Reliability of trawl surveys on cod in Norwegian fjords

T. M. Lunde, O. R. Godø, and R. Rosland

Lunde, T. M., Godø, O. R., and Rosland, R. 2008. Reliability of trawl surveys on cod in Norwegian fjords. – ICES Journal of Marine Science, 65: 937–945.

According to ICES, the International Council for the Exploration of the Sea, populations of coastal cod (CC) in Norway north of 62°N have been declining since 1994. The estimates are based on analytical assessment in which the most recent estimates are tuned with survey information. We evaluate the quality of bottom-trawl surveys conducted in four North Norwegian fjords during autumn of the years 1995–2004. Surveys tended to be carried out later in autumn in the more recent years than in the earlier years. Consequently, there was a significant decrease in sun's altitude from 1995 to 2004 at the time the surveys were carried out. Further inconsistency among years dominated when comparing catch per unit effort (cpue) by year class and age over time. Often, the observed cpue at age $a + 1$ in year $y + 1$ was greater than in year y at age a. Spearman's rank correlation of cpue vs. year also demonstrated inconsistencies in the data. The problems related to separating CC and northeast Arctic cod are discussed.

Keywords: coastal cod, fjords, Norway, survey methodology, trawl survey.

Received 20 September 2007; accepted 24 March 2008; advance access publication 1 May 2008.

T. M. Lunde and O. R. Godø: PO Box 1870 Nordnes, N-5817, Bergen, Norway. R. Rosland: Department of Biology, University of Bergen, PO Box 7800, N-5020, Bergen, Norway. Correspondence to T. M. Lunde: Faculty of Medicine, Center for International Health, PO Box 7804, N-5020 Bergen, Norway. tel: +47 454 28 780; fax: +47 55 97 49 79; e-mail torleif.lunde@cih.uib.no.

Introduction

According to ICES, the International Council for the Exploration of the Sea (ICES, 2006), populations of coastal cod (CC) in Norway north of 62°N have been declining since 1994. ICES recommended stopping the fisheries for CC from 2004 (ICES, 2005), and in 2006, CC were classified as endangered by the Norwegian Biodiversity Information Centre (Nedreås *et al.*, 2006). The reliability of fish stock assessments depends heavily on the quality of survey data and knowledge of the biology of the fish species for which the survey is designed. Therefore, enhanced knowledge of species biology and life history are required, and survey strategies and methods need to be scrutinized. Here, we focus on quality aspects of trawl data on CC collected off northern Norway from 1995 to 2004, and discuss potential methodological constraints and biological factors with implications for quality and reliability of current survey strategies and methods.

The population structure of CC is complex and not fully understood. Some 75% of the CC stock is found north of 67°N, and inshore areas have better catch rates than offshore ones, and shallow areas better catch rates than deeper ones (Berg and Albert, 2003). Considering the relatively large geographical areas and wide range of environments inhabited by CC, it would be reasonable to assume that distinct subpopulations develop variable life history traits (Law, 2000). Variable migration patterns (Jakobsen, 1987), growth and maturation (Berg and Pedersen, 2001; Olsen *et al.*, 2004; Salvanes *et al.*, 2004), and variations in non-coding DNA, which show a north–south gradient in frequency distribution of neutral isozymes (Mork and Giæver, 1999), indicate that cod populations are more or less discrete in North Norwegian fjords. However, Godø and Moksness (1987) suggested that differences in growth and age at first spawning of CC and northeast Arctic cod (NAC) reflect differences in the environment rather than genetic variation. Given that the early life stages remain near the spawning grounds and are not drained out of the fjords, that migrations are limited, and that CC do not interbreed with NAC (Nordeide, 1998; Pogson and Fevolden, 2003), it can be argued that each fjord has one or perhaps several independent subpopulations. Despite these indications, however, the concept of isolated subpopulations has not yet been adopted in fisheries management (ICES, 2007).

The basis for the population estimates of CC are combined trawl and acoustic surveys carried out north of 62°N (Michalsen, 2003). Hjellvik *et al.* (2002a) found that in the Barents Sea, the measurement error was small, 2–5% on a log scale in terms of variance of catch per towed distance. Therefore, bottom-trawl surveys would give a good estimate of the density of cod at a given site at any given time. However, trawl surveys in fjord systems (and offshore) do not necessarily reflect the abundance of CC, because cod are mobile organisms capable of vertical movements (Hjellvik *et al.*, 2002b, 2004), and migration to coastal areas and other fjords does take place (Jakobsen, 1987). The distribution and migration of NAC is also related to temperature (Drinkwater, 2006). Although the biology of CC is less well understood, a potential interannual variation in its patterns of migration and distribution should not be overlooked.

Our overall goal with this work was to evaluate whether the surveys currently being conducted are suitable for stock assessments. In particular, survey design in relation to variations in the physical environment need to be evaluated, questioning whether violation of standardization survey protocol has invalidated the time-series. Studied factors include:

(i) annual timing of the survey;
(ii) time of day when the work was carried out;

(iii) the fraction of the fjord area available for trawling;

(iv) the vessel effect.

We also investigate time/space consistency in density and composition measurements, and discuss the potential impacts of migration of CC and NAC in and out of the fjord systems, including a discussion of the classification based on otolith reading.

Material and methods

As most CC are found north of 67°N, we selected that area for our study. In all, 11 fjords with different geographical characteristics were included in the analysis. The trawl data have been rigorously quality controlled since 1995 (E. Berg, pers. comm.), and should therefore be suitable for purpose.

Four major fjord systems in Troms and Finnmark (Varangerfjord, Porsangefjord, Lyngenfjord, and Malangen) were selected as the main areas for investigation (Figure 1), based on their data coverage and spatial dispersion. The number of positive hauls per year is limited (Table 1), and generally just three hauls are made in each fjord system each year. For comparison, material from some other fjords was also included, so totally including 11 fjords (Varangerfjord, Tanafjord, Porsangerfjord, Laksefjord, Revsbotn, Tubåen, Altafjord, Sørøysund, Kvænangen, Lyngenfjord, and Malangen). The fjords cover a total of 31 subareas in which random trawls are made (within their trawlable parts). Trawls were clustered, and the limit of each subarea defined as the maximum and minimum latitude and longitude of trawls made in each cluster. We also compared the results from the main fjords with the winter survey data on NAC (Aglen *et al.*, 2005).

The fjord surveys were carried out from 1995 to 2004, and all surveys were conducted between 20 August and 11 November. Samples were taken by day and night, and at dusk and dawn, but each survey did not necessarily include hauls from each diel period.

