Stock Annex: Cod (*Gadus morhua*) in Subarea 4 and divisions 7.d and 20 (North Sea, eastern English Channel, Skagerrak)

Stock specific documentation of standard assessment procedures used by ICES.

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A. General

A.1. Stock definition

Cod are widely distributed throughout the North Sea. Scientific survey data indicate that historically, young fish (ages 1 and 2) have been found in large numbers in the southern part of the North Sea, whilst in recent decades the Skagerrak has also become important. Adult fish have in the past been located in concentrations of distribution in the Southern Bight, the north east coast of England, in the German Bight, the east coast of Scotland and in the north-eastern North Sea. As stock abundance fluctuates, these groupings appear to be relatively discrete but the area occupied has contracted. During recent years, the highest densities of 3+ cod have been observed in the deeper waters of the central to northern North Sea.

Population genetic research has shown that Atlantic cod populations are structured over both large and smaller geographical scales, for instance between the North Sea and Baltic Sea (Nielsen *et al*., 2003). Within the North Sea and neighbouring areas, several studies have indicated finer scale structuring on substock scales. Whilst differentiation was weak in past studies employing microsatellite DNA (typical of marine fishes with large population sizes and high dispersal potentials), the move to using suites of single nucleotide polymorphisms (SNP) has substantially increased the power and reliability of these estimates. Recent evidence points to two populations; one inhabiting the north east North Sea (centred on the Viking Bank) and the other in shallower waters. This is supported by studies using both microsatellite DNA (Nielsen *et al*., 2009) and SNPs (Poulsen *et al*., 2011, Heath *et al*., 2014; WD1 by Wright *et al*., in WKNSEA 2015). Investigations of life stage connectivity suggest that this isolation may have partly arisen through oceanographic barriers to early life-stage dispersal (Heath et al. 2008, Munk et al. 2009) as well as limited mixing of adults as they appear to remain within waters > 100 m (Wright *et al*., 2006a,b, Neat *et al*., 2014). However, the latest unpublished genetic and otolith microchemistry evidence also indicates that many Viking juveniles settle in the Skagerrak and subsequently make a return migration prior to spawning (WD1 by Wright et al. in WKNSEA 2015). This would explain the high abundance of 0- and 1-group cod in the Skagerrak, which is not reflected in age 2+ abundance (Svedäng and Svenson 2006), and why a relatively strong year class of cod in the Skagerrak was genetically assigned to the North Sea rather than local adults (Knutsen *et al.*, 2004). Consequently, the reproductive isolation of Viking fish appears to be supported both by limited mixing with neighbouring groups and natal homing.

There may be further structuring within the North Sea than that indicated by the genetic evidence alone. There is extensive evidence for persistent resident behaviour in many groups of cod since the 1960s associated with spawning aggregations from the eastern channel north to Shetland (ICES NSRWG 1971, Metcalfe 2006, Neat *et al.*, 2006, Wright *et al.*, 2006b, Righton *et al.*, 2007, Neat *et al.*, 2014). Indeed, temporal changes in abundance and local genetic composition at one such spawning aggregation near Flamborough, off the north east English coast, suggests that a complete collapse and re-colonisation of the area took place in the latter half of the twentieth century (Hutchinson *et al.*, 2003). Potential larval transport (Heath *et al.*, 2008, WD1 by Wright *et al.*, in WKNSEA 2015) and juvenile dispersal derived from tag recapture (Riley and Parnell 1984) and otolith microchemistry studies (Wright *et al.*, 2006a) indicate that early stages do not mix throughout the shallow North Sea region. Differences in life history traits have been found among the shallow North Sea region consistent with some degree of segregation (Harrald *et al.*, 2010, Wright *et al.*, 2011), although the most pronounced differences are found in Viking, as these cod have retained a reproductive investment strategy similar to that reported decades ago (Yoneda and Wright 2004, Wright *et al*,. 2011).

In order to explore whether there are sub-area differences in population synchrony, Holmes *et al.* (2014) divided the North Sea into three subareas, Viking, south and northwest. Using survey based indices of spawning stock biomass they found significant differences among all three areas, although the most substantial difference was between Viking and the shallow areas.

Available information indicates that the majority of spawning takes place from the beginning of January through to April offshore in waters of salinity 34–35% (Brander 1994, Riley and Parnell 1984). Around the British Isles there is a tendency towards later timing with increasing latitude (ICES 2005). Older females start to spawn earlier than young females, which may be important to age related reproductive success (Morgan *et al.*, 2013). Cod spawn throughout much of the North Sea but spawning adult and egg survey data and fishermen's observations indicate a number of spawning aggregations. Results from the first ichthyoplankton survey to cover the whole of the North Sea, conducted in 2004 to map spawning grounds of North Sea cod, are reported in Fox *et al.* (2008). This study compared the results from the plankton survey with estimates of egg production inferred from the distribution of mature cod in contemporaneous trawl surveys. The comparison found general agreement of hot spots of egg production around the southern and eastern edge of the Dogger Bank, in the German Bights, the Moray Firth and to the east of the Shetlands, which mapped broadly into known spawning areas from the period 1940–1970, but was unable to detect any significant spawning activity off Flamborough (a historic spawning ground off the northeast coast of England). The study showed that most of the major cod spawning grounds in the North Sea are still active, but that the depletion of some localised populations may have made the detection of spawning activity in the corresponding areas difficult (Fox *et al.*, 2008).

At the North Sea scale, there has been a northerly shift in the mean latitudinal distribution of the stock (Hedger *et al.* 2004, Perry *et al.*, 2005). However the evidence for this being a migratory response is slight or non-existent. More likely, cod in the North Sea are composed of a complex of more or less isolated substocks (as indicated above) and the southern units have been subjected to disproportionately high rates of fishing mortality (STECF-SGRST-07-01). Blanchard *et al*. (2005) demonstrated that the contraction in range of juvenile North Sea cod could be linked to reduced abundance as well as increased temperature, and further noted that the combined negative effects of increased temperature on recruitment rates and the reduced availability of optimal habitat may have increased the vulnerability of the cod stock to fishing mortality.

Rindorf and Lewy (2006) linked the northward shift in distribution to the effect of a series of warm, windy winters on larvae and the resultant distribution of recently settled cod, followed by a northwards shift in the distribution of older age groups (because of the tendency for northerly distributed juveniles to remain northerly throughout their life). They noted further that this effect is intensified by the low abundance of older age cod due to heavy fishing pressure. However, simulations of larval transport did not support the northward transport proposed (Heath *et al*., 2008). Northward adult movements are also unlikely as, based on 129 electronic tagging records, Neat and Righton (2007) found no evidence that adult cod in the southern North Sea moved away from the warm waters that were super-optimal for growth even though they had the capacity to find cooler water. This suggests that the thermal regime of the North Sea is not yet causing adult cod to move to cooler waters. Despite the drastic decline in stock abundance over the period 1983–2006, and the movement of the centre of gravity of the distribution towards the northeast, Lewy and Kristensen (2009) found that the spatial correlation and dispersion of IBTS–Q1 survey catches remained unchanged throughout this 24–year period, with the concentration of the stock remaining constant or declining. They therefore concluded that cod does not follow the theory of density-dependent habitat selection, because stock concentration does not increase with decreasing stock abundance.

Several tagging studies have been conducted on cod in the North Sea since the mid–1950s in order to investigate the migratory movements and geographical range of cod populations (Bedford 1966, ICES NSRWG 1971, Daan 1978, Righton *et al*., 2007). These studies indicate that cod separate during the spawning season and, in some cases, intermix during the feeding season (Metcalfe 2006; Neuenfeldt *et al*., 2013). Righton *et al*. (2007) re-analysed some of the historical datasets of conventional tags and used recent data from electronic tags to investigate movement and distribution of cod in the southern North Sea and English Channel. Their re-analysis of conventional tags showed that, although most cod remained within their release areas, a larger proportion of cod were recaptured outside their release area in the feeding season than the spawning season, and a larger proportion of adults were recaptured outside their release area than juveniles, with the displacement (release to recapture) occurring mostly to the southern North Sea for fish released in the English Channel, and to areas further north for fish released in the southern North Sea (see Table 5 in Righton *et al*., 2007). This suggests a limited net influx of cod from the English Channel to the southern North Sea, but no significant movement in the other direction (Metcalfe 2006). Recent electronic tagging indicates that cod from the shallow water population inhabiting the east of Shetland may also overlap with the western range of Viking cod outside the spawning season (Neat *et al*., 2014).

The lack of obvious physical barriers to mixing in the North Sea suggests that behavioural and/or environmental factors are responsible for maintaining the relative discreteness of populations (Metcalfe 2006). For example, Righton *et al*. (2007) conclude that behavioural differences between cod in the southern North Sea and English Channel (such as tidal stream transport being used by fish tagged and released in the southern North Sea to migrate, but rarely being used by those tagged and released in the English Channel) may limit mixing of adult cod from these two areas during feeding and spawning seasons. Robichaud and Rose (2004) describe four behavioural categories for cod populations: "sedentary residents" exhibiting year-round site fidelity, "accurate homers" that return to spawn in specific locations, "inaccurate homers" that return to spawn in a broader area around the original site, and "dispersers" that move and spawn in a haphazard fashion within a large geographical area. These categories are not necessarily mutually exclusive and behaviours in different regions may be best described by differing degrees of each category (Heath *et al*., 2008).

Evidence from electronic tags suggest that cod populations have a strong tendency for site attachment (even in migratory individuals), rapid and long-distance migrations, the use of deeper channels as migratory "highways" and, in some cases, clearly defined feeding and spawning "hot spots" (Righton *et al*., 2008; Neat *et al*., 2014). Andrews *et al*. (2006) used a spatially and physiologically explicit model describing the demography and distribution of cod on the European shelf in order to explore a variety of hypotheses about the movements of settled cod. They fitted the model to spatial data derived from International Bottom Trawl Surveys, and found that structural variants of the model that did not recognise an active seasonal migration by adults to a set of spatially stable spawning sites, followed by a dispersal phase, could not explain both the abundance and distribution of the spawning stock. Heath *et al*. (2008) investigated different hypotheses about natal fidelity, and their consequence for regional dynamics and population structuring, by developing a model representing multiple demes, with the spawning locations of fish in each deme governed by a variety of rules concerning oceanographic dispersal, migration behaviour and straying. They used an age-based discrete time methodology, with a spatial representation of physical oceanographic patterns, fish behaviour patterns, recruitment, growth and mortality (both natural and fishing). They found that although active homing is not necessary to explain some of the sub-population structures of cod (with separation possible through distance and oceanographic processes affecting the dispersal of eggs and larvae, such is in the Southern Bight), it may well be necessary to explain the structure of other sub-populations.

A.2. Fishery

Cod are caught by virtually all the demersal gears in Sub-area 4 and Divisions 20 (Skagerrak) and 7.d, including beam trawls, otter trawls, seine nets, gill nets, trammel nets and lines. Most of these gears take a mixture of species. In some of them cod are considered to be a bycatch (for example in beam trawls targeting flatfish), and in others the fisheries are directed mainly towards cod (for example, some of the fixed gear fisheries).

