BENCHMARK WKSAN REPORT 2010

ICES ADVISORY COMMITTEE

ICES CM 2010/ACOM:57

Report of the Benchmark Workshop on Sandeel (WKSAN)

6–10 September 2010

Copenhagen, Denmark

ICES International Council for the Exploration of the Sea

CIEM Conseil International pour l'Exploration de la Mer

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

Recommended format for purposes of citation:

ICES. 2010. Report of the Benchmark Workshop on Sandeel (WKSAN), 6–10 September 2010, Copenhagen, Denmark. ICES CM 2010/ACOM:57. lɣ1 pp.
https://doi.org/10.17895/ices.pub.19280747

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Executive summary

A Benchmark Workshop on Sandeel in Subarea IV excluding the Shetland (WKSAN) met at ICES Headquarters in Copenhagen, Denmark on September 6–10, 2010. Dr. Jim Berkson (US) served as the Workshop's Chair, Dr. Ewen Bell (UK) served as the ICES Coordinator, and Dr. Robert Furness (UK) served as an external expert.

WKSAN has adopted the recomendataions of previous ICES Workshops on Sandeel in terms of moving from a single area assessment to assessing separate stock components based on stock structure identified using published information on larval distribution, connectivity, and growth differences. There are now seven separate stock components identified, although analytical assessments are only possible in four areas. In addition to this fundamental change in the treatment of North Sea sandeels, the assessment model structure has evolved to now utilize a statistical catch-at-age model as opposed to a deterministic VPA approach as used in the past. The inclusion of the dredge survey has eliminated historic retrospective patterns in Areas 1–3, a problematic artifact of previous assessments. New analyses demonstrate that the dredge survey in Area 1 allows for greater confidence in short-term forecasts. All of these developments represent significant improvements in assessment and forecast methodology.

Four alternative sandeel management scenarios were presented to WKSAN: the current ICES management plan, the plan being implemented by the Norwegian government in the Norwegian EEZ, a proposal by the Danish Fisherman's Association, and a proposal by the Norwegian Fishermen's Association. All four management plans could be implemented in Areas 1, 2, and 3 using existing data sources with agreed-upon assessment and forecasting methods. Both the Norwegian government's and the Norwegian Fisherman's Association's proposed management scenarios could be implemented in Area 5. Data is insufficient to evaluate whether the management scenarios could be implemented in Areas 4 and 6.

Intensive in-season catch sampling and data processing has been required to provide TAC advice in the past in areas 1–3. The WKSAN determined that pre-season dredge survey information is sufficient to provide TAC advice in Areas 1 and 2 in most years, without requiring the more intensive in-season catch sampling and data processing. Increasing the time-series length and coverage in Areas 3, 5 and 6 may lead to a similar reduction or elimination of the need for more intensive in-year data collection and processing. However, the dredge survey in area 4 cannot be used to produce a stock assessment without additional within season sampling, preferably from fisheries catches.

Improving the assessment will require its further spatial stratification, including providing natural mortality rate estimates by area. Current natural mortality rate estimates were derived from predator stomachs collected 20 years ago region-wide. A new stomach collection study is required to provide updated, area-specific mortality estimates. Additional research priorities include studies of the relationship between sandeel biomass and predator condition, growth or recruitment success to provide better knowledge for setting reference points which takes account of effects on predator populations. A more detailed list of research needs is provided within the document.

Industry representatives from both Denmark and Norway attended the entire WKSAN. Although they were invited to attend as observers, their expertise and

opinions were sought throughout. As a result, they provided useful information throughout the workshop. In particular, they provided critical information on the timing and causes of changes in catchability, which were then incorporated into the assessment model. Industry representatives also provided details on marine spatial planning issues having the potential to impact the sandeel fishery in the future (e.g. windfarms, Natura2000). Their participation was not only welcome, but also necessary.

1 Terms of Reference

2009/2/ACOM57 A **Benchmark Workshop on Sandeel** (External Chair: (to be confirmed) and ICES coordinator: Ewen Bell (UK) and one invited external expert) will be established and will meet in ICES HQ, Copenhagen, Denmark, 6–10 September 2010 to:

a) Evaluate the appropriateness of data and methods to determine stock status and investigate methods for short term outlook taking agreed or proposed management plans into account for the stocks listed in the text table below. The evaluation shall include consideration of fishery-dependent, fishery independent, and life history data currently being collected for use in the current assessment work and the proposed assessment;

b) Agree and document preferred method for evaluating stock status and (where applicable) short-term outlook and update the assessment handbooks as appropriate;

c) Develop recommendations for future improving assessment methodology and data collection;

d) d) As part of the evaluation:

  i) conduct a one day data compilation workshop. Stakeholders shall be invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality. As part of the data compilation workshop consider the quality of data including discard and estimates of misreporting of landings;

  ii) consider the possible inclusion of environmental drivers for stock dynamics in the assessments and outlook;

  iii) evaluate the role of stock identity and migration;

  iv) evaluate the role of multispecies interactions on the assessments.

Stock	Assessment Lead
Sandeel in Subarea IV excluding the Shetland	Steen Christensen, Denmark

The Benchmark Workshop will report for the attention of ACOM by 16 September 2010.

2 Stock Identity

Past ICES sandeel expert groups have reported that the single North Sea stock assumption is invalid (ICES AGSAN 2007-9). This is important because past management regimes have failed to avoid local depletion in some areas and to account for regional differences in productivity and catch rates. The sub-stock area based approaches presented in this report (Figure 2.1) follow recommendations for area divisions in ICES AGSAN (2009). The area divisions agreed are based on estimates of larval exchange between fishing grounds. This section summarises why this approach is appropriate for the benchmark. Sandeel inhabit shallow, turbulent sandy areas, where the content of silt and clay is low (Macer, 1966; Reay, 1970; Wright *et al*., 2000; Holland *et al*., 2005). Because of the limited availability of such substrate (Wright *et al*., 1998), the distribution of post-settled sandeels is highly patchy (Macer, 1966; Wright *et al*., 2000; Freeman *et al*., 2004; Holland *et al*., 2005). Following settlement sandeels are rarely found further than 15 km away from known habitat (Wright, 1996; Engelhard *et al*., 2008) and the maximum distance travelled by tagged individuals displaced from grounds was only 64 km over 1–3 years (Gauld, 1990). As sandeel eggs are demersal and the larvae are only pelagic for 50–90 days at a time prior to the appearance of strong density driven currents there is generally little exchange across the entire North Sea (Wright and Bailey, 1996; Proctor *et al*., 1998; Jensen, 2001; Munk *et al*., 2002; Christensen *et al*., 2008). Nevertheless, model simulations of larval transport suggest that aggregations of banks at scales from 50–300 kms apart can be connected by the annual dispersal and advection of larvae (Proctor *et al*., 1998; Christensen *et al*., 2008). Hence attempts to sub-divide the North Sea into sub-population areas have focussed on the exchange of larvae between grounds.

The first proposal for area divisions was presented in 1998 based on larval hatching areas as starting locations, estimates of passive transport derived from a 35 km grid resolution 2 D sea circulation model and observations of pre-settled 0-group distribution (Proctor *et al*., 1998; Wright *et al*., 1998; see also Pedersen *et al*., 1999). The basis for area divisions proposed by AGSAN2 (2009) used fishing grounds as starting locations and a bio-physical model of sandeel larval drift derived from a 5 km grid 3 D sea circulation model (Christensen *et al*., 2007, 2008 and 2009). There was generally high agreement in the stock divisions proposed in both studies. Both attempts at defining areas first distinguished the northwest (area 4) as being hydrographically isolated from other grounds in the North Sea. Other divisions based on these models were similar with the exception of the new area 2 near the Danish coast. To avoid the division of some fishing grounds suggested by the latest drift model, AGSAN2 (2009) proposed some minor modifications to area boundaries.

Regional differences in productivity between the area divisions have been indicated from differences in size, maturity and fecundity-at-age, particularly with respect to area 4 and other areas (Jensen *et al*., 2001; Boulcott *et al*., 2007; Boulcott and Wright, in press). Even within the proposed divisions, differences in recruitment and local mortality patterns coupled with the limited movement of settled fish, can give rise to significant differences in length composition at scales > 28 kms (Jensen *et al*., in press).

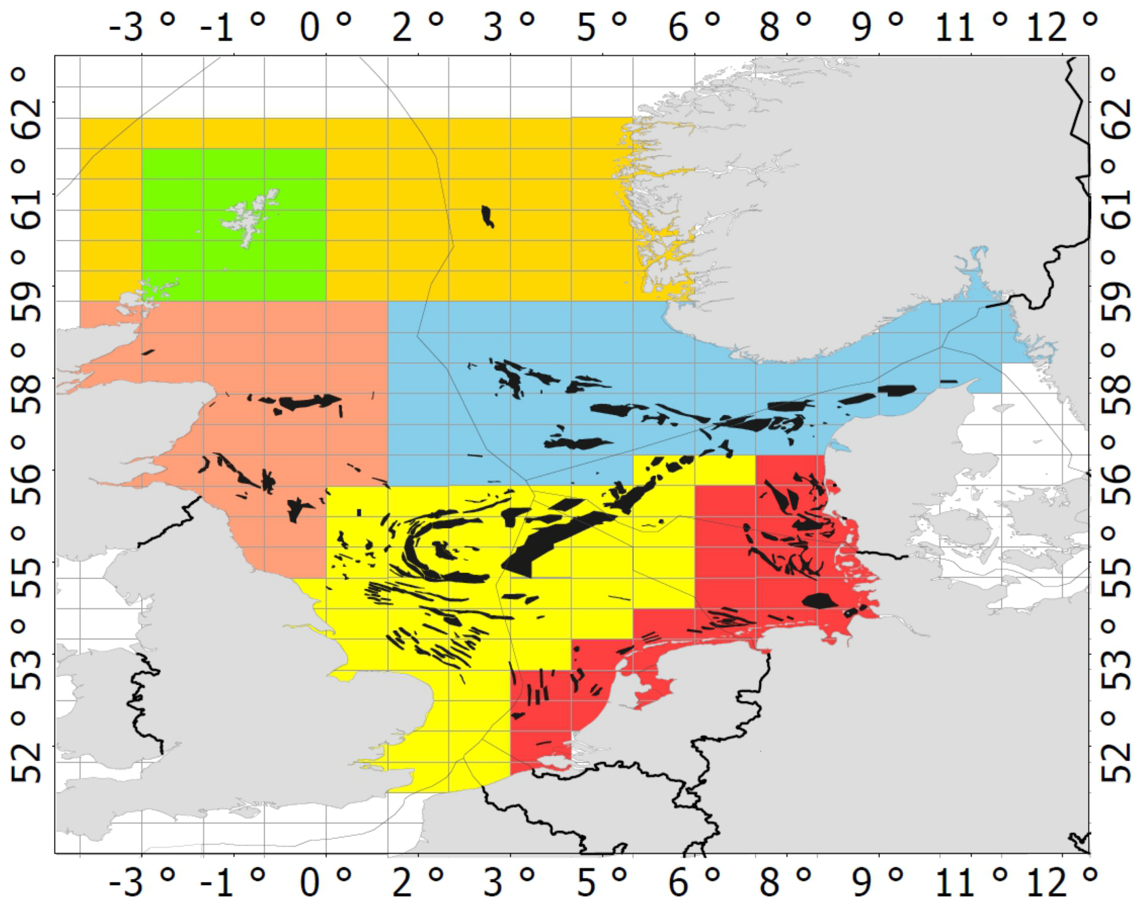

Figure 2.1. Sandeel assessment regions as defined by AGSAN (2009). Yellow denotes area 1, red area 2, blue area 3, pink area 4, orange area 5 and green area 6.

3 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*., 1994). 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).

3.1 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).

3.2 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.

3.3 Top-down effects of sandeels on zooplankton

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

3.4 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 3.1 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 3.2) 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, kittiwakes 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.

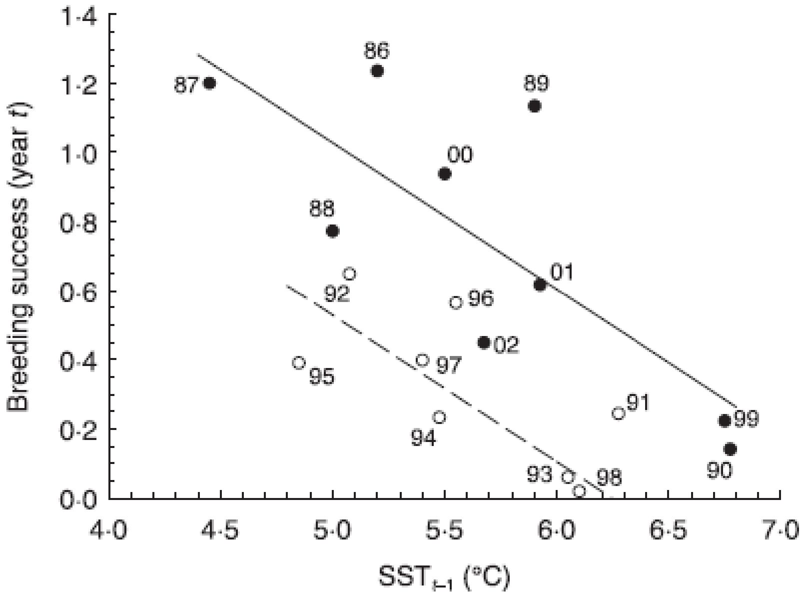

Figure 3.1. Kittiwake breeding success as a function of local SST in February–March of the previous year and presence/absence of the Wee Bankie sandeel fishery. Data labels indicate current year. Regression lines estimated from weighted multiple regression. Filled circles and solid line, non-fishery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

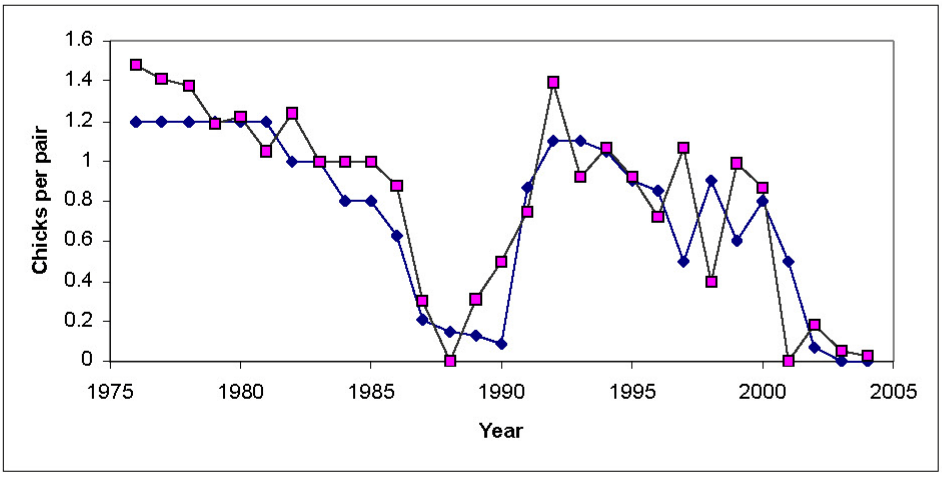

Figure 3.2. Breeding success of black-legged kittiwakes (pink) and Arctic skuas (blue) at Foula, Shetland, during 1976–2004, showing a close correlation between the success of the two species in this time-series, and periods of particularly low success in 1987–1990 and in 2001–2004.

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.

3.5 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 3.3). 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.

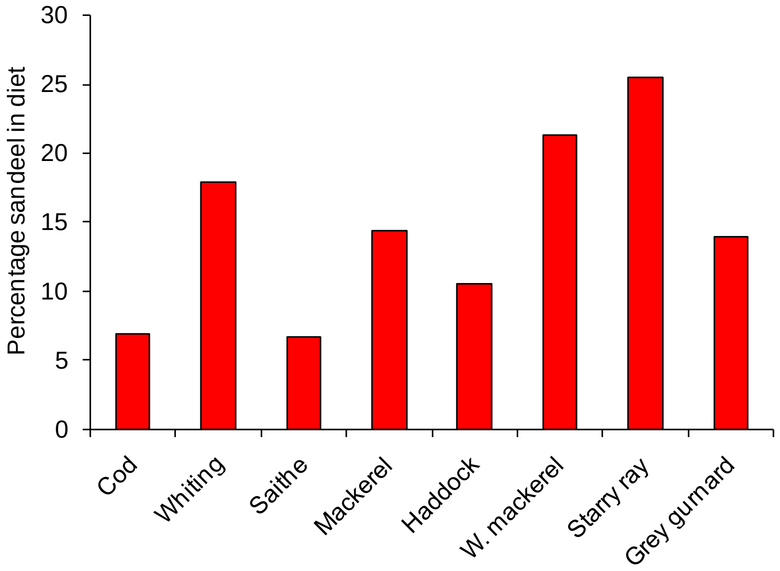

Figure 3.3. Proportion of the diet consisting of sandeel for different predatory fish (ICES 1997)

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 between 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 3.4; see also Greenstreet 2006).

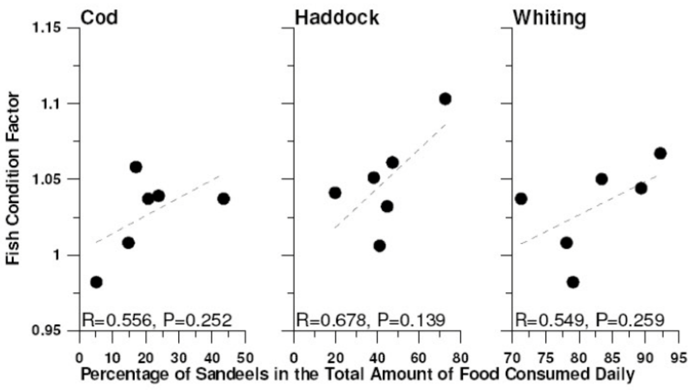

Figure 3.4. Relationship between the body condition of gadoid predators in the Firth of Forth, and the quantity of sandeels consumed (from Greenstreet *et al.*, 2006).

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/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 Forth, including the Dogger Bank). 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.

3.6 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.

3.7 Implications for ecosystem-based management

Due to the stationary habit of post-settled sandeels, a patchy distribution of the sandeel habitat (Wright *et al.*, 2000; 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 (Proctor *et al.*, 1998; 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 kittiwakes had fallen close to zero due to shortages of sandeels around most of Shetland. Predators dependent on sandeels (such as kittiwakes) 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, kittiwake breeding success tends to correlate strongly with abundance of sandeels over about a 50 km foraging radius around kittiwake colonies. In regions where kittiwakes 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 very low stock size will significantly increase the probability of effects on top predators and is hence highly unlikely to be compatible with an ecosystem approach to fisheries.

4 Data availability

4.1 Commercial data

4.1.1 Age composition and mean individual weight

4.1.1.1 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 (per month year and old Sandeel sampling area; see Figure 4.2.1).

$$W = aL^b$$

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.

4.1.1.2 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 rectangle level (confidence limits of the estimate exceeds +/- 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 10. 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.

4.1.1.3 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 was estimated by combining the age–length key and the length distribution specific to that square and period (periods given in Table 4.1.1). 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 that age from 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.

4.1.1.4 Estimating catch in ton per rectangle 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 rectangle and months were assumed to represent the distribution of sandeel catches. The total catch in tones was derived from the report of the working group on the assessment of Norway pout and sandeel (ICES 1995) and distributed on rectangles 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 rectangle and month from the Danish fishery are available at DTU-AQUA. These were used to distribute total landings to rectangle and month. From **1994 to 1998**, international sandeel catches in ton per rectangle per year are available. These catches were distributed to months according to the monthly distribution of Danish catches in the rectangle in the given year. If no Danish catches were recorded from the rectangle, the monthly distribution of the total catches in the ICES division was used. **After 1999**, international sandeel catches in ton per rectangle per month and year are available.

All catches were scaled in order to sum to official ICES landing statistics. Total catches per area are seen in Figure 4.1.1.

4.1.1.5 Estimating catch in numbers and mean weight

The catch in numbers per age (1000s), month and rectangle of sandeel was estimated as the product of sandeel catches in kg and the number-at-age of sandeel per kg in the particular rectangle. The total number in a larger area and longer time period is estimated as the sum over individual rectangles and months in this area. The mean weight is estimated as the weighted average mean weight (weighted by catch in numbers of the age group in the rectangle and month). Mean weight is given in kg. The resulting age-distribution of the catches are seen in Figure 4.1.1.

4.1.1.6 Number of samples taken in each area

The number of biological samples taken was insufficient to conduct analytical assessments for areas 5, 6 and 7 and for area 4 outside the years 1993 to 2005 (Table 4.1.3).

Table 4.1.1. Aggregation levels for age–length keys and length distributions. For sandeel sampling areas, see Figure 4.1.2.

Level	Space	Time
1	Square	Jan–Feb, March, April (1–15),April (16–30), May (1–15), May (16–31), June (1–15), June (16–30), July, Aug, Sep–Oct, Nov–Dec
2	Sandeel sampling areas within asesment areas(Figure 1)	Jan–Feb, March, April (1–15),April (16–30), May (1–15), May (16–31), June (1–15), June (16–30), July, Aug, Sep–Oct, Nov–Dec
3	Aggregated sandeel sampling areas within assessment areas: 1A+1B, 1C, 2A+6, 2B+3, 4+5, 3AS+3AN	Jan–Feb, March, April (1–15),April (16–30), May (1–15), May (16–31), June (1–15), June (16–30), July, Aug, Sep–Oct, Nov–Dec
4	Aggregated sandeel sampling areas within assessment areas: 1A+1B, 1C, 2A+6, 2B+3, 4+5, 3AS+3AN	Jan–Mar, April–May, June–Aug, Sep–Dec
5	Sandeel assessment areas	Jan–Mar, April–May, June–Aug, Sep–Dec
6	Sandeel assessment areas	Jan–June, July–Dec
7	All areas together	Jan–June, July–Dec
8	All areas together	Jan–Dec

Table 4.1.2. Aggregation levels for estimating the number of sandeel per age per kg. For sandeel sampling areas, see Figure 4.1.2.

Level	Space	Time
1	Rectangle	Jan–Feb, March, April, May, June, July, Aug, Sep–Oct, Nov–Dec
2	Sandeel sampling areas within asessment areas(Figure 1)	Jan–Feb, March, April, May, June, July, Aug, Sep–Oct, Nov–Dec
3	Aggregated sandeel sampling areas within assessment areas: 1A+1B, 1C, 2A+6, 2B+3, 4+5, 3AS+3AN	Jan–Feb, March, April, May, June, July, Aug, Sep–Oct, Nov–Dec
4	Aggregated sandeel sampling areas within assessment areas: 1A+1B, 1C, 2A+6, 2B+3, 4+5, 3AS+3AN	Jan–Mar, April–May, June–Aug, Sep–Dec
5	Sandeel assessment areas	Jan–Mar, April–May, June–Aug, Sep–Dec
6	Sandeel assessment areas	Jan–June, July–Dec
7	All areas together	Jan–June, July–Dec
8	All areas together	Jan–Dec

Table 4.1.3. Number of length samples taken in each area and year (Norwegian and Danish samples together).

Area	1	2	3	4	5	All
1982	58	20	9	0	0	87
1983	73	21	15	0	0	109
1984	116	15	31	0	2	162
1985	97	26	9	19	2	151
1986	28	2	39	1	0	70
1987	63	6	65	1	0	135
1988	40	4	76	0	0	120
1989	38	7	47	0	0	92
1990	2	1	39	0	0	42
1991	25	9	53	0	0	87
1992	54	19	49	5	0	127
1993	21	17	112	11	0	161
1994	20	9	79	17	0	125
1995	42	15	74	9	7	140
1996	39	15	164	6	19	224
1997	37	24	180	43	0	284
1998	47	14	167	10	0	238
1999	258	32	72	44	1	406
2000	102	16	80	59	0	257
2001	219	10	93	90	0	412
2002	289	28	114	62	0	493
2003	261	65	164	153	0	643
2004	446	66	183	54	0	749
2005	305	41	49	30	0	425
2006	539	27	98	2	0	666
2007	287	17	257	0	0	561
2008	291	11	164	1	0	467
2009	303	7	125	0	0	435
2010	172	28	279	1	0	480

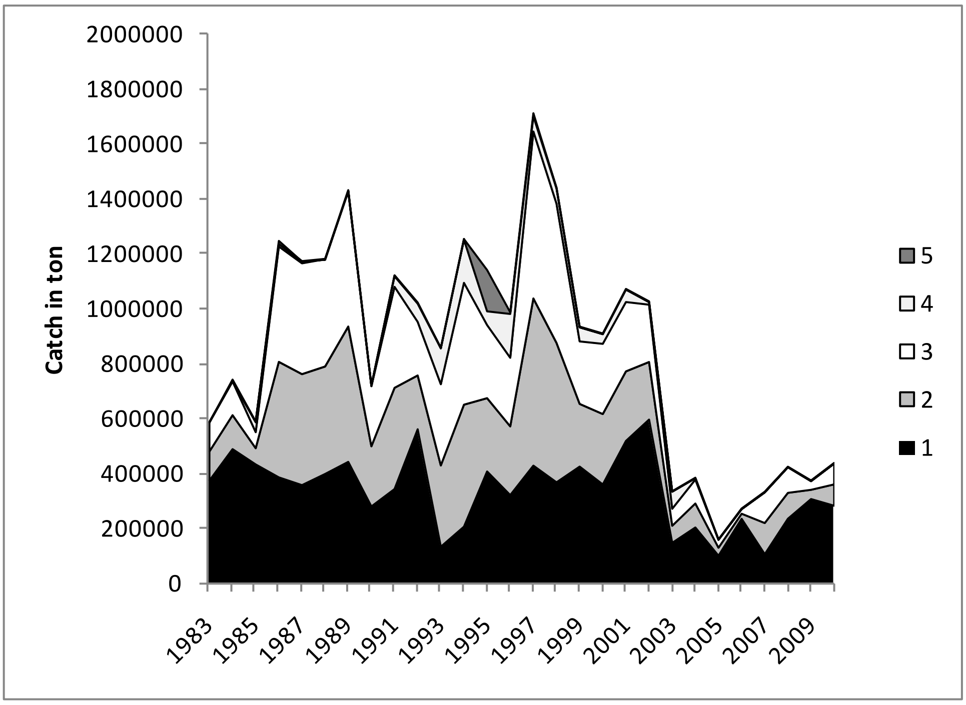

Figure 4.1.1. Total catches per sandeel assessment area (Figure 2.1).

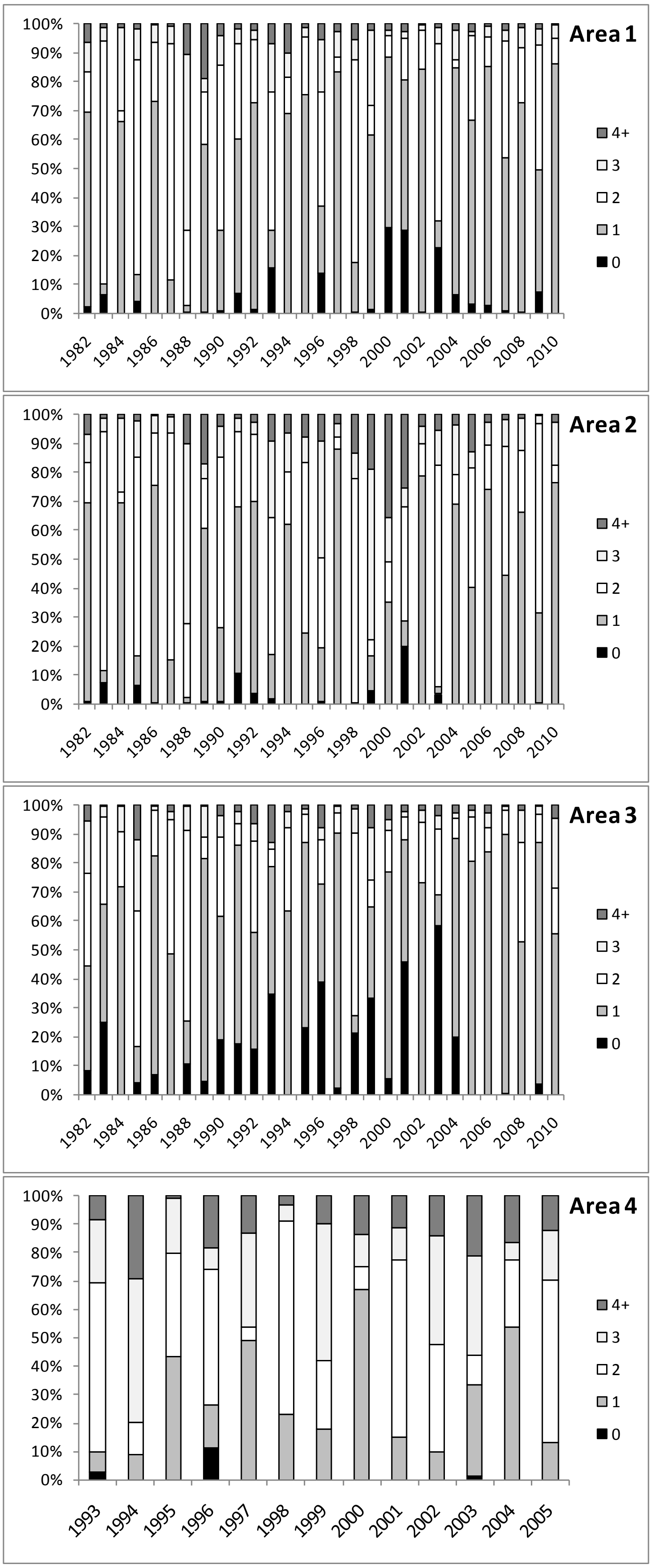

Figure 4.1.2. Development in age composition of biomass in catches in areas 1 to 4.

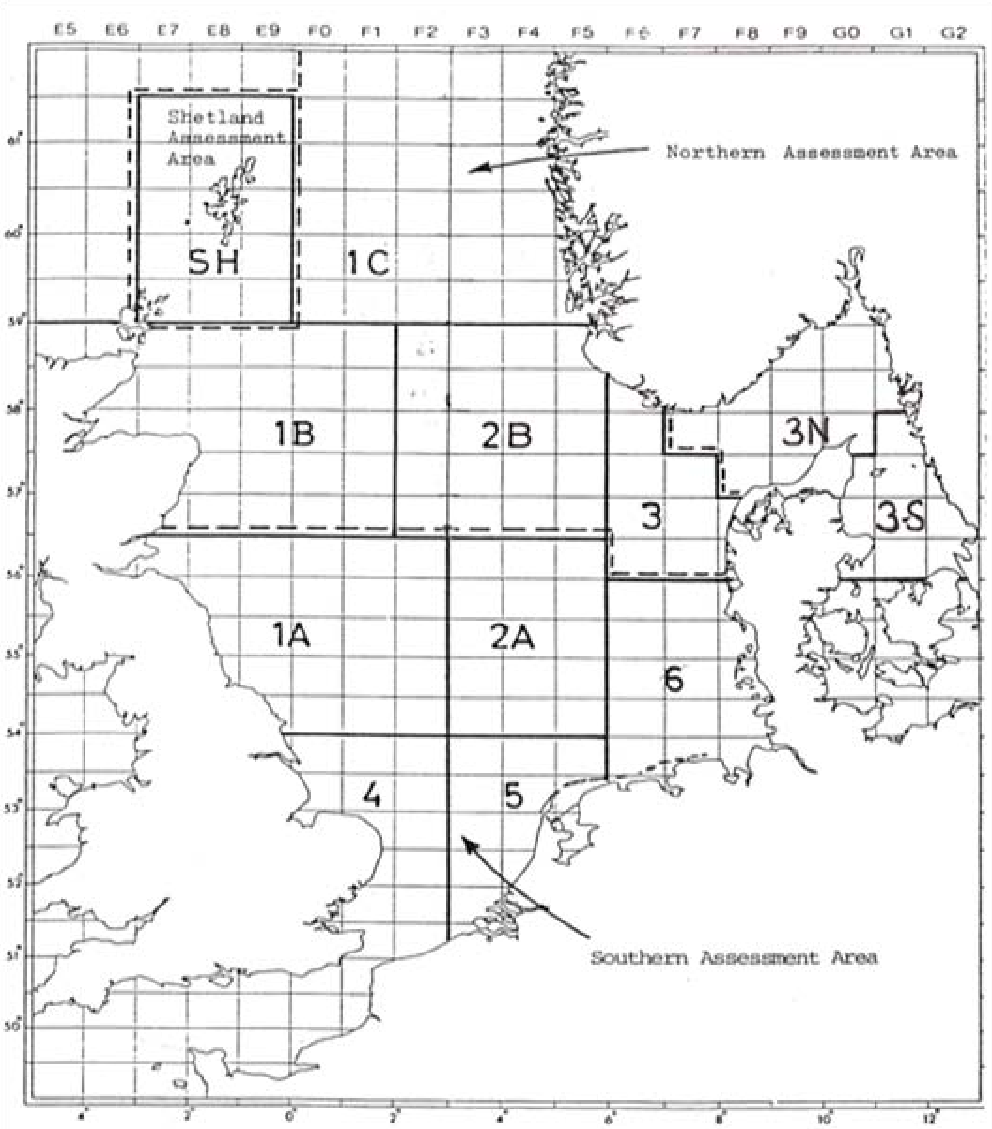

Figure 4.1.3. Historical Sandeel sampling areas used. The areas are identical to the sampling areas given in the report of the working group on the assessment of Norway pout and sandeel (ICES C.M. 1995/Assess: 5) except that the original areas 1C and 2c are joined to one and the border between area 1B and 2B has been moved 1oW. This border was moved to avoid dividing a fishing ground into two.

4.1.2 Estimation of sandeel fishing effort

Estimates of fishing effort is often used in assessment models and the assumption is that on a given day *t*, fishing mortality *F* is

$$F_t = \sum_i q_{t,i} E_{t,i}$$

Where $E_{t,i}$ is effort of vessel *i* on day *t* and $q_{t,i}$ is a catchability coefficient. Often, catchability is assumed to be constant over time and vessels. However, in the case of sandeel, we know this to be wrong as catchability varies with vessel size and the size composition of the fleet has changed over time. In this case, it is preferable to standardise effort to a particular vessel size for which catchability can be assumed constant over time. One way to do this is to use the relationship between catch per unit of effort $cpue_t$, biomass B_t is and catchability:

$$CPUE_{t,i} = \frac{C_{t,i}}{E_{t,i}} = q_{t,i} B_t$$

Where C_t is total catch on that day in combination with the general relationship between vessel size V and catchability apparent from logbook data:

$$CPUE_{t,V} = q_0 \left(\frac{V}{V^*} \right)^b B_t$$

where V^* is a standard vessel size. In this case, q_0 denotes the catchability of a standard vessel and is thus independent of changes in size composition in the fleet. Hence,

$$F_t = q_0 \sum_i \left(\frac{V}{V^*} \right)^b E_{t,i} \tag{1}$$

To obtain the total standardised effort ($\sum_i \left(\frac{V}{V^*} \right)^b E_{t,i}$) in a given time interval, it is thus necessary to know the size of each vessel, the number of days fished and the value of *b*. Vessel size can be measured in any desirable unit. In the case of sandeel, the units used have traditionally been gross tonnage *GT*. *KW* standardization was also attempted but consistently explained less of the variation in $cpue_t$.

4.1.2.1 Estimating *b*

For each area, effort was standardized using eq. 1 above. The parameter *b* was estimated using the model

$$\ln(\hat{CPUE}_{w,r,y,V}) = a_{w,r,y} + b_y \ln\left(\frac{V}{V^*} \right)$$

where indices *sq*, *w* and *y* denote square, week ((Julian day of midpoint of trip/7) rounded to the nearest integer) and year, respectively, *V* is vessel size, $\hat{CPUE}_{w,r,y,V}$ is median cpue in the given rectangle, week and year for a vessel size of *V* and *a* and *b* are estimated using general linear models with normal error distribution. Observations used to estimate the parameters were Danish logbook records of catch of sandeel per day for the years 1983 to 2010. Cpue was estimated as catch per day fished and allocated for each day to the square where the majority of the catch was taken. Trips were allocated to the week where the middle of the trip occurred.

The parameter estimates of *b* are given in Table 4.1.3 along with the r^2 of the general linear model and the partial r^2 of the vessel size term (*b*). Residuals were examined for signs of non-linearity in the relationship between *cpue* and *V*, but no such signs were found. Apart from random variation, there seems to have been a trend in the effect of vessel size, with initially high values followed by low effects of vessel size in the 1990's and increasing effects in later years (Figure 4.1.2, Table 4.1.4). The temporal development in standardised effort using the new method is broadly similar to that obtained using the old method and in both series, there is a clear drop in effort after 2004 (Figure 4.1.3).

Table 4.1.4. Estimates of *b*, r^2 of the general linear model and the partial r^2 of the vessel size term (*b*) for models of the effect of gross tonnage (*GT*).

	GT			
Year	*b*	r^2 model	Partial r^2 of *b*	Number of observations
1983	0.439	0.612	0.046	1944
1984	0.392	0.650	0.029	3177
1985	0.379	0.582	0.032	5279
1986	0.412	0.550	0.040	5209
1987	0.406	0.671	0.028	3441
1988	0.357	0.531	0.040	6937
1989	0.323	0.529	0.033	9550
1990	0.269	0.389	0.024	7212
1991	0.394	0.548	0.045	7506
1992	0.365	0.598	0.040	8318
1993	0.285	0.501	0.028	6260
1994	0.364	0.542	0.057	6354
1995	0.318	0.550	0.048	6670
1996	0.322	0.588	0.025	5003
1997	0.396	0.621	0.045	5429
1998	0.405	0.587	0.039	4790
1999	0.326	0.537	0.015	4152
2000	0.368	0.526	0.029	4096
2001	0.390	0.518	0.028	4952
2002	0.417	0.688	0.040	3730
2003	0.446	0.538	0.032	3348
2004	0.439	0.513	0.057	3876
2005	0.398	0.597	0.029	1410
2006	0.494	0.702	0.042	1946
2007	0.517	0.644	0.080	834
2008	0.394	0.735	0.025	1189
2009	0.519	0.781	0.047	1791
2010	0.389	0.781	0.035	1996
Mean	0.391	0.596	0.037	
Mean(1982–1989)	0.391	0.601	0.034	
Mean(1990–1999)	0.344	0.546	0.037	
Mean(2000–2010)	0.434	0.638	0.040	

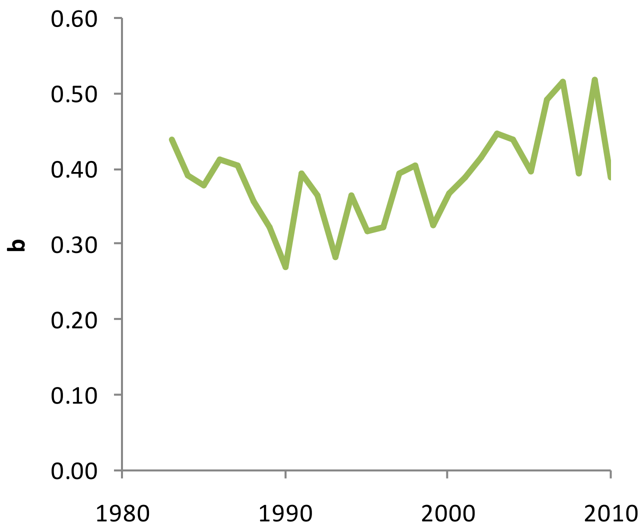

Figure 4.1.2. Temporal development in estimated *b*. Effect of gross tonnage on ln(cpue).

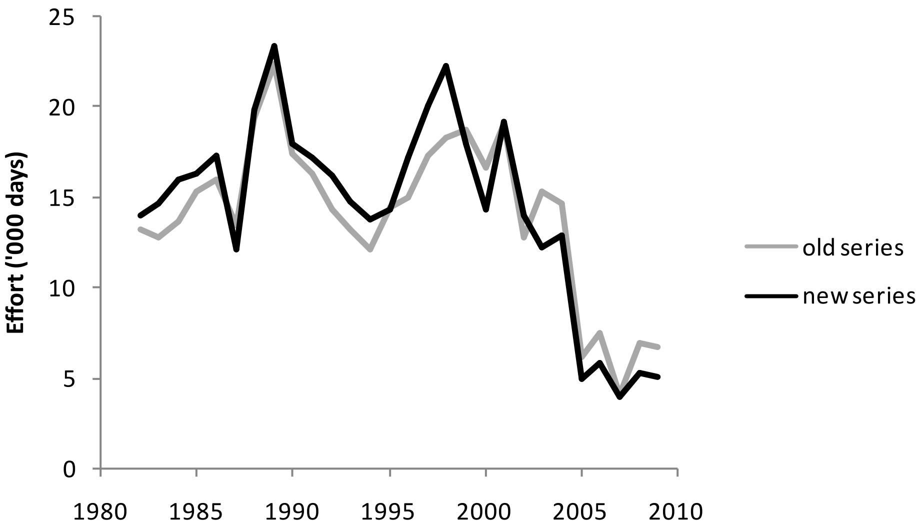

Figure 4.1.3. Temporal development in estimated standardised effort using the new (black) and old (grey) method.

4.1.3 Catch per unit of effort

Using total catches per area and the new estimate of fishing effort, the commercial catch per unit of effort of each age group was estimated. These estimates were evaluated for internal and external consistence (Figures 4.1.4 and 4.1.5). In general, the internal consistency was high in area 1 for all ages, high in area 2 for age 1 only and high in area 4 for age 2 only. In area 3, consistency was low for all ages. External consistency was high between areas 1 and 2, low for all ages but age 1 between areas 1 and 3 and low for all comparisons with area 4.

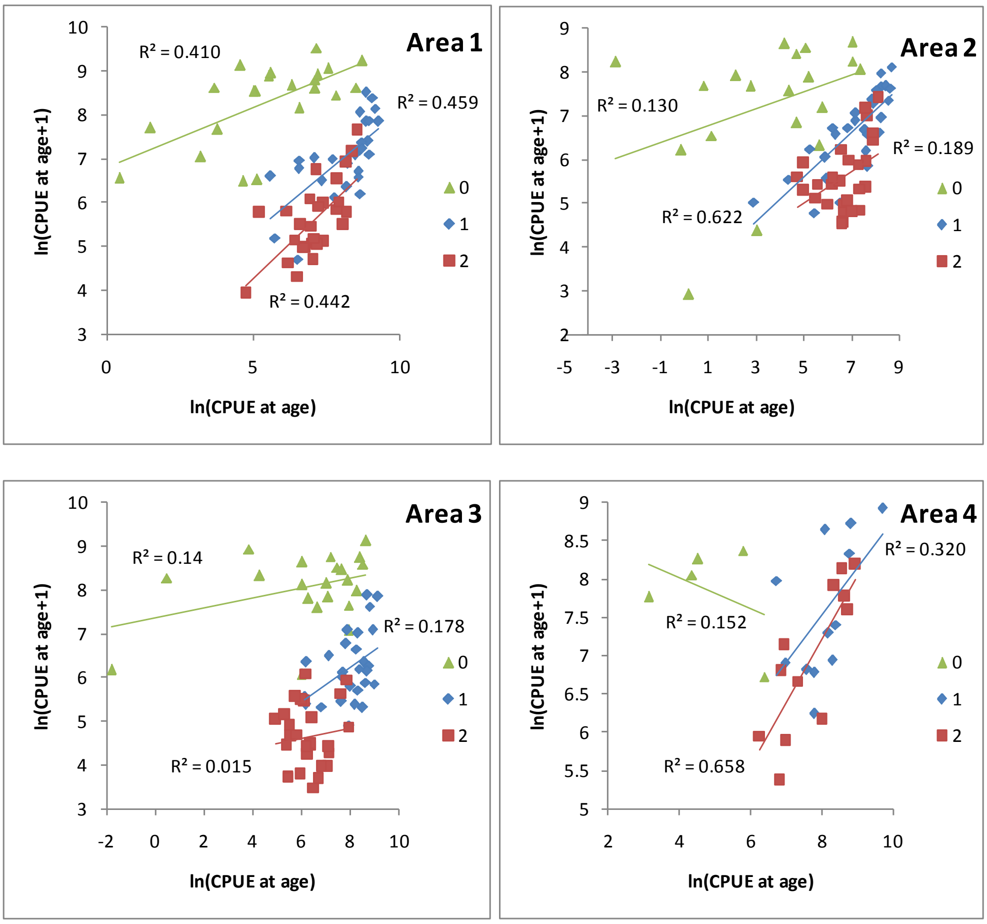

Figure 4.1.4. Internal consistency of commercial cpues (number caught/day) in areas 1 to 4.

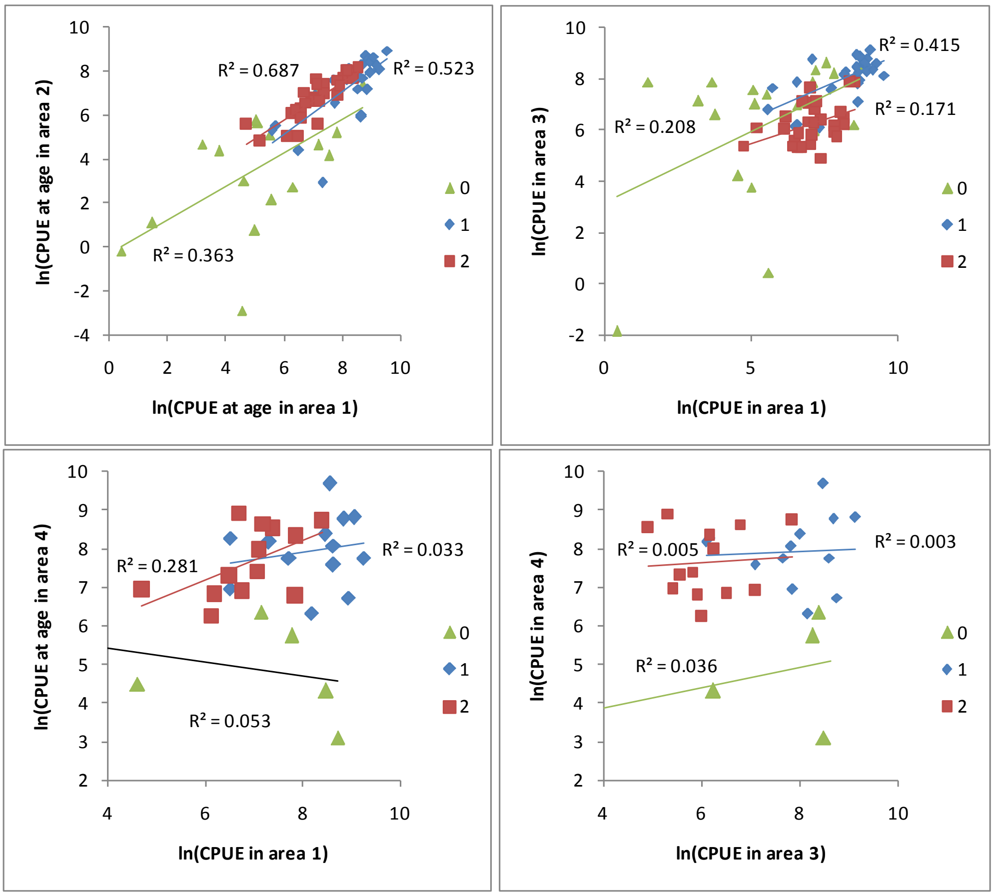

Figure 4.1.5. External consistency of commercial cpues (number caught/day) in areas 1 to 4.

4.2 Survey data

4.2.1 Dredge

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. 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 a total of 828 hauls have been made with four dredge types of which 790 were made with types DK1 and DK2 (Table 4.2.1.1). As indicated in Table 4.2.1.1 and Figure 4.2.1.1, the dredge survey covers Areas 1 and 3 except for seven hauls taken in Area 2 in 2005. The data from Area 2 are not included in the present analysis.

Sampling is carried out at fixed positions on known sandeel habitats at known fishing banks in the North Sea from the little Fisher Bank in the North Eastern North Sea, to the Dogger Bank in the South Western North Sea (Figure 4.2.1.1). From 2006 additional positions were sampled in the Norwegian EEZ.

