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Forsmark site investigation

Studies of fish abundance, densities and species composition at Forsmark

May and August/September 2004

Axenrot Tomas, Hansson Sture
Stockholm University, Department of Systems Ecology

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Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Keywords: Hydroacoustics, Herring, Abundance, Biomass, Forsmark, Öregrund, Gudinge, AP PF 400-04-55.

Abstract

Fish abundance, biomass, densities and species composition were investigated at Forsmark using hydroacoustics and trawling. The studies were performed twice, in May and August/September 2004. The results from Forsmark were compared with two reference areas, NW Öregrund and NE Gudinge. The Forsmark area is influenced by cooling-water from the nuclear power plant at Forsmark. This area had higher fish abundance than Gudinge in May as well as in August/September 2004. The fish size distributions were similar in May but differed in August/September having more small, young-of-the-year, juvenile fish at Gudinge. Öregrund seems to differ from both Forsmark and Gudinge, which probably reflects general differences in depths, topography etc. The trawling results show that herring is the dominant species in these areas both in spring and late summer/early autumn. Increased water temperatures at Forsmark were observed in the part closest to the cooling water outlet. In May we observed gas super-saturation in this area outside the cooling water outlet which may cause fish mortality. This has, however, not been observed.

Sammanfattning

Fiskbeståndens täthet, biomassa och artsammansättning studerades vid Forsmark genom att använda hydroakustik och trålning. Studierna genomfördes i maj och augusti/september. Resultaten från Forsmark jämfördes med två referensområden, ett NV om Öregrund och ett annat NO om Gudinge. Forsmarksområdet är påverkat av kylvattenutsläpp från Forsmarks kärnkraftverk, vilket också temperaturmätningarna i det ekointegrerade området visade. Detta område hade högre fisktäthet jämfört med Gudinge i både maj och augusti/september 2004. Fiskens storlekssammansättning var likartad i maj men skiljde sig åt i augusti/september. Således förekom mera unga fiskar, årsyngel, vid Gudinge. Öregrundsområdet skiljer sig från både Forsmark och Gudinge bl a genom att fiskarna är större. Detta avspeglar sannolikt generella skillnader i djup, topografi etc. Trålningarna visade att strömming är den helt dominerande arten i dessa områden både på våren och sensommaren. I maj iakttogs gasövermättnad i Forsmarksområdet i närheten av kylvattenplymen vilket kan orsaka fiskdöd. Någon sådan har dock inte observerats.

Contents

1 Introduction

This document reports the data gained by the hydroacustic surveys, which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-04-55. In Table 1-1 controlling documents for performing this activity are listed (activity plans are SKB's internal controlling documents). The data have been stored in SKB's database SICADA and is traceable by the activity plan number.

The purpose of this study is to present data on species composition, densities and biomasses of the pelagic fish populations in the Forsmark area. These data are compared to an area NV of Öregrund and another area NO of Gudinge, see Figure 1-1. The id-codes used for these three areas as well as centre coordinates (in RT90) are as follows:

Öregrund	AFM001248	x: 164 32 00, y: 669 56 00
Forsmark	AFM001249	x: 163 27 00, y: 670 40 00
Gudinge	AFM001250	x: 162 53 00, y: 671 67 00

Table 1-1. Controlling documents for the performance of the activity.

Activity plan	Number	Version
Beståndsuppskattning av fisk i havet	AP PF 400-04-55	1.0