An analysis of cod catches by gear category (excluding Norwegian data) highlighted the following fleets as important in terms of cod for 2005–13 (each accounting for ≥ 1% of the EU landings), listed with the main use of each gear (STECF 2014):

- Otter trawl and seine, ≥ 120 mm: a directed roundfish fishery by UK, Danish and German vessels.
- Otter trawl and seine, 70–99 mm: comprising a 90–99 mm Danish and Swedish mixed demersal fishery centred in the Skagerrak, a 70–79 mm French whiting trawl fishery centred in the Eastern Channel, but extending into the North Sea, and UK and Swedish *Nephrops* fisheries.
- Beam trawl, ≥ 120 mm: a Danish, Belgian and UK fishery targeting plaice.

- Beam trawl, 80–120 mm: a directed Dutch, Belgian and German flatfish fishery.
- Gillnets: a targeted cod and plaice fishery.
- Trammel nets: operated by a number of countries but cod are particularly important for the Danish fishery.

Small catches of cod are also taken by small meshed (16–32 mm) otter trawl fisheries targeting shrimp and small-scale longline fisheries. For Norway in 2013, trawls/seines (mainly bycatch in the saithe fishery) and gillnets account for around 75% (by weight) of cod catches, with the remainder taken by other gears mainly in the fjords and on the coast, whereas in the Skagerrak trawls, seines and gillnets account for up to 90% of cod catches.

The overall effort by demersal trawls/seines has shown a reduction since 2003, especially in the North Sea, due to a combination of decommissioning and days-at-sea regulations. The effort by larger meshed trawls/seines had remained relatively stable over the previous cod plan (2004–2009) but has been declining since the full implementation of the new cod plan in 2010 (STECF 2014). For otter trawls, vessels are using either 120 mm+ (in the directed whitefish fishery), 100–119 mm in the southern North Sea plaice fishery, or 80–99 mm (primarily in the *Nephrops* fisheries and in a variety of mixed fisheries). The use of other mesh sizes largely occurs in the adjacent areas, with the 70–79 mm gear being used in the Eastern Channel/Southern North Sea Whiting fishery, and the majority of the landings by 90–99 mm trawlers coming from the Skagerrak. Higher discards are associated with these smaller mesh trawl fisheries, but even when these are taken into account, the directed roundfish fishery (trawls with ≥ 120 mm mesh) still has the largest impact of any single fleet on the cod stock, followed by the mixed demersal fishery (90–99 mm trawls) in the Skagerrak.

A.2.1. Technical Conservation Measures

The present technical regulations for EU waters came into force on 1 January 2000 (EC 850/98 and its amendments). The regulations prescribe the minimum target species' composition for different mesh size ranges. Additional measures were introduced in Community waters from 1 January 2002 (EC 2056/2001).

Two closures areas have been implemented in the past to protect cod stocks: an emergency closure of a large area of the North Sea from 14 February to 30 April 2001 (EC 259/2001) and a cod protection area in 2004 (EC 2287/2003 and its amendments), which defined conditions under which certain stocks, including haddock, could be caught in Community waters. Neither measure has been adopted again since. A recent study on the use of MPAs to address regional-scale ecological objectives in the North Sea (Greenstreet *et al.*, 2009) concluded that MPAs on their own are unlikely to achieve significant regional-scale ecosystem benefits, because local gains are largely negated by fishing effort displacement into the remainder of the North Sea.

Apart from the technical measures set by the Commission, additional unilateral measures are in force in the UK, Denmark and Belgium. The EU minimum landing size (mls) is 35cm, but Belgium operate a 40 cm mls, while Denmark operate a 35 cm mls in the North Sea and 30 cm in the Skagerrak. Additional measures in the UK relate to the use of square mesh panels and multiple rigs, restrictions on twine size in both whitefish and *Nephrops* gears, limits on extension length for whitefish gear, and a ban on lifting bags. The use of technical measures in the UK *Nephrops* fishery has particularly increased in 2012 following an agreement at the 2011 December Council on a requirement for UK vessels to use highly selective gear for part of the year. In 2001, vessels fishing in the Norwegian sector of the

North Sea had to comply with Norwegian regulations setting the minimum mesh size at 120 mm. Since 2003, the basic minimum mesh size for towed gears targeting cod is 120 mm.

In 2009 a new system of effort management was introduced in accordance with the new cod management plan (EC 1342/2008), providing Member States greater flexibility in managing their fleets, in order to encourage a more efficient use of fishing opportunities and stimulate fishing practices that lead to reduced discards and lower fishing mortality of both juvenile and adult fish. This measure allowed a Member State that fulfilled the requirements laid out in EC 40/2008 to manage a fleet (i.e. group of vessels with a specific combination of geographical area, grouping of fishing gear and special condition) to an overall kilowatt-days limit for that fleet, instead of managing each individual vessel in the fleet to its own days-at-sea limit. The overall kilowatt-days limit for a fleet is initially calculated as the sum of all individual fishing efforts for vessels in that fleet, where an individual fishing effort is the product of the number of days-at-sea and engine power for the vessel concerned. This provision allowed Member States to draw up fishing plans in collaboration with the Fishing Industry, which could, for example, specify a target to reduce cod discards to below 10% of the cod catch, allow real-time closures for juveniles and spawners, implement cod avoidance measures, trial new selective devices, etc.

The cod management plan (EC 1342/2008) has incentives in place that allow Member States to increase fishing effort relative to the annual allocation (Article 13) or to be excluded from the effort allocation entirely (Article 11) for fleet segments engaged in cod avoidance measures. The incentive to increase fishing effort applies to national fleet segments that can provide proof that they use highly selective gears (Article 13.2a), that their catches per fishing trip comprise less than 5% cod (Article 13.2b) and/or whose activity are conducted in accordance with a cod avoidance or discard reduction plan (Article 13.2c). National fleet segments with less than 1.5% cod catches can apply to be excluded from the effort management regime entirely. There are a number of Article 13 derogations used for trawls/seines fisheries in the North Sea. Germany, Scotland and England have reported 54%, 100% and 100% of their effort by otter trawls of mesh ≥ 100 mm in Article 13 respectively. UK has also reported 100% of effort by trawls of mesh 70–99 mm under Article 13. There is only a limited use of Article 13 in the Skagerrak, operated by the German saithe fishery (STECF 2014). The fishing effort regime was discontinued in 2017 (EC 2094/2016).

Under Article 13.2c of the cod management plan (EC 1342/2008), Scotland introduced a voluntary programme known as "Conservation Credits", which involved seasonal closures, real-time closures (RTCs) and various selective gear options. This was designed to reduce mortality and discarding of cod. The scheme was incentivised by rewarding participating skippers with additional days at sea. The real-time closures system (15 were implemented in 2008) discouraged vessels from operating in areas of high cod abundance. In 2009, the number of closures implemented was increased substantially (to 144 for all areas subject to the cod management plan) and made mandatory, with up to 12 being implemented at any one time. Closures are determined by landings per unit effort, based on fine scale VMS data and daily logbook records and also by on-board inspections. Based on new in-year information on cod movement from tagging, the dimensions of the RTCs were increased by just over four times (from 50 square nautical miles to 225) from July 2010. The use of more species and size selective gears (some trialled by the Marine Laboratory in Aberdeen) formed a further series of options within the scheme. These included the 'Orkney trawl', the use of nets with 130 mm codends and larger meshes in the square meshed panels of *Nephrops* trawls. The scheme has delivered a total of 165, 185, 173, 166, 94, 97 and 114 closures in 2010, 2011, 2012, 2013, 2014, 2015 and 2016 respectively. ICES notes that from the initial year of operation (2008) cod discarding rates in Scotland decreased from 61% to 24% in 2011 and 2012, but increased again to 34% in 2015 and 33% in 2016; it is hypothesised that the increase may be due in part to FDF (fully documented fisheries) vessels putting upward pressure on the lease price of cod, resulting in non-FDF vessels increasing the amount of cod they discard because they are unwilling to pay an above-market price for cod quota. The scheme was suspended on 20th November 2016 and there are no plans for its reintroduction.

The expansion of the closed-circuit TV (CCTV) and FDF programmes in 2010–2016 in Scotland, Denmark, Germany, England and the Netherlands is expected to have contributed to the reduction of cod mortality. Under this scheme, UK vessels are not permitted to discard any cod, while Danish and German vessels are still permitted to discard undersized cod. For participating vessels, all cod caught are counted against the quota, and in return fishers are permitted additional catches of cod. Landings by FDF métiers comprised less than 2% of total landings in 2009, rising to 27% in 2012, but declined to 20% in 2016 (InterCatch data). The cod-specific FDF scheme terminated at the end of 2016.

A.2.2. Changes in fleet dynamics

The ICES WGFTFB report now only provides a description of changes in EU fishing fleets and effort relevant to assessment working groups every second year; there is no such information in the latest WGFTFB reports (ICES WGFTFB 2013, 2014).

The introduction of the one-net rule as part of the Scottish Conservation Credit Scheme and new Scottish legislation implemented in January 2008 were both likely to improve the accuracy of reporting of Scottish landings to the correct mesh size range, although some sectors of the Scottish industry have been granted derogations to continue carrying two nets (seiners until the end of January 2009, and others until the end of April 2008). The concerted effort to reduce cod mortality, through implementation of the Conservation Credit Scheme from February 2008, could have lead to greater effort being exerted on haddock, whiting, monk, flatfish and *Nephrops*.

Shifts in the UK fleet in 2007/8 included: (a) a move of Scottish vessels using 100–110 mm for whitefish on west coast ground (subarea 6) to the North Sea using 80 mm prawn codends (motivated by fuel costs, and could increase effort on North Sea stocks; the simultaneous requirement to use 110 square mesh panels may mitigate unwanted selectivity implications - see below); (b) a move away from the Farne Deeps *Nephrops* fishery into other fisheries for whitefish because of poor *Nephrops* catch rates (implying increased effort in whitefish fisheries); and (c) a move of Scottish vessels from twin trawls to single rig, and increased use of pair trawls, seines and double bag trawls (motivated by fuel costs). For 2008 in the Scottish fleet, all twin-rig gear in the 80–99 mm category have to use a 110 mm square mesh panel, but this also applied to single-rig gears from July 2008 onwards, which was likely to have improved whitefish selection. A large number of 110mm square mesh panels have been bought by Scottish fishers at the beginning of 2008 in order to qualify for the Conservation Credit Scheme, which dramatically improved the uptake of selective gear. The ban on the use of multi-rigs in Scotland, implemented in January 2008, may have limited the potential for an uncontrolled increase in effective effort.

The Dutch fleet was reduced, through decommissioning, by 23 vessels from the beginning of 2008, while 5 Belgian beam trawlers (approximately 5% of the Belgian fleet) left the fishery in 2007, both changes implying reductions in effort in the beam trawl sector. The introduction of an ITQ regulation system in Denmark in 2007 might have influenced the effort distribution over the year, but this should not have affected the total Danish effort deployed or the size distribution of catches.

Dutch beam trawlers have gradually shifted to other techniques such as twin trawling, outrigging and fly-shooting, as well as opting for smaller, multi-purpose vessels, implying a shift in effort away from flatfish to other sectors. These changes were likely caused by TAC limitations on plaice and sole, and rising fuel costs. Belgian and UK vessels have also experimented with outrigger trawls as an alternative to beam trawling, motivated by more fuel efficient and environmentally friendly fishing methods.

