Annex 12 Stock Annex—Sandeel in IV

Quality Handbook: Annex_SAN-NSEA
Stock-specific documentation of standard assessment procedures used by ICES

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General

Stock definition
For assessment purposes, the European continental shelf was divided into four regions for sandeel assessment purposes up to 1995: Division IIIa (Skagerrak), northern North Sea, southern North Sea, and Shetland Islands and Division VIa. These divisions were based on regional differences in growth rate and evidence for a limited movement of adults between divisions (e.g. ICES CM 1977/F:7, ICES CM 1991/Assess:14.). The two North Sea divisions were revised in 1995, and it was decided to amalgamate the two stocks into a single stock unit with two fleets, one fleet in the northern North Sea and one in the southern North Sea. The Shetland sandeel stock was assessed separately. ICES assessments used these stock definitions from 2005 to 2009.

However, larval drift models (Proctor et al., 1998; Christensen et al., 2007, 2008 and 2009) and studies on growth differences (e.g. Boulcott et al., 2007) indicate that the assumption is invalid and that the total stock is divided in several sub-populations as first proposed by Wright et al. (1998). On the basis of the latest information ICES (ICES CM 2009\ACOM:51) suggested that the North Sea should be divided into six sandeel assessment areas as indicated in Figure 4.2. ICES assessment used these stock definitions from 2010 onwards (ICES 2010, (WKSAN 2010)).
Fishery

Technical measures for the sandeel fishery include a minimum percentage of the target species at 95% for meshes <16 mm, or a minimum of 90% target species and maximum 5% of the mixture of cod, haddock, and saithe for 16 to 31 mm meshes.

Most of the sandeel catch consists of the lesser sandeel *Ammodytes marinus*, although small quantities of other *Ammodytoidei* spp. are caught as well. There is little bycatch of protected species (ICES WGNSSK 2004).

The fishery is seasonal. The geographical distribution of the sandeel fishery varies seasonally and annually, taking place mostly in the spring and summer. In the third quarter of the year the distribution of catches generally changes from a dominance of the west Dogger Bank area back to the more easterly fishing grounds.

The sandeel fishery developed during the 1970s, and landings peaked in 1999 with 1.2 million tons. There was a significant shift in landings in 2003. The average landings of the period 1994 to 2002 was 880 000 tons whereas the average landings of the period 2003 to 2009 was 288 000 tons.

As indicated in Figure 3.2, Denmark is the main contributor to the sandeel landings. Up to 2002 Denmark in average contributed 73% of the total landings and after 2002 83%.
Figure 3.3 indicates the sandeel landings by assessment area (Figure 3.1). The Figure indicates that in average 84% of the total landings came from the areas 1 and 3 in the period 1994 to 2009. However, there has been a significant shift in the relative contribution of the two areas over the period. Up to 2002 area 1 and 3 contributed 46 and 37% respectively whereas their contributions were 65 and 20% in the period 2003 to 2009.

The third most important area for the sandeel fishery is area 2. In the period 2003 to 2009 landings from this area contributed 12% of the total landings in average. The contribution of area 2 over the entire period is 9% in average.

Area 4 has contributed about 6% of the total landings since 1994 but there has been a few outstanding years with particular high landings (1994, 1996 and 2003 contributing 19, 17 and 20% of the total landings respectively). In the periods 1994 to 2002 and 2003 to 2009 the average contributions from area 4 was 8 and 3% respectively. There has been a moratorium on sandeel fisheries on Firth of Forth area along the U.K. coast since 2000.
The spatial distribution of sandeel landings is considered as a good representation of stock distribution, except for areas where severe restrictions on fishing effort is applied (i.e. the Firth of Forth, Shetland areas, and Norwegian EEZ in 2006 and 2009). Up to 2002 and particularly prior to 1998, most landings of sandeels in March were taken from the eastern North Sea banks whilst sandeel landings in April–June were mainly from the west Dogger Bank. In some years a relatively large part of the sandeel landings are taken from the central and eastern North Sea along the Danish west coast. From 1991, grounds off the Scottish east coast have been targeted particularly in June. However, since 2000 the banks in the Firth of Forth area have been closed to fishing.

In the Northern North Sea, mainly NEEZ, the change in the spatial pattern was significantly different from southern part. The highest landings from a single statistical square were taken in 1995 on the Vikingbank, the most northerly fishing ground for sandeel in the North Sea. However, in 1996 landings from the Vikingbank dropped substantially, and since 1997 have been close to nil. The marked reduction in landings around 2000 in NEEZ was accompanied by a marked contraction of the fishery to a small area in the southern part of NEEZ, the Vestbank area. In this area landings remained high in 2001 and 2002 due to the strong 2001 year class. However, the 2001 year class was only abundant in the Vestbank area, which resulted in a highly concentrated fishery and the decimation of the year-class before it reached maturity in 2003. This may have led to the collapse of the sandeel fishery in NEEZ. In the EU EEZ any contraction of the fishery has been less apparent.

The sandeel fishing season was unusual short in both 2005 and 2006, starting later and ending earlier than in previous years. The late start of the fishery was partly because the Danish fishery first opened the 1st April, in accordance with a national regulation introduced in 2005. Further, weekly data on the oil content of sandeels in the commercial landings, provided by Danish fish meal factories, indicated a late onset of sandeels feeding season in both 2005 and 2006 and that sandeels therefore became available to the fishery later than usual. Landings in the second half year of both 2005 and 2006 were on a low level compared to previous years. Only 14 000 tonnes were recorded in 2005 and 17 000 tonnes in 2006.

There has been a significant reduction in fishing effort in the sandeel fishery in recent years (Figure 3.4 and 3.5).

![Figure 3.4](image-url)
The number of Danish vessels fishing sandeel declined about 50% (from 200 to 84 vessels) from 2004 to 2009. The introduction of an ITQ system in Denmark in 2007 is considered to have contributed to further reducing the fleet capacity and accelerating a change towards fewer and larger vessels. In addition, in 2008, when the TAC was not reached, high fuel prices and low prices of fish meal were claimed by the industry to have limited the fishery.

Also for the Norwegian fleet a drastic decline in number of vessels fishing sandeels has been observed in recent years. Of the 41 Norwegian vessels that fished sandeel in 2007, nine participated for the first time. Since 1998 25 of the 41 vessels entered the fishery during this ten year period, nine vessels were rebuilt (either extended or had larger engines installed) whereas only seven vessels remained unaltered. In addition, there is likely to be a continuous increase in efficiency due to improvement in fishing gear, instruments, etc.

**Ecosystem aspects**

Sandeels are small, short-lived, lipid-rich, shoaling fish. As such, they represent high quality food for many predatory fish, seabirds and marine mammals (Greenstreet et al., 1997, 1998; Brown et al., 2001; Stafford et al., 2006; Macleod et al., 2007; Daunt et al., 2008). They are especially important in the diet of top predators during the summer, as sandeels then spend much time feeding during the day on zooplankton but burying in the sand at night (Freeman et al., 2004; Engelhard et al., 2008; Greenstreet et al., 2010). At other times of year they mainly remain buried in the sand, where they are inaccessible to many predators such as surface-feeding seabirds, though they continue to be eaten by some predatory fish, seals, and diving seabirds which apparently can dig them out of the sand (Hammond et al., 1990). Although the larvae drift with currents, and following metamorphosis may select on a local scale where to settle on the basis of sediment composition, they do not show extensive horizontal movements after that life-history stage (Gauld, 1990; Wright, 1996; Pedersen et al., 1999; Christensen et al., 2008, Jensen et al., in press).

**Top-down effects on sandeels**

Demonstrating top-down effects of predators on sandeel stocks is difficult as it is not amenable to experimentation, but relies on detection of correlations; due to different spatial distributions of key predators it is also quite likely that the relative strength of
top-down versus bottom-up control of sandeel abundance may vary between different parts of the North Sea (Frederiksen et al., 2007). However, we can assess the likelihood of such top-down effects from information on the amounts of sandeel consumed by different predators; it is unlikely that predators taking only small amounts of sandeel would exert significant top-down effects. Predation rates of seabirds and marine mammals on sandeels are trivial by comparison with predation rates by large fish, as shown by the MSVPA analysis. There is no evidence for depletion of sandeels by seabirds or marine mammals, even locally at major breeding colonies. However, some predatory fish consume very large amounts of sandeels. There is evidence that sandeel stocks increased in abundance in the North Sea following major reductions in the stocks of cod, haddock, whiting, herring, and mackerel, apparently a top-down effect resulting from reduced predation by these fish (Sherman et al., 1981).