The 2 positions off southern Jutland in 2007 were found to have unsuitable sediment and were thus given low priority and not subsequently sampled in 2008 and 2009. In 2009 three new positions were sampled on the shallow areas of Dogger Bank. On each new position five sediment samples were taken with the Van Veen 0.2 m² grab and five hauls with the mussel dredge (DK2).

The Danish modified scallop dredge survey has been enrolled under the DCF programme with the locations indicated on the map in Figure 4.2.1.5

In order to complement the Danish survey, Marine Scotland Science began a dredge survey in 2008 with the aim of producing a year-class index for area 4, off the north-east UK coast. The survey is targeted at banks off the Firth of Forth and around Turbot bank and is timed to coincide with the Danish sampling. The distribution of stations in 2009 is shown in Figure 4.2.1.2. In addition to the two recent years of data, similar data are also available from research surveys at Firth of Forth banks undertaken in October-November between 1999 and 2003. The data from all years for this region were used to evaluate the utility of dredge surveys in area 4.

Industry representatives at the WKSAN have raised concern about operating above certain wind speeds. Consultations on actual levels should be held and reported back accordingly.

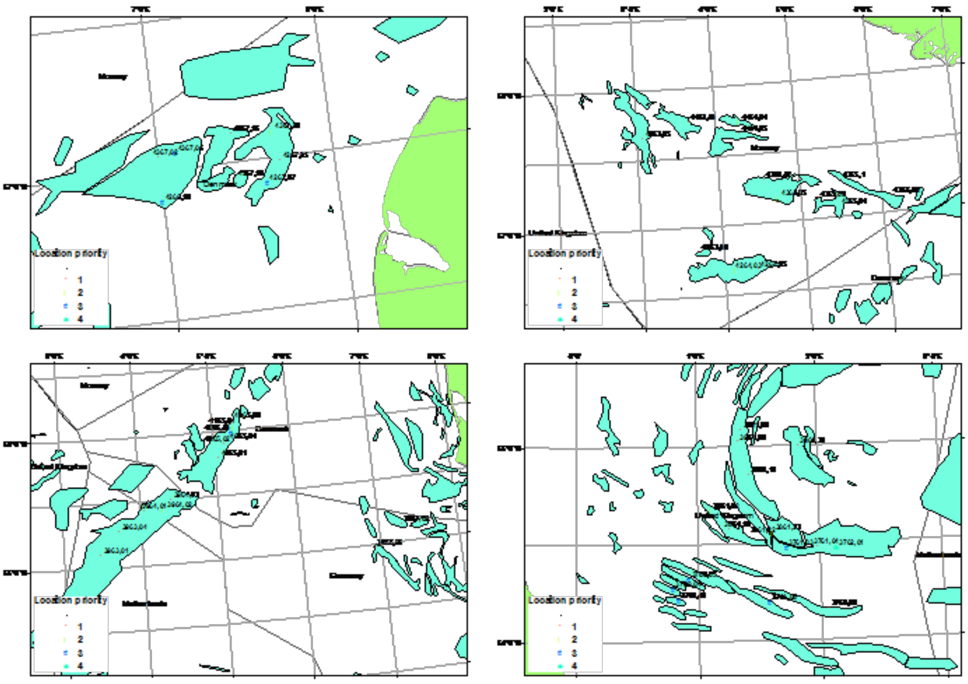

Figure 4.2.1.1 Map showing the sampling locations in the sandeel dredge survey from 2004–2009 in the four subareas (Little Fisher, Norwegian EEZ, Tail End/ South of Jutland and Dogger Bank.

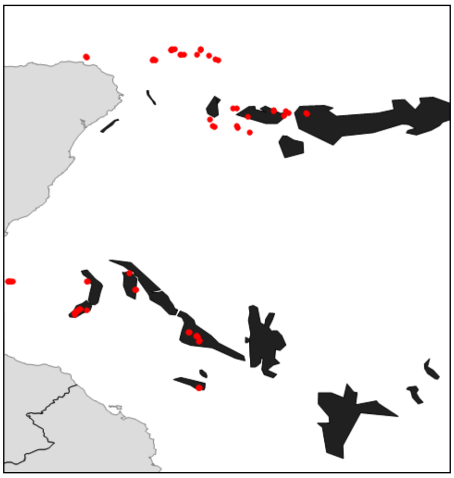

Figure 4.2.1.2. Location of Area 4 dredge stations in 2009, from MSS survey.

4.2.1.1 Description of the gear

During the development of the gear four different dredge types have been tried during the Danish survey: DK1 standard dredge; DK2 Modified standard dredge with video camera and a bottom contact sensor (Figure 4.2.1.3); DK3 Modified standard dredge with an additional net roof; DF1 modified standard dredge with an additional net. As the DF 1 dredge was used on an experimental basis only and analysis indicated that the DK3 dredge had catch rates significantly different from the DK1 and DK2, only data from DK2 (DK1 only as back-up) was used in the present analysis. These two dredges were compared and yielded similar catch rates and therefore their data was aggregated in the analysis.

Figure 4.2.1.3. Modified Scallop Dredge DK2 showing set up of video equipment.

The Scottish dredge survey uses a video system mounted on a towing bar (see Appendix A2). It has been shown that the efficiency of this gear can be improved by 61% (CV = 6%) with the addition of a net hood (Figure 4.2.1.4). However, this addition has not been used routinely.

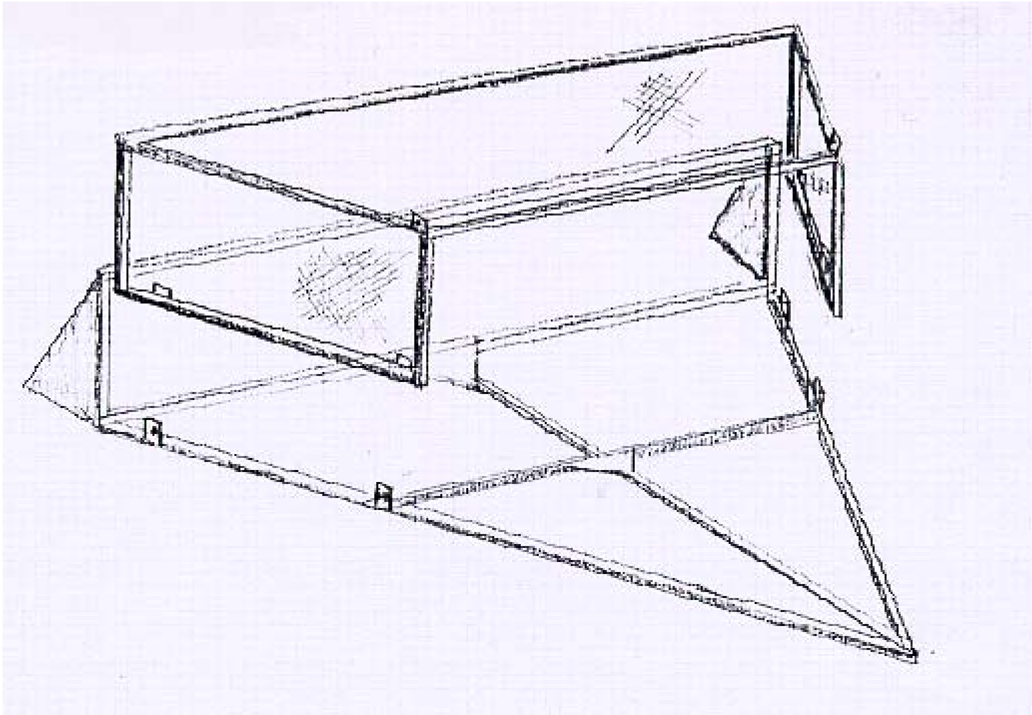

Figure 4.2.1.4. Hood attachment used to compare with conventional dredge.

4.2.1.2 Description of the operation

On every position (stated in Tables 4.2.1.1 and 4.2.1.2) one sediment sample is taken with a Van Veen 0.2 m^2 grab in the Danish survey or a 0.1 m^2 Day grab in the Scottish survey. Thereafter normally 3–5, 10 minutes hauls are conducted with the modified scallop dredge (normally DK2) on the same position. Hauls are conducted within a radius of 0.3 nm from the fixed position. Two mechanical bottom contact sensors register with high frequency the performance of the dredge during operations.

All sandeels from a haul are sorted out from the catch but in cases of large catches only a weight based sub sample is frozen and later worked up in the lab. Length, weight, sex and maturity are registered and otoliths are dissected for age determination. Sub sampling at this level is performed for stomach content and dry weight determination of individuals. Further details of the Danish and Scottish surveys can be found in appendix A1 and A2 respectively.

A varying number of hauls have been made at the different positions over the years (Table 1a). Therefore, 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:

(1)

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

where

(2)

$$\overline{CPUE}_{a,sq} = \frac{\sum_{pos} \overline{CPUE}_{a,sq,pos}}{n_{a,sq,pos}}$$

where

(3)

$$\overline{CPUE}_{a,sq,pos} = \frac{\sum_{st} \overline{CPUE}_{a,sq,pos,st}}{n_{a,sq,pos,st}}$$

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

Table 4.2.1.1. Number of stations (hauls) by area, square and position made by dredges DK1 and DK 2.

			Year						
Area	Square	Position	2004	2005	2006	2007	2008	2009	Total
1			114	135	126	83	63	58	579
	37F0		0	15	14	7	7	8	51
		3760.01					1		1
		3760.03		5					5
		3760.04		5	5	3	1	3	17
		3760.05		5	4	4	2	3	18
		3760.06			5		3	2	10
	37F1		11	24	15	6	3	3	62
		3761.03	6	10	5				21
		3761.04	5	9	5	3	3	2	27
		3761.08		5	5	3		1	14
	37F2		5	5	4	3	4	5	26
		3762.01					3	3	6
		3762.02	5	5	4	3	1	2	20
	38F1		20	30	27	27	13	10	127
		3861.02		5			2		7
		3861.14	5	5	4	3	1	2	20
		3861.19	5	5	5	5	2	2	24
		3861.22	5	5	5	6	3	2	26
		3861.23		5	5	6	1	2	19
		3861.32	5	5	8	7	4	2	31
	39F1		15	13	13	3	6	5	55
		3961.01		2					2
		3961.02					1		1
		3961.22		1					1
		3961.28	10	5	6		2	3	26
		3961.29	5	5	7	3	3	2	25
	39F3		19	9	11	14	9	7	69
		3963.01	10	4	6	6	3	2	31
		3963.04	9	5	5	4	3	3	29
		3963.07				4			4
		3963.08					3	2	5
	39F4		25	14	15	8	10	8	80
		3964.01	10	9	10		1	3	33
		3964.02	10	5		4	3	2	24
		3964.03	5		5	4	6	3	23
	40F5		10	15	17	7	7	7	63
		4065.01	5	5	5	7	3	2	27
		4065.02	5	5	5		3	3	21

			Year						
Area	Square	Position	2004	2005	2006	2007	2008	2009	Total
		4065.03			2				2
		4065.04		5	5		1	2	13
	41F5		9	10	10	8	4	5	46
		4165.01	5	5	5		3	2	20
		4165.02	4	5	5	8	1	3	26
2			0	7	0	0	0	0	7
	38F6		0	4	0	0	0	0	4
		3866.01		4					4
	39F7			3					3
		3967.02		3					3
3			20	13	48	40	46	37	204
	42F3		0	1	5	3		1	10
		4263.02		1	5	3		1	10
	42F4		0	0	1	5	6	0	12
		4264.01					2		2
		4264.03				3	1		4
		4264.05			1	2	3		6
	42F7		15	10	10	4	7	9	55
		4267.08	1						1
		4267.12	10	5			2	3	20
		4267.25	4	5	5	4	2	3	23
		4267.27			5		3	3	11
	43F4		0	0	0	0	7	4	11
		4364.01					3		3
		4364.05					2	1	3
		4364.07					2	3	5
	43F5		0	0	16	9	6	8	39
		4365.04			6	3		2	11
		4365.08			5	3	3	3	14
		4365.1			5	3	3	3	14
	43F6		0	0	6	3	3	3	15
		4366.06			6	3	3	3	15
	43F7		5	2	10	10	11	12	50
		4367.02			5	4	3	3	15
		4367.06					3	3	6
		4367.16		2		4	3	3	12
		4367.23	5		5	2	2	3	17
	44F4		0	0	0	6	6	0	12
		4464.04				3	3		6
		4464.05				3	3		6
Grand Total			134	155	174	123	109	95	790

Table 4.2.1.3. Scottish dredge survey. Number of hauls by ICES rectangle and year.

Rectangle	Year						
	1999	2000	2001	2002	2003	2008	2009
41E7	3	4	3	3	3	18	15
41E8	4	5	3	3	3	8	8
40E8	2	5	0	2	2	6	8

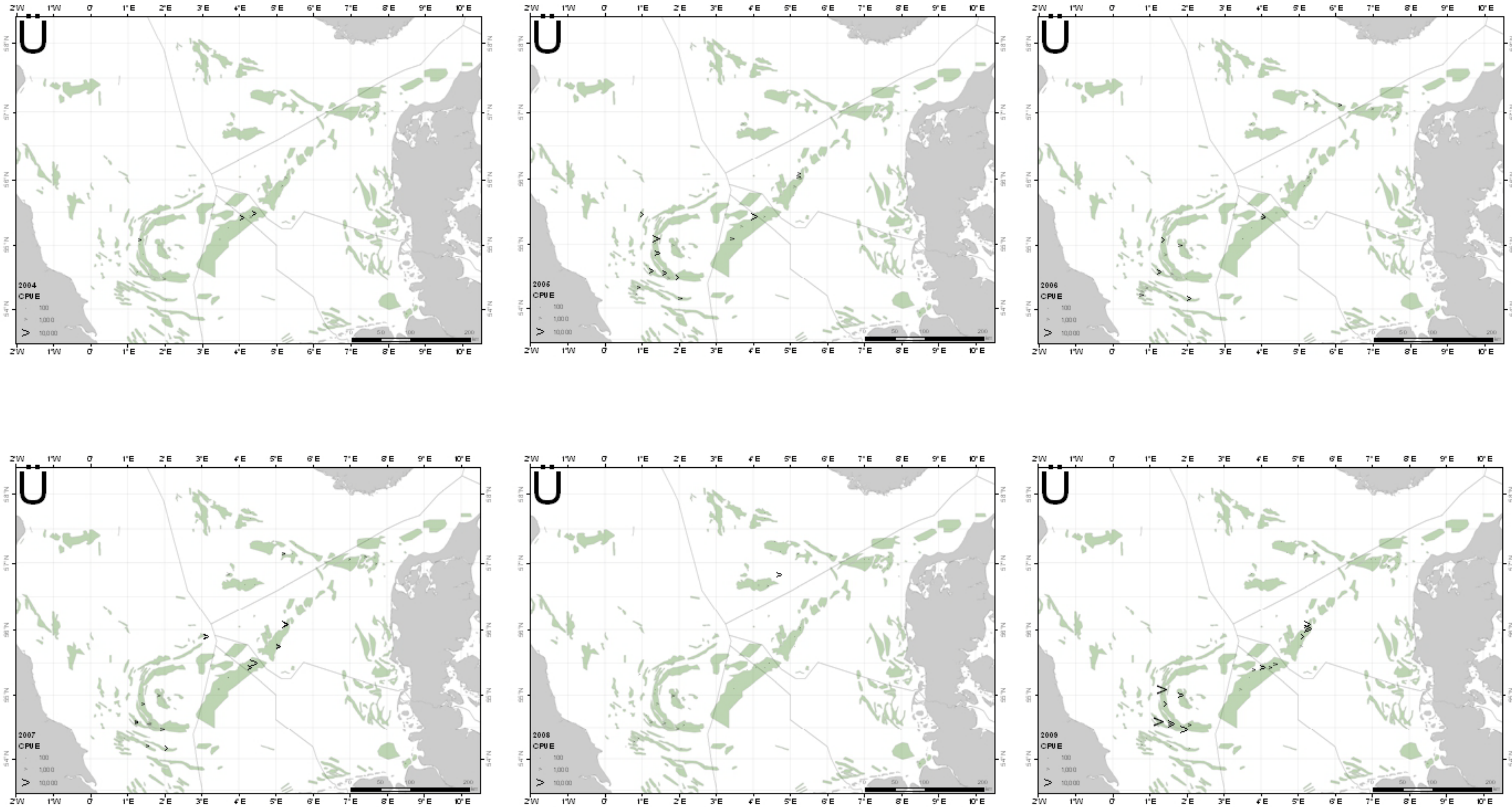

Figure 4.2.1.5. Map of Danish dredge sample locations (2004–2009) with area of circles indicating catch rates per 60 min haul.

4.2.1.3 Time-series, coverage and trends in cpue

The time-series of coverage and catch rates for the Danish dredge survey is detailed in WDA1 in the Appendeces (Christensen, 2010), and a map of locations for the period 2004–2009 with indicated catch rates is found in Figure 3. Standardized cpues for the survey has an apparent slight positive trend for area 1 as well as area 3 in time-series 2004–2009.

4.2.1.4 Internal and external consistency

The internal consistency, i.e. the ability of the survey to follow cohorts, was evaluated for each area by plotting catch rates of an age group in a given year versus the catch rates of the next age group in the following year.

Exploratory analysis indicated that the internal consistency did not improve by standardization to the square means or by weighting by total commercial catches by square or by the size of the sandeel distribution area of the catch rate indices.

Internal consistency of the dredge surveys was high in all areas (Figure 4.2.1.6). External consistency between dredge catch rates and commercial cpues was very high in area 1 with the exception of the oldest fish (age 2) (Figure. 4.2.1.7). In area 3, the consistency was somewhat lower, in particular for 2-year olds in the cpue. In area 4, the consistency with the cpues as used in the assessment was very high for 2+ in the cpues but low for age 1. However, this appeared to be linked to the aggregation level of the data, as consistency between the dredge survey and catch rates based directly on haul time and catches derived from part of the fleet in cooperation between the Danish Fishers and DTU-AQUAed very high consistency for this group (Figure 4.2.1.7).

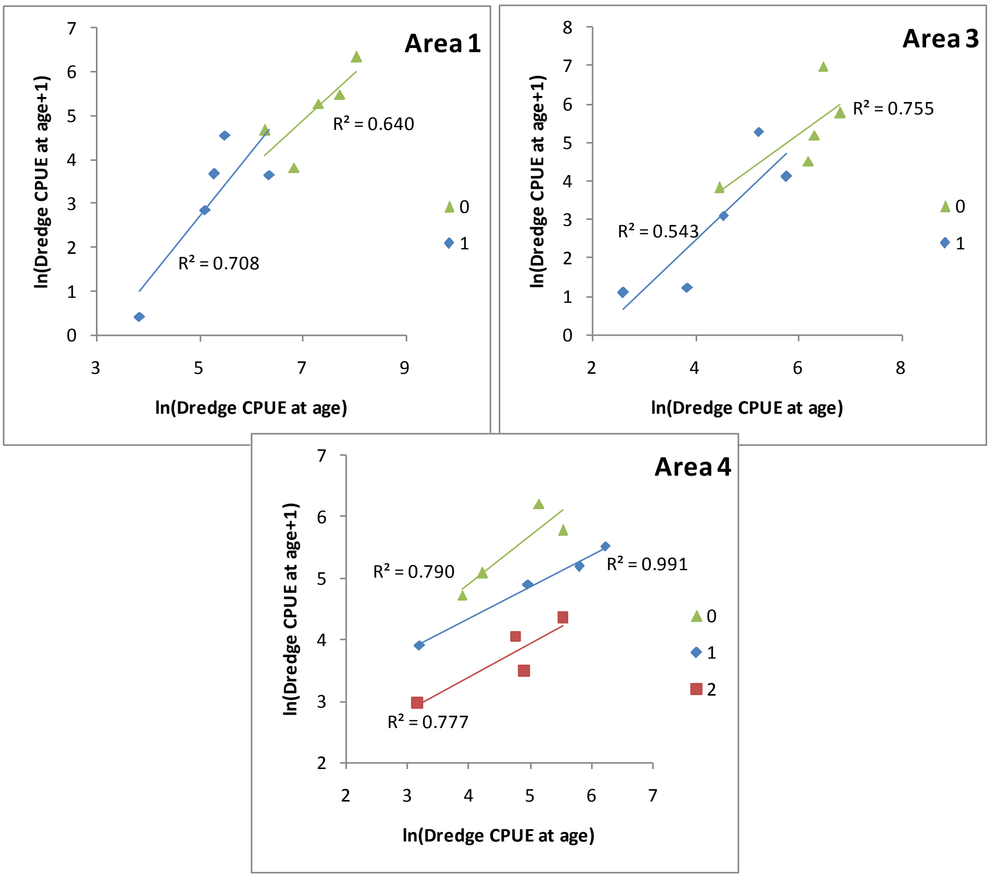

Figure 4.2.1.6. Internal consistency of the dredge survey in areas 1, 3 and 4.

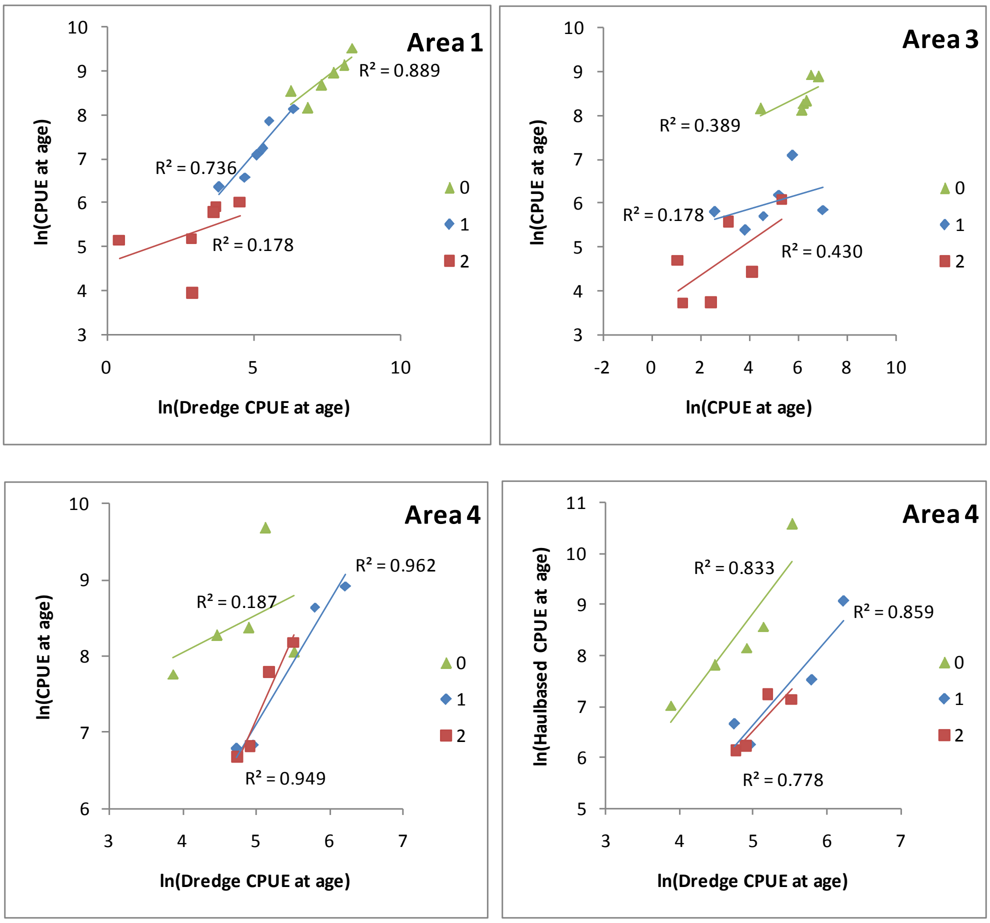

Figure 4.2.1.7. External consistence of dredge surveys compared to commercial cpues as included in the assessment or haul based cpues (no per minute hauled) from the detailed Danish sampling of selected vessels.

4.2.1.5 Error structure

Analysis of variation among stations within locations show a low CV, internal consistency indicate low among year variation within locations, thus the highest error component arrives from among locations. Area effects explain part of this variation but a good coverage within areas is needed to reduce variance on the area index.

Identifying problems

Although survey design in the Scottish dredge survey in area 4 is quite similar to the design in the Danish survey in areas 1 and 3, comparison of internal consistency indicate different age specific catchabilities among areas. This may be explained by a negative size selectivity for sandeels less than 8.5 cm (Appendix A2) and that size at age is much smaller in area 4 than in the other two areas.

4.2.1.6 Index development

Input into assessment

The preseason survey in December with present coverage yields an age structured index including assessment year estimates of maturity ogives for areas 1, 3, and 4; whereas extension of the survey with more locations is needed for production of an index for area 2. However recruitment estimates from area based assessment show a high correlation between area 1 and 2 and thus indicate that the survey index from area 1 may be used as a fisheries independent index proxy for area 2 as well.

Input into short term prediction

The index should be integrated in an update preseason assessment including an appropriate short-term prediction of fishing opportunities.

4.2.2 Acoustic estimates by sandeel fishing ground in the Norwegian EEZ in the North Sea

Acoustic abundance-estimation methods (Simmonds and MacLennan, 2005) using vertical echosounders have been used to estimate numerous pelagic stocks since 1970 (Gjøsæter *et al*., 1998). When carefully used, the method provides absolute abundance estimates, as demonstrated for capelin (*Mallotus villosus)* stocks in the Barents Sea (Dommasnes and Røttingen, 1985; Toresen *et al*., 1998), Iceland (Vilhjalmsson, 1994), and Newfoundland (Miller and Carscadden, 1990).

Institute of Marine Research has carried out acoustic sandeel surveys in the North Sea since 2005 with the objective to develop a robust survey methodology for sandeel combining advance acoustic technology and catching devices for sandeel buried in the sediments (Johnsen *et al*., 2009). Concurrently, we have monitored the sandeel grounds in the Norwegian Economical Zone, and in some surveys also the grounds in the EU EEZ. In this working document we present the methodology used to establish acoustic abundance estimates for the period 2007–2010 for the major sandeel grounds in the Norwegian EEZ.

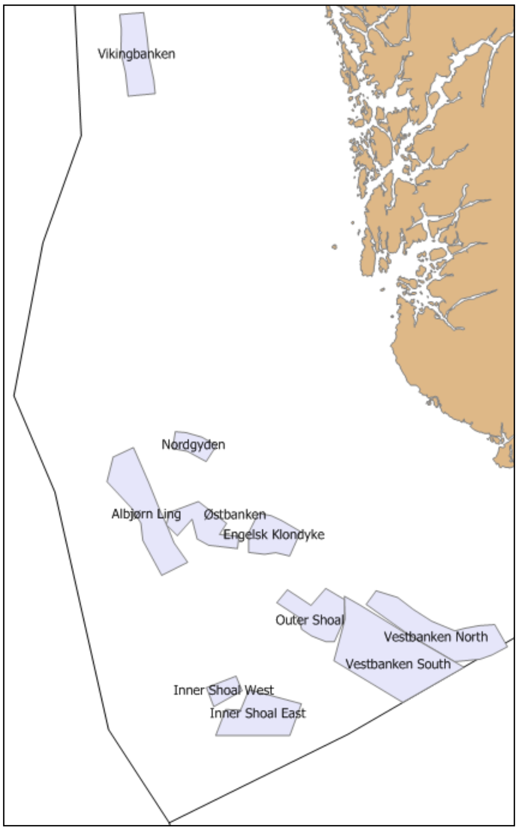

Figure 4.2.2.1. Sandeel fishing grounds in the Norwegian EEZ.

Sandeel fishing grounds in the North Sea have been identified from WMS data (satellite tracking data) of the Danish and Norwegian sandeel fleets. In addition, several Norwegian vessels have generously provided trawl trajectories from the sandeel fishing grounds obtained the last 8–10 years. The fishing grounds form a patchwork of clearly defined areas spread all over the North Sea at depths between 20–70 m, except at the Viking bank were sandeel are found between 90 and 110 m.

Survey grounds in Norwegian EEZ

- Vikingbanken
- Nordgyden
- Albjørn-Ling
- Østbanken (Kadaveret is on the northern part of the ground)
- Engelsk Klondyke
- Inner Shoal West
- Inner Shoal East
- Outer Shoal
- Vestbanken North
- Vestbanken South

These fishing grounds were used to define the survey areas in the Norwegian EEZ, which for all cases included larger areas than the fishing grounds. It has been a slight change in the survey areas in the 2007–2010 periods, but the change is ignorable with regard to the abundance estimates. Figure 1 shows the survey areas used during the 2009 and 2010 surveys.

4.2.2.1 Survey design

Standard random parallel and zig-zag transect designs are used, where the parallel design is mostly used on the larger Vestbanken North and South and on the Outer Shoal. In the planning of the cruise track, the direction of the fishing fields are consider as the track should be perpendicular to the normal industry towing direction.

In general, the effort allocation or the degree of coverage is based on the expected density of sandeel on each ground, and the day light time available is also considered in the planning.

Acoustic data are recorded with an 18, 38, 120, and 200 kHz echosounder system (and also with 70 and 333 kHz in 2009) (Simrad EK60) which was calibrated using standard procedures. The transducers are mounted on a retractable keel in accordance with recommended settings. Pulse duration for all frequencies was 1.024 ms and a ping repetition frequency of typically four Hz was chosen to maximize the number of echoes from small sandeel schools.

The acoustic survey began each morning after sandeel emerged from the seabed and continued until about 20:00 UTC. The data were post-processed using the Large Scale Surveying System (LSSS) (Korneliussen *et al.*, 2006). The borders of the schools were delineated in the 200 kHz echogram because the S_v from sandeel is strongest and the reverberant noise from gas-bearing phytoplankton is lowest at this frequency. The mean nautical area scattering coefficient (NASC) (MacLennan *et al.*, 2002) was measured for each school at each frequency. Frequency responses are now commonly used for the acoustic identification of species (see summaries in Reid, 2000; Simmonds and MacLennan, 2005). Korneliussen and Ona (2002) proved that the relative frequency responses of acoustic targets can be used to identify their taxa or species. The use of relative frequency responses to discriminate between several species was further developed by Anon. (2006) for swim-bladdered fish, such as sardine, anchovy, saithe, cod, Norway pout, and also fish without swim-bladders, such as mackerel. In addition to relative frequency responses, metrics of fish-school morphology and behaviour can sometimes be used to classify echoes, and validated by trawl samples.

The boundary towards the bottom, where schools were in the vicinity of this boundary was cutoff at about 0.3–0.5 meters off the detected bottom to be safe that no bottom echo was included inside the school energy. Scrutinized data was stored to database in bins of 10 m depth and 0.1 nmi (185.2) meters resolution. Distribution maps and computations are made at this resolution.

During the surveys, three different trawls have been used to catch sandeel: a Campelen 1800 bottom trawl; a Harstad pelagic trawl (originally a 16 x 16 fathom Capelin trawl with 5 mm meshes in the codend) to catch schools in the pelagic zone and near the surface; and a large commercial Steintrawl sandeel trawl with a 700 m headline circumference to sample the entire water column. Trawls targeting acoustically identified sandeel schools are restricted to daytime. In addition, a 0.25 m^2 Van Veen grab and a modified scallop dredge (the same as used in the Danish dredge surveys) were used both daytime and night-time to sample fish burrowed into the seabed.

4.2.2.2 Abundance estimation

The acoustic estimates presented in this report use the 38 kHz NASC, and the mean was calculated for data scrutinized as sandeel and collected along the transects (acoustic recordings taken during trawling, etc are excluded).

The number of sandeel in each length group within the surveyed area is then computed as:

$$N_i = f_i \frac{< s_A > \quad A}{< \sigma >},$$

where:

$$f_i = \frac{n_i L_i^2}{\sum_{i=1}^{m} n_i L_i^2},$$

is the "acoustic contribution" from the length group L_i to the total energy. $<s_A>$ is the mean backscattering coefficient [m^2/nmi.^{2}] (NASC) for the survey ground. A is the area of the survey ground [nmi.^{2}] and $<\sigma>$ is the mean backscattering cross section of the sandeel at length L_i. With the present lack of target strength data on sandeel, we have preliminarily used the one suggested at 38 kHz (MacLennan and Simmonds, 1992): $<TS> = 20 \log L - 93$ dB where the conversion: $<\sigma> = 4\pi \, 10^{(<TS>/10)}$ is used for estimating the backscattering cross section from the mean TS.

An age–length key estimated based on both data from the survey and catches from the commercial vessels from the area is then used to get number by age. The biomass of the survey area can be computed from the weight–length keys estimated from data sampled during the survey: $w = aL^b$.

4.2.2.3 Acoustic availability

Day and night dredge hauls are on all survey grounds carried out on adjacent positions (pairs) in the survey areas. As all lesser sandeels (age 1+) probably are buried in the seabed at night, the difference in catch rates in dredge at night and the subsequent day at a given location (*i*) will presumably reflect the acoustic availability ($1 - {catch_{di}}/{catch_{ni}}$). Based on the observed day–night ratio, it is possible to adjust the acoustic NASC values with the estimated acoustic availability, but there are relatively large uncertainty connected to such a procedure. A more robust method is therefore to repeat the acoustic survey when the day–night ratio is below a predefined level. During our surveys we have not found high numbers of sandeels in the sand on any of the survey grounds in the Norwegian EEZ.

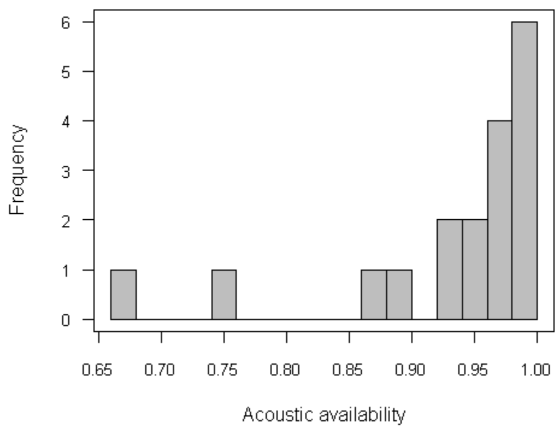

Figure 4.2.2.2. A histogram of the distribution of the acoustic availability defined as $1 - {catct_{di}}/{catch_{ni}}$ where catch rates in dredge at night is compared with the day catches the subsequent day at a given location (*i*). The presented data (n=18) were collected during the 2008 survey and shows stations with night catches larger than 50 sandeels.

4.2.2.4 Results

As pointed out above, the main purpose of the surveys has been to develop a robust survey methodology, which has reduced the effort spent on monitoring the abundance. Still, the results presented below can be regarded as a good indicator of the abundance of sandeel by ground.

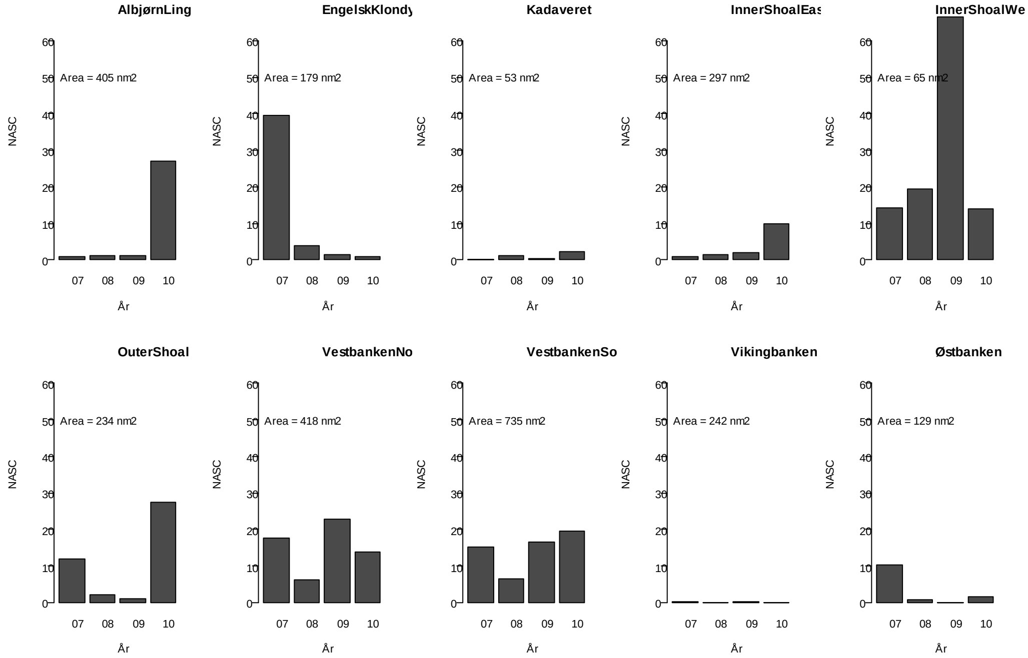

Figure 4.2.2.3. Acoustic densities of sandeel on the survey grounds for the period 2007–2010. Nordgyden is not shown.

4.3 Maturity

4.3.1 Background

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 that 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 (January 1st). In area 4, sandeels were found to mature at a smaller size than in 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.

4.3.2 Available time-series of maturity data

A time-series (2004–2009) of spatially resolved maturity data from the Danish December dredge survey for areas 1-3 is held by the Danish institute. The working paper of Steen (Appendix 7) evaluates the assumption of knife edge maturity from these data. Whilst most sandeels from the time-series were mature at age 1, the benchmark group found, contrary to the conclusion of the WD, that there was sufficient deviation from the knife edge age-at-maturity assumption to decide that annual differences should be considered in area based assessments (see Section 5). Low sample sizes for age classes >1 make the application of annually varying maturity ogives dubious. For area 4, only the age maturity key of Boulcott *et al.* (2007) was applied, as there was no time-series of data available.

4.3.3 Applicability to stock–recruitment analysis

A comparison of the stock–recruitment relationship with constant maturity ogives and annually varying ogives for the available years in the Danish dataset did not influence the perception of the SSB breakpoint with the present relatively short time-series.

4.4 Natural mortality

The values of natural mortalities for sandeel used in the previous historical assessment are based on MSVPA model output, and have been kept constant since 1989 (ICES CM 1989/Asssess:13).

The most recent estimate of natural mortality was done in 2008 by the Working Group on Multispecies Assessment Methods (WGSAM) in the latest North Sea key-run (ICES, 2008). The model does not provide spatial estimates of natural mortality. Compared to the MSVPA results used as basis for M in the pre-2010 WGNSSK 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 4.4.1 shows the partial predation mortality (M2) of sandeel by year as estimated by WGSAM. To obtain the total natural mortality, a value of 0.2 representing additional natural mortality (M1) should be added (M=M1+M2). The average of the estimated annual M is quite close to the values used by the assessment (Table 4.4.1). It should be noted that the sum of the half-year M may deviate from the annual M due to different F in the two half-years. The estimated yearly natural mortality is shown in Figure 4.4.2. 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 (Figure 4.4.3), while the M used by the assessment are much higher in the first half year.

The group considered that since there were updated estimates of half-yearly natural mortality available from WGSAM, these should be used in the assessment. 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. However, the group considered it unfortunate that spatially explicit natural mortalities were not available as it is unlikely that natural mortality is constant across the assessment areas.

Table 4.4.1. Natural mortalities for sandeel as used by the ICES assessments and as estimated by WGSAM.

	Assessment			WGSAM 2008
Age	First half year (halfyear^{-1})	Second half year (halfyear^{-1})	Sum (year^{-1})	Average 1982-2007 M=0.2+M2 (year^{-1})
0	-	0.8	0.8	0.96
1	1.0	0.2	1.2	1.04
2	0.4	0.2	0.6	0.86
3	0.4	0.2	0.6	0.68
4	0.4	0.2	0.6	0.64

Table 4.4.2. Agreed natural mortalities for sandeel.

	Assessment		
Age	First half year (halfyear^{-1})	Second half year (halfyear^{-1})	Sum (year^{-1})
0	-	0.96	0.96
1	0.46	0.58	1.04
2	0.44	0.42	0.86
3	0.31	0.37	0.68
4	0.28	0.36	0.64

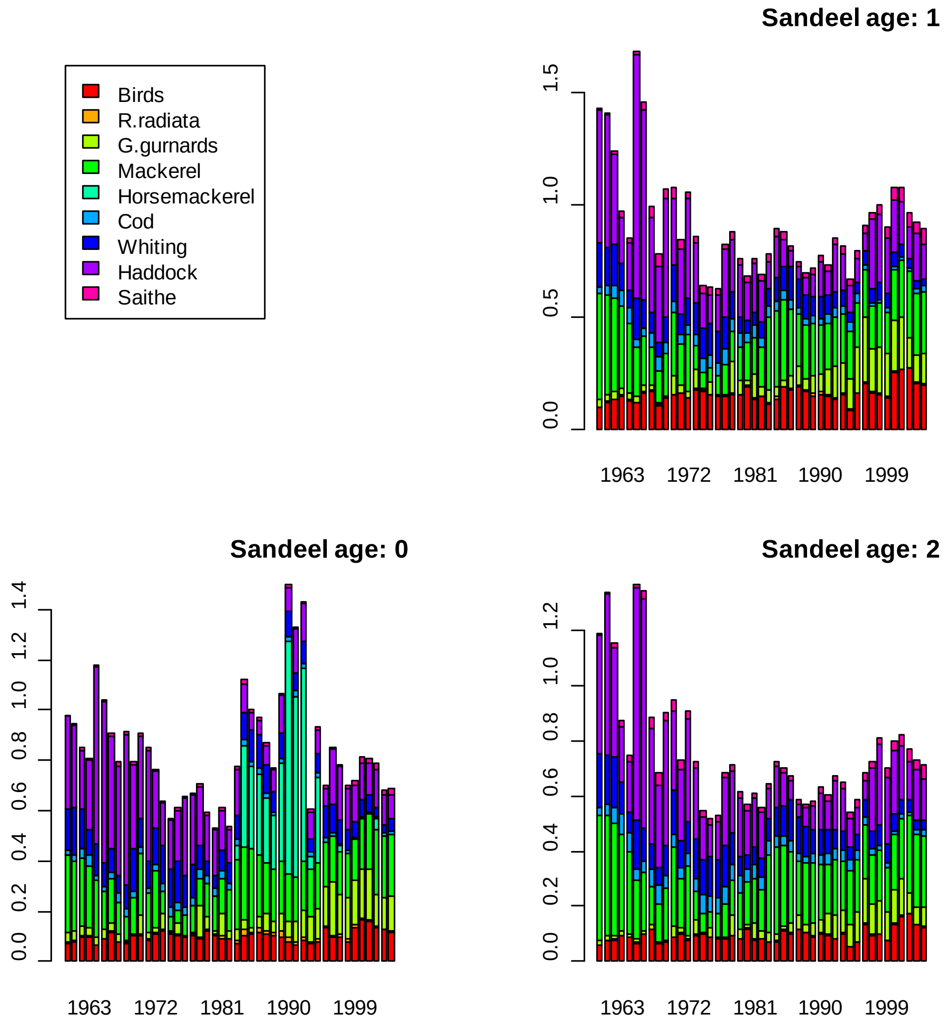

Figure 4.4.1. Partial predation mortality (M2) for the period 1966 to 2007 as estimated by the SMS model, Annual values are used for age 1 and 2, while M2 for age 0 is for the second half year is by half year (from ICES 2008).

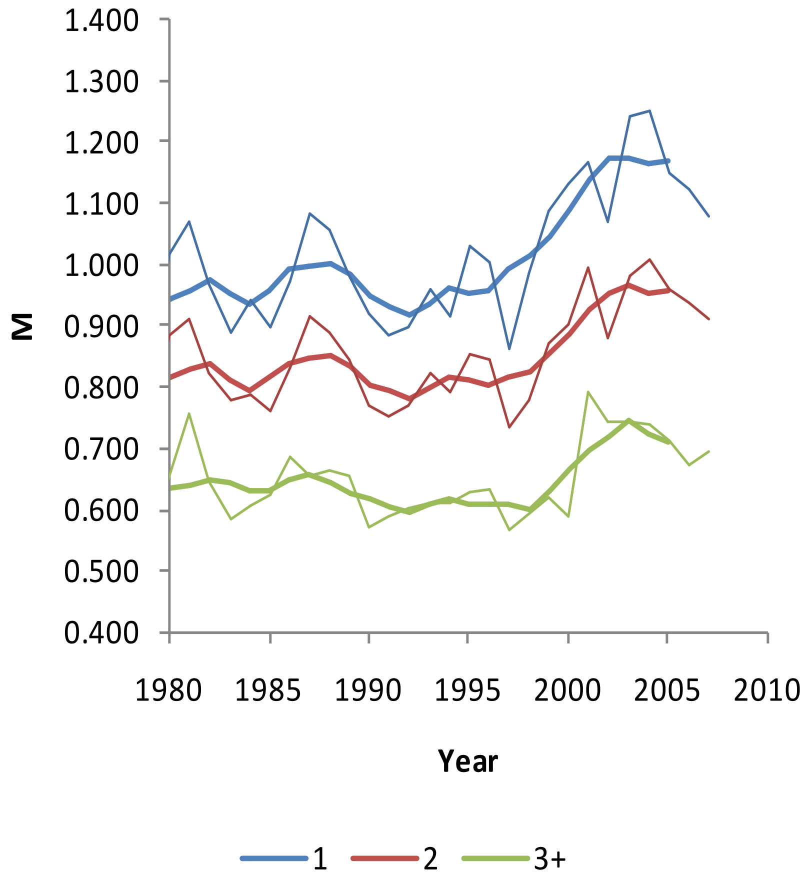

Figure 4.4.2. Yearly natural mortality for different age groups of sandeel estimated by WGSAM (ICES 2008). Heavy lines are 5-year moving averages.

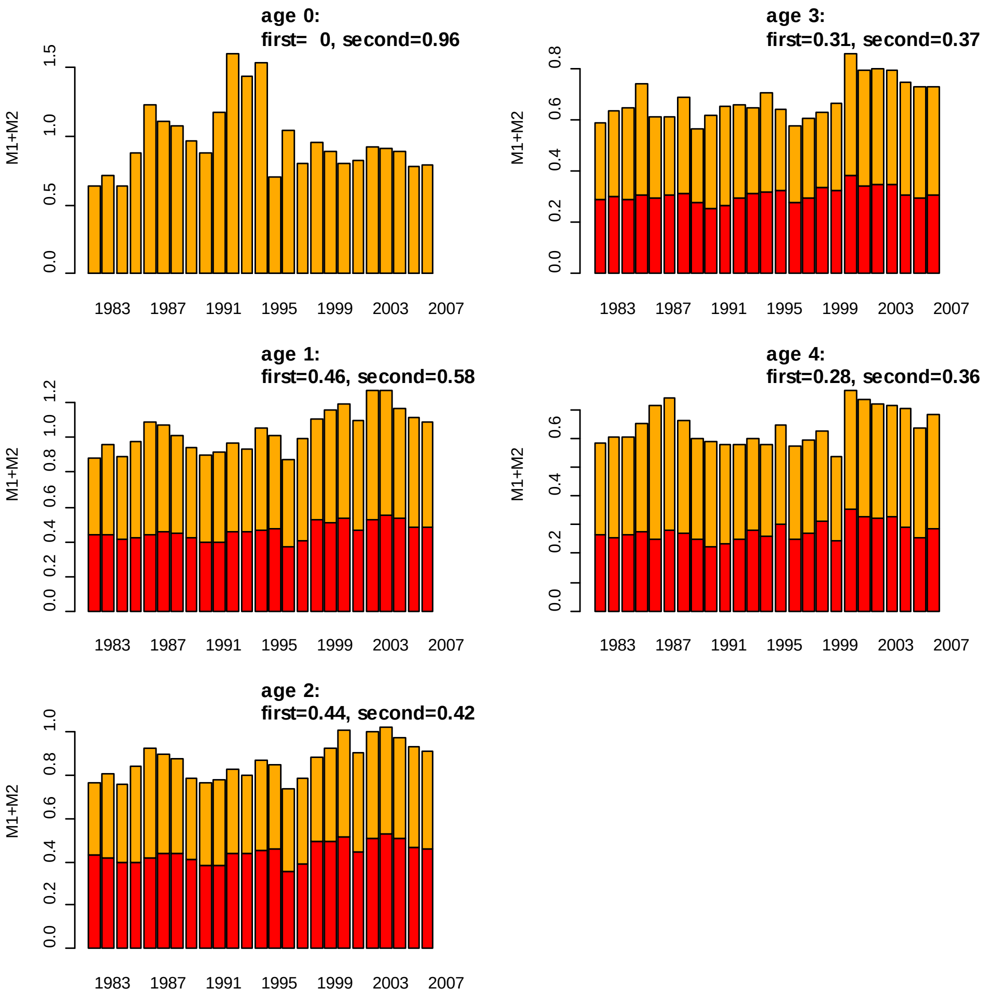

Figure 4.4.3. Natural mortality (M1+M2) of sandeel by half year. Mean values (1982–2007) for first and second half year are presented in the headings.