Samples used here were taken by shrimp trawl, the Campellen 1800. Three different vessels were used: FVs "Jan Mayen" (1998–2004), "Johan Hjort" (2003–2004 in Varangerfjord, Tanafjord, and Laksefjord), and "Michael Sars" (1995–1997). The cod were grouped into five types based on the growth rings on the otoliths: (1) CC, (2) questionable CC, (3) Svalbard type, (4) questionable NAC, and (5) NAC (Rollefsen, 1933, 1934). All fish were measured to the nearest centimetre below, and the age of a variable number of cod was determined for each trawl. The age of cod with missing age data was estimated by the function aregImpute routine from the Hmisc library (Harrell, 2006) in the software R (R Development Core Team, 2006). The imputations were done separately for each fjord with 100 imputations. There are two main limitations of this method: (i) age determination is problematic for cod <20 cm, and (ii) length–age relationships may overlap for ages 4–5. The first problem is covered because the lengths-at-age of cod <20 cm have a lower standard deviation (s.d.) than those for larger cod, and the second issue is partly

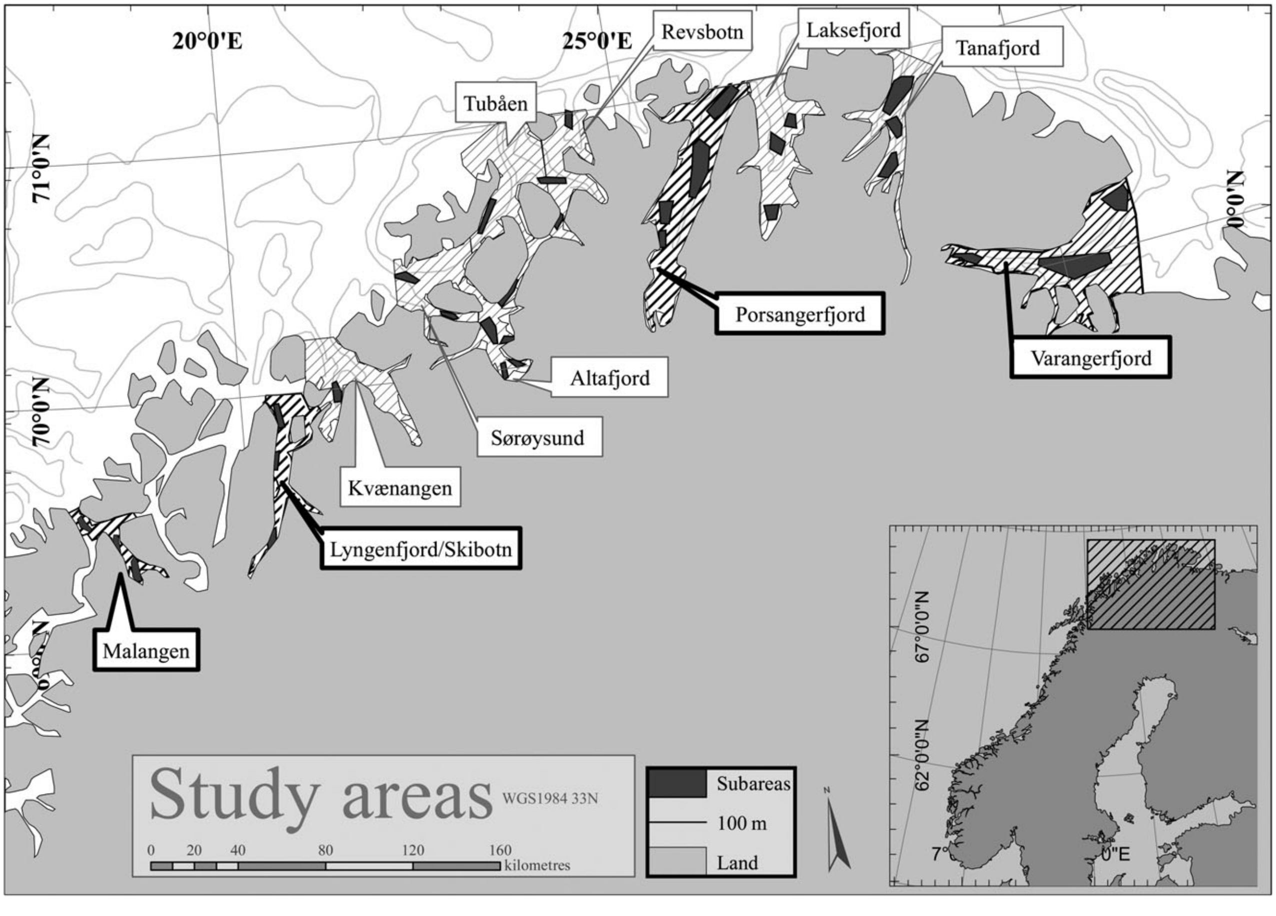

Figure 1. The study areas. The main focus was on Malangen, Lyngenfjord, Porsangefjord, and Varangerfjord. The dark areas are the subareas.

Table 1. Number of trawls in the different main areas and subareas, 1995–2004.

Main area	Subarea	Number of trawls
Varangerfjord	1	10
	2	12
	3	10
Porsangerfjord	1	9
	2	10
	3	18
	4	16
Lyngenfjord	1	14
	2	12
	3	10
Malangen	1	12
	2	14
	3	9

addressed by the use of a large number of imputations. This method was preferred over the standard age–length key commonly used, because the imputation method generates a completely raw dataset by age, rather than making use of just the catch per unit effort (cpue) and the percentage of different year classes in each trawl. The raw data, with imputation, were used in the preparation phase where differences in age composition were investigated. Donders *et al.* (2006) provide an introduction to multiple imputations of missing values.