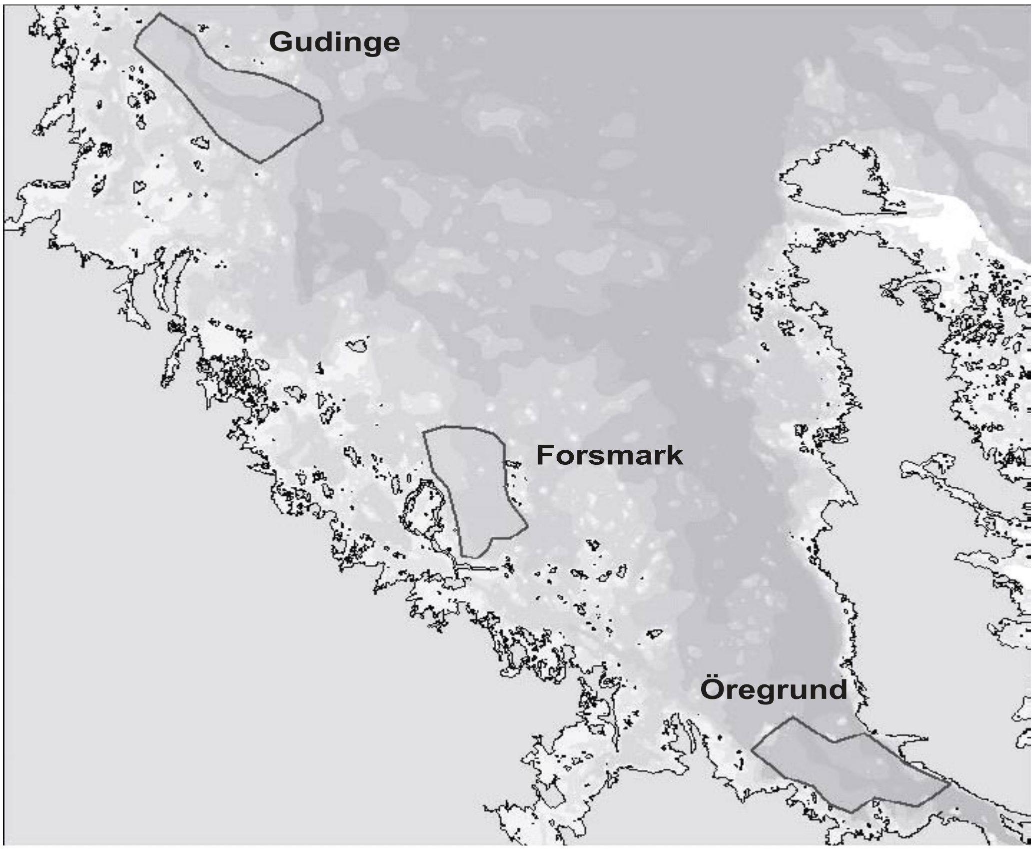

Figure 1-1. *The investigation areas.*

2 Material and methods

In May 3–6, August 30–31 and September 9–10 2004 hydroacoustic surveys were performed to investigate fish abundance, densities and distribution at the cooling water outlet at Forsmark nuclear power plant and two reference areas, NW Öregrund and NE Gudinge (Figure 1-1 and 2-1). The survey at Gudinge in September was originally planned to be performed in close proximity in time to the other two surveys (August/September), but was postponed due to weather conditions. Pelagic trawling was used for biological sampling. Temperature profiles were taken at start, stop and trawling (STD-sond, Sensordata AS, Bergen, Norway). Surface water temperatures were registered every ten seconds at 1 m depth along the surveys (Skye Instruments Ltd, Powys, U.K.).

