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Development of wild Atlantic salmon stocks in the rivers of the northern Baltic Sea in response to management measures

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Since 1980, the abundance of wild Atlantic salmon has been monitored by means of catch records, adult counts, electrofishing and smolt trapping in six rivers flowing into the northern Baltic Sea. River abundance (spawners, parr and smolts) was compared with implemented large-scale and river-specific management measures and with natural factors potentially affecting abundance. Since the 1980s, the wild stocks have recovered in a synchronous cyclical pattern. The recovery occurred mainly in two jumps, first a sudden increase dating back to around 1990 and a second sharp rise in the late 1990s. River abundance of young salmon commonly rose about 10-fold and approached the previously estimated production capacity in some of the rivers. This positive development may be explained by a decline in fishing pressure together with covarying natural factors influencing survival and growth. The offshore fishery started to decline at the time of the first increase, while the reduction in the total allowable catches together with seasonal restrictions on the coastal fishery strengthened the second increase. Improved natural conditions seem to have increased both survival and escapement during the first rise. Spawners producing the second rise were the offspring of the spawners of the first rise. The outbreak of the M74 mortality syndrome among alevins reduced the abundance of several year-classes that hatched during the first half of the 1990s. In most rivers, the fraction of older and female fish in the spawning run has increased over the period, thereby increasing the reproductive capacity of the populations. No distinct effects of variations in river-specific management regimes were observed. Instead, the results emphasize the role of fisheries management in the open sea as well as in coastal waters, and also of non-human factors in controlling overall abundance of wild salmon in northern Baltic rivers.

Keywords: Baltic Sea, fishery management, river monitoring, *Salmo salar*, enhancement, M74 syndrome, stock recovery.

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Introduction

The Baltic Sea supports an extensive Atlantic salmon (*Salmo salar* L.) fishery. During recent decades, annual nominal landings have commonly been 2000–4000 t, while landings from the North Atlantic declined lately from 5000–10000 to 2000–3000 t (ICES, 2001b). Baltic salmon is geographically isolated from North Atlantic salmon, and only few individuals migrate between the two areas (Christensen and Larsson, 1979; Christensen *et al.*, 1994; Karlsson and Karlström, 1994).

Construction of hydroelectric power plants and damming for other reasons have reduced or eliminated possibilities for successful natural reproduction in most Baltic rivers. Only 13 wild salmon rivers have been left out of the original 45–50 salmon rivers flowing into the Gulf of Bothnia (Anon., 1951; Hurme, 1962; Figure 1). Hydropower companies are obliged to release reared smolts in