4.5 Fleet development in vessels and gear in the Danish sandeels fishery 1985-2010

1985–1995: Seven new trawlers were built in 1985. Vessels that could hold about 1000 tonnes and which had bigger engines and propellers compared to the rest of the fleet.

Before 1985, an ordinary vessel had a constant drag at about 6–7 tonnes and a machine at 600–700 hp. An average catch in a good fishery was 40–50 tonnes per set of 3 hours. 4 to 5 set were possible per day.

The new trawlers that were introduced in 1985 had a constant drag at about 20–30 tonnes and a machine at 1500–2000 hp. An average catch in a good fishery was 150–200 tonnes per set of 4–5 hours. 3 set were possible per day.

The new trawlers were able to use a bigger codend, which meant that the sandeels in the codend was kept alive and consequently much larger catches were possible because the trawl did not close.

The small trawlers now started to use as big codends as possible. Too big codends created “dead waters” inside the codend and therefore, the fishing was not effective. So there is an upper end to the size of the codend with regard to the size of the trawl.

In the beginning of the 1990s most of the trawlers were lengthened and stronger engines were put into the vessels. The investment and thereby the improvement of the vessels lead to a much larger fleet of "super" trawlers, at a sizes which made it possible for them to use bigger trawls and bigger codends.

In 1995–2000 and forward Dyneema became a component in the trawl and some trawls used up to 80% Dyneema. This made it possible to make the trawls bigger compared to trawls made of nylon. The Dyneema fibre was thinner compared to nylon at the same strength and thereby the water resistance was much lower allowing bigger trawls to be dragged by the same hp. Where a trawl made of nylon was able to open 18–20 metre the trawl made of Dyneema could open up to 40–50 metre.

From 2000 and forward there has not been any big advancement in the vessels and gear used for targeting sandeels. The big increase seen from 2000 and forward in Figure 4.5.1 is because of a couple of big ships entering the fishery (Figure 4.5.2).

The development in the Norwegian sandeels fishery follows the same pattern as the Danish development.

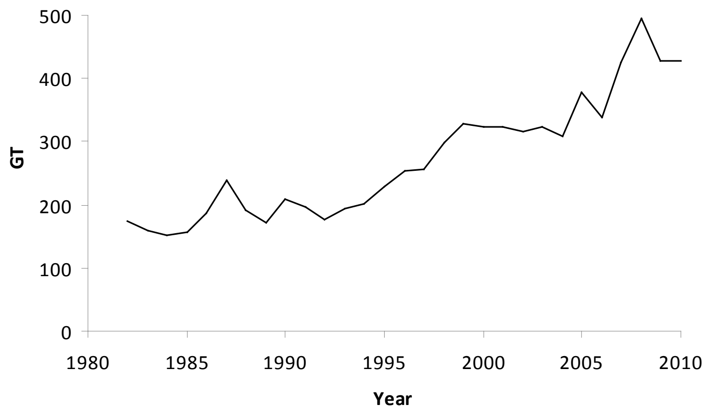

Figure 4.5.1. Development in average vessel size.

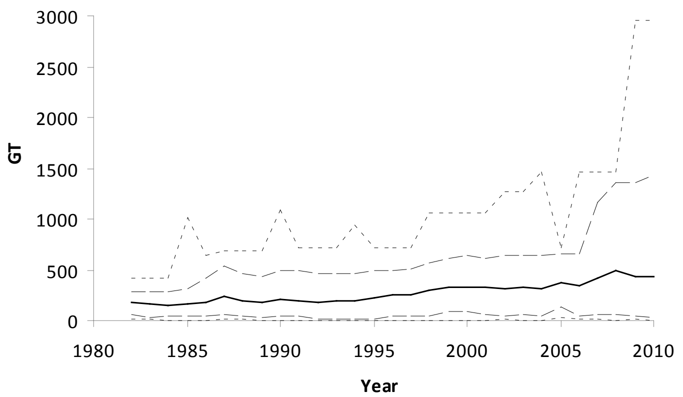

Figure 4.5.2. Development of fishing days weighted average vessel size. Mean (solid), 5 and 95 percentiles (dash) and minimum and maximum vessel size (dotted).

5 Assessment Models

Three assessment models were considered as potential candidates for the historical assessment of the different stock units, a VPA based model (SXSA) (Skagen, 1994) and two statistical catch-at-age models. Prior to the meeting a state-space model was investigated but found to be unstable for these stocks and therefore was not presented to the group. Table 5.1 summarises the differences between the three model approaches.

Previous whole-area assessments of sandeel showed no consistent relationship between effort and F (Figure 5.1). 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 (Figure 5.2). This relationship has been used by the statistical catch models as the driver for estimating F.

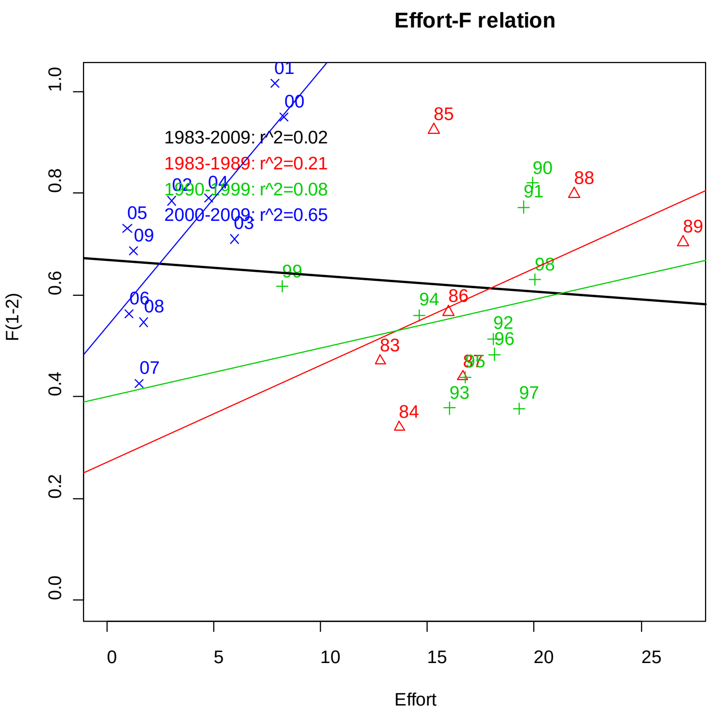

Figure 5.1. Relationship between standardised effort and F from the whole-area assessment (WGNSSK, 2009).

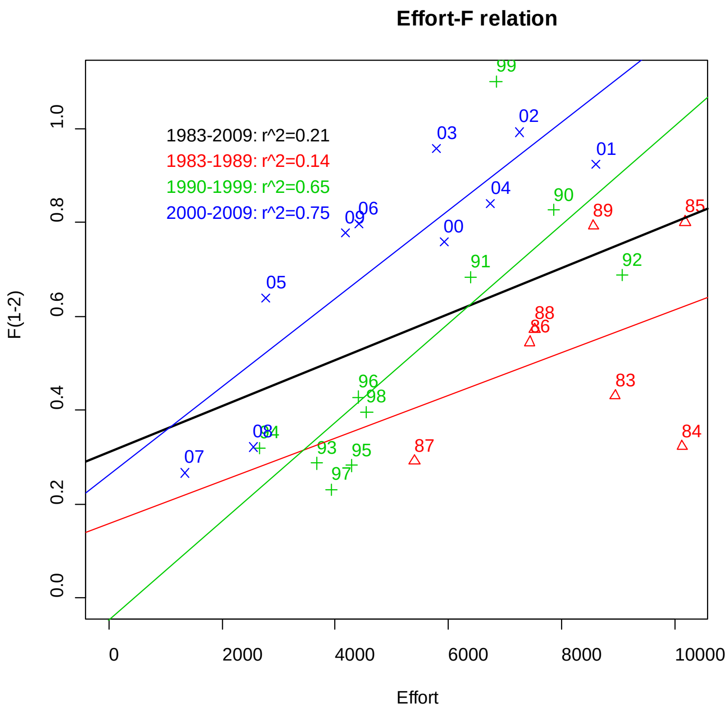

Figure 5.2. Relationship between standardised effort and F derived from a SXSA run for area 1.

5.1 SXSA (EB)

Seasonal XSA (SXSA, Skagen, 1994) has been the model used by ICES (WGNSSK) for the assessment of North Sea Sandeel since the mid nineties. SXSA is essentially a standard VPA, tuned with some index of abundance and split into two seasons. The advantage of using this model over the standard (single season) XSA (Shepherd, 1999) was that SXSA was able to incorporate the different levels of natural mortality considered to occur between the seasons. For assessments undertaken in the second half of the year, landings from the first half of the current year could be incorporated and was also able to give a more up to date estimate of stock status than other methods.

Previous ICES Sandeel assessments have implemented the model as a single stock prosecuted by two fleets (Northern and Southern). Eight tuning fleets were provided, all derived from commercial cpue comprising all combinations of areas and seasons, split into two time periods at 1998 to reflect a change in gear development. The model diagnostics consistently gave cause for concern with large residual patterns and consistent retrospective patterns. The ratio of estimated fishing mortalities between age 1 and 2 were also erratic with large interannual variations. The use of commercial cpue as the only tuning index, although the only tuning-series available was never particularly satisfactory. In addition the same catch numbers are used twice; in the catch at age and in the cpue data, which causes unwanted correlation, and probably the large variation in exploitation pattern from one year to the next. These changes also indicates, that the assumption of fixed catchability-at-age (~fixed exploitation pattern) for tuning fleet is violated.

Following the decision to assess the different stock components separately, a trial run of SXSA was made for area 1 using the newly-revised estimates of natural mortality and maturity. A model run using data up to 2010 failed to give a satisfactory result, the model opting to fit very closely to a single tuning fleet.

5.2 SMS-effort (MV)

Summary

As effort has been shown to be a reasonable proxy for F the SMS model was modified to model fishing mortality as a function of total commercial fishing effort. The new 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. Model results show a significant increase in fleet efficiency and a change in exploitation pattern, with more effort directed to the fishing banks with the highest abundance of the one-group sandeel. 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.

$F_{y,q,a}$ = SesonEffect(Y,A1) * AgeEffect(Y,A2,q) * YearEffect$_y$ (1, original version)

$F_{y,q,a}$ = SesonEffect(Y,A1) * AgeEffect(Y,A2,q) * Effort$_{y,q}$ (2, new version)

where

indices A*1* 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).

	Season effect A1=age 0 and age 1-4										
	First half year						Second half year				
YY	Age 0	Age 1	Age 2	Age 3	Age 4		Age 0	Age 1	Age 2	Age 3	Age 4
1983-1998	0.00*	0.426	0.426	0.426	0.426		1.0*	0.5*	0.5*	0.5*	0.5*
1999-2009	0.00*	0.337	0.337	0.337	0.337		1.0*	0.5*	0.5*	0.5*	0.5*

*** kept constant**

	Age effect A2=age 0, age 1, age2 and age 3-4										
	First half year						Second half year				
YY	Age 0	Age 1	Age 2	Age 3	Age 4		Age 0	Age 1	Age 2	Age 3	Age 4
1983-1998	0.00*	0.488	1.024	1.248	1.248		0.014	0.772	0.847	0.585	0.585
1999-2009	0.00*	0.772	0.857	0.585	0.585		0.010	0.176	0.195	0.133	0.133

"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.

$$F_{y,q,a} = \text{SesonEffect}(Y,A1) * \text{AgeEffect}(Y,A2,q) * \text{Effort}_{y,q} * (\text{y-firstYear})^{\text{commonCreep}(Y)} \quad (3)$$

$$F_{y,q,a} = \text{SesonEffect}(Y,A1) * \text{AgeEffect}(Y,A2,q) * \text{Effort}_{y,q} * (\text{y-firstYear})^{\text{ageCreep}(Y,A1)} \quad (4)$$

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 indicate 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

$$L_{CATCH} = \prod_{a,y,q} \frac{1}{\sigma_{CATCH\ a,q}\sqrt{2\pi}} \exp\left(-\frac{(\log(C_{a,y,q}) - E(\log(C_{a,y,q})))^2}{2\sigma^2_{CATCH\ a,q}} \right)$$

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:

$$l_{CATCH} = -\log(L_{CATCH}) \propto NOY \sum_{a,q} \log(\sigma_{CATCH\,a,q}) + \sum_{a,y,q} (\log(C_{a,y,q}) - E(\log(C_{a,y,q})))^2 / (2\sigma^2_{CATCH\,a,q}))$$

Survey indices

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

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

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:

$$l_{SURVEY} = -\log(L_{SURVEY}) \propto \sum_{survey,a} NOY_{survey} \sum_{survey,a} \log(\sigma_{SURVEY\,survey,a}) +$$
$$\sum_{survey,a,y} (\log(CPUE_{survey,a,y}) - E(\log(CPUE_{survey,a,y}))^2 / (2\sigma^2_{SURVEY\,survey,a}))$$

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 $R_y = R(SSB_y \mid \alpha, \beta)$ 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

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

where

$E(\ln(R_y)) = \ln(\alpha\ SSB_y \exp(-\beta\ SSB_y))$ for the Ricker case. Other stock–recruitment relations (Beverton–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.

5.3 TED

The temporally explicit model is a statistical catch-at-age model it is developed to better match seasonal effort allocation pattern used in the sandeel fishery. The model is run separately in three areas, and its results compare well with results from other models (SMS, and XSA). In addition to the estimates produced by SMS and XSA the model is estimating the within year catchability pattern for separate age groups, and from that the instantaneous fishing mortality is computed by multiplying the catchability and the effort corresponding at each specific point in time. The model incorporates the new dredge survey from DTU-Aqua in the two areas (1 and 3) where it is available. Furthermore, the model is stochastic and quantification of uncertainties is a natural part of the model. A detailed model description is available in appendix A3 and model results can be found at:

http://www.nielsensweb.org/sandeelIdx/

5.4 Rationale for model selection

Comparison of the results and diagnostics from the SMS-effort and TED models showed that the ability to fit to the available data was similar for both models. However, as the SMS model is currently used to assess other ICES stocks (blue whiting and multispecies assessments) and therefore of the two statistical models, SMS-effort was the preferred separable approach.

The remaining decision was therefore between a statistical or deterministic model. The group considered that the ability of the SMS model to handle uncertainty in the catch-at-age data gives the SMS-effort model an advantage over the VPA approach. In addition the inability of SXSA to provide a satisfactory fit to the data including 2010 where SMS could provide a fit naturally raised concerns about the stability of the model. This, coupled to the ease of obtaining uncertainty estimates, lead to the Group opting to use SMS-effort for the assessment of Sandeels in the North Sea.

However, even with the move to a more realistic concept of stock definition, the ability of the catch data to track cohort strength remains weak for some areas. This could be a result of variable natural mortality, uncertainty within the age sampling process, spatial variability of fishing patterns by the fleet or (more likely) some combination of all these processes. These factors violate basic assumptions for both models; in particular changing spatial patterns in the fishery violates the assumption of fishing from a single dynamic pool. For the Sandeel fishery changes in the spatial pattern could result from sequentially depleting areas. This would be of less concern in stocks with a greater range of ages as the fishery would have several chances to prosecute a year class on any given, but for sandeels with essentially two main age classes annual changes in fishing pattern may have a significant impact.

	SXSA	SMS-effort	TED
Model type	Deterministic VPA	Statistical catch-at-age	Statistical catch-at-age
Catch at age data	Assumed exact	Observation error estimated within model	Observation error estimated within model
Tuning data	Commercial CPUE & survey	Survey	Survey
Timestep	Half-year	Half-year	Yearly catches, weekly effort
Catchability	Constant by age ('83–98 & '99–)	Constant by age ('83–98 & '99–)	seasonal pattern, constant for all years
Use of Commercial effort	Into cpue	F Proportional to effort	F Proportional to effort
Natural mortality	Half-yearly	Half-yearly	Half-yearly
Ability to estimate technical creep?	none	Possible	Possible
Statistical distribution of parameter estimates	No	Yes (all)	Yes (all)
Forecast internal to model	No	Built-in	No
implementation	Fortran	ADMB & R	ADMB & R
Stock-recruit	None assumed	Can be included in likelihood	None assumed
Number of stocks currently used for	N Sea Norway Pout & North Sea Sandeel	N. Sea multispecies, Baltic multispecies, Blue Whiting (core SMS only)	Bespoke for N Sea Sandeel.
Documentation	Skagen, 1994	Lewy and Vinther, 2004; Vinther 2010	Nielsen, 2010
Peer-reviewed?	ICES acceptance	ICES acceptance (core SMS only)	New model

6 Short-term forecasting

6.1 Pre-season assessment

The investigations using the different models show consistently large retrospective patterns 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 is somewhat lower than in the other areas (Figures. 4.2.1.6 and 4.2.1.7). 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 (Figure 4.1.5) 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. The production of 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 good (areas 1 and 2) but the estimates for area 3 would be less reliable. 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 the case.

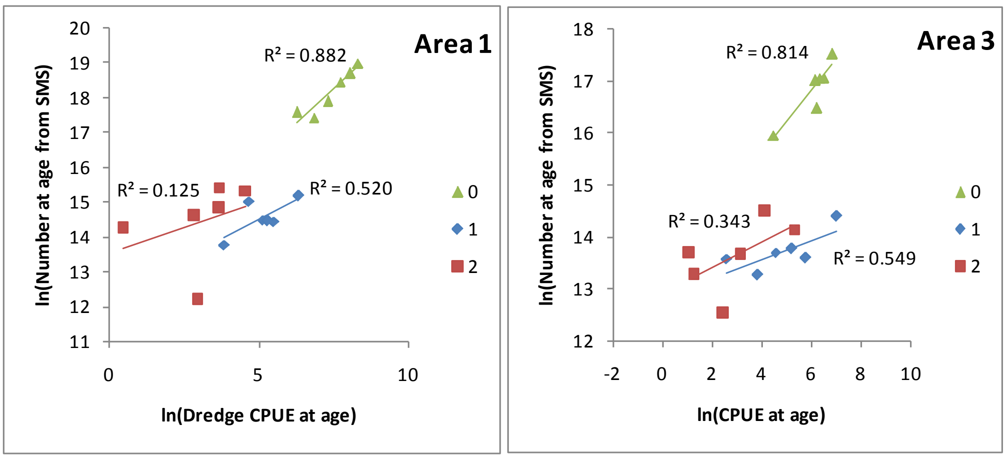

Figure 6.1.1. Relationship between dredge catch rate and SMS predicted stock size at age. Note that the data are not independent as the dredge survey is used in the estimation of stock size.

6.2 In-season monitoring

In-season monitoring using commercial catch rates in the beginning of the season has been used in sandeel management for a number of years. However, it is not clear whether the relationship between early season cpue in stock size is equally good in all areas or even whether it exists in all areas. Therefore, Figure 6.2.1 shows the catch rate prior to first of May (approximately the end of the real time monitoring period) as a function of stock abundance as estimated by the regional SMS models of area 1 and 3. It is clear that the relationship between catch rates in the early part of the season and stock abundance is very tight in area 1, which indicates that real time monitoring can be a valuable tool in in-season assessments of stock size in this area. However, the value of in-season monitoring would appear to be lower in area 3, reflecting the generally lower internal and external consistency in this area of both dredge catch rates and commercial catches. Whereas in area 1, all ages could potentially be used, it is clear that only age 1 can be used with any confidence in area 3. The poorer relationship for 1-year olds in area 3 appeared to be linked to a temporal shift, in catchability as trends in residuals over the period 1993 to 2010 suggested increased catchability after 2000 rather than 1998 in this area. Obviously there is some circularity in the relationship as the assessment is tuned using commercial cpue, but this is the approach taken (out of necessity) for the determination parameters of the in-year TAC revision performed in recent years.

A reliable in-season monitoring requires that both biomass indices and the age-composition of the biomass are available with minimum delay. Commercial catch rates are reported within three days and biological samples from the catch are collected continually. Similarly, the acoustic data are analysed as they are collected. Hence, if in-season monitoring is required, the data are available without additions to the normal sampling programme but with an additional requirement for the speed at which the data are analysed.

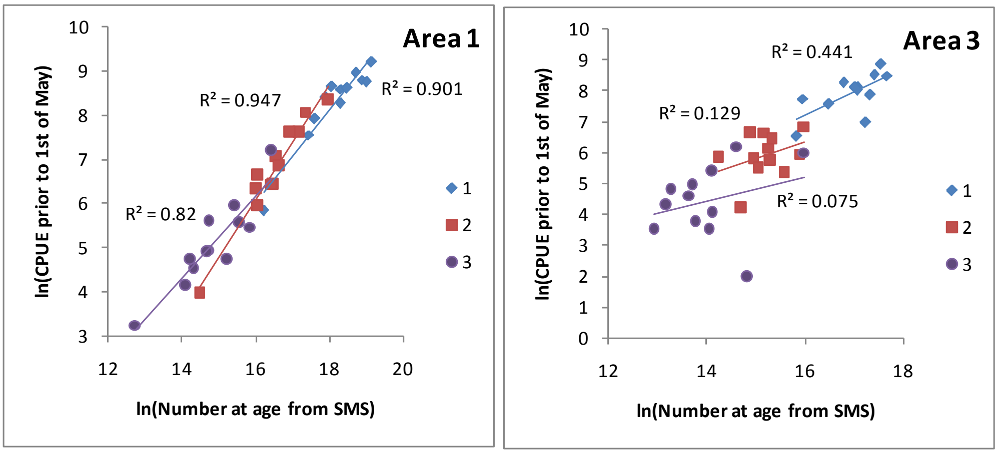

Figure 6.2.1. Catch rate in the real time monitoring period as a function of stock numbers estimated in SMS in area 1 and 3. Years 1998 to 2010.

6.3 Necessary sampling programmes

The rise in importance and reliability of the dredge survey has potential implications for the in-season monitoring programme which has been an important feature of Sandeel assessment and management over the past few years.

6.3.1 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.

6.3.2 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.

6.3.3 Area 3

Pre-season estimates of the incoming year class appear 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.

6.3.4 Area 4

Whilst it is important to continue 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. Until there is sufficient overlap in the time-series of dredge survey and commercial data there will be no scientific basis to propose a TAC at present.

6.4 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_{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_{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_{lim} was therefore set as the median biomass in these years of low SSB (2000–2006) giving the values 160 000 tons for area 1 and 70 000 tons 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_{lim} was set at 100 000 tons, 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.

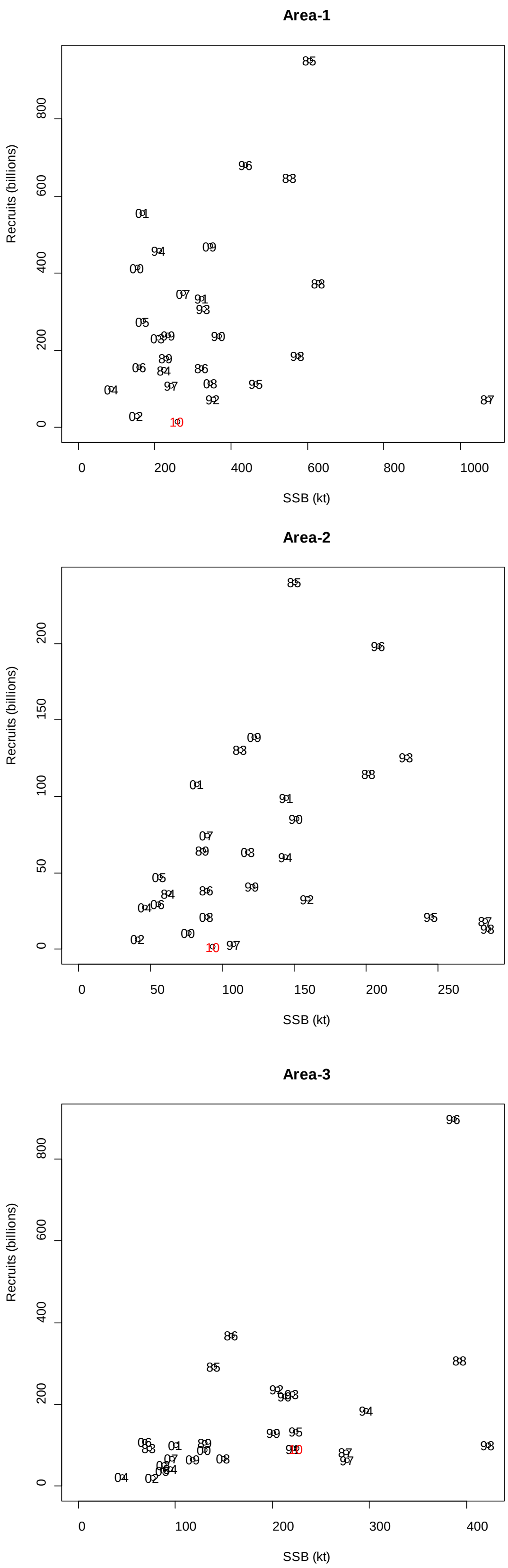

Figure 6.4.1. Stock–recruitment relationship in areas 1 to 3. Note that the recruit estimate for 2010 is based on very little input data and is therefore highly unreliable.

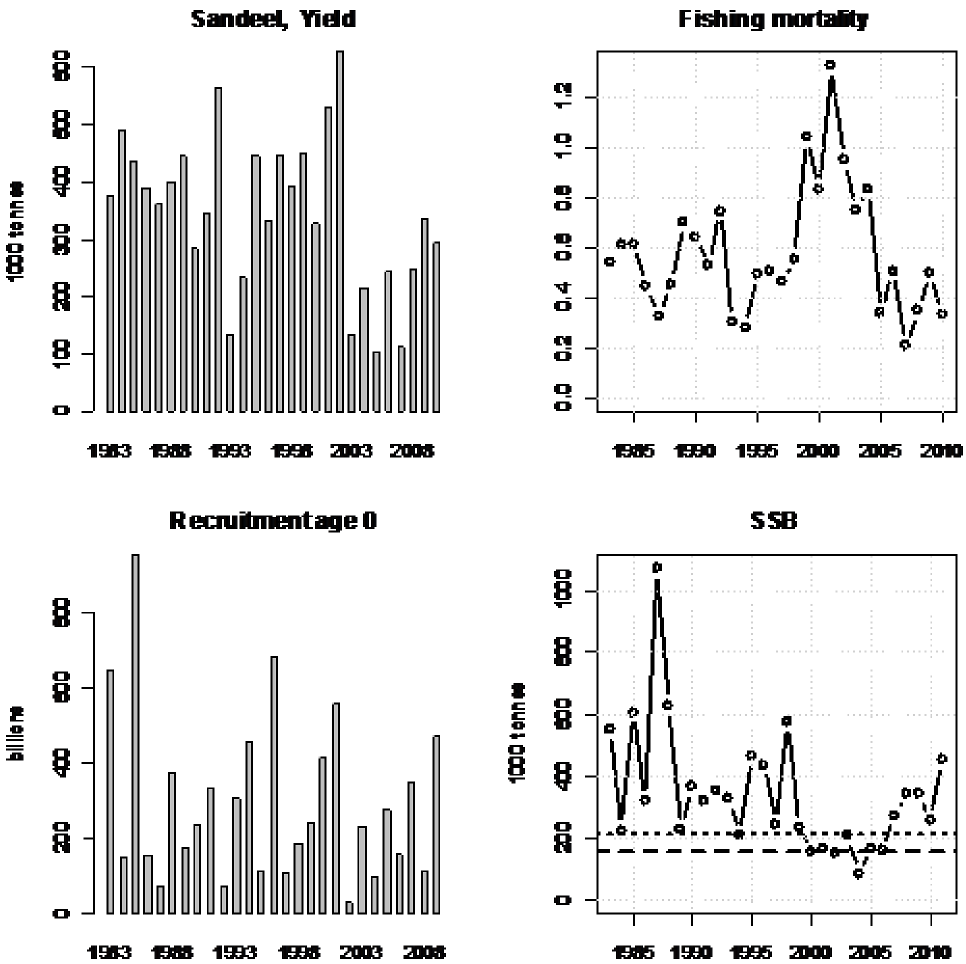

Figure 6.4.2. Stock summary for area 1.

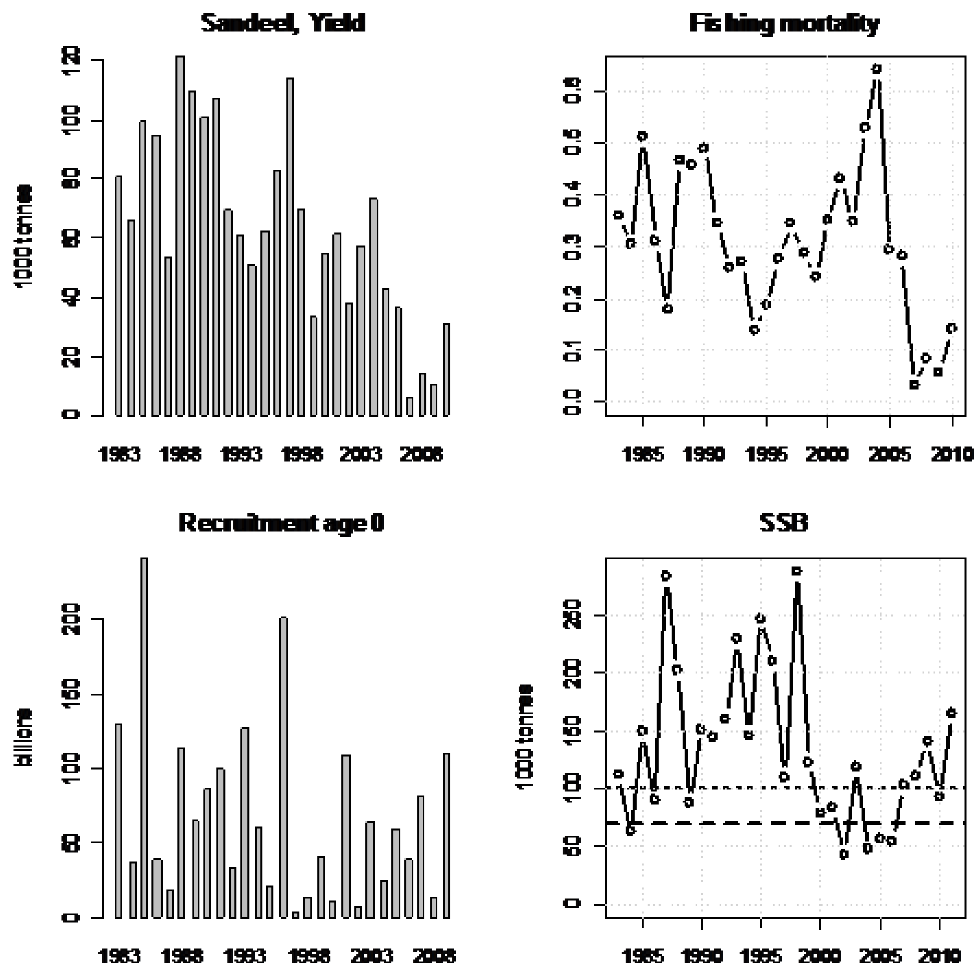

Figure 6.4.3. Stock summary for area 2.

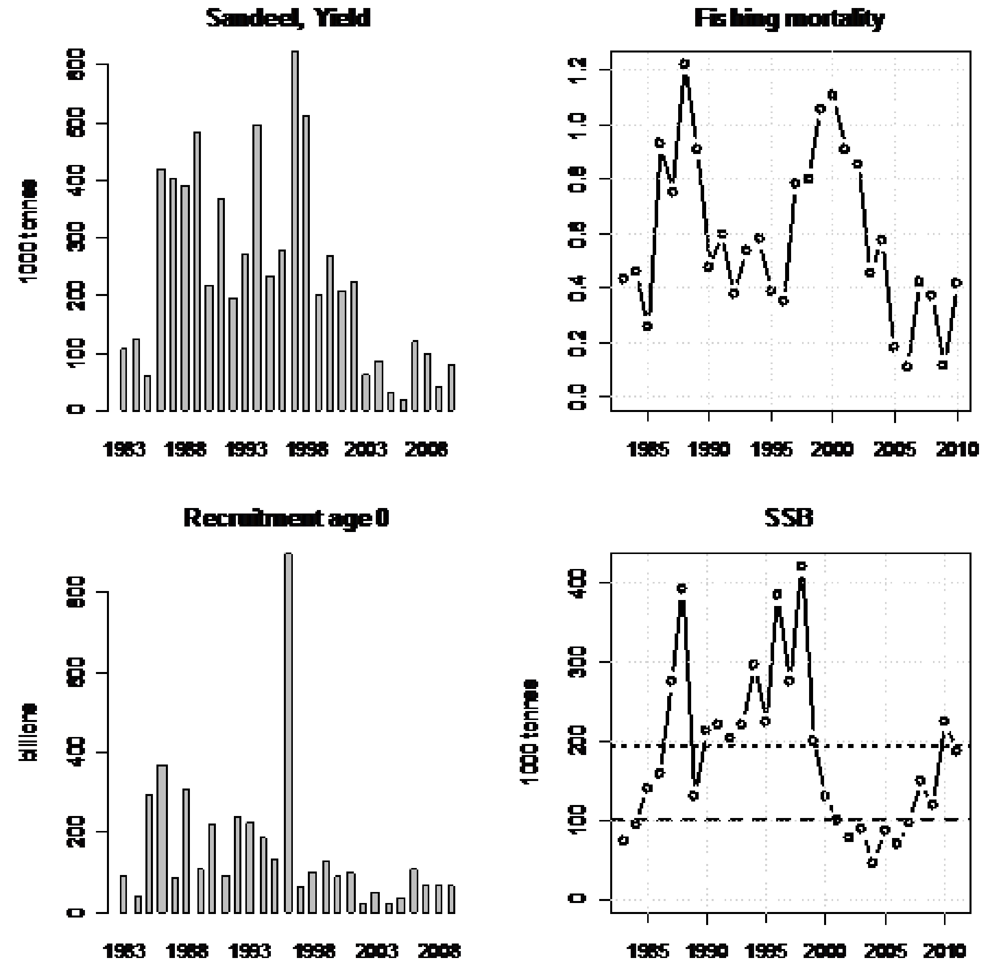

Figure 6.4.4. Stock summary for area 3.

For short-lived species such as Sandeel, the ICES interpretation of the MSY concept uses B_{pa} estimates as the value for $B_{msy\text{-}trigger}$. 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_{msy} is achieved in year y+1. No fishery should be allowed if this level of escapement can be achieved.

Table 6.4.1. Summary of Biomass reference points for areas 1–3.

Area	B_{lim}	SSB CV	B_{pa}
1	160 000	18%	215 000
2	70 000	23%	100 000
3	100 000	40%	195 000

The total of the B_{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_{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_{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.

7 Existing and proposed management plans

7.1 Norwegian EEZ

7.1.1 Background

Landings of sandeel from the North Sea have decreased substantially in recent years. The decrease has been particularly severe in the Norwegian EEZ (Figure 7.1.1). Several banks have not provided landings for the last 8–12 years (Figure 5.3). These fishing banks are considered commercially depleted, i.e. the concentrations are too low to provide a profitable fishery. For several years after 2001 almost all landings from the Norwegian EEZ came from the Vestbank area (Figure 5.4).

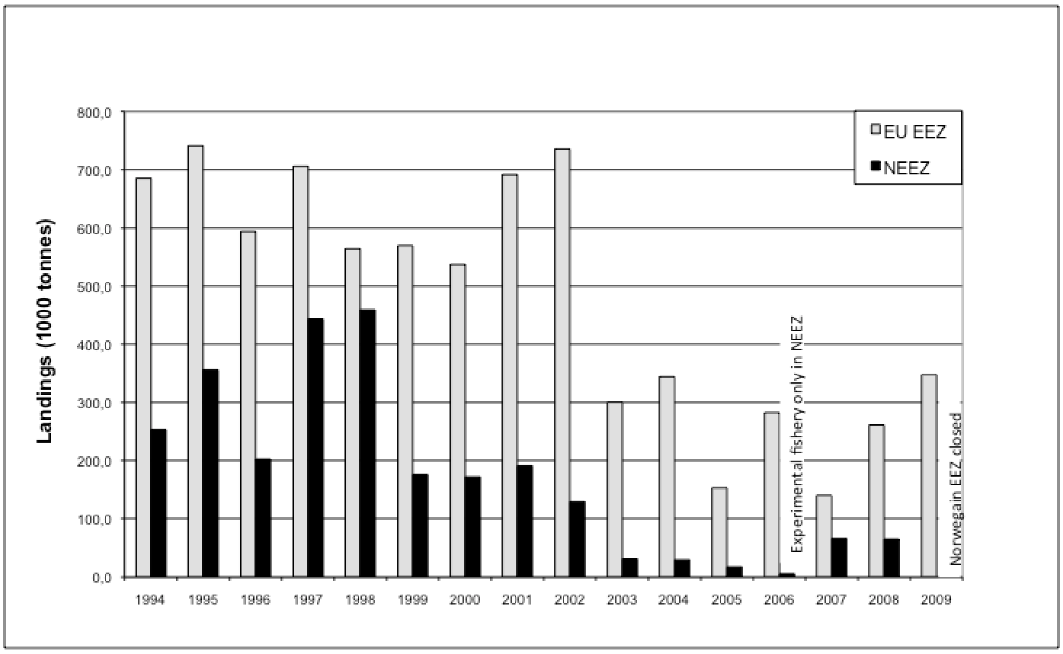

Figure 7.1.1. Landings of sandeel from the EU and Norwegian EEZ 1994–2009.

Some of the more southerly banks were repopulated by new recruitment in 2006, but commercially depleted again in 2007 or 2008; Inner Shoal East and Outer Shoal were commercially depleted in 2007, and English Klondyke, which was closed after the RTM fishery in 2007, was commercially depleted in 2008. The main concentrations of sandeel in the Norwegian EEZ are again found in the Vestbank area (Figure 7.1.2). There are high concentrations on Inner Shoal West too, but this is a very small fishing ground. In the Vestbank area and Inner Shoal West there are natural refuges that prevent the fleet from depleting the local sandeel stocks.

Most of the fishing grounds in the Norwegian EEZ were commercially depleted during a period when the assessment suggested that SSB was well above B_{pa}. In addition, evidence from 2007 and 2008 suggests that fishing grounds can be commercially depleted within a few weeks without marked decreases in cpue in tonnes (AGSAN 2009).

The commercial depletion of fishing grounds and the long-term implications this may have for the local fishery is of major concern. Because the present management of sandeel has not prevented commercial depletion of the majority of the Norwegian sandeel grounds, the Norwegian Department Fisheries and Coastal Affairs requested the Directorate of Fishery and the Institute of Marine Research, in collaboration with the fishing fleet, to propose an alternative management strategy that may prevent commercial depletion of fishing banks.

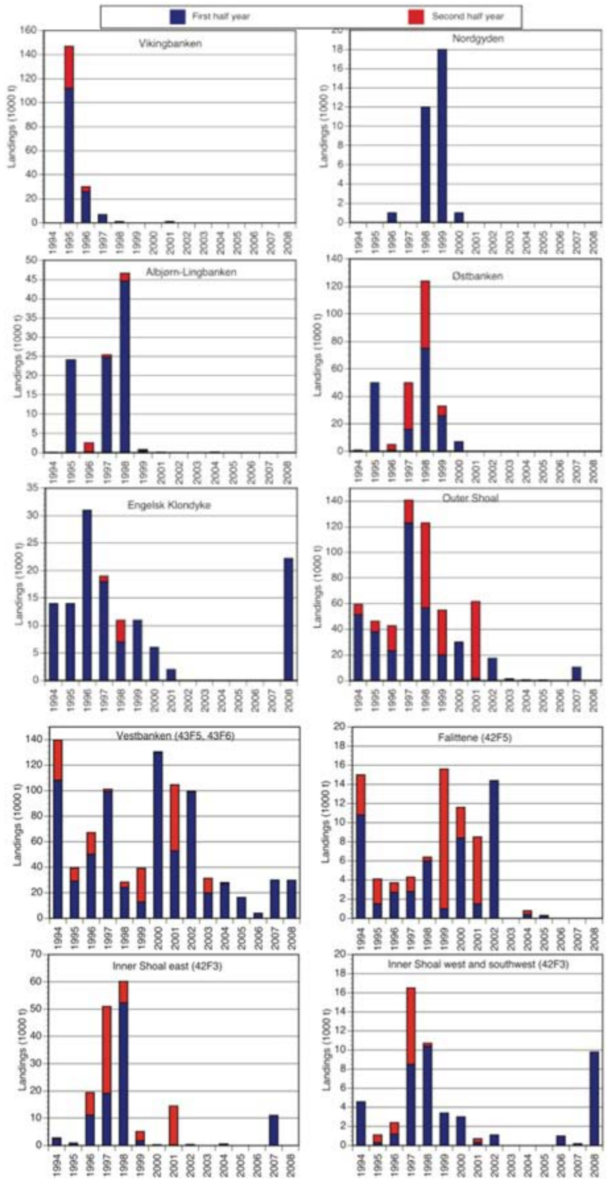

Figure 7.1.2 Sandeel landings from Norwegian fishing banks 1994-2008 in the first (blue) and second (red) half of the year. Landings in second half are mainly 0-group.

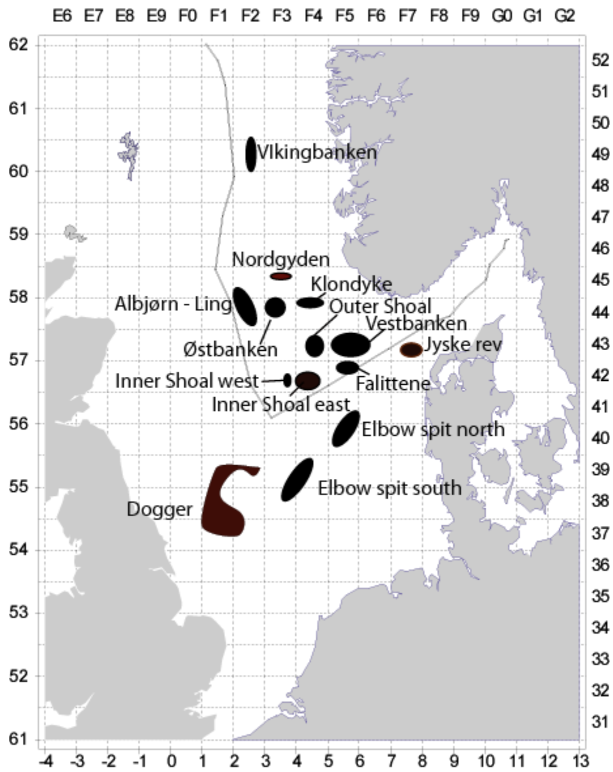

Figure 7.1.3. Sandeel fishing grounds in the Norwegian EEZ and the main fishing grounds in the EU EEZ.

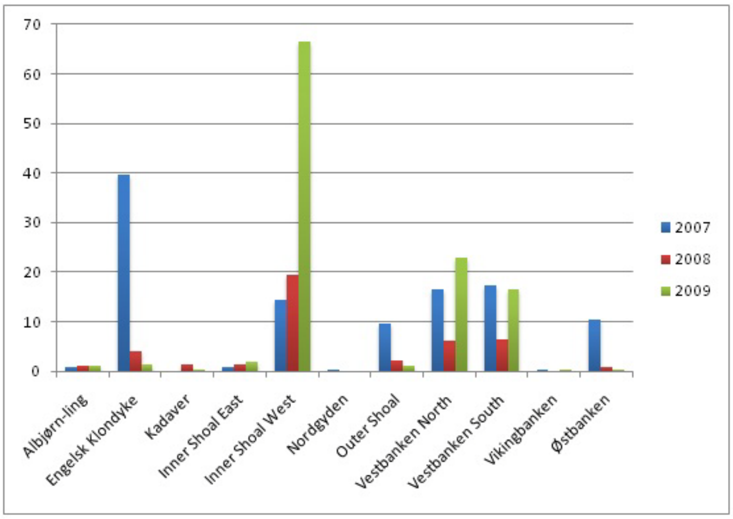

Figure 7.1.4. Relative densities (sA) of sandeel on various fishing grounds in the Norwegian EEZ in April–May 2007, 2008 and 2009.

7.1.2 Proposed management plan

Main objective: Sandeel will be managed spatially to ensure sustainable local spawning stocks in all areas where sandeel is distributed in the Norwegian EEZ, sufficient supply of food for predators and maximise fishing yield.

Method:

1) The Norwegian EEZ have been divided into six areas (may be altered in the future) (see Figure 7.1.5). Each area is divided in two sub-areas. The sub-areas will be opened and closed alternately (year to year). If the spawning-stock in a particular area stock falls below a predefined limit, both sub-areas will be closed.

2) An acoustic survey will be carried out in April–May to measure the abundance of sandeel (I-group and II+-group).

3) Based on results from the acoustic survey there will be an advice on which areas that can be opened for fishing and a proposal of a preliminary TAC for the Norwegian EEZ the following year.

4) Based on the acoustic abundance estimates there will be an in-season evaluation of whether closed area can be re-opened and an update the TAC for the rest of the fishing season.

5) Fishing season is limited to the period April 23 and June 23. The relative late start of the fishing season is to allow sandeel to gain weight and fat. Sandeels are very lean when emerging from the sand in early spring. Stop date is related to hibernation of I^{+}-group sandeel.

6) If the number of sandeel <10 cm comprise more than 10% of the landings a particular fishing ground, the fishing ground will be closed for seven days and then automatically re-opened.

The proposed method is based on the assumptions that the closed sub-areas will protect sandeel from local depletion and that local spawning stocks are important for local recruitment. Although there are observations to support both assumptions, neither has been fully tested. Therefore, the proposed management method should be considered an imperative experiment to improve the dismal situation for sandeel in the Norwegian EEZ.

The spatial management method will be evaluated after each fishing season based on the following success criteria:

1) Prevent local depletion of sandeel.

2) More stable recruitment than during the period 1994–2009.

3) A higher proportion of II^{+}- group sandeel in the landings compared to 1994–2009.

4) Reduced inter-annual variability in landings compared to 1994–2009.

5) Increased landings compared to 2000–2009.

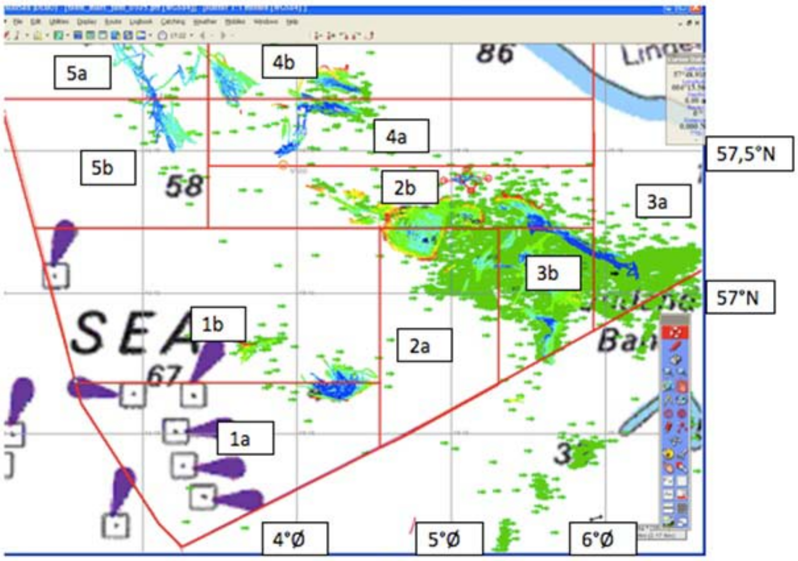

Figure 7.1.5. Management areas.