The increased effort costs in the Kattegat (2.5 days at sea per effort day deployed) in 2008 has led to a shift in effort by Swedish vessels to the Skagerrak and Baltic Sea. There has also been an increase in the number of Swedish *Nephrops* vessels in recent years, attributed to the input of new capital transferred from pelagic fleets following the introduction of an ITQ–system for pelagic species, and leading to further increases in effort. The Swedish trawler fleet operating in 3.a has had a steady increase in the uptake of the *Nephrops* grid since the introduction of legislation in 2004 (use of the grid is mandatory in coastal waters), and given the strong incentives to use the grid (unlimited days at sea). Uptake of the *Nephrops* grid should have resulted in improved selection.

A squid fishery in the Moray Firth has continued to develop using very unselective 40mm mesh when squid species are available on the grounds. Although the uptake was poor in 2007 due to the lack of squid, the potential for high bycatches of young gadoids in future, including those of cod and haddock, remains. This fishery may provide an alternative outlet for the Scottish *Nephrops* fleet seasonally, and hence reduce effort in the *Nephrops* sector.

A.3. Ecosystem aspects

Section A.3 was not updated during WKNSEA 2015. However, although outdated, some of the information is still relevant. This section will be updated in due course.

Cod are predated upon by a variety of species through their life history. The Working Group on Multi-species Assessment Methods (ICES WGSAM 2008) estimated predation mortalities using SMS (Stochastic Multi Species Model) with diet information largely derived from the Years of the Stomach databases (stomachs sampled in the years 1981–1991). Long-term trends have been observed in several partial predation mortalities with significant increases for grey gurnard preying on 0–group cod. In contrast, predation mortalities on age 1 and age 2 cod decreased over the last 30 years due to lower cannibalism. Predation on older cod (age 3–6) increased due to increasing numbers of grey seals in the North Sea.

SMS identified grey gurnard as a significant predator of 0–group cod. The abundance of grey gurnard (as monitored by IBTS) is estimated to have increased in recent years resulting in a rise in estimated predation mortality from 1.08 to 1.76 between 1991 and 2003. A degree of caution is required with these estimates as they assume that the spatial overlap and stomach contents of the species has remained unchanged since 1991. Given the change in abundance of both species this assumption is unlikely to hold and new diet information is required before 0-group predation mortalities can be relied upon.

Several other predators contribute to predation mortality upon 0-group cod, whiting and seabirds being the next largest components. Speirs *et al.* (2010) developed a length-structured partial ecosystem model for cod and nine of its most important fish predators and prey in the North Sea, utilising time series of stock biomass, recruitment and landings, as well as survey data on length distributions and diet data. Their results suggest that herring predation on early life history stages of cod is dynamically important, and that high abundances of herring may lead to the decline of cod stocks, even during periods of declining fishing pressure. Furthermore, they show that the MSY of cod is strongly dependent on herring abundance, and that current levels of cod exploitation may become unsustainable if herring recruitment returns to historic high levels.

The consumption of cod in the North Sea in 2002 by grey seals (*Halichoerus grypus*) has recently been estimated (Hammond and Grellier 2006). For the North Sea it was estimated that in 1985 grey seals consumed 4 150 tons of cod (95% confidence intervals: 2 484–5 760 tons), and in 2002 the population tripled in size (21–68 000) and consumed 8 344 tons (95% confidence intervals: 502 814 941 tons). These consumption estimates were compared to the Total Stock Biomass (TSB) for cod of 475 000 tons and 225 000 tons for 1985 and 2002 respectively. The mean length of cod in the seal diet was estimated as 37.1 cm and 35.4 cm in 1985 and 2002 respectively. It should be noted, however, that seal diet analysis must be treated with a degree of caution because of the uncertainties related to modelling complex processes (e.g. using scat analysis to estimate diet composition involves complex parameters, and can overestimate species with more robust hard parts), and the uncertainties related to estimating seal population size from pup production estimates (involving assumptions about the form of density-dependent dynamics). The analysis may also be subject to bias because scat data from haul-out sites may reflect the composition of prey close to the sites rather than further offshore.

The effect of seal predation on cod mortality rates has been estimated for the North Sea within a multispecies assessment model (MSVPA), which was last run in 2007 during the EU project because (contract number SSP8-CT-2003-502482) using revised estimates of seal consumption rates. The grey seal population size was obtained from WGMME (ICES WGMME 2005) and was assumed to be 68,000 in 2002 and 2003 respectively. Estimates of cod consumption were 9657 tonnes in 2002 and 5124 tonnes in 2003, which is similar to the values estimated by Hammond and Grellier (2006). Sensitivity analysis of the North Sea cod stock assessment estimates to the inclusion of the revised multi-species mortality rates were carried out at the 2009 meeting of the WKROUND. Inclusion of the multispecies mortality rates for older ages of cod had a relatively minor effect on the high levels of estimated fishing mortality rates and low levels of spawning stock biomass abundance. This suggests that the estimates of seal predation will not alter the current perception of North Sea cod stock dynamics (also stated by STECF-SGRST-07-01).

The overlap between predator and prey is a key parameter in multispecies assessment models and is notoriously difficult to parameterise. Kempf *et al*. (2010) attempt this by using overlap indices derived from trawl surveys in a North Sea SMS model in order to investigate the recovery potential of North Sea cod. They found that the spatial-temporal overlap between cod and its predators increased with increasing temperature, indicating that foodweb processes might reduce the recovery potential of cod during warm periods. Furthermore, they found that multispecies scenarios predicted a considerably lower recovery potential than single-species ones.

A recent meeting (2007) of the STECF reviewed the broad scale environmental changes in the north-eastern Atlantic that has influenced all areas under the cod recovery plan (STECF-SGRST-07-01), and concluded that:

- Warming has occurred in all areas of the NW European shelf seas, and is predicted to continue.
- A regime shift in the North Sea ecosystem occurred in the mid-1980s.

- These ecological changes have, in addition to the decline in spawning stock size, negatively affected cod recruitment in all areas.
- Biological parameters and reference points are dependent on the time-period over which they are estimated. For example, for North Sea cod FMSY, MSY and BMSY are lower when calculated for the recent warm period (after 1988) compared to values derived for the earlier cooler period.
- The decline in FMSY, MSY and BMSY can be expected to continue due to the predicted warming, and possible future change should be accounted for in stock assessment and management regimes.
- Modelling shows that under a changing climate, reference points based on fishing mortality are more robust to uncertainty than those based on biomass.
- Despite poor recruitment, modelling suggests that cod recovery is possible, but ecological change may affect the rate of recovery, and the magnitude of achievable stock sizes.
- Recovery of cod populations may have implications to their prey species, including *Nephrops*.

With the exception of the general effects noted above, the overall conclusion from the STECF meeting (STECF-SGRST-07-01) for the North Sea was that there is no specific significant environmental or ecosystem change in the Skagerrak, North Sea and eastern Channel (e.g. the effects of gravel extraction, etc.) affecting potential cod recovery. The conclusions from the STECF meeting merit further discussion within ICES, which is ongoing (e.g. ICES WKREF 2007).

A.4. Fisheries-Science Partnerships

The three Fisheries-Science Partnerships detailed below have been discontinued, but their descriptions have been left for information.

UK – North East Coast Cod Survey

The NE Coast cod survey (De Oliveira *et al*., 2013) was a designated time-series survey conducted since 2003 as part of the UK Fisheries Science Partnership (FSP). The objective of the survey series was to provide year-on-year comparative information on distribution, relative abundance and size/age composition of cod and whiting off the NE coast of England. The surveys also provided data on catches of other species important to the NE coast fishery, including haddock. The population of cod in the survey area has primarily comprised 1- and 2-year-olds, with some 3- and 4-year-olds. Older fish have been scarce due to offshore migration of mature fish. The relative strength of recent year classes of cod, as indicated by the time-series of FSP catch rates of 1-year-olds, has been similar to the trends given by recent ICES assessments for North Sea cod, but did not pick out the 2009 year class as being any larger than the surrounding year classes, and estimated the 2011 year class to be very weak; in contrast, the assessment indicates relatively stronger 2009 and 2011 year classes (2009 being almost the same size as the 2005 year class). Furthermore, overall catch rates for cod in the 2012 FSP survey were below average for the time series in terms of both total numbers (well below in this case) and total weight. However, it should be noted that this FSP survey only covers a small portion of the North Sea cod distribution area. A comparison of different seabed types indicates that for most years catches of cod are significantly greater on the hard ground, but that trends are similar between hard and soft ground. Unfortunately, due to FSP project priorities having changed slightly in

2013/14, the North East cod FSP survey has been discontinued in lieu of other targets for the programme, so 2012 is the final year for this time series.

UK – North Sea Whitefish Survey

The North Sea whitefish survey was designed to provide a time-series of information on commercial vessel catch per unit effort from representative fishing grounds within the North Sea, with the eventual aim of providing a long-enough time series to be used to support the estimation of stock trends (Darby *et al*., 2013). The participating vessel used a combination of traditional English fishing gears appropriate to hard and soft ground in order to provide information on comparative catch rates. The tows were distributed over sub-areas defined to provide information on catch rate, size/age composition and species catch composition from as many different locations as feasible, given time and cost constraints, within the area where the fishery takes place, and not necessarily at constant locations each year. The size of the whole catch was recorded, but detailed measurements were made of the catches of cod, whiting and haddock, and of plaice if resources permitted. Surveys have been held in 2009–2012.

Cod catch rates have varied, with the hard ground catch rates being higher in 2009, soft ground catch rates in 2010 and similar rates on each ground type in 2011. The difference between ground types was constant across ages until 2012. In 2012, though, catches of cod at older ages were greater on soft ground, especially in the south, whereas in the north and at younger ages, catch rates were similar between ground types. Despite the substratum differences in catch rates, when averaged at an overall North Sea scale, the relative indices at age of cod, haddock and whiting abundance from the survey compare well with the ICES–IBTS–Q3 survey data. However, the IBTS has greater selectivity at the youngest ages due to the smaller mesh size and therefore detected incoming year-class strength earlier than that of the North Sea Whitefish survey. Nevertheless, catches of older fish were more common and exhibited less noise in the North Sea Whitefish survey data than in the IBTS–Q3.

The results demonstrated the value in developing a time-series for gadoids based on commercial vessels. The North Sea Whitefish time-series showed consistent agreement with the IBTS survey, but with higher, less noisy catch rates at the oldest ages. As such a time-series continued to develop the results would allow differences in stock dynamics on hard and soft ground to be examined in detail and determination made of whether substratum type can affect survey estimates of stock abundance, especially as the stocks of cod and whiting rebuild under the current management regime, providing valuable input to the debate on the dynamics of the stocks and survey practices. Unfortunately, due to FSP project priorities having changed slightly in 2013/14, the North Sea Whitefish survey has been discontinued in lieu of other targets for the programme, so 2012 is the final year for this time series.

Denmark – RESOURCE Project

The Danish RESOURCE project represents the finalization of seven years of fishermen-scientists cooperation - a cooperation that was commenced on the initiative of the fishermen because they wanted to demonstrate that there are far more large Atlantic cod in the north-eastern North Sea than indicated by the catch rates obtained from the International Bottom trawl Survey (IBTS). This earlier initiative developed into the REX project, a predecessor of RESOURCE (Wieland *et al*., 2010). The RESOURCE project concentrated on the north-eastern North Sea, focusing on the importance of the geographical distribution of Atlantic cod at different scales (Beyer *et al*., 2012). The project collected data from fishermen and scientists and assimilated knowledge on fishery practice, the geographical distribution of cod in the North Sea, and the vital mechanisms or processes in the sea (larval drift, growth, recruitment) that are important to explain the distribution dynamics. It used the GeoPop statistical model to integrate data from trawl hauls (REX, RESOURCE, IBTS) in order to estimate the geographical distribution of cod by body size class, thus providing a possible way towards integrated stock assessments, combining space, time and fish size.