**Bottom-up effects on sandeels**

There is strong evidence that sandeel stocks are affected by bottom-up processes involving climate and changing plankton stocks. A study of early larval survival suggested that the match between hatching and the onset of zooplankton production may be an important contributory factor to year-class variability in this species (Wright and Bailey, 1996). Frederiksen et al. (2005) used Continuous Plankton Recorder (CPR) data to develop an index of sandeel larval abundance for the Firth of Forth area. The sandeel larval index was strongly positively related to the abundance of phyto- and zooplankton, suggesting strong bottom-up control of sandeel larval survival (Frederiksen et al., 2005). Van Deurs et al. (2009) showed for the “North Sea sandeel” in ICES area IV 1983–2006 (with anomalous data from 1996 excluded) that a positive spawning stock–recruitment relationship is decoupled in years associated with high abundances of age-1 sandeels, and that survival success of early larvae depends on the abundance of *Calanus finmarchicus* but not *C. helgolandicus* or total Calanus density (again measured by CPR). They postulated that 0-group sandeels compete with older sandeels for copepods and so recruitment is reduced by the presence of high abundance of older (normally predominantly 1-group) sandeels. This conclusion contradicts an earlier finding by Arnott and Ruxton (2002) who studied the same sandeel area but for 1983–1999 only, and found a significant positive relationship between sandeel recruitment and total Calanus density over that time period. It is suggested by Van Deurs et al. (2009) that this changed pattern of correlation reflects coincidence of the switch in Calanus species at the same time as a run of poor recruitment years of sandeels after 1999. Van der Kooij et al. (2008) showed that sandeel distribution and abundance on the Dogger Bank was best explained by seabed substrate, temperature and salinity. However, contrary to the authors’ expectation, their data showed that sandeel local abundance was not strongly related to zooplankton local density.

**Top-down effects of sandeels on zooplankton**

There appears to be no information on sandeels depleting zooplankton densities over their grounds.

**Bottom-up effects of sandeels on higher predators: seabirds**

Seabirds are long-lived animals with a low reproductive output. Life-history theory predicts that seabirds should buffer their adult survival rates against fluctuations in their food supply (Boyd et al., 2006), and since food-fish are short-lived animals with high but also variable recruitment rates (Jennings et al., 2001), it is inevitable that seabirds will experience large changes in the abundance of the food fish on which they
depend. They must, therefore, have evolved the ability to cope with variation in food abundance. The literature indicates that, seabird breeding success does show a close correlation with food fish abundance (Furness and Tasker, 2000; Rindorf et al., 2000; Davis et al., 2005; Frederiksen et al., 2005), whereas breeding numbers and adult survival may not track these short-term fluctuations (Boyd et al., 2006). Nevertheless, several recent studies do show a trade-off between adult survival rate (Frederiksen et al., 2008b) and reproductive performance, as a result of adults increasing investment when food supply declines and so incurring costs (e.g. Davis et al., 2005). But variation in breeding success is much greater, and easier to measure, and so is likely to provide a much clearer signal of food shortage (Furness, 2002; Mitchell et al., 2004; Mavor et al., 2006).

Most species of seabirds in the North Sea suffered delayed breeding and widespread reproductive failures in 2003, 2004, 2005 and 2006 (Frederiksen et al., 2004; Mavor et al., 2005, 2006, 2007; Reed et al., 2006). The most severe problems, including total failures of some species, occurred in Shetland and Orkney in the northernmost part of the North Sea. Although bad weather during the chick-rearing period was partly to blame at some colonies, the main proximate cause of the breeding failures was a lack of high-quality food (Davis et al., 2005; Wanless et al., 2005). Most seabirds in the North Sea feed mainly on sandeels during the breeding season (Wanless et al., 1998; Furness and Tasker, 2000; Furness, 2002). Since the 1970s, sandeels have been the dominant mid-trophic pelagic fish in the North Sea, and around Shetland no other high-lipid prey fish occur in sufficient numbers to support successful breeding of most piscivorous seabirds (Furness and Tasker, 2000). There is thus little doubt that the observed seabird breeding failures were linked to low availability of sandeel prey (Frederiksen et al., 2004).

Furness and Tasker (2000) reviewed the ecological characteristics of seabirds in the North Sea and ranked species from highly sensitive (e.g. terns, kittiwake, Arctic skua) to insensitive (e.g. northern gannet) to reductions in sandeel abundance. They argued that the most sensitive seabirds would be those with high foraging costs, little ability to dive below the sea surface, little ‘spare’ time in their daily activity budget, short foraging range from the breeding site, and little ability to switch diet. This prediction was supported by empirical data from studies at Shetland (Furness and Tasker, 2000; Poloczanska et al., 2004) and at the Isle of May, east Scotland (Frederiksen et al., 2004). As one example, Figure 3.1a shows breeding success of kittiwakes on the Isle of May during years of sandeel fishing in the area and in years without sandeel fishing. Breeding success of kittiwakes in both periods varied with sea surface temperature, but was considerably lower when there was a sandeel fishery in the area where these birds were foraging. In Shetland, breeding success of kittiwakes and Arctic skuas (Figure 3.1b) shows very low success during periods of low Shetland sandeel stock biomass (late 1980s and 2000 onwards). Arctic skuas in Shetland feed almost exclusively on sandeels, although they obtain these by stealing them from terns, kitiwakes and auks, and so the link between their breeding success and sandeel stock size is indirect (Davis et al., 2005). We can estimate the amount of sandeels consumed by Arctic skuas from data on the numbers and energy requirements of these birds. The annual consumption of sandeels by Arctic skuas at Shetland in the period 1980–2000 is estimated to have been around 65 tonnes per year. This contrasts strongly with the observation that Arctic skua breeding success at Shetland fell to less than half of the level seen in years of high sandeel abundance when the sandeel stock biomass was below about 30 000 tonnes. The data indicate that Arctic skuas require a sandeel stock biomass about 460 times greater than the amount that they consume, in order to be able to gain energy at a rate
sufficient to sustain a good level of breeding success. This seems to be the extreme case, with much lower ratios for kittiwake and even lower for guillemots. Throughout this period, breeding success of gannets remained consistently high in Shetland as those birds were able to switch to feed on adult herring and mackerel, fish too large to be caught (or swallowed) by kittiwakes or Arctic skuas.

Figure 3.1a. Kittiwake breeding success as a function of local SST in February–March of the previous year and presence/absence of the Wee Bankie sandeel fishery. Data labels indicate current year. Regression lines estimated from weighted multiple regression. Filled circles and solid line, non-fishery years; open symbols and dashed line, fishery years. From Frederiksen et al., 2004.

Figure 3.1b. Breeding success of black-legged kittiwakes (pink) and Arctic skuas (blue) at Foula, Shetland, during 1976–2004, showing a close correlation between the success of the two species in this time-series, and periods of particularly low success in 1987–1990 and in 2001–2004.

In 2004, breeding success was exceptionally low for most seabird species on the Isle of May, despite sandeel larvae being abundant in the spring of 2003 so this low breeding success was unexpected. Detailed studies showed that the energy content of both
sandeels and sprat fed to seabird chicks in 2004 was extremely low, indicating poor 
food availability for the fish (Wanless et al., 2005). Data from chick-feeding puffins and 
CPR samples also indicate that the size-at-date of both larval, 0 group and older 
sandeels has declined substantially since 1973, although it is unclear what the cause of 
this decline might be (Wanless et al., 2004). There is thus evidence that both abundance 
and quality of seabird prey is under bottom-up control in this region, and this is likely 
to have affected seabird breeding success.

**Bottom-up effects of sandeels on higher predators: fish**

Sandeel is an important prey species for a range of natural predators (Hislop et al., 1991; 
WGSAM 2008). Of these, the species most likely to be affected are the species for which 
the sandeel make up a large proportion of the diet. In the North Sea, this would include 
whiting, haddock, mackerel, starry ray and grey gurnard (Figure 3.3b). These species 
all have a diet composition consisting of at least 10% sandeel. However, the proportion 
only exceeds 20% in the diets of western mackerel and starry ray. Of these two, the diet 
of western mackerel refers only to the time they spend in the North Sea, and hence the 
overall average percentage is likely to be lower.

![Figure 3.3b. Proportion of the diet consisting of sandeel for different predatory fish (ICES 1997).](image)

Whiting might also be affected by a decline in sandeel availability. However they might 
also switch prey to consume greater quantities of herring and sprat, since populations 
of these species have increased in recent years, as has the apparent spatial overlap be-
tween whiting and sprat distributions. Two sources of recent data are available to test 
this hypothesis, from research carried out in the Firth of Forth region as part of the EU 
FP6 IMPRESS project (1997–2003), and from research carried out on western Dogger 
Bank (‘MF0323’ project; 2004–2006).

Three gadoid populations (cod haddock, whiting) were sampled at 19 evenly spaced 
stations in the Firth of Forth (including Wee Bankie and Marr Bank) on seven research 
cruises. The contribution of sandeels to the diet of the three gadoid predators varied 
markedly from year to year, although the importance of sandeels in particular years 
was consistent across all three species. No evidence of any beneficial effect of the local
sandeel fishery closure in 2000 on the abundance or biomass of any of the three gadoid predators was apparent, however, there was evidence that fish condition was greater in years when the proportion of sandeel prey in the diet of each predator was higher (Figure 3.3c; see also Greenstreet 2006).