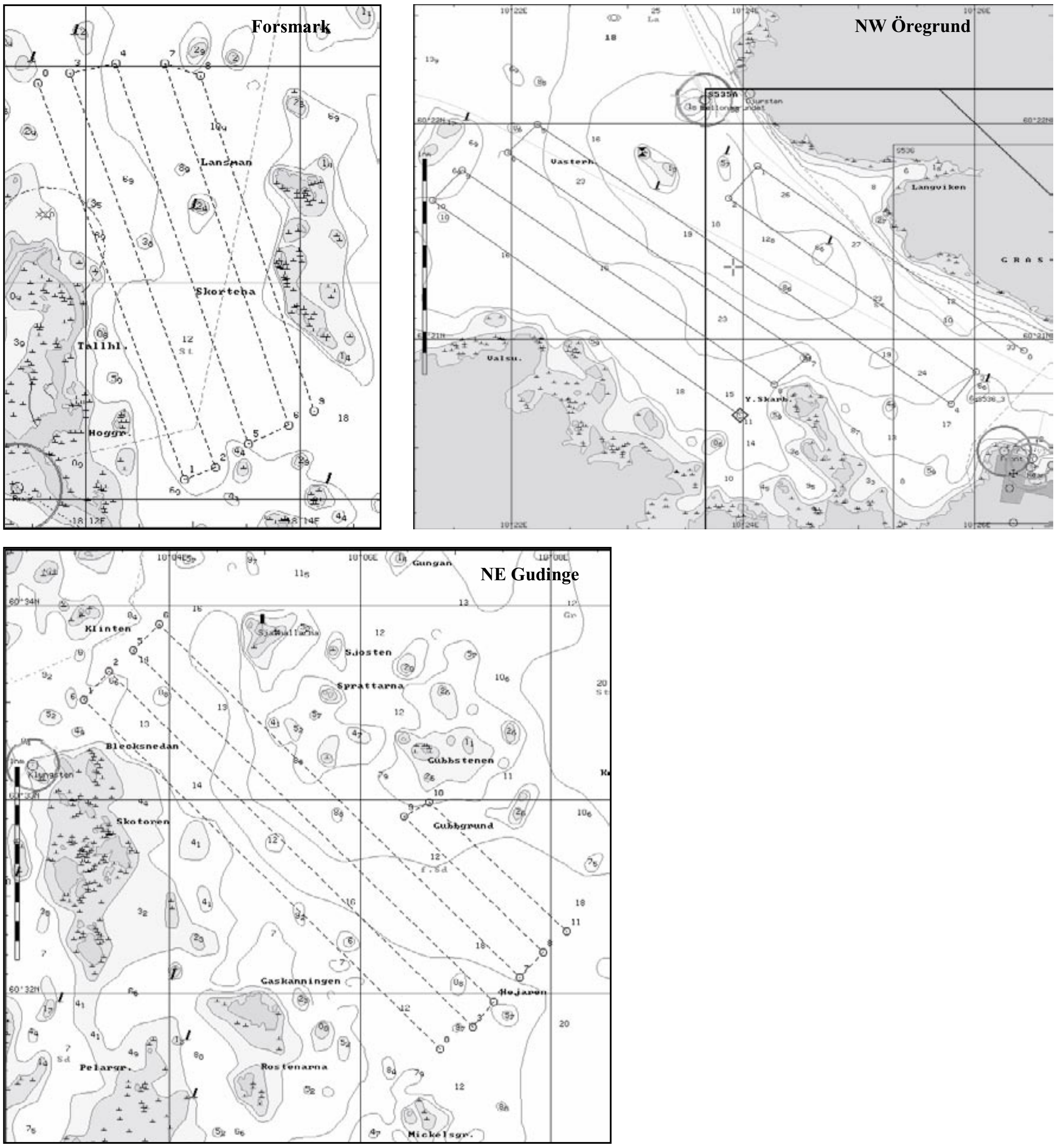

Figure 2-1. *Transects for hydroacoustic surveys at Forsmark and two reference areas, NW Öregrund and NE Gudinge.*

The surveys were conducted with a 70 kHz split beam transducer (Simrad ES 70-11) and a Simrad EY500 portable scientific echo sounder. Calibration was performed with a standard copper sphere and the Lobe software /Simrad, 1997/, as recommended by the manufacturer and according to ICES standards /Anon, 1987/. In all surveys a pulse length of 0.6 ms, bandwidth of 7.0 kHz, and pulse rate of 0.5 $ping \cdot s^{-1}$ were applied. A 10 m fishing-boat was used with the transducer mounted on a tow body, pulled at ~5 knots, at 1 m depth and 1.5 m away from the boat. Data were scrutinised and analysed with the software Sonar5-Pro (version 5.9.4, /Balk and Lindem, 2004/). Post processing threshold for volume backscattering was –80 dB, and for TS (target strength for single fish) –60 dB. The geostatistical coefficient of variation (CV_{geo}) and estimation standard error (SE) for arithmetic mean /Clark, 1987; Rivoirard et al. 2000/ of the nautical area scattering coefficient (s_A; /MacLennan et al. 2002/) and fish biomass were calculated using EVA2 /Petitgas and Lafont, 1997/ and Surfer (7.0). Survey design is specified in Table 1 in Appendix 1.