The project has demonstrated that, on a small geographical scale, it was difficult for the fisherman to obey the RTC (real time closure) rules because the risk of catching small cod in a single haul was high, even if there were few small cod in the specific area. Furthermore, on a larger scale, data from REX/RESOURCE hauls gave a more nuanced picture of the geographical distribution of cod in the REX area as compared to the rough image produced by exclusive use of IBTS data. Future fishermen-scientists' projects should be result-based and focus on ecosystem research. Increased process knowledge and real time REX data will ensure the necessary understanding of the factors controlling the annual recruitment to the North Sea cod stocks.

B. Data

B.1. Commercial catch

Commercial catch-at-age from 2002 onwards have been estimated through InterCatch, following uploads by various nations of relevant landings data, and where available discards data, along with age compositions of both the landings and discards, by area (4, 20 and 7.d), quarter and métier. Prior to the reform of the EU's data collection framework in 2008 (see http://datacollection.jrc.ec.europa.eu/), sampling for discards and age compositions was poor in area 7.d, and this necessitated combining areas 4 and 7.d for 2002–2008 in order to facilitate computations in Intercatch. Table B.1.1 indicates the level of discard ratio coverage of the landings, together with the age coverage of both the landings and observed discards (InterCatch data: 2002–2013). Coverage for discard ratios and ages has been good (at least 50%) for areas 4 and 20, but poor for area 7.d prior to 2009.

Norwegian discarding is illegal, so although this nation has accounted for 7–14% of cod landings over the period 2002–2013 (InterCatch data), it does not provide discard estimates. Nevertheless, the agreed procedure applied in Intercatch is that discards raising should include Norway (i.e. Norway will be allocated discards associated with landings in reported métiers). Furthermore, tagging and genetic studies have indicated that Norwegian coastal cod are different to North Sea cod and do not generally move into areas occupied by North Sea cod. Therefore, Norwegian coastal cod data have been removed from North Sea cod data by uploading only North Sea cod data into Intercatch for 2002 onwards, and by adjusting catches prior to 2002 to reflect the removal of Norwegian coastal cod data (an annual multiplicative adjustment of no more than 2.5% was made using Norwegian coastal cod data - see ICES WKNSEA 2015 for more details).

Table B.1.1: Proportion of landings (as a percentage) taken in each of three areas (first block), together with (by area) discard ratio coverage of the landings (second block), age coverage of the landings (third block) and age coverage of the observed discards (fourth block). Shaded cells indicate where there has been less than 50% coverage. Detailed results were reported in WD6 of ICES WKNSEA (2015).

	Landings proportions (%)			Discard ratio coverage			Landings age coverage			Discards age coverage		
	IV	IIIaN	VIId	IV	IIIaN	VIId	IV	IIIaN	VIId	IV	IIIaN	VIId
2002	81	13	6	50%	73%	0%	64%	83%	0%	88%	69%	0%
2003	80	13	7	57%	67%	0%	59%	93%	3%	88%	42%	0%
2004	82	14	4	54%	67%	6%	68%	93%	7%	81%	94%	100%
2005	81	14	4	58%	55%	5%	75%	91%	4%	81%	82%	100%
2006	82	13	6	75%	66%	6%	77%	91%	14%	85%	96%	100%
2007	79	12	9	58%	60%	5%	71%	90%	11%	99%	92%	100%
2008	81	13	6	65%	59%	10%	73%	89%	16%	95%	100%	100%
2009	83	11	6	57%	85%	81%	72%	95%	80%	97%	93%	100%
2010	84	11	5	70%	77%	81%	80%	95%	84%	100%	90%	100%
2011	83	12	4	69%	83%	74%	72%	95%	74%	97%	90%	100%
2012	83	13	4	66%	79%	76%	82%	88%	81%	95%	89%	100%
2013	83	14	3	77%	72%	78%	82%	85%	81%	91%	96%	100%

Discard numbers-at-age were estimated for areas 4 and 7.d by applying the Scottish discard ogives to the international landings-at-age for years prior to 2002, while those in 20 were based on observer sampling estimates. Table B.1.2 reports the discard ratio coverage of the most important métiers (those that comprised 1% or more of cod landings over all areas and quarters for 2011–2013.

Table B.1.2. Discard ratio coverage by métier and country for the years 2011–2013 for those métiers which comprised 1% or more of cod landings over all areas and quarters.

2011

	Belgium	Denmark	France	Germany	Netherlands	Norway	Sweden	UK (England)	UK(Scotland)
GNS_DEF_120-219_0_0_all	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
GNS_DEF_all_0_0_all	NA	NA	NA	NA	NA	0	NA	0.1071281	NA
GTR_DEF_all_0_0_all	NA	NA	0.3652579	NA	NA	NA	NA	NA	NA
LLS_FIF_0_0_0_all	NA	NA	NA	NA	NA	0	NA	NA	NA
MIS_MIS_0_0_0_HC	NA	0.1012391	NA	NA	NA	NA	NA	NA	NA
OTB_CRU_70-99_0_0_all	NA	NA	NA	NA	NA	NA	NA	0.8271698	NA
OTB_CRU_90-119_0_0_all	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
OTB_DEF_>=120_0_0_all	NA	1.0000000	NA	0.9938589	NA	0	NA	0.9973467	1
OTB_DEF_>=120_0_0_all_FDF	NA	1.0000000	NA	NA	NA	NA	NA	NA	1
OTB_DEF_70-99_0_0_all	NA	NA	0.6850180	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all_FDF	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_100-119_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA
TBB_DEF_>=120_0_0_all	3.581356e-05	NA	NA	NA	NA	NA	NA	NA	NA
TBB_DEF_70-99_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA

2012

	Belgium	Denmark	France	Germany	Netherlands	Norway	Sweden	UK (England)	UK(Scotland)
GNS_DEF_120-219_0_0_all	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
GNS_DEF_all_0_0_all	NA	NA	NA	NA	NA	0	NA	NA	NA
GTR_DEF_all_0_0_all	NA	NA	0.6967654	NA	NA	NA	NA	NA	NA
LLS_FIF_0_0_0_all	NA	NA	NA	NA	NA	0	NA	NA	NA
MIS_MIS_0_0_0_HC	NA	0.0000000	NA	NA	NA	NA	NA	NA	NA
OTB_CRU_90-119_0_0_all	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
OTB_DEF_>=120_0_0_all	NA	1.0000000	NA	0.9834082	NA	0	NA	NA	1
OTB_DEF_>=120_0_0_all_FDF	NA	1.0000000	NA	0.9658608	NA	NA	NA	NA	1
OTB_DEF_70-99_0_0_all	NA	NA	0.7796973	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all	NA	0.7133178	NA	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all_FDF	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_>=120_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA
TBB_DEF_>=120_0_0_all	0	NA	NA	NA	NA	NA	NA	NA	NA
TBB_DEF_all_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA

2013

	Belgium	Denmark	France	Germany	Netherlands	Norway	Sweden	UK (England)	UK(Scotland)
GNS_DEF_120-219_0_0_all	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
GNS_DEF_all_0_0_all	NA	NA	NA	NA	NA	0	NA	NA	NA
LLS_FIF_0_0_0_all	NA	NA	NA	NA	NA	0	NA	NA	NA
MIS_MIS_0_0_0_HC	NA	0.0000000	NA	NA	NA	NA	NA	NA	NA
OTB_CRU_90-119_0_0_all	NA	1.0000000	NA	NA	NA	NA	1	NA	NA
OTB_DEF_>=120_0_0_all	NA	1.0000000	NA	0.8996081	NA	0	NA	NA	0.9999979
OTB_DEF_>=120_0_0_all_FDF	NA	1.0000000	NA	0.8963346	NA	NA	NA	NA	0.9973569
OTB_DEF_70-99_0_0_all	NA	NA	0.8093578	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all	NA	0.8255804	NA	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all_FDF	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_>=120_0_0_all	NA	0.9506375	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_100-119_0_0_all	NA	NA	NA	NA	0.6776727	NA	NA	NA	NA
TBB_DEF_>=120_0_0_all	0.4450264	NA	NA	NA	NA	NA	NA	NA	NA
TBB_DEF_70-99_0_0_all	NA	NA	NA	NA	1.0000000	NA	NA	NA	NA

For cod in 4, 20 (Skagerrak) and 7.d, ICES first raised concerns about the mis-reporting and non-reporting of landings in the early 1990s, particularly when TACs became intentionally restrictive for management purposes. Some WG members have since provided estimates of under-reporting of landings to the WG, but by their very nature these are difficult to quantify. In terms of events since the mid–1990s, the WG believes that under-reporting of landings may have been significant in 1998 because of the abundance in the population of the relatively strong 1996 year-class as 2-year-olds. The landed weight and input numbers at age data for 1998 were adjusted to include an estimated 3 000 tons of under-reported catch. The 1998 catch estimates remain unchanged in the present assessment, apart from the small adjustment for the removal of Norwegian coastal cod data (see above).

For 1999 and 2000, the WG has no *a priori* reason to believe that there was significant under-reporting of landings. However, the substantial reduction in fishing effort implied by the 2001, 2002 and 2003 TACs is likely to have resulted in an increase in unreported catch in those years. Anecdotal information from the fisheries in some countries indicated that this may indeed have been the case, but the extent of the alleged under-reporting of catch varies considerably. Since the WG has no basis to judge the overall extent of under-reported catch, it has no alternative than to use its best estimates of landings, which in general are in line with the officially reported landings. An attempt is made to incorporate a statistical correction to the sum of reported landings and discards data in the assessment of this stock. Buyers and Sellers legislation introduced in the UK towards the end of 2005 is expected to have improved the accuracy of reported cod landings for the UK. This has brought the UK in line with existing EU legislation.

Age compositions

Age compositions are currently provided by Denmark, England, France, Germany, the Netherlands, Scotland and Sweden. However, not all of the most important métiers (those that comprised 1% or more of cod landings over all areas and quarters) are sampled (Table B.1.3), and the Netherlands does not routinely provide age compositions (except for one métier in 2012).

Table B.1.3. Age coverage by métier and country for the years 2011–2013 for those métiers which comprised 1% or more of cod landings over all areas and quarters.