Between 2004 and 2006, CEFAS conducted investigations into sandeels and their predators on the Dogger Bank (‘MF0323’ project). Two survey grids were sampled each containing 48 stations, the grids were separated by 28 km. The northernmost survey grid (‘grid 1’), on an area known as the ‘North-West Riff’, was characterised as having high sandeel abundance and was an important area for the sandeel fishing fleet. The southernmost grid (‘grid 2’) on an area known as ‘The Hills’ was characterised by much lower sandeel abundance, and was less important to the sandeel fishery. Predator stomachs (mostly whiting, plaice, lesser weeverfish, grey gurnard, haddock, and mackerel) were sampled on six research cruises. The diets of all species were found to vary markedly and consistently between the two sampling grids (Pinnegar et al., 2006). Sandeels were much more important to predators (especially whiting and lesser weeverfish) at grid 1, and this coincides with the greater abundance of sandeels at grid 1, as determined by dredge survey during the night.

Clear seasonal differences were observed in predator diets for all species. Diets were much more diverse during autumn as compared to those in spring. Whiting ate substantially more crabs and sprat during the autumn period as well as hyperid amphipods, and much less sandeel at both sampling grids. Sandeels bury themselves in the sediment during autumn and winter months and are thus less accessible to predators, even though they were more abundant in real terms than was the case during the spring. Preliminary analyses (G. Engelhard, unpublished data) suggest that for some predators, most notably lesser weeverfish *Echiichthys vipera*, body ‘condition’ was slightly better at the high-sandeel site (grid 1) compared to the low-sandeel site (grid 2). An examination of interannual variability in fish body condition revealed that plaice and weever condition was better in sandeel-rich years and at the sandeel-rich survey grid. Whiting and haddock condition was better in sandeel-rich years, but no site difference was apparent in these mobile species which forage over a large area. Grey gurnard and greater sandeel (*Hyperoplus lanceolatus*) condition appeared not to be significantly linked to sandeel numbers, but positively linked to per-capita sandeel consumption (condition was better when more sandeels were observed to have been consumed). Thus it was concluded that various predatory fish species do have better condition in years/sites where sandeels are more abundant. In a parallel study carried out in August and October 2006, whiting were sampled aboard commercial fishing vessels all along the North East coast of England (from Flamborough to the Firth of
It was noted by the crew that the fish caught over areas of hard ground with empty stomachs during the August survey were very thin and of poor condition (Stafford et al., 2006). Where stomachs were not empty, the main contents were small crustaceans in August and fish in October. Fish consumed were often non-commercial prey species such as pipefish or hagfish, although gadoids and clupeoids were also consumed. The data show changes from the 1981 and 1991 ICES ‘year of the stomach’ sampling exercises, when far more sandeel and clupeoids and far less crustaceans were consumed. The authors of this study (Stafford et al., 2006) speculate that the limited availability of sandeels in 2006 may have been responsible for the poor body condition of the fish in that year and the selection of nutritionally poor prey items such as snake pipefish.

Other impacts on sandeels

Hassel et al. (2004) showed that seismic shooting can kill sandeels, and may impact commercial catches on banks where seismic shooting is occurring. There are concerns that marine wind farms could possibly affect sandeels by altering sediment around turbines and possibly by noise/vibrations. Van Deurs et al. (2008) reported that they found no adverse effects of beam trawling on sandeels where beam trawling was carried out over sandeel grounds.

Implications for ecosystem–based management

Due to the stationary habit of post-settled sandeels, a patchy distribution of the sandeel habitat (Holland et al., 2005), and a limited interchange of the planktonic stages between the spawning areas, the sandeel stock in IV consists of a number of sub-populations (Pedersen et al., 1999; Christensen et al., 2008). Within these sub-populations, fishing for sandeels may deplete numbers on particular banks. Recent evidence indicates that although closures can lead to rapid recovery of sandeel numbers in some cases (Greenstreet et al., 2010), in others, banks may not be recolonised for some years. Although hydrographical features and the general distribution pattern of the sandeel spawning populations are responsible for most of the variation in recolonisation (Christensen et al., 2008), possibly some of the variation in recolonisation of banks after depletion may reflect habitat preferences of sandeels that are seeking sites to settle, with optimal substrate being more attractive (Wright et al., 2000). This pattern may also result from some local movement of settled sandeels between adjacent but especially within banks from poorer habitat to preferred habitat (Jensen et al., in press). There was evidence for such relocation in Shetland, for example, where high fishery catches continued to be taken from Mousa even when all surrounding banks had become depleted, and breeding success of seabirds such as terns and kitiwakes had fallen close to zero due to shortages of sandeels around most of Shetland. Predators dependent on sandeels (such as kitiwakes) may therefore be adversely affected by local or regional depletion of sandeels. Serial depletion of banks in an area seems to be a particular risk. There is a need for sandeel stock assessment and management to take these risks into account. Exact local densities of sandeels needed to sustain healthy populations of predators are not known, and no doubt vary according to a range of ecological conditions and predator communities. But research has shown that certain top predators show particularly strong responses to depletion of sandeels. In particular, kitiwake breeding success tends to correlate strongly with abundance of sandeels over about a 50 km foraging radius around kitiwake colonies. In regions where kitiwakes feed predominantly on sandeels while breeding, which is the case in the North Sea, poor breeding success of these “indicator” seabirds can be used as evidence that the local stock of sandeels is depleted. Such evidence is less direct than can be obtained from dredge or
acoustic surveys, but may help to identify problem areas where sandeel aggregations
need to be allowed to recover. Sandeel stock assessments and subsequent management
should also aim to avoid depletion of stocks to levels where damage to ecosystems
becomes evident through its impact on dependent predators. Though the actual level
at which these adverse effects occur is presently unknown in most cases, it is clear that
a stock below the level where recruitment is impaired will significantly increase the
probability of effects on top predators and is hence highly unlikely to be compatible
with an ecosystem approach to fisheries.

**Northeast UK closure**

Due to their importance in North Sea food webs, ICES has advised that management
should ensure that sandeel abundance be maintained high enough to provide food for
a variety of predator species. During the early 1990s a sandeel fishery developed in
Area 4, off the Firth of Forth. The landings from this fishery peaked at over 100,000 t in
1993 and then subsequently fell. The Firth of Forth area is important for breeding sea-
birds and the removal of such large quantities of sandeels within their foraging range
soon became a matter of concern. In 1999, the UK called for a moratorium on sandeel
fishing adjacent to seabird colonies along the UK coast and in response the EU re-
quested advice from ICES. An ICES Study Group was convened in 1999 in response to
this request with two terms of reference (ICES 1999):

a) assess whether removal of sandeel by fisheries has a measurable effect on
sandeel predators such as seabirds, marine mammals, and other fish species;

b) assess whether establishment of closed areas and seasons for sandeel fisher-
ies could ameliorate any effects. Identify possible seasons/areas as specifi-
cally as possible.

This study group noted that there was suggestion of a negative effect of the Firth of
Forth fishery on the local sandeel abundance in 1993 which coincided with a particu-
larly low breeding success of seabirds, especially kittiwakes. The study group con-
cluded that there were two reasons for continued concern about this area that provided
the basis for a precautionary closure:

1) sandeels supported a number of potentially sensitive seabird colonies
   (Lloyd et al., 1991).

2) work on population structure indicated that sandeels in this region are re-
productively isolated from the main fished aggregations in the North Sea
   (Wright et al., 1998).

The ICES study group noted that, as sandeel assessments are only conducted for the
North Sea, there was no reliable information on the state of the sandeel aggregations
near the Firth of Forth, which forms part of area division 4 (see Figure 4). Given avail-
able information the study group proposed that kittiwake breeding success was the
best practical indicator of sandeel availability at least to seabirds and threshold levels
of the breeding success of this species should be used to guide futures decisions on re-
opening. After ICES Advisory committees and STECF acceptance of the study group’s
advice, the EU advised that the fishery should be closed whilst maintaining a commer-
cial monitoring. However, the EU did not accept the use of kittiwake breeding success
as a harvest control threshold. A three year closure, from 2000 to 2002, was decided
and the Commission was requested to produce annual reports to the Council on the
effects of the restrictions in the sandeel fishery in the Firth of Forth area. On the basis
of the second of these reports (Wright et al., 2001) and uncertainty over the impact of
the closure the commission proposed a further three year extension of the closure. The
wording of the Act is stated in article 29a of: “Council Regulation (EC) no 850/98 of 30 March 1998 for the conservation of fishery resources through technical measures for the protection of juveniles of marine organisms”. A further scientific review of the closure was made by STECF in 2007, together with other EU fishery closures. That group proposed that it would be prudent to wait for enhanced recruitment and productivity in the area before any re-opening is considered.

Evaluating changes in sandeel abundance in the region has been difficult due to the lack of a single reliable sampling method for assessing sandeel abundance. Nevertheless, the various research (acoustic, trawl and dredge) and commercial abundance indices suggested an initial increase in sandeel abundance during the period of the closure (Greenstreet et al., 2006). This increase began with a relatively large recruitment in the first year of the closure, which would not have been related to any recovery in the spawning stock. Dredge surveys in 1999 and 2000 indicated a detectable decrease on total mortality on 1+ sandeels following the closure. A further indication that sandeel abundance increased in the region came from the observation that in 2003, when landings in the North Sea as whole had severely declined, 39 060 tonnes were taken in the ICES rectangle adjacent to the closed area near Marr and Berwick banks.