For each trawl, cpue (as catch per hour) was calculated for all cod and for otolith types (1)–(5) separately. Towing time, recorded from start to stop, differs slightly from the time estimated by dividing the distance by the vessel speed. Our cpue calculations are based on estimated time. The cpue values used are therefore deduced from:

$$\mathrm{cpue}_a = f_a(sv^{-1})^{-1} \qquad (1)$$

and

$$\mathrm{cpue}_{k,a} = f_{k,a}\mathrm{cpue}_a\left(\sum_{k=1}^{5} f_{k,a}\right)^{-1}, \qquad (2)$$

where f is the catch, s the distance trawled in nautical miles recorded in the data, and v the velocity of the vessel in nautical miles h^{-1}, and a refers to age, and k to cod type (1–5). Annual timing of the survey, time of day, and sample location are all likely to influence trawling conditions. The effect of annual timing is evaluated based on the actual time difference in towing time at a given fjord location, and we have arbitrarily defined 10-d difference as the threshold for accepting period uniformity. Sun's altitude is used as a proxy to show any changes in the physical environment, e.g. a shorter daylength and changing temperature. From September to December, a difference of 10 d represents approximately a change in sun's altitude of -3.5° to 0°. Although a difference of 10 d is not linearly related to sun's altitude, there are probably also other time-related factors that influence the spatial distribution of cod. Our annual timing definition will indicate when a substantial temporal effect might be expected, but it is not directly associated with differences in light. To test for increasing or decreasing trends caused by light, we used a linear model specified as

$$Y_{\mathrm{altitude}} = (\alpha + \beta_1) \times (\mathrm{year} + \beta_2) \times (\mathrm{main\ area} + \varepsilon). \qquad (3)$$

Sun's altitude was calculated with the SunAPI (Sunlit Design, 2006). Local time was converted to Modified Julian Day, and altitude was calculated by the sdxAlt function.

Consistency in survey results over time was tested by comparing the cpue of a specific year class with the cpue of that same year class in the same area 1 year later. As the expected catch in each area is unknown, it is difficult to use a theoretical curve for the age distribution, and similar for mortality over time. One way to detect whether the same population is sampled each year or whether the trawl is able to catch a representative age distribution of CC each year is to follow the year classes from age a in year y to age $a+1$ in year $y+1$. If the same population is sampled each year, and the trawl manages to catch a representative group of the true population, it should at least be expected that

$$\mathrm{cpue}_{a+1,y+1} < \mathrm{cpue}_{a,y}. \qquad (4)$$

Two independent reference curves were used, one calculated from the mean of all 31 subareas, and one based on the bottom-trawl surveys on cod in the Barents Sea (Aglen *et al.*, 2005). The Barents Sea curve is an indicator of expected mortality if the coastal populations follow the same patterns as the cod in the Barents Sea, whereas the curve based on all subareas in the fjords would describe a common mortality pattern based on the idea that the sum of all fjords eliminates migration disturbances and smoothes the uncertainty of the samples taken in the different fjords. To make these curves comparable, they were all standardized according to

$$\mathrm{cpue}_{\mathrm{st},a,y} = 100\ \mathrm{cpue}_{a,y}\left(\sum_{a=2}^{6}\mathrm{cpue}_{a,y}\right)^{-1}. \qquad (5)$$

Spearman's rank correlation (r_{Sp}) was also applied to test the correlation between cpue and year by ranking cpue and year. Assuming consistency, the expected result would be $r_{\mathrm{Sp}} = -1$. The formula used was

$$r_{\mathrm{Sp}} = \left(\sum_{i=1}^{n}(R_i - \bar{R})(S_i - \bar{S})\right)\left(\sum_{i=1}^{n}(R_i - \bar{R})^2(S_i - \bar{S})^2\right)^{-0.5}, \qquad (6)$$

where R is the cpue-rank and S the year-rank. This test not only compares cpue at $y+1$ with that at y for a specific year class, but looks too at the entire series, which can be used to describe the total cpue–year correlation for the specified year class. The test was applied only on data from the year that the maximum cpue had been reached and beyond.

The total area for each of the 11 main areas and for the 31 subareas (Figure 1) was calculated in ArcGIS with the geographical coordinate system WGS84 and the projected coordinate system WGS84 UTM zone 33N. The trawlable areas were then calculated from

$$\%A = 100\left(\sum_{k=1}^{k} A_{\text{subareas}\cap\text{main area}}\right)(A_{\text{main area}})^{-1}, \quad (7)$$

and the trawled areas of the whole fjord were calculated from

$$\%A_{\text{trawled}} = s \times 1852 \times dn(A_{\text{main area}})^{-1}, \quad (8)$$

where s is 1.5 nautical miles, d the door spread (50 m), n the number of trawls, and A the fjord surface area in m^2 (1 nautical mile = 1852 m).

Results

Annual and diel timing

The linear model demonstrated a decreasing trend in sun's altitude from 1995 to 2004. The trend was significant ($p < 0.01$), but the r^2 was low (0.14). There was no significant west–east trend expressed by area (Figure 2). The first three years, 1995, 1996, and 1997, the samples were taken in August and September, whereas for the subsequent years, the surveys were conducted between mid-October and mid-November. Haul data from the inner part of Varangerfjord (Table 2) show that 60% of the trawls had an absolute temporal distance of at least 10 d. Observations were similar for the other subareas.

Figure 3 shows that the start time of the trawls in the years 1995–2004 reflects a non-significant trend. In different years, various times of the day are represented in the dataseries. A closer look reveals that the variations are not only on the level of the main area, but also that there are large variations in sampling time from year to year in the subareas, as exemplified by the tow times from the inner part of Varangerfjord. There, the mean time difference from 1995, when the starting time was 05:35, was 7 h 39 min, with an s.d. of 6 h 28 min.

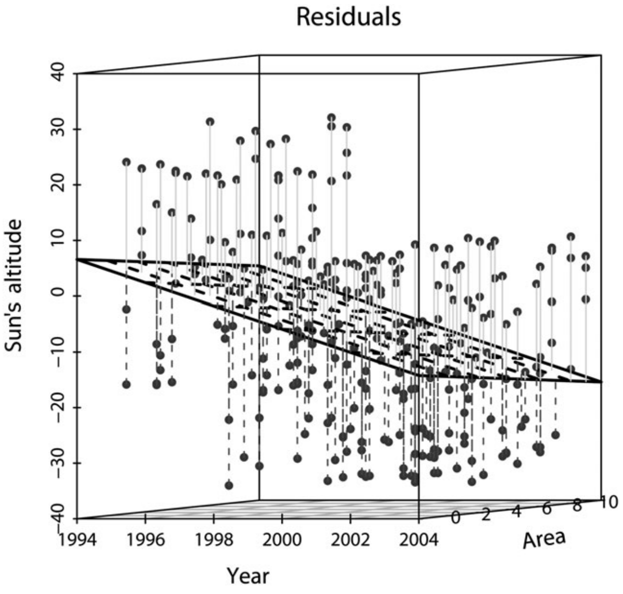

Figure 2. Residuals of the model (sun's altitude)$\sim$Year + Area. The sun's altitude is given as degrees over the horizon, and is calculated from date, time, latitude, and longitude of the start position of each trawl. Area refers to the areas described in text. The model of the sun's altitude over years had $p < 0.01$ and $r^2 = 0.14$, and a decline from an altitude of 4.5° over the horizon in 1995 to 14.3° below the horizon in 2004.

