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Long-term development in a Baltic fish community exposed to bleached pulp mill effluent

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Abstract

Observations near a Swedish pulp mill at the Bothnian Sea during 1982-1992 revealed low fish abundance and a disturbed community structure. The presence of endocrine disrupting or toxic substances in effluent water was indicated by biomarker responses, impaired reproduction and stimulated growth in perch (*Perca fluviatilis*). In 1992 the bleaching process was altered and a secondary treatment system was installed, improving the quality and decreasing the amount of effluent. This paper presents the results of follow-up studies during 1995-1998 with the objective to analyse any recovery of the fish community due to changes in mill operations. Although abundance and diversity of the fish community did recover, an effect of enrichment, indicated by high catches of cyprinids, was still visible in the vicinity of the mill outlet. Sexual maturation was delayed, gonad development was retarded, average growth rate was faster, and the condition factor was higher in perch caught in the vicinity of the effluent outlet, than in perch captured elsewhere. It is concluded that substances inhibiting reproduction and causing growth disturbance were still present in the effluents in effective concentrations.

Introduction

In 1982 the Swedish Environmental Protection Agency started a research program (Södergren et al. 1984) with the objective to study the fate and effects of bleached pulp mill effluents. Most of these studies focused on the Norrsundet mill on the Bothnian Sea coast. Severe disturbances in the local fish community were observed (Neuman and Karås 1988). Close to the mill only few fish were caught, and diversity was low. At some kilometers from the mill a zone with high abundance of roach (*Rutilus rutilus*) and ruffe (*Gymnocephalus cernua*) appeared. Evidence of impaired reproduction was seen in perch (*Perca fluviatilis*), expressed as delayed maturation, retarded gonad growth (Sandström et al. 1988) and a low young-of-the-year abundance (Neuman and Karås 1988). These impacts on reproduction were associated with stimulated somatic growth and increased body condition. Also increased adult mortality (Sandström and Thoresson 1988) was observed, and gross pathology symptoms like fin erosions and, in pike (*Esox lucius*) a skeletal deformity of the upper jaw, were common during the first years of the study (Lindesjöö and Thulin 1990, 1992). It was concluded that the fish community suffered from both toxic substances and high organic loading. Exposure to toxic substances was verified by biomarker responses, e.g. elevated EROD activity (Andersson et al. 1988).

Continued studies in 1987 on spawning, egg and embryo development and larval survival, indicated that perch recruitment was impaired due to a low survival of newly hatched larvae (Karås et al. 1991). This was explained by high frequencies of embryo malformations and poor embryo growth.

Similar results were obtained from studies on fish conducted near a Canadian mill at Jackfish Bay, Lake Superior, and a US mill at Pigeon River during the 1980’s (McMaster et al. 1991; Munkittrick et al. 1992a; Adams et al. 1992). Sexual maturation and gonadal growth in white sucker (*Catostomus commersoni*) were inhibited, and pathological changes such as external lesions were common in Lake Whitefish (*Coregonus clupeaformis*). Gonadal steroid disruptions were considered as possible factors causing the impacts on reproduction (Van Der Kraak et al. 1992). The Canadian studies were further verified in a ten-mill survey, but it was not well possible to identify any mill-specific impacts (Munkittrick et al. 1994).

Several improvements have been made at the Norrsundet mill to reduce environmental impacts. The bleaching process has been changed by introducing oxygen delignification of the pulp, to remove additional lignin prior to bleaching, and substituting elemental chlorine with chlorine dioxide (elemental chlorine-free or ECF bleaching) which was completed in 1992. A secondary treatment system (aerated stabilization basin) was also installed during the fall of that year. A retrospective analysis of biomarker responses in feral perch showed that fish health did improve after the change in bleaching process and effluent reductions. Only few responses were recorded some years after the secondary treatment system was installed (Larsson et al. 2002). There was no evidence, however, that ecological variables like abundance, recruitment, reproduction and growth had fully recovered (Sandström 1994), and organic enrichment still affected the fish community.

The objective of this study was to analyse any further improvements in response of technical measures taken at the mill. The study focused on a) changes in the community structure and fish abundance indicating enrichment, and b) deviations in perch growth and reproduction indicating toxic or endocrine impact.

