock biomass profiles, but the data are extremely variable. Nevertheless, all the information suggests that North Sea cod are at very low levels, with few surviving to maturity.

The estimated increases in total fishing mortality, generated using the English and Scottish surveys in 2005, appear unreasonable against the cuts in effort described below. The discrepancy suggests that the relationship between the stock index and stock size is uncertain, and perhaps has changed over the years as cod distribution has changed (Blanchard *et al.*, 2005b). With relatively few older cod caught on the surveys, the models may be sensitive to the assumed error distribution. Given the current difficulties with the assessment, plans that rely on precise measures of cod abundance may be impractical.

The validity of the current targets themselves has been raised. Has environmental change reduced recruitment to levels so low that the present targets, set against an assumption of no regime shift, are untenable? ICES advice emphasizes overfishing as a cause of reduced productivity, but admits that the environment may play some part. It is possible to calculate whether the biomass targets are achievable under the assumption that average recruitment is strongly influenced by the environment.

Figure 5 plots modelled equilibrium SSB against absolute values of instantaneous fishing mortality rate (F), for three levels of cod recruitment: the average since 1963, the average since 1988, and the average over the low recruitment since 1997. It can be seen that the current recovery target of 150 000 t is achievable for all three scenarios, but that each requires different levels of equilibrium fishing mortality rate, ranging from 0.4 to 0.7 y^{-1}. Therefore, even if the most recent low levels of recruitment continue, the targets are achievable over some appropriate time scale. We need not consider abandoning the cod – in some quarters termed the "sod-the-cod" scenario (Hansard, 2005).

How far have we progressed cod recovery? The ICES assessment indicates that it is not far, but the future will be determined by both annual recruitment levels and fishing mortality. The latter is determined by the fishing pressure or effort on cod. It is possible to form a view of the effective reduction in cod mortality from effort measures. After some difficulty, the EU's Scientific, Technical, and Economic Committee for Fisheries (STECF) collated the international fishing effort over the period 2000–2004, by gear sector

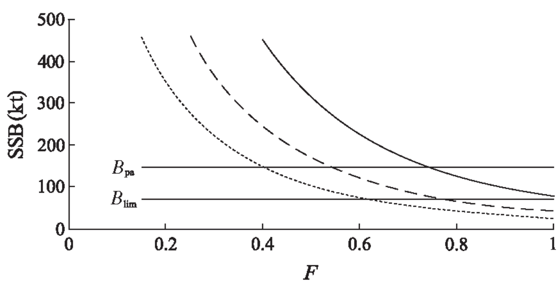

Figure 5. Equilibrium spawning-stock biomass ('000 t) plotted against absolute values of instantaneous fishing mortality rate (F; y^{-1}), for three levels of cod recruitment: average since 1963 (350 million age-1 cod – top bold line), average since 1988 (190 million – dashed line), and average since 1997 (115 million – dotted line). The ICES limit (70 000 t) and precautionary (150 000 t) biomass levels are also given.

and country, and the total catch by gear sector for 2004 (Table 1; STECF, 2005b). French and German >100 mm mesh gear is not included in Table 1, because it is believed that those gears, which increased effort over the period, target saithe (*Pollachius virens*), with a negligible bycatch of cod. The data show that the sector catching the largest component, that using >100 mm mesh gear, has reduced by 50%. The UK has by far the largest cod quota, and its large-mesh fleet has reduced activity by about 65% (STECF, 2005b). Table 1 also shows that this gear sector now takes some 40% of the North Sea cod caught, and that beam trawlers and the 70–99 mm sector take 35% between them. Most management measures have targeted the >100 mm sector.

To understand the change in the relative impacts of the sectors since 2000 we need to know the total catch (landings plus discards) by sector for 2000. Unfortunately, adequate discard data are only available for 2004. Although total cod discarded may have varied by sector over this period, because of differences between TAC levels and effort levels, we can make a first-order assumption that the fishing mortality rates per unit effort were similar within sectors. We produce a model that generates estimated changes in fishing mortality on cod, between 2000 and 2004, based on this assumption.

The partial fishing mortality of gear sector g in 2004 can be defined as $f(g)_{04} = p(g)F_{04}$, where F_{04} is the total fishing mortality rate in 2004, and $p(g)_{04}$ is the proportion of all cod caught by gear g in 2004. The total fishing mortality rate in 2000 can then be estimated from

$$F_{00} = \sum_g (E(g)_{00}/E(g)_{04})p(g)F_{04},$$

where $E(g)_{00}$ and $E(g)_{04}$ are the effort (or relative effort) levels in 2000 and 2004, respectively, for each gear g, and the summation is over all gear sectors. The proportion of fishing mortality remaining in 2004 relative to 2000 is then

$$F_{04}/F_{00} = \left(\sum_g \psi(g)\right)^{-1}, \tag{1}$$

where $\psi(g) = (E(g)_{00}/E(g)_{04})p(g)$.