Catch per unit effort

The 1993–1998 year classes were used to evaluate consistency in the cpue data. Age-at-maximum-recruitment to the trawl surveys was defined as the maximum cpue for the year class yc_n. Therefore, for each year class, we first identified age-at-recruitment. Of the CC year classes in the four main areas, Varangerfjord, Porsangerfjord, Lyngenfjord, and Malangen, 4% reached maximum recruitment at age 0, 29% at age 1, 46% at age 2, and 21% at age 3. The situation was not the same in each fjord system, though. For example, in Varangerfjord, the analogous figures were 33% at age 1, 50% at age 2, and 17% at age 3. Also, taking 9 of the 11 main areas (excluding areas 4 and 6, where the measurements from 1998 and 2004 were missing) as one area, 6% had maximum recruitment at age 0, 31% at age 1, 44% at age 2, 15% at age 3, 2% at age 4, and 2% at age 5. The results by fjord are summarized in Table 3.

If CC are considered non-migratory, it should be expected that an increase in cpue by age class should not occur after maximum recruitment, cf. Equation (4). In Varangerfjord, this rule was broken in 30% of the measurements for CC, and in 29% of the measurements for CC and NAC combined, in Porsangerfjord 24% for CC and 38% for NAC and CC combined, in Lyngenfjord 33% for CC and 42% for NAC and CC combined, and in Malangen 9% for CC and 9% for NAC and CC combined. Negative mortality was more frequent at a fjord level than when combining data from all fjords. The 1996 year class had an interesting development in the whole area. After standardization, the mortality of CC was only 22% from ages 2 to 5. The other year classes from 1993–1998 had a mortality between 57% and 89%. In the Barents Sea data, 21% of the measurements showed an increase at age $a+1$ in year $y+1$ over age a in year y. Corresponding values for CC when all fjords were merged were 21% (if the increase before maximum recruitment is included) or 17% (after the maximum), and 38% or 25%, respectively, for CC and NAC combined. Comparing the individual fjord data with the whole area revealed great variation around the mean for all fjords. The variations can be seen in Figure 4 for the open fjord Varangerfjord (year class 1997), the more closed Malangen (year class 1996), and Lyngenfjord (year class 1998). If the mortality rates were equal in Varangerfjord, Porsangerfjord, Lyngenfjord, and Malangen, the delta cpue (the difference between the observed, standardized cpue for each fjord and the same parameter for all fjords) would be expected to fluctuate little around the total, not as observed. The analysis was carried out for ages 2–6, and the increase in cpue was only recorded after the age at maximum recruitment. Note that the lines indicating an increase in cpue are before those showing maximum cpue, although these are not included in the analyses. Table 4 lists the results from the Spearman's rank correlation analysis. The expected value for cpue and time would be -1, whereas the expected value for cpue vs. cpue would be 1, but in only a few cases were the expected values obtained. For the categories all cod (types 1–5) and CC (types 1 and 2) against time, Malangen showed the most reliable results, whereas there was great variability for the other fjords. When observed cpue at a fjord level was compared with the cpue in all fjords for CC, all fjords had year classes

Table 2. Date differences in days for trawl hauls.

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	Mean
1996	−1	NA								–
1997	NA	NA	NA							–
1998	50	51	NA	NA						–
1999	45	46	NA	−5	NA					–
2000	47	48	NA	−3	2	NA				–
2001	44	45	NA	−6	−1	−3	NA			–
2002	52	53	NA	2	7	5	8	NA		–
2003	29	30	NA	−21	−16	−18	−15	−23	NA	–
2004	30	31	NA	−20	−15	−17	−14	−22	1	–
Mean	37	43	NA	−9	−5	−8	−7	−23	1	–
s.d.	18	9	NA	9	10	11	13	1	NA	–
|Mean|	37	43	NA	10	8	11	12	23	1	18
|s.d.|	17	9	NA	9	7	8	4	1	NA	8
% |dist.| > 10 d	88%	100%	NA	33%	40%	50%	67%	100%	0%	60%

Inner area, Varangerfjord; NA, not available.

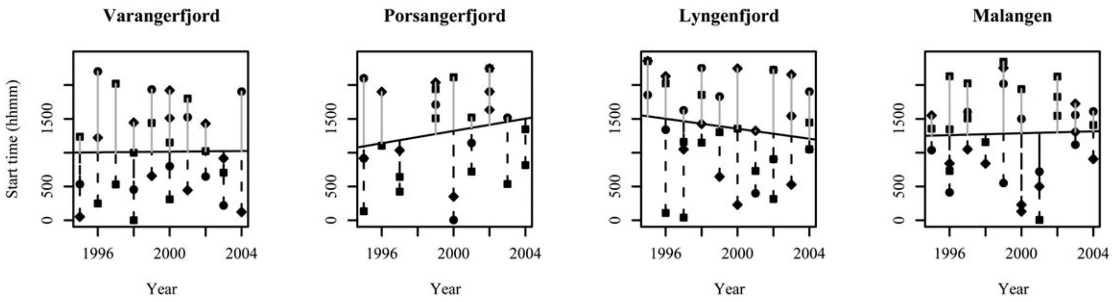

Figure 3. Start times for the trawl surveys in the different fjords. The lines indicate the non-significant trend. Circles, subarea 1; squares, subarea 2; diamonds, subarea 3; inverted triangles, subarea 4.

Table 3. Distribution of age where cpue had its maximum for year classes from 1995 to 1998.

Main area	0 year	1 year	2 years	3 years	4 years	5 years
Varangerfjord (%)	0	33	50	17	0	0
Porsangerfjord (%)	17	33	17	33	0	0
Lyngenfjord (%)	0	50	50	0	0	0
Malangen (%)	0	0	67	33	0	0
All areas (%)	6	31	44	15	2	2

that differed from the total mortality or the mean cpue. The results were the same when all cod were compared with all cod in all fjords and when cpue for all cod were compared with the cpue in the Barents Sea for coincident years and year classes. However, because of the sparseness of observations, *p*-values were not reliable, so are not listed.

When the trawl survey was completed, the numbers of CC and NAC were recorded. This raises the questions: how reliable is the separation between CC and NAC when classified by otoliths, and do NAC stay in the fjords after arriving there? The data described earlier show that the proportion of NAC is greater in the open fjords to the east. In Malangen, the proportion of NAC was low, and migration of NAC into the other fjords was variable. The 1996 year class of NAC in Varangerfjord (Figure 5a) showed close to zero mortality, indicating a continuous migration into the fjord between ages 2 and 6. The same result was observed for the 1997 and 1998 year classes, but not for 2001, where the proportion of NAC seemed to be high compared with CC. Except from the 1995 year class at ages 5 and 6, the proportion of NAC seems to be small in Porsangerfjord (Figure 5b).