Material and methods

The Norrsundet mill is situated on the SW coast of the Bothnian Sea (northern Baltic; Figure 1). The annual production of bleached kraft pulp varied between ca 240 000 and ca 290 000 t pulp during the 1990's (Table 1). Emissions of oxygen-consuming organic substances and chlorinated organic compounds (COD, BOD_7, AOX) were measured at the mill under supervision of the regional authority. Effluent characteristics changed due to several process modifications and the installation of secondary treatment in 1992 (Table 1). There are no other major sources of pollution in the area besides the mill.

Surface water salinity in the study area is 4–5 psu. Annual salinity fluctuations are small. There are no tidal effects. The inner part of the effluent area is shallow and sheltered from the open sea. Upwelling of colder and more saline deep water is insignificant (Södergren et al. 1989). Effluent is diluted (ca. 40 times) with water pumped from a nearby bay before being discharged. A dilution gradient is typically apparent along the northern shore of the effluent area with a dilution of about 200 times at station 2, 400 times at station 4 and over 1000 times at station 7 (Södergren et al. 1989).

Test-fishing for species diversity and relative abundance comparisons (Thoresson 1996) was done in August 1998 at seven stations along the exposure gradient (Figure 1; Stn 1–7), corresponding to the sites investigated by Neuman and Karås (1988). Two multi-mesh-size gill nets, 3 m high and 35 m long, were set in shallow water (3–5 m) at each station. The nets were set at ca. 16.00 p.m. and lifted at ca. 08.00 a.m. the following day. The results are presented as catch-per-unit-of-effort, CPUE, calculated as the catch per net and night. The fishing was repeated six times during a 2-week period. All fish were visually inspected for external injuries and malformations like fin erosions previously observed by Lindesjöö and Thulin (1990). Temperature and Secchi disk depths were measured on all fishing occasions. Secchi disk readings were made to indicate eutrophication related changes in water transparency. Station 7 was considered as reference because of high effluent dilution (Södergren et al. 1989) and no or very low impact shown by Neuman and Karås (1988). Additional reference data were available from the Finbo reference program (Ådjers 1995) at NW Åland (Figure 1), which is performed annually since 1983 following the same guidelines as used in the Norrsundet studies (Thoresson 1996).

For comparison of catch data, The Kruskal-Wallis test (Kruskal and Wallis 1952) was used accompanied by a method analogous to Neuman-Keul's test (Zar 1974) to identify significant differences among stations. Differences were considered significant at the 5% level.

Samples for determination of condition factor (CF) and gonad development in perch were collected at the end of September 1995, 1997 and 1998 from stations 1 and 2 (Figure 1). For growth analysis, opercular bones were removed from the samples collected in 1998. Reference samples were collected in the Forsmark archipelago in 1995 and from the local reference area Axmarfjärden in 1997 and 1998 (Figure 1). The samples were taken within a 3 days period to allow unbiased gonad size comparisons between stations. The shift from a distant (Forsmark) to a local (Axmarfjärden) reference area was preceded by analysing CF and gonad development data. No significant differences between these areas were detected.

Length (mm), total weight (0.1 g), somatic weight (0.1 g; alimentary tract and gonad removed), and gonad weight were measured on each collected fish, and