The hydroacoustic results are presented as fish abundance (s_A), density (number of fish per area unit), and biomass (kg per area unit). The s_A–value is derived from the backscattered echo energy received by echo sounder, in comparison to what was sent out and compensated for sound travelling distance (i.e. depth of targets). Fish densities are calculated using the s_A values and the size distribution of the targets. Based on fish length (L) to weight (W) relationship from trawling results in August and September 2004 including all three areas (Equation 1), fish biomass was calculated using fish size distributions and densities derived from the hydroacoustic data. Herring was chosen as the "model" species since this species dominated in catches.

$$W = 4E\text{-}06 \times L^{3.089} \qquad (1)$$

Pelagic trawls were performed immediately after the hydroacoustics, for approximately one hour at a speed of 2–3 knots using a modified surface trawl. The trawling was done at one depth layer only, guided by the hydroacoustically observed depth distribution of the fish. The trawl cod end mesh size was 3 mm in order to catch also young-of-the-year juveniles. Problems with the trawl most likely affected the catches and subsequently species composition and size distributions.

3 Results

3.1 May surveys

3.1.1 Hydroacoustics

Fish abundance (s_A–value) and density (number or biomass/square nautical mile, nmi^2) was twice as high in Forsmark as in Gudinge. In Öregrund, the fish abundance was eight times higher than at Forsmark, although densities were about the same (Table 3-1 and 3-2, Figure 3-1). The size distributions at Forsmark and Gudinge were not significantly different, while Forsmark and Öregrund differed significantly (Kolmogorov-Smirnov test $p < 0.001$, Figure 3-2).

Table 3-1. Results and statistics from hydroacoustic surveys. Coverage calculation from /Aglen, 1983/. n_s represents the number of segments into which each survey was divided (100 acoustic pings per segment) to provide input data for statistical analysis. s_A is the arithmetical mean nautical area scattering coefficient, given with the geostatistical coefficient of variation (CV_{geo}) and estimated standard error (SE) derived from geostatistical analysis with different variogram models (see e.g. /Rivoirard et al. 2000/). Densities are given as millions of fish.

Stratum	Area (nmi^2)	Coverage	n_s	Mean s_A	CV_{geo}	SE	Density (#/nmi^2 x 10^{-6})	Model
Forsmark (May)	1.9	6.8	137	91.2	3.4	3.1	0.8	24500 Sph(h/0.004)
Öregrund (May)	1.9	6.7	128	741.9	3.5	25.6	0.9	1580000 Sph(h/0.006)
Gudinge (May)	2.6	9.9	195	50.1	7.7	3.9	0.4	24200 Sph(h/0.0116)
Forsmark (Aug/Sept)	1.9	6.9	132	161.1	1.0	1.6	1.2	10600 Sph(h/0.0024)
Öregrund (Aug/Sept)	2.1	7.1	144	191.5	1.1	2.1	0.9	8000 Exp(h/0.01)
Gudinge (Aug/Sept)	2.6	7.9	178	136.1	1.0	1.3	1.4	8550 Sph(h/0.005)

Table 3-2. Calculated fish biomass in May.