2011

	Belgium	Denmark	France	Germany	Netherlands	Norway	Sweden	UK (England)	UK(Scotland)
GNS_DEF_120-219_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
GNS_DEF_all_0_0_all	NA	NA	NA	NA	NA	0	NA	0.6624181	NA
GTR_DEF_all_0_0_all	NA	NA	0.3652579	NA	NA	NA	NA	NA	NA
MIS_MIS_0_0_0_HC	NA	1	NA	NA	NA	NA	NA	NA	NA
OTB_CRU_70-99_0_0_all	NA	NA	NA	NA	NA	NA	NA	0.9937665	NA
OTB_CRU_90-119_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
OTB_DEF_>=120_0_0_all	NA	1	NA	0.9692616	NA	0	NA	0.9973467	1
OTB_DEF_>=120_0_0_all_FDF	NA	1	NA	NA	NA	NA	NA	NA	1
OTB_DEF_70-99_0_0_all	NA	NA	0.6850180	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all_FDF	NA	1	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_100-119_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA
TBB_DEF_>=120_0_0_all	0	NA	NA	NA	NA	NA	NA	NA	NA
TBB_DEF_70-99_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA

2012

	Belgium	Denmark	France	Germany	Netherlands	Norway	Sweden	UK (England)	UK(Scotland)
GNS_DEF_120-219_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
GNS_DEF_all_0_0_all	NA	NA	NA	NA	NA	0.9992355	NA	NA	NA
GTR_DEF_all_0_0_all	NA	NA	0.7192067	NA	NA	NA	NA	NA	NA
LLS_FIF_0_0_0_all	NA	NA	NA	NA	NA	0.0000000	NA	NA	NA
MIS_MIS_0_0_0_HC	NA	1	NA	NA	NA	NA	NA	NA	NA
OTB_CRU_90-119_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
OTB_DEF_>=120_0_0_all	NA	1	NA	0.9501721	NA	0.5850162	NA	NA	1
OTB_DEF_>=120_0_0_all_FDF	NA	1	NA	0.8544592	NA	NA	NA	NA	1
OTB_DEF_70-99_0_0_all	NA	NA	0.7796973	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all_FDF	NA	1	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_>=120_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA
TBB_DEF_>=120_0_0_all	0	NA	NA	NA	NA	NA	NA	NA	NA
TBB_DEF_all_0_0_all	NA	NA	NA	NA	1	NA	NA	NA	NA

2013

	Belgium	Denmark	France	Germany	Netherlands	Norway	Sweden	UK (England)	UK(Scotland)
GNS_DEF_120-219_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
GNS_DEF_all_0_0_all	NA	NA	NA	NA	NA	0.9898023	NA	NA	NA
LLS_FIF_0_0_0_all	NA	NA	NA	NA	NA	0.0000000	NA	NA	NA
MIS_MIS_0_0_0_HC	NA	1	NA	NA	NA	NA	NA	NA	NA
OTB_CRU_90-119_0_0_all	NA	1	NA	NA	NA	NA	1	NA	NA
OTB_DEF_>=120_0_0_all	NA	1	NA	0.8996081	NA	0.6049244	NA	NA	0.9999979
OTB_DEF_>=120_0_0_all_FDF	NA	1	NA	0.8963346	NA	NA	NA	NA	0.9973569
OTB_DEF_70-99_0_0_all	NA	NA	0.8093578	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all_FDF	NA	1	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_>=120_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_100-119_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA
TBB_DEF_>=120_0_0_all	0	NA	NA	NA	NA	NA	NA	NA	NA
TBB_DEF_70-99_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA

Landings in numbers at age for age groups 1–11+ and 1963–present form the basis for the catch at age analysis but do not include industrial fishery bycatches landed for reduction purposes. Bycatch estimates are available for the total Danish and Norwegian small-meshed fishery in Sub-area 4 and separately for the Skagerrak.

Data exploration

Data exploration for commercial catch data for North Sea cod currently involves:

(a) expressing the total catch-at-age matrix as proportions-at-age, normalised over time, so that year classes making above-average contributions to the catches are shown as large positive residuals (and vice-versa for below-average contributions);

(b) performing log-catch-curve analyses to examine data consistency, fishery selectivity and mortality trends over time - the negative slope of a regression fitted to ages down a cohort (e.g. ages 2–4) can be used as a proxy for total mortality.

B.2. Biological Information

B.2.1. Weight-at-age

Mean catch weight-at-age is a catch-number weighted average of individual catch weight-at-age, available by country, area and type (i.e. landings and discards). For ages 1-9 there have been short-term trends in mean weight at age throughout the time series with a decline over the recent decade at ages 3–5 that recently seems to have been reversed. The data also indicate a slight downward trend in mean weight for ages 3-6 during the 1980s and 1990s. Ages 1 and 2 show little absolute variation over the long-term.

Using weight-at-age from annual ICES assessments and International Bottom Trawl Surveys, Cook *et al*. (1999) developed a model that explained weight-at-age in terms of a von Bertalanffy growth curve and a year-class effect. They found that the year-class effect was correlated with total and spawning stock biomass, indicating density-dependent growth, possibly through competition. Further evidence for density-dependent growth had previously been found by others (Houghton and Flatman 1981, Macer 1983 and Alphen and Heessen 1984), although they pointed to different mechanisms (Rijnsdorp *et al*., 1991, ICES 2005). Results from Macer (1983) imply that juvenile cod compete strongly with adults, while the data from Alphen and Heessen (1984) suggest strong within-year-class competition during the first three years of life.

Growth rate can be linked to temperature and prey availability (Hughes and Grand 2000, Blanchard *et al*., 2005). Growth parameters of North Sea cod given in ICES (1994) demonstrate that cod in the southern North Sea grow faster than those in the north, but reach a smaller maximum length (Oosthuizen and Daan 1974, ICES 2005). Furthermore, older and larger cod have lower optimal temperatures for growth (Björnsson and Steinarsson 2002), and distributions of cod are known to depend on the local depth and temperature (Ottersen *et al*., 1998, Swain 1999, Blanchard *et al*., 2005).

Differences in mean length by age and sex can also be found for mature vs. immature cod (ICES 2005). For example, Hislop (1984) found that within an age group, mature cod of each sex are, on average, larger than immature cod.

B.2.2. Natural mortality

Since the benchmark in 2009 (ICES WKROUND 2009) variable natural mortality estimates are used in the assessment for North Sea cod. An update of natural mortality estimates is produced by the Working Group on Multi Species Stock Assessment Methods (WGSAM) every three years in so called keyruns with the stochastic multi species model SMS. The model SMS (Lewy and Vinther 2004) is a stock assessment model including biological interaction estimated from a parameterised size dependent food selection function. The model is formulated and fitted to observations of total catches, survey cpue and stomach contents for the North Sea. Parameters are estimated by maximum likelihood and the variance/covariance matrix is obtained from the Hessian matrix.

In the most recent SMS analysis (ICES WGSAM 2014), the following predator and prey stocks were available: predators and prey (cod, whiting, haddock), prey only (herring, sprat, northern and southern sandeel, Norway pout), predator only (saithe), no predator prey interactions (sole and plaice) and 'external predators' (8 seabirds, starry ray, grey gurnard, western mackerel, North Sea mackerel, North Sea horse-mackerel, western horse-mackerel, grey seals, harbour porpoise and hake). The population dynamics of all species except 'external predators' were estimated within the model.

A working document (Kempf WD4) was provided to ICES WKNSEA (2015) describing the latest keyrun 2014 (ICES WGSAM 2014) with focus on natural mortality estimates for cod. In general, the keyrun in 2014 is an update of the 2011 keyrun. But compared to the 2011 keyrun, the time series of grey gurnard and raja abundances were revised, sandeel was split into a southern and northern component and hake was included as additional other predator in the model (but no cod was found in the available hake stomachs). In addition, the start year was changed from 1963 to 1974 because, for the early years, data on forage fish are highly uncertain.

Overall, the changes in estimated predation mortalities for cod were small between the 2011 and 2014 keyruns. However, a further change in the 2014 keyrun settings occurred after the WGSAM meeting. For age 3 cod a sudden jump in predation mortalities appeared in the original keyrun. This was caused by harbour porpoise which starts to prey on age 3 cod in the 1st quarter from 1998 onwards. The reason behind this is that the cod mean weight at age in the sea in the SMS input data are lower after 1998. Therefore, it just falls below the highest observed mean weight in harbour porpoise stomachs and harbour porpoise starts to prey on age 3 cod in the model. However, after 1999 no mean weight at age in the sea per quarter was available from WGNSSK and fixed values were used as input constant from 2000 onwards. In addition, the estimated mortality of cod eaten by harbour porpoise might be biased. A preliminary study of the effect of differences in digestion rate of different sizes of otoliths in harbour porpoise stomach content was presented to the group and demonstrated that the consumption of large fish may be overestimated, if diet is estimated directly from the presence of otholiths in the stomach. ICES WGSAM (2014) considered that this may potentially have a considerable impact on the estimated consumption by harbour porpoise and that the estimation of correction rates applicable to North Sea harbour porpoises should be a priority area of study before the next key run is conducted. However, as no quantitative correction factors were available to the group, no correction could be made during the WGSAM meeting. Therefore, it was suggested to take the alternative 2014 keyrun as basis for the North Sea cod assessment because it is more consistent over time and more conservative by reducing the predation impact on large cod. The general trends stay the same as in the original keyrun; only the absolute level of M2 values is different.

Table B.1.4 gives the values for natural mortality, as derived by ICES WGSAM (2014). These values will continue to be used until the next keyrun is performed, scheduled for 2017. In the meantime, values from M-at-age from 2014 onwards will be kept constant and set equal to the 2013 values.

Table B.1.4. Cod in Subarea 4, Divisions 20 (Skagerrak) and 7.d. Natural mortality by age-group.

	Age						
	1	2	3	4	5	6	7+
1963	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1964	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1965	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1966	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1967	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1968	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1969	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1970	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1971	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1972	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1973	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1974	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1975	1.238	0.755	0.222	0.200	0.2	0.2	0.2
1976	1.261	0.735	0.222	0.200	0.2	0.2	0.2
1977	1.285	0.719	0.223	0.200	0.2	0.2	0.2
1978	1.307	0.709	0.223	0.200	0.2	0.2	0.2
1979	1.325	0.703	0.223	0.200	0.2	0.2	0.2
1980	1.339	0.702	0.223	0.200	0.2	0.2	0.2
1981	1.347	0.705	0.222	0.200	0.2	0.2	0.2
1982	1.348	0.710	0.222	0.200	0.2	0.2	0.2
1983	1.340	0.714	0.222	0.200	0.2	0.2	0.2
1984	1.325	0.717	0.221	0.200	0.2	0.2	0.2
1985	1.304	0.719	0.221	0.200	0.2	0.2	0.2
1986	1.279	0.720	0.221	0.200	0.2	0.2	0.2
1987	1.252	0.721	0.220	0.200	0.2	0.2	0.2
1988	1.226	0.722	0.220	0.200	0.2	0.2	0.2
1989	1.200	0.724	0.220	0.200	0.2	0.2	0.2
1990	1.177	0.725	0.220	0.200	0.2	0.2	0.2
1991	1.158	0.726	0.220	0.200	0.2	0.2	0.2
1992	1.144	0.728	0.220	0.200	0.2	0.2	0.2
1993	1.134	0.730	0.220	0.200	0.2	0.2	0.2
1994	1.129	0.733	0.220	0.200	0.2	0.2	0.2
1995	1.126	0.739	0.220	0.200	0.2	0.2	0.2
1996	1.123	0.747	0.221	0.200	0.2	0.2	0.2
1997	1.119	0.756	0.222	0.200	0.2	0.2	0.2
1998	1.113	0.767	0.223	0.200	0.2	0.2	0.2
1999	1.106	0.781	0.226	0.200	0.2	0.2	0.2
2000	1.100	0.796	0.228	0.200	0.2	0.2	0.2
2001	1.098	0.815	0.231	0.200	0.2	0.2	0.2
2002	1.102	0.836	0.234	0.200	0.2	0.2	0.2
2003	1.109	0.859	0.237	0.200	0.2	0.2	0.2
2004	1.120	0.881	0.239	0.200	0.2	0.2	0.2
2005	1.133	0.900	0.241	0.200	0.2	0.2	0.2
2006	1.146	0.914	0.241	0.200	0.2	0.2	0.2
2007	1.162	0.925	0.241	0.200	0.2	0.2	0.2
2008	1.179	0.934	0.240	0.200	0.2	0.2	0.2
2009	1.201	0.943	0.239	0.200	0.2	0.2	0.2
2010	1.228	0.955	0.239	0.200	0.2	0.2	0.2
2011	1.262	0.971	0.238	0.200	0.2	0.2	0.2
2012	1.303	0.991	0.238	0.200	0.2	0.2	0.2
2013	1.345	1.014	0.239	0.200	0.2	0.2	0.2
2014*	1.345	1.014	0.239	0.200	0.2	0.2	0.2

*A new key run was performed in 2014 with data up to 2013 (ICES WGSAM 2014), so 2014 M–values are assumed equal to 2013.