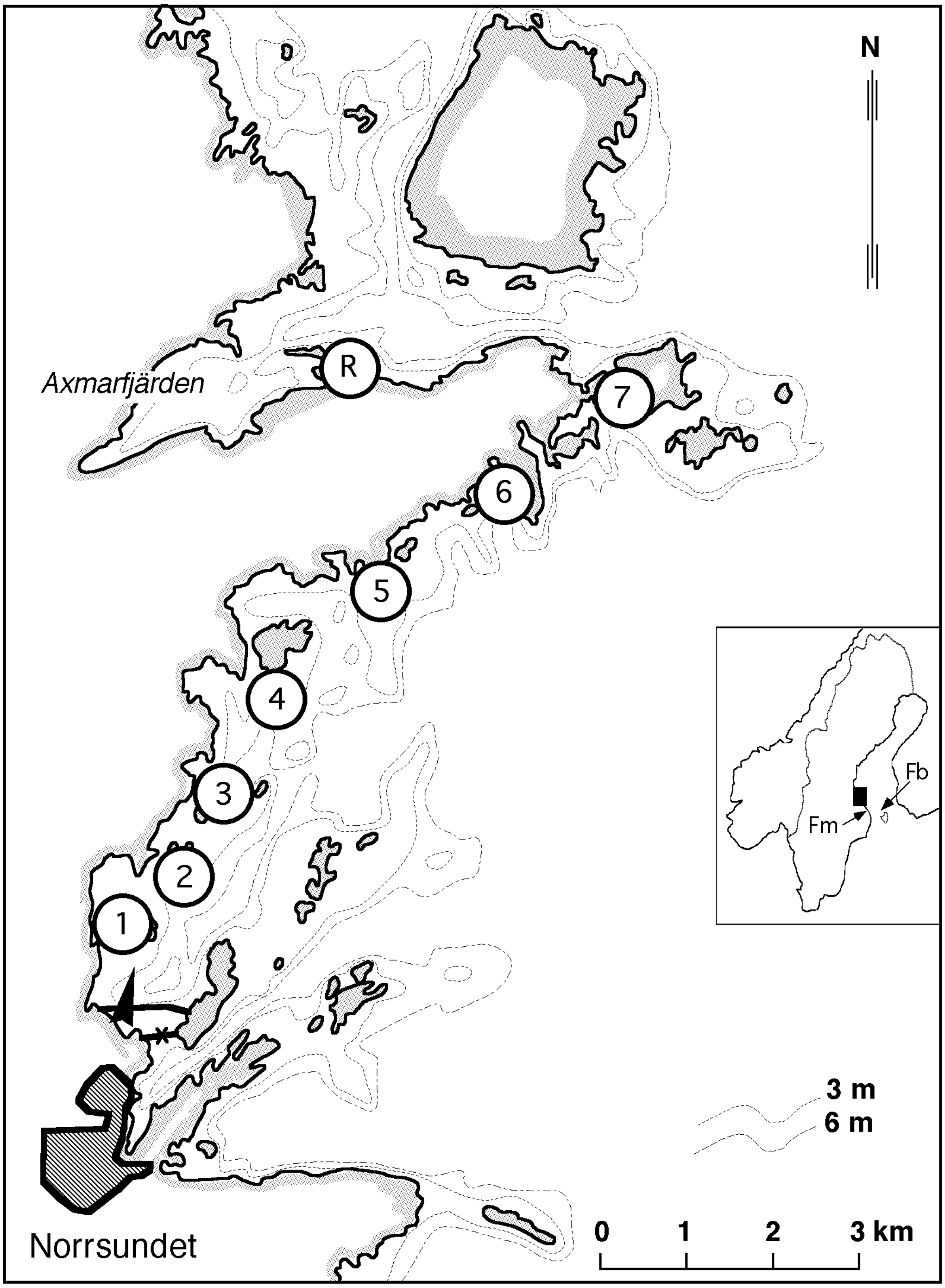

Figure 1. Sampling sites near Norrsundet and the local reference area in Axmarfjärden (R). Distant reference sites at Forsmark (Fm) and Finbo (Fb). The effluent outlet is indicated by an arrow. Depth contours are given for 3 and 6 m.

sex and sexual maturation stage (classified as (1) mature fish with developing gonads, or (2) fish with immature or resting gonads not preparing for spawning the coming spring) were determined. CF was calculated as somatic weight in grams × 100/(total length in centimeters)^3. The gonadosomatic index (GSI) was calculated as the proportion (%) of gonad weight to somatic fish weight. Age and growth were estimated

Table 1. Annual bleached pulp production (t/y) and emissions from the Norrsundet pulp mill during 1980-1998. COD = chemical oxygen demand (tons/day), BOD_7 = biological oxygen demand (tons/day), AOX = adsorbable organic halogens (kg/ton pulp). Data from the Norrsundet Mill

Year	Prod. t/y	COD	BOD_7	AOX
1980	145 200	52	13	8.0
1981	144 700	63	16	8.0
1982	132 800	53	13	8.0
1983	203 100	69	16	6.0
1984	233 600	51	13	3.5
1985	222 187	36	9	3.1
1986	227 533	40	10	2.9
1987	240 380	36	9	2.8
1988	243 726	37	10	2.1
1989	246 392	38	9	1.8
1990	239 819	38	9	1.9
1991	244 745	36	9	1.6
1992	282 616	33	8	0.5
1993	272 398	22	4	0.3
1994	262 125	21	4	0.3
1995	268 500	23	5	0.2
1996	257 594	24	6	0.3
1997	283 168	26	7	0.2
1998	278 340	26	6	0.2

under a stereomicroscope (magnification 6×) by analyzing distance between annuli on the opercular bone, using back-calculation technique (Thoresson 1996). By this method, it was possible to estimate growth not only as length-age relationships but also as length increment of different age classes during separate years. Differences in growth between areas could thus be analyzed during several years before the year of catch.