7.2 ICES / EU

The aim of Real Time Monitoring (RTM) of sandeel is to estimate the abundance of the 2009 year class for a previously established harvest control rule (HCR; see COUNCIL REGULATION (EC) No 23/2010, ANNEX IID). The overall objective of the HCR for 2010 is to ensure that SSB is above B_{pa} in 2011. Fishing and the final TAC in 2010 will depend on the latest stock assessment plus the size of the 2009 year class:

$$TAC_{2010} = -333 + 3.692 * N1$$

Where N1 is the real-time estimate of age group 1 in billions derived from the exploratory fishery in 2010; the TAC is expressed in 1000 tonnes.

The estimate of the 2009 year class (N1) is derived using a regression between historical cpue observations and age 1 cpue as outlined in ICES 2009.

The European Community (EC) requested ICES to provide further advice to allow EC to apply the procedure described in COUNCIL REGULATION (EC) No 23/2010. ICES responded that based on real-time monitoring data available from weeks 15 to 18 in 2010, the estimated stock size of age 1 sandeel in 2010 is approximately 159 billion individuals and the estimated mean weight of an age 1 sandeel in 2010 is 3.12 g.

Using these estimates, the calculated 2010 TAC becomes 253 000 t.

On the basis of subsequent very high catch rates observed in the fishery, STECF was requested to evaluate the RTM sampling and additional information. The final TAC was set at the maximum allowed by the COUNCIL REGULATION (EC) No 23/2010, 400 000 tonnes.

7.3 Danish fishers proposal

The Danish fishermen association's proposal for a management plan with regard to sandeels in the North Sea can be found in appendix A4. The data and survey procedures available today are sufficient enough to implement this proposal as the coming management for sandeels in the North Sea.

7.4 Norwegian fishers proposal

The Norwegian fishermen association's proposal for a management plan with regard to sandeels in the North Sea can be found in appendix A5. The data and survey procedures available today are sufficient enough to implement this proposal as the coming management for sandeels in the North Sea.

8 Marine Spatial Planning and sandeel fisheries

8.1 Marine conservation zones and Natura 2000

In recent years the processes of designating areas to protect the nature in regard to the habitat and bird directive under the Natura2000 have increased. New designated areas under the Natura2000 include some of the most productive sandeel grounds in the North Sea. At this time, it is not possible to tell if the designating of the areas will influence the fishery, as it will be up to scientist to decide how the habitat 1110 "Sandbanks which are slightly covered by sea water all the time" should look like in a favourable conservations status. If this favourable conservations status can be achieved together with an active fishery in the area, will be a very important question to answer in coming years.

The Dogger Bank has always been one of the most important areas of sandeel fishery.

Germany and Holland have designated their parts of the Dogger Bank as Natura2000 areas and England have just suggested their part of the Dogger Bank as a SAC area (special area of conservation). The situation will be that most of the Dogger Bank will end up as Natura2000 area where sandbanks must be protected. The process of Natura2000, where actions plans for obtaining or creating favourable conservations status inside the different areas in the North Sea will be produced, could potentially affect the whole fishery considerably by closing the most important areas for sandeel fishing today.

The Marine Strategy Framework Directive from 2008 are building on top on the habitat- and bird directive by giving member states the opportunity to designate new MPAs on behalf of an ecosystem-based approach to the management of human activities while enabling a sustainable use of marine goods and services. The Marine Strategy Framework Directive can potentially affect the sandeel fishery in the same way as the habitat- and bird directive.

8.2 Windfarms in the North Sea, existing and future plans

The proposed construction of vast windmill farms has the potential to seriously impact sandeel populations, habitat, and fisheries in the North Sea. The United Kingdom Crown Estate is proposing the addition of new windmill farms on important sandeel fishing grounds, including significant portions of the Dogger Bank. Details about the proposals and what is currently known about their potential impacts are presented in Appendix A6. Additional research studies are needed to answer many of the questions concerning the short and long-term impacts of the windmill farms.

8.3 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 000t in 1993 and then subsequently fell. The Firth of Forth area is important for breeding seabirds and the removal of such large quantities of sandeels within their foraging range soon became a matter of concern. In 1999, the U.K called for a moratorium on sandeel fishing adjacent to seabird colonies along the U.K. coast and in response the EU requested 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 fisheries could ameliorate any effects. Identify possible seasons/areas as specifically 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 particularly low breeding success of seabirds, especially kittiwakes. The study group concluded 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 reproductively 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 available 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 commercial 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.

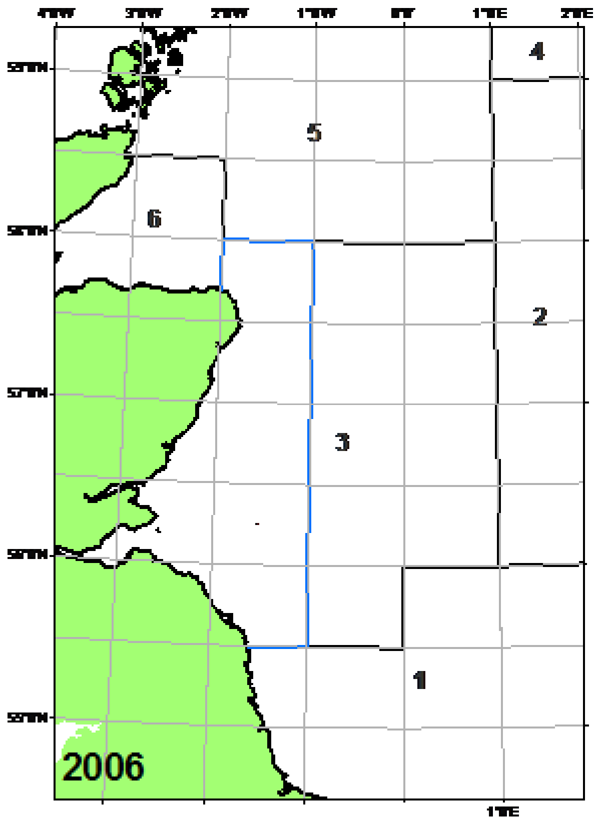

Figure 8.3.1. Chart showing the closed area (blue line).

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 UK 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 Northeast 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.

9 Research recommendations

1) Updated stomach contents studies across areas and times. The primary cause of natural mortality in sandeel is predation, and because of this, studies of predators' stomach contents are used to estimate natural mortality rates. Current natural mortality rate estimates are area-wide and were estimated using stomachs collected twenty years ago. There are several problems with this. First, natural mortality will change over time, as populations of predators, competitors, and prey change. Changes due to both trends over time as well as and year-to-year variation are expected. Natural mortality rates estimated from samples collected from the most abundant predators twenty years ago are not necessarily representative of current rates as both the composition and abundance of predators and prey has changed. The magnitude of the difference cannot be estimated or input to current assessment models without new stomach content studies. Second, the current natural mortality rate is estimated area-wide. Assessments will now be conducted on an area-specific basis and natural mortality rates are expected to vary by area. Using a common region-wide natural mortality rate across all areas does not allow for important variation between areas, and will force the variation to be incorrectly accounted for within the assessment model. This information is critical to the incorporation of an ecosystem approach to assessment and management. To account for time-varying and region-specific natural mortality rates, the following studies are suggested:

   1.1) An analysis of natural mortality based on the stomach contents previously collected, by area. Data from the stomach contents collected twenty years ago are still available and can be identified by area. Using this information, natural mortality rates can be estimated by area for this earlier time period.

   1.2) A new study to collect and identify predator stomach contents reflecting the present composition and abundance of predators. This should be conducted on an area-specific basis, across all areas, allowing for current natural mortality rates to be estimated to use as input in the area-specific stock assessment model.

   1.3) Annual stomach contents studies. Ideally, studies could be conducted on an annual basis allowing for annual estimates of natural mortality rates by area to be incorporated into future assessment models. If annual studies cannot be conducted, studies should be conducted on a regular timeline (i.e. every x years) to ensure significant changes in natural mortality rates over time are discovered and accounted for.

2) Restructuring of otolith sampling effort of the sandeel catch across areas and time. Otolith collection is necessary for identifying the relative proportion of the catch by age. This important component of the assessment varies within and among years, as well as, among areas. In addition, older age classes are least likely to be observed in the fishery, but may be an important component of the catch and population, nonetheless. There is a high degree of autocorrelation of age composition within samples; therefore increasing the sampling of otoliths would increase the likelihood of

identifying older age classes in the catch. Note that this information is also critical for the application of in-season monitoring in those cases when needed.

2.1) It might be possible for the fishermen to provide area-specific samples. Currently samples are collected at landing sites, both samples collected by fishermen as well as landings collected by port agents. Specific catch locations are not identified in the samples collected by port agents, limiting the utility of the samples. To verify the samples taken for in-season monitoring, these samples consist entirely of port samples. Fishermen representing the national fishery associations attending WKSAN have volunteered to collect site-specific samples, which would allow for improved incorporation of this critical information into area-specific assessment models. It would be necessary to identify whether adequate and effective protocols, incorporating appropriate levels of oversight, could be established before this sampling could proceed. In addition, sampling of this kind would be required on a regular basis, and hence, must be dependable to be of any value.

3) <u>Increasing the coverage of the dredge survey across areas and time.</u> The dredge survey is critical to the assessment, providing the status in previous years and management reference points, and just as importantly, to projections of upcoming abundance needed for making management decisions for upcoming fishing seasons. The relative coverage of the dredge survey varies by area. Area 1 currently has the greatest coverage. Because of the extent of coverage in Area 1, the need for in-season monitoring has been relegated to use in only extreme circumstances (e.g. when densities below the range historically observed are recorded), improving the management process for all parties involved. Increasing the coverage of the dredge survey in the other areas has the potential to provide similar benefits. Currently, the greatest benefits would likely come from increasing the coverage in Area 3. Note that samples collected during the dredge survey provide information on population age structure, and in addition, the only information available on maturation. Increasing coverage of the dredge survey would also require increasing the magnitude of aging and maturity studies of the collected samples.

3.1) <u>Successive annual sampling of sandeel habitats outside known fishing banks.</u> This may provide important information to improve area-specific natural mortality rate estimates.

3.2) <u>Studies to develop and evaluate more efficient and robust dredge surveys.</u> Additional standardization should be identified, coordinated and reported back to technical staff responsible for development and maintenance.

4) <u>Ecosystem effects of sandeel density.</u> Currently, assuring that the biomass of sandeel is sufficient to avoid adverse effects on top predators is hampered by the lack of knowledge of the biomass below which these adverse effects occur. Research on the relationship between sandeel biomass and predator condition, growth or recruitment success, could provide better knowledge for setting reference points which do not only assure that recruitment of sandeel is not impaired but also takes account of the fact that adverse effects on predator populations should be avoided.

5) <u>Per-Recruit analyses.</u> Information needed to conduct both yield-per-recruit analyses and spawner-per-recruit analyses is available. Yield-per-recruit analysis provides estimates of fishing rates that likely cause growth overfishing. Spawner-per-recruit analysis provides a proxy for maximum sustainable yield. Both analyses are relatively straightforward to conduct. Both analyses also are based on a large number of assumptions, which may or may not hold for the sandeel population. Completion of these analyses would likely provide helpful information for assessment and management, but the analyses must be conducted, interpreted, and communicated effectively and cautiously, keeping their limitations in mind.

6) <u>Additional dredge survey and fishery monitoring in area 4.</u> Further data from both the dredge survey and fishery monitoring is required in order to provide advice to management for area 4. The dredge survey in area 4 cannot be used to produce a stock assessment until the relationship between stock size and dredge survey catch in the area can be estimated from a longer time-series than is presently the case. This requires not only the continuation of the survey but also within season sampling, preferably from fisheries catches to ensure the compatibility with historical data.

7) <u>Further analysis of the acoustic surveys of sandeel used as input data for assessment.</u> The inclusion of acoustic survey data as input requires an extensive analysis of the internal and external consistency of the survey similar to the analyses performed at the benchmark for the dredge survey.

10 Conclusions

Four alternative sandeel management scenarios were presented to WKSAN: the current EU management plan, the plan being implemented by the Norwegian government in the Norwegian EEZ, a proposal by the Danish Fishermen's Association, and a proposal by the Norwegian Fishermen's Association. All four management plans could be implemented in Areas 1, 2, and 3 using existing data sources with agreed-upon assessment and forecasting methods. Both the Norwegian government's and the Norwegian Fishermen's Association's proposed management scenarios could be implemented in Area 5. Data is insufficient to evaluate whether the management scenarios could be implemented in Areas 4 and 6.

Pre-season dredge survey information is sufficient to provide TAC advice in Areas 1 and 2, without requiring in-season data processing 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.

WKSAN has recommended assessing sandeel stocks by area based on stock structure identified using information on larval drift and other sources described in Section 2. In doing so, assessment has changed from being region-wide to area-specific. Model structure has evolved to now utilize a statistical catch-at-age model as opposed to a deterministic VPA approach as used in the past. The inclusion of the dredge survey has eliminated historic retrospective patterns in Areas 1–3, a problematic artefact of previous assessments. New analyses demonstrate that the dredge survey in Area 1 allows for greater confidence in short-term forecasts.

Improving the assessment will require its further spatial stratification, including providing natural mortality rate estimates by area. Current natural mortality rate estimates were derived from predator stomachs collected 20 years ago region-wide. A new stomach collection study is required to provide updated, area-specific mortality estimates. Additional research priorities include studies of the relationship between sandeel biomass and predator condition, growth or recruitment success to provide better knowledge for setting reference points which takes account of effects on predator populations.

Industry representatives from both Denmark and Norway attended the entire WKSAN and provided useful information throughout the workshop. In particular, they provided critical information on the timing and causes of changes in catchability, which were then incorporated into the assessment model. Industry representatives also provided details on marine spatial planning issues having the potential to impact the sandeel fishery in the future (e.g. windfarms, Natura2000). Their participation was not only welcome, but also necessary.

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12 Stock Annex-Sandeel in IV

Quality Handbook Annex__SAN-NSEA

Stock-specific documentation of standard assessment procedures used by ICES

Working Group	North Sea Demersal Working Group
Updated	09/09/2010 Steen Christensen (sc@aqua.dtu.dk)

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)).

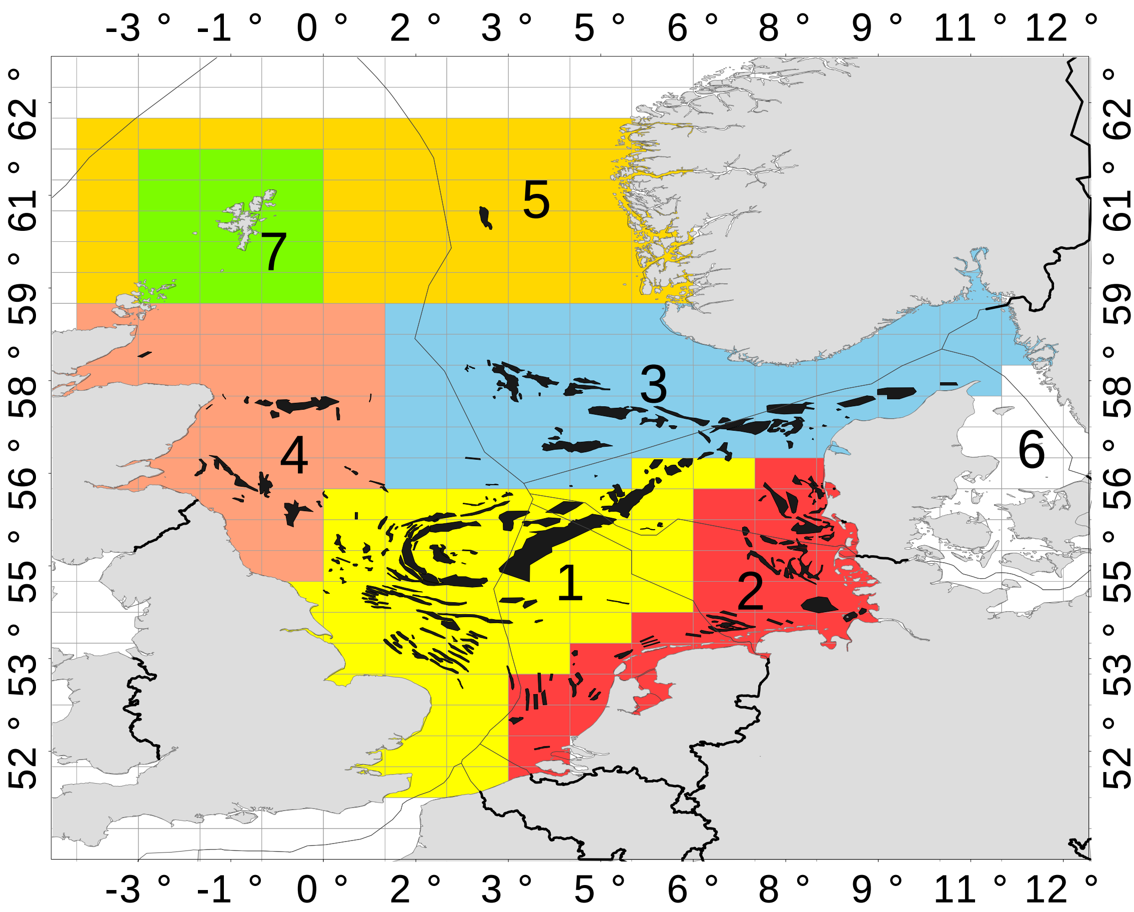

Figure 4. 2. Sandeel fishing banks (black areas), EEZ borders, and assessment areas: eastern area (red), northern area (blue), southern area (yellow), western area (dark orange), Shetland area (green) and Viking bank area (light orange).

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.

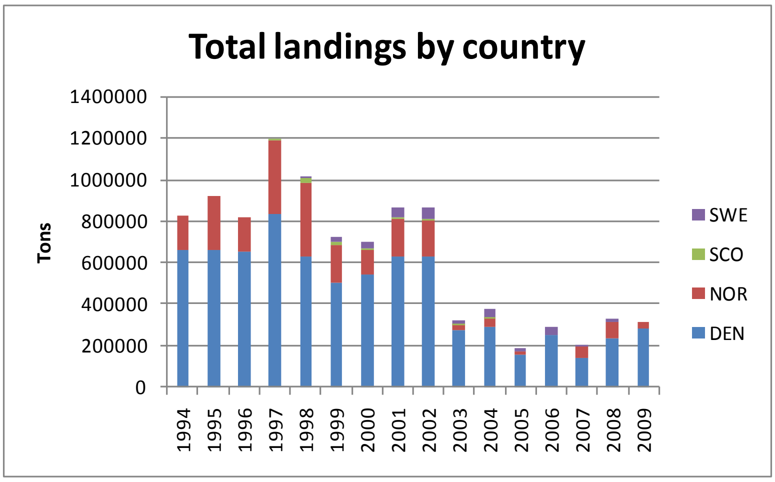

Figure 3.2.

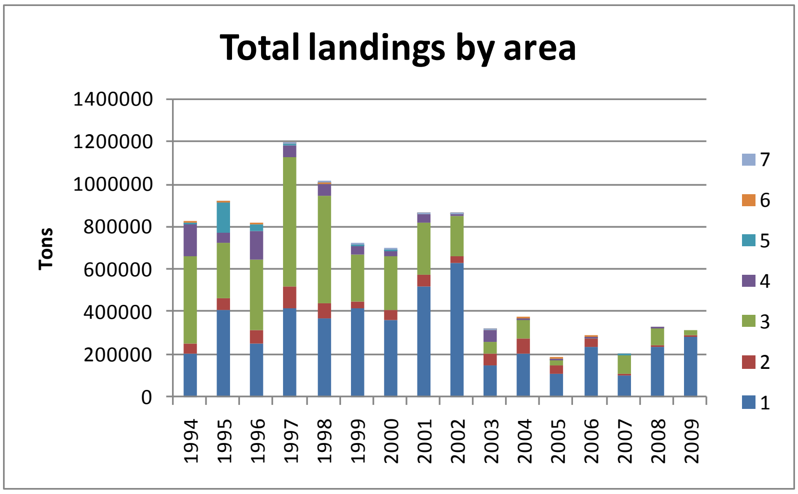

Figure 3.3.

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).

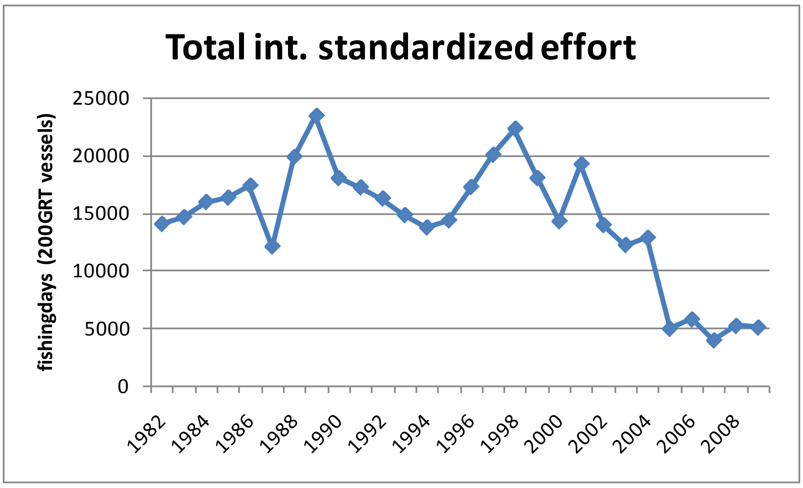

Figure 3.4.

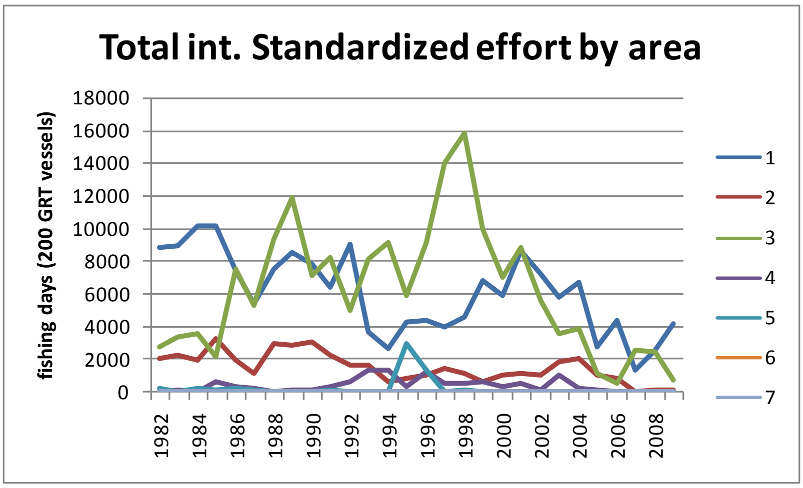

Figure 3.5.

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*., 1994). 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, kittiwakes 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.

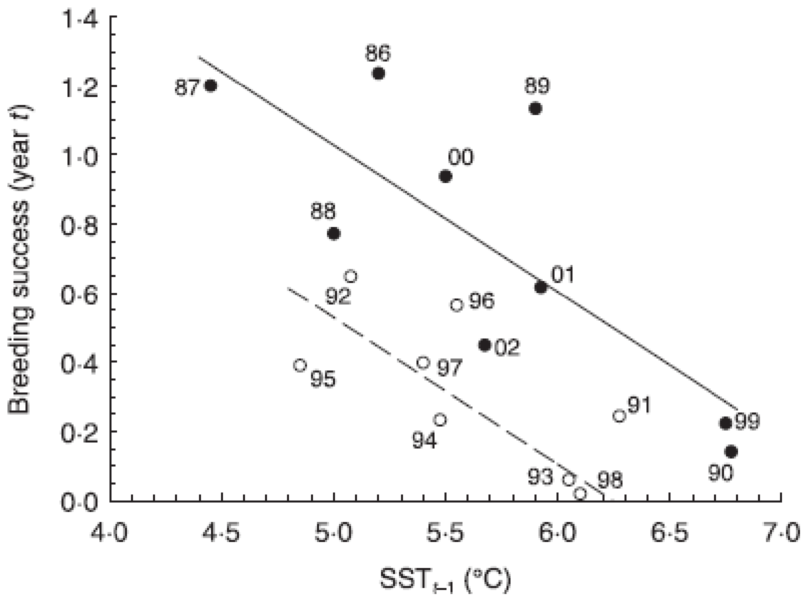

Figure 3.1a. Kittiwake breeding success as a function of local SST in February–March of the previous year and presence/absence of the Wee Bankie sandeel fishery. Data labels indicate current year. Regression lines estimated from weighted multiple regression. Filled circles and solid line, non-fishery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

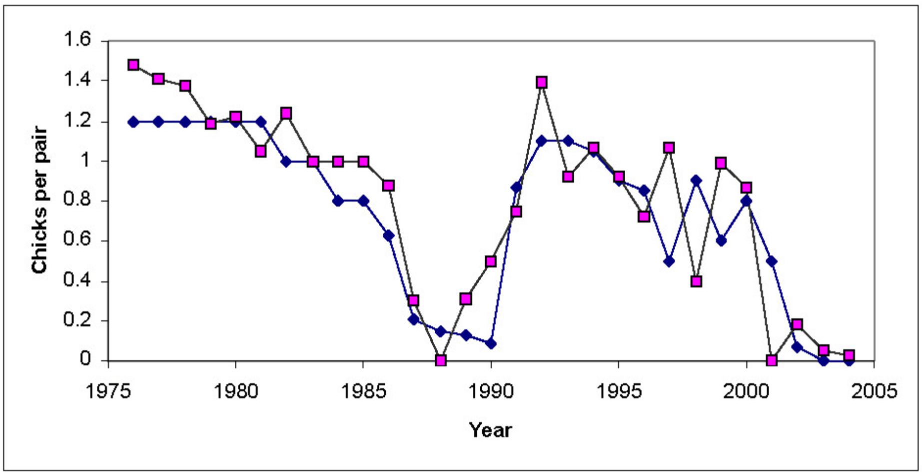

Figure 3.1b. Breeding success of black-legged kittiwakes (pink) and Arctic skuas (blue) at Foula, Shetland, during 1976–2004, showing a close correlation between the success of the two species in this time-series, and periods of particularly low success in 1987–1990 and in 2001–2004.

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.

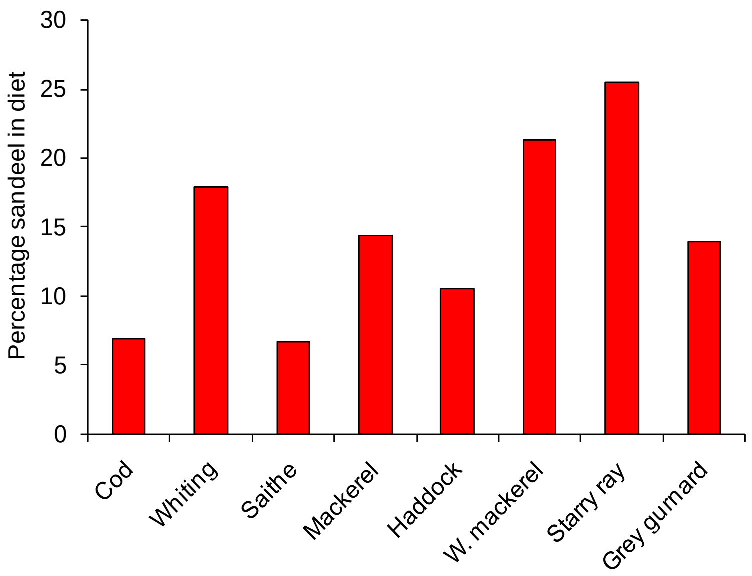

Figure 3.3b. Proportion of the diet consisting of sandeel for different predatory fish (ICES 1997).

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 between 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).

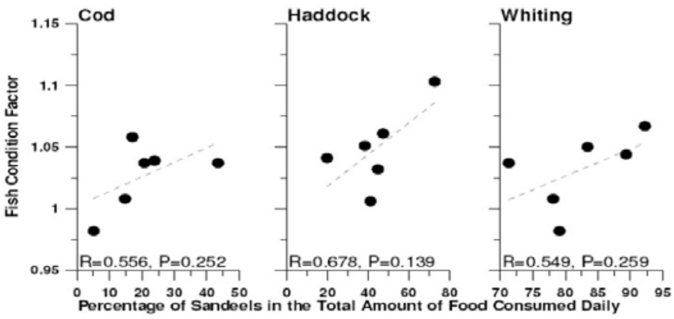

Figure 3.3c. Relationship between the body condition of gadoid predators in the Firth of Forth, and the quantity of sandeels consumed (from Greenstreet *et al.*, 2006).

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 Forth, including the Dogger Bank). 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 subpopulations (Pedersen *et al.*, 1999; Christensen *et al.*, 2008). Within these subpopulations, 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 kittiwakes had fallen close to zero due to shortages of sandeels around most of Shetland. Predators dependent on sandeels (such as kittiwakes) 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, kittiwake breeding success tends to correlate strongly with abundance of sandeels over about a 50 km foraging radius around kittiwake colonies. In regions where kittiwakes 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 seabirds 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 requested 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 fisheries could ameliorate any effects. Identify possible seasons/areas as specifically 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 particularly low breeding success of seabirds, especially kittiwakes. The study group concluded 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 reproductively 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 available 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 commercial 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.

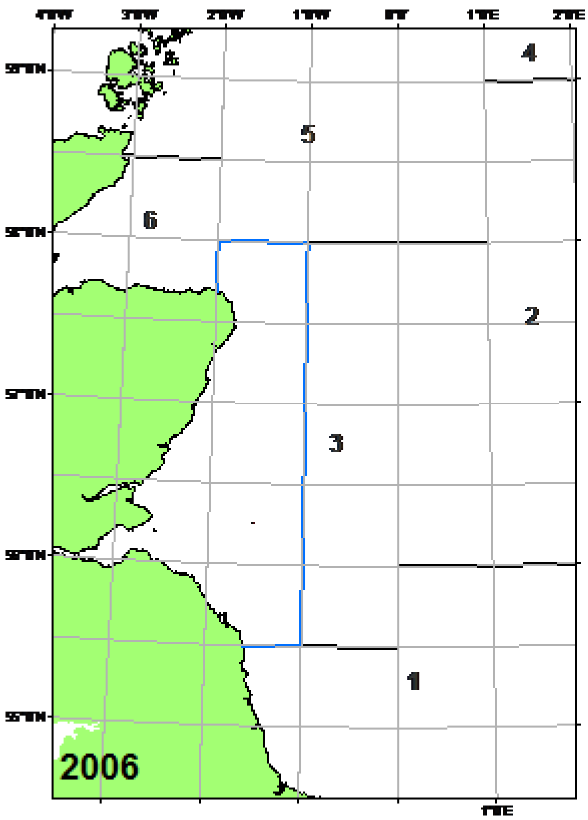

Figure 4. Chart showing the closed area (blue line).

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 Northeast 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 exceeds +/-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:

	Data				
Country	Caton (catch in weight, month square)	Length samples from catches	Weca (weight-at-age in the catch)	Matprop (proportion mature-by-age)	
Denmark	x	x	x	x	
Norway	x	x	x		
UK/Scotland	x				
Sweeden	x				
Farao Islands	x				

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/Asssess: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 (M2) 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.

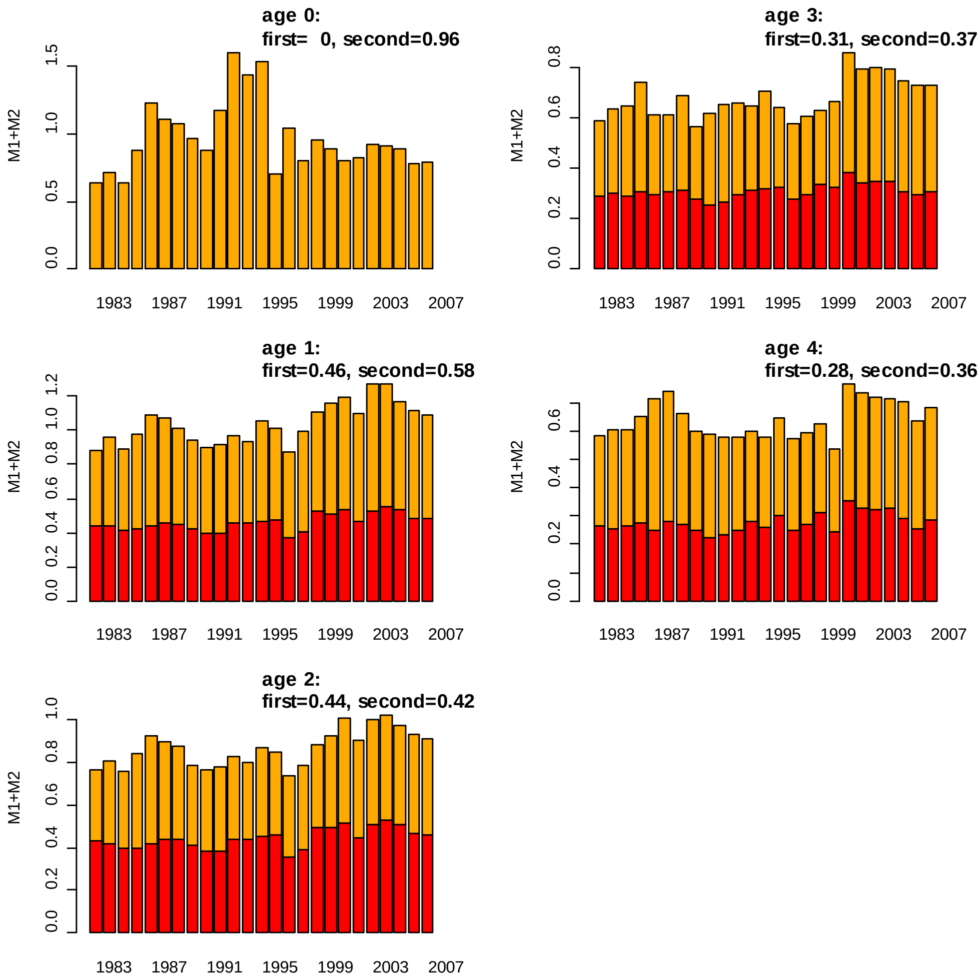

Figure 3.5. Natural mortalities of sandeel by half year. Mean values (1982–2007) for first and second half year are presented in the headings.

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:

(1)

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

where

(2)

$$\overline{CPUE}_{a,sq} = \frac{\sum_{pos} \overline{CPUE}_{a,sq,pos}}{n_{a,sq,pos}}$$

where

(3)

$$\overline{CPUE}_{a,sq,pos} = \frac{\sum_{st} \overline{CPUE}_{a,sq,pos,st}}{n_{a,sq,pos,st}}$$

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.

$F_{y,q,a}$ = SesonEffect(Y,A1) * AgeEffect(Y,A2,q) * $YearEffect_y$ (1, original version)

$F_{y,q,a}$ = SesonEffect(Y,A1) * AgeEffect(Y,A2,q) * $Effort_{y,q}$ (2, new version)

where

indices A*1* 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).

	Season effect A1=age 0 and age 1-4										
	First half year						Second half year				
YY	Age 0	Age 1	Age 2	Age 3	Age 4		Age 0	Age 1	Age 2	Age 3	Age 4
1983–1998	0.00*	0.426	0.426	0.426	0.426		1.0*	0.5*	0.5*	0.5*	0.5*
1999–2009	0.00*	0.337	0.337	0.337	0.337		1.0*	0.5*	0.5*	0.5*	0.5*

*** kept constant**

	Age effect A2=age 0, age 1, age2 and age 3-4										
	First half year						Second half year				
YY	Age 0	Age 1	Age 2	Age 3	Age 4		Age 0	Age 1	Age 2	Age 3	Age 4
1983–1998	0.00*	0.488	1.024	1.248	1.248		0.014	0.772	0.847	0.585	0.585
1999–2009	0.00*	0.772	0.857	0.585	0.585		0.010	0.176	0.195	0.133	0.133

"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.

$F_{y,q,a}$ = SesonEffect(Y,A1) * AgeEffect(Y,A2,q) * $Effort_{y,q}$ * $(y\text{-}firstYear)^{commonCreep(Y)}$ (3)
$F_{y,q,a}$ = SesonEffect(Y,A1) * AgeEffect(Y,A2,q) * $Effort_{y,q}$ * $(y\text{-}firstYear)^{ageCreep(Y,A1)}$ (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

$$L_{CATCH} = \prod_{a,y,q} \frac{1}{\sigma_{CATCH\,a,q}\sqrt{2\pi}} \exp\left(-\frac{(\log(C_{a,y,q}) - E(\log(C_{a,y,q})))^2}{2\sigma^2_{CATCH\,a,q}}\right)$$

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:

$$l_{CATCH} = -\log(L_{CATCH}) \propto NOY\sum_{a,q}\log(\sigma_{CATCH\,a,q}) + \sum_{a,y,q}(\log(C_{a,y,q}) - E(\log(C_{a,y,q})))^2/(2\sigma^2_{CATCH\,a,q}))$$

Survey indices

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

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

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:

$$l_{SURVEY} = -\log(L_{SURVEY}) \propto \sum_{survey,a} NOY_{survey} \sum_{survey,a} \log(\sigma_{SURVEY\,survey,a}) + \sum_{survey,a,y} (\log(CPUE_{survey,a,y}) - E(\log(CPUE_{survey,a,y}))^2 / (2\sigma^2_{SURVEY\,survey,a}))$$

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 $R_y = R(SSB_y \mid \alpha, \beta)$ 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

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

where

$E(\ln(R_y)) = \ln(\alpha\ SSB_y \exp(-\beta\ SSB_y))$ 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.

Option	Area 1	Area 2	Area 3
Data first year	1983	1983	1983
Time step	Half-year	Half-year	Half-year
First age	Age 0	Age 0	Age 0
Last age	Age 4+	Age 4+	Age 4+
Spawning time	Start of 1st half-year	Start of 1st half-year	Start of 1st half-year
Recruitment time	Start of 2nd half-year	Start of 2nd half-year	Start of 2nd half-year
Age range for use of catch data in likelihood	Age 0 – age 4+	Age 0 – age 4+	Age 0 – age 4+
Last age with age dependent selection	Age 3	Age 3	Age 3
Objective function weighting (catch, survey, S/R)	1.0, 0.5, 0.01	1.0, 0.25, 0.01	1.0, 0.5, 0.01
Minimum CV of catch observations	0.2	0.2	0.2
Minimum CV of survey observations	0.2	0.2	0.2
Minimum CV of S/R relation	0.2	0.2	0.2
Catch observations: variance group	Age 0, ages 1 & 2 combined and ages 3 & 4 combined	Age 0, ages 1 & 2 combined and ages 3 & 4 combined	Age 0, ages 1 & 2 combined and ages 3 & 4 combined
Treatment of zero catch observations	Not used in likelihood	Not used in likelihood	Not used in likelihood
Year ranges for constant exploitation pattern	1983–1988, 1989–1998 & 1999-	1983–1998 & 1999-	1983–1988, 1989–1998 & 1999-
Ages for seasonal exploitation pattern	Age 0, and ages 1–4+ combined	Age 0, and ages 1–4+ combined	Age 0, and ages 1–4+ combined
Ages for calculation of mean F	Age 1 & age 2	Age 1 & age 2	Age 1 & age 2
Exclusion of catch data (no or very small catches are available)	2007 second half year	2007 second half year	2007 second half year
Catch Variance	Calculated within SMS	Calculated within SMS	Calculated within SMS
Survey variance	Free parameter	Free parameter	Free parameter
S/R variance	Calculated within SMS	Calculated within SMS	Calculated within SMS
Inflexion point (B_{lim})	160 000	70 000	100 000
Survey information			
Survey	Area 1: Dredge survey December 2004 Age 0 & age 1	Area 1 (copy) :Dredge survey December 2004 Age 0	Area 3:Dregde survey December 2004 Age 0 & age 1
Half year	2	2	2
Time: Alfa & beta	0.75, 1.0	0.75, 1.0	0.75, 1.0

Option	Area 1	Area 2	Area 3
Last age with age dependent selection	Age 1	Age 0	Age 1
Ages for separate variance estimate	Age 0 and age 1	Age 0	Age 0 and age 1
Power model	Not applied	Not applied	Not applied

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 or 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: Fsq=F(2010)=0.143; Yield(2010)=31; Recruitment(2011)= geometric mean = 2 billions; SSB(2011)=232						
F- multiplier	Basis: Recruitment(2010)	F(2011)	Landings(2011)	SSB(2012)	%SSB change	%TAC change
1.792	Geometric mean* 0	0.256	52	100	-57%	64%
2.326	Geometric mean* 0.2	0.332	68	100	-57%	115%
2.859	Geometric mean* 0.4	0.408	84	100	-57%	167%
3.389	Geometric mean* 0.6	0.484	100	100	-57%	219%
3.916	Geometric mean* 0.8	0.559	117	100	-57%	271%
4.437	Geometric mean* 1	0.633	134	100	-57%	325%

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: Fsq=F(2010)=0.143; Yield(2010)=31; Recruitment(2010)=2 billions; Recruitment(2011)= geometric mean = 2 billions; SSB(2011)=232						
F multiplier	Basis	F(2011)	Landings(2011)	SSB(2012)	%SSB change	%TAC change
0	F=0	0	0	141	-39%	-100%
0.25	Fsq*0.2	0.036	8	135	-42%	-74%
0.5	Fsq*0.5	0.071	16	129	-45%	-49%
0.75	Fsq*0.8	0.107	24	123	-47%	-25%
1	Fsq*1	0.143	31	117	-49%	-2%
1.25	Fsq*1.2	0.178	38	112	-52%	20%
1.5	Fsq*1.5	0.214	45	107	-54%	42%
1.886	MSY	0.269	55	100	-57%	73%

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_{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_{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_{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_{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_{pa} estimates as the value for $B_{msy\text{-}trigger}$. 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_{msy} is achieved in year y+1. No fishery should be allowed if this level of escapement can be achieved.

Table 3. Summary of Biomass reference points for areas 1–3.

Area	B_{lim}	SSB CV	B_{pa}
1	160 000	18%	215 000
2	70 000	23%	100 000
3	100 000	40%	195 000

The total of the B_{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_{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.

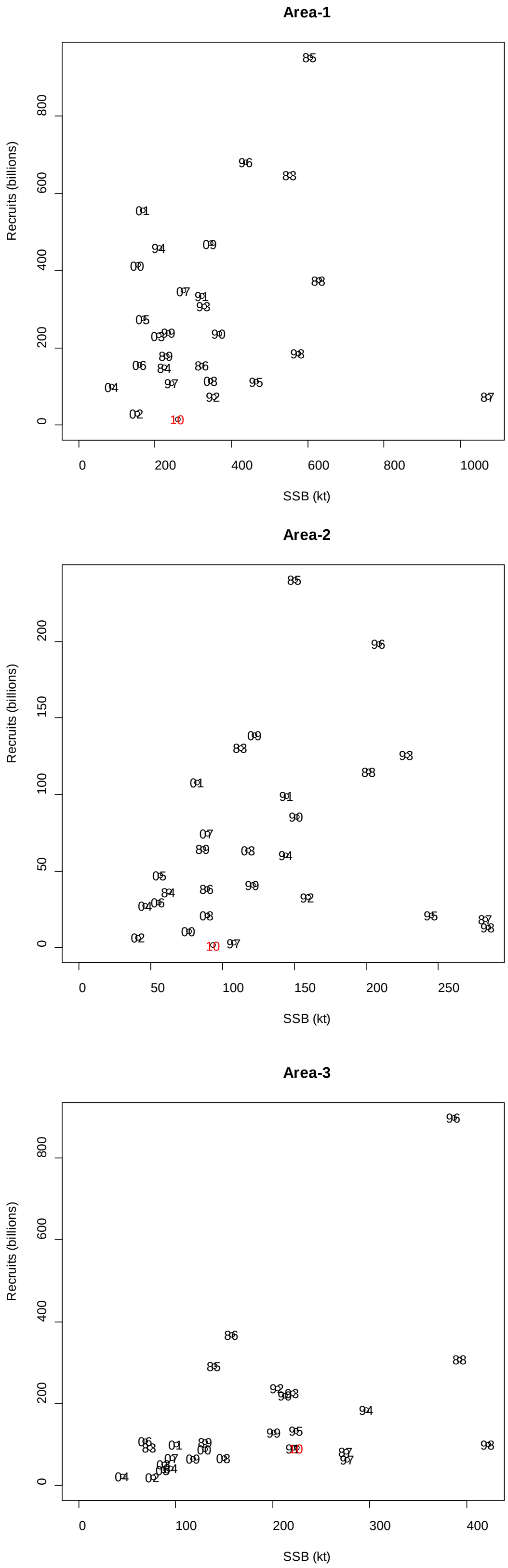

Figure 4. Stock–recruitment relationship in areas 1 to 3. Note that the recruit estimate for 2010 is based on very little input data and is therefore highly unreliable.

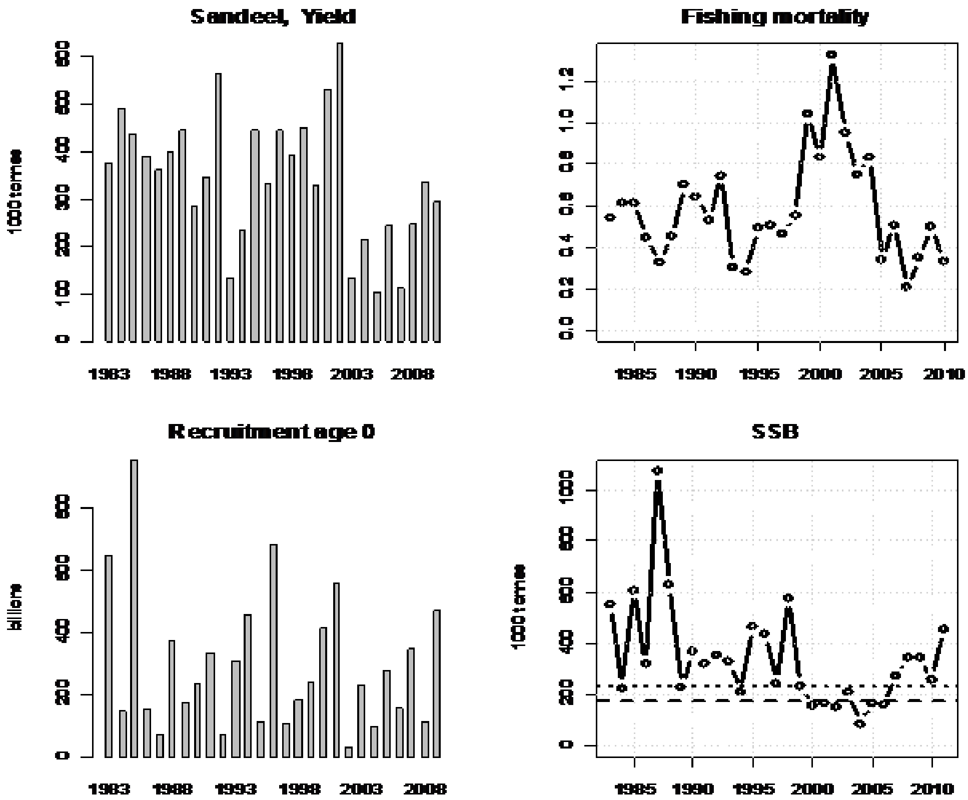

Figure 5. Stock summary for area 1.