	Forsmark	Öregrund	Gudinge
Mean s_A	91.2	741.9	50.1
Estimation. SE	3.1	25.6	3.9
Area density (number/nmi^2 (millions; 2 m layers))	0.8	0.9	0.4
per m^2	0.2	0.3	0.1
per ha	2,408	2,738	1,210
per km^2	240,750	273,789	121,029
Biomass (kg/nmi^2)	8,683	31,249	1,788
Estimation SE (biomass)	169	1,884	69
per m^2	0.003	0.009	0.001
per ha	25	91	5
per km^2	2,532	9,111	521

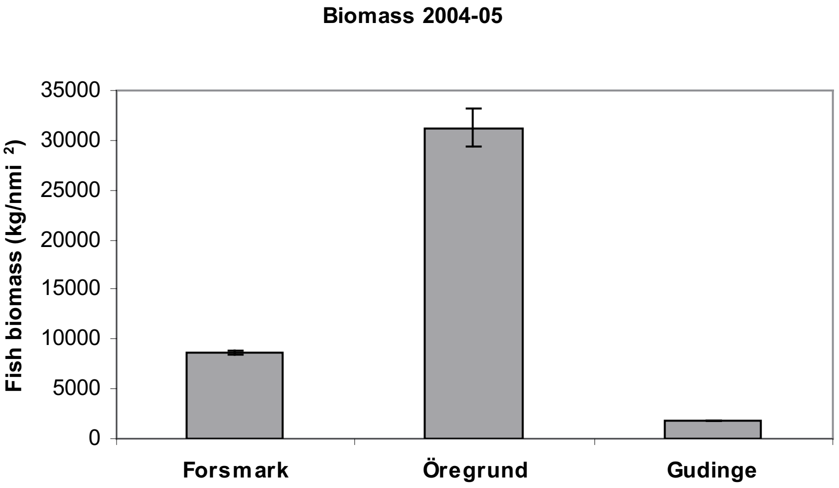

Figure 3-1. Fish biomass calculated from hydroacoustic data from surveys in May 2004 at Forsmark and the reference areas, Öregrund and Gudinge. The error bars show the geostatistic standard error (SE).

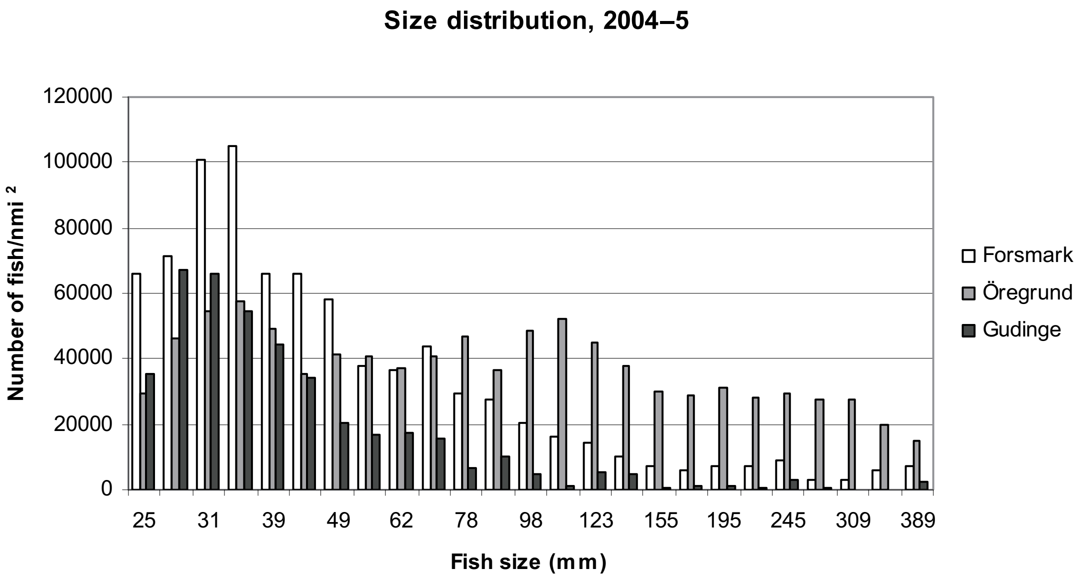

Figure 3-2. Fish size distribution based on hydroacoustic data from the May surveys.

3.1.2 Trawling

The May trawlings caught few species and individuals. In numbers, herring dominated in all three areas, but three-spined stickleback contributed about 25% in Forsmark and Gudinge (Table 3-3). Herring at Öregrund had a total length of > 11 cm, while Forsmark and Gudinge had considerable quantities < 10 cm (about 18 and 50%, respectively) albeit only a total of 16 and 24 herring, respectively, were caught.