Differences between areas in annual length increment, CF and GSI in perch were analysed by t-test. Impacts on sexual maturation were analysed by comparing length at 50% maturation between samples with probit analysis (Thoresson 1996).

Sampling techniques, sampling periods and sample treatment were kept as identical as possible to those used in previous studies by Neuman and Karås (1988), Sandström et al. (1988), Karås et al. (1991) and Sandström (1994).

Results

Abundance and community structure

Two species, roach and perch, dominated the 1998 catches (Table 2). There were no significant differences among stations in average CPUE in perch, but roach catches were significantly higher at stations 1 and 2 than at station 7 (Kruskal-Wallis test, $p < 0.05$), which was considered to represent local reference conditions. Herring was also common, the biggest catches being made at station 1, indicating that the pulp mill effluent did not prevent this migratory pelagic species from entering this area (Table 2). The total CPUE at the two most exposed stations in Norrsundet (Stns 1 and 2) was about 50% higher than in the Finbo reference area, an effect mainly due to the high roach abundance close to the mill. External disease symptoms were seen on only few specimens.

Compared with 1987 and 1992, the abundance of fish close to the mill had increased in 1998 (Table 2). A maximum of roach abundance was observed 2–4 km (Stns 2–4) from the mill in 1987 and 1992, with still very low catches at station 1 in 1992. This maximum had moved to the innermost part of the effluent area in 1998. CPUE of perch were significantly depressed at the two most exposed stations (Stns 1 and 2) in 1987 and 1992, but in 1998 differences among stations were no longer significant (Kruskal-Wallis test, $p > 0.05$).

The number of species observed in 1998 was 8–10 at stations 1–7, compared with 7 in the Finbo reference area (Table 2). Species diversity was very low close to the mill in the beginning of the 1980's, when only three species were observed at Stns 1 and 2 (Neuman and Karås 1988). Species diversity thus had recovered to normal levels during the 1990's.

The Secchi disk depth readings indicated improvements in water quality (Table 3). During the 1980's the area affected by poor water transparency reached several km out from the mill. In 1998 only stations 1 and 2 had decreased water transparancy as compared with the general background conditions at the more remote stations.

When analysing possible influence of water transparency on community structure, expressed as the relation between the dominating species roach and perch in the catches, low Secchi disk depths and high shares of roach were observed at the two most exposed stations in 1998 (Figure 2). Only small differences were seen further out along the gradient.

Table 2. Mean catch-per-unit-of-effort (CPUE) of the most abundant fish species at stations 1–7 in Norrsundet, compared with the Finbo reference area (Ref.). The 1987 data are from Sandström (1994)

Station	Year	Roach	Perch	Herring	Total CPUE	No. of species
1	1987	2	1	0	3	3
	1992	6	2	<1	9	5
	1998	65	9	13	89	9
2	1987	13	4	<1	20	4
	1992	36	7	8	53	13
	1998	68	12	3	88	9
3	1987	21	7	2	35	6
	1992	20	10	7	39	9
	1998	31	27	9	73	9
4	1987	34	7	3	49	7
	1992	26	9	5	43	10
	1998	40	20	8	80	10
5	1987	22	5	1	31	6
	1992	5	2	4	13	9
	1998	18	11	9	41	8
6	1987	7	10	4	22	6
	1992	1	5	5	15	9
	1998	16	9	5	34	8
7	1987	16	12	1	33	8
	1992	21	27	2	51	9
	1998	19	16	<1	42	9
Ref.	1998	5	39	15	62	7
Ref.	1983-99	6	26	9	44	26

Table 3. Secchi disk depth readings (m) during test-fishing in August. Mean values and standard deviations (within brackets) based on six measurements

	Stations						
Year	1	2	3	4	5	6	7
1982	1.2 (0.4)	1.6 (0.6)	2.0 (0.4)	2.4 (1.0)	3.8 (0.3)	4.8 (2.3)	4.9 (4.2)
1987	1.3 (0.6)	1.4 (0.8)	1.7 (0.9)	3.0 (1.1)	3.4 (1.5)	5.0 (5.8)	5.1 (9.6)
1998	1.5 (1.6)	2.5 (2.6)	5.0 (11.1)	5.5 (9.7)	5.0 (4.1)	5.0 (11.0)	5.0 (6.2)

Growth, body condition and gonad development

Annual length increment in perch females during the period 1991–1997 was estimated for ages 1 to 7. Samples from Stns 1 and 2 were compared with the Axmarfjärden reference area. Faster growth was observed in the Norrsundet samples in nearly all comparisons. The 1991 year-class was most abundant in the samples and was selected for the statistical analysis of growth differences. Growth was significantly faster for the first four years of life in the exposed fish (Figure 3, Table 4). A higher growth rate in the Norrsundet fish than in the reference area was also found in 1998 (Table 5).