Interpretation of the results needs also to consider the relative size of the areas sampled. The areas accessible to trawling, expressed as a percentage of the total fjord area, totalled 12%. In Varangerfjord, Porsangerfjord, Lyngenfjord, and Malangen, respectively, trawlable areas represented 15%, 17%, 13%, and 18% of the total area. However, the areas trawled during each survey are much smaller still. Given that there were three trawls per fjord per year, 0.02% of Varangerfjord (0.11% of the trawlable areas), 0.03% of Porsangefjord (0.17%), 0.06% of Lyngenfjord (0.45%), and 0.09% of Malangen (0.51%) were trawled annually. The area trawled each year as a percentage of the total area of all fjords was 0.03%, or 0.28% of the trawlable areas in all fjord systems.

Discussion

Our analysis has shown unexpected high variability in mortality recorded from trends in cpue. Also, the age-at-maximum-recruitment to the bottom-trawl survey varied over the time-series. Factors that may have caused these inconsistencies include: changes in the annual timing of the survey, inconsistency in handling time of day in the survey design, lack of geographical

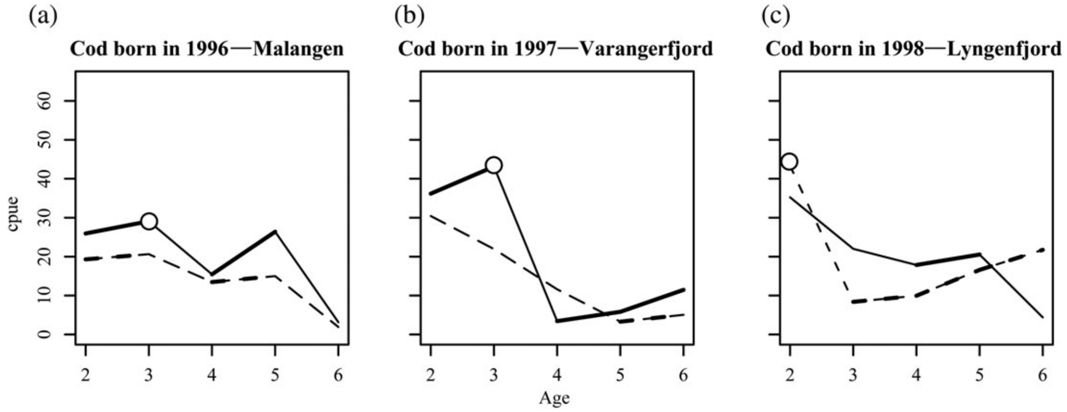

Figure 4. Variation in cpue for the year classes 1996 (Malangen), 1997 (Varangerfjord), and 1998 (Lyngenfjord). (a) and (b) Solid line, cpue CC; strong solid line, increase cpue CC; broken line, cpue CC all areas; strong broken line, increase cpue CC all areas; and circle, max cpue CC. (c) Solid line, cpue Barents Sea; strong solid line, increase cpue Barents Sea; broken line, cpue CC and NAC; strong broken line, increase cpue CC and NAC; and circle, max cpue CC and NAC.

Table 4. Results of the Spearman's rank correlation.

Year	Varangerfjord					Porsangerfjord					Lyngenfjord					Malangen				
	G1	G2	G3	G4	G5	G1	G2	G3	G4	G5	G1	G2	G3	G4	G5	G1	G2	G3	G4	G5
1993	−0.2	−0.7	0.7	0.5	0.5	−0.8	−0.8	0.8	0.8	0.8	−0.2	−0.2	0.2	0.2	0.2	−1.0	−1.0	1.0	1.0	1.0
1994	−0.3	−0.6	0.6	0.3	0.1	−0.2	−0.8	0.8	0.5	0.6	−0.9	−1.0	1.0	0.9	0.8	−1.0	−1.0	0.4	0.4	0.2
1995	−0.7	−0.9	1.0	0.6	0.6	−0.5	−0.9	1.0	1.0	0.2	−0.3	−0.3	0.1	0.4	0.4	−1.0	−1.0	0.9	0.5	0.9
1996	−1.0	−1.0	0.8	0.5	0.9	−0.9	−0.9	0.5	0.2	1.0	−0.7	−0.7	0.8	0.6	0.4	−0.8	−0.8	0.9	0.9	0.5
1997	−1.0	−0.2	0.6	0.8	0.8	−0.8	−1.0	0.8	0.9	0.9	−0.3	−0.3	0.6	0.6	0.6	−1.0	−1.0	0.9	0.9	0.9
1999	−0.8	−0.9	1.0	0.9	0.9	−0.5	−0.5	0.8	0.8	0.8	0.0	−0.1	0.3	0.1	0.1	−0.7	−0.7	0.6	0.6	0.6
Mean	−0.7	−0.7	0.8	0.6	0.6	−0.6	−0.8	0.8	0.7	0.7	−0.4	−0.4	0.5	0.5	0.4	−0.9	−0.9	0.8	0.7	0.7
s.d.	0.3	0.3	0.2	0.2	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.1	0.1	0.2	0.2	0.3

Where cpue and time are correlated, the expected value would be −1, and where cpue is compared with cpue the expected value is 1. G1, cpue for all cod (1–5) and time; G2, cpue for CC (1, 2) and time; G3, cpue for CC (1, 2) and cpue for CC in all areas; G4, cpue for all cod (1–5) and cpue for all cod in all areas; G5, cpue for all cod (1–5) and cpue for cod in the Barents Sea.

and habitat coverage, and, finally, migration into and impact of NAC in the fjords. We now discuss our cpue results in relation to these potential effects, and comment on the basic quality of the data we have analysed.