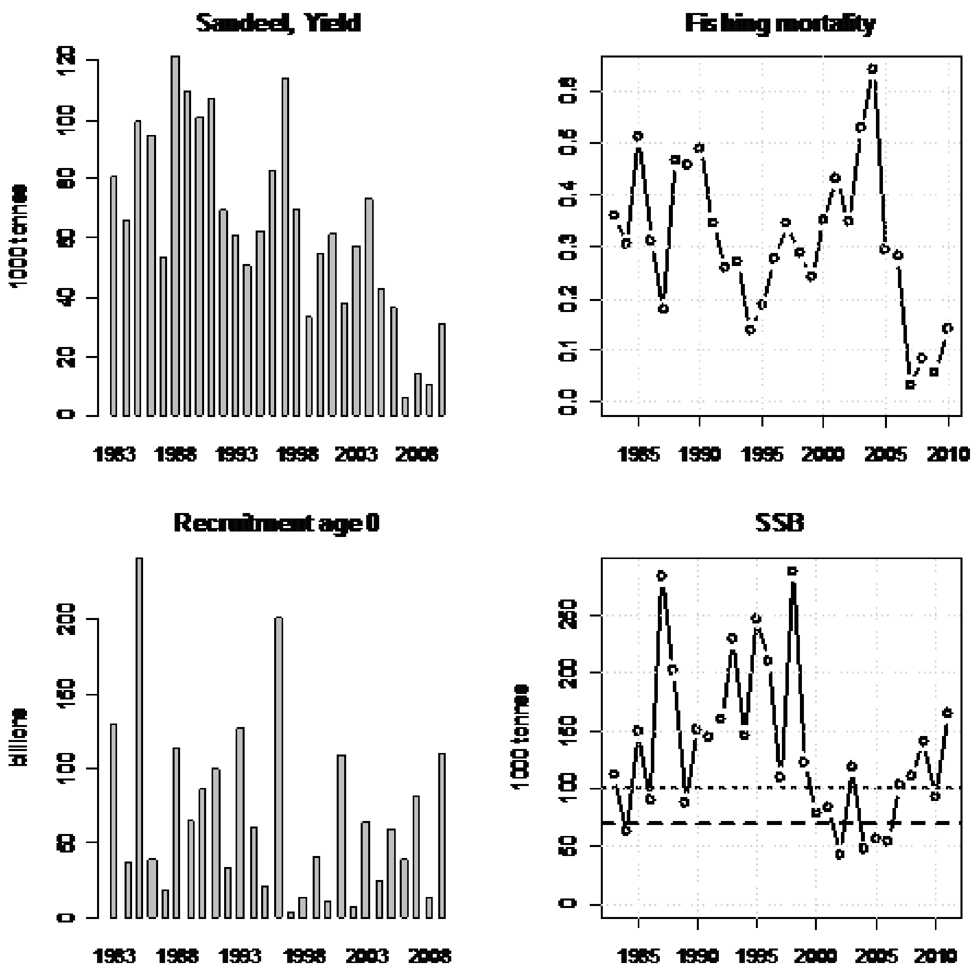

Figure 6. Stock summary for area 2.

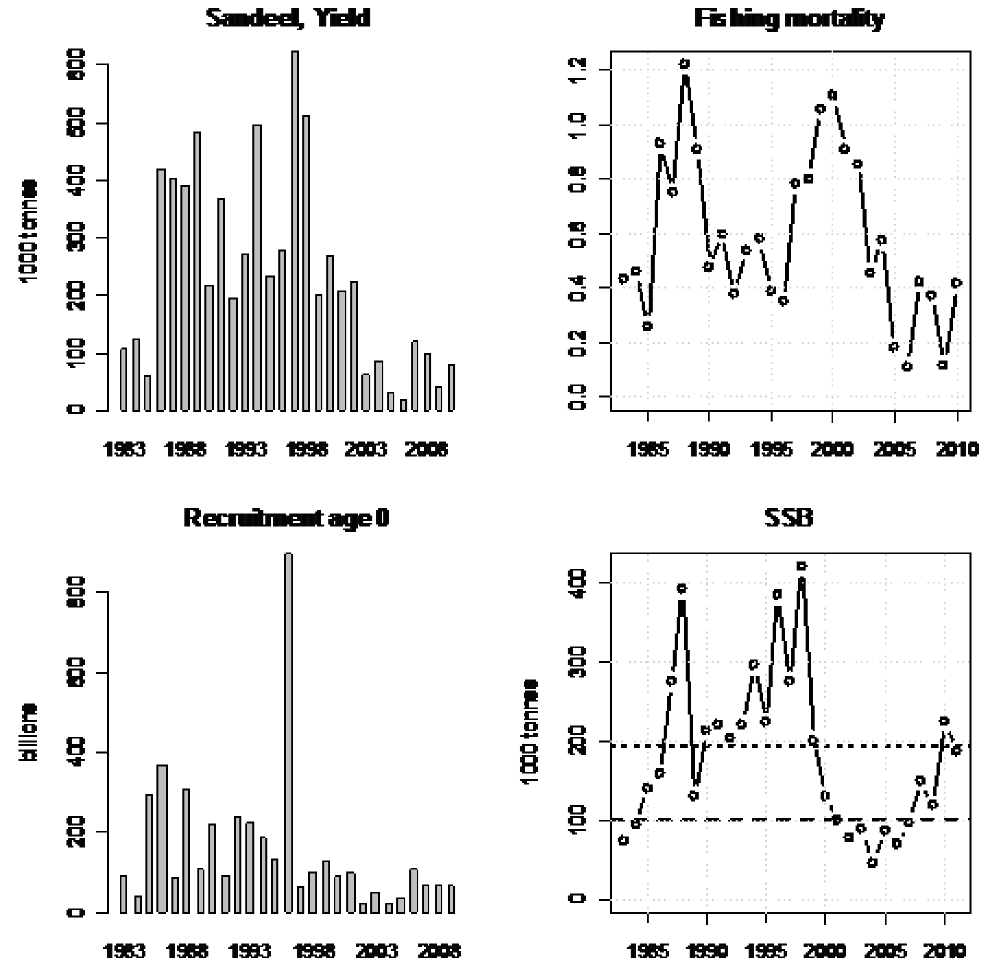

Figure 7. Stock summary for area 3.

The total of the B_{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_{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_{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.

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.

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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
annual 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,
#                            >100= hockey stick with known breakpoint
(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 objec-
tive.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) (de-
fault=1)
1
# phase.SSB.R.beta (beta parameter in SSB-recruitment relation) (de-
fault=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 spe-
cies
   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 op-
tion/100 /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
#  Sandeel
0
########################################
##
# catch observations: number of year groups with the same age and sea-
sonal 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 catchs, 1=yes there are year-season com-
binations 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 catchs, 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
########################################
## Uncertanties 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