The condition factor (CF) was significantly higher in perch sampled close to the mill (Stns 1 and 2) compared with the reference areas in 1995, 1997 and 1998 (Table 6).

All female perch were sexually mature at a length >25 cm in exposed as well as in reference areas. Maturation, however, was delayed in the Norrsundet fish compared to the reference area (Figure 4) in 1995, 1997 and 1998. Length at 50% maturation differed significantly between areas in all years (probit analysis, $p < 0.05$). Delayed maturation was found also in

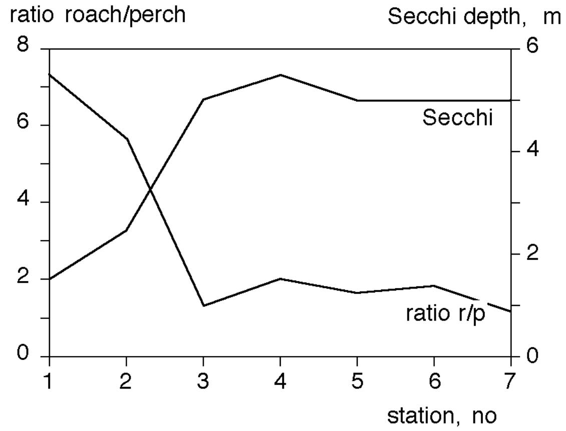

Figure 2. The ratio roach/perch in the catches (based on total catch) at stations 1–7 at Norrsundet 1998 compared to the Secchi disk depth (mean values based on six measurements).

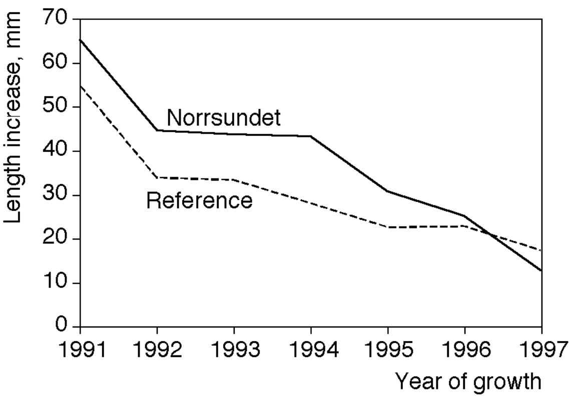

Figure 3. Mean annual length increment in the 1991 year class of perch (females) at Norrsundet (Stn 1 and 2) and in the local reference area Axmarfjärden.

male perch (Figure 4), but too few fish were available in the smaller length classes to perform probit analysis.

Relative gonad size (GSI) was lower in small-sized (< 20 cm) first-spawning female perch as well as in larger (> 25 cm) fish from the effluent area compared with reference fish (Table 7). The difference was statistically significant in 1997 and 1998.

Discussion

Oxygen delignification, substitution of elemental chlorine with chlorine dioxide, and installation of a secondary effluent treatment system at the Norrsundet mill changed the effluent chemistry and lead to reduced discharges since the 1980's. These measures were made to serve two purposes: (1) to reduce local eutrophication and (2) to eliminate toxic impacts. Organic substances and nutrients in the effluent water can lead to oxygen deficiency and increased primary

Table 4. Annual length growth in perch of year class 1991 during the first 7 years of life. NS = Norrsundet (Stn 1 and 2), REF = Axmarfjärden reference area. N = sample size. Lg = annual length growth, mm. SD = standard deviation. Significance levels in t-test: * = $p < 0.05$, *** = $p < 0.001$. ns = not significant

Age	Area	N	Lg	SD	t-value
1	NS	12	65.3	5.0	
	REF	19	54.9	12.8	2.68*
2	NS	12	44.2	9.1	
	REF	19	34.4	8.9	2.95*
3	NS	12	42.9	7.2	
	REF	19	33.1	5.2	4.41***
4	NS	12	42.6	8.3	
	REF	19	28.0	6.2	5.58***
5	NS	12	30.8	5.2	
	REF	19	23.0	14.5	1.79^{ns}
6	NS	12	26.5	7.4	
	REF	19	23.2	13.1	0.80^{ns}
7	NS	12	13.5	8.0	
	REF	19	17.2	9.2	1.85^{ns}