Data analysed

Data separation between CC and NAC, as well as age determination, was based on otolith reading. More than showing differences between species, the shape of the rings in the otoliths reflects variations in migration patterns. Therefore, if a NAC remains at a single locality, the otoliths will seemingly be similar to those of a virtually resident CC. In an experiment, Otterå *et al.* (1999) tested the disparity in spatial movement between NAC and Norwegian CC reared and released under similar conditions. The patterns were found to be indiscriminate. Therefore, otolith reading may fail to separate NAC and CC restricted to the same environment. Typing by otoliths to separate the two cod groups was a method developed by Rollefsen (1933, 1934), and classification is still based on those methods. Relying on these methods might result in misinterpretation, exemplified, for example, by the results of Berg *et al.* (2005), who emphasized the instability of the separations, and the error added by otolith reading compared with a system when genotypes were investigated. Our interpretation of the data is a little different from the original paper, but more relevant to the coastal areas. Three of the coastal areas investigated are of interest here. In the inner part of Varangerfjord, 13 cod were classified on genotype as CC, 31 as uncertain, and 16 as NAC. Four readers classified between 0 and 54 cod to be definitely CC, with an average of 23 and an s.d. of 23. When both certain and uncertain cod were included, the maximum was 54 and the minimum 4, the average 31, and the s.d. 21. In Ullsfjord (next to but west of Lyngenfjord), where NAC are fewer, the classification seemed more reliable, with better correspondence with the genotype distinctions. In the outer part of the Tanafjord (next to and west of Varangerfjord), 1 cod was classified as CC based on genotype, 14 as uncertain, and 38 as NAC. The readers found from 0 to 27 to be definitely CC (average 11, s.d. 11) and 5–27 to be certain or uncertain CC (average 14, s.d. 9). Hence, classification by otolith reading might lead to unexpected errors in the understanding and interpretation of the data.

When following a year class, in addition to type classification, it is essential to determine the number of each age group in the trawl, or in each area. There are several means of doing this, each with its advantages and disadvantages. Campana (2001) discusses various procedures, and describes a number of examples of the consequences of misinterpretation. We used otolith reading, and the possibility of misinterpretation (leading to biased conclusions)

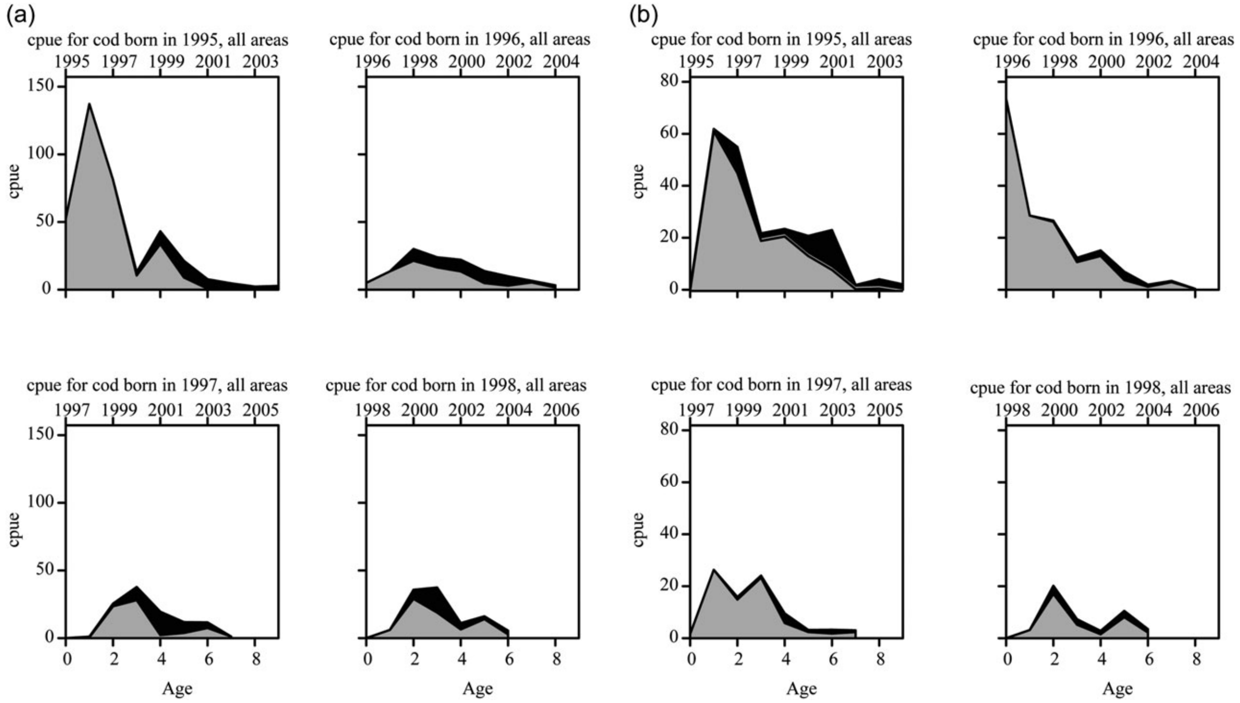

Figure 5. The relative proportion of CC (grey) and NAC (black) in (a) Varangerfjord, and (b) Porsangerfjord for cod born from 1995 to 1998. The recorded fraction of NAC relative to NAC is highly variable from year to year. The upper line shows the standardized total cpue.

should not be excluded. Two factors might have influenced our cpue for the age groups: first, the uncertainty associated with otolith reading, and second, the method of modelling age may have added errors to the results. However, more of the cod caught during the surveys were classified in later years of the series, so the uncertainty is more likely linked to otolith interpretation.

Annual timing of the survey

Most fish species follow an annual life cycle that influences its seasonal distribution and behaviour (e.g. NAC; Bergstad *et al*., 1987). Standardization of scientific surveys normally aims, therefore, to maintain seasonal stability (see Gunderson, 1993). In our case, the shift in the annual timing of the survey led to reduced light intensity during later surveys. The overall change was greatest when comparing the years 1995–1997 with the subsequent years. From commercial catch data, it is known that cpue changes seasonally, sometimes abruptly from month to month (Trout, 1962; Godø, 1994). Such factors may therefore seriously influence the outcome of our surveys. Mello and Rose (2005) found that cod in Placentia Bay, Canada, aggregated in a few large congregations, and that the centre of the cluster moved between October (inner bay) and November (outer bay). Therefore, the distribution of cod at different times may be a basic and critical factor to consider in the sampling process. Further information about the clustering process parameters would give better understanding of the variance, as well as allowing for better design, utilization, and assessment of surveys (Brown and Cowling, 1998). If aggregation and movement of the aggregations seasonally is an important behaviour of CC, it might help us explain the unexpected trajectories of the cpue by year classes between years.

Changes in the annual timing of the surveys, of course, also mean variation in daylight length and intensity, and our results are also subject to a diel influence (see below).