B.2.3. Maturity

Until 2015 the maturity values applied to all years were left unchanged from year to year. They were estimated using the International Bottom trawl Survey series for 1981–1985. These values were derived for the North Sea.

Age group	Proportion mature
1	0.01
2	0.05
3	0.23
4	0.62
5	0.86
6	1.0
7+	1.0

However, maturity at age has changed in this stock with a positive trend over time (Cook *et al.*, 1999, Yoneda and Wright 2004). There are also substantial population level differences in the rate of maturation change, with no significant shift in maturation probability being detected in Viking but substantial increases in the northwest and southern North Sea (Wright *et al.*, 2011). To address these changes in the stock, a maturity age key was constructed for the assessment region that was weighted by population subarea. The maturity-at-age key was re-estimated in 2017 to produce a time-series of maturity estimates that are calculated consistently over time in a manner that is transparent and reproducible, according to the methodology described by ICES-WKNSEA (2015). Records from 1978 are extracted from the DATRAS–Q1 exchange data and assigned to a population subarea (Figure B.1.1), with data from the Skagerrak excluded from the calculations. Age-length keys are fit to the CA data by population subarea using continuation ratio logits (Berg and Kristensen, 2012; see Section B.3) with age 6 modelled as a plus group and subsequently discarded as only fish <6 years old are considered in the maturity calculations. Survey numbers-at-age ($n_{a,y,p}$) are then calculated using the observed numbers-at-length (raised to 60 minutes of effort) and the estimated ALKs. Proportion mature in each subarea ($M_{a,y,p}$) is taken as the ratio of numbers of mature fish-at-age to total numbers of fish-at-age in the CA data. Proportion mature-at-age by year is then estimated as:

$$M_{a,y} = \frac{\sum N_{a,y,p} \cdot M_{a,y,p}}{\sum N_{a,y,p}}$$

Where $N_{a,y,p}$ is the total number of cod-at-age in a subarea, obtained by raising the survey numbers-at-age ($n_{a,y,p}$) according to:

$$N_{a,y,p} = \frac{A_p}{A_s} \cdot n_{a,y,p}$$

Where A_p is the area of a population subarea (NW: 209 822 km^2, S: 732 104 km^2 and V: 233 372 km^2; ICES, 2015) and A_s is the swept area of the GOV (ICES, 2015). This gives an estimate of the numbers-at-age per year and subpopulation to weight maturity across the stock. Full source code is provided in Walker and Poos (2017).

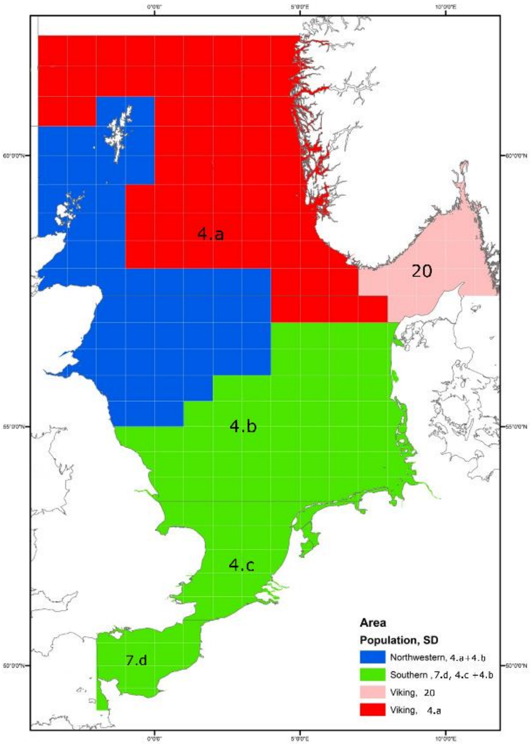

Figure B.1.1. Subareas adopted for the spatial analysis of North Sea cod. The subareas are referred to: Sk (Skagerrak); V (Viking); NW (northwestern) and S (southern), corresponding to pink, red, blue and green colours on the map, respectively.

As variation in sampling intensity added to the inter-annual variation, a smoother was applied to the maturity age key. This smoothed maturity age key was then applied to the estimation of spawning stock biomass, using the following R-code (based in the R mgcv package):

```
skipYears=1:10
columnsToSmooth=1:5
mo=prop.mature[-c(skipYears),]

for(cc in columnsToSmooth){
    ww = mo[,cc];
    tt = 1:length(ww)
    tmp = gam(ww ~ s(tt))
    mo[,cc] = predict(tmp);
}
prop.mature[-c(skipYears),]=mo
```

The time-varying maturity ogive now used in the assessment is given in Table B.1.5. These values are the result of the smoothing code given above, and will change as each new year of data is added, and annual updates will be given in the WG report.

Table B.1.5. Cod in Subarea 4, Divisions 20 (Skagerrak) and 7.d. Maturity by age-group.

	Age					
	1	2	3	4	5	6+
1963	0.010	0.050	0.230	0.620	0.860	1.000
1964	0.010	0.050	0.230	0.620	0.860	1.000
1965	0.010	0.050	0.230	0.620	0.860	1.000
1966	0.010	0.050	0.230	0.620	0.860	1.000
1967	0.010	0.050	0.230	0.620	0.860	1.000
1968	0.010	0.050	0.230	0.620	0.860	1.000
1969	0.010	0.050	0.230	0.620	0.860	1.000
1970	0.010	0.050	0.230	0.620	0.860	1.000
1971	0.010	0.050	0.230	0.620	0.860	1.000
1972	0.010	0.050	0.230	0.620	0.860	1.000
1973	0.008	0.051	0.238	0.642	0.878	1.000
1974	0.008	0.053	0.229	0.617	0.846	1.000
1975	0.008	0.056	0.221	0.592	0.814	1.000
1976	0.007	0.057	0.214	0.567	0.784	1.000
1977	0.007	0.059	0.210	0.545	0.756	1.000
1978	0.007	0.060	0.207	0.525	0.731	1.000
1979	0.007	0.059	0.207	0.507	0.711	1.000
1980	0.007	0.059	0.207	0.494	0.697	1.000
1981	0.007	0.058	0.209	0.484	0.688	1.000
1982	0.006	0.057	0.213	0.479	0.686	1.000
1983	0.006	0.058	0.218	0.480	0.689	1.000
1984	0.006	0.061	0.227	0.487	0.698	1.000
1985	0.007	0.067	0.241	0.500	0.713	1.000
1986	0.007	0.075	0.262	0.518	0.731	1.000
1987	0.007	0.085	0.288	0.542	0.751	1.000
1988	0.007	0.095	0.320	0.570	0.774	1.000
1989	0.007	0.104	0.355	0.600	0.797	1.000
1990	0.007	0.111	0.389	0.632	0.819	1.000
1991	0.007	0.115	0.420	0.662	0.841	1.000
1992	0.008	0.115	0.444	0.691	0.860	1.000
1993	0.008	0.113	0.460	0.715	0.877	1.000
1994	0.008	0.111	0.468	0.736	0.893	1.000
1995	0.009	0.110	0.471	0.753	0.906	1.000
1996	0.010	0.115	0.471	0.767	0.916	1.000
1997	0.011	0.126	0.473	0.778	0.925	1.000
1998	0.012	0.144	0.481	0.787	0.933	1.000
1999	0.013	0.169	0.496	0.795	0.938	1.000
2000	0.015	0.198	0.520	0.802	0.943	1.000
2001	0.017	0.230	0.552	0.810	0.946	1.000
2002	0.019	0.261	0.591	0.818	0.949	1.000
2003	0.022	0.289	0.631	0.827	0.951	1.000
2004	0.024	0.313	0.671	0.835	0.952	1.000
2005	0.027	0.331	0.706	0.844	0.953	1.000
2006	0.031	0.344	0.734	0.852	0.954	1.000
2007	0.034	0.353	0.752	0.860	0.955	1.000
2008	0.037	0.360	0.762	0.867	0.956	1.000
2009	0.041	0.364	0.761	0.872	0.956	1.000
2010	0.045	0.367	0.752	0.876	0.955	1.000
2011	0.049	0.368	0.736	0.878	0.953	1.000
2012	0.052	0.367	0.712	0.877	0.951	1.000
2013	0.056	0.362	0.683	0.874	0.946	1.000
2014	0.060	0.355	0.649	0.868	0.941	1.000
2015	0.064	0.345	0.613	0.861	0.934	1.000
2016	0.067	0.333	0.575	0.852	0.927	1.000

In the analysis of International Bottom Trawl Survey maturity data, Cook *et al*. (1999) found that although accounting for changes in growth and maturity for North Sea cod altered the scale of SSB values, it did not make substantial changes to trajectories over time, and did not substantially alter the estimates of sustainable exploitation rates for the stock. The WKNSEA 2015 benchmark found, similarly, that although the SSB values were changed, the variable maturity ogive had no other material effect on assessment results.

The use of spawning stock biomass as a measure of reproductive potential has the implicit assumption that the eggs per adult biomass remain constant, i.e. there is no age or size related difference in relative fecundity (eggs per gram of body mass). However, the relative fecundity of cod does vary with age and has changed over time. Rijnsdorp *et al*. (1991) found that relative fecundity of cod from the southern and central North Sea in the late 1980s was approximately 20% higher than that in the early 1970s, an increase that coincided with a 4–fold decline in spawning stock biomass. Yoneda and Wright (2004) found that fecundity - size relationships for the north west North Sea cod also changed between the late 1960s and early 2000s and this was not related to any increase in individual condition. In 2002–3, 5 year old females from the north west North Sea were found to have 1.36 and 1.14 times the relative fecundity of a 3 and 4 year old female, respectively. That study also found differences in the relative fecundity between the Viking and north west subareas, with the latter having on average a 37% greater relative fecundity than the former.

B.2.4. Recruitment

Recruitment has been linked not only to SSB, but also to temperature (Dickson and Brander 1993, Myers *et al*., 1995, Planque and Fredou 1999, O'Brien *et al*., 2000), plankton production timing and mean prey size (Beaugrand *et al*. 2003), the NAO (Brander and Mohn 2004, ICES 2005) and the demographic composition of spawners (Wright, 2014).