Table 5. Average length growth (Lg, mm) in perch age-classes 4-8 during 1998. NS = Norrsundet (Stn 1 and 2), REF = Axmarfjärden reference area. N = sample size, SD = standard deviation. Significance level in t-test: * = $p < 0.05$. ns = not significant

Age	Area	Sex	N	Lg	SD	t-value
4	NS	Female	37	21.0	7.4	
		Male	42	13.7	3.8	
	REF	Female	20	15.4	3.6	2.79*
		Male	13	9.8	3.9	2.34*
5	NS	Female	20	14.9	6.9	
		Male	13	10.8	8.0	
	REF	Female	26	13.0	5.5	0.73^{ns}
		Male	11	8.1	10.0	0.51^{ns}
6	NS	Female	4	16.3	4.2	
		Male	16	10.7	5.2	
	REF	Female	16	10.7	4.9	1.29^{ns}
		Male	18	12.9	8.5	0.95^{ns}
7	NS	Female	24	13.3	4.2	
		Male	48	6.3	3.5	
	REF	Female	27	8.5	4.9	2.55*
		Male	20	7.3	2.0	1.05^{ns}
8	NS	Female	12	9.3	2.6	
		Male	15	5.5	2.0	
	REF	Female	19	8.0	3.8	0.81^{ns}
		Male	12	6.6	4.4	0.62^{ns}

Table 6. Condition factor (CF) in female and male perch sampled at Norrsundet (NS; Stn 1 and 2). Reference data (REF) from Forsmark 1995 and the local reference area Axmarfjärden 1997 and 1998. N = sample size, SD = standard deviation. Significance level in t-test: *** = $p < 0.001$

Year	Sex	Area	N	Mean CF	SD	t-value
1995	Female	NS	60	1.15	0.06	
		REF	63	1.09	0.04	4.62***
	Male	NS	37	1.11	0.13	
		REF	49	0.98	0.06	4.19***
1997	Female	NS	68	1.16	0.08	
		REF	87	1.09	0.07	3.89***
	Male	NS	96	1.09	0.07	
		REF	119	1.03	0.08	4.29***
1998	Female	NS	127	1.11	0.10	
		REF	134	1.02	0.16	3.46***
	Male	NS	157	1.05	0.07	
		REF	96	0.98	0.08	5.00***

production. The fish community may respond to such changes in the ecosystem by alterations in species distribution. In the Baltic littoral fish community, dominated by cyprinids and percids, the former are favored by eutrophication (Neuman and Sandström 1996).

The most easily measured indicator of eutrophication in the Baltic is the Secchi disk depth. Previous studies in the Baltic showed a strong negative correlation between Secchi disk depth and the ratio roach/perch in the catches (Neuman and Sandström 1996). Reduced water transparency was seen within three km from the mill in 1998, with corresponding roach dominance. Further out from the mill, perch and roach appeared in approximately equal abundance, which indicates natural conditions in these parts of the Baltic (Neuman and Sandström 1996). The area of organic enrichment was larger during the 1980's, impacting fish abundance and species distribution far out from the outlet (Neuman and Karås 1988). At the end of the 1990's, the diversity of the fish community seemed to be fully restored. The efforts made to reduce COD and nutrients in the effluent water did evidently result in a recovery of the fish community. Similar fast ecosystem recoveries were seen at the Swedish west coast after closure of a sulphite pulp mill in 1966 (Rosenberg 1973). Already three years later a significant re-colonization of benthic fauna had appeared in the effluent area. A succession towards a more mature community similar to that found forty years earlier, when organic loading was comparatively small, was almost complete in 1972.

Impacts due to toxic exposure on fish physiology, pathology, growth, reproduction, recruitment, adult survival and abundance were documented during the 1980's by Andersson et al. (1988), Neuman and Karås (1988), Sandström and Thoresson (1988), Sandström et al. (1988), Karås et al. (1991) and Lindesjöö and Thulin (1990, 1992). Many symptoms of physiological disturbance had disappeared in the beginning of the 1990's, shortly after technical measures were taken at the mill (Larsson et al. 2002). A decreased occurrence of fin erosions and other severe pathological symptoms were seen already in 1984, and the 1998 test-fishing results proved this decrease to be consistent.