Table 3-3. Species composition (%) in trawl catches in May 2004.

Species	Forsmark	Öregrund	Gudinge
Herring	68.6	95.2	76.2
Three-spined stickleback	25.7	4.8	23.8
Smelt	5.7	–	–
Total number of fish (N)	35	105	21

3.2 August/September surveys

3.2.1 Hydroacoustics

The fish abundance was 18% higher in Forsmark than in Gudinge, but fish density was slightly lower (14% lower). Öregrund had the highest abundance (19% higher than Forsmark) but the lowest density of all three areas (Table 3-1 and 3-4, Figure 3-3). The fish size distributions - Forsmark vs. Gudinge and Öregrund - were significantly different (K-S test both $p < 0.001$), with higher abundance of small fish in Gudinge and larger fish in both Gudinge and Öregrund (Figure 3-4).

Table 3-4. Calculated biomass in August/September.

	Forsmark	Öregrund	Gudinge
Mean s_A	161.2	191.5	136.1
Estimation. SE	1.6	2.1	1.3
Area density (number/nmi^2 (millions; 2 m layers))	1.2	0.9	1.4
per m^2	0.3	0.3	0.4
per ha	3,455	2,699	3,940
per km^2	345,516	269,879	394,023
Biomass (kg/nmi^2)	14,164	9,645	8,235
Estimation SE (biomass)	129	75	83
per m^2	0.004	0.003	0.002
per ha	41	28	24
per km^2	4,129	2,812	2,401

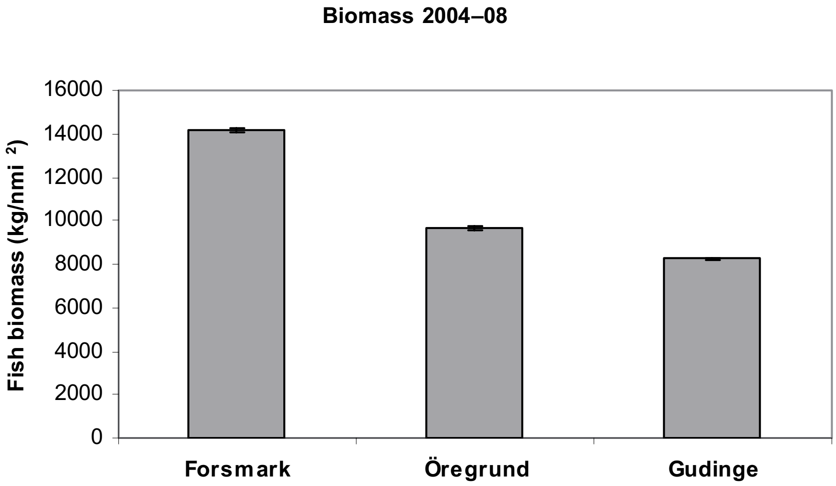

Figure 3-3. *Fish biomass calculated from hydroacoustic data from surveys in August/September 2004 at Forsmark and the reference areas, Öregrund and Gudinge. The error bars show the geostatistic standard error (SE).*