Table 2 evaluates this equation based on data from Table 1, and shows that the estimated reduction in fishing mortality on cod between 2000 and 2004 was 37%. This result is similar to the ICES estimate, of a 39% reduction in F, using in the assessment the combined IBTS spring surveys and estimated missing catches. It is a much smaller reduction than that estimated from using all surveys for tuning and assuming that the catch is known exactly (59%), and of course, it is a much larger reduction than the results of the English and Scottish surveys, which predict a rise in F (ICES, 2005).

We can also extend this model to explore what level of sector-based, effort reductions will deliver agreed levels of reductions in total fishing mortality relative to 2000. If $F(m)$ is the modelled fishing mortality rate in 2004 under various effort scenarios $E(g)m$, then

$$F(m) = \sum_g f(g)_{00}(E(g)m/E(g)_{00}) = \sum_g (E(g)_{00}/E(g)_{04})p(g)F_{04}(E(g)m/E(g)_{00}),$$

and

$$F(m)/F_{00} = \left(\sum_g \psi(g)(E(g)m/E(g)_{00})\right)F_{04}/F_{00}.$$

We have already evaluated F_{04}/F_{00} and $\psi(g)$ in Table 2. If we define θ as the modelled, gear-specific, proportional cut in effort relative to 2000, and ψ as the gear-specific terms from Table 2, then

$$F(m)/F_{00} = \sum_g \psi(g)(1-\theta(g))F_{04}/F_{00}. \tag{2}$$

Table 1. Fishing effort at sea (million kW-days at sea) from the North Sea and Skagerrak, and the catch of North Sea cod by gear sector (after STECF, 2005b).

	Effort (million kW-days)			Catch (t)				
Gear	2000	2004	%Change	Landings	Discards	Total take	Discard rate (%)	%Catch
Beam trawl over 80 mm	71.6	54.0	−25	3 754	3 309	7 063	47	21
Demersal trawl over 100 mm	53.2	26.5	−50	12 264	2 024	14 288	14	42
Demersal trawl 16–31 mm	0.3	0.1	−59	2	0	2	0	0
Demersal trawl 70–99 mm	16.3	25.0	54	3 408	1 721	5 129	34	15
Longlines	0.2	0.1	−69	740	0	740	0	2
Static nets	5.1	3.4	−34	5 862	0	5 862	0	17
Others	27.0	24.7	−8	753	4	757	1	2
Total effort	173.7	133.8	−23	26 783	7 058	33 841	21	100

Table 2. Calculations for the reductions in fishing mortality, F, 2000–2004, from Equation (1) and data from Table 1. E_{00}/E_{04} is the relative effort level in 2000 relative to 2004 by gear sector and $p(g)$ is the proportion of all cod caught by gear sector g. ψ is a parameter in the calculation.

Gear	E_{00}/E_{04}	$p(g)$	$\psi(g)$
Beam trawl over 80 mm	1.33	0.21	0.28
Demersal trawl over 100 mm	2.01	0.42	0.85
Demersal trawl 16–31 mm	2.44	0.00	0.00
Demersal trawl 70–99 mm	0.65	0.15	0.10
Longlines	3.25	0.02	0.07
Static nets	1.52	0.17	0.26
Others	1.09	0.02	0.02
Total		1.00	1.58
F(2004)/F(2000)			0.63

Table 3 shows four scenarios of the effects that cuts in different gear sectors would have in reducing total fishing mortality. The first cuts the >100 mm gear by 65% (which was the implicit EU target), and removes the large increase in the 70–99 mm gear. This would reduce the fishing mortality by about 48% relative to 2000. A further removal of all large-mesh gears would reduce F by 67%. Keeping the large-mesh reduction at 65% and reducing the beam trawls and 70–99 mm sector by a further 10% would reduce F by 50%. Finally, a range of further reductions on those sectors is modelled, which achieve a 60% cut in F.

The model shows how difficult it is to bring fishing mortality to low levels without severely impacting all sectors. However, it should be appreciated that the calculated actual and modelled reductions are based on an Occam's razor assumption of constant catchability by sector over the period 2000–2004. Different assumptions may give more optimistic or pessimistic results. Effort constraints may have generated increased efficiency per unit effort, and German and French large-mesh effort may have increased fishing on cod. On the other hand, reduced cod and increased haddock TACs may have taken the fleet into less productive waters for cod.

The predictive model is also unrefined, and within sectors there are significant differences in cod catches. For example, the southern North Sea 70–99 mm sector is a mixed whitefish fishery, whereas in the central and northern North Sea some vessels operate in fisheries for Norway lobster (*Nephrops norvegicus*), which in some instances have negligible catches of cod. Consequently, effort reductions in these sectors would have different conservation benefits, depending on which sub-component of the sector was most affected.

What needs to be done?

There are a variety of issues that need to be addressed relating to process, and there needs to be continued progress on managing fishing effort.