Impacts on growth, condition factor and reproduction, however, still remained. Growth stimulation during the 1980's was apparent in juvenile as well as adult perch. This was evident also during the late 1990's. A higher condition factor accompanied the growth stimulation. Stimulated growth and increased condition factor, however, should not be seen as positive reactions when observed in combination with inhibited reproduction. This response pattern is not in agreement with general life-history theory (Stearns and Crandall 1984) and should more indicate metabolic disruption, possibly of endocrine origin. In a recent assessment of the Canadian pulp and paper environmental effects monitoring programme (Lowell et al. 2002) the overall median response was an increase in condition and liver weight and a decrease in gonad weight in fish exposed to effluent. The conclusion was that fish downstream of pulp mill effluent experienced a combination of metabolic disruption and nutrient enrichment.

A pattern of stimulated growth and inhibited reproduction was reported also by Sandström (1996) in a review of 25 studies on fish exposed to pulp mill effluent. Growth was explicitely studied only in a few cases, but the condition factor was commonly used as a rough indicator of metabolic changes leading to growth effects. Generally, when a deviation in condition factor had been detected, or when a direct analysis of growth had shown significant differences, the response was positive. Significant positive deviations were seen in 12 studies, and negative in two. Elevated MFO (mixed function oxygenase) activities indicated that the responses were related to toxic exposure. In 10 cases there were negative effects on reproduction, either delayed maturity or reduced gonad size or both

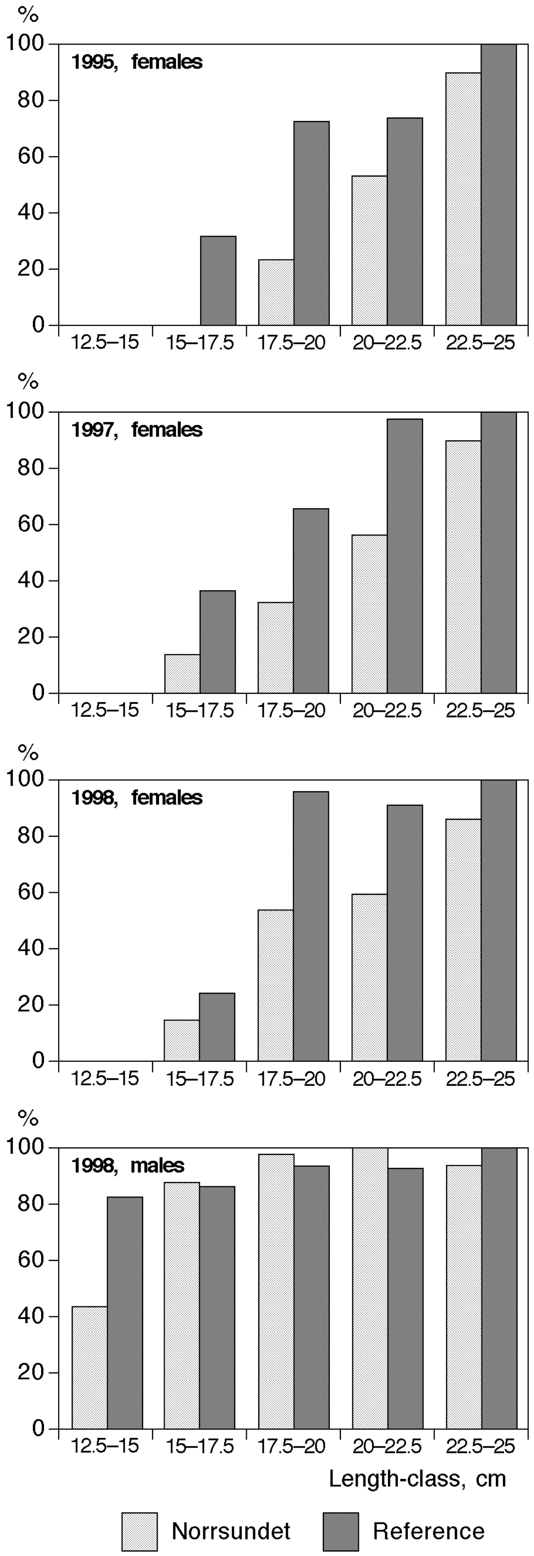

Figure 4. Proportion (%) of mature perch in samples collected near Norrsundet (Stn 1 and 2) for five 2.5 cm length-classes. Reference data from Forsmark 1995 and the local reference area Axmarfjärden 1997–1998.