#
```

13 Appendices

A1. Working Paper WKSAN2010-Results from the Danish dredge survey

Steen Christensen, DTU Aqua

Background

Since 2004 DIFRES has used a modified scallop dredge to measure the relative abundance of sandeels in the seabed. The survey is conducted in November/December when the 0-group sandeels have been recruited to the adult population and the whole population is assumed to reside in the seabed.

Four different dredges have been used in the survey: DK1: standard dredge; DK2: modified standard dredge with video camera; DK3: modified standard dredge with additional net roof; DF1: modified standard dredge with additional net. As the DF1 dredge was used at an experimental basis only and analysis indicated that and the DK3 dredge had catch rates significantly different from the DK1 and DK2, in the present analysis only data from DK 1 and DK 2 was used. These two dredges obtained similar catch rates and therefore their data was aggregated in the analysis.

Since 2004 in total 828 hauls were made with the four different dredges of which 790 were made with DK1 and DK2 (Table 1). As indicated in Table 1 and Figures 1 and 2, the dredge survey covers Areas 1 and 3 only except for seven hauls taken in Area 2 in 2005. The data from Area 2 are not included in the present analysis.

Sampling is carried out at fixed positions on known sandeel habitats at some of the most important fishing banks in the North Sea from the Little Fisher Bank in the North Eastern North Sea, to the Dogger Bank area in the southwestern North Sea (Figure 1). In 2006 additional positions were sampled in the Norwegian EEZ.

Methods

A varying number of hauls have been made at the different positions over the years (Table 2). Therefore, 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:

(1) $$\overline{CPUE}_a = \frac{\sum_{sq} \overline{CPUE}_{a,sq}}{n_{a,sq}}$$

where

(2) $$\overline{CPUE}_{a,sq} = \frac{\sum_{pos} \overline{CPUE}_{a,sq,pos}}{n_{a,sq,pos}}$$

where

(3) $$\overline{CPUE}_{a,sq,pos} = \frac{\sum_{st} \overline{CPUE}_{a,sq,pos,st}}{n_{a,sq,pos,st}}$$

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

Results

The total number of hauls made with DK1 and DK2 by year, area and square are indicated in Table 3 and the associated stratified average catch rates in Table 4 and Figure 3. For each area, the stratified catch rates by age are indicated in Table 5.

The internal consistency, i.e. the ability of the survey to follow cohorts, was evaluated for each area by plotting catch rates of an age group in a given year versus the catch rates of the next age group in the following year. The analysis indicated that the internal consistency of the dredge survey is acceptable for both areas (R^2 varying between 0.541 and 0.755) using the unweighted catch rate indices (Figure 4).

Exploratory analysis indicated that the internal consistency did not improve by standardization to the square means (Figure 5) or by weighting by total commercial catches by square (Figure 6) or by the size of the sandeel distribution area (Figure 7) of the catch rate indices.

The external consistency, i.e. the consistency of catch rates at age between areas, was evaluated for each age group by plotting the catch rates of the two areas against each other. As indicated in Figure 8 the external consistency was absent for age groups 0 and 1, whereas R^2 was 0.63 for age group 2.

Table 1. Total number of hauls by type of dredge (DF1, DK1, DK2, DK3) and area (1, 2 and 3) in the period 2004–2009.

Dredge	Area	2004	2005	2006	2007	2008	2009	Total
DF1					**10**	**3**		**13**
	1				6	3		9
	3				4			4
DK1		**134**	**155**	**63**	**95**	**105**		**552**
	1	114	135	43	58	59		409
	2		7					7
	3	20	13	20	37	46		136
DK2				**111**	**28**	**4**	**95**	**238**
	1			83	25	4	58	170
	3			28	3		37	68
DK3				**5**	**10**	**10**		**25**
	1			3		1		4
	3			2	10	9		21
	Total	**134**	**155**	**179**	**143**	**122**	**95**	**828**

Table 2. Number of stations (hauls) by area, square and position made by dredges DK1 and DK 2.

			Year						
Area	Square	Position	2004	2005	2006	2007	2008	2009	Total
1			**114**	**135**	**126**	**83**	**63**	**58**	**579**
	37F0		**0**	**15**	**14**	**7**	**7**	**8**	**51**
		3760.01					1		**1**
		3760.03		5					**5**
		3760.04		5	5	3	1	3	**17**
		3760.05		5	4	4	2	3	**18**
		3760.06			5		3	2	**10**
	37F1		**11**	**24**	**15**	**6**	**3**	**3**	**62**
		3761.03	6	10	5				**21**
		3761.04	5	9	5	3	3	2	**27**
		3761.08		5	5	3		1	**14**
	37F2		**5**	**5**	**4**	**3**	**4**	**5**	**26**
		3762.01					3	3	**6**
		3762.02	5	5	4	3	1	2	**20**
	38F1		**20**	**30**	**27**	**27**	**13**	**10**	**127**
		3861.02		5			2		**7**
		3861.14	5	5	4	3	1	2	**20**
		3861.19	5	5	5	5	2	2	**24**
		3861.22	5	5	5	6	3	2	**26**
		3861.23		5	5	6	1	2	**19**
		3861.32	5	5	8	7	4	2	**31**
	39F1		**15**	**13**	**13**	**3**	**6**	**5**	**55**
		3961.01		2					**2**
		3961.02					1		**1**
		3961.22		1					**1**
		3961.28	10	5	6		2	3	**26**
		3961.29	5	5	7	3	3	2	**25**
	39F3		**19**	**9**	**11**	**14**	**9**	**7**	**69**
		3963.01	10	4	6	6	3	2	**31**
		3963.04	9	5	5	4	3	3	**29**
		3963.07				4			**4**
		3963.08					3	2	**5**
	39F4		**25**	**14**	**15**	**8**	**10**	**8**	**80**
		3964.01	10	9	10		1	3	**33**
		3964.02	10	5		4	3	2	**24**
		3964.03	5		5	4	6	3	**23**
	40F5		**10**	**15**	**17**	**7**	**7**	**7**	**63**
		4065.01	5	5	5	7	3	2	**27**
		4065.02	5	5	5		3	3	**21**

			Year						
Area	**Square**	**Position**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Total**
		4065.03			2				**2**
		4065.04		5	5		1	2	**13**
	41F5		**9**	**10**	**10**	**8**	**4**	**5**	**46**
		4165.01	5	5	5		3	2	**20**
		4165.02	4	5	5	8	1	3	**26**
2			**0**	**7**	**0**	**0**	**0**	**0**	**7**
	38F6		**0**	**4**	**0**	**0**	**0**	**0**	**4**
		3866.01		4					**4**
	39F7			**3**					**3**
		3967.02		3					**3**
3			**20**	**13**	**48**	**40**	**46**	**37**	**204**
	42F3		**0**	**1**	**5**	**3**		**1**	**10**
		4263.02		1	5	3		1	**10**
	42F4		**0**	**0**	**1**	**5**	**6**	**0**	**12**
		4264.01					2		**2**
		4264.03				3	1		**4**
		4264.05			1	2	3		**6**
	42F7		**15**	**10**	**10**	**4**	**7**	**9**	**55**
		4267.08	1						**1**
		4267.12	10	5			2	3	**20**
		4267.25	4	5	5	4	2	3	**23**
		4267.27			5		3	3	**11**
	43F4		**0**	**0**	**0**	**0**	**7**	**4**	**11**
		4364.01					3		**3**
		4364.05					2	1	**3**
		4364.07					2	3	**5**
	43F5		**0**	**0**	**16**	**9**	**6**	**8**	**39**
		4365.04			6	3		2	**11**
		4365.08			5	3	3	3	**14**
		4365.1			5	3	3	3	**14**
	43F6		**0**	**0**	**6**	**3**	**3**	**3**	**15**
		4366.06			6	3	3	3	**15**
	43F7		**5**	**2**	**10**	**10**	**11**	**12**	**50**
		4367.02			5	4	3	3	**15**
		4367.06					3	3	**6**
		4367.16		2		4	3	3	**12**
		4367.23	5		5	2	2	3	**17**
	44F4		**0**	**0**	**0**	**6**	**6**	**0**	**12**
		4464.04				3	3		**6**
		4464.05				3	3		**6**
Grand Total			**134**	**155**	**174**	**123**	**109**	**95**	**790**

Table 3. Danish dredge survey. Number of hauls made with DK1 and DK2 by area and square.

Number of hauls								
		year(year)						
Area	**square**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Total**
1	**37F0**	0	15	14	7	7	8	51
	37F1	11	24	15	6	3	3	62
	37F2	5	5	4	3	4	5	26
	38F1	20	30	27	27	13	10	127
	39F1	15	13	13	3	6	5	55
	39F3	19	9	11	14	9	7	69
	39F4	25	14	15	8	10	8	80
	40F5	10	15	17	7	7	7	63
	41F5	9	10	10	8	4	5	46
Total area 1		114	135	126	83	63	58	579
2	**38F6**	0	4	0	0	0	0	4
	39F7	0	3	0	0	0	0	3
Total area 2		0	7	0	0	0	0	7
3	**42F3**	0	1	5	3	0	1	10
	42F4	0	0	1	5	6	0	12
	42F7	15	10	10	4	7	9	55
	43F4	0	0	0	0	7	4	11
	43F5	0	0	16	9	6	8	39
	43F6	0	0	6	3	3	3	15
	43F7	5	2	10	10	11	12	50
	44F4	0	0	0	6	6	0	12
Total area 3		20	13	48	40	46	37	204
Total all areas		134	155	174	123	109	95	790

Table 4. Danish dredge survey. Stratified CPUE (number per 60min) per square and area.

		Stratified CPUE					
Area	Square	2004	2005	2006	2007	2008	2009
1	37F0		950	1727	297	585	378
	37F1	1356	1482	993	2609	3029	6458
	37F2	301	2493	4256	3626	757	1613
	38F1	409	2723	3149	2258	1445	6538
	39F1	1720	3518	2044	136	812	7998
	39F3	342	1786	92	1931	189	1111
	39F4	3372	4049	1853	6638	166	3639
	40F5	523	1062	248	3834	263	4695
	41F5	827	2491	1048	7877	1799	5755
Average area 1		1106	2284	1712	3245	1005	4243
2	38F6		34				
	39F7		29				
Average area 2			32				
3	42F3		1030	871	2894		6523
	42F4			12	26	3582	
	42F7	93	333	637	512	221	245
	43F4					127	140
	43F5			1438	890	879	1700
	43F6			1974	498	1197	550
	43F7	117	240	882	768	89	174
	44F4				307	68	
Average area 3		105	534	969	842	880	1556

Table 5. Danish Dredge survey. Stratified cpue (number per hour) by age for area 1, 3 and for area 1 and 3 combined.

Area 1			
	Age		
Year	0	1	2
2004	928.12	166.52	11.61
2005	2242.27	35.68	5.78
2006	1485.45	244.36	0.34
2007	3121.29	176.40	31.64
2008	522.75	568.58	26.32
2009	4116.66	96.11	30.01
Area 3			
	Age		
Year	0	1	2
2004	85.85	13.39	5.76
2005	486.66	46.70	1.00
2006	906.10	62.28	0.57
2007	547.78	321.20	9.53
2008	643.75	183.70	52.90
2009	454.97	902.71	197.86

Area 1 and 3 combined			
	age		
year	0	1	2
2004	759.66	135.89	10.44
2005	1803.37	38.44	4.58
2006	1253.71	171.53	0.43
2007	1995.38	239.75	21.97
2008	575.69	400.19	37.95
2009	2651.98	418.75	97.15

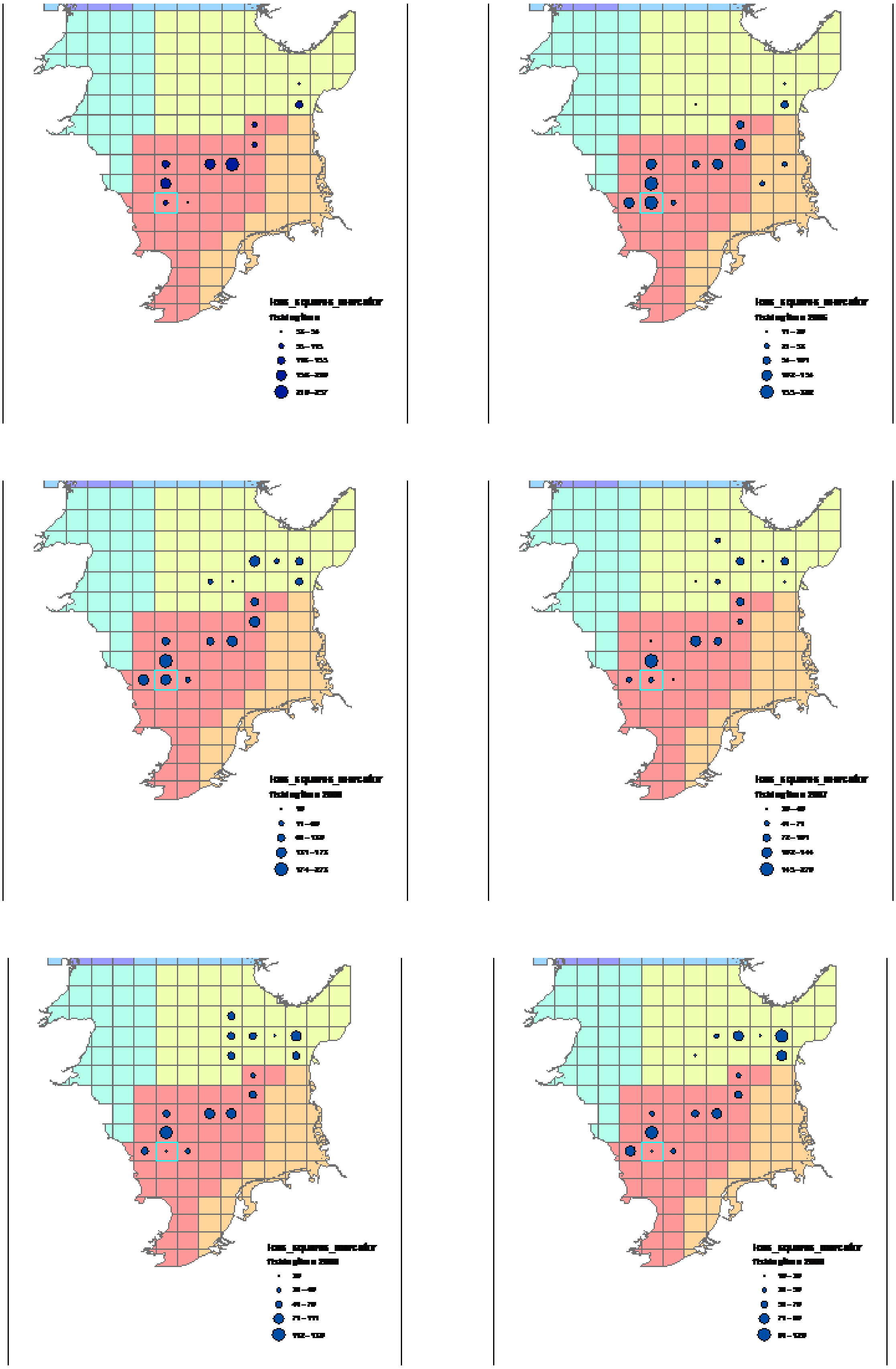


Figure 1. Danish dredge survey. Distribution of effort 2004–2009.

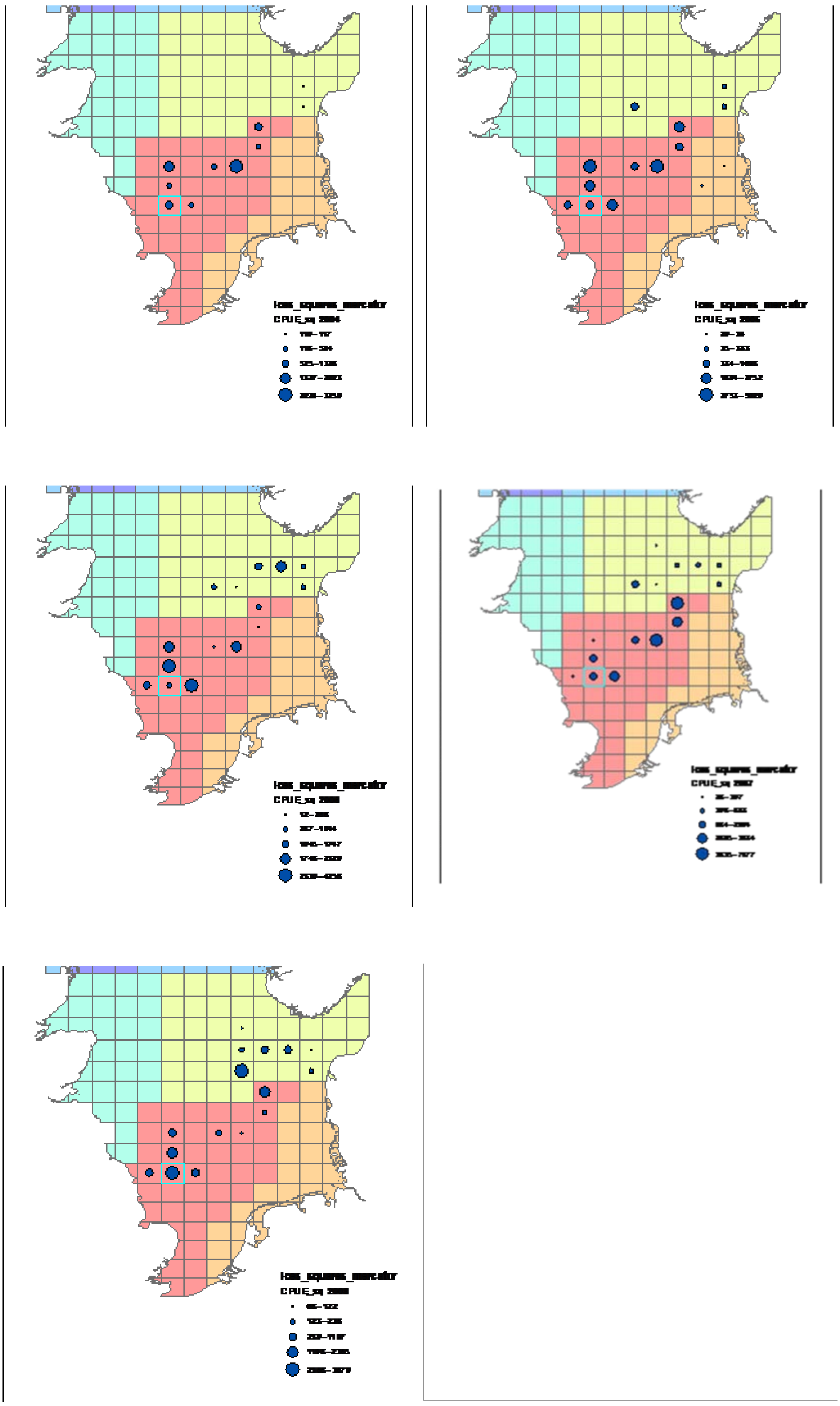


Figure 2. Danish dredge survey. Cpue 2004–2009.

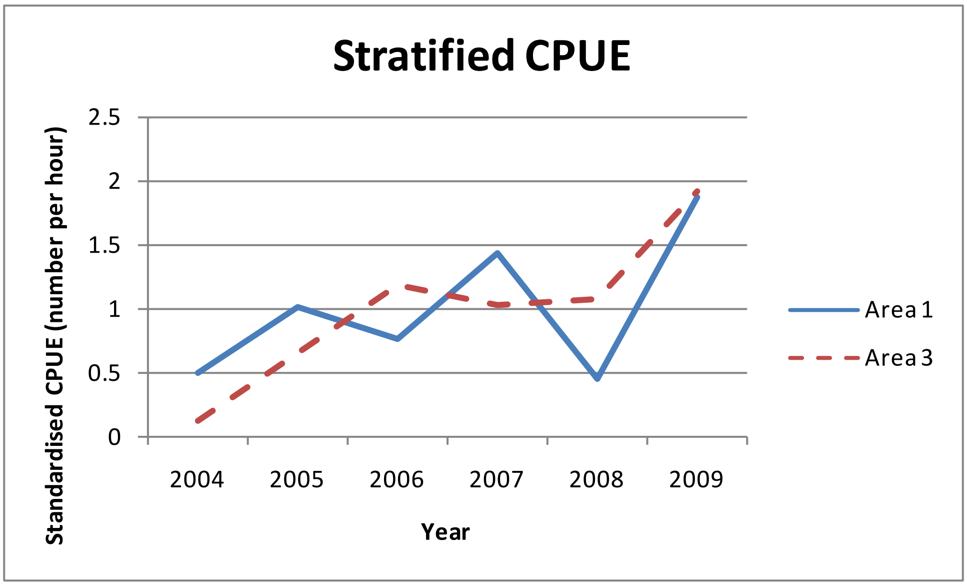


Figure 3. Danish dredge survey. Stratified average catch rate indices by area (number per hour standardized to their means).

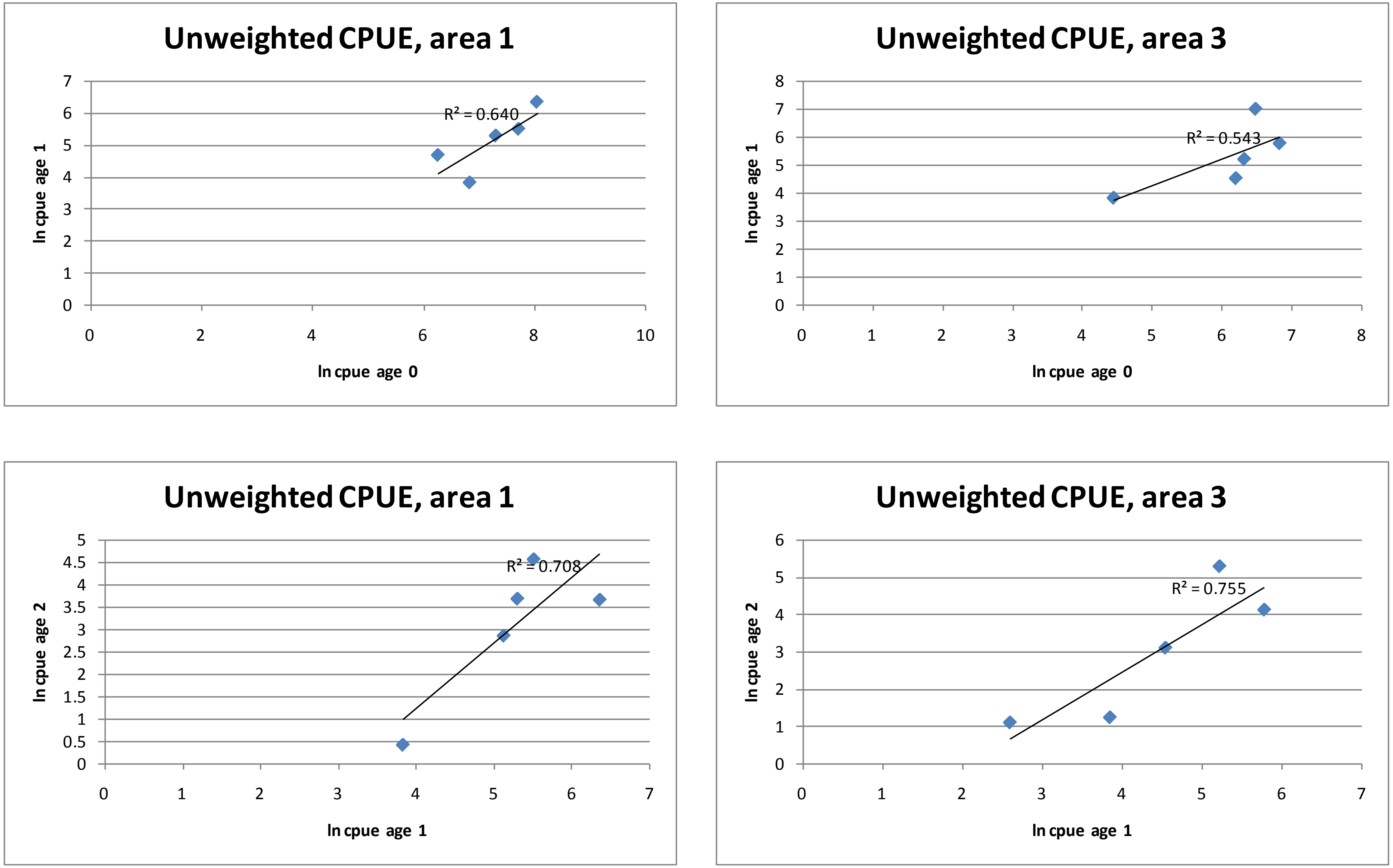


Figure 4. Dredge survey. Internal consistency plot. Raw data.

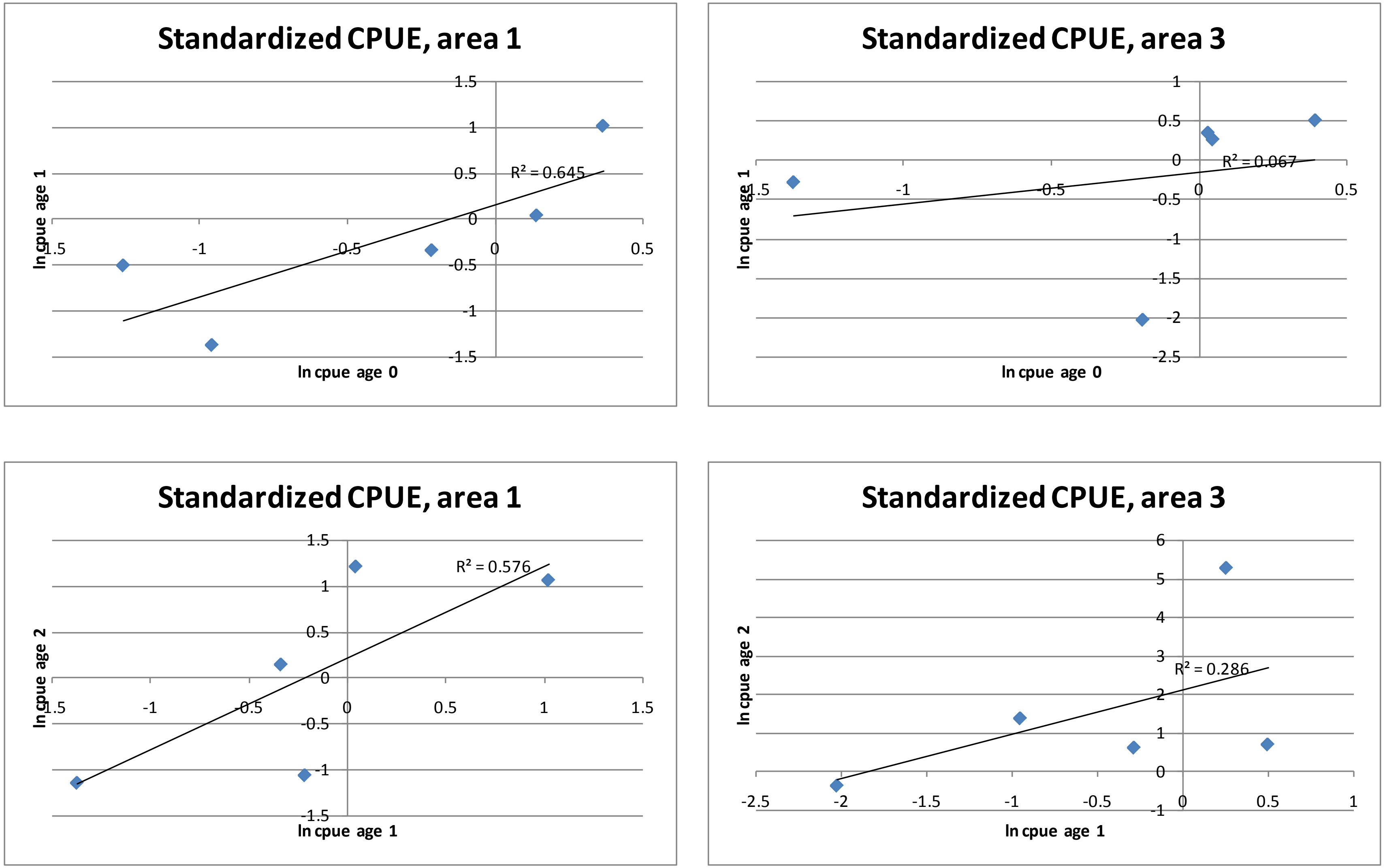


Figure 5. Dredge survey. Internal consistency plot: average of indices standardized by square means.

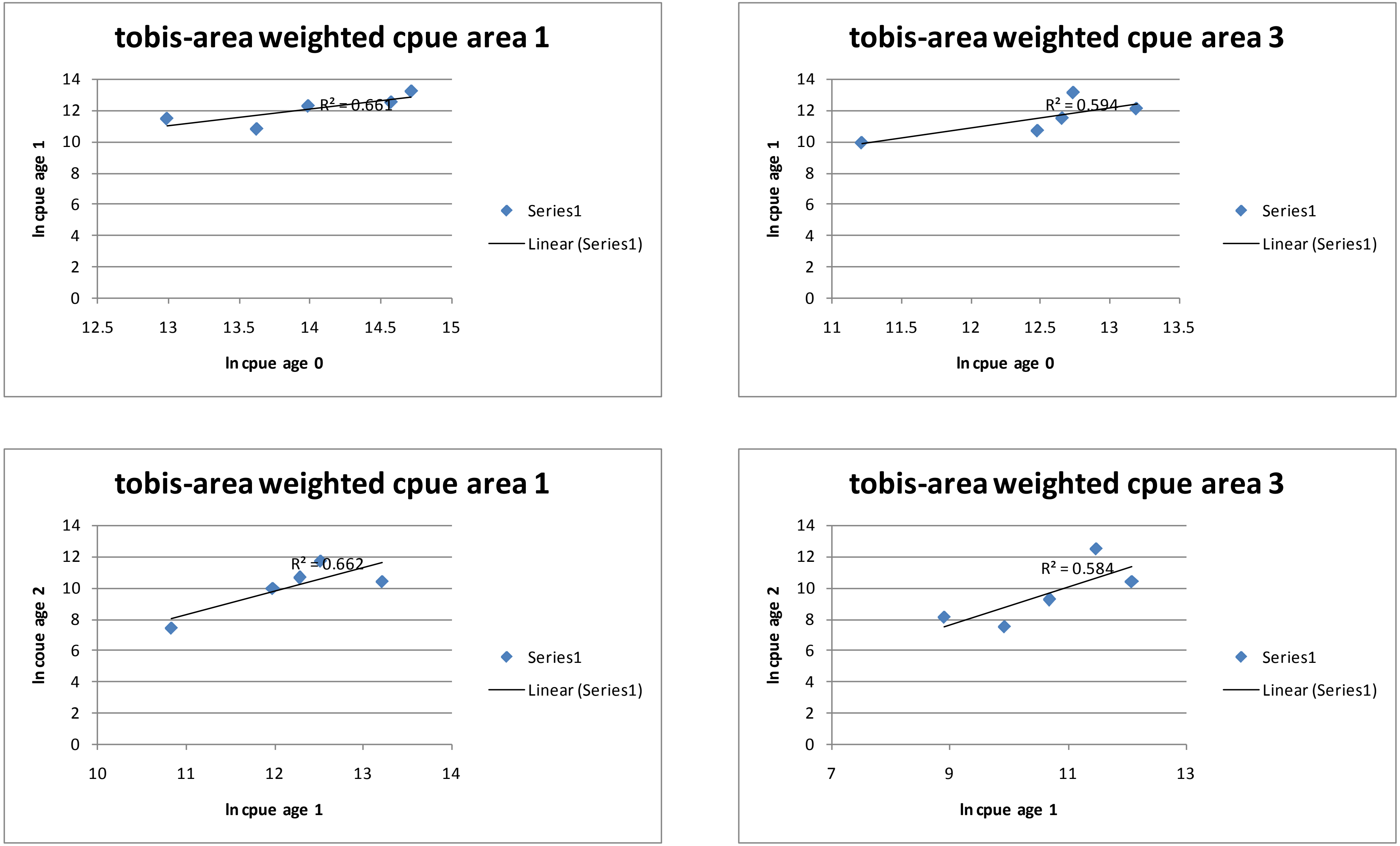


Figure 6. Dredge survey. Internal consistency plot. Average of standardized indices weighted by tobis area by square.

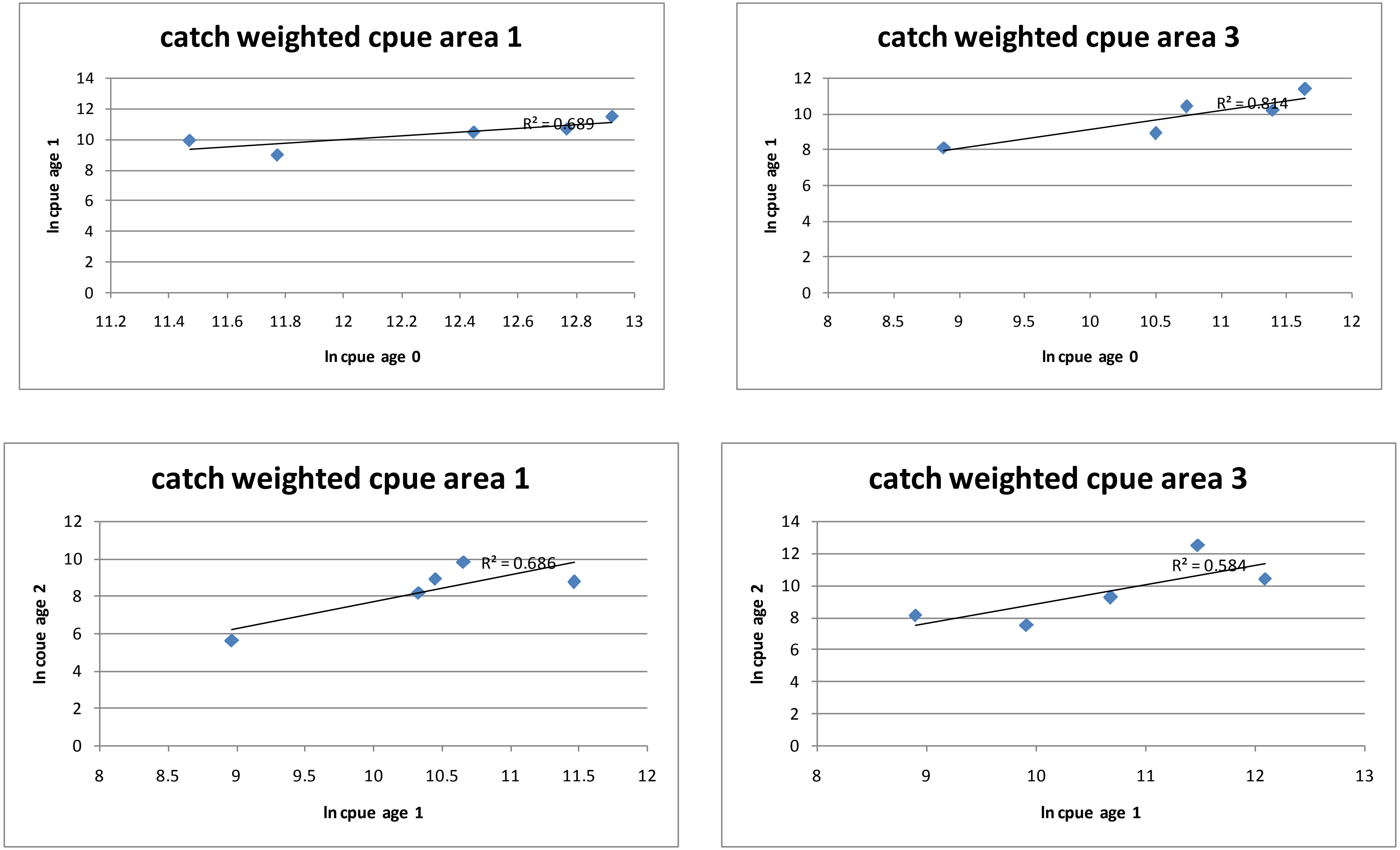
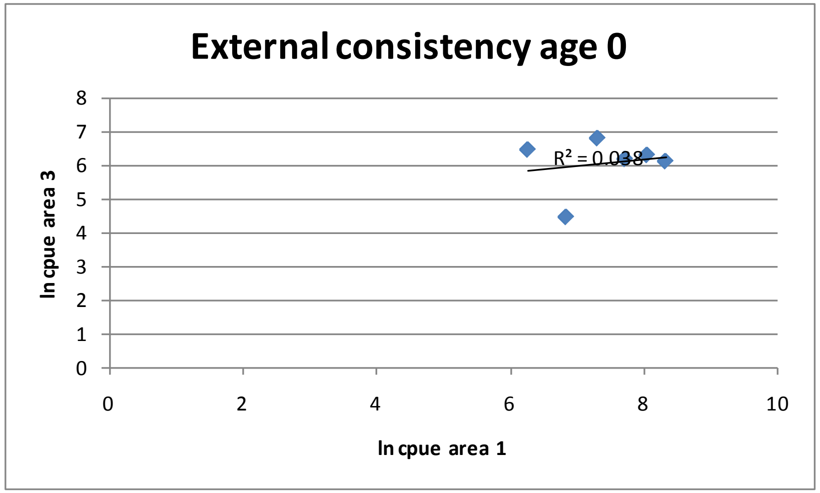
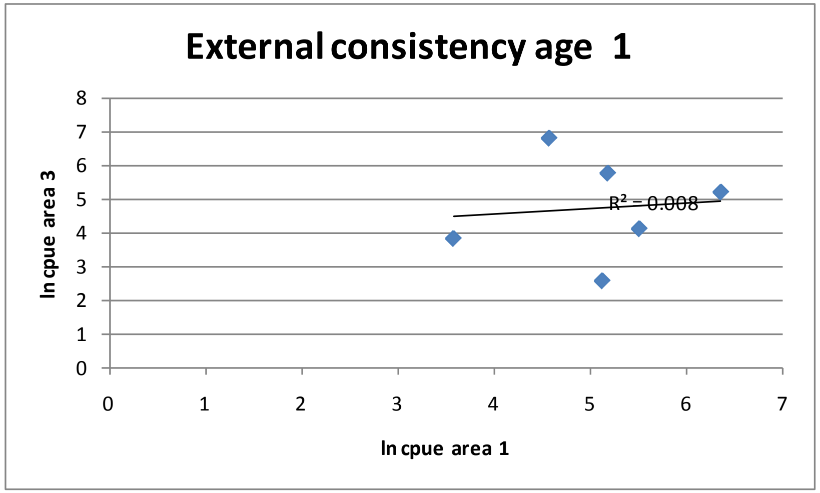


Figure 7. Dredge survey. Internal consistency plot. Average of raw indices weighted by the total catch of tobis by square.





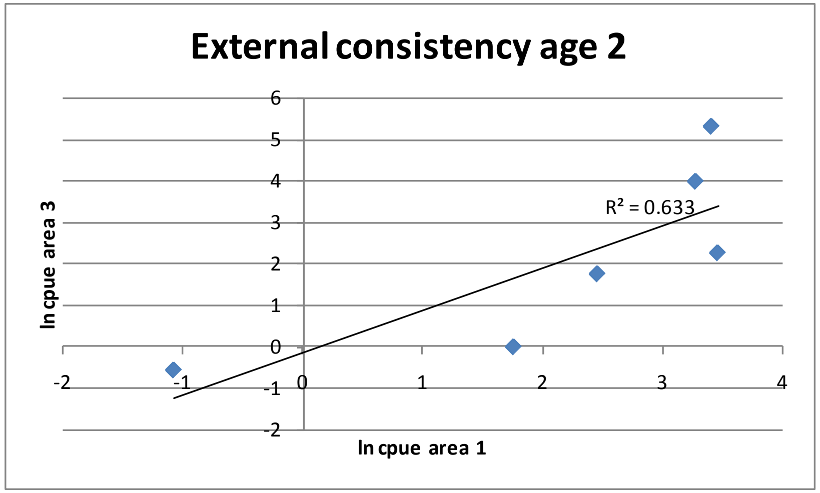


Figure 8. Dredge survey. External consistency plot. Unweighted catch rate indices.

A2. Working Document 2/9/10–Marine Scotland Science sandeel dredge survey indices for Area 4 (Firth of Forth)

P.J. Wright and R. Watret

Introduction

There are several reasons why it is difficult to design a survey to estimate sandeel abundance. Once settled, sandeels exhibit a diel emergence pattern and can occur in the sediment, near the bottom or throughout the water column during the day. Sandeels also overwinter in the sand and their period of emergence differs with age and condition. For example, 1-group sandeels may emerge from March/April to July whilst older age-classes may emerge later (Reeves, 1994). 0-group sandeels tend to metamorphose into juveniles capable of burrowing in May to June (Wright and Bailey, 1996). Many seabirds and fish predators begin to feed on 0-group during this period of metamorphosis (Lewis *et al*., 2001). However, 0-group may not settle to some fishing grounds until July (Jensen, 2001). These young sandeels tend to remain active in the water column until August or September, before beginning an overwintering phase in the sand. Sandeel distribution is limited by the patchiness of suitable sand for burrowing (Wright *et al*., 2000). Because of the age related differences in emergence and settlement, sampling of the water column at any one time will generally only provide reliable estimates of one or two age classes. Surveys of buried sandeels have been used to overcome this problem.

MSS research in the North Sea has focussed on sandeel availability to predators near the Firth of Forth. Many types of sampling approaches have been applied to consider sandeel abundance and accessibility to surface feeding seabirds and fish predators. An attempt to estimate changes in age specific biomass using a combination of acoustics, trawling, dredge and grabs and information on primary productivity has also been made (see Greenstreet *et al*., 2006). Until 2007, the sampling times and mix of approaches used were not designed with the specific aim of producing a year-class index. However, in order to complement the Danish dredge survey a dedicated sampling programme was begun in 2008 with the aim of producing a year-class index for area 4, off the northeast UK coast. The survey is targeted at banks off the Firth of Forth and around Turbot bank and takes place in November–December, coinciding with the Danish sampling. This report presents the results from this survey for just the Firth of Forth banks and compares with similar data collected in October–November between 1999 and 2003.

Methods

The Scottish surveys used a video dredge system developed in 1999 that enabled estimates of the time spent on sediments suitable for sandeels to be made (see Figure 1). This corresponds to the gear DK2 described in the Danish survey (Christensen WDA1). Catch rates of the Scottish and Danish gears were found to be highly correlated in a previous gear trial (Jensen, unpubl. data). Dredge hauls encompassing the major sandeel banks were taken at eight stations in 1999–2003 and 2008–2009; three stations on the Wee Bankie, three on Marr Bank and two on Berwick bank. At each station 1–6 tows over the same ground were made and each haul comprised a 10–15 minute tow. All sandeels were measured and a length stratified sample was aged. Numbers caught were converted to numbers per area swept and then raised to numbers per hour based on the average area swept in one hour. Average cpue for area 4

(Firth of Forth) was calculated using the same averaging used in the Danish surveys (Christensen, WDA1) in order to enable comparison.

Results

The total number of hauls are given in Table 1. Due to the different requirements of surveys, sample sizes were low prior to the establishment of a dedicated recruit survey in 2008. Based on a catch curve for 2009, only sandeels≥8.5 cm appear to be fully selected by the gear (Figure 2). As 0-group ranged from 4.5–11.5 cm, the gear appears unsuitable for estimating absolute numbers of 0-group. Nevertheless, the proportion of very small 0-group is likely to be small since grab samples from the same region only recorded 0-group ≥7 cm. The bias against small 0-group sizes resulted in higher catches for age 1 compared to age 0 for a given year-class. Nevertheless, there was a consistency in catch rates between age 0 and 1 as well as between age 1 and 2, based on the limited comparisons that could be made (Figure 3).

Estimated average cpue indicated that the 2009 year class was the largest year class recorded (Table 2). The 1999 and 2000 year classes were larger than those in 2001–2003 and 2008. Large year classes were characterised by high densities at most stations.

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Table 1. Scottish dredge survey. Number of hauls by ICES rectangle and year.

Rectangle	Year						
	1999	2000	2001	2002	2003	2008	2009
41E7	3	4	3	3	3	18	15
41E8	4	5	3	3	3	8	8
40E8	2	5	0	2	2	6	8

Table 2. Average cpue by age for area 4, Firth of Forth.

		Age		
Year	0	1	2	3
1999	169.8943	142.9584	116.1867	54.96475
2000	251.44	504.8271	135.828	58.39198
2001	48.48734	329.096	250.5868	32.34407
2002	88.0291	114.231	179.1284	77.85894
2003	135.4006	NA	NA	NA
2008	68.25798	24.37893	23.85956	15.55977
2009	982.8225	164.2795	50.21453	19.33099

Figure 1. The video dredge system developed by Marine Scotland Science.

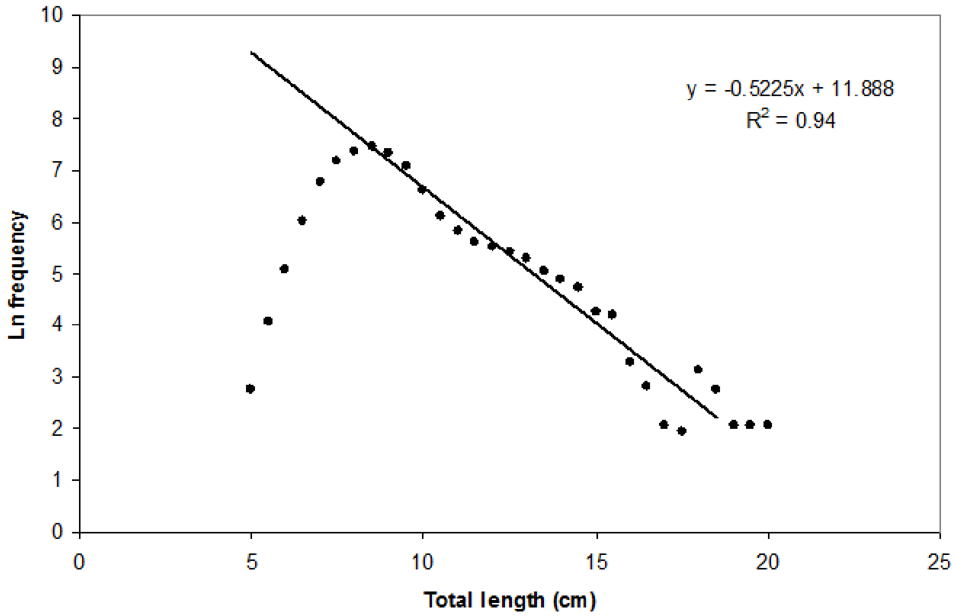

Figure 2. Log transformed frequency by total length of *A. marinus* from the 2009 Firth of Forth stations.

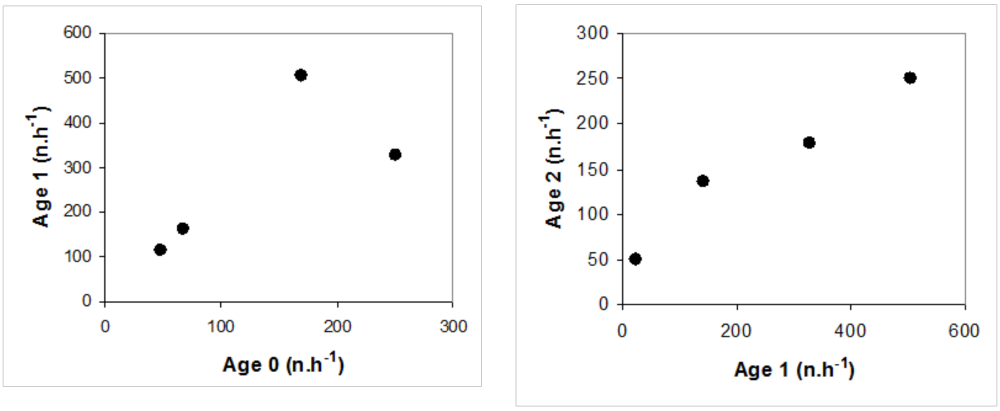

Figure 3. Internal consistency plot. Average cpue of consecutive ages from the same year class.

A3. Statistical catch-at-age model for sandeel with temporally explicit fishing mortality

Statistical catch-at-age model for sandeel with temporally explicit fishing mortality

September 10, 2010

Abstract

A statistical catch-at-age model has been developed to better match seasonal effort allocation pattern used in the sandeel fishery. The model is run separately in three areas, and its results compare well with results from other models. The model is estimating the within year catchability pattern for certain age classes, and from that the instantaneous fishing mortality is computed by multiplying the catchability and the effort corresponding to each specific time. The model incorporates the new dredge survey from DTU-Aqua in the two areas (1 and 3) where it is available. Furthermore, the model is stochastic and quantification of uncertainties is a natural part of the model.

Data

For a given area the model uses total yearly non-zero age classified catches $\{C_{a,y}\}_{a=0...4+;y=1982...2007}$ and corresponding weekly effort numbers $\{e_{t_i}\}_{t_1...t_n}$. Notice the two different time scales. Effort numbers are given weekly, but the catches are yearly totals.

A newly developed dredge survey is available for the last 5 years in area 1 (Dogger Bank) and 3 (North East North Sea) (see separate working document about the dredge survey). The dredge-survey supplies an index vector $(\mathscr{I}_a)_{a=0,1,2}$ of the 0, 1, and 2 year old population.

The instant natural mortality rate M_a is assumed known, separate for first half year $M_0 = 0$, $M_1 = 2$ and $M_{2+} = 0.8$, and the second half year $M_0 = 1.6$ and $M_{1+} = 0.4$, but constant for all years. The weight in stock is assumed to be equal to the weight in catch, and yearly averages are used.

Model

Within each area the yearly log-catches $\log C_{a,y}$ are assumed to follow a normal distribution, with the predicted log-catch as mean, a variance parameter for the recruits σ_0^2, and another variance parameter for the remaining ages σ_{1+}^2. Similarly the yearly log-indices $\log \mathscr{I}_{a,y}$ are assumed to be normally distributed with mean proportional to the stock size, but with separate survey catchability for each age class.

The instantaneous fishing mortality is assumed to be a product of the effort e_t and catchability $q_{a,t}$. Catchability is represented as a set of cubic spline functions with a number of support points $\varphi_{a,1}, \varphi_{a,2}, \ldots, \varphi_{a,n_\varphi}$. The catchability pattern is assumed common for all years.

The usual stock equation $N_{a+1,y+1} = N_{a,y}\exp(-F_{a,y} - M_{a,y})$ and catch equation $C_{a,y} = F_{a,y}/(F_{a,y} + M_{a,y})(N_{a,y} - N_{a+1,y+1})$ are derived by solving the following ordinary differential equation (ODE) under the assumption of constant mortality parameters within a year, for a certain age class.

$$\begin{aligned}
\frac{d}{dt}N_t &= -(F_t + M_t)N_t \\
\frac{d}{dt}C_t &= F_t N_t
\end{aligned}$$

For the sandeel assessment we know explicitly that the effort, and thereby the fishing mortality, is concentrated in a few months (April, May, and June), with very little effort outside those months, so the assumption of constant yearly F is not valid.

To allocate the fishing mortality correctly to the time of year where the catch is taken. The ODE above is solved numerically for each year and age group, and the solution is used instead of the stock and catch equations to calculate the predicted catch $\widehat{C}_{a,y}$ and stock size $N_{a+1,y+1}$

The logarithm of the stock size in the first year $(N_{a,1982})_{a=0\ldots4}$ and at the youngest age $(N_{0,y})_{y=1983\ldots2007}$ are model parameters. The negative log likelihood is computed by:

$$\begin{aligned}
\ell(\theta|C,\mathscr{I}) = &-\sum\{\log\phi_{\sigma_a}(\log C_{a,y} - \log\widehat{C}_{a,y})\} \\
&-\sum\{\log\phi_{\sigma_{\mathscr{I}}}(\log\mathscr{I}_{a,y} - \log(Q_a N_{a,y+\tau}))\}
\end{aligned}$$

Here ϕ_σ denotes the density function for the normal distribution with mean zero and standard error σ, τ is the fraction into the year where the survey is conducted, and θ is the vector containing all model parameters $\theta = ((N_{a,1982})_{a=0\ldots4}$, $(N_{0,y})_{y=1983\ldots2007}$, $(\varphi_{a,i})_{a=0,1,2^+;i=1\ldots n_\varphi}$, σ_0, σ_1^+, $(Q_a)_{a=0,1,2}$, $\sigma_{\mathscr{I}})$.

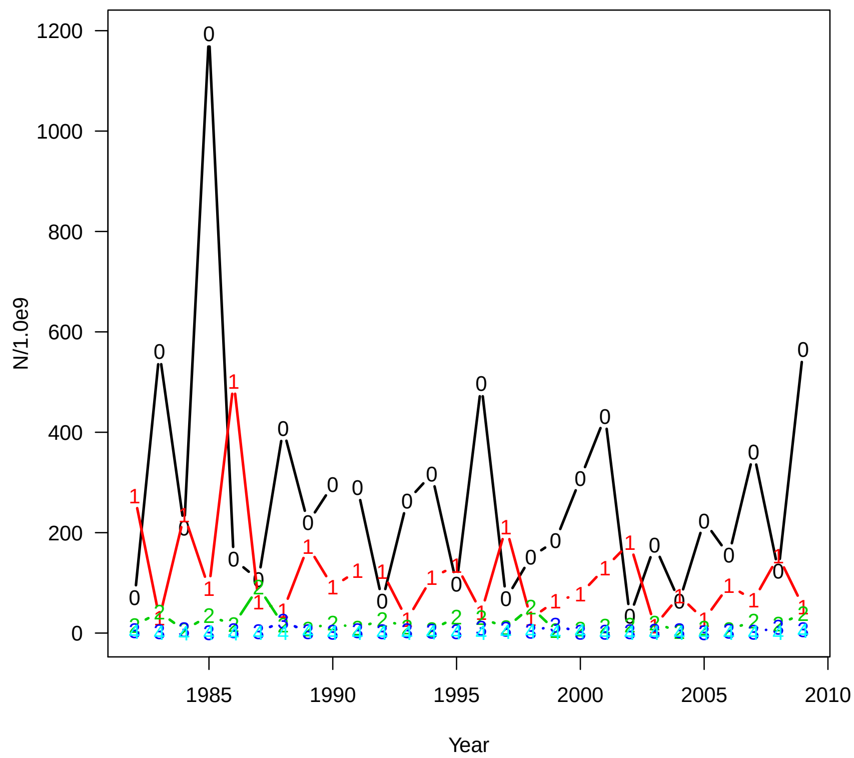

Figure 1: Estimated stock numbers for the different age classes in area 1. The integer used as plotting symbol denotes the age

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Results

Results from all three areas are collected at `http://www.nielsensweb.org/sandeelIdx/`. Here only a selection of graphs from Dogger Bank is included to better explain their content.

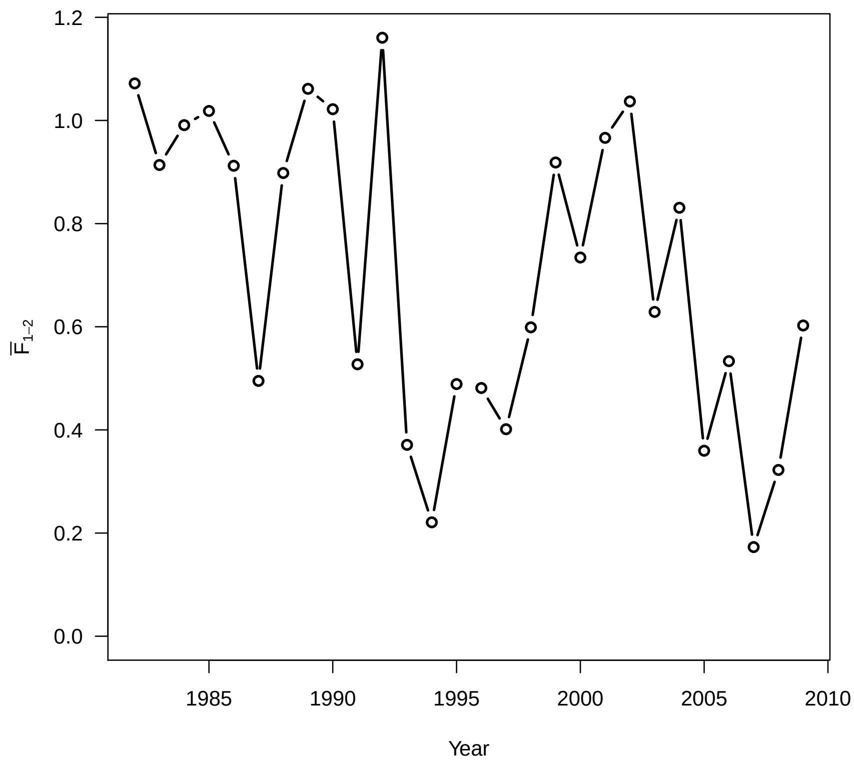

Figure 2: Estimated average fishing mortality (ages 1 and 2) in area 1.

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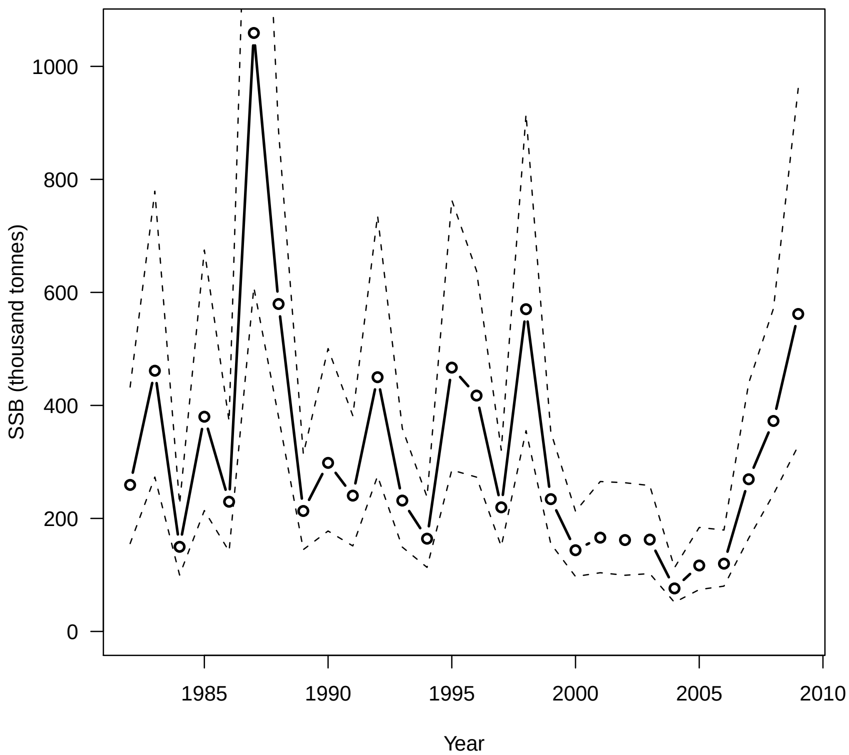

Figure 3: Estimated spawning stock biomass for area 1 with corresponding 95% confidence regions

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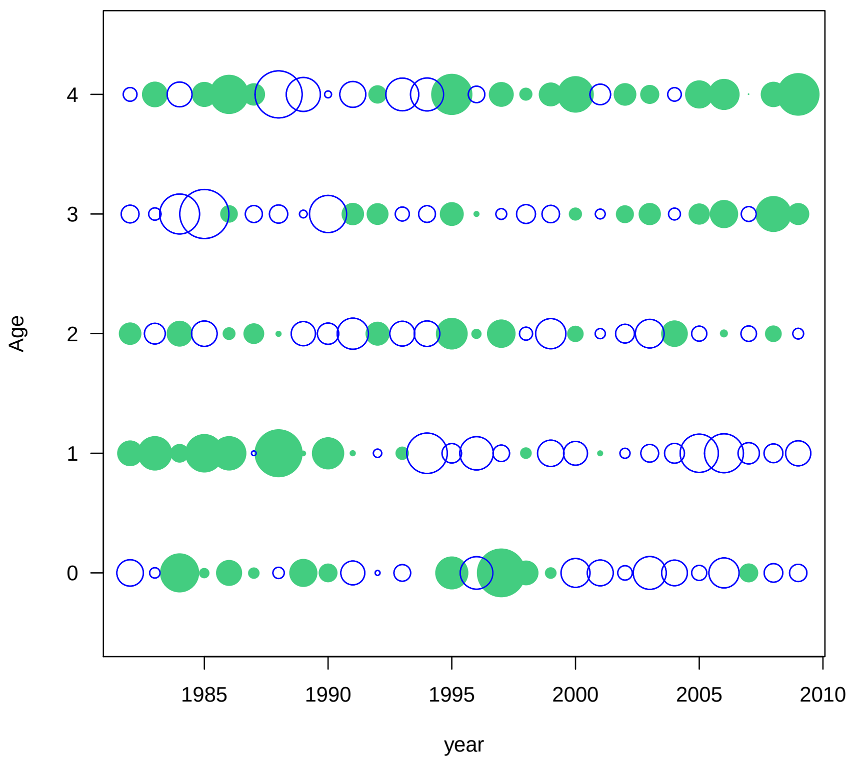


Figure 4: Normalized catch residuals ((obs-pred)/std) from area 1. The area of the circle is proportional to the absolute value of the normalized residual, the empty circles correspond to positive residuals, and the shaded circles correspond to negative residuals.

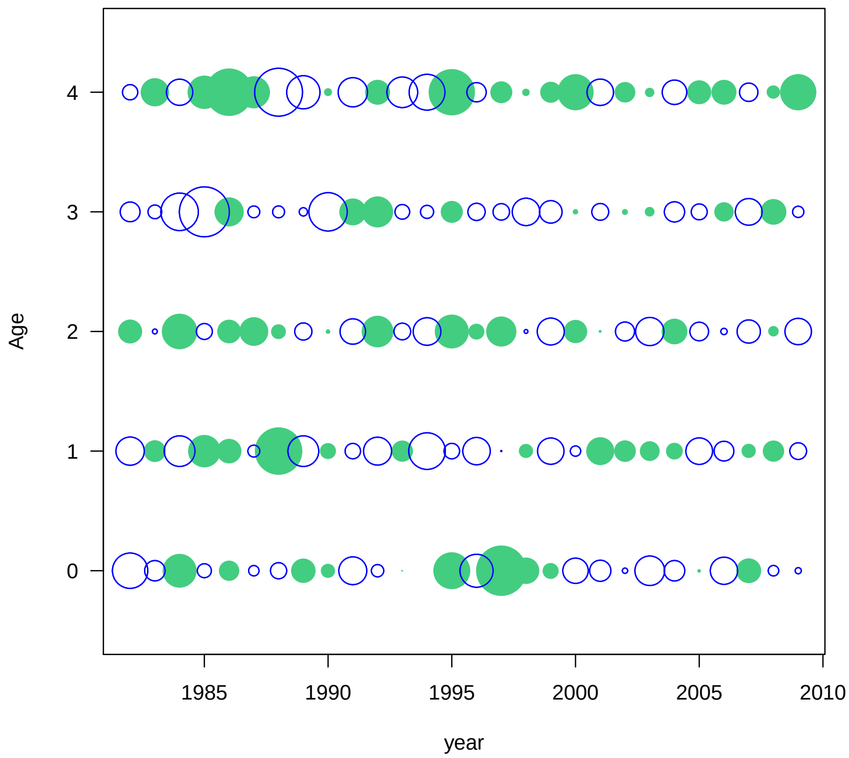


Figure 5: Normalized catch residuals ((obs-pred)/std) from area 1 for the model where technical creep is included for ages 0, 1, and 2. The area of the circle is proportional to the absolute value of the normalized residual, the empty circles correspond to positive residuals, and the shaded circles correspond to negative residuals.

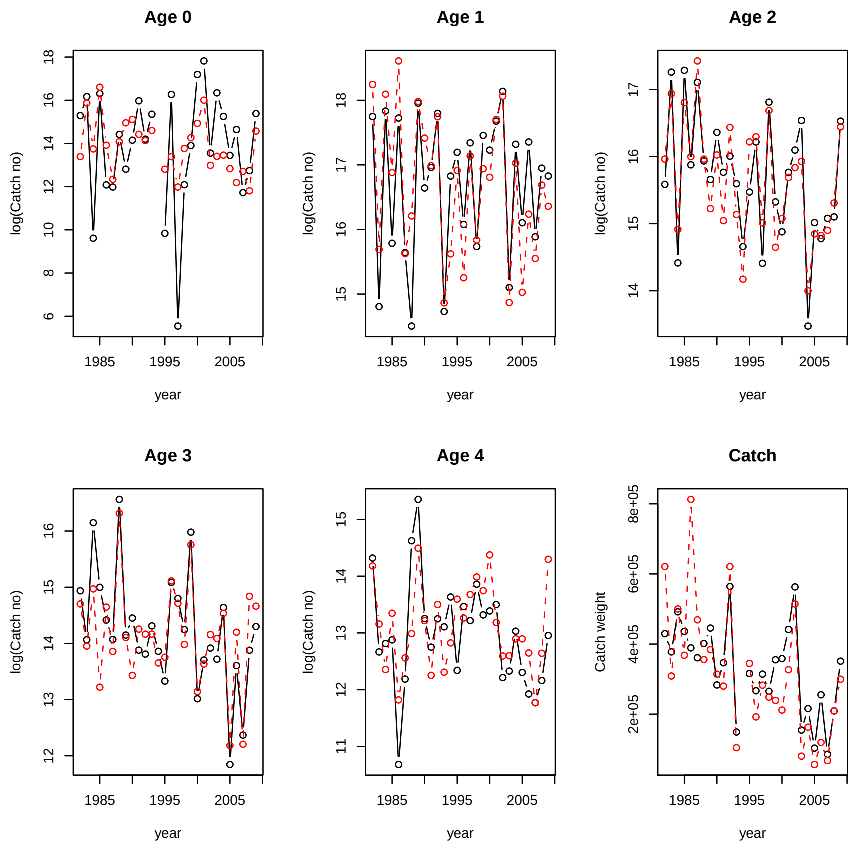


Figure 6: Observed log-catches (solid black line) and predicted log-catches (dashed red line) for the different age classes and for catch weight (last frame) in area 1.

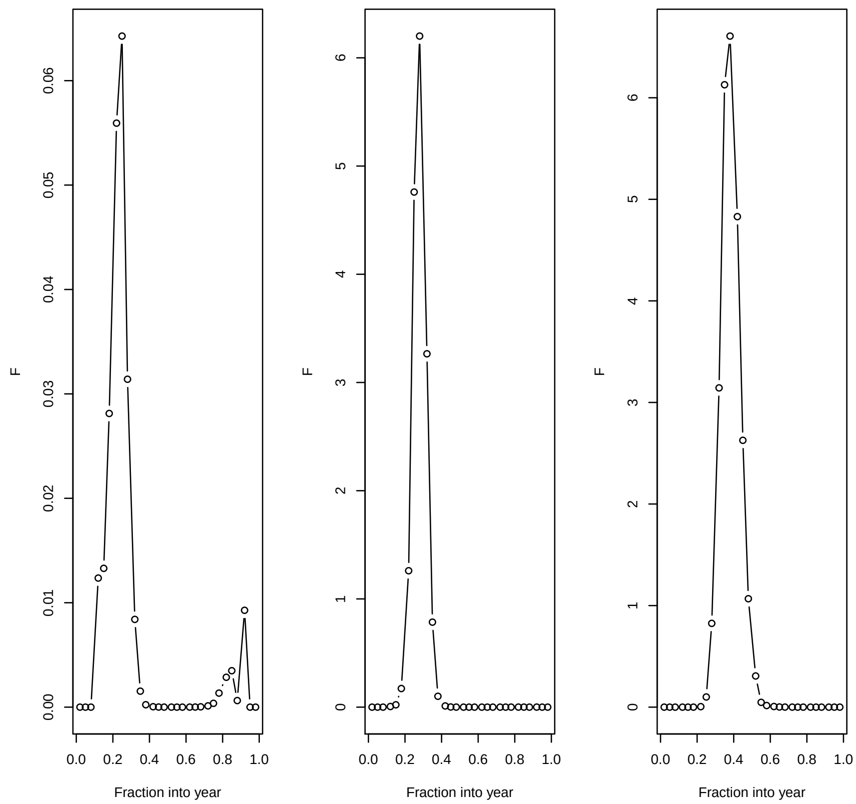


Figure 7: The average estimated allocation of F within a year. Left frame is for age 0, middle frame is for age 1, and right frame is for ages 2, 3, and 4+. These curves are drawn from the estimates within year catchability function multiplied by the average effort allocation pattern.

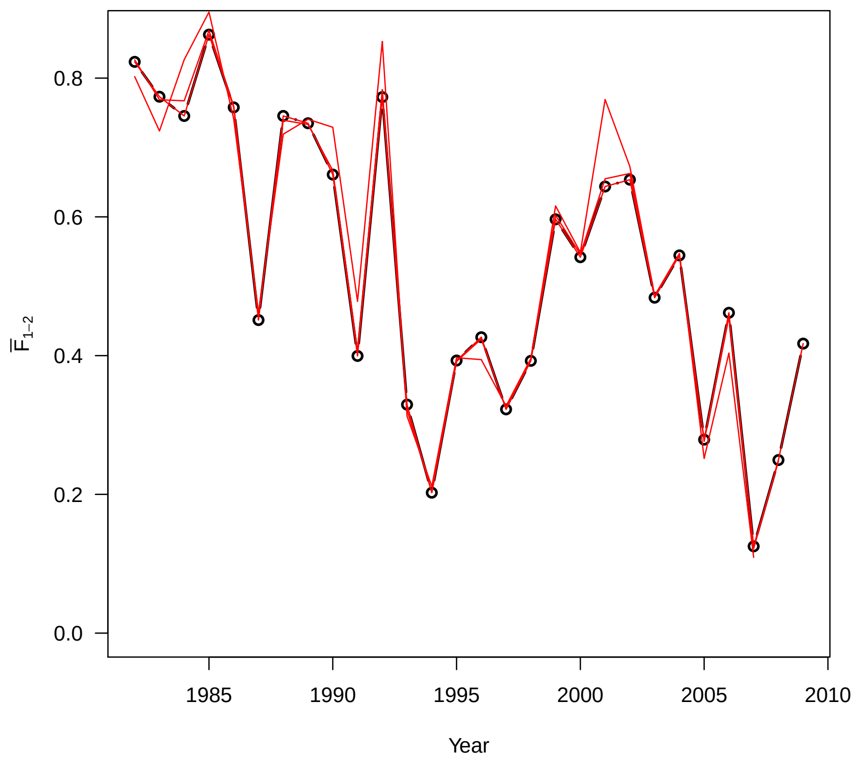


Figure 8: Retrospective pattern for $\overline{F}_{1--2}$. Only one and two years back due to the short dredge survey.

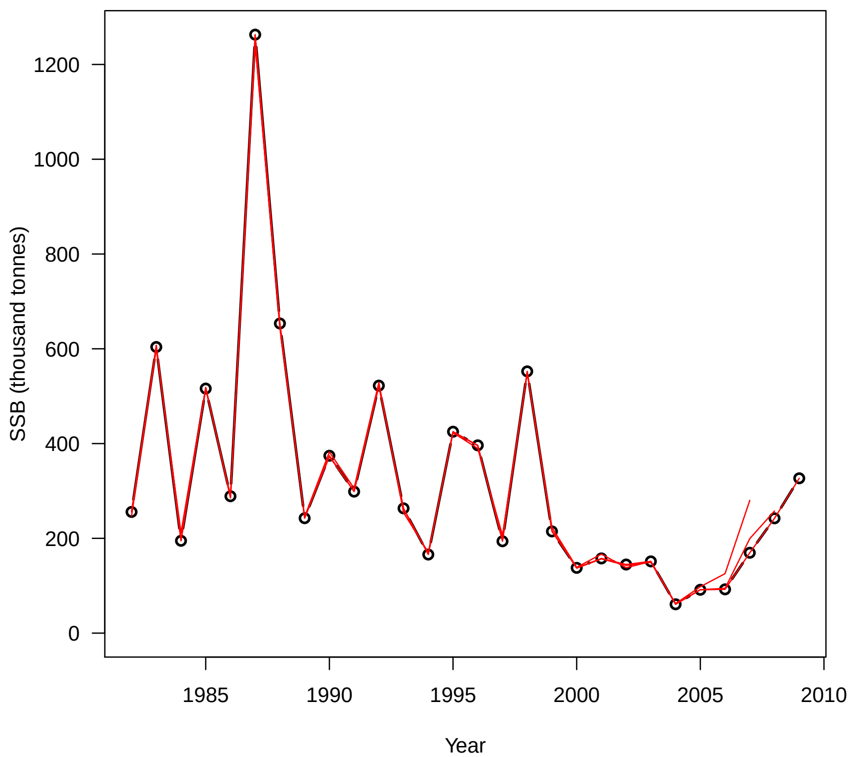


Figure 9: Retrospective pattern for SSB. Only one and two years back due to the short dredge survey.

A4. Proposal for a future North Sea sandeel management

Prepared August 2010 by the Danish Fishermen's Association

Proposal for a future North Sea sandeel management

DANMARKS FISKERIFORENING

Introduction

This paper outlines a proposal for the future management of the sandeel fishery. It has been developed through an intensive series of meetings in August 2010 between a small working group within the Danish Fishermen's Association (DFA) and all the key stakeholders in relation to the Danish sandeel fishery. The proposal thus originates in the DFA, but through the intensive process it has been possible to adapt the proposal to incorporate or align with the views, knowledge and outlooks of the other stakeholders to a surprisingly high degree.

The proposal was conceived in a wish to get beyond the year-to-year instability, seasonal uncertainty and last-minute decisions we have experienced in the North Sea sandeel management for several years. The problems can be briefly summarised as:

- The biological difficulties of finding the exact combination of the right monitoring period for the real-time management, and a pre-defined formula which automatically ensures the correct quota based on the monitoring.

- The operational and financing problems for the participating vessels that can never plan for the fishing season, because the quota is only known half-way through.

- The large and tightly compressed work-load the current real-time management places upon the advisory bodies as well as the Commission and Member State administrations.

It is probably safe to say that these problems all came to a peak in 2010, and that all stakeholders the working group have met with – fishermen, processors, scientists and the Commission as well as Member State managers – in each their way felt the burden of a management system that just does not work.

The proposal

1. Separate the advice, management and quotas for North Sea sandeel in two separately managed areas, the EU-zone and the Norwegian zone – through mutual agreement between Norway and the EU.

2. Attach the management of the sandeel in the Skagerrak (EU-part) to the EU-zone in the North Sea, either as part of sub-zone 3 or sub-zone 2 (see attached map)

3. Yearly procedure for setting the TAC for in the EU area.
   Advisory process:
   - **a** September previous year: Stock assessment incorporating data from the fishery in that year, gives an estimate of the stock of two year and older fish in TAC-year.
   - **b** December previous year: Update assessment incorporating data from dredge surveys gives an estimate of one year old fish in the TAC-year.
   - **c** a. and b. are combined to give advice for a TAC (in simple terms a. plus b. minus Bpa).

Management:

- **d** If the advice is that a TAC of 500.000 t or more would be sustainable, the TAC is set at 500.000 t for the entire season.
- **e** If the advice is that a TAC between 400.000 t and 500.000 t would be sustainable, the TAC is set at this level for the entire season.
- **f** If the advice shows that neither d. or e. can be followed, the TAC is set at 400.000 t and a real-time monitoring of the fishery is set in place.
- **g** Based upon the real-time monitoring, the Commission is advised upon the need for in-season restrictions – "safe-guards".

Possible safe-guards include:

1. Closing predefined sub-zones of the North Sea (see attached map) for the remaining season, when a certain part of the quota has been taken there (e.g. the total North Sea quota remains 400.000 t, but no more than 50.000 t may be taken in area X).
2. Closing predefined sub-zones at a certain time during the season.
3. Closing the entire fishery at a certain time during the season.

Effects

The proposal would create four inter-linked changes to the current system:

1. Currently each season starts with a low TAC, and then the fishery is monitored in real-time to be able to raise the TAC to the sustainable level. This is reversed to a higher TAC and if necessary real-time monitoring as a basis for introducing safe-guards. Because of basic EU regulations, introducing safe-guards during the season is much faster and less bureaucratically cumbersome than raising the TAC.

2. This reversal also means that there is no longer a legal necessity for a pre-defined, exact formula for turning monitoring into TAC during the season. In stead the safeguards can be introduced on the basis of real biological advice, which is able to take account of the multitude of factors that influence the sustainability of the fishery, in a way that no formula can do.

3. As real-time monitoring is only used in those years when the stock assessment and dredge survey do not give sufficient certainty that the stock can sustain a fishery of 400.000 t or more, much of the large amounts of resources currently spent upon real-time monitoring can be saved – and better spent on e.g. expanding the coverage of the dredge surveys.

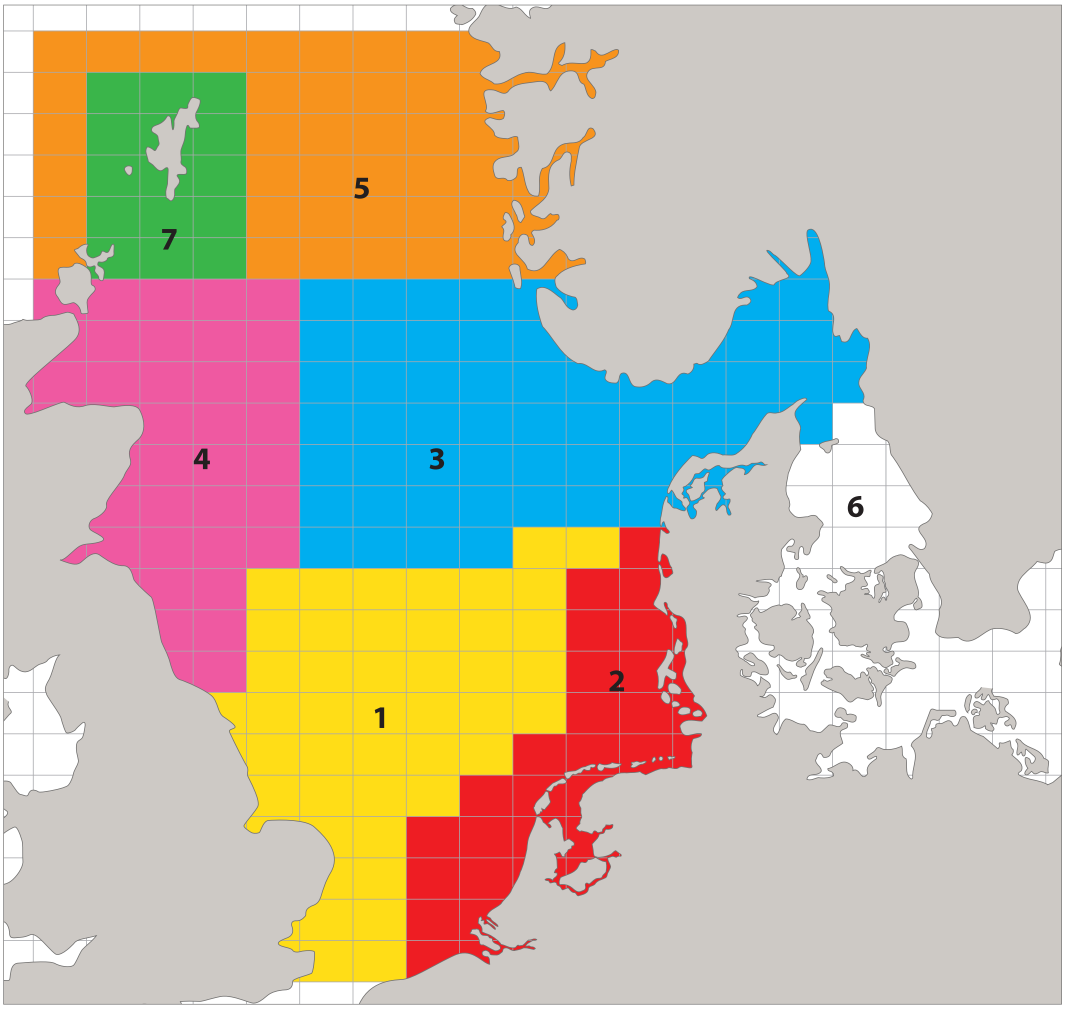
4. As the TAC is set before the start of the fishing season, each vessel will be able to plan its fishing according to the available quota. In those years where there is real-time monitoring showing the need for safe-guards, this will coincide with low catch-rates and thus a fishery which may already be unprofitable before the restrictions set in.

Regulations outside the proposal

- No fishing from August 1 to March 31.
- 95 % target species rule and probably the tightest level of MCS in any EU fishery.
- A large area closed to fishing since 2000 (Wee Banke / Firth of Forth) to ensure sandeel availability for nesting sea-birds.
- In 2009 the main fishing ground for sandeel, the Dogger Bank, was closed mid-season (June 15) because fishermen were experiencing too large levels of 0 year old fish in the catches. It is envisaged that such a system of catch-triggered real-time closures should be implemented in parallel with the above proposal, in order to protect the recruitment for the coming years' fisheries.

Stakeholders consulted in the process

The working group – or parts of it – has held meetings with:
The European Commission
DTU Aqua – the Danish National Institute of Aquatic Resources
The Ministry of Food, Agriculture and Fisheries and the Directorate of Fisheries
The Danish Association of Fishmeal and Fishoil Processors
The DFA's Committee for Industrial and Pelagic Fisheries
The Danish Pelagic Producers' Organisation



A5. Management proposal on sandeel in the North Sea from the Norwegian Fishermen's Association

1) TAC should be set separately for each zone/area 1–7 based upon the best available sources of information.

2) Proposal for TAC to ICES in zone 3 (NEEZ + part of EEZ in Skagerrak included in zone 3) should be set in cooperation between the Norwegian and Danish authorities in due time before 23rd April. This requires a close cooperation between DTU Aqua and IMR.

3) Proposal for TAC to ICES in area 5 should be set by ???

4) Proposal for TAC to ICES in zone 1, 2 and 6 should be set by ??? in due time before 1st April.

5) Proposal for TAC to ICES in area 4 and 7 should be set by ????

6) There should be a close cooperation between IMR, DTU Aqua and other relevant institutes in EU on sandeel research in all zones.

7) We acknowledge that IMR uses acoustic survey as their tool to measure the sandeelstock in zone 3. IMR should also consider using the results from the Danish dredge surveys.

8) The season in zone 3 should be from 23rd April to 23rd June.

9) There should be a quota in zone 3 set by the 23rd April which should be revised no later than the 15th May. Methods used in the revision of the quota could be another in-season acoustic survey, real-time monitoring and/or sampling of catches delivered ashore.

10) The Norwegian management plan launched in 2010 for area 3 continues in 2011 with an evaluation in August 2011 with participants from both Norwegian and Danish fishermen as well as scientists and representatives from the authorities in both countries.

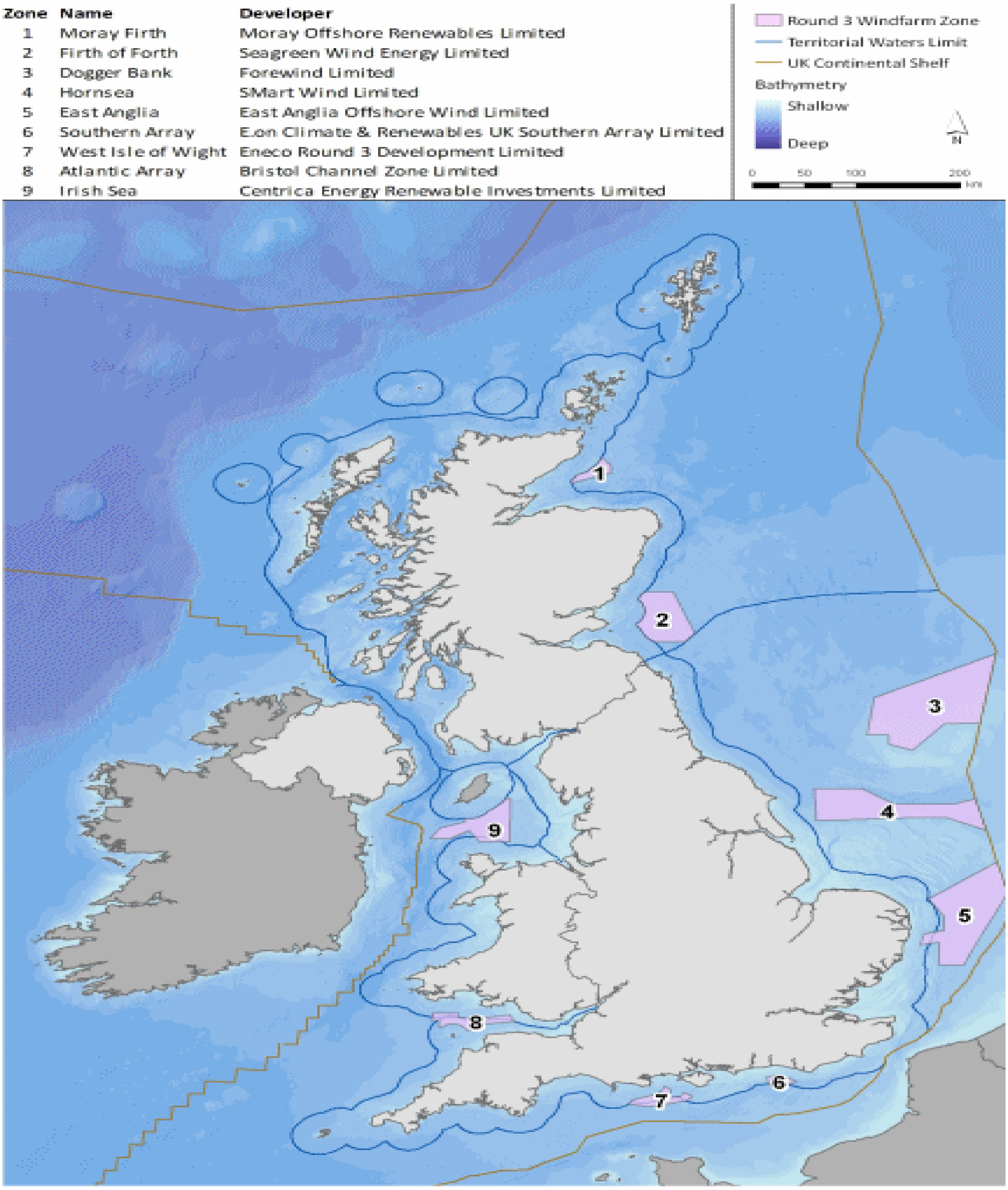
sign.

Harald Oestensjoe

Copenhagen, 8th September 2010

A6. Windmills in the North Sea-existing and planned plants

The United Kingdom Crown Estate round three of possible areas for developing windmill parks in the North Sea where some areas will have big effects on the sandeel fisheries and habitats.



Zone	Name	Developer
1	Moray Firth	Moray Offshore Renewables Limited
2	Firth of Forth	Seagreen Wind Energy Limited
3	Dogger Bank	Forewind Limited
4	Hornsea	SMart Wind Limited
5	East Anglia	East Anglia Offshore Wind Limited
6	Southern Array	E.on Climate & Renewables UK Southern Array Limited