Figure 4. Chart showing the closed area (blue line).
Kittiwake breeding success has tended to be higher since the fishery closure than in the preceding five years. However, poor breeding success in 2004 seen along the whole of the east U.K. coast appears partly related to environmental factors affecting the incoming year class of sandeels. Evidence from studies published since the ICES (1999) study group suggest that the breeding success of this species is not a reliable indicator of sandeel availability to some other coastal seabirds. For example, a downward trend in guillemot breeding success throughout the 1990s has not been reversed by fishery closure (but that species feeds extensively on sprats as well as sandeels in this area). After a series of very poor breeding seasons for seabirds since 2004 on the Isle of May, Firth of Forth, the 2009 season was the most successful in recent years, matching evidence of increased sandeel abundance from the dredge survey. Of six seabird species studied intensively, European shag had its highest productivity on record with only razorbill having productivity below average. All other species studied had their most productive season for at least four years. Sandeels remained the main food of young Atlantic puffins, razorbills and kittiwakes. Comparatively few 1+ group sandeels were present in food samples during the chick-rearing period in 2009, however 0-group appeared in large numbers and were substantially longer than in recent years, again matching dredge results. Kittiwakes had a good season with productivity (0.70 chicks per incubated nest) the highest since 2005 and well above the long-term average. The proportion of sandeel in kittiwake diet (89% by biomass) in 2009 was the highest since 2005. However, the concern over a possible local impact of sandeel fishing expressed in 1999 has not fundamentally changed. On re-opening, the sandeel aggregations in the North-east closure could be subject to significant depletion unless there were revised management controls. As originally agreed by the Commission, STECF would have to convene an international meeting of scientists to come up with a consensus on criteria for re-opening.

Data

Age composition and mean individual weight

Data available

Data available included Danish and Norwegian samples from harbour sampling and Danish samples taken by skippers on board vessels and frozen immediately (available from 1999 onwards). The Danish samples cover both age and length distributions whereas the Norwegian samples cover only length distribution prior to 1997 and both age and length samples after 1997. Sandeel measured for length distribution were weighed in the Danish samples whereas only aged sandeel were weighed from the Norwegian samples. To obtain weight-at-length for Norwegian samples, the parameters of the weight–length relationship.

\[ W = aL^b \]

were estimated using the sandeel weighed in the Norwegian age samples after 1997 and Danish length–weight relationships before 1997 and weight-at-length estimated for sandeel which were not weighed. All data are combined in the analyses, corresponding to the assumption that the composition of catches taken in a given year and month did not differ between countries and that no differences in age reading existed.

Estimating age–length keys

Only age readings of *Ammodytes marinus* and unidentified sandeel *Ammodytes* spp. are used. The method suggested by Rindorf and Lewy (2001) is used to assure that the
estimation is optimized when sampling is sparse. This method is used to estimate an age–length-key for each combination of year, time and area (Table 4.1.1). When the number of fish aged is too low to allow a reliable estimation on square level (confidence limits of the estimate exceed +/-25%), higher aggregation levels are used (Table 1). When a given age is not observed in an age sample, this is assumed to reflect an absence of this age only if the number of fish sampled of this age or older exceeds ten. Otherwise, the absence of the particular age is assumed to be a result of low sampling efforts, and the probability of being of the particular age compared to the probability of being older taken from a higher aggregation level. The probability of being of a given age is set to zero at lengths outside the interval of lengths observed for this age +/-2 length groups (1 cm groups from 6 to 20 cm, 2 cm groups between 20 and 30 cm). Overdispersion (Rindorf and Lewy, 2001) was not estimated.

**Estimating age distributions and mean weight-at-age**

The number of *A. marinus* of each age (0 to 4+) per kg and the mean weight per individual of each age in each length distribution sample is estimated by combining the age–length key and the length distribution specific to square and period. The average number of sandeel per age per kg and their mean weight in a given rectangle in each month was estimated as the average of that recorded in individual samples when at least five samples were available. Mean weight was only estimated when the total catch of a given age in the square exceeded ten. If the total North Sea sampling resulted in less than ten sandeel of a particular age, the mean weight for the North Sea as a whole was used. When less than five length samples were taken, the next aggregation level (Table 4.1.2) was used. Hence, for each rectangle, month and year, the average number of *A. marinus* per age and kg caught was estimated and the level noted. No correction was made for differences in condition between on-board samples and harbour samples.

**Estimating catch in ton per square per month**

**Before 1989**, only logbook information stating the catch in directed Danish sandeel fishery is known. As the large majority of the catch in the sandeel fishery consists of sandeel, the distribution of catches in the directed sandeel fishery on squares and months were assumed to represent the distribution of sandeel catches. The total catch in tonnes was derived from the report of the working group on the assessment of Norway pout and sandeel (ICES, 1995) and distributed on squares and month in the particular year according to the distribution of catches derived from Danish logbooks. From **1989 to 1993**, the landings of sandeel per square and month from the Danish fishery are available at DTU-AQUA. These were used to distribute total landings to square and month. From **1994 to 1998**, international sandeel catches in ton per square per year are available. These catches were distributed to months according to the monthly distribution of Danish catches in the square in the given year. If no Danish catches were recorded from the square, the monthly distribution of the total catches in the ICES division was used. **After 1999**, international sandeel catches in ton per square per month and year are available.

All catches were scaled in order to sum to official ICES landing statistics.

**Estimating catch in numbers and mean weight**

The catch in numbers per age (1000s), month and square of sandeel is estimated as the product of sandeel catches in kg and the number-at-age of sandeel per kg in the particular square. The total number in a larger area and longer time period is estimated as
the sum over individual squares and months in this area. The mean weight (kg) is estimated as the weighted average mean weight (weighted by catch in numbers of the age group in the square and month).

The text table below shows which country supplies which kind of data:

<table>
<thead>
<tr>
<th>Country</th>
<th>Caton (catch in weight, month square)</th>
<th>Length samples from catches</th>
<th>Weca (weight-at-age in the catch)</th>
<th>Matprop (proportion mature-by-age)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Norway</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>UK/Scotland</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swedden</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farao Islands</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Biological**

Both the proportion of natural mortality before spawning ($M_{prop}$) and the proportion of fishing mortality before spawning ($F_{prop}$) are set to 0.

The values of natural mortalities for sandeel used in the assessment are based on MSVPA model output, and have been kept constant since 1989 (ICES CM 1989/Assess:13). However, the benchmark assessment group (ICES, 2010) considered that since there were updated estimates of half-yearly natural mortality available from WGSAM, these should be used in the assessment. The most recent estimate of natural mortality was done in 2008 by the Working Group on Multispecies Assessment Methods (WGSAM) in the so-called North Sea key-run (ICES, 2008). Compared to the MSVPA results used as basis for $M$ in the assessment the WGSAM results are based on almost twice as many stomachs observations including both additional stomach samples for the main predators (cod, haddock, whiting, Saithe and mackerel) and additional predators (horse mackerel, grey gurnard, *Raja radiata*, and ten bird species). Figure 3.5 shows the partial predation mortality ($M_2$) of sandeel by year as estimated by WGSAM. It is clear that there has been a significant increase in $M$ since the late 1990s. The natural mortalities by age as estimated by WGSAM show almost equal values for the two half-years, while the $M$ used by the assessment are much higher in the first half year. As the trends in natural mortality were only apparent in the end of the time period where the uncertainty is greatest, it was decided not to use annual estimates of $M$. Instead, the average over the period 1982 to 2007 for each age and half-year was used.
Past estimates of spawning stock size assumed a knife edge age-at-maturity, with all sandeels spawning at age 2. A model of maturity in relation to size, age and area found that this assumption did not hold for all sub-population areas (Boulcott et al., 2007). The data used in this publication were collected during dredge surveys in 1999 and 2004. Data from 1999, indicated that a significant proportion of sandeels from area 3 were mature by age 1. In area 4, sandeels were found to mature at a smaller size than other areas but because of their low growth rate, the proportion mature by age 2 was still less than 1. Unpublished data for area 4 from 2000 were consistent with the published results. A time-series (2004–2009) of spatially resolved maturity data from the December dredge survey for areas 1–3 is held by the Danish institute. The working paper of Steen (WDA1 in Appendices) evaluates the assumption of knife edge maturity from these data. Whilst most sandeels from the time-series were mature at age 2, there was sufficient deviation from the knife edge age-at-maturity assumption for the benchmark group to decide that annual differences should be considered in area based assessments (see Section 5). For area 4, only the age maturity key of Boulcott et al. (2007) was applied, as there was no time-series of data available.

Surveys

Since 2004 DTU Aqua (formerly DIFRES) has carried out a survey with a modified scallop dredge to measure the relative abundance of sandeel in the seabed (REF). The
Danish dredge survey is conducted in late November–early December when the 0-group sandeel have been recruited to the settled population and the entire population is assumed to reside in the seabed.

Since 2004, in total 828 hauls have been at fixed positions on known sandeel habitats at known fishing banks in the North Sea from the little Fisher Bank in the Northeastern North Sea, to the Dogger Bank in the Southwestern North Sea (Figure 4.2.1.1). From 2006 additional positions were sampled in the Norwegian EEZ.