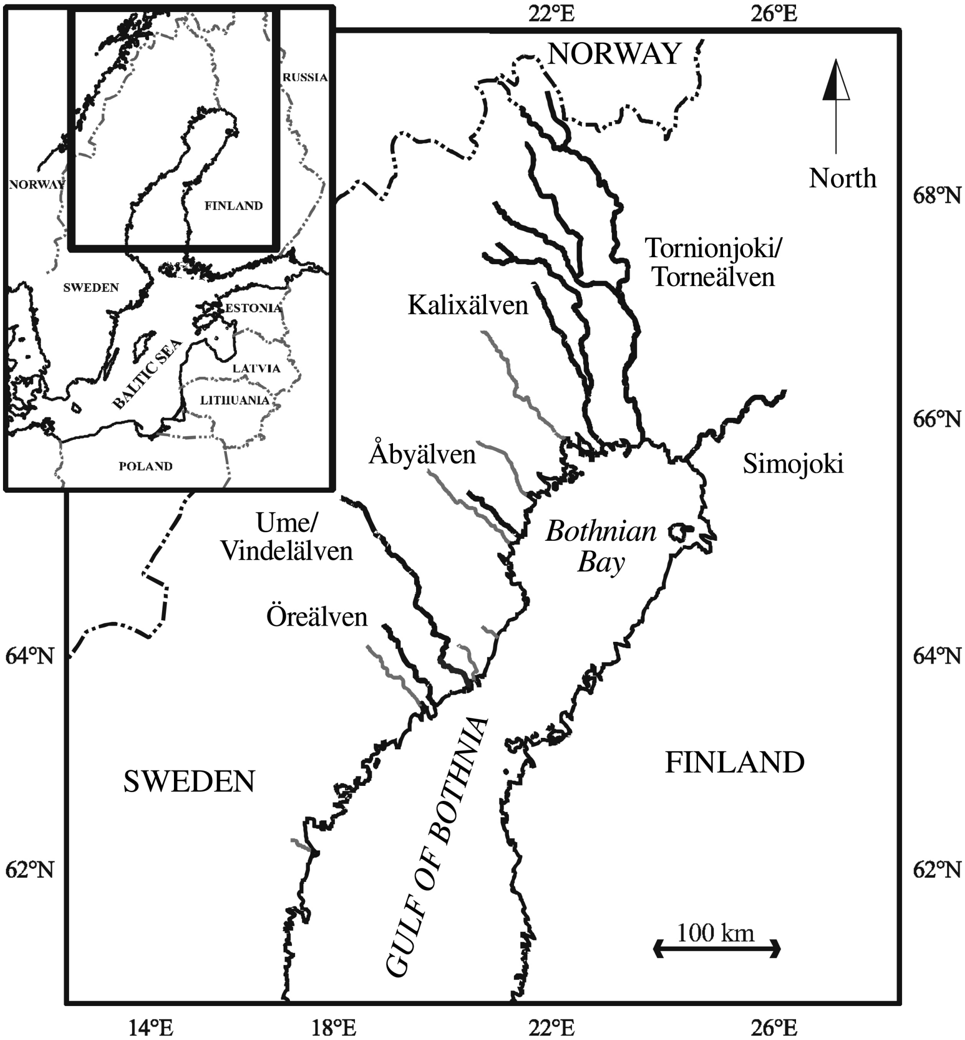

Figure 1. The remaining wild-salmon rivers (named and black, investigated ones; grey, others) flowing into the Gulf of Bothnia, northern Baltic Sea.

compensation for the losses in natural reproduction. About five million smolts are released annually, which accounted for over 90% of the total smolt production in the late 1980s and during the 1990s (ICES, 2001b), and also resulted in a predominance of hatchery-reared salmon in the catches.

Salmon are exploited by offshore, coastal, river mouth and river fisheries (Alm, 1934; Carlin, 1969; Christensen and Larsson, 1979; Christensen *et al.*, 1994). Most wild and reared salmon extend their feeding migration to the central and southern parts of the Baltic Sea (hereafter referred to as the Main Basin). Salmon originating from the northernmost rivers in the Gulf of Bothnia are the ones most prone to exploitation, because they undergo the longest migrations and may be intercepted by every form of fishery on their migration route.

The high level of exploitation, since the Second World War until the 1980s, reduced the abundance of wild salmon (Jutila, 1992; Pruuki, 1993a; Karlsson and Karlström, 1994; Karlström, 1995). Several northern stocks were close to extinction by the end of the 1980s, and stocks from two rivers (Pyhäjoki, Kiiminkijoki) actually completely disappeared in the 1970s and 1980s (Kaukoranta *et al.*, 2000). The late 1980s was a starting point for changes in the salmon fishery and the stocks. Karlsson and Karlström (1994) discussed the factors affecting both the fishery and the natural conditions prevailing at that time.

The goal of this study was to update and review the knowledge on the development of the northern salmon stocks from the 1980s onwards. The analysis is based on Swedish and Finnish monitoring data for six salmon rivers flowing into the Bothnian Bay, the northernmost part of the Gulf of Bothnia (Figure 1). In the light of the declining trend in the abundance of wild salmon almost throughout its distribution range in the North Atlantic since the 1970s

(Parrish *et al.*, 1998; ICES, 2001b), the development of wild Baltic stocks is of particular interest. A second goal was to bring in the management actions and the natural factors that might explain the observed development, and to investigate whether these factors act locally or on larger scales. We chose primarily a descriptive analysis paying attention to major changes in potential key factors and order-of-magnitude differences among and within stocks. The chosen set of rivers represents different river types and somewhat varying local management schemes, but all the stocks share the same feeding area and a largely similar migration route. They are, thus, affected by the same factors for most of their residence in the sea.