B.3. Surveys

Four survey series are available for this assessment:

- English third-quarter groundfish survey (EngGFS), ages 0–7, which covers the whole of the North Sea in August-September each year to about 200m depth using a fixed station design of 75 standard tows. The survey was conducted using the Granton trawl from 1977–1991 and with the GOV trawl from 1992–present. Only ages 1–6 should be used for calibration, as catch rates for older ages are very low.
- Scottish third-quarter groundfish survey (ScoGFS): ages 1–8. This survey covers the period 1982–present. This survey is undertaken during August each year using a fixed station design and the GOV trawl. Coverage was restricted to the northern part of the North Sea until 1998, corresponding to only the northernmost distribution of cod in the North Sea. Since 1999, it has been extended into the central North Sea and made use of a new vessel and gear. Only ages 1–6 should be used for calibration, as catch rates for older ages are very low.
- Quarter 1 international bottom-trawl survey (IBTS–Q1): ages 1–6+, covering the period 1976–present (usually data are available up to the year of the assessment for this survey, whereas it is only available up to the year prior to the assessment year for the other surveys). This multi-vessel survey covers the whole of the North Sea using fixed stations of at least two tows per rectangle with the GOV trawl.
- Quarter 3 international bottom-trawl survey (IBTS–Q3): ages 0–6+, covering the period 1991–present. This multi-vessel survey covers the whole of the North Sea

using fixed stations of at least two tows per rectangle with the GOV trawl. The Scottish and English third quarter surveys described above contribute to this index.

Since the EngGFS and ScoGFS already form part of the IBTS–Q3 survey, the WG only considers the IBTS–Q1 and IBTS–Q3 surveys for assessments.

The last benchmark of North Sea Cod resulted in the exclusion of the IBTS–Q3 survey index, because divergent trends in recent years were observed when the Q3 index was applied independently of the Q1 index (ICES WKCOD 2011). At that time it was decided that until the reasons for the discrepancies were resolved, the Q1 was more likely to reflect the stock, and hence the Q3 index was dropped from the assessment. The indices were calculated using the standard stratified mean methodology (mean by rectangle within year, followed by mean over rectangles by year), applied to an extended area (Figure B.1.2). This simple design based estimator is unable to account for systematic changes in experimental conditions (e.g. change of survey gear). Given these issues, an alternative methodology that calculates standardized age-based survey indices based on GAMs and Delta-distributions (see also Berg WD3, ICES WKNSEA 2015) has now been adopted. The general methodology is described in Berg and Kristensen (2012) and Berg *et al*. (2014) and is implemented in R based on the DATRAS (http://rforge.net/DATRAS/) and surveyIndex packages.

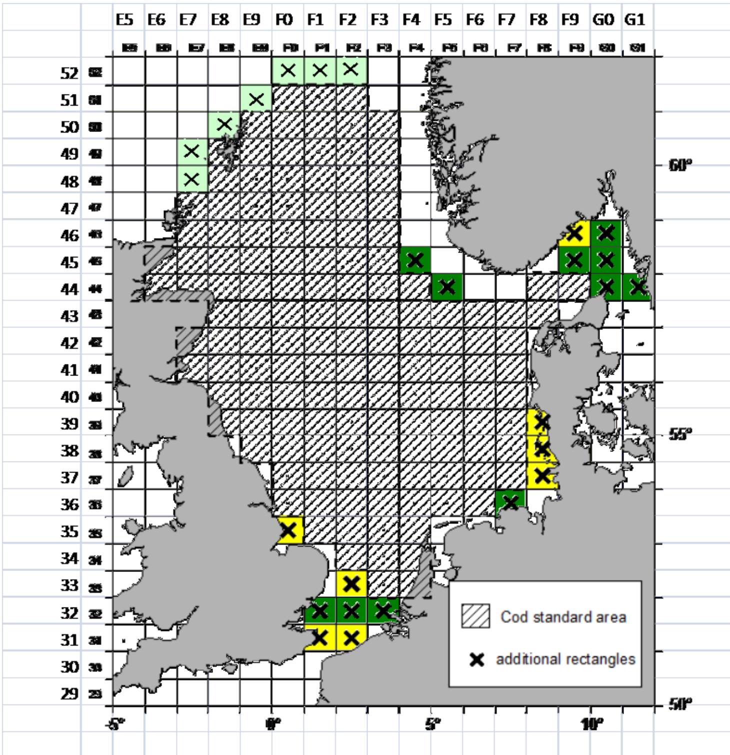

Figure B.1.2. Extension of cod standard area used for the NS–IBTS extended index. Crosses indicate suggested extensions to the survey (ICES WKROUND 2009; ICES WKCOD 2011); green squares (light and dark) indicate where the IBTS group indicate data is available; yellow squares indicate where intermittent coverage does not allow inclusion and the IBTS WG considered should be omitted; light green squares indicate the recommended extension around Shetland (ICES WKCOD 2011).

B.3.1. Description of methodology

Smooth spatially varying age length keys are estimated using the methodology described in Berg and Kristensen (2012). Numbers-at-age are then calculated using the observed numbers-at-length and the estimated ALKs. This methodology was found to give higher internal consistencies in survey indices for haddock when compared to the current standard approach of estimating ALKs that are constant within "Roundfish" (RF) areas. It avoids ad-hoc borrowing of samples from neighbouring RF areas, when certain age groups are missing, and it provides an objective fill-in procedure for missing length groups also. This is possible because the probability of age given length is modelled using smooth functions of the length of a fish and the spatial coordinates where the haul was taken, rather than relying on some specific stratification of length and space. The methodology has been implemented in the DATRAS package with full source code available. The differences between the standard ALKs and the ones used here were not investigated in detail, but comparisons of the survey indices calculated using the smooth ALKs and the stratified mean method with the standard DATRAS–produced survey indices displayed little differences, indicating that the choice of ALK method is not crucial for cod.

The primary purpose of the Delta–GAM model is to derive survey indices by age free of nuisance factors caused by changes in experimental conditions. The indices are obtained by summing filtered model predictions over a spatial grid. The Delta-GAM model is able to account for changes in experimental conditions such as different gears, ship/country effects, day/night effects, and changes in spatial coverage. Such effects may be balanced out by the relatively stable survey design in the later years; however, several changes in the gear used, proportion of night hauls, haul duration etc. have occurred for most surveys during the entire time-series.

Each age group and quarter is modelled independently. The most complex equation considered for the expected numbers-at-age in the i^{th} haul (or probability of non-zero catch for the presence-absence part), μ_i , is as follows:

$$g(\mu_i) = Year(i) + Gear(i) + U(i)_{ship} + f_1(Year_i, lon_i, lat_i) + f_2(depth_i) + f_3(time_i) + \log(HaulDur_i)$$

where the two first terms are categorical effects for year and gear type, U is a random vessel effect, f_1 is a 3-dimensional tensor product spline (a 2D thin-plate spline basis for space and a 1D cubic spline for time), f_2 is a 1-dimensional thin plate spline for the effect of bottom depth, and f_3 is a cyclic cubic regression spline on the time of day (i.e. with same start and end point). The function g is the link function, which is taken to be the logit function for the binomial model. The strictly positive observations can be modelled using either a Gamma or a log-normal distribution, and a Gamma distribution was found to provide the best fit. The Gamma part of the delta-Gamma model is fitted with a log link. The nuisance parts of the model (here gear, ship, time of day, and haul-duration) are held constant when the filtered predictions on the grid are calculated so as to remove their effect on the index.

Ten possible models of varying complexity were considered during the 2015 WKNSEA benchmark (ICES WKNSEA 2015). An important choice was whether a 3D space-time smoother f_1 (Year, lon, lat) was necessary, or whether the spatial distribution could be considered stationary over the whole time-series f_1(lon, lat). The best model (in AIC terms) for the Q1 data included the space-time interaction f_1(Year, lon, lat), whereas for Q3, the stationary model using f_1(lon, lat) (and including ship effects) seemed most appropriate.

A comparison of the effects of all ten models on the resultant indices indicated that the Q1 index was reasonably robust to model choice, but that the Q3 index showed greater sensitivity, particularly for the latest years (2011+) where the Q3 index showed bigger increases than Q1 for several ages, the timing of which coincided with the replacement of the Swedish "ARG" vessel with "DANS", and the simultaneous introduction of a more randomised set of haul positions for Q3 (but not Q1) for "DANS". These changes also coincided with an increase in the IBTS–Q3 index in the Skagerrak over this period, and because the Swedish survey is the only one covering the Skagerrak, a confounding effect arises where it is difficult to separate out the effects of changing both the vessel and sampling positions in Q3 from a simultaneous potential increase in abundance. This confounding was noted, because when the stationary model was used for Q3, the large catches observed by "DANS" in the Skagerrak compared to "ARG" were explained by the ship effect, whereas they were attributed to space-time effect in the non-stationary model.

Given all these factors and the fact that the stationary model including ship effects was best for Q3, WKNSEA decided to adopt the stationary model using f_1(lon, lat) and including a ship effect for Q3, and since the stationary model was also second best for Q1 with only a slightly higher AIC compared to the non-stationary model, it was decided, for the sake of consistency, to adopt the same model for Q1. Consideration of the effect of model choice on assessment residuals also played a role in model choice (ICES WKNSEA 2015), with the final choice exhibiting improved residual patterns for Q3 compared to those seen in the past (ICES WKCOD 2011). All Delta–GAM models except the very simple year-effect only model had better consistencies than the standard stratified mean approach, which is similar to the currently used index produced by DATRAS.

In summary the final Delta–GAM models selected for NS-IBTS–Q1 and Q3 comprised a stationary model using f_1(lon, lat), and included ship, year, depth, time-of-day and haul-duration effects. In addition, the Q3 model also included a gear effect (Q1 only has a single gear, GOV, so this effect is not an issue).

B.3.2. Data exploration

Data exploration for survey data for North Sea cod currently involves:

(a) expressing the survey abundance indices (IBTS–Q1 and IBTS–Q3) in log-mean standardised form, both by year and cohort, to investigate whether there are any year effects, and the extent to which the surveys are able to track cohort signals;

(b) performing log-catch-curve analyses on the abundance indices to examine data consistency and mortality trends over time - the negative slope of a regression fitted to ages down a cohort (e.g. ages 2–4) can be used as a proxy for total mortality;

(c) performing within-survey consistency plots (correlation plots of a cohort at a given age against the same cohort one or more years later) to investigate self-consistency of a survey;

(d) performing between-survey consistency plots (correlation plots of a given age for IBTS–Q1 against the same age for IBTS–Q3) to investigate the consistency between surveys;

(e) applying a SURBA analysis to the survey data for comparison with models that include fishery-dependent data.

B.4. Commercial CPUE

Reliable, individual, disaggregated trip data were not available for the analysis of CPUE. Since the mid-to-late 1990s, changes to the method of recording data means that individual trip data are now more accessible than before; however, the recording of fishing effort as hours fished has become less reliable because it is not a mandatory field in the logbook data. Consequently, the effort data, as hours fished, are not considered to be representative of the fishing effort actually deployed.

The WG has previously argued that, although they are in general agreement with the survey information, commercial cpue tuning series should not be used for the calibration of assessment models due to potential problems with effort recording and hyper-stability (ICES WGNSSK 2001), and also changes in gear design and usage, as discussed by ICES WGFTFB (2006, 2007). Therefore, although the commercial fleet series are available, only survey and commercial landings and discard information are analysed within the assessment presented.