7	West Isle of Wight	Eneco Round 3 Development Limited
8	Atlantic Array	Bristol Channel Zone Limited
9	Irish Sea	Centrica Energy Renewable Investments Limited

Area 3 is on the Dogger Bank and is going to be developed by The Forewind Consortium.

These areas are further detailed in an interactive map which can be found at http://www.thecrownestate.co.uk/our_portfolio/marine/offshore_wind_energy/round 3/70-interactive-maps-r3.htm.

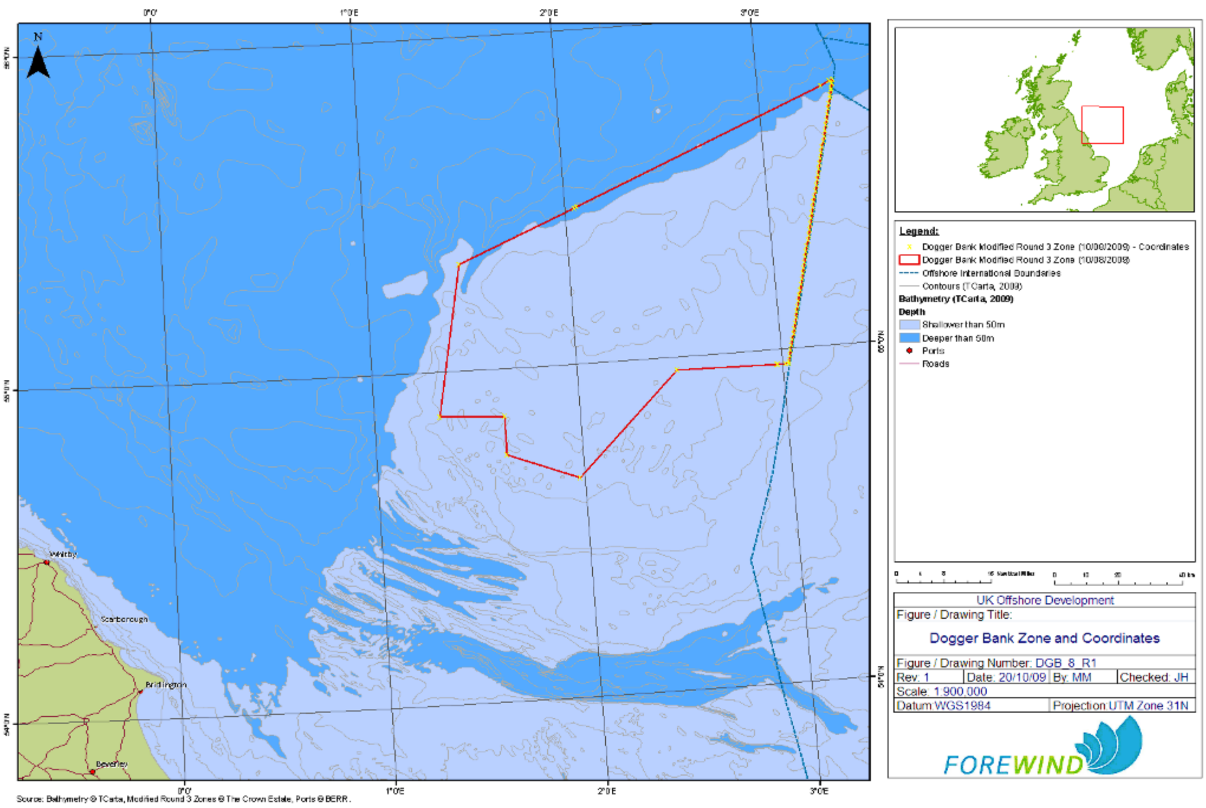
Area 2, 4 and 5 is also within the sandeel fishing areas.

Operational offshore wind farms in Europe at the end of 2009 you are given in Annex 9.

Annex 10 contains a datasheet with amended windmill projects at sea in Europe updated in 2009.

There is an official Norwegian initiative for finding suitable sites for windmills in the North Sea, and two of the areas they so far have found are in the southern part of NEZ nearby the sandeel banks. However, they are for the time being outside the banks.

The Forewind project on Dogger Bank is clearly the biggest threat for the sandeel fisheries.

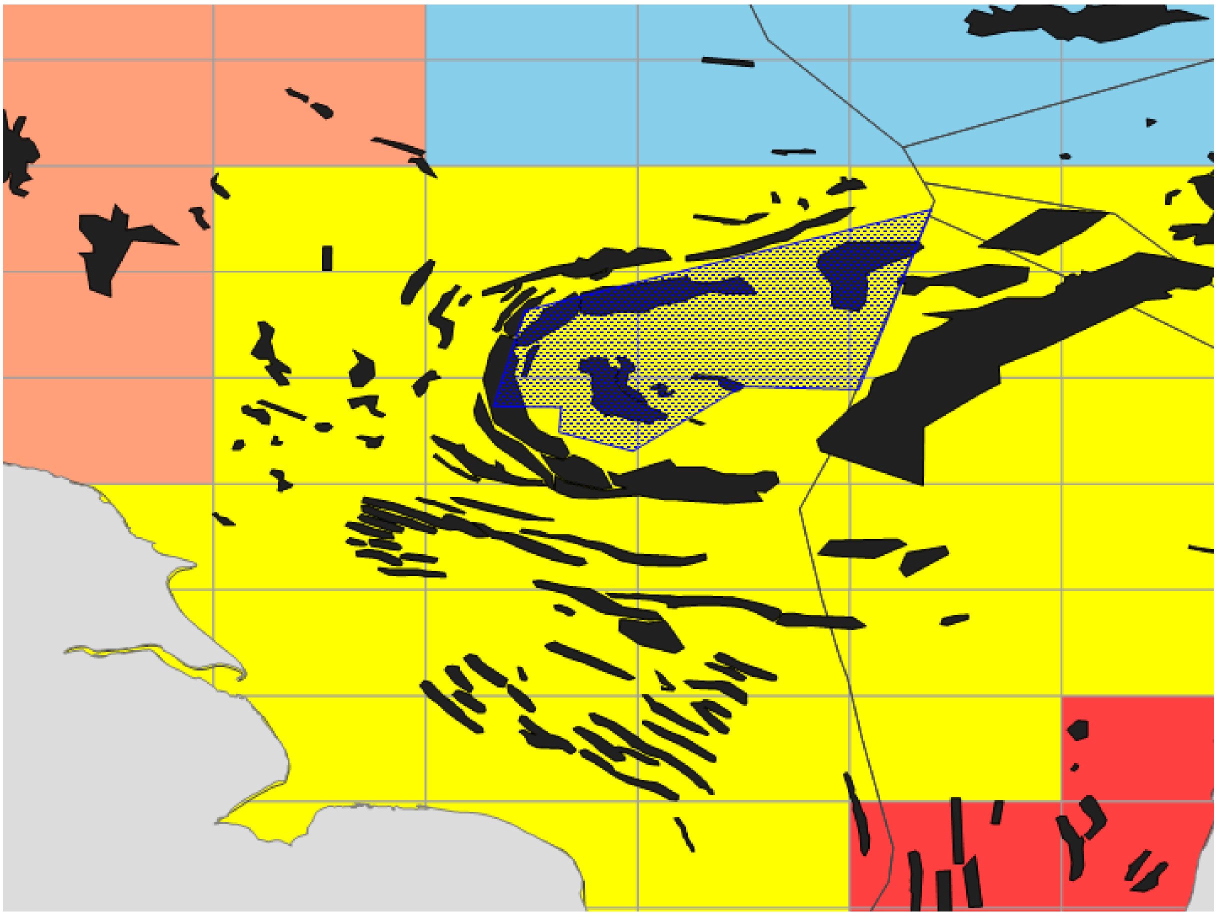


At 8660 square kilometres, the Dogger Bank zone is not only the largest of the proposed offshore sites; it is also the farthest from shore (between 125 and 195 kilometres), presenting a number of significant technical challenges.

- Water depth 18–63 meters (59 to 206 feet).
- Forewind has agreed with The Crown Estate a target installed capacity of 9 GW, though the zone has a potential for approximately 13 GW, which equates to around 10 per cent of total UK electricity requirements. If developed it is likely to be the world's largest offshore wind project.

- The UK target is to have a total of 33 GW of installed offshore wind energy by 2020.
- Investments estimated to 300 billion NOK.
- 2–3000 windmills, really big ones.

Here you can see how the Dogger Bank project (in blue) covers the sandeel fisheries (in black):



The timeline for the development of Dogger Bank:

We are concerned about the consequences for:

- habitats (sandeels, plaice, turbots)?
- the biology on the sea bottom?
- the spread of sandeels?
- other species eating sandeels?
- the fisheries?
- the land industry?

There are mainly three kinds of fisheries on the Dogger Bank:

Gillnetters;

Danish seines;

Sandeel trawlers from both Denmark and Norway and other countries.

Main fish species are:

Turbot;

Plaice;

Sandeel.

Danish landings from Dogger Bank (2008):

Catch	150 000 tons of sandeels;
	1000 tons of plaice;
	100 tons of turbot.
Value	23 million Euro to the fishermen (6.6 % of the total value from Danish landings)

The Norwegian sandeel fishery on Dogger Bank is dependent on size of quota in EU waters.

In 2009 and 2010 it was 27 500 tons with an approx. value of 40 million NOK in 2009 and 55 million NOK in 2010. In earlier years the Norwegians fished much more with a relatively high quota.

The area of the southern North Sea including the Dogger Bank is, beside for the Norwegian and Danish sandeel fishers, very important for a number of other commercial fisheries for the Dutch, German and British fishing fleet. It includes fisheries for cod, haddock, plaice, sole, dab and lemon sole.

The Dogger Bank has also been identified as an important spawning ground for herring, and an important feeding ground for fulmars, particularly in autumn and winter, when high densities have been reported in the area. Other species known to feed on the Dogger Bank include gannets, kittiwake, guillemot, razorbill and gulls.

A7. Draft Working Paper–Sandeel maturity estimates based on data from DTU Aqua dredge survey

Steen Christensen, DTU AQUA.

Background

Based on data from the DTU Aqua dredge survey from 2004 to 2009 the present working paper evaluates the assumption of knife edge maturity curve applied in the sandeel assessment.

Data

Two sets of data from the DTU Aqua dredge survey (2004–2009) were used to estimate the maturity ogives: Dataset 1 giving age, length and maturity (Table 1) of subsamples of the catches and dataset 2 giving the total number by length group (Table 2, Figure 1) of the total catches (or of representative samples of the catches).

For various reasons (broken otholits, unidentifiable gonads, etc.) some records in dataset 1 did not include information about age and/or maturity. Provided that these fish were less than 100 mm they were assumed to belong to the age group 0. Fish larger than 100 mm were not included in the analysis if age information was missing (Table 1).

The Macer Index (1–6) was used to measure the maturity condition. In the present analysis fish with Macer Index 1 was considered juvenile and with Macer Index >1 mature. Fish without information about maturity was not included in the analysis.

Method

Age–length keys (giving the age distribution of each length group) and the maturity percentage by length and age was estimated from dataset 1.

Three age–length keys were estimated:

ALKEY1 giving the age distribution by year, area and length group

ALKEY2 giving the age distribution by area and length group

ALKEY3 giving the age distribution by length group

Three maturity percentages were estimated:

MATKEY1 giving the maturity percentages by year, area and length group

MATKEY2 giving the maturity percentages by area and length group

MATKEY3 giving the maturity percentages by length group.

The total number of fish by length group (Dataset 2) was distributed into age groups by applying the age–length keys. Records in the length distribution data not covered by ALKEY1 were distributed into age groups by applying ALKEY2. The few records not covered by ALKEY2 either was distributed into age groups by applying ALKEY3. The average age distribution over the years and areas (ALKEY3) are indicated in Figure 2 (upper panel) and the total number of fish by length and age group estimated from Dataset 2 by applying ALKEY3 in Figure 2 (middle panel).

The total number of mature fish by length and age group was estimated from the age distributed length groups by applying the maturity keys. The maturity distribution of records in the age distributed length group data that were not covered by MATKEY1 was estimated by applying MAKEY2. The maturity of the few records not covered by MATKEY2 either was estimated by applying MATKEY3.

Results

As indicated in Table 3 and Figure 3 the maturity ogives for age group 0 has been less than 5% in both areas since 2005. Age group 2 usually has maturity ogives above 80% and age group 2+ close to 100%. In area 1 the maturity ogive for age group 1 was above 90% until 2008. In contrast in 2008 and 2009 it declined to 60%. In area 3 the age group 1 maturity ogive declined from 90% in 2004 to 50% in 2008. However, in 2009 the maturity percentage was back to 90%.

Conclusion

Taking into consideration that the dredge survey is implemented in December, the age group 1 will appear in the fishery the following year as age group 2. Therefore the analysis gave no reason to change the assumption applied in the sandeel assessment with regard to the knife edge maturity curve and it is suggested to keep the maturity ogives for age 0, 1, 2+ at 0, 0 and 1 respectively.

Table 1. Summary of data from DTU dredge survey. A & M: Total number of fish with age, length and maturity. NULL: age and/or maturity not available. Maturity Index 1: juvenile, 2+: mature. Raw data given by ICES square.

		maturityIndex							
		1	2	3	4	5	6	NULL	A & M
		Number Sum	Number Sum	Number Sum	Number Sum	Number Sum	Number Sum	Number Sum	Sum
year	age								
2004	0	1436	176	265	36	.	.	18	1913
	1	24	138	844	273	.	.	1	1279
	2	.	.	13	7	.	.	.	20
	3	.	1	10	5	.	.	.	16
	4	.	.	3	.	.	.	.	3
	NULL	7	5	8	4	.	.	.	
Total 2004		1467	320	1143	325	0	0	19	3231
2005	0	483	28	7	.	.	.	374	518
	1	6	56	46	.	.	.	50	108
	2	.	6	8	1	.	.	.	15
	3	.	1	1	.	.	.	.	2
	4	.	.	1	.	.	.	.	1
	5	.	1	.	.	.	.	.	1
	NULL	9	1	1	.	.	.	220	
Total 2005		498	93	64	1	0	0	644	645
2006	0	255	5	3	1	.	.	376	264
	1	15	155	163	41	.	.	65	374
	2	.	4	.	3	.	.	1	7
	3	.	.	.	1	.	.	.	1
	NULL	.	1	2	.	.	.	.	
Total 2006		270	165	168	46	0	0	442	646
2007	0	291	32	11	1	.	.	186	335
	1	79	125	273	111	23	15	89	626
	2	8	19	32	10	8	7	10	84
	3	.	1	4	2	1	.	2	8
	4	.	.	2	.	.	.	1	2
	5	.	.	.	.	.	.	2	0
	NULL	37	2	37	9	.	.	26	
Total 2007		415	179	359	133	32	22	316	1055
2008	0	269	4	.	.	1	.	210	274
	1	196	75	202	35	1	21	101	530
	2	7	.	26	8	7	28	7	76
	3	.	1	5	1	.	.	1	7
	4	.	.	1	.	.	1	.	2
	7	.	.	.	1	.	.	.	1
	NULL	16	1	.	.	.	.	5	
Total 2008		488	81	234	45	9	50	324	890
2009	0	1989	30	38	1	.	.	42	2058
	1	47	37	84	20	.	.	5	188
	2	3	8	30	11	.	.	.	52
	3	.	.	9	8	.	.	.	17
	4	.	.	1	3	.	.	.	4
	NULL	3	.	.	.	.	.	39	
Total 2009		2042	75	162	43	0	0	86	2319
Overall total		5180	913	2130	593	41	72	1831	8786

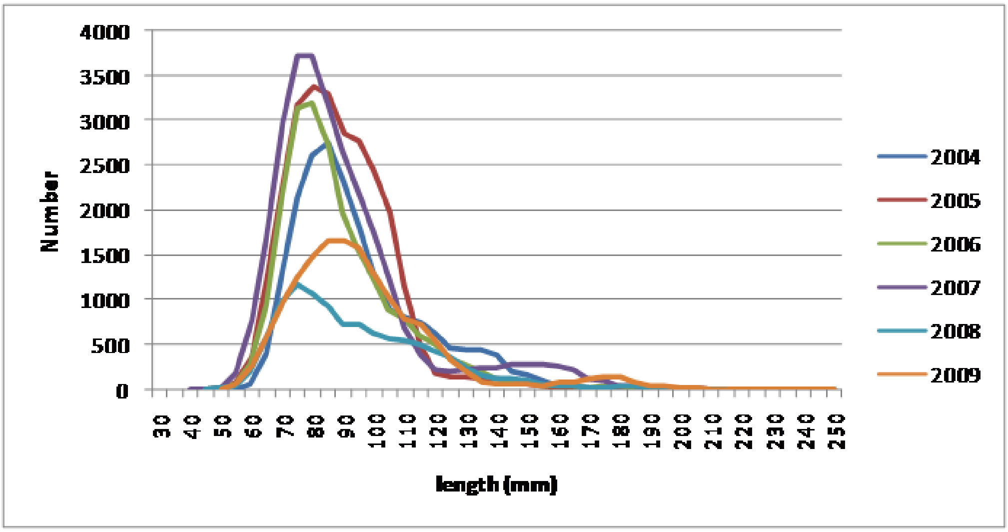
Table 2. Number by length group (5 mm). Raw data were given by square.

Sum of number	Column Labels						
Row Labels	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Grand Total**
30					1		1
35	3						3
40				1			1
45			4	3	6		13
50		11	23	14	13	5	66
55	9	82	56	174	39	58	418
60	69	368	274	768	204	266	1949
65	411	1213	954	1690	587	576	5431
70	1242	2295	2084	2978	972	962	10533
75	2144	3182	3127	3716	1179	1246	14594
80	2615	3380	3187	3710	1071	1491	15454
85	2753	3303	2716	3168	942	1650	14532
90	2339	2850	1964	2650	741	1645	12189
95	1830	2768	1565	2188	727	1566	10644
100	1291	2442	1234	1765	637	1282	8651
105	892	1983	880	1204	564	1013	6536
110	814	1148	778	696	552	779	4767
115	752	486	606	378	508	717	3447
120	623	176	515	214	431	551	2510
125	475	142	352	200	370	321	1860
130	439	139	277	216	242	193	1506
135	444	133	205	237	161	88	1268
140	389	131	129	243	121	68	1081
145	204	106	99	286	121	53	869
150	159	70	74	283	102	55	743
155	96	39	49	291	68	49	592
160	51	19	47	256	41	76	490
165	44	9	34	215	43	87	432
170	23	5	27	131	23	124	333
175	22	5	33	94	28	133	315
180	7	2	44	42	35	134	264
185	16	3	24	32	39	84	198
190	7		12	16	30	52	117
195	1		11	15	12	44	83
200			3	10	7	25	45
205			2	12	8	14	36
210			1	8	1	10	20
215			2	4	4	6	16
220				4	1	7	12
225				3	3	6	12
230				1		3	4
235				1		5	6
240						5	5
245					1	5	6
250					1	2	3
Grand Total	**20164**	**26490**	**21392**	**27917**	**10636**	**15456**	**122055**

Table 3. Maturity ogives (percent) for area 1 and 3. Data from DTU-Aqua dredge survey.

AREA 1						
Sum of MatOgive	**Column Labels**					
Row Labels	**0**	**1**	**2**	**3**	**4**	**7**
2004	6	98	100	100	100	
2005	1	90	100	100	100	
2006	1	94	78	100		
2007	2	97	89	100		
2008	0	61	73	100	100	100
2009	1	56	85	100	100	

AREA 3					
Sum of MatOgive	**Column Labels**				
Row Labels	**0**	**1**	**2**	**3**	**4**
2004	12	96	100	100	
2005	8	78	98	100	
2006	2	80	100	100	
2007	3	69	77	100	100
2008	1	48	95	100	100
2009	4	92	100	100	100



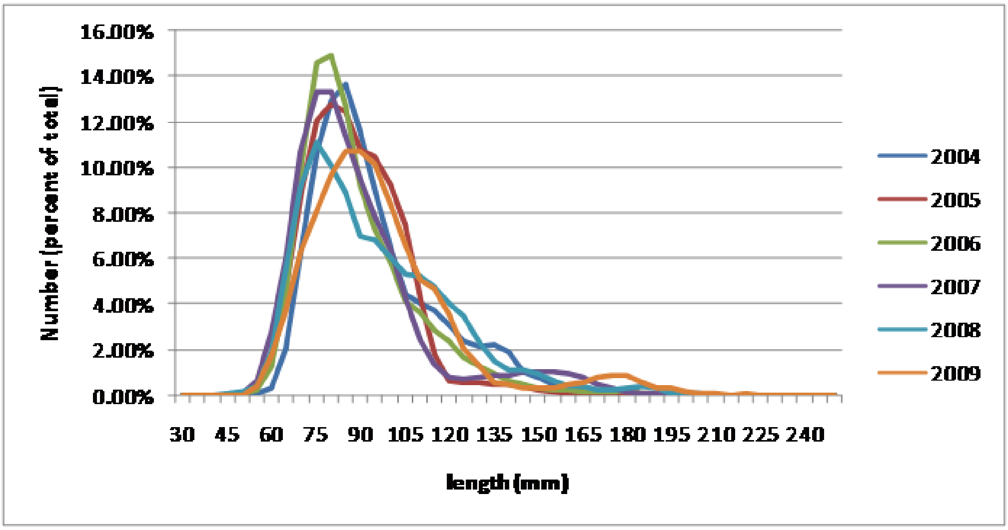


Figure 1. Length distribution. Average over year and area.

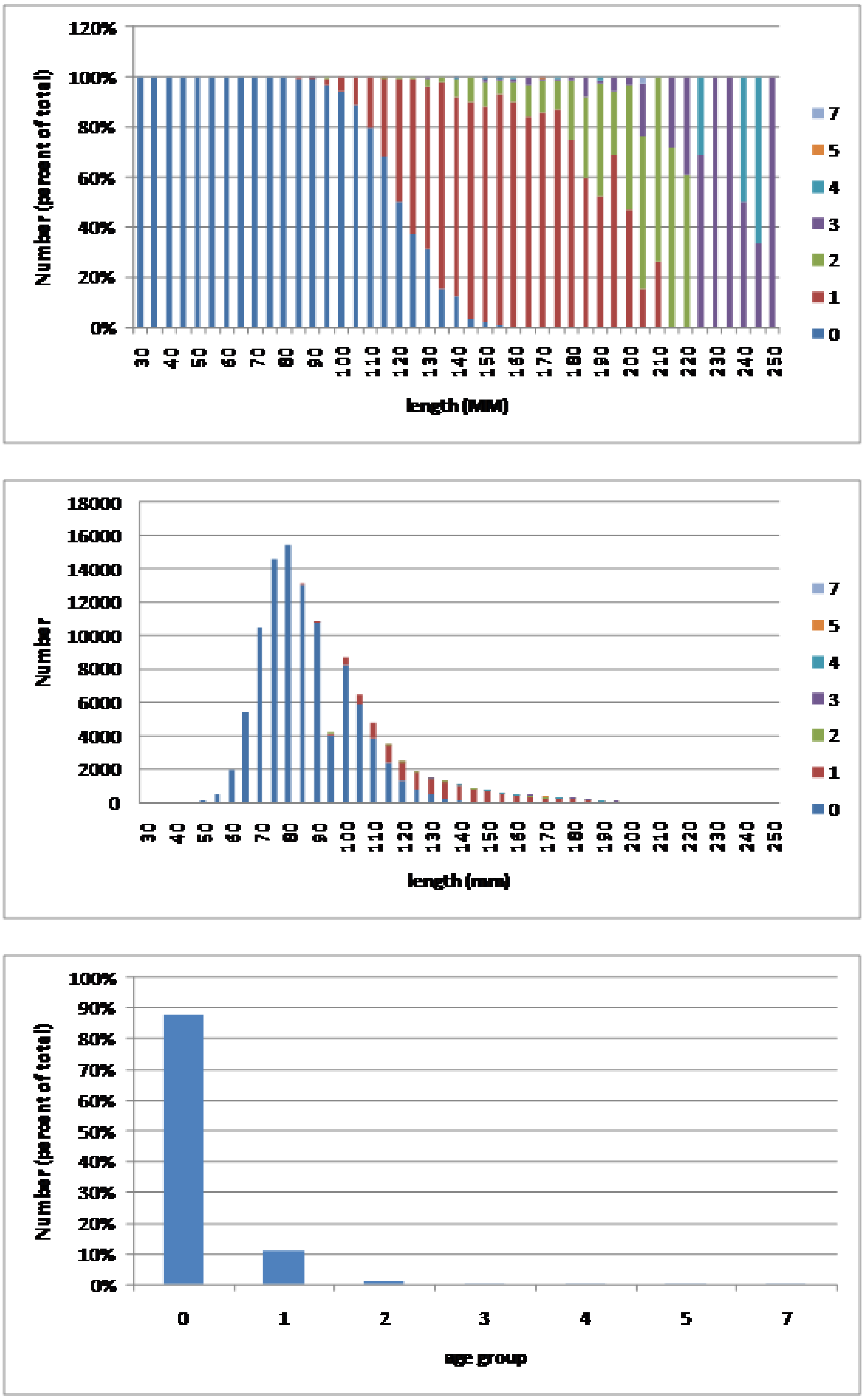
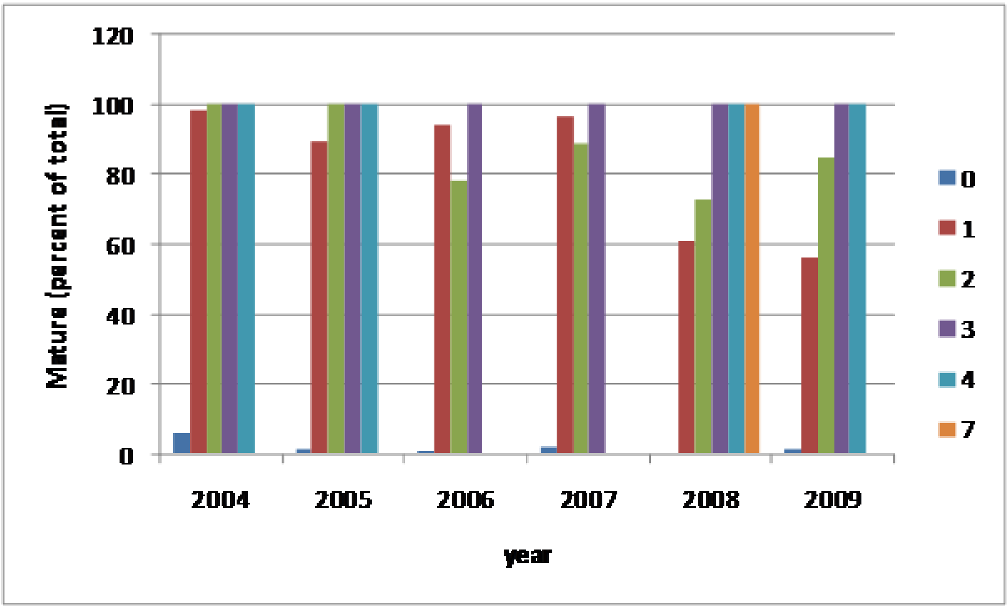


Figure 2. Average age and length distributions of dredge survey data from 2004–2009.



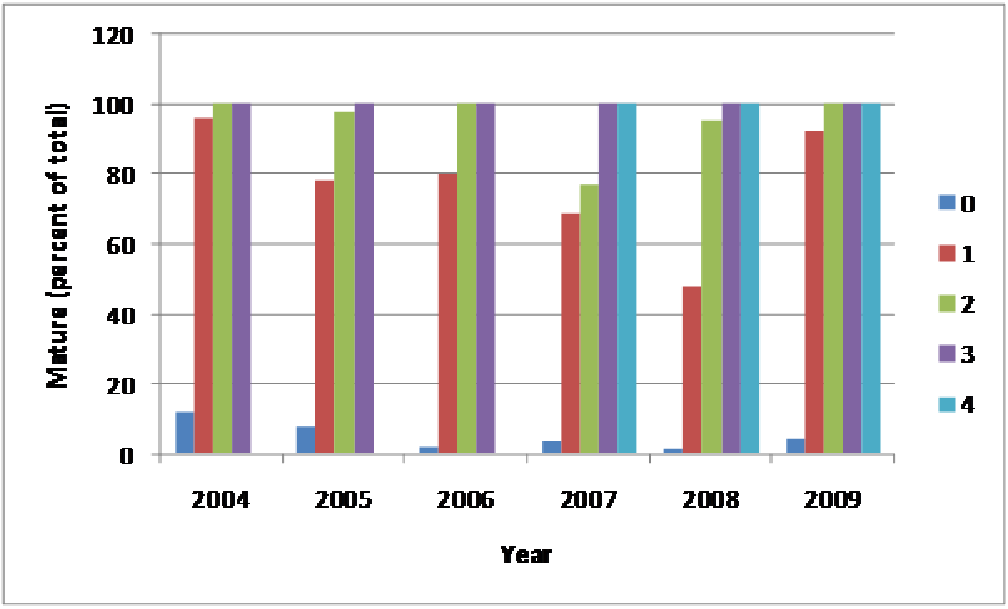


Figure 3. Maturity ogives (percent) for area 1 (upper) and area 3 (lower).

A8 Amended wind-farm database for BDC 2010

ID No	Country	Name	Location	Distance from coast	Operator	No of wind turbines	Current Status	Capacity in MW	Foundation type	Water depth (m)	Height (m)	EIA	Remarks
Be01	Belgium	Seanergy		11/12,5 *	Electrabel-Jan De Nul	50	refused	100	monopile	less than 10 m	118	yes	authorisation withdrawal
Be02	Belgium	C-Power Wenduinebank		6	C-Power	50	refused	100	monopile	4-11 m	98	yes	
Be03	Belgium	C-power II	(Block10) 2.89796,51.54472 2.92499,51.55248 2.95435,51.53946 2.92741,51.53167 (Block 2) 2.95576,51.56077 2.99146,51.57988 3.01841,51.56483 2.98264,51.54558	27	C-power	60	authorised	216-300	gravity-based	10 to 25 m	130	yes	Authorisation for project layout in 2 blocks, groundsurvey finished in September 2004. Prework ecological monitoring finished in June 2006.
Be04	Belgium	SPE Zeebrugge		0-15	SPE Power Company	14	refused	28	monopile	o-less than 5	116	yes	project situated half on the harbour/half in the sea, permit refused
Be05	Belgium	Eldepasco	2.872406;51,59558 2.904308,51.60846 2.906422,51.60719 2.923025,51.6139 2.930356,51.61757 2.94461,51.62589 2.926872,51.63656 2.912725,51.6283 2.905525,51.62469 2.888622,51.61788 2.892,51.61585 2.860097,51.60298	37	Electrawinds-Depret-Aspiravi-We power	36	authorised	216	other	15-20 m	130	yes	Foundation type not decided yet, depending on results groundsurvey. Area concession granted in June 2006.
Be06	Belgium	Belwind	2.800711, 51.712290 2.867403,51.672295 2.801326, 51.620236 2.791981,51.636446 2.763609,51.649857	46	Belwind nv, Ecocem	66 (5 MW) or 110 (3 MW)	authorised	330	other	25-50 m	126	yes	Foundation type not decided yet, depending on results groundsurvey. Area concession granted in June 2007. Permit granted in February 2008.
Be07	Belgium	Rentel	Area A 2.889653,51.591950 2.902606,51.597183 2.904719,51.595919 2.931389,51.606697 2.939722,51.610864 2.950603,51.617231 3.001992,51.588136 2.991944,51.587606 2.964722,51.587275 2.939756,51.585422 2.932856,51.584294 2.919122,51.581247 2.912286,51.579164 Area B 2.918033,51.575914 2.921928,51.577094 2.934983,51.579997 2.941058,51.580992 2.965289,51.582789 2.972908,51.582936 2.963950,51.578672 2.956928,51.573975 2.950250,51.569278 2.941975,51.564464 2.920633,51.574442	31	Rent-a-port	48	application	288	other				Foundation type not decided yet, depending on results groundsurvey. Area concession granted in June 2009.
~~Dk01~~	~~Denmark~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Tender~~	~~400~~	~~unknown~~	~~unknown~~	~~unknown~~	~~yes~~	~~In tender. Operational by the end of 2012.~~
Dk02	Denmark	Horns Rev	7.79511,55.50134 7.87488,55.50210 7.88344,55.46721 7.80374,55.46646	14-17	Vattenfall	80	operational	160	monopile	less than 15	120	yes	
Dk03	Denmark	Frederikshavn	10.56588,57.44570 10.56560,57.44370 10.56534,57.44199	1	Dong Energy	1	operational	2.5	monopile	0-less than 5	123	yes	
Dk04	Denmark	Roenland	8.21489,56.66853 8.21900,56.66000 8.22416,56.65132	1	Vindenergi Aps	8	operational	17	monopile	less than 5	120	yes	

Dk05	Denmark	Horns Rev 2	7.57690,55.63457 7.58466,55.64142 7.59320,55.64797 7.59999,55.64494 7.60679,55.64191 7.61359,55.63887 7.62038,55.63584 7.62719,55.63281 7.63399,55.62977 7.62744,55.62476 7.62148,55.61951 7.61615,55.61406 7.61144,55.60842 7.60737,55.60262 7.60400,55.59669 7.60129,55.59065 7.59929,55.58451 7.59799,55.57833 7.59738,55.57210 7.59751,55.56586 7.59834,55.55965 7.58974,55.55912 7.58115,55.55859 7.57256,55.55807 7.56397,55.55754 7.55538,55.55702 7.54679,55.55648	30	Dong Energy	91	operational	209	monopile	9 - 17 m	up to 132 m	yes	
De01	Germany	alpha ventus	6.62333,54.00000 6.59000,54.00000 6.58833,54.02667 6.62167,54.02667	45	Stiftung Offshore Windenergie	12	operational	60	monopile / tripod / gravity-based / other	25 to 50 m	118 to 150	yes	
De02	Germany	DanTysk	7.24083,55.06694 7.17778,55.06333 7.17725,55.06392 7.17083,55.07111 7.16962,55.10983 7.16806,55.15972 7.18417,55.16111 7.16639,55.22806 7.16639,55.22806 7.17000,55.23500 7.20111,55.23056 7.20889,55.22278 7.24694,55.07417	50	GEO mbH	80	authorised	max. 400	tripod	10 to 25 m / 25 to 50 m	130	yes	
De03	Germany	Borkum Riffgrund West	6.28753,54.06033 6.28937,54.02250 6.28931,54.02251 6.18087,54.03448 6.17903,54.07215	40	Energiekontor AG	80	authorised	max. 280	monopile / tripod / other	25 to 50 m	120	yes	
De04	Germany	Borkum Riffgrund	6.61694,53.94028 6.54833,53.94028 6.49139,53.97389 6.49111,53.99444 6.56000,53.99444 6.61694,53.96083	34	PNE2 Riff I GmbH	77	authorised	max. 230	tripod / other	10 to 25 m / 25 to 50 m	115	yes	
De05	Germany	Amrumbank West	7.77694,54.50639 7.64056,54.50639 7.64056,54.53889 7.77694,54.53889	35	Amrumbank West GmbH	80	authorised	max. 400	other	10 to 25 m	130	yes	
De06	Germany	Nordsee Ost	7.72639,54.43417 7.64028,54.40083 7.64056,54.47083 7.73917,54.47194 7.73972,54.46111	30	Essent Wind Nordsee Ost Planungs- und Betriebsgesellschaft mbH	80	authorised	400	monopile / tripod	10 to 25 m	140	yes	
De07	Germany	Meerwind Ost	7.71667,54.37488 7.70500,54.37052 7.69615,54.39333 7.69333,54.41077 7.75262,54.43383 7.76202,54.42500 7.76667,54.38590	22	Meerwind Südost GmbH & Co Rand KG	40	authorised	max. 200	monopile / tripod	10 to 25 m / 25 to 50 m	110	yes	

De08	Germany	Butendiek	7.80000,54.96667 7.78435,54.96667 7.73750,55.01054 7.73751,55.04124 7.78446,55.06762 7.80000,55.06762	34	Butendiek Offshore Windpark GmbH & Co. KG	80	authorised	240	monopile	10 to 25 m	130	yes	
De09	Germany	GlobalTech I	6.41582,54.54083 6.38867,54.45392 6.38867,54.45392 6.31813,54.49900 6.31817,54.54087 6.31817,54.54087 6.36702,54.54085 6.41582,54.54083	100	Nordsee Windpower GmbH & Co. KG	80	authorised	360	tripod	25 to 50 m	150	yes	
De10	Germany	OWP Delta Nordsee 1	6.78417,54.00617 6.74767,54.00617 6.74767,54.06917 6.78417,54.06920 6.78417,54.06917	40	OWP Delta Nordsee GmbH	48	authorised	max. 240	monopile / tripod / other	25 to 50 m	130	yes	
De11	Germany	Hochsee Windpark Nordsee	6.38540,54.44178 6.36852,54.38922 6.25915,54.45992 6.30933,54.48943	90	EnBW Nordsee Offshore GmbH	80	authorised	360	tripod	25 to 50 m	110	yes	
De12	Germany	Sandbank 24	6.90953,55.11842 6.87861,55.11425 6.85975,55.12133 6.80039,55.27983 6.81294,55.29053 6.84386,55.29414	100	Sandbank Power GmbH & Co. KG	80	authorised	max. 420	tripod / monopile	25 to 50 m	100	yes	
De13	Germany	Gode Wind	7.04694,53.99944 7.03083,53.99944 6.94167,54.05167 6.94167,54.07083 7.02278,54.07083 7.04694,54.05667	45	Plambeck Neue Energien AG	80	authorised	320	monopile / tripod	25 to 50 m	125	yes	
De14	Germany	Weiße Bank	6.97083,54.84167 6.87917,54.77500 6.84167,54.80417 6.83750,54.83750 6.86667,54.87917 6.89583,54.88167	83	Energiekontor	170	application	320	other	25 to 50 m	150	no	
De15	Germany	Ventotec Nord 1	5.97616,54.69571 5.99829,54.68191 6.00887,54.68331 6.05983,54.65146 6.06351,54.64916 6.01608,54.62507 6.00832,54.62113 6.00732,54.62175 5.99662,54.62842 5.94577,54.66015 5.90745,54.68405 5.95793,54.70708	130	GHF GmbH	80	application	150	tripod	25 to 50 m	80	no	
De16	Germany	Ventotec Nord 2	6.10515,54.57112 6.09514,54.56567 6.02123,54.61290 6.08904,54.64912 6.10531,54.63870 6.11997,54.62930 6.16231,54.60217 6.11984,54.57910	112	GHF GmbH	80	application	150	tripod	25 to 50 m	80	no	
De17	Germany	Nördlicher Grund	6.97222,55.09833 6.99750,55.02722 6.88833,55.03028 6.86306,55.10139	84	Konsortium Nördlicher Grund (ABB, GEO, GREP)	80	authorised	360	monopile / tripod	10 to 25 m / 25 to 50 m	100	yes	
De18	Germany	Hochsee Windpark He dreiht	6.22222,54.37778 6.29167,54.32917 6.13333,54.32917 6.13333,54.37778	85	EnBW Nordsee Offshore GmbH	80	authorised	360	tripod	25 to 50 m	110	yes	

De19	Germany	Nordergründe	8.18028,53.82361 8.16806,53.82194 8.14917,53.84139 8.18361,53.83917 8.18361,53.82722	11	Energiekontor GmbH	max. 25	application	max. 125	monopile / tripod	less than 10 m / 10 to 25 m	150	yes	
De20	Germany	Riffgat	6.51433,53.69233 6.44083,53.68200 6.43667,53.69250 6.51000,53.70283	14.5	ENOVA Offshore Projektentwicklungs-GmbH & Co.KG	max. 44	application	max. 220	monopile / tripod	10 to 25 m	140 to 180	yes	
De21	Germany	H2-20	4.19389,55.77889 4.19361,55.61778 4.07806,55.66000 4.07806,55.79806	200	GEO	800	application	400	tripod	25 to 50 m	150	no	Hydrogen production. Planned start of construction in 2020
De22	Germany	BARD Offshore 1	6.01889,54.30639 5.93833,54.30222 5.93861,54.38750 6.01917,54.42333	87	Bard Engineering GmbH	80	authorised	max. 400	other	25 to 50 m	110	yes	
De23	Germany	Deutsche Bucht	5.82750,54.27475 5.81000,54.27473 5.74255,54.30411 5.82869,54.34169	87	Eolic Power GmbH	50	application	250	gravity-based	25 to 50 m	110	no	
De24	Germany	Austerngrund	5.79978,54.41466 5.63713,54.34979 5.79927,54.51827	87	Global Wind Support GmbH	80	application	400	gravity-based	25 to 50 m	110	no	
De25	Germany	MEG Offshore I	6.57924,54.00036 6.50476,54.00003 6.50317,54.02977 6.54044,54.07377 6.53955,54.08908 6.55967,54.08931 6.61882,54.04351 6.61877,54.03067 6.57827,54.03053	45	Multibrid Entwicklungsgesellschaft mbH	80	authorised	400	tripod	25 to 50 m	150	no	
De26	Germany	Borkum West II	6.48957,54.00003 6.42066,54.00003 6.41560,54.08756 6.52456,54.08892 6.52558,54.07132 6.51280,54.05355 6.48782,54.03142	40	Trianel Windkraftwerk Borkum GmbH & Co. KG	80	authorised	400	tripod	10 to 25 m / 25 to 50 m	150	yes	
De27	Germany	Innogy Nordsee 1	6.93400,54.09250 6.93400,53.97933 6.74767,53.95233 6.74767,53.99983 6.79417,53.99983 6.79433,54.07767 6.79433,54.07767 6.74767,54.07767 6.74767,54.09250	40	Innogy Nordsee 1 GmbH	163	application	815	monopile / tripod	25 to 50 m	150	no	
De28	Germany	OWP Delta Nordsee 2	6.79433,54.07767 6.79417,53.99983 6.74767,53.99983 6.74767,54.00617 6.78417,54.00617 6.78417,54.06917 6.74767,54.06917 6.74767,54.07767 6.79433,54.07777	40	OWP Delta Nordsee GmbH	32	authorised	192	monopile / tripod	25 to 50 m	160	yes	
De29	Germany	Borkum Riffgrund II	Area 1: 6.47984,53.97409 6.54848,53.93371 6.60558,53.93371 6.51424,53.92021 6.49141,53.92019 6.45752,53.94057 6.42272,53.96728 6.42261,53.99427 6.47979,53.99433 Area 2: 6.61703,53.99436 6.61701,53.96741 6.57128,53.99436	26	Plambeck Neue Energien AG	96	application	480	monopile / tripod	25 to 50 m	150	no	

De30	Germany	OWP West	6.29785,54.02123 6.29817,54.01645 6.10693,54.01665 6.10260,54.02267 6.15435,54.05770 6.17967,54.05860 6.17967,54.05859 6.18087,54.03448 6.28933,54.02220	58	LCO Nature	42	application	240 to 480	monopile / tripod	25 to 50 m	120 to 150	no	
De31	Germany	Borkum Riffgrund West 2	6.29460,54.08675 6.29817,54.01645 6.29785,54.02123 6.28937,54.02123 6.28933,54.02220 6.28931,54.02251 6.28753,54.06033 6.17903,54.07215 6.17969,54.05859 6.17967,54.05859 6.15435,54.05770 6.10260,54.02267 6.07140,54.06920	52	Energiekontor	83	application	415	tripod / other	25 to 50 m	160	no	
De32	Germany	Hochsee Testfeld Helgoland	7.75306,54.48667 7.64056,54.48667 7.64056,54.49278 7.75306,54.49278	35	Hochsee Testfeld Helgoland GmbH	19	application	95	monopile / tripod	10 to 25 m	130	no	
De33	Germany	Gode Wind II	6.99790,53.98903 6.94190,53.98033 6.94179,54.02483 6.94682,54.03612 7.01592,53.99240 6.99790,53.98903 7.07007,54.09312 7.10465,54.07609 7.11524,54.06985 7.11516,54.03249 7.06226,54.00137 7.05959,54.06191 7.00519,54.07988 6.94165,54.07984 6.94162,54.09229	34	Plambeck Neue Energien Gode Wind II GmbH	80	authorised	400	monopile / tripod	25 to 50 m	150	no	
De34	Germany	Sandbank extension	Area 1: 6.87861,55.11425 6.86317,55.11258 6.84478,55.11936 6.78883,55.26914 6.80039,55.27983 6.85975,55.12133 6.87861,55.11425 Area 2: 6.91867,55.13786 6.90953,55.11842 6.84386,55.29414 6.85933,55.29608 6.91867,55.13786	90	Sandbank Power Extension GmbH	40	application	200	monopile / tripod	25 to 50 m	100	no	
De35	Germany	Veja Mate	5.82750,54.27475 5.82870,54.34169 5.90961,54.37686 5.91037,54.27485	89	Cuxhaven Steel Construction GmbH	80	authorised	400	other	25 to 50 m	110	no	
De36	Germany	Kaskasi	7.79883,54.39074 7.78183,54.38816 7.77738,54.42562 7.75888,54.43997 7.75507,54.47211 7.78834,54.47253	23	Essent Wind Nordsee Ost Planungs- und Betriebsgesellschaft mbH	40	application	max. 320	monopile / tripod / gravity-based / other	10 to 25 m	160	no	
De37	Germany	Meerwind Süd	7.70500,54.37052 7.64125,54.34662 7.64125,54.39230 7.65513,54.39590 7.69333,54.41077 7.69615,54.39333	22	Meerwind Südost GmbH & Co Föhn KG	40	authorised	max. 200	monopile / tripod	10 to 25 m / 25 to 50 m	110	yes	

De38	Germany	Albatros	6.30972,54.49472 6.25306,54.46139 6.18472,54.50611 6.32368,54.56203 6.35201,54.57343 6.36833,54.58000 6.38998,54.56370 6.41667,54.54361 6.31817,54.54361 6.31026,54.54361 6.30972,54.54361 6.30972,54.49615	105	LCO Nature	80	application	400	tripod / other	25 to 50 m	165	no	
De39	Germany	Kaikas	6.27712,54.61348 6.13241,54.55533 6.11980,54.56339 6.11984,54.57910 6.11997,54.62930 6.12007,54.66689	88	Eos Kaikas GmbH	88	application	528	other	25 to 50 m	153	no	
De40	Germany	Notos	6.28881,54.50096 6.24003,54.47238 6.20634,54.49410 6.19676,54.50028 6.27362,54.53308 6.28727,54.53891	88	EOS Offshore Notos GmbH	50	application	300	other	25 to 50 m	153	no	
De41	Germany	Aiolos	Area 1: 6.27039,54.73590 6.27588,54.68538 6.19018,54.71471 Area 2: 6.47131,54.69099 6.37326,54.65193 6.35100,54.65958 6.29891,54.67748 6.29201,54.67985 6.28552,54.73988 6.28222,54.77017 6.28188,54.77332 6.28283,54.77332 6.30542,54.77327 6.49510,54.77285 6.49416,54.76961	88	Eos Aiolos GmbH	310	application	1550	other	25 to 50 m	153	no	
De42	Germany	Sea Wind I	6.44985,54.54836 6.41496,54.43699 6.38867,54.45392 6.38867,54.45392 6.41582,54.54083 6.41582,54.54083 6.36702,54.54085 6.31817,54.54087 6.31817,54.54087 6.31817,54.54361 6.31817,54.55883 6.32368,54.56203 6.34600,54.57497 6.35201,54.57343 6.38998,54.56370	90	Northern Energy SeaWind I GmbH	44	application	400	tripod / other	25 to 50 m	150	yes	
De43	Germany	Sea Wind II	6.30972,54.49615 6.25370,54.46317 6.20578,54.49378 6.20634,54.49410 6.27362,54.53308 6.31025,54.55430 6.31026,54.54361 6.31032,54.49650	90	Northern Energy SeaWind II GmbH	60	application	300	tripod / other	25 to 50 m	150	yes	
De44	Germany	Sea Storm I	6.03226,54.59056 5.94254,54.56125 5.87572,54.59507 5.93368,54.65322	110	Northern Energy SeaStorm I GmbH	80	application	400	tripod / other	25 to 50 m	150	yes	
De45	Germany	He dreiht II	6.30465,54.32075 6.13334,54.31231 6.13340,54.32897 6.29180,54.32901	110	EOS Offshore AG	28	application	168	other	25 to 50 m	153	no	

De46	Germany	Diamant	5.35661,54.68574 5.20674,54.53569 5.18394,54.54555 5.18131,54.68475	113	Bard Schiffsbetriebs GmbH & Co. Natalie KG	160	application	800	monopile / tripod / gravity-based / other	25 to 50 m	151	no	
De47	Germany	Bernstein	6.00742,54.50501 5.80711,54.42430 5.80649,54.50486	108	Bard Schiffsbetriebs GmbH & Co. Natalie KG	80	application	400	monopile / tripod / gravity-based / other	25 to 50 m	151	no	
De48	Germany	Citrin	6.01687,54.50950 5.80648,54.50935 5.80644,54.51577 5.87329,54.58441	111	Bard Schiffsbetriebs GmbH & Co. Natalie KG	80	application	400	monopile / tripod / gravity-based / other	25 to 50 m	151	no	
De49	Germany	Aquamarin	6.01903,54.22797 5.92853,54.22280 5.82013,54.27026 5.91811,54.27036 5.91789,54.29658 6.01887,54.30202	83	Bard Schiffsbetriebs GmbH & Co. Natalie KG	80	application	400	monopile / tripod / gravity-based / other	25 to 50 m	151	no	
De50	Germany	SeaWind IV	5.99662,54.62842 5.99477,54.62775 5.94555,54.65900 5.94577,54.66015 5.94701,54.66656 5.97616,54.69571 5.99133,54.71088 6.10823,54.67141 6.07389,54.65658 6.05983,54.65146	110	Northern Energy SeaWind IV GmbH i. Grdg.	80	application	400	gravity-based	25 to 50 m	150	no	
De51	Germany	GAIA II	6.24534,54.80559 6.23441,54.79982 6.12081,54.83956 6.15458,54.87304 6.20460,54.82307	100	Northern Energy GAIA II GmbH	80	application	400	tripod / other	25 to 50 m	150	no	
De52	Germany	GAIA III	6.13795,54.74702 6.12124,54.73785 6.04469,54.76394 6.11311,54.83172 6.22226,54.79334 6.18058,54.77044	90	Northern Energy GAIA III GmbH i. Grdg.	80	application	400	tripod / other	25 to 50 m	150	no	
De53	Germany	GAIA IV	6.27029,54.74526 6.17454,54.72008 6.13775,54.73263 6.13521,54.73349 6.13778,54.73488 6.20327,54.77038 6.25359,54.79766 6.26495,54.79479 6.26760,54.77021	90	Northern Energy GAIA IV GmbH i. Grdg.	80	application	400	tripod / other	25 to 50 m	150	no	
De54	Germany	Skua	6.68885,54.46937 6.48382,54.40312 6.51997,54.52636	85	OPG Projekt GmbH	80	application	400	tripod	25 to 50 m	165	no	
De55	Germany	Horizont II	6.34986,54.84123 6.27595,54.83955 6.26934,54.89798 6.26085,54.97302 6.35079,54.89771 6.37405,54.87824 6.41645,54.84274	125	Germany Mainstream Renewable Power Developments GmbH	76	application	380	monopile / tripod / gravity-based / other	25 to 50 m	165	no	
De56	Germany	Nordpassage	7.17778,55.06333 7.16056,55.06306 7.03722,55.26056 7.17000,55.23500 7.16639,55.22806 7.16639,55.22806 7.18417,55.16111 7.16806,55.15972 7.16962,55.10983 7.17083,55.07111 7.17725,55.06392	75	Vattenfall	80	application	480	monopile / tripod / gravity-based / other	10 to 25 m / 25 to 50 m	160	no	

De57	Germany	Horizont III	6.42658,54.83397 6.49361,54.78268 6.31183,54.78307 6.28177,54.78314 6.28116,54.78314 6.27822,54.81070 6.27611,54.83056 6.34389,54.83210	121	Germany Mainstream Renewable Power Developments GmbH	71	application	355	monopile / tripod / gravity-based / other	25 to 50 m	165	no	
De58	Germany	Horizont I	6.26324,54.81074 6.26364,54.80714 6.21607,54.83069 6.16374,54.88326 6.24742,54.95577 6.25382,54.89712 6.26134,54.82820 6.26152,54.82658	131	Germany Mainstream Renewable Power Developments GmbH	65	application	325	monopile / tripod / gravity-based / other	25 to 50 m	165	no	
De59	Germany	GlobalTech II	6.22205,54.26639 6.13309,54.26008 6.13309,54.26008 6.13336,54.28574 6.18156,54.30571 6.21928,54.30757 6.22450,54.30783 6.25705,54.30943 6.26142,54.26919 6.22725,54.26676	70	Northern Energy GlobalTech II GmbH i. Grdg.	76	application	380	gravity-based	25 to 50 m	150	no	
De60	Germany	GlobalTech III	6.27663,54.27016 6.27663,54.27016 6.27235,54.30971 6.27230,54.31018 6.31659,54.31234 6.31680,54.31040 6.32072,54.27323	70	Northern Energy GlobalTech III GmbH i. Grdg.	21	application	105	gravity-based	25 to 50 m	150	no	
De61	Germany	GAIA I	6.42549,55.00444 6.30168,54.95481 6.26688,54.98383 6.34353,55.05900 6.34501,55.05802 6.42030,55.00790	145	Northern Energy GAIA I GmbH	80	application	400	tripod / other	25 to 50 m	150	no	
De62	Germany	SeaStorm II	6.10347,54.54512 6.03140,54.51595 5.95398,54.55524 6.04265,54.58394	110	Northern Energy SeaStorm II GmbH	38	application	190	tripod / other	25 to 50 m	150	no	
De63	Germany	SeaWind III	6.10515,54.57112 6.10512,54.55743 6.00541,54.62102 6.00732,54.62175 6.01608,54.62507 6.10535,54.65898 6.10531,54.63870	110	Northern Energy SeaWind III GmbH	80	application	400	tripod / other	25 to 50 m	150	no	
De64	Germany	Bight Power I	6.22432,54.23275 6.12052,54.23052 6.11559,54.30622 6.21919,54.30896 6.21928,54.30757 6.22205,54.26639	74	Airtricity Germany Developments GmbH	80	application	400	monopile / tripod / gravity-based / other	25 to 50 m	163	no	
De65	Germany	Bight Power II	6.35036,54.24180 6.22910,54.23926 6.22725,54.26676 6.22450,54.30783 6.22442,54.30897 6.27235,54.30971 6.31680,54.31040 6.33090,54.31062 6.34624,54.30104	74	Airtricity Germany Developments GmbH	80	application	400	monopile / tripod / gravity-based / other	25 to 50 m	163	no	
De66	Germany	AreaC I	6.65828,54.25760 6.64003,54.24639 6.59466,54.24995 6.46756,54.33227 6.47033,54.37027 6.48969,54.37958 6.64160,54.27965	66	Airtricity Germany Developments GmbH	80	application	400	monopile / tripod / gravity-based / other	25 to 50 m	163	no	

De67	Germany	AreaC II	6.81390,54.25209 6.67094,54.24924 6.63634,54.29528 6.63544,54.30591 6.75542,54.30820 6.75493,54.31729 6.80891,54.31846	66	Airtricity Germany Developments GmbH	80	application	400	monopile / tripod / gravity-based / other	25 to 50 m	163	no	
De68	Germany	AreaC III	6.95550,54.30990 6.95722,54.27531 7.02972,54.27551 7.03080,54.25290 6.84166,54.24999 6.82352,54.25982 6.82070,54.31852 6.87444,54.31981 6.87495,54.31000	66	Airtricity Germany Developments GmbH	80	application	400	monopile / tripod / gravity-based / other	25 to 50 m	163	no	
De69	Germany	Euklas	5.17336,54.68554 5.17614,54.54892 5.00572,54.62236 5.00536,54.68424	143	BARD Foundation GmbH	160	application	1040	monopile / tripod / gravity-based / other	25 to 50 m	151	no	