General information

Historic overview

Over the past centuries, salmon fishing moved gradually from the rivers to the sea. During the second half of the 20th century, the offshore fishery targeted at feeding salmon had become the dominant fishery (Christensen and Larsson, 1979; Christensen *et al.*, 1994) accounting for over 80% of the total catch during the 1960s, 1970s and 1980s (Karlsson and Karlström, 1994), while river catches accounted for only 1–3%. Extended economic zones were established in 1978, but disagreement between Sweden and the former Soviet Union led to the establishment of the so-called White Zone in the central Main Basin, which was regarded as international water with open access to fishing vessels. Elimination of the White Zone in 1988 increased the control over the offshore fishery, at a time when salmon market value reached a historic low. Since the 1980s, both coastal and river fisheries have increased as a proportion of the catch (Pruuki, 1993b; Christensen *et al.*, 1994; Karlsson and Karlström, 1994). During 1995–2000, 66, 26 and 8% of the total salmon catch from the Main Basin and the Gulf of Bothnia was caught by offshore, coastal and river fisheries, respectively.

The offshore fishing effort for salmon gradually declined between the 1960s and the start of the 1990s (Christensen *et al.*, 1994), followed by a further decline during the 1990s by almost two-thirds in Sweden, Finland and Denmark, the three nations catching the most Baltic salmon, during the 1990s (Table 1). A reduction of this magnitude within a fairly short time can hardly have been offset by improvements in fishing technology (Christensen *et al.*, 1994).

The coastal fishery targeting salmon on their spawning migration underwent technological improvements by the late 20th century. Finnish trap net effort was highest in the early 1990s and is supposed to have declined thereafter to about two-thirds. Similarly, the number of Swedish trap nets decreased by 36% from 1992 to 1999.

Table 1. TAC and nominal catches of Baltic salmon in weight (W) and/or number (N) and total Finnish, Swedish and Danish driftnet and longline effort (number of fishing days multiplied by number of nets or hooks) in the Main Basin and the Gulf of Bothnia during 1980–2001 (ICES, 1989, 2001b, 2002).

	TAC		Landings		Effort	
Year	W ('000 t)	N ('000)	W ('000 t)	N ('000)	Driftnet ('000 net d)	Longline ('000 hook d)
1980	–	–	2.25	–	–	–
1981	–	–	2.51	–	–	–
1982	–	–	1.92	–	–	–
1983	–	–	2.22	–	–	–
1984	–	–	3.33	–	–	–
1985	–	–	3.71	–	–	–
1986	–	–	3.12	–	–	–
1987	–	–	3.59	891	3170	3137
1988	–	–	2.85	784	3112	2500
1989	–	–	3.92	1035	3596	1888
1990	–	–	4.96	1113	2719	2335
1991	3.35[a]	–	4.03	757	2981	1551
1992	3.55[a]	–	3.90	710	3167	1489
1993	–	650	3.40	679	2657	1035
1994	–	600	2.83	584	2946	888
1995	–	500	2.65	553	2574	636
1996	–	450	2.50	534	1182	871
1997	–	410	2.31	431	854	975
1998	–	410	2.11	418	1417	929
1999	–	410	1.82	360	908	956
2000	–	450	1.97	413	1138	1046
2001	–	450	1.76	383	901	1293

[a]≈630 000–650 000 individuals.

Angling is the predominant form of fishing in wild salmon rivers of the Gulf of Bothnia. Angling effort appears to have increased during the late 1990s in some rivers.