As a varying number of hauls have been made at the different positions over the years, calculation of the annual stratified average catch rates (total number caught by hour) for each area was done in a three step procedure: first, for each year, the average catch rate of each position was calculated as the average of the catch rates of all hauls (stations) made on this position, then the average catch rate of each ICES square was calculated as the average of the catch rates of its positions, and finally the average catch rate of each area was calculated as the average of the catch rates of its ICES squares. In other words, the annual average catch rate by area is calculated by:

$$\overline{CPUE}_a = \frac{\sum_{sq} CPUE_{a,sq}}{n_{a,sq}}$$

(1)

where

$$CPUE_{a,sq} = \frac{\sum_{pos} CPUE_{a,sq,pos}}{n_{a,sq,pos}}$$

(2)

where

$$CPUE_{a,sq,pos} = \frac{\sum_{st} CPUE_{a,sq,pos,st}}{n_{a,sq,pos,st}}$$

(3)

where n: number of hauls, a: area, sq: square, pos: position and st: station.

Descriptions of the survey and consistency analysis are given in WP on survey and ICES benchmark report.

**Commercial cpue**

Until 2009 the sandeel assessment was calibrated by the commercial cpue indices. With the introduction of the dredge survey from 2010 commercial cpue are no longer used for calibration.

**Other relevant data**

None.

**Estimation of historical stock development**

The Seasonal XSA (SXSA) developed by Skagen (1993) was up to 2001 used for stock assessment of sandeel in IV. Annual XSA was tried in 2002 WG where it was concluded that the two approaches gave similar results. For a standardization of methodology, it was decided to shift to XSA in 2003. From 2004 to 2009 SXSA was used again for the final assessment. In 2010 the SMS model was used as the assessment in 2009 indicated that the SXSA was sensitive to model settings and changes in effort distribution (ICES, 2009).
Previous whole-area assessments of Sandeel showed no consistent relationship between effort and F but, when moving towards a more biologically plausible assessment area, there is evidence that fishing effort may be used as a reasonable proxy for fishing mortality (Benchmark report, ICES 2010). This relationship has been used by the SMS model as the driver for estimating F. The SMS model has options to estimate rates for technical creeping and thereby take into account that the efficiency has increased in the sandeel fishing fleet. The results show that the new model fits to data in a reasonable way, and give results without retrospective bias. The model can be applied for assessment with just catch and effort, and for assessment where additional fisheries independent data are available.

Methodology

The SMS model, presently used for the ICES assessment of blue whiting (WGWIDE), and for the North Sea and Baltic Sea multispecies (WGSAM), was modified slightly to estimate fishing mortality from observed effort. In the original SMS version, fishing mortality, $F_{y,q,a}$ was modelled as an extended separable model including a seasonal, age and year effect. The new version substitutes the year effect by observed effort.

\[
F_{y,q,a} = \text{SeasonEffect}(Y,A1) \times \text{AgeEffect}(Y,A2,q) \times \text{YearEffect}_y \quad (1, \text{ original version})
\]

\[
F_{y,q,a} = \text{SeasonEffect}(Y,A1) \times \text{AgeEffect}(Y,A2,q) \times \text{Effort}_{y,q} \quad (2, \text{ new version})
\]

where

indices $A1$ and $A2$ are groups of ages, (e.g. ages 0, 1–2, 3–4) and $Y$ is grouping of years (e.g. 1983–1998, 1999–2009). The SMS-effort defines that the years included in the model can be grouped into a number of period clusters ($Y$), for which the age selection and seasonal selection are assumed constant. Fishing mortality is assumed proportional to effort. The grouping of ages for age selection, $A1$, and season selection, $A1$, can be defined independently.

An example of parameterization with maximum annual effort at 1.0 is shown below. (Unique parameters in bold).

<table>
<thead>
<tr>
<th>Season effect A1=age 0 and age 1–4</th>
<th>Second half year</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>YY</th>
<th>Age 0</th>
<th>Age 1</th>
<th>Age 2</th>
<th>Age 3</th>
<th>Age 4</th>
<th>Age 0</th>
<th>Age 1</th>
<th>Age 2</th>
<th>Age 3</th>
<th>Age 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983–1998</td>
<td>0.00*</td>
<td>0.426</td>
<td>0.426</td>
<td>0.426</td>
<td>0.426</td>
<td>1.0*</td>
<td>0.5*</td>
<td>0.5*</td>
<td>0.5*</td>
<td>0.5*</td>
</tr>
<tr>
<td>1999–2009</td>
<td>0.00*</td>
<td>0.337</td>
<td>0.337</td>
<td>0.337</td>
<td>0.337</td>
<td>1.0*</td>
<td>0.5*</td>
<td>0.5*</td>
<td>0.5*</td>
<td>0.5*</td>
</tr>
</tbody>
</table>

* kept constant

<table>
<thead>
<tr>
<th>Age effect A2=age 0, age 1, age 2 and age 3–4</th>
<th>Second half year</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>YY</th>
<th>Age 0</th>
<th>Age 1</th>
<th>Age 2</th>
<th>Age 3</th>
<th>Age 4</th>
<th>Age 0</th>
<th>Age 1</th>
<th>Age 2</th>
<th>Age 3</th>
<th>Age 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983–1998</td>
<td>0.00*</td>
<td>0.488</td>
<td>1.024</td>
<td>1.248</td>
<td>1.248</td>
<td>0.014</td>
<td>0.772</td>
<td>0.847</td>
<td>0.585</td>
<td>0.585</td>
</tr>
<tr>
<td>1999–2009</td>
<td>0.00*</td>
<td>0.772</td>
<td>0.857</td>
<td>0.585</td>
<td>0.585</td>
<td>0.010</td>
<td>0.176</td>
<td>0.195</td>
<td>0.133</td>
<td>0.133</td>
</tr>
</tbody>
</table>
“Catchability”-at-age, or more correctly the relation between effort and F by age group, is included in the AgeEffect parameter.

There are two additional options for the SMS-effort version, where technical creeping is taken into account.

\[
F_{y,q,a} = \text{SessionEffect}(Y,A1) \times \text{AgeEffect}(Y,A2,q) \times \text{Effort}_{y,q} \times (y-\text{firstYear})^\text{common\_Creep}(Y)
\]

(3)

\[
F_{y,q,a} = \text{SessionEffect}(Y,A1) \times \text{AgeEffect}(Y,A2,q) \times \text{Effort}_{y,q} \times (y-\text{firstYear})^\text{age\_Creep}(Y,A1)
\]

(4)

Equation (3) uses a common creeping exponent for all ages by one or more year clusters (Y), e.g. the efficient increase by 3.8% per year in the first year range, and 2.8% per year in the second. Equation (4) is more flexible as it allows an age dependent creeping exponent. If we assume that we only use one year cluster (the whole year range) an example could be that the technical creep for age 1 is 5.5% per year, while age 2 has a negative exponent, -2.7% (equivalent to parameter=0.973). As the product of effort and “technical creep” express both the fishing power and the directivity towards a specific age group, such an example indicates that there has been an overall increase in (standardised) fishing power, but the fishery has been less directed towards older sandeel in recent years.

SMS is a statistical model where three types of observations are considered: Total international catch-at-age; research survey cpue (and stomach content observations, which are not used here). For each type a stochastic model is formulated and the likelihood function is calculated. As the three types of observations are independent the total log likelihood is the sum of the contributions from three types of observations. A stock-recruitment (penalty) function is added as a fourth contribution.

**Catch-at-age**

Catch-at-age observations are considered stochastic variables subject to sampling and process variation. Catch-at-age is assumed to be lognormal distributed with log mean equal to log of the standard catch equation. The variance is assumed to depend on age and season and to be constant over years. To reduce the number of parameters, ages and seasons can be grouped, e.g. assuming the same variance for age 3 and age 4 in one or all seasons. Thus, the likelihood function, \( L_C \), associated with the catches is

\[
L_C = \prod_{a,q,y} \frac{1}{\sigma_C a,q \sqrt{2\pi}} \exp\left\{ -\frac{(\log(C_{a,y,q}) - E(\log(C_{a,y,q})))^2}{2\sigma_C a,q^2} \right\}
\]

Where

\[
E(\log(C_{a,y,q})) = \log\left( \frac{F_{a,y,q}}{Z_{a,y,q}} N_{a,y,q}(1-e^{-Z_{a,y,q}}) \right)
\]

Leaving out the constant term, the negative log-likelihood of catches then becomes:

\[
l_C = -\log(L_C) \propto \text{NOY} \sum_{a,q} \log(\sigma_C a,q) + \sum_{a,y,q} (\log(C_{a,y,q}) - E(\log(C_{a,y,q})))^2 / (2\sigma_C a,q^2)
\]
Survey indices