Recovery Plan targets need to be reassessed in the light of significant, but not necessarily predominant, environmental pressures on productivity. This should also take into account additional pressures such as increased seal predation (SCOS, 2003). Lack of recovery of northern cod has been attributed to a combination of increased natural mortality, decreased growth, reduced recruitment, and continued fishing (Shelton *et al.*, 2006). Nevertheless, this study shows that, even with current low recruitment productivity, management biomass targets can be met. Under the reduced productivity in recruitment of the last decade, a fishing mortality rate of about 0.4 y^{-1} is required to reach a target biomass of 150 000 t. This is, by coincidence, the target fishing mortality rate agreed by the EU and Norway for when the cod has recovered. It is also larger than the F_{MSY} of 0.2 y^{-1}. The World Summit on Sustainable Development (WSSD) in Johannesburg agreed that stocks should be managed at maximum sustainable yield (MSY) levels by 2015, although it is not yet evident how multispecies fisheries, such as those of the North Sea, should be managed under such an agreement. We conclude that the current

Table 3. Calculated reductions in F from F(2000), using Equation (2), and four different assumed reductions in gear-specific effort relative to 2000. Emboldened values show changes from the 2004 reductions.

Gear	Reductions by 2004 (%)	$\psi(g)$	Model reduction (%)	Model reduction (%)	Model reduction (%)	Model reduction (%)
Beam trawl over 80 mm	25	0.28	25	25	**35**	**45**
Demersal trawl over 100 mm	50	0.85	**65**	**100**	**65**	**70**
Demersal trawl 16–31 mm	59	0.00	59	59	59	59
Demersal trawl 70–99 mm	−54	0.10	**0**	**0**	**10**	**25**
Longlines	69	0.07	69	69	69	69
Static nets	34	0.26	34	34	34	**60**
Others	8	0.02	8	8	8	**10**
F(model)/F(2000)	**63**		**52**	**33**	**50**	**40**
Cut in F cf. 2000	**37**		**48**	**67**	**50**	**60**

biomass recovery target is achievable under the current level of reduced recruitments, and that this could be achieved with fishing mortality rates consistent with current international agreements.

The Recovery Plans place too great a demand on precision in the annual assessments. The current position, of robust advice that the cod is still very depleted but uncertainty about the quantitative effects of different management actions, puts managers in an invidious position, and *ad hoc* annual decisions give fishers and national managers no scope for medium-term planning. A more medium-term, robust application needs to be sought.

Associated with the above is the credibility of the scientific advice. The most basic information is that of the research surveys, which have been undertaken consistently over several decades. It is mostly this information that drives the assessments. Fishers have argued that such surveys are inappropriate for cod. Scientists have pointed to the problems with the Canadian northern cod, on which the mobile commercial fleets maintained high catch rates on cod that aggregated in small areas (Rose and Kulka, 1999; Shelton and Lilly, 2000; Shelton, 2005). Nevertheless, the views of fishers cannot be summarily dismissed. First, the gear used in the North Sea research surveys is not optimal for cod, and is worked on soft ground. Fishers argue that cod are found on rougher ground, and we have noted above the contraction of the distribution of the cod – which may be, but we do not know, onto harder ground. The research surveys are not strictly random surveys, and as such do not necessarily sample cod randomly. Second, science needs to persuade stakeholders that it is correct if it is asking for 60% cuts in activity and income from the individuals concerned. Changing the pattern of research vessel surveys risks a loss of the ability to track stock size. However, we can encourage the establishment of complementary, industry-based surveys to work in parallel.

The most material consideration is the management of fishing effort. In December 2005, the EU Council of Ministers agreed further cuts in days at sea of 5%, 8%, and 10%, respectively, for vessels in the large-mesh, beam trawl, and 70–99 mm sectors. Some of the lost days could be recovered through additional measures. However, there remains no statement about the desired target level for fishing mortality during the recovery phase, or a view as to what this might mean for fishing effort in total or by gear sector. This results in annual *ad hoc* decisions. Fishers and EU Member States cannot plan in the medium term. If they do all that is asked of them, will they be asked to do more the next year?

For North Sea cod to recover to current target biomass levels within a decade would require cuts significantly greater than the current 37% reduction. Our view is that the current level of total effort reduction should deliver a value of F of about 0.65 y^{-1}, the precautionary fishing rate. This should allow the stock to recover, but slowly and possibly not to 150 000 t if recruitment is insufficient (Figure 5). If recruitment remains at its current depressed level, then such a rate of fishing would barely allow the stock to reach B_{lim}. This fishing rate is also well above the EU–Norway target, and above the single-species MSY level. It would be prudent to begin to plan the alignment of fishing mortality and effort levels for cod recovery, EU–Norway management targets, and WSSD targets in the North Sea multispecies and multi-fleet fisheries, taking account of the complex stock structures.

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