International regulations

Concerns over the salmon stocks and calls for international fishing regulations have been documented since the late 19th century (Malmgren, 1884). International management developed gradually after a series of negotiations and conventions in the 1950s and 1960s, which eventually resulted in decision-making under the International Baltic Sea Fishery Commission (IBSFC) established in 1976.

The first multilateral agreement on the Baltic salmon fishery was enforced in the mid-1960s and consisted of the introduction of a minimum landing size and minimum hook and mesh sizes of the fishing gear. In the 1970s, restrictions on number of gear units per boat were introduced. A closure of offshore driftnetting and longlining during the summer months was introduced in 1976. All these regulations have remained more or less in place.

Total allowable catches (TAC) were introduced for the first time in 1991. Initially, TACs were close to the realized average catches in the 1980s, but they gradually reduced during the first half of the 1990s. Since 1996, the annual TAC in the Main Basin and the Gulf of Bothnia has been ≤450 000 salmon (Table 1). The Gulf of Finland is a separate management unit, involving a separate TAC (ICES, 2001b).

In 1995, the IBSFC adopted long-term management goals, which led to the Salmon Action Plan (SAP) agreed in 1997. The most important goal concerning wild stocks is to attain at least 50% of the estimated potential smolt-production capacity in each wild salmon river by 2010 (IBSFC and HELCOM, 1999).

National regulations

Finland enforced an early-season closure of the coastal fishery in 1986. This regulation was aimed at increasing the survival of early migrants, because the wild spawners to be protected, and especially old females, tend to migrate earlier in the season than reared fish to be harvested (Ikonen and Kallio-Nyberg, 1993; Karlsson *et al.*, 1994; McKinnell *et al.*, 1994). Pre-spawning migrants from both Finnish and Swedish rivers in the Gulf of Bothnia mainly follow the Finnish coastline (Westerberg *et al.*, 1999), and the regulation therefore affects all local wild stocks.

The early-season closures were enforced in most years, but were of relatively short duration till 1995. In 1996, the restrictions were strengthened. The Gulf of Bothnia was divided from south to north into four management regions. During 1996–1997, fishing targeting pre-spawning migrants were allowed to start on 16 June in the southernmost region, and opening dates were delayed by 5 days for each consecutive region in northern direction. Since 1998, these restrictions have been somewhat alleviated by setting all opening dates 5 days earlier. According to the timing of the

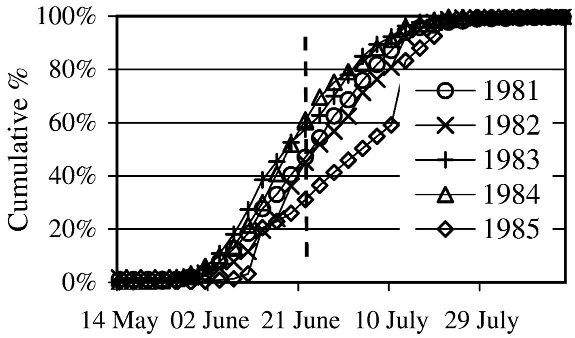

Figure 2. Comparison of the timing of salmon spawning runs along the Finnish coast (62°30′N–64°N) of the Gulf of Bothnia based on cumulative catch during unregulated years (1981–1985), with the opening date of the coastal fishery (dashed vertical line) enforced by Finland during 1996–1997.

catches at the Finnish coast, the early-season closures should have saved many early-running salmon (Figure 2). Practically, no salmon fishing has been allowed in demarcated areas off the Simojoki since 1994 and the Tornionjoki since 1996, while no spatial restrictions have been enforced off regulated rivers with compensatory releases.

Swedish national restrictions on exploitation of wild salmon were established in 1983, when the fishery with trap nets and standing nets was closed until 19 June in demarcated areas outside river mouths. In 1993, a ban on the fishery with trap nets before 15 June was introduced along the coast and the fishery inside the protected areas was allowed from 25 June onwards. In 1994, the fisheries in all demarcated areas were closed. In 1997, many protected areas were enlarged and fishing was either