Time of day

Diel factors strongly influence behaviour and hence the cpue of many fish species and stocks (Shepherd and Forrester, 1987; Perry and Neilson, 1988; Walsh, 1991; Engås and Soldal, 1992; Michalsen *et al*., 1996; Aglen *et al*., 1999). Earlier work on NAC has shown that diel variability adds substantial and variable noise to the data if not adjusted for (Hjellvik *et al*., 2002b, 2004). However, as the latter work was on NAC in the Barents Sea, their results cannot be applied directly to CC. Tagging studies in coastal areas off eastern Canada showed that cod were active by day and passive by night (Clark and Green, 1990). Such behaviour could dramatically influence the results of a bottom-trawl survey carried out around the clock. However, the relatively few stations per fjord in our surveys, and the random timing of the start of each tow makes modelling of any diurnal effect virtually impossible. Also, as shown above, the seasonal signal reduces the amount of light during the survey as calendar time passes. This may imply that the samples will indicate the presence of cod in the given year and time, but not necessarily support trends in biomass, age, or length distribution over years. Of course, standardization of the surveys by season/month and time of day would remove some of the influential factors in the uncertainty, but such an approach would violate the principle of randomization with respect to time.

Survey coverage

The fjords are difficult for bottom trawling because the seabed is not smooth. As only a small fraction of the fjord area is available for sampling (13–18%) and only 0.02–0.09% of the area was actually trawled each year, the survey is susceptible to distribution effects in relation to this habitat. Ideally, the sampled area would reflect the distribution and abundance of fish in time and space in a representative manner. Massé and Retiere (1995) concluded that the number and location of trawls had a powerful influence on the estimates of less abundant species. In the fjords where only smooth substrata can be trawled, the sampling location is only random within the trawlable areas, so it is an open question whether the fish available in these areas are representative of the overall composition of age and species in each fjord.

Diel effects in the cpue have been discussed already, but are important in relation to habitat coverage. Clark and Green (1990) show that cod may seek different habitat by day and night, so there is a critical need to improve our knowledge of the distribution patterns of cod in the fjords to allow a more effective scientific survey design to be employed.

Migration and impact of NAC

CC in fjords are normally considered resident (Godø, 1986), but there is a variable extent of emigration and immigration (Jakobsen, 1987). The same conclusion was reached for NE Atlantic cod by Robichaud and Rose (2004). We also know that migration can be triggered by environmental change. Drinkwater (2006) described extensive movements of cod in the 1920s and 1930s related to temperature, so the possibility of variable migration of CC populations should not be overlooked. If offshore migration of CC took place between 1995 and 2004, it would be recorded in the surveys as a decrease in population biomass, and considered the consequence of mortality. Also, migration between fjords could cause unexpected variation in cpue. If this was the case, we would have expected more stable trends in cpue by combining the data from several fjords. Although this did happen to some small degree, probably due to the larger dataset available for analysis, our analyses did not support a migration hypothesis.

The varying influence of NAC may have influenced our results. Interaction between NAC and CC may cause behavioural or distribution changes critical to the efficiency of the survey. For example, could migratory behaviour of NAC influence migration of CC? Also, we cannot rule out the possibility that the variable number of NAC in the material collected for age determination may have affected our classification and confused the cpue analysis, although no trends in our material support this possibility.

Vessel effect

Comparative trawling experiments among vessels are reported by Hjellvik *et al.* (2002a). The experiments demonstrated systematic differences among the vessels used in the CC surveys, FVs "Jan Mayen" and "Michael Sars" being more efficient than FV "Johan Hjort". FVs "Michael Sars" and "Jan Mayen" were not compared. Importantly, there is no guarantee that the available comparisons are valid under fjord conditions, so we have not used vessel comparison data in our analysis. Assuming, however, that FV "Johan Hjort" is significantly less efficient than the other two vessels, as suggested by Hjellvik *et al.* (2002a), our conclusions for Varangerfjord in 2003 and 2004 as well as the overall picture for the same years might be open to question.

Concluding remarks

We believe that we have demonstrated some of the problems and uncertainties associated with noise in trawl survey data on Norwegian CC. However, we suggest that the situation could be improved by a more consistent survey design, including a fixed time of year and standardized trawl positions and times of day. Also, improved otolith interpretation techniques for distinguishing CC and NAC, and better precision in the age determination may improve data quality. Nevertheless, because knowledge of how and why cod of different types are distributed in time and space (habitats and areas) is still poor, any standardization cannot guarantee better quality. Addressing this lack of knowledge remains the most basic challenge in designing an appropriate survey for assessing CC in the fjords.

Acknowledgements

We thank V. Hjellvik, A. Aglen, and D. Tjøstheim for valuable discussions, E. Berg for making the data available, and Jacques Massé and John Wallace for excellent reviews. The work was financed by IMR, Norway's Institute of Marine Research.

References

Aglen, A., Alvsvåg, J., Grekov, A., Høines, A., Mehl, S., and Zhukova, N. 2005. Investigations of demersal fish in the Barents Sea, winter 2005. IMR/PINRO Joint Report Series, 4/2005. 58 pp.

Aglen, A., Engås, A., Huse, I., Michalsen, K., and Stensholt, B. K. 1999. How vertical fish distribution may affect survey results. ICES Journal of Marine Science, 56: 345–360.

Berg, E., and Albert, O. T. 2003. Cod in fjords and coastal waters of North Norway: distribution and variation in length and maturity at age. ICES Journal of Marine Science, 60: 787–797.

Berg, E., and Pedersen, T. 2001. Variability in recruitment, growth and sexual maturity of coastal cod (*Gadus morhua* L.) in a fjord system in northern Norway. Fisheries Research, 52: 179–189.

Berg, E., Sarvas, T. H., Harbitz, A., Fevolden, S. E., and Salberg, A. B. 2005. Accuracy and precision in stock separation of north-east Arctic and Norwegian coastal cod by otoliths—comparing readings, image analyses and a genetic method. Marine and Freshwater Research, 56: 753–762.

Bergstad, O. A., Jørgensen, T., and Dragesund, O. 1987. Life-history and ecology of the gadoid resources of the Barents Sea. Fisheries Research, 5: 119–161.

Brown, B. M., and Cowling, A. 1998. Clustering and abundance estimation for Neyman–Scott models and line transect surveys. Biometrika, 85: 427–438.

Campana, S. E. 2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. Journal of Fish Biology, 59: 197–242.

Clark, D. S., and Green, J. M. 1990. Activity and movement patterns of juvenile Atlantic cod, *Gadus morhua*, in Conception Bay, Newfoundland, as determined by sonic telemetry. Canadian Journal of Zoology, 68: 1434–1442.

Donders, A. R. T., van der Heijden, G., Stijnen, T., and Moons, K. G. M. 2006. Review: a gentle introduction to imputation of missing values. Journal of Clinical Epidemiology, 59: 1087–1091.

Drinkwater, K. F. 2006. The regime shift of the 1920s and 1930s in the North Atlantic. Progress in Oceanography, 68: 134–151.