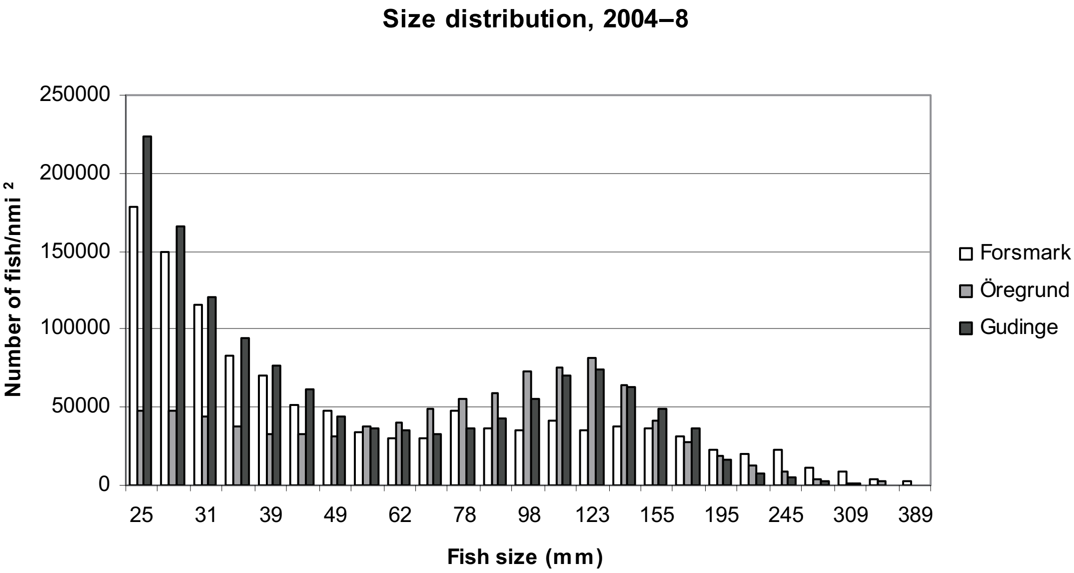

Figure 3-4. *Fish size distribution based on hydroacoustic data from the August/September surveys.*

3.2.2 Trawling

In numbers, herring was the dominating species in the trawl hauls in August/September, but also sprat and gobies were caught in large numbers (Table 3-5). Sprat contributed most at Forsmark and were generally > 9 cm, while gobies dominated at Gudinge and were young-of-the-year larvae/juveniles < 35 mm. Forsmark and Gudinge had rather distinct size distributions of herring with similar peaks for young-of-the-year juveniles. Öregrund seemed to have a more even size distribution of herring, but with one peak of slightly larger juveniles/small herring compared to Forsmark and Gudinge, and a second peak for herring 10–14 cm that was also found at Forsmark.

Table 3-5. Species composition (%) in trawl catches in August/September 2004.

Species	Forsmark	Öregrund	Gudinge
Herring	59.3	87.6	43.6
Sprat	32.0	10.4	14.2
Smelt	–	1.3	–
Three-spined stickleback	–	–	1.6
Nine-spined stickleback	–	–	2.0
Gobies	7.3	0.7	38.1
Roach	1.3	–	–
Straightnose pipefish	–	–	0.5
Total number of fish (N)	150	461	557

4 Discussion

Forsmark and Gudinge both had lower fish abundance and densities in May than in August/September. Data for August/September are available also for 2003 see /Axenroth et al. 2005/. The observation of higher fish abundance in late summer is consistent with findings from other areas in the Baltic Sea /Axenrot and Hansson, 2004/ and reflects the annual recruitment of young-of-the-year fish. Forsmark and Gudinge also have a similar fish size distribution in May. These two areas share many similarities in e.g. bottom depths, topography, temperature (apart from the cooling water outlet region), and it is quite probable that they have similar fish communities at this time of the year. The trawling results in May support this assumption. The main difference between Forsmark and Gudinge is that Forsmark has a significantly higher fish abundance, which was also the case in August/September (both 2003 and 2004).

The results from Öregrund in May are exceptional, even in comparison with all other surveys in these areas made through 2003 and 2004. The fish abundance was eight times higher than at Forsmark (May), and the variation was substantial resulting from patchy fish distribution. The fish size distributions in these two areas were also significantly different. Öregrund, as a reference area, is different in many respects (depths, topography etc) compared to both Forsmark and Gudinge, and most likely the results reflect differences in the fish communities, size distributions etc. The extraordinary high abundance and variation at Öregrund this time of the year indicate presence of pre-spawning herring aggregations, and fish aggregations are observed on the echograms. In Forsmark, the mean temperature (vertical profile) was notably higher at the survey stop point, which was close to the cooling water outlet region (6°C compared to between 2–3°C at all other survey start/stop points). In the cooling water affected area the echograms clearly indicated substantial gas super-saturation. In areas where the fish can not avoid these areas this may cause mortality. It has not, however, been observed in association with the cooling water plume.