Table 7. Table 7. Gonadosomatic index (GSI) in mature female perch in two length-classes sampled at Norrsundet (NS; Stn 1 and 2). Reference data (REF) from Forsmark 1995 and the local reference area Axmarfjärden 1997 and 1998. N = sample size, SD = standard deviation. Significance level in t-test: *** = p < 0.001. ns = not significant

Year	Area	Length-class, cm	N	GSI	SD	t-value
1995	NS	<20	5	4.42	1.14	
	REF	<20	10	5.45	1.09	1.21^{ns}
	NS	>20	29	5.16	0.84	
	REF	>20	36	5.75	1.28	1.58^{ns}
1997	NS	<20	5	3.56	0.58	
	REF	<20	15	6.22	1.23	4.62***
	NS	>20	65	5.45	1.17	
	REF	>20	63	6.79	1.19	6.57***
1998	NS	<20	20	2.88	0.81	
	REF	<20	28	4.69	1.28	5.34***
	NS	>20	61	4.30	1.27	
	REF	>20	80	5.90	0.94	8.50***

symptoms together. In some of these studies a negative impact on sex hormone levels was also evident.

Delayed sexual maturation, or more correctly, maturation at a larger size of Norrsundet perch compared to reference fish, was detected when monitoring started in the early 1980's, and gonad growth in mature fish (both sexes) was significantly slower (Sandström et al.1988). In 1989 and 1990 the data suggested that these effects were reduced or eliminated (Sandström 1994). This improvement could not be verified in 1997–1998, as exposed fish both had a reduced gonad development and a significant delay of sexual maturation compared with the reference. These effects are not acceptable according to the national environmental objectives for the pulp and paper industry (Anon 1997). The results also indicate that the whole-organism response is not clearly related to variations in effluent quality, and that short-term studies may fail to detect impacts.

Pulp mill effluents are known to interfere with the steroid regulatory system, reducing sex hormone concentrations (McMaster et al. 1991; Munkittrick et al. 1992a, 1992b). A study by Karels et al. (1999) demonstrated significantly decreased plasma estradiol-17 beta and testosterone concentrations in feral perch and roach exposed to effluent from a mill using elementary chlorine free bleaching. A study on male white sucker (*C. commersoni*), caged in effluent from a bleached kraft mill, demonstrated that ligands for the aryl hydrocarbon receptor and fish sex steriod receptors were bioavailable and that the hepatic burden of these ligands increased with exposure (Hewitt et al. 2000). This could provide a mechanistic linkage to the effects on somatic development and reproductive performance of fish.

Obviously, compounds capable of inhibiting normal reproduction and with possible stimulatory effects on growth, are present also in effluents from modern pulp mills (Hewitt et al. 2000; Lowell et al. 2002). It has been suggested that substances in chemical recovery condensates may be responsible for hormonal activitities, particularly estrogenic effects (Hewitt et al. 2002). Androgenic activity has been attributed to, e. g., androstenedione, a bacterial modification of phytosterols in effluent (Jenkins et al. 2001). The cause and effect analysis is, however, still not simple to perform. The stimulated growth and reduced reproductive performance of female fish indicates an exposure to androgenic substances. However, this interpretation is contradicted by the observations of similar effects in males in the 1980's as well as in 1998, although these responses have been considerably weaker.

The results suggest that the chlorinated substances resulting from usage of elementary chlorine for bleaching can not be a main factor impacting fish growth and reproduction. The Norrsundet studies cover a long time period, from 1982 to 1998. The switch to elementary chlorine free bleaching was completed in 1992. This has resulted in very low AOX discharges for more than five years before the follow-up studies were made, and the risk that persistent chlorinated compounds remaining in the effluent area could still influence fish reproduction should be considerably reduced.

Although the identity of the substances responsible for observed impacts on fish still remains unknown, it is likely that these are organic compounds that can be degraded in biological treatment systems. Secondary treatment as a technique to eliminate chronic toxicity to fish has, however, been questioned in Canada (Munkittrick et al. 1992b). The Norrsundet mill is equipped with a small aerated stabilization basin reducing COD. There has been an evident recovery of the fish community since the fish monitoring started in 1982 as a result of the improved mill operations and the introduced secondary treatment. However, significant inhibition of gonadal growth and maturation in perch accompanied by stimulated somatic growth were still visible at the end of the 1990's. It is concluded that the efforts made to reduce toxic or endocrine substances by regulating AOX and COD in the effluent did not eliminate the risk of negative impacts on fish growth and reproduction.

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