Similarly, the survey indices, $cpue(survey,a,y,q)$, are assumed to be log-normally distributed with mean

$$E(\log(\text{CPUE}_{survey,a,y,q})) = \log(Q_{survey,a} \overline{N}_{SURVEY,a,y,q})$$

where $Q$ denotes catchability by survey and $\overline{N}_{SURVEY}$ mean stock number during the survey period. Catchability may depend on a single age or groups of ages. Similarly, the variance of log $cpue$, $\sigma(survey,a)$, may be estimated individually by age or by clusters of age groups. The negative log likelihood is on the same form as for catch observations:

$$l_{SURVEY} = -\log(l_{SURVEY}) \propto \sum_{survey,a} \text{NOY}_{survey} \sum_{survey,a} \log(\sigma_{SURVEY,survey,a}) + \sum_{survey,a,y} (\log(\text{CPUE}_{survey,a,y}) - E(\log(\text{CPUE}_{survey,a,y}))^2 / (2\sigma_{SURVEY,survey,a}^2))$$

Stock-recruitment

In order to enable estimation of recruitment in the last year for cases where survey cpue and catch from the recruitment age is missing (e.g. saithe) a stock–recruitment relationship $R_y = R(\text{SSB}_y | \alpha, \beta)$ penalty function is included in the likelihood function. Assuming that recruitment takes place at the beginning of the third quarter of the year and that recruitment is lognormal distributed the parameters the log penalty contribution, $l_{SR}$, equals

$$l_{SR} = -\log(l_{SR}) \propto \text{NOY} \log(\sigma_{SR}) + \sum_y ((\log(N_{a=0,y,q=3}) - E(\log(R_y)))^2 / 2\sigma_{SR}^2)$$

where

$$E(\ln(R_y)) = \ln(\alpha \text{ SSB}_y \exp(-\beta \text{ SSB}_y))$$

for the Ricker case. Other stock–recruitment relations (Beverton and Holt and “Hockey stick”) and stock-independent geometric mean recruitment have also been implemented. As indicated in equation (26) recruitment-at-age zero in the beginning of the third quarter was considered.

Total likelihood function and parameterisation

The total negative log likelihood function, $l_{TOTAL}$, is found as the sum of the four terms:

$$l_{TOTAL} = l_{CATCH} + l_{SURVEY} + l_{STOM} + l_{SR}$$

Initial stock size, i.e. the stock numbers in the first year and recruitment over years are used as parameters in the model while the remaining stock sizes are considered as functions of the parameters.

The parameters are estimated using maximum likelihood (ML) i.e. by minimizing the negative log likelihood, $l_{TOTAL}$. The variance/covariance matrix is approximated by the inverse Hessian matrix. The variance of functions of the estimated parameters (such as biomass and mean fishing mortality) has been calculated using the delta method.

The SMS model was implemented using the AD Model Builder (ADMB Project 2009), freely available from ADMB Foundation (www.admb-project.org). ADMB is an efficient tool including automatic differentiation for Maximum likelihood estimation of many parameters in nonlinear models.
Settings of the SMS model is implicated in the Text Table 1 and the configuration file for Area 1 in Appendix AA.

**Text Table 1. Settings of the SMS model.**

<table>
<thead>
<tr>
<th>Option</th>
<th>Area 1</th>
<th>Area 2</th>
<th>Area 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data first year</td>
<td>1983</td>
<td>1983</td>
<td>1983</td>
</tr>
<tr>
<td>Time step</td>
<td>Half-year</td>
<td>Half-year</td>
<td>Half-year</td>
</tr>
<tr>
<td>First age</td>
<td>Age 0</td>
<td>Age 0</td>
<td>Age 0</td>
</tr>
<tr>
<td>Last age</td>
<td>Age 4+</td>
<td>Age 4+</td>
<td>Age 4+</td>
</tr>
<tr>
<td>Spawning time</td>
<td>Start of 1st half-year</td>
<td>Start of 1st half-year</td>
<td>Start of 1st half-year</td>
</tr>
<tr>
<td>Recruitment time</td>
<td>Start of 2nd half-year</td>
<td>Start of 2nd half-year</td>
<td>Start of 2nd half-year</td>
</tr>
<tr>
<td>Age range for use of catch data in likelihood</td>
<td>Age 0 – age 4+</td>
<td>Age 0 – age 4+</td>
<td>Age 0 – age 4+</td>
</tr>
<tr>
<td>Last age with age dependent selection</td>
<td>Age 3</td>
<td>Age 3</td>
<td>Age 3</td>
</tr>
<tr>
<td>Objective function weighting (catch, survey, S/R)</td>
<td>1.0, 1.0, 0.01</td>
<td>1.0, 1.0, 0.01</td>
<td>1.0, 1.0, 0.01</td>
</tr>
<tr>
<td>Minimum CV of catch observations</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Minimum CV of survey observations</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Minimum CV of S/R relation</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Catch observations: variance group</td>
<td>Age 0, ages 1 &amp; 2 combined and ages 3 &amp; 4 combined</td>
<td>Age 0, ages 1 &amp; 2 combined and ages 3 &amp; 4 combined</td>
<td>Age 0, ages 1 &amp; 2 combined and ages 3 &amp; 4 combined</td>
</tr>
<tr>
<td>Treatment of zero catch observations</td>
<td>Not used in likelihood</td>
<td>Not used in likelihood</td>
<td>Not used in likelihood</td>
</tr>
<tr>
<td>Ages for seasonal exploitation pattern</td>
<td>Age 0, and ages 1–4+ combined</td>
<td>Age 0, and ages 1–4+ combined</td>
<td>Age 0, and ages 1–4+ combined</td>
</tr>
<tr>
<td>Ages for calculation of mean F</td>
<td>Age 1 &amp; age 2</td>
<td>Age 1 &amp; age 2</td>
<td>Age 1 &amp; age 2</td>
</tr>
<tr>
<td>Exclusion of catch data (no or very small catches are available)</td>
<td>2007 second half year 2012 second half year 2013 second half year</td>
<td>2007 second half year 2012 second half year</td>
<td>2007 second half year 2011 second half year 2013 second half year</td>
</tr>
<tr>
<td>Catch Variance</td>
<td>Calculated within SMS</td>
<td>Calculated within SMS</td>
<td>Calculated within SMS</td>
</tr>
<tr>
<td>Survey variance</td>
<td>Free parameter</td>
<td>Free parameter</td>
<td>Free parameter</td>
</tr>
<tr>
<td>S/R variance</td>
<td>Calculated within SMS</td>
<td>Calculated within SMS</td>
<td>Calculated within SMS</td>
</tr>
<tr>
<td>Inflexion point (B_{lm})</td>
<td>160 000</td>
<td>70 000</td>
<td>100 000</td>
</tr>
<tr>
<td>Survey information</td>
<td>Area 1: Dredge survey December 2004</td>
<td>Area 1 (copy):Dredge survey December 2004</td>
<td>Area 3:Dredge survey December 2004 Age 0 &amp; age 1</td>
</tr>
</tbody>
</table>
### Table

<table>
<thead>
<tr>
<th>Option</th>
<th>Area 1</th>
<th>Area 2</th>
<th>Area 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age 0 &amp; age 1</td>
<td>Age 0</td>
<td>Age 0</td>
<td></td>
</tr>
<tr>
<td>Half year</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Time: Alfa &amp; beta</td>
<td>0.75, 1.0</td>
<td>0.75, 1.0</td>
<td>0.75, 1.0</td>
</tr>
<tr>
<td>Last age with age dependent selection</td>
<td>Age 1</td>
<td>Age 0</td>
<td>Age 1</td>
</tr>
<tr>
<td>Ages for separate variance estimate</td>
<td>Age 0 and age 1</td>
<td>Age 0</td>
<td>Age 0 and age 1</td>
</tr>
<tr>
<td>Power model</td>
<td>Not applied</td>
<td>Not applied</td>
<td>Not applied</td>
</tr>
</tbody>
</table>

**Short-term projection**

Analysis presented at the benchmark assessment (ICES, 2010) showed consistently large retrospective patterns in the assessments unless the dredge survey is included. Including the dredge survey largely removes this pattern, making it possible to produce unbiased estimate of terminal stock size. Further, the dredge survey shows high consistency both internally and externally in all areas, though the consistency in area 3 was somewhat lower than in the other areas. Though there is currently no coverage of area 2 in the dredge survey, recruitment in area 2 is highly correlated with that in area 1 and it is therefore possible to use the dredge catch rate in area 1 in the assessment of area 2. In area 3, the consistency of the survey is less and the CV of the SMS predictions is greater. Hence, producing an updated assessment following the December survey should provide reliable estimates of stock size in the areas where the relationship between the assessed stock size and dredge catch rate is tight (areas 1 and 2) but less reliable estimates for area 3. The dredge survey in area 4 cannot be used to produce pre-season assessments until the relationship between stock size and dredge catch in the area can be estimated from a longer time series than is presently available.