De70	Germany	Witte Bank	6.53592,55.03743 6.45988,55.00720 6.42030,55.00790 6.29653,55.01007 6.34501,55.05802 6.43793,55.14994	120	Projekt Ökovest GmbH	171	application	855	other	25 to 50 m	163	no	
De71	Germany	ENOVA Offshore NSWP 4	4.97450,55.31133 5.14650,55.24483 5.19067,55.24483 5.09067,55.19113 4.97450,55.26217	205	ENOVA Energieanlagen GmbH	81	application	486	monopile / tripod / gravity-based / other	25 to 50 m	163	no	
De72	Germany	ENOVA Offshore NSWP 5	5.29783,55.20133 5.17850,55.13767 5.10133,55.18483 5.21383,55.24483 5.22667,55.24483	158	ENOVA Energieanlagen GmbH	85	application	486	monopile / tripod / gravity-based / other	25 to 50 m	163	no	
De73	Germany	ENOVA Offshore NSWP 6	5.32406,55.12563 5.25650,55.08967 5.18917,55.13100 5.32350,55.20267 5.39083,55.16117 5.35035,55.13962	190	ENOVA Energieanlagen GmbH	84	application	504	monopile / tripod / gravity-based / other	25 to 50 m	163	no	
De74	Germany	ENOVA Offshore NSWP 7	5.24500,55.08350 5.20017,55.05950 4.97450,55.20250 4.97450,55.24900	190	ENOVA Energieanlagen GmbH	95	application	570	monopile / tripod / gravity-based / other	25 to 50 m	163	no	
De75	Germany	Gode Wind III	7.13751,54.00790 7.06809,53.99858 7.11853,54.02825 7.11861,54.06451 7.11525,54.07579 7.07372,54.09649 7.11013,54.09676	34	Plambeck Neue Energien AG	15	application	75	monopile / tripod	25 to 50 m	150	no	
De76	Germany	He dreiht	6.13313,54.43780 6.21601,54.38269 6.14279,54.38274 6.13588,54.38734 6.12892,54.42851	85	EnBW Nordsee Offshore GmbH	39	application	195	tripod	25 to 50 m	110	no	
De77	Germany	Jules Verne I	5.51821,55.09372 5.40793,54.98510 5.23847,55.04094 5.32406,55.12563 5.33597,55.13741 5.35035,55.13962 5.36994,55.14263	170	PNE Wind AG	120	application	600	monopile / tripod / gravity-based / other	25 to 50 m	158	no	
De78	Germany	Jules Verne II	5.40793,54.98510 5.51821,55.09372 5.67400,55.04200 5.56343,54.93352	170	PNE Wind AG	120	application	600	monopile / tripod / gravity-based / other	25 to 50 m	158	no	

FR01	France	Cote d'Albatre	0.58133, 49.91275 0.54714, 49.94981 0.62622, 49.91322 0.59206, 49.95031	7 km	Enertrag	21	authorized, but court case in process	105	tripod	25	160	yes	
IE01	Ireland	Arklow Bank	-5.9975,52.78269 -5.96417,52.67472 -5.8975,52.91445 -5.93417,52.91805	10	Arklow Energy subleased from Sure Partners	200	operational	520	monopile	5 to 30	125 m	yes	currently 7 x 3.6 MW turbines are in place. It is intended that the final output will be 520MV with all turbines with the area specified.
IE02	Ireland	Codling Bank	-5.82917,53.07167 -5.71667,53.07167 -5.71667,53.10883 -5.78333,53.14333 -5.84350,53.14333	13 km	Codling Wind Park Ltd	220	authorised	1100	Not yet determined. Monopile or tripod proposed.	5 to 20	160 (max)	yes	Phased development over the period 2009 to 2016.Foreshore Lease granted (copy available at http://www.dcmnr.gov.ie/NR/rdonlyres/665CD3AA-C74D-4FBE-9329-70186FC44F3E/0/MS538LForeshoreLease.pdf)
IE03	Ireland	Oriel Wind Farm	-6.09230,53.94789 -6.04121,53.94664 -6.02737,53.92036 -6.04839,53.88695 -6.09030,53.88798 -6.10840,53.92226	7	Oriel Wind Farm Ltd	55	application	max 330	Not yet determined. Concrete Caisson gravity foundation proposed	15 to 30	160m (max)	yes	Formal application submitted with EIS
IE04	Ireland	Sceirde Rocks	-9.96766,53.29433 -10.03150,53.26617 -10.02000,53.25000 -9.95000 ,53.23333 -9.91833,53.26833	5 km	Fuinneamh Sceirde Teoranta	20	application	100	Not yet determined. Monopile proposed.	5 to 35	140 (max)	yes	Formal application submitted with EIS
NL01	Netherlands	Prinses Amaliapark (new name; was Q7 WP)	4.24033, 52.60778 4.19544, 52.60536 4.18436, 52.57669 4.24814, 52.56897 4.26447, 52.58514	23	Eneco (new operator)	60	operational	120	monopile	10 to 25	97	yes	coordinates in WGS 84
NL02	Netherlands	Offshore Windpark Egmond aan Zee (new name; was Near Shore Windpark (demonstration park))	4.49472, 52.60461 4.48756, 52.57381 4.43097, 52.57411 4.35183, 52.63117 4.37986, 52.63514 4.39453, 52.62575 4.41819, 52.63944	11	Noordzeewind	36	operational	108	monopile	10 to 25	112	yes	coordinates in WGS 84. .
NL04	Netherlands	Beaufort (new name; was Katwijk)	3.94290,52.24997 3.97587,52.24998 3.99473,52.31075 3.98288,52.31023 3.97645,52.31150 3.96235,52.30830 3.95070,52.30982 4.00623,52.34767 3.99713,52.34647 3.95555,52.34677 3.96077,52.38650 4.01887,52.38812	24	NUON (was WEOM)	100	authorized	300	monopile	20 to 28	115	yes	coordinates in WGS 84
NL07	Netherlands	Scheveningen Buiten	3.70638,52.19427 3.71780,52.20632 3.85905,52.20740 3.85927,52.20055 3.74393,52.17750 3.70638,52.19427	30	Evelop	89	authorised	320	monopile	19 to 30	137 to 165	yes	coordinates in WGS 84.
NL08	Netherlands	Q4-WP	4.25427,52.64785 4.23800,52.65657 4.23542,52.65883 4.24295,52.66692 4.24095,52.71680 4.26968,52.67880 4.28607,52.64965	24	E-connection	40	authorised	120	monopile	±25	109	yes	coordinates in WGS 84.

NL10	Netherlands	West Rijn	3.63703,52.32000 3.68537,52.31168 3.67762,52.30542 3.69815,52.30010 3.62375,52.21683 3.58458,52.23398	40	Airtricity	72	authorised	260	monopile	19 top21	130	yes	coordinates in WGS 84
NL13	Netherlands	Breeveertien II	3.51617,52.54848 3.56745,52.58857 3.60608,52.61867 3.60712,52.61932 3.62725,52.60532 3.63395,52.60065 3.64067,52.59597 3.65818,52.58357 3.66592,52.57627 3.67048,52.56443 3.65210,52.54880 3.64135,52.54208 3.54115,52.54718	65	Airtricity	79	authorised	285	monopile	19-25	130	yes	coordinates in WGS 84.
~~NL14~~	~~Netherlands~~	~~Helmveld~~	~~4.02069, 52.50383~~ ~~4.04514, 52.53364~~ ~~4.09327, 52.49131~~ ~~4.06203, 52.47176~~ ~~4.05389, 52.47189~~	~~34~~	~~Evelop/Eneco~~	~~137~~	~~application & negative draft decision~~	~~493~~	~~monopile~~	~~23-28~~	~~142~~	~~yes~~	~~coordinates in WGS 84. Final decision before end 2009.~~
~~NL15~~	~~Netherlands~~	~~Rijnveld Noord/Oost~~	~~3.52541, 52.22397~~ ~~3.52533, 52.21190~~ ~~3.52148, 52.20388~~ ~~3.49427, 52.20393~~ ~~3.51187, 52.22199~~ ~~3.47552, 52.18485~~ ~~3.47345, 52.18289~~ ~~3.49248, 52.17449~~ ~~3.49420, 52.17241~~ ~~3.50199, 52.17228~~ ~~3.50543, 52.16413~~ ~~3.51494, 52.16192~~ ~~3.52066, 52.15584~~ ~~3.52274, 52.16180~~ ~~3.52381, 52.18188~~ ~~3.52210, 52.18396~~	~~35~~	~~E-Connection~~	~~72~~	~~application & negative draft decision~~	~~216~~	~~monopile~~	~~20-30~~	~~110~~	~~yes~~	~~final decision before end 2009~~
~~NL17~~	~~Netherlands~~	~~Rijnveld West~~	~~534.683, 5.796.089~~ ~~532.302, 5.791.647~~ ~~532.682, 5.791.035~~ ~~533.401, 5.791.058~~ ~~534.161, 5.789.834~~ ~~535.521, 5.792.373~~ ~~535.141, 5.792.985~~ ~~536.841, 5.796.158~~	~~45~~	~~E-Connection~~	~~41~~	~~application & negative draft decision~~	~~123~~	~~monopile~~	~~30~~	~~110~~	~~yes~~	~~coordinates in UTM zone 31 ED50.~~
NL18	Netherlands	Brown Ridge Oost	3.43795,52.75877 3.43673,52.66168 3.44598,52.66487 3.46468,52.68420 3.47395,52.68738 3.49268,52.70672 3.50195,52.70990 3.51132,52.71957 3.52060,52.72275 3.52078,52.73570 3.48402,52.74883 3.46553,52.74892 3.43795,52.75877	74	E-Connection	94	authorized	282	monopile	30	142	yes	coordinates in WGS 84

~~NL19~~	~~Netherlands~~	~~Callantsoog Noord~~	~~575000, 5865848~~ ~~575263, 5868178~~ ~~575600, 5868388~~ ~~575859, 5868629~~ ~~576106, 5868962~~ ~~576319, 5869525~~ ~~576349, 5870244~~ ~~576231, 5870694~~ ~~577131, 5871467~~ ~~581170, 5870943~~ ~~577994, 5866594~~ ~~577569, 5866688~~ ~~577173, 5866694~~ ~~576759, 5866616~~ ~~576336, 5866440~~ ~~575938, 5866128~~ ~~575652, 5865776~~ ~~575459, 5865398~~ ~~575227, 5865663~~ ~~579248, 5865271~~ ~~582978, 5870679~~ ~~584073, 5870476~~ ~~581545, 5863665~~ ~~579324, 5864569~~ ~~579325, 5864829~~ ~~579306, 5865055~~	~~30~~	~~Eneco~~	~~101~~	~~application & negative draft decision~~	~~303~~	~~monopile~~	~~24-36~~	~~115~~	~~yes~~	~~coordinates in UTM zone 31 ED50. Final decision before end 2009.~~
NL20	Netherlands	Den Helder I	3.60188,52.90002 3.65790,52.93892 3.74602,52.90107 3.68715,52.85975 3.67095,52.86100 3.61182,52.88512	63	Airtricity	78	authorised	468	monopile	23	160	yes	Coordinates in WGS 84. Final decision before end 2009.
~~NL21~~	~~Netherlands~~	~~Rotterdam NW~~	~~3.69770,52.20615~~ ~~3.85905,52.20740~~ ~~3.85927,52.20055~~ ~~3.81612,52.19192~~ ~~3.68363,52.19193~~	~~30~~	~~Evelop/Eneco~~	~~50~~	~~Application & negative draft decision~~	~~180~~	~~monopile~~	~~20-30~~	~~137 to 165~~	~~yes~~	~~Coordinates in WGS 84.~~
NL22	Netherlands	BARD Offshore NL1	6.05458,54.07498 5.98863,54.07013 6.09532,54.00383 6.02677,54.00420	56	Bard Engineering GmbH	60	authorised	300	tripile	29-33	150	yes	coordinates in WGS 84
NL23	Netherlands	EP Offshore NL 1	5.98103,54.06953 5.91532,54.06417 6.01870,54.00425 5.95015,54.00455	56	Eolic Power GmbH	55	authorised	275	tripile	29-33	150	yes	coordinates in WGS 84
NL24	Netherlands	GWS Offshore NL1	5.90777,54.06402 5.81385,54.05625 5.94208,54.00458 5.87755,54.00485	56	Global Wind Support GmbH	60	authorised	300	tripile	29-33	150	yes	coordinates in WGS 84
NL25	Netherlands	Tromp Binnen	3.60797,52.80467 3.61278,52.80307 3.61827,52.80282 3.62343,52.80393 3.62738,52.80625 3.63980,52.80117 3.61368,52.78040 3.49928,52.82705 3.42825,52.85587 3.42663,52.87767 3.42722,52.87813 3.51837,52.84115	75	RWE	59	authorised	295	gravity based	20-33	152	yes	coordinates in WGS 84.
NO1	Norway	Karmøy	5.01786, 59.08406		StatoilHydro ASA	1	authorised	3	floating prototype			yes	

NO2	Norway	Havsul I	6.22179,62.78594 6.23994,62.77237 6.20353,62.78659 6.26712,62.82155 6.38935,62.85867 6.47046,62.83154 6.45481,62.82605 6.43562,62.82874 6.38096,62.81429 6.38320,62.78919 6.35700,62.77721 6.27331,62.79956 6.22179,62.78594	6 km	Havgul AS	78	authorised	350	Other	5 - 35	160	yes	The turbine's specific information is based upon the most likely turbines to be used
NO3	Norway	Havsul II	5.95625,62.67455 6.08520,62.62281 6.05914,62.61214 6.04730,62.61189 6.03228,62.60729 6.03850,62.60695 5.91653,62,55916 5.89581,62.57011 5.88834,62.64148 5.95625,62.67455 6.08520,62.62281 5.95610,62.67461 5.98920,62.69023 6.03297,62.71042 6.07096,62.70713 6.14195,62.69041 6.12738,62.65740 6.08520,62.62281	2	Havgul AS	178	refused	800	other	5 - 35	160	yes	The turbine's specific information is based upon the most likely turbines to be used
NO4	Norway	Havsul IV	7.16936,63.12408 7.25626,63.12408 7.30304,63.11913 7.30410,63.09548 7.26448,63.07001 7.23404,63.07001 7.16884,63.10164 7.16936,63.12408 7.32153,63.07872 7.32112,63.08726 7.36300,63.09253 7.36336,63.08414 7.32153,63.07872 7.33012,63.05623 7.32313,63.05628 7.32281,63.06337 7.36818,63.07930 7.38051,63.07934 7.38074,63.07386 7.33012,63.05623	3	Havsul IV AS	78	refused	350	other	5 - 35	160	yes	The turbine's specific information is based upon the most likely turbines to be used
~~NO5~~	~~Norway~~	~~Steinshamn Offshore Vindpark~~	~~7.00, 63.00 (approx)~~	~~3~~	~~Offshore Vindenergi AS~~	~~21 - 30~~	~~notification~~	~~105~~	~~not decided~~	~~10 to 25~~	~~140 - 150 m~~	~~yes~~	~~notification. EIA work ongoing.~~
~~NO6~~	~~Norway~~	~~Fosen Offshore Vindpark~~	~~10.20, 64.20 (approx)~~	~~3~~	~~Offshore Vindenergi AS~~	~~120 - 170~~	~~notification~~	~~600~~	~~not decided~~	~~10 to 25~~	~~140 - 150 m~~	~~yes~~	~~notification. Waiting for EIA programme from NVE~~
~~NO7~~	~~Norway~~	~~Selvær offshore vindkraftverk~~	~~12.31593, 66.62242~~ ~~12.31258, 66.65330~~ ~~12.25126, 66.67323~~ ~~12.21214, 66.67254~~ ~~12.09709, 66.62153~~ ~~12.09912, 66.60422~~ ~~12.28173, 66.60749~~ ~~12.28297, 66.59623~~ ~~12.23058, 66.56640~~ ~~12.23116, 66.56115~~ ~~12.30881, 66.56236~~ ~~12.30373, 66.60922~~ ~~12.31593, 66.62242~~	~~30~~	~~Nord-Norsk Vindkraft AS~~	~~100~~	~~notification~~	~~450~~	~~not decided~~	~~5 to 30~~	~~130-180~~	~~yes~~	~~notification. Waiting for EIA programme from NVE.~~ …………………………………… ~~Within the wind farm there are significant areas with depths 30 to 80 meters, which during the planning prosess will be taken into consideration for possible utilization. Hence the number of wind turbines may increase.~~
~~NO8~~	~~Norway~~	~~Gimsøy~~	~~14.08530, 68.22140 (centre)~~	~~1~~	~~Lofokraft Vind AS~~	~~45 - 85~~	~~notification~~	~~250~~	~~not decided~~	~~10 to 25~~	~~130 - 185~~	~~yes~~	~~notification. Waiting for EIA-program form NVE.~~
~~NO9~~	~~Norway~~	~~Lofoten Havkraftverk~~	~~14.19500, 68.25300 (centre)~~	~~2.5~~	~~Lofotkraft Vind~~	~~125 - 250~~	~~notification~~	~~500 - 750~~	~~not decided~~	~~25 to 50~~	~~130 - 185~~	~~yes~~	~~notification March 2008~~

~~NO10~~	~~Norway~~	~~Utsira~~	~~4.555785, 59.155593 4.565769, 59.155780 4.57210, 59.152071 4.55245, 59.151697 4.55168, 59.152342~~	~~15~~	~~Lyse Produksjon AS~~	~~5~~	~~notification~~	~~25~~	~~floating~~	~~150~~	~~150~~	~~yes~~	~~notification. Proposed EIA programme been on public hearing, awaiting final EIA programme from NVE~~
~~NO11~~	~~Norway~~	~~Utsira~~	~~4.28246, 59.193657 4.344612, 59.195046 4.283421, 59.153809 4.351709, 59.155194~~	~~30~~	~~Lyse Produksjon AS~~	~~56~~	~~notification~~	~~280~~	~~floating~~	~~270~~	~~150~~	~~yes~~	~~notification. Waiting for EIA programme from NVE~~
~~NO12~~	~~Norway~~	~~South of North Sea~~	~~5.492, 56.571 6.543, 57.159 6.1055, 56.572 5.5431, 56.523~~	~~130~~	~~Lyse Produksjon AS~~	~~200~~	~~notification~~	~~1000~~	~~steel jacket (but not decided)~~	~~45 to 60~~	~~150~~	~~yes~~	~~notification. Waiting for EIA programme from NVE~~
NO13	Norway	Siragrunnen	6.225, 58.272 6.340, 58.282 6.288, 58.238 6.406, 58.248	1	Siragrunnen AS	40	application	200	gravitation (concrete)	15 to 40	150	yes	
~~NO14~~	~~Norway~~	~~Stadtvind~~	~~4.30665, 62.14932 4.11766, 62.12665 3.56653, 62.35516 4.15601, 62.27705~~	~~33~~	~~Vestavind Kraft AS~~	~~216~~	~~notification~~	~~1080~~	~~floating prototype~~	~~160 to 200~~		~~yes~~	~~notification. Waiting for EIA programme from NVE~~
~~NO15~~	~~Norway~~	~~Idunn energy park~~	~~3.537654, 56.587294 3.660098, 56.616607 3.795923, 56.258281 3.921266, 56.291654~~	~~250~~	~~Fred. Olsen Renawables~~	~~200~~	~~notification~~	~~1200~~	~~not decided~~	~~60 to 70~~	~~Not decided~~	~~yes~~	~~notification April 2008. Wave and wind~~
~~NO16~~	~~Norway~~	~~Aegir energy park~~	~~7.748879, 65.166771 7.894365, 65.208441 8.197564, 64.857656 8.347250, 64.899128~~	~~120~~	~~Fred. Olsen Renawables~~	~~200~~	~~notification~~	~~1200~~	~~not decided~~	~~200 to 250~~	~~Not decided~~	~~yes~~	~~notification April 2008. Wave and wind~~
SE1	Sweden	Fladen		25	Göteborg En-y	60	refused	Total 300 MW	gravity-based	10 to 25	120	yes	Application dismissed because Fladen is a Natura 2000 site.
SE2	Sweden	Stora Middlegrund	12.03532, 56.65295 12.06134, 56.65899 12.08176, 56.65979 12.08910, 56.66148 12.11229, 56.63124 12.12933, 56.62739 12.14440, 56.60751 12.16143, 56.60366 12.18202, 56.57647 12.17501, 56.56708 12.18003, 56.56045 12.16554, 56.54098 12.14155, 56.53544 12.13546, 56.52624 12.13797, 56.52292 12.13499, 56.52223	35	Universal Wind	110	apllication	800	not decided	0-30	200	yes	near the Danish border
SE3	Sweden	Risholmen - Arendal	11.81423, 57.68374 11.82048, 57.68547 11.80816, 57.70327	0-0,02	Göteborg Energi	3	apllication	9	concrete	0-12	150	yes	
SE4	Sweden	Lövstaviken	12.46977, 56.88748	0-1	Falkenberg Energi	5	authorised	10	both monopile and gravity	0-10	100	yes	wind-farm consist of 6 wind turbines of which 5 are located on land
UK01	UK	Scroby Sands	1.77340, 52.62715 1.77378, 52.66197 1.80750, 52.66172 1.80711, 52.62692	2km	E.on	30	operational	60	monopile	less than 10m	100	yes	operational since 2004.
UK02	UK	North Hoyle	-3.47420, 53.40333 -3.41518, 53.41029 -3.42208, 53.43121 -3.48134, 53.42491	8km	Npower Renewables	30	operational	60	monopile	less than 10m	130	yes	operational since 2003
UK03	UK	Rhyl Flats	-3.65395, 53.39262 -3.60799, 53.38226 -3.61995, 53.36333 -3.69251, 53.37971 -3.68711, 53.39030 -3.65937, 53.38404	8km	Npower Renewables	30	authorised	100	monopile	less than 10m	130	yes	
UK04	UK	Barrow	-3.33136, 53.99518 -3.30577, 54.01186 -3.26065, 53.98774 -3.28598, 53.97107	10km	DONG/Centrica	30	operational	90	monopile	10 to 25 m	125	yes	operational since 2006.

UK05	UK	Robin Rigg	-3.73993, 54.76293 -3.70173, 54.75223 -3.70505, 54.74815 -3.69013, 54.74431 -3.67755, 54.75220 -3.66930, 54.77274 -3.68454, 54.78279	9.5km	E.on	60	authorised	216	monopile	less than 10m	130	yes	
UK06	UK	Kentish Flats	1.05383, 51.46850 1.10700, 51.47383 1.13400, 51.45233 1.08083, 51.44700	8.5km	Elsam	30	operational	90	monopile	less than 10m	140	yes	operational since 2005.
UK07	UK	Burbo Bank	-3.22000, 53.50283 -3.18665, 53.50319 -3.14751, 53.48185 -3.17905, 53.47023 -3.22399, 53.49471	6.4km	Elsam	25	operational	90	monopile	less than 10m	130	yes	under construction
UK08	UK	Lynn	0.42914, 53.14750 0.48896, 53.14747 0.48766, 53.12503 0.42787, 53.12505	5.2km	Centrica	30	operational	108	monopile	less than 10m	150	yes	under construction
UK09	UK	Inner Dowsing	0.43320, 53.21332 0.46313, 53.21334 0.46319, 53.16841 0.43329, 53.16840	5km	Centrica	30	operational	120	monopile	less than 10m	145	yes	under construction
~~UK10~~	~~UK~~	~~Cromer~~	~~1.35633, 53.03216~~ ~~1.37950, 53.03366~~ ~~1.39200, 52.97866~~ ~~1.36916, 52.97666~~	~~7.5km~~		~~30~~	~~application withdrawn~~	~~108~~	~~monopile~~	~~10 to 25 metres~~	~~140~~	~~yes~~	~~not being persued~~
UK11	UK	Gunfleet Sands	1.18153, 51.72783 1.24281, 51.75173 1.25820, 51.73651 1.19693, 51.71261	6 km	GE Wind Energy	30	operational	108	monopile	less than 10m	150	yes	
~~UK12~~	~~UK~~	~~Shell Flat 1~~	~~-3.354453, 53.85739~~ ~~-3.16334, 53.85519~~ ~~-3.16390, 53.84819~~ ~~-3.35552, 53.85029~~	~~7.1km~~	~~Shell Wind Energy Ltd~~	~~30~~	~~application withdrawn~~	~~324~~	~~monopile/gravity based~~	~~less than 10m/10 to 25 metres~~	~~160~~	~~yes~~	~~Application on hold - new application submitted in revised location. See Cirrus Shell Flat Array~~
UK13	UK	Scarweather Sands	-3.88839, 51.48594 -3.86649, 51.49613 -3.83030, 51.49819 -3.82410, 51.48448 -3.81685, 51.47589 -3.83136, 51.47449 -3.85691, 51.47411 -3.88371, 51.47569	9.5	E.on	30	application	108	monopile/gravity based	less than 10m	130	yes	
UK14	UK	Blyth	-1.48965,55.13503 -1.49083,55.13725	1km	Blyth Offshore Wind Ltd	2	operational	4	drilled monopile	less than 10m	91	yes	Operational since 2000
UK15	UK	Teesside	-1.08900,54.63100 -1.05200,54.64000 -1.11100,54.66800 -1.13300,54.65200	1.5 km	EDF	30	authorised	90	drilled monopile	10 to 25	130	yes	
UK16	UK	Ormonde	-3.44468,54.10850 -3.40135,54.08350 -3.42802,54.06850 -3.47301,54.09183	10 km	Ormonde Energy	30	authorised	108	monopile	10 to 25	130	yes	combined wind farm/gas field
UK17	UK	London Array	1.34924, 51.60440 1.44748, 51.66220 1.50193, 51.70240 1.56083, 51.76010 1.63268, 51.75040 1.55491, 51.70046 1.66583, 51.70030 1.66583, 51.65520 1.57156, 51.56820 1.38756, 51.58130	21 km	London Array	271	authorised	1000	monopile/gravity based	0 to 25	140	yes	

UK18	UK	Greater Gabbard	Inner Gabbard 1.93400, 51.97850 2.00000, 51.97850 2.00000, 51.88750 1.86950, 51.85130 1.84460, 51.87180 1.87280, 51.95580 1.88750, 51.96120 1.89350, 51.95910 1.89680, 51.96470 The Galloper 2.00000, 51.81100 2.00000, 51.75400 1.93850, 51.73300 1.91640, 51.76600 1.93400, 51.79600	23 km	Greater Gabbard Offshore Wind Ltd	140	authorised	300	monopile/gravity based	20 to 50	170	yes	
UK19	UK	Thanet	1.56957, 51.44295 1.60120, 51.46080 1.63535, 51.46078 1.68790, 51.42435 1.68779, 51.40085 1.62770, 51.40269	11km	Thanet Offshore Wind Ltd	100	authorised	500	monopile/gravity based	0 to 30	150	yes	
UK20	UK	Gwynt y Mor	-3.767098,53.495198 -3.692035,53.501690 -3.544143,53.501813 -3.456768,53.451828 -3.458598,53.451475 -3.481888,53.447800 -3.500255,53.445453 -3.515118,53.444418 -3.532743,53.441228 -3.548947,53.438053 -3.560877,53.434508 -3.569970,53.431002 -3.580478,53.427473 -3.593065,53.422647 -3.605617,53.416972 -3.616683,53.409620 -3.628345,53.417933 -3.642153,53.426642 -3.650775,53.429488 -3.663107,53.436518 -3.674602,53.440170 -3.681102,53.443045 -3.692582,53.446272 -3.707662,53.450717 -3.716968,53.452702 -3.735548,53.455822 -3.759840,53.459703 -3.765670,53.459617	13km	Gwynt y Mor Offshore Wind Farm Ltd	250	authorised	750	monopile/multipile/ gravity based/ suction caisson	13	165	yes	
UK21	UK	Walney	-3.63156, 54.12671 -3.44433, 54.02959 -3.52591, 54.01227 -3.53295, 54.01900 -3.54755, 54.02967 -3.56460, 54.03899 -3.58468, 54.04670 -3.60174, 54.05214 -3.62464, 54.05734 -3.64297, 54.05952 -3.65569, 54.07402 -3.66950, 54.09328	14km	Dong Walney Ltd	152	authorised	600	monopile/tripod/gravity base	18 to 30	157	yes	
UK22	UK	West of Duddon	-3.55859, 54.00255 -3.44334, 54.02872 -3.37940, 53.97193 -3.42159, 53.94403 -3.42159, 53.94530	13km	Scottish Power/Elsam/Euros Energy	139	authorised	500	monopile/tropod/gravity base/suction caisson	18 to 23	183	yes	
UK23	UK	Sherringham Shoal	1.07777, 53.17464 1.18243, 53.14968 1.21717, 53.09644 1.11248, 53.12152	17km	Scira Offshore Energy	108	application	315	monopile/tripod/gravity base/suction caisson	15 to 22	172	yes	

UK24	UK	Shell Flat 2	-3.33898, 53.86579 -3.27128, 53.86499 -3.27084, 53.87049 -3.24391, 53.87019 -3.24243, 53.87649 -3.16148, 53.87559 -3.16339, 53.86229 -3.33894, 53.86429	7.1km	CeltPower Ltd	30	application	324	monopile/gravity based	less than 10m/10 to 25 metres	160	yes	Application on hold - new application submitted in revised location. See Cirrus Shell Flat Array
UK25	UK	Shell Flat 3	-3.33963, 53.84309 -3.16417, 53.84129 -3.16289, 53.82789 -3.23038, 53.82869 -3.23132, 53.83509 -3.28544, 53.83559 -3.28560, 53.84109 -3.33958, 53.84169	7.1km	Elsam A/S	30	application	324	monopile/gravity based	less than 10m/10 to 25 metres	160	yes	Application on hold - new application submitted in revised location. See Cirrus Shell Flat Array
UK26	UK	Gunfleet Sands 2	1.19777, 51.7129 1.27995, 51.754 1.28568, 51.73933 1.20350, 51.70723	8.5km	DONG Energy	20	application	48 - 64	monopile/gravity based	7 to 24	135	yes	
UK27	UK	Lincs	0.45769, 53.24188 0.50127, 53.24845 0.51897, 53.20635 0.51896, 53.15115 0.48786, 53.12513 0.48920, 53.14771 0.47315, 53.14776 0.47560, 53.19937	8km	Centrica	120	application	190 - 250	monopile/gravity based	8 to 20	170	yes	
UK28	UK	Cirrus Shell Flat Array	-3.16139, 53.9214 -3.15641, 53.9162 -3.12553, 53.9265 -3.12516, 53.9088 -3.25500, 53.8654 -3.26009, 53.8705 -3.27935, 53.8640 -3.28441, 53.8692 -3.29408, 53.8660 -3.30207, 53.8743	5km	CeltPower Ltd/Shell Wind Energy/Dong Energy	90	application	284	gravity/pile/tripod/bucket/jacket	2 to 21	177	yes	
UK29	UK	Docking Shoal	0.721000, 53.230000 0.765000, 53.204000 0.785000, 53.198000 0.831000, 53.175000 0.891000, 53.134000 0.742000, 53.142000 0.719000, 53.143000 0.639000, 53.157000	14km	Centrica	83 - 166	application	500		3 to 14	180	Yes	
UK30	UK	Dudgeon East	1.324068, 53.298047 1.459595, 53.235157 1.456812, 53.201668 1.321383, 53.264553	32km	Warwick Energy	168	application	560				Yes	
UK31	UK	Humber Gateway	0.246866, 53.668410 0.331365, 53.683891 0.331409, 53.633651 0.281592, 53.597121 0.270673, 53.587944 0.271334, 53.613033	8km	E-on	42 to 83	application	300	monopile/jack-up vessel			Yes	
UK32	UK	Triton Knoll	0.724000, 53.523000 0.893000, 53.509000 0.994000, 53.409000 0.933000, 53.409000 0.700000, 53.484000		Npower Renewables	83	application	1200					
UK33	UK	Westermost Rough	0.087247, 53.812037 0.160250, 53.842923 0.212387, 53.799705 0.139417, 53.768852	9km	Dong Energy	65	application	234					

A9 Operational offshore farms 2009

BELGIUM

ONLINE

Project Name	Location	Capacity	N° of Turbines	Water depth	Distance to shore	Online	WT manufacturer	Owner/ operator	Foundation type	Foundation supply
Thornton Bank phase 1	Off Zeebrugge	30	6	12 to 27	27 to 30	2008	Repower	C-power (RWE Innogy)	Gravity	GeoSea
TOTAL		**30**								

DENMARK

ONLINE

Project Name	Location	Capacity	N° of Turbines	Water depth	Distance to shore	Online	WT manufacturer	Owner/ operator	Foundation type	Foundation supply
Vindeby	NW of Vindeby, Lolland	4,95	11	2,5 to 5	2,5	1991	Siemens	Dong Energy	Gravity	
Tunø Knob	Off Aarhus, Kattegat Sea	5	10	0,8 to 4	6	1995	Vestas	Dong Energy	Gravity	
Middelgrunden	Oresund, E of Copenhagen	40	20	2 to 6	2	2001	Siemens	Dong Energy	Gravity	MT Højgaard
Horns Rev 1	NW of Esbjerg	160	80	6 to 14	14	2002	Vestas	Vattenfall, Dong	Jacket	SIF, Smulders, MTHS Entreprenør
Nysted	Off Rødsand, Lolland	165,6	72	6 to 10	6 to 10	2003	Siemens	E.On, Dong Energy	Gravity	Per Aarsleft
Samsø	Palludan Flak, S of Samsø	23	10	11 to 18	3,5	2003	Siemens	Samsø Kommune	Monopile	Bladt Industries
Frederikshavn	Frederikshavn Harbour	10,6	4	3	0,8	2003	Vestas, Bonus Nordex	Dong Energy		
Horns Rev 2	Blåvandshuk	209	91	9 to 17	30	2009	Siemens	Dong Energy	Monopile	Bladt, Per Aarsleft & Bilfinger Berger
Storebaelt/Sprogø	N of Sprogø	21	7	6 to 16	2	2009	Vestas	Sund & Baelt	Gravity	Per Aarsleft & Bilfinger Berger
TOTAL		**639,15**								

FINLAND

ONLINE

Project Name	Location	Capacity	N° of Turbines	Water depth	Distance to shore	Online	WT manufacturer	Owner/ operator	Foundation type	Foundation supply
Kemi Ajos phases 1+2	Ajos Harbour	24	8	3	<1	2008	WinWind	Pohjolan Voima	Gravity	
TOTAL		**24**								

EWEA
THE EUROPEAN WIND ENERGY ASSOCIATION

GERMANY

ONLINE

Project Name	Location	Capacity	N° of Turbines	Water depth	Distance to shore	Online	WT manufacturer	Owner/ operator	Foundation type	Foundation supply
Enova offshore - Emden	Ems River in Emden	4,5	1		<1	2004	Enercon	Enova, EWE		
Breitling	Rostock Harbour	2,5	1	2	1	2006	Nordex	Nordex AG		
Hooksiel	Hooksiel Harbour	5	1	2 to 8	0,4	2008	Bard	Bard-Group	Tripod	Bard
Alpha Ventus - Borkum West	N of Borkum	30*	6	30	43	2009	Multibrid	DOTI (EWE, E.On, Vatenfall)	Tripod	Aker, BiFab
TOTAL		42								

IRELAND

ONLINE

Project Name	Location	Capacity	N° of Turbines	Water depth	Distance to shore	Online	WT manufacturer	Owner/ operator	Foundation type	Foundation supply
Arklow Bank	Off Arklow, Co Wicklow	25,2	7	2.5 to 5	10	2004	GE	GE	Monopile	Sif, Smulders
TOTAL		25,2								

NETHERLANDS

ONLINE

Project Name	Location	Capacity	N° of Turbines	Water depth	Distance to shore	Online	WT manufacturer	Owner/ operator	Foundation type	Foundation supply
Lely	Medemblik, Ijsselmeer	2	4	7,5	0,75	1994	Nedwind	Nuon	Monopile	
Irene Vorrink	Dronten, Ijsselmeer	16,8	28	2	0,03	1996	NordTank	Nuon	Monopile	
Offshore Wind Farm Egmond aan Zee	Off Egmond aan Zee	108	38	19 to 22	8 to 12	2007	Vestas	NoordzeeWind	Monopile	Bladt
Prinses Amalia	Off Ijmuiden	120	60	19 to 24	23	2008	Vestas	Econcern, Eneco	Monopile	Sif, Smulders
TOTAL		246,8								

NORWAY

ONLINE

Project Name	Location	Capacity	N° of Turbines	Water depth	Distance to shore	Online	WT manufacturer	Owner/ operator	Foundation type	Foundation supply
Floating Hywind	Off Karmoy	2,3	1	220	12	2009	Siemens	Statoil	Floating	
TOTAL		2,3								

*Wind farm only partially grid connected on 31 December 2009

SWEDEN

ONLINE

Project Name	Location	Capacity	N° of Turbines	Water depth	Distance to shore	Online	WT manufacturer	Owner/ operator	Foundation type	Foundation supply
Bockstigen	Gotland	2,75	5	6 to 8	3	1998	NEG-Micon		Monopile	
Utgrunden I	Kalmarsund	10,5	7	4 to 10	7	2001	GE	Vattenfall	Monopile	
Yttre Stengrund	Kalmarsund	10	5	8 to 12	4	2002	NEG-Micon	Vattenfall	Monopile	
Lillgrund	Oresund Straight	110,4	48	2,5 to 9	10	2007	Siemens	Vattenfall	Gravity	Hochtief
Gässlingegrund	Vänern	30	10	4 to 10	4	2009	WinWind	Vindpark Väners	Gravity	PEAB
TOTAL		**163,65**								

UNITED KINGDOM

ONLINE

Project Name	Location	Capacity	N° of Turbines	Water depth	Distance to shore	Online	WT manufacturer	Owner/ operator	Foundation type	Foundation supply
Blyth Offshore	Blyth Harbour	4,0	2	6	1	2000	Vestas	E.On	Monopile	
North Hoyle	Prestatyn and Rhyl	60,0	30	5 to 12	3 to 10	2003	Vestas	Npower (RWE Innogy)	Monopile	Sif, Smulders
Scroby Sands	NE of Greater Yarmouth	60,0	30	2 to 10	2,5	2004	Vestas	E.On	Monopile	
Kentish flats	Off Whitstable	90,0	30	5	8,5	2005	Vestas	Vattenfall	Monopile	MT Højgaard, Sif, Smulders
Barrow	Off Walney Island	90,0	30	21 to 23	7	2006	Vestas	Dong, Centrica	Monopile	Sif, Smulders, KBR
Beatrice	Beatrice Oilfield, Moray Firth	10,0	2	40	25	2007	Repower	Scottish and Southern, Talisman	Jacket	BiFab
Burbo Bank	Crosby	90,0	25	10	5,2	2007	Siemens	Dong	Monopile	MT Højgaard
Inner Dowsing	Ingoldmells/ Skegness	97,2	27	10	5	2008	Siemens	Centrica	Monopile	MT Højgaard
Lynn	Ingoldmells/ Skegness	97,2	27	10	5,2	2008	Siemens	Centrica	Monopile	MT Højgaard
Rhyl Flats	Rhyl	90	25	4 to 15	8	2009	Siemens	Npower (RWE)	Monopile	MT Højgaard
Robin Rigg	Maryport, Rock Cliffe	90*	30	>5	9,5	2009	Vestas	E.On	Monopile	MT Højgaard
Gunfleet Sands 1 and 2	Clacton-on-Sea	104,4*	29	2 to 15	7	2009	Siemens	Dong	Monopile	MT Højgaard
TOTAL		**882,8**								

TOTAL CAPACITY 2055,9

*Wind farm only partially grid connected on 31 December 2009

Annex 1: List of participants

NAME	ADDRESS	PHONE/FAX	EMAIL
Michael Andersen	Danish Fishermen's Association Fredericia Nordensvej 3 Taulov 7000 Fredericia Denmark	Phone +45 70 10 9645 Cell: +45 4026 5040	ma@dkfisk.dk
Ewen Bell ICES Coordinator	Centre for Environment, Fisheries and Aquaculture Science Lowestoft Laboratory Pakefield Road NR33 0HT Lowestoft Suffolk United Kingdom	Phone +44 1 502 524 238 Fax +44 1 502 562 244	ewen.bell@cefas.co.uk
Jim Berkson Chair	National Marine Fisheries Services NMFS RTR Unit at Virginia Tech 114 Cheatham Hall Blacksburg VA 24061-0321 United States	Phone +1 540 231-5910 Fax +1 540 231-7580	Jim.berkson@noaa.gov
Steen Christensen	DTU Aqua - National Institute of Aquatic Resources Section for Fisheries Advice Charlottenlund Slot Jægersborg Alle 1 DK-2920 Charlottenlund Denmark	Phone +45 35 88 33 52 Fax +45 33 96 33 33	sc@aqua.dtu.dk
Bob Furness External Expert	University of Glasgow Graham Kerr Building G12 8QQ Glasgow United Kingdom	Phone + 44 141 330 3560 Fax + 44 141 330 5971	r.furness@bio.gla.ac.uk
Tore Johannessen	Institute of Marine Research Flødevigen Marine Research Station N-4817 His Norway	Phone +47 37 05 90 21 Fax +47 37 05 90 01	torejo@imr.no
Espen Johnsen	Institute of Marine Research P.O. Box 1870 N-5817 Bergen Norway	Phone +47 55 23 53 55 Fax +47 55 23 86 87	espen.johnsen@imr.no
Jesper Juul Larsen	Danish Fishermen's Association Esbjerg Auktionsgade 2 DK-6700 Esbjerg Denmark	Phone +45 7515 5619 Cell +45 4018 5619	jjl@esbjerg-fiskeriforening.dk

Name	Address	Phone/Fax	Email
Henrik S. Lund	Danish Fishermen's Association Nordensvej 3 Taulov DK-7000 Fredericia Denmark	Phone +45 7610 9652 Cell +45 2924 5565 Fax +45	hl@dkfisk.dk
Henrik Mosegaard	DTU Aqua - National Institute of Aquatic Resources Section for Fisheries Advice Charlottenlund Slot Jægersborg Alle 1 DK-2920 Charlottenlund Denmark	Phone +45 35 88 34 61 Fax +45 33 96 33 33	hm@aqua.dtu.dk
Anders Nielsen	DTU Aqua - National Institute of Aquatic Resources Jægersborg Allé 1 DK-2920 Charlottenlund Denmark	Phone +45 35 88 33 75 Fax +45	an@aqua.dtu.dk
Anna Rindorf	DTU Aqua - National Institute of Aquatic Resources Jægersborg Allé 1 DK-2920 Charlottenlund Denmark	Phone +45 35 88 33 78 Fax +45 35 88 33 33	ar@aqua.dtu.dk
Esben Sverdrup-Jensen	Danish Ministry of Food, Agriculture and Fisheries Slotsholmsgade 12 DK-1216 Copenhagen K Denmark	Phone +45 Fax +45	esje@fvm.dk
Morten Vinther	National Institute of Aquatic Resources Section for Fisheries Advice Charlottenlund Slot Jægersborg Alle 1 DK-2920 Charlottenlund Denmark	Phone +45 35 88 33 50 Fax +45 33 96 33 33	mv@aqua.dtu.dk
Peter Wright	Marine Scotland Marine Laboratory Aberdeen P.O. Box 101 AB11 9DB Aberdeen United Kingdom	Phone +44 1224 295436 Fax +44 1224 295511	wrightp@marlab.ac.uk

Name	Address	Phone/Fax	Email
Harald Østensjø	Fiskebåtredernes Forbund and Sør-Norges Trålerlag Sørhauggt. 128 5527 Haugesund Norway	Phone + 47 52 86 69 80 Fax + 47 52 73 32 0147 Cell +47 91 55 55 62	post@tralerlaget.no