Engås, A., and Soldal, A. V. 1992. Diurnal-variations in bottom trawl catch rates of cod and haddock and their influence on abundance indexes. ICES Journal of Marine Science, 49: 89–95.

Godø, O. R. 1986. Dispersion and mingling of cod from various nursery and feeding areas along the Norwegian coast and the Barents Sea. *In* Workshop on Cooperative Biology, Assessment, and Management of Gadoids from the North Pacific and Atlantic Oceans II, Seattle. Northwest and Alaska Fisheries Center, Alton.

Godø, O. R. 1994. Factors affecting the reliability of groundfish abundance estimates from bottom trawl surveys. *In* Marine Fish

Behaviour in Capture and Abundance Estimation, pp. 166–195. Ed. by A. Fernö, and S. Olsen. Blackwell Science, Oxford.

Godø, O. R., and Moksness, E. 1987. Growth and maturation of Norwegian coastal cod and northeast Arctic cod under different conditions. Fisheries Research, 5: 235–242.

Gunderson, D. R. 1993. Surveys of Fisheries Resources. John Wiley, New York.

Harrell, F. E. J. 2006. Hmisc: Harrell Miscellaneous. R package version 3.1–1.

Hjellvik, V., Godø, O. R., and Tjøstheim, D. 2002a. The measurement error in marine survey catches: the bottom trawl case. Fishery Bulletin US, 100: 720–726.

Hjellvik, V., Godø, O. R., and Tjøstheim, D. 2002b. Diurnal variation in bottom trawl survey catches: does it pay to adjust? Canadian Journal of Fisheries and Aquatic Sciences, 59: 33–48.

Hjellvik, V., Godø, O. R., and Tjøstheim, D. 2004. Decomposing and explaining the variability of bottom trawl survey data from the Barents Sea. Sarsia, 89: 196–210.

ICES. 2005. Report of the ICES Advisory Committee on Fishery Management. ICES Advice, 1–11. 1418 pp.

ICES. 2006. Report of the ICES Advisory Committee on Fishery Management, Advisory Committee on the Marine Environment and Advisory Committee on Ecosystems, 2006. ICES Advice, 1–10.

ICES. 2007. Report of the Arctic Fisheries Working Group, 18–27 April 2007. ICES Document CM 2007/ACFM: 16.

Jakobsen, T. 1987. Coastal cod in Northern Norway. Fisheries Research, 5: 223–234.

Law, R. 2000. Fishing, selection, and phenotypic evolution. ICES Journal of Marine Science, 57: 659–668.

Massé, J., and Retiere, N. 1995. Effect of number of transects and identification hauls on acoustic biomass estimates under mixed-species conditions. Aquatic Living Resources, 8: 195–199.

Mello, L. G. S., and Rose, G. A. 2005. Seasonal variation in abundance and stock composition of Atlantic cod (*Gadus morhua* L.) in Placentia Bay, Newfoundland, in relation to fisheries. Fisheries Research, 74: 142–156.

Michalsen, K. 2003. Havets ressurser 2003. Fisken og havet, særnummer, 1–2003: 30–33.

Michalsen, K., Godø, O. R., and Fernø, A. 1996. Diel variation in the catchability of gadoids and its influence on the reliability of abundance indices. ICES Journal of Marine Science, 53: 389–395.

Mork, J., and Giæver, M. 1999. Genetic structure of cod along the coast of Norway: results from isozyme studies. Sarsia, 84: 157–168.

Nedreås, K. H., Byrkjedal, I., Christiansen, J. S., Gjøsaeter, J., Langhelle, E., Pethon, P., and Uiblein, F. 2006. Marine fish. *In* 2006 Norwegian Red List, pp. 341–350. Ed. by J. A. Kaalaas, A. Viken, and T. Bakken. Artsdatabanken, Norway.

Nordeide, J. T. 1998. Coastal cod and North-east Arctic cod—do they mingle at the spawning grounds in Lofoten? Sarsia, 83: 373–379.

Olsen, E. M., Knutsen, H., Gjosaeter, J., Jorde, P. E., Knutsen, J. A., and Stenseth, N. C. 2004. Life-history variation among local populations of Atlantic cod from the Norwegian Skagerrak coast. Journal of Fish Biology, 64: 1725–1730.

Otterå, H., Jørstad, K. E., Svåsand, T., and Kristiansen, T. S. 1999. Migration patterns and recapture rates of North-east Arctic and Norwegian coastal cod reared and released under similar conditions. Journal of Fish Biology, 54: 213–217.

Perry, R. I., and Neilson, J. D. 1988. Vertical distributions and trophic interactions of age-0 Atlantic cod and haddock in mixed and stratified waters of Georges Bank. Marine Ecology Progress Series, 49: 199–214.

Pogson, G. H., and Fevolden, S. E. 2003. Natural selection and the genetic differentiation of coastal and Arctic populations of the Atlantic cod in northern Norway: a test involving nucleotide sequence variation at the pantophysin (PanI) locus. Molecular Ecology, 12: 63–74.

R Development Core Team. 2006. R: a Language and Environment for Statistical Computing v. 2.3.0. R Foundation for Statistical Computing, Vienna, Austria.

Robichaud, D., and Rose, G. A. 2004. Migratory behaviour and range in Atlantic cod: inference from a century of tagging. Fish and Fisheries, 5: 185–214.

Rollefsen, G. 1933. The otoliths of the cod: preliminary report. Fiskeridirektoratets skrifter, Serie Havundersøkelser, 4(3). 14 pp.

Rollefsen, G. 1934. The cod otolith as a guide to race, sexual development and mortality. Rapports et Procès-Verbaux des Réunion du Conseil Permanent Internationale pour l'Exploration de la Mer, 88: 1–15.

Salvanes, A. G. V., Skjæråsen, J. E., and Nilsen, T. 2004. Sub-populations of coastal cod with different behaviour and life-history strategies. Marine Ecology Progress Series, 267: 241–251.

Shepherd, J. G., and Forrester, J. 1987. Diurnal variation in catchability during bottom trawl surveys off the Northeastern United States. ICES Document CM 1987/B: 44. 15 pp.

Sunlit Design. 2006. The SunAPI. http://www.sunlit-design.com retrieved January 2007.

Trout, G. C. 1962. Specific seasonal density changes in cod and haddock populations. ICES Document CM 1962/Comparative Fishing Committee No. 24. 12 pp.

Walsh, S. J. 1991. Diel variation in availability and vulnerability of fish to a survey trawl. Journal of Applied Ichthyology, 7: 147–159.

doi:10.1093/icesjms/fsn068