The benchmark assessment (ICES 2010) recommends that:

- Two forecasts are provided. The assessment done in September does not include a reliable estimate of recruitment in the second half of the assessment year and forecast will be based on assumptions of recruitment as outlined Table 2a. Another forecast is provided in January of the TAC year when data from the dredge survey are processed and included in the updated assessment. An example of such forecast with known recruitment in the assessment year is shown in Table 2b;
- The forecast will be deterministic and be based on half yearly data;
- Proportion mature in TAC year is based on latest information from dredge survey;
- Proportion mature in year following TAC year is computed as the long-term average (unless a distinct trend is suspected);
- WECA and WEST are computed as averages of last three years;
- Exploitation pattern as estimated by SMS for most recent year;
- Initial stock size start of TAC year is estimated by SMS assessment;
- 0-group in start of second half of the TAC year is obtained from long-term geometric mean.
Table 2a. Example of forecast provided in September, where recruitment in the assessment year is unknown. This forecast is based on the escapement strategy of reaching BMSY_{escapement} (100 kt) in the year after the TAC year. (Please note that catch options are not based on real stock estimates).

| Area–2 Sandeel | Basis: F_{sq}=F(2010)=0.143; \text{Yield}(2010)=31; \text{Recruitment}(2011)=[\text{geometric mean}=2\text{ billions}; \text{SSB}(2011)=232 |

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.792</td>
<td>Geometric mean* 0</td>
<td>0.256</td>
<td>52</td>
<td>100</td>
<td>-57%</td>
<td>64%</td>
</tr>
<tr>
<td>2.326</td>
<td>Geometric mean* 0.2</td>
<td>0.332</td>
<td>68</td>
<td>100</td>
<td>-57%</td>
<td>115%</td>
</tr>
<tr>
<td>2.859</td>
<td>Geometric mean* 0.4</td>
<td>0.408</td>
<td>84</td>
<td>100</td>
<td>-57%</td>
<td>167%</td>
</tr>
<tr>
<td>3.389</td>
<td>Geometric mean* 0.6</td>
<td>0.484</td>
<td>100</td>
<td>100</td>
<td>-57%</td>
<td>219%</td>
</tr>
<tr>
<td>3.916</td>
<td>Geometric mean* 0.8</td>
<td>0.559</td>
<td>117</td>
<td>100</td>
<td>-57%</td>
<td>271%</td>
</tr>
<tr>
<td>4.437</td>
<td>Geometric mean* 1</td>
<td>0.633</td>
<td>134</td>
<td>100</td>
<td>-57%</td>
<td>325%</td>
</tr>
</tbody>
</table>

Table 2b. Example of forecast provided in January, where recruitment in the assessment is known. This forecast provides catch options for a range of F multipliers and for MSY (reaching BMSY_{escapement} (100 kt) in the year after the TAC year). (Please note that catch options are not based on real stock estimates).

| Area–2 Sandeel | Basis: F_{sq}=F(2010)=0.143; \text{Yield}(2010)=31; \text{Recruitment}(2010)=2\text{ billions}; \text{Recruitment}(2011)=[\text{geometric mean}=2\text{ billions}; \text{SSB}(2011)=232 |

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>F=0</td>
<td>0</td>
<td>0</td>
<td>141</td>
<td>-39%</td>
<td>-100%</td>
</tr>
<tr>
<td>0.25</td>
<td>F^{sq}*0.2</td>
<td>0.036</td>
<td>8</td>
<td>135</td>
<td>-42%</td>
<td>-74%</td>
</tr>
<tr>
<td>0.5</td>
<td>F^{sq}*0.5</td>
<td>0.071</td>
<td>16</td>
<td>129</td>
<td>-45%</td>
<td>-49%</td>
</tr>
<tr>
<td>0.75</td>
<td>F^{sq}*0.8</td>
<td>0.107</td>
<td>24</td>
<td>123</td>
<td>-47%</td>
<td>-25%</td>
</tr>
<tr>
<td>1</td>
<td>F^{sq}*1</td>
<td>0.143</td>
<td>31</td>
<td>117</td>
<td>-49%</td>
<td>-2%</td>
</tr>
<tr>
<td>1.25</td>
<td>F^{sq}*1.2</td>
<td>0.178</td>
<td>38</td>
<td>112</td>
<td>-52%</td>
<td>20%</td>
</tr>
<tr>
<td>1.5</td>
<td>F^{sq}*1.5</td>
<td>0.214</td>
<td>45</td>
<td>107</td>
<td>-54%</td>
<td>42%</td>
</tr>
<tr>
<td>1.886</td>
<td>MSY</td>
<td>0.269</td>
<td>55</td>
<td>100</td>
<td>-57%</td>
<td>73%</td>
</tr>
</tbody>
</table>

Medium–term projections
Not done.

Long–term projections
Not done.

Biological reference points
Inspection of the stock–recruitment plots from area 1, 2 and 3 revealed a decrease in recruitment at low SSB in all areas (Figure 6.4.1). However, no clear plateau was visible and this was reflected in a very flat surface of the likelihood when attempting to estimate an inflection point. Hence, the group considered that the relationship in all areas
fell into the category where there is a relationship between R and SSB but no clear plateau. In this category, SGPRP advised that \( B_{\text{lim}} \) should be set after evaluation of historic patterns (SGPRP 2003, Figures 6.4.2 to 6.4.4). The group did not consider the lack of plateau to have occurred through a consistent fishing down of the stock and hence did not think that there was evidence that \( B_{\text{lim}} \) was above the range of observed SSBs. It was also considered that a period of continuous low recruitment has only occurred around year 2000 and only in areas 2 and 3. After 2000, there has been a very low SSB in all areas but this followed the poor recruitment years rather than the opposite. For area 1 and 2, \( B_{\text{lim}} \) was therefore set as the median biomass in these years of low SSB (2000–2006) giving the values 160 000 tonnes for area 1 and 70 000 tonnes for area 2. In area 3, the drop in recruitment was also followed by a drop in SSB, but the level in the low period was more variable. For this area, \( B_{\text{lim}} \) was set at 100 000 tonnes, encompassing the lowest eight SSBs recorded. The level was set at the highest SSB observed in the period 2001–2007 (the period of low SSBs) rather than the median as there has been no really good recruitment years in the latter half of the period.

For short-lived species such as Sandeel, the ICES interpretation of the MSY concept uses \( B_{\text{pa}} \) estimates as the value for \( B_{\text{msy}} \)-trigger. This means that should advice follow the same escapement strategy as previously used the fishing opportunities for year \( y \) must be set at a level which ensures that \( B_{\text{msy}} \) is achieved in year \( y+1 \). No fishery should be allowed if this level of escapement can be achieved.

<table>
<thead>
<tr>
<th>Area</th>
<th>( B_{\text{lim}} )</th>
<th>SSB CV</th>
<th>( B_{\text{pa}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>160 000</td>
<td>18%</td>
<td>215 000</td>
</tr>
<tr>
<td>2</td>
<td>70 000</td>
<td>23%</td>
<td>100 000</td>
</tr>
<tr>
<td>3</td>
<td>100 000</td>
<td>40%</td>
<td>195 000</td>
</tr>
</tbody>
</table>

The total of the \( B_{\text{lim}} \) estimates from areas 1, 2 and 3 is 330 kt and substantially below the historical level of 430 kt determined for the whole North Sea. This is partially due to not having areas 4 and 5 included. However, stock biomasses from these areas represent only a small fraction of the total their contribution to the combined total \( B_{\text{lim}} \) will be equally small. The difference is therefore mainly caused by two changes in the procedure used. Firstly, the new SMS assessments generate lower estimates of SSB compared to the old data and methodology and secondly, the revised maturity.
Figure 4. Stock–recruitment relationship in areas 1 to 3. Note that the recruit estimate for 2010 is based on very little input data and is therefore highly unreliable.
Figure 5. Stock summary for area 1.
Figure 6. Stock summary for area 2.
The total of the $B_{	ext{lim}}$ estimates from areas 1, 2 and 3 is 330 kt and substantially below the historical level of 430 kt determined for the whole North Sea. This is partially due to not having areas 4 and 5 included. However, stock biomasses from these areas represent only a small fraction of the total their contribution to the combined total $B_{	ext{lim}}$ will be equally small. The difference is therefore mainly caused by two changes in the procedure used. Firstly, the new SMS assessments generate lower estimates of SSB compared to the old data and methodology and secondly, the revised maturity estimates provide lower SSBs at the same biomass of 2+-year olds. Further, the previous $B_{	ext{lim}}$ level was set in 1998 at the lowest observed spawning-stock since there was no indication of a relationship between SSB and recruitment at the time. Since then the stocks have been through a period of lower SSB, some of which have still produced reasonable recruitments, and it is these observations which now inform the selection of reference points.

**In-season monitoring of sandeel**

The sandeel fishery and stock are in most years dominated by 1-group sandeel for which very little information exists before the fishery is opened. Commercial cpue is a poor predictor of 0-group recruitment and reliable indices from surveys were not available until 2010 when the Danish dredge survey data from area 1 and 3 was applied.
Since 2004, therefore, information on the 1-group abundance has been obtained from in-season monitoring of the fishery in the start of the fishery (1 April to around 5 May). The methodology for in-season monitoring has been unchanged since 2007 and is described in detail in ICES CM 2007/ACFM:38.

The benchmark meeting (WKSAN 2010) considered that the rise in importance and reliability of the dredge survey has potential area specific implications for the in-season monitoring programme:

**Area 1**
Statistics show that the dredge survey is sufficiently robust to provide an estimate of the incoming 1-group such that the fishing opportunities for the coming year can be established in January. Although this relationship appears to be robust it may be prudent to continue some level of real-time monitoring in years where the dredge survey result is outside the bounds of the current observations particularly at the lower bound. There will be regular samples passed to DTU-Aqua as part of the standard monitoring process every year, but the requirement for real-time monitoring would only occur when the dredge survey is beyond historically observed bounds.