In August/September 2004, the results on fish abundance are generally similar to what was observed in August and September 2003 see /Axenrot et al. 2005/. Forsmark had a higher fish abundance than Gudinge, but the fish density was higher at Gudinge and dominated by small fish. Contrary to May, the fish size distributions differed between Forsmark and Gudinge in August/September. This was also the case in September 2003. Öregrund had a higher fish abundance than Forsmark in August/September 2004, which was the same trend as in August 2003, but opposite to the result in September 2003. It is difficult to hypothesize if this is an effect of the slightly different timing of the surveys in 2003 and 2004 or – more probably – ordinary annual differences. Despite the higher fish abundance at Öregrund, the density was the lowest implying more large fish at Öregrund which is supported by the fish size distribution that is significantly different from Forsmark.

The trawling results show that herring was the dominant species in both spring and late summer/early autumn. However, in spring there were mainly adult herring contrary to the situation in late summer/early autumn when young-of-the-year herring juveniles dominated. Although not caught in the trawl in late summer/early autumn, three-spined stickleback caught in spring are most likely present in the area also in late summer. Sprat were common in the late summer catches while absent in spring. Juvenile gobies were caught only in late summer, but in large numbers only at Gudinge.

In August/September, at the starting point in Forsmark (south-eastern part), the thermocline started at ~6 m depth, while at the stop (north-western part, close to the cooling water outlet) the temperature was about the same from surface to bottom. At Öregrund there was a weak thermocline starting at ~4 m at the stop (south-western part), and at Gudinge temperatures were about the same from surface to bottom. Through the survey period August/September the weather was occasionally rather windy which affects the vertical temperature distribution.

In summary, Forsmark had a higher fish abundance than Gudinge in May 2004 as well as in August/September 2003 and 2004. The fish size distributions were similar in May, but differed in August/September with more small fish at Gudinge. This was the same in September 2003. Öregrund seems to differ from both Forsmark and Gudinge, which probably reflects general differences in depths, topography etc. The trawling results show that herring is the dominant species in the area both in spring and late summer/early autumn. Effects on water temperatures at Forsmark were observed in the part closest to the cooling water outlet. Similar observations were made also in 2003. In May we observed probable gas super-saturation outside the outlet.

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Appendix 1

Survey design

Table 1. Hydroacoustic surveys and survey design.

Stratum	Date (start)	Time	Distance (nmi)	Pings	Design type
Forsmark (AFM001249, May)	2004-05-04	22:13–00:22	9.4	13,700	Parallel
NW Öregrund (AFM001248, May)	2004-05-03	23:19–01:28	9.2	12,800	Parallel
NE Gudinge (AFM001250, May)	2004-05-05	22:52–01:44	12.9	19,500	Parallel
Forsmark (AFM001249, Aug/Sept)	2004-08-31	21:54–23:51	9.5	13,200	Parallel
NW Öregrund (AFM001248, Aug/Sept)	2004-08-30	22:26–00:38	10.1	14,400	Parallel
NE Gudinge (AFM001250, Aug/Sept)	2004-09-09	21:26–00:08	12.6	17,800	Parallel

Appendix 2

English, Swedish and scientific fish names

English, swedish and scientific names for fish species treated in this study.

English	Swedish	Latin
Herring	Strömming	*Clupea harengus*
Sprat	Skarpsill	*Sprattus sprattus*
Smelt	Nors	*Osmerus eperlanus*
Three-spined stickleback	Storspigg	*Gasterosteus aculeatus*
Nine-spined stickleback	Småspigg	*Pungitius pungitius*
Gobies	Stubbar	*Pomatoschistus spp.*
Roach	Mört	*Rutilus rutilus*
Straightnose pipefish	Mindre havsnål	*Nerophis ophidion*