B.5. Other relevant data

The annual North Sea Fishers' Survey presents fishers' perceptions of the state of several species including cod; the survey has been carried out annual since 2003, following a pilot in 2002 (Napier, 2014). In addition, a number of collaborative research projects (fisheries science partnerships) have in the past been reported to the WGNSSK. These studies have provided time series of quantitative information have been relatively local, whereas those with wider coverage have been qualitative. The studies have therefore been used to corroborate assessment results and highlight differences in perception, and have proven useful in examining the dynamics of sub-stocks within the North Sea, for instance local recruitment, and thereby in the provision of advice to managers. However, there are no currently active Fisheries-Science partnerships for North Sea cod.

C. Historical Stock Development

C.1. Model used as a basis for advice

The state-space model SAM (Nielsen and Berg, 2014) offers a flexible way of describing the entire system, with relative few model parameters. It allows for objective estimation of important variance parameters, leaving out the need for subjective *ad-hoc* adjustment numbers, which is desirable when managing natural resources.

For North Sea Cod two survey indices (IBTS–Q1 and Q3) are used, along with the total catch-at-age data. No commercial fleets with effort information are used. A recruitment random walk process is used to model recruitment (in log scale), but there is no visual difference in the results if a Ricker or Beverton-Holt curve is used in its place. Fishing mortality random walks are allowed to be correlated among the ages.

For North Sea Cod the model is extended to allow estimation of possible bias (positive or negative) in the reported total catches from 1993 to 2005. The model assumes that reported catches should simply be scaled by a year and possibly age specific factor $S_{a,y}$. This leads to the following updated catch equation for the total catches.

$$\log C^{(\circ)}_{a,y} = -\log S_{a,y} + \log\left(\frac{F_{a,y}}{Z_{a,y}}(1-e^{-Z_{a,y}})N_{a,y}\right) + \varepsilon^{(\circ)}_{a,y}$$

In the main scenario considered the multiplier $S_{a,y}$ is set according to:

$$S_{a,y} = \begin{cases} 1, & y < 1993 \text{ or } y > 2005 \\ \tau_y, & 1993 \le y \le 2005 \end{cases}$$

The total vector of model parameters for this model is:

$$\vartheta = (Q_{s=1,a=1,2,3,4,5}, Q_{s=2,a=1,2,3,4}, \sigma^2_R, \sigma^2_S, \sigma^2_{F,a=1,2+}, \sigma^2_{0,a=1,2,3+}, \sigma^2_{s=1,a=1,2+}, \sigma^2_{s=2,a=1,2+}, \tau_{1993}, \tau_{1994}, \ldots, \tau_{2005}, \rho)$$

The Q parameters are catchabilities corresponding to the survey fleets (these parameters are survey- and age-specific, covering ages 1–5 for IBTS–Q1 and ages 1–4 for IBTS–Q3). The variance parameters σ^2_R, σ^2_S, and $\sigma^2_{F,a=1,2+}$ are process variances for recruitment, survival, and development in fishing mortality respectively (the latter separately for ages 1 and 2+). The remaining σ^2 parameters are describing the variance of different observations divided into fleet and age classes. Finally the τ parameters are the scaling factors for the total catches, and ρ is the correlation parameter (among the ages) for the random walks on the fishing mortalities.

The WKNSEA benchmark introduced an extension to allow for varying correlation between different ages by setting the correlation of the log F annual increments to be a simple function of the age difference (AR(1) process over the ages). By doing this, individual log F processes will develop correlated in time, but in such a way that neighbouring age classes have more similar fishing mortalities than more distant ones. This correlation structure does not introduce additional parameters to the model, and is referred to below as an AR correlation structure (see Nielsen and Berg 2014 for more details).

Model used: SAM (with correlated fishing mortality at age based on an AR correlation structure)

Software used: Source code and all scripts are freely available at http://www.stockassessment.org [Username: guest; Password: guest]

C.2. Model Options chosen

A configuration file is used to set up the model run once the data files, in the usual Lowestoft format, have been prepared. The file has the following form:

```
# Min Age (should not be modified unless data is modified accordingly)
 1
 # Max Age (should not be modified unless data is modified accordingly)
 6
 # Max Age considered a plus group (0=No, 1=Yes)
 1
 # The following matrix describes the coupling
 # of fishing mortality
 # Rows represent fleets.
 # Columns represent ages.
```

```
 1      2       3       4       5       6
 0      0       0       0       0       0
 0      0       0       0       0       0
# Use correlated random walks for the fishing mortalities
 # ( 0 = independent, 1 = correlation estimated)
 2
 # Coupling of catchability PARAMETERS
 0      0       0       0       0       0
 1      2       3       4       5       0
 6      7       8       9       0       0
 # Coupling of power law model EXPONENTS (if used)
 0      0       0       0       0       0
 0      0       0       0       0       0
 0      0       0       0       0       0
 # Coupling of fishing mortality RW VARIANCES
 1      2       2       2       2       2
 0      0       0       0       0       0
 0      0       0       0       0       0
 # Coupling of log N RW VARIANCES
 1      2       2       2       2       2
 # Coupling of OBSERVATION VARIANCES
 1      2       3       3       3       3
 4      5       5       5       5       0
 6      7       7       7       0       0
 # Stock recruitment model code (0=RW, 1=Ricker, 2=BH, ... more in time)
 0
 # Years in which catch data are to be scaled by an estimated parameter
 # first the number of years
13
 # Then the actual years
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
 # Then the model config lines years cols ages
  1    1    1    1    1    1
  2    2    2    2    2    2
  3    3    3    3    3    3
  4    4    4    4    4    4
  5    5    5    5    5    5
  6    6    6    6    6    6
  7    7    7    7    7    7
  8    8    8    8    8    8
  9    9    9    9    9    9
 10   10   10   10   10   10
 11   11   11   11   11   11
 12   12   12   12   12   12
 13   13   13   13   13   13
```

```
# Define Fbar range
2     4
```

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1963–present	-	Y
Canum	Catch at age in numbers	1963–present	1–6+	Y
Weca	Weight at age in the commercial catch	1963–present	1–6+	Y
West	Weight at age of the spawning stock at spawning time.	Weca used for West	Weca used for West	Weca used for West
Mprop	Proportion of natural mortality before spawning	1963–present	1–6+	N
Fprop	Proportion of fishing mortality before spawning	1963–present	1–6+-	N
Matprop	Proportion mature at age	1963–present	1–6+	Y
Natmor	Natural mortality	1963–present*	1–6+	Y

*Updated values for natural mortality will only be provided every 3 years

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	IBTS–Q1, stationary delta–GAM with ship effect	1983–final year of catch data + 1	1–5
Tuning fleet 2	IBTS–Q3, stationary delta–GAM with ship effect	1992–final year of catch data*	1–4

*When performing autumn short term forecast, this becomes 1992–final year of catch data + 1

C.3. Recruitment estimation:

Estimation of recruitment is an integrated part of the model. Recruitment parameters are estimated within the assessment model. Currently the assumed parametric structure is a random walk model.

D. Short-Term Forecast

Due to the uncertainty in the final year estimates of fishing mortality, the WG agrees that a standard (deterministic) short-term forecast is not appropriate for this stock. Therefore, stochastic projections are performed, from which short-term projections are extracted.

Forecasting takes the form of short-term stochastic projections. These projections have in the past been carried out by starting at the final year's estimates, and the covariance matrix of those estimates. However, estimates of survivors are also available, and now form the starting point for the projections. A total of 1 000 samples are generated from the estimated distribution of these estimates. These replicates are then simulated forward according to model and forecast assumptions (Table B.1.6), using the usual exponential decay equations, but also incorporating the stochastic survival process (using the estimated survival standard deviation) and subject to different catch-options scenarios. Until 2017 recruitment in the intermediate year was sampled with replacement from the year 1998 to the final year of catch data (a period during which recruitment has been low) replacing the SAM estimate of recruitment which, in May, is based on only the IBTS–Q1 data point. Given that there is a high correlation between the IBTS–Q1 age 1 estimate and the IBTS–Q3 age 1 estimate the same year, and the IBTS–Q1 age 2 estimate the next year, the WG in 2017 decided to use the latest estimate of recruitment from SAM in the intermediate year and resampled recruitments in subsequent years.

Table B.1.6. Forecast assumptions. [Note that the values that appear in the catch options table of the advice sheet are medians from the distributions that result from the stochastic forecast.]

Initial stock size	**Starting populations are simulated from the estimated distribution at the start of the intermediate year (including co-variances).**
Maturity	Maturity for the intermediate year is taken from the smoothed maturity ogive. Maturity for the TAC year onwards is the average of final four years of assessment data
Natural mortality	Average of final three years of assessment data.
F and M before spawning	Both taken as zero.
Weight at age in the catch	Average of final three years of assessment data.
Weight at age in the stock	Assumed to be the same as weight at age in the catch.
Exploitation pattern	Fishing mortalities taken as a three year average divided by the three year average fishing mortality for ages 2–4, scaled to the final year.
Intermediate year assumptions	Multiplier reflecting intended changes in effort (and therefore F) relative to the final year of the assessment, assumed to be 1 to reflect a status quo intermediate year assumption.
Stock recruitment model used	Recruitment for the intermediate (the year the WG meets) is taken from the SAM assessment. Recruitment for the TAC year onwards is sampled, with replacement, from 1998 to the final year of catch data.
Procedures used for splitting projected catches	The final year landing fractions-at-age are used in the forecast period.

Since introduction of an annually varying maturity ogive in 2015, maturity information has been available for the intermediate year, and necessitates increasing the forecast assumption for maturity from a three to a four-year average. This is consistent with the start period over which the other data are averaged and allows inclusion of the most recent maturity estimate in the forecast.

E. Medium-Term Forecast

Medium-term projections are not carried out for this stock.

F. Long-Term Forecast

Long-term projections are not carried out for this stock.

G. Biological Reference Points

The reference points for cod in 4, 20 (Skagerrak) and 7.d were reviewed at WGNSSK 2017 following a rescaling of SSB due to re-estimation of the annually varying maturity ogive. More information is available in the expert group report (2017).

The updated reference points and their technical bases are as follows.

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY Btrigger	150 000 t.	The default option of Bpa.(=1.4×Blim)	
	FMSY	0.31	EQSim analysis based on recruitment period 1988–2016	2017 assessment
Precautionary approach	Blim	107 000 t.	SSB associated with the 1996 year class	2017 assessment
	Bpa	150 000 t.	Blim multiplied by 1.4. This is the current ICES default approach.	
	Flim	0.54	EQSim analysis based on recruitment period 1998–2016	2017 assessment
	Fpa	0.39	Flim/1.4	
EU Management plan	SSBlower	70 000 t.	Former Blim	EC 1342/2008
	SSBupper	150 000 t	Former Bpa	
	Flower	0.2	Fishing mortality when SSB <SSBlower.	
	Fupper	0.4	Fishing mortality when SSB>SSBupper	
EU-Norway agreement	SSBlower	107 000 t.	Revised Blim	2008 EU–Norway agreement
	SSBupper	150 000 t	Revised Bpa	
	Flower	0.2	Fishing mortality when SSB <SSBlower.	
	Fupper	0.4	Fishing mortality when SSB>SSBupper	

H. Other Issues

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