**Area 2**
There appears to be a sufficiently robust relationship between the recruitments in areas 1 and 2 to be able to use the same data sources and procedures from area 1 for the estimation of the incoming year class. There should, however, be an increase in the sampling coverage within this area.

**Area 3**
Pre-season estimates of the incoming year class appears less robust for this area and it is therefore appropriate that in-season monitoring (e.g. acoustic monitoring and age-based commercial cpue) to continue in area 3. The internal and external consistency of the acoustic survey is yet unknown and the consistency of commercial and dredge data is less in area 3 than in the other areas.

**Area 4**
Whilst it is important to continue the Scottish dredge survey the overlap between this and the commercial time-series is too short to provide robust estimates of incoming 1-group strength. There has been little or no information for this area from the in-year monitoring system in recent years due to the low commercial effort level expended in the area.

The dredge survey information is sufficient to provide TAC advice in Areas 1 and 2, without requiring the in-season processing and incorporation of in-season monitoring in most cases. Increasing the coverage and time-series length of dredge surveys in other areas may lead to a similar reduction or elimination of the need for in-year processing in those areas.

**Area 5**
This stock is in the stock category 5.3.0. Catch statistics are available for SA 5. No landings have occurred since 2004 (except for 4 t landed in 2007). The available information is inadequate to evaluate stock status or trends, and the state of the stock is therefore
unknown. It should be noted that the Norwegian acoustic survey conducted in the Viking Bank during 2005–2013 indicates that the stock in this area is very small. Norway closed fisheries on the Viking Bank area in 2011 because of very low estimates of sandeel abundance based on acoustic surveys in 2007–2010 (ICES, 2010).

Area 6
This stock is in the stock category 5.2.0. Only catch statistics are available for SA 6. Catches are low (< 500 t annually). This information is inadequate to evaluate stock status or trends, and the state of the stock is therefore unknown.

Area 7
This stock is in the stock category 5.3.0. Catch statistics are available for SA 7. However, the available information is inadequate to evaluate stock status or trends and the state of the stock is therefore unknown. Catches are low (< 500 t annually).

Other issues
Recent investigations (Greenstreet et al., 2006) showed the biomass of age 1+ sandeels increased sharply in the Firth of Forth area in the first year of the closure and remained higher in all four of the closure years analysed, than in any of the preceding three years, when the fishery was operating. Further, the biomass of 0-group sandeels in three of the four closure years exceeded the biomass present in the three years of commercial fishing. The closure appears to have coincided with a period of enhanced recruit production.

References
Christensen A., Hochbaum U., Jensen H, Mosegaard H, St. John M., and Schrum C. Hydrodynamic backtracking of fish larvae by individual-based modelling. Accepted by MEPS.


Jensen, H., Rindorf, A., Wright P. J., Mosegaard, H. Inferring the location and scale of mixing between habitat areas of lesser sandeel through information from the fishery. ICES Journal of Marine Science. (in press).


Appendix A. Configuration file for Area 1

# SMS.dat option file
# the character "#" is used as comment character, such that all text
# and numbers after # are skipped by the SMS program
# # Produce test output (option test.output)
# # 0 no test output
# # 1 output file SMS.dat and file fleet.info.dat as read in
# # 2 output all single species input files as read in
# # 3 output all multi species input files as read in
# # 4 output option overview
# # 11 output between phases output
# # 12 output iteration (obj function) output
# # 13 output stomach parameters
# # 19 Both 11, 12 and 13
#
# # Forecast options
# # 51 output HCR_option.dat file as read in
# # 52 output prediction output summary
# # 53 output prediction output detailed
# 0
# # Single/Multispecies mode (option VPA.mode)
# # 0=single species mode
# # 1=multi species mode, but Z=F+M (used for initial food suitability
# parameter estimation)
# # 2=multi species mode, Z=F+M1+M2
# 0
# # first year of input data (option first.year)
# 1983
# # last year of input data (option last.year)
# 2010
# # last year used in the model (option last.year.model)
# 2010
# # number of seasons (option last.season). Use 1 for annual data
# 2
# # last season last year (option last.season.last.year). Use 1 for an-
# # nual data
# 2
# # number of species (option no.species)
# 1
# # Species names, for information only. See file species_names.in
# # first age all species (option first.age)
# 0
# # recruitment season (option rec.season). Use 1 for annual data
# 2
# # maximum age for any species(max.age.all)
# 4
# # various information by species
# # 1. last age
# # 2. first age where catch data are used {else F=0 assumed}
# # 3. last age with age dependent fishing selection
# # 4. Last age included in the catch at age likelihood (normally last
# # age)
# 5. plus group, 0=no plus group, 1=plus group
# 6. predator species, 0=no, 1=VPA predator, 2=Other predator
# 7. prey species, 0=no, 1=yes
# 8. Stock Recruit relation, 1=Ricker, 2=Beverton & Holt, 3=Geom mean,
# 4= Hockey stick, 5=hockey stick with smoother,
# (given as input)
# 4 0 3 4 1 0 0 170000
# adjustment factor to bring the beta parameter close to one (option beta.cor)
# 1e+08
# year range for data included to fit the R-SSB relation (option SSB.R.year.range)
# first (option SSB.R.year.first) and last (option SSB.R.year.last) year to consider.
# the value -1 indicates the use of the first (and last) available year in time series
# first year by species
# -1
# last year by species
# 2009
# Objective function weighting by species (option objective.function.weight) (default=1)
# first=catch observations,
# second=CPUE observations,
# third=SSB/R relations
# fourth=stomach observations
# SPECIAL SANDEEL -1=Creep by year, -2=Creep by age-group
# 1 0.5 0.01 0
# parameter estimation phases for single species parameters
# phase.rec (stock numbers, first age) (default=1)
# 1
# phase.rec.older (stock numbers, first year and all ages) (default=1)
# 1
# phase.F.y (year effect in F model) (default=1)
# 1
# phase.F.q (season effect in F model) (default=1)
# 1
# phase.F.a (age effect in F model) (default=1)
# 1
# phase.catchability (survey catchability) (default=1)
# 1
# phase.SSB.R.alfa (alfa parameter in SSB-recruitment relation) (default=1)
# 1
# phase.SSB.R.beta (beta parameter in SSB-recruitment relation) (default=1)
# -1
# minimum CV of catch observation used in ML-estimation (option min.catch.CV) (default=0.2)
# 0.20
# minimum CV of catch SSB-recruitment relation used in ML-estimation
# (option min.SR.CV) (default=0.2)
# 0.2
# use seasonal or annual catches in the objective function (option combined.catches)
# do not change this options from default=0, without looking in the manual
# 0=annual catches with annual time steps or seasonal catches with seasonal time steps
# 1=annual catches with seasonal time steps, read seasonal relative F from file F_q_ini.in (default=0)
0

# use seasonal or common combined variances for catch observation
(option seasonal.combined.catch.s2)
# seasonal=0, common=1 (use 1 for annual data)
0

# catch observations: number of separate catch variance groups by species
3
# first age group in each catch variance group
0 1 3  # Sandeel

# catch observations: number of separate catch seasonal component groups by species
2
# first ages in each seasonal component group by species
0 1  # Sandeel

# first and last age in calculation of average F by species (option avg.F.ages)
1 2

# minimum 'observed' catch, (option min.catch). You cannot log zero catch at age!
# value 0 = Ignore data point in likelihood
# negative value gives percentage (e.g. -10 ~ 10%) of average catch in age-group for
# input catch=0
# negative value less than -100 substitute all catches by the option/100 *average
# catch in the age group for catches less than (average catch*-option/10000
# if option>0 then will zero catches be replaced by catch=option
# else if option<0 and option >-100 and catch=0 then catches will be replaced by catch=average(catch at age)*(-option)/100
# else if option<-100 and catch < average(catch at age)*(-option)/10000 then catches will be replaced by catch=average(catch at age)*(-option)/10000
0  # Sandeel
0

# catch observations: number of year groups with the same age and seasonal selection
3
# first year in each group
1983 1989 1999

# year season combinations with zero catch (F=0) (option zero.catch.year.season)
# 0=no, all year-seasons have catches, 1=yes there are year-season combinations with no catch. Read from file zero_catch_seasons_ages.in
# default=0
1

# season age combinations with zero catch (F=0) (option zero.catch.season.ages)
# 0=no, all seasons have catches, 1=yes there is seasons with no catch.
Read from file zero_catch_seasons_ages.in
# default=0
1

# Factor for fixing last season effect in F-model (default=1)
(fix.F.factor)
1

# Uncertainties for catch, CPUE and SSB-R observations (option calc.est.sigma)
# values: 0=estimate sigma as a parameter (the right way of doing it)
# 1=Calculate sigma and truncate if lower limit is reached
# 2=Calculate sigma and use a penalty function to avoid lower limit
# catch-observation, CPUE-obs, Stock/recruit
2 0 2

# Read HCR_option file (option=read.HCR) default=0
# 0=no 1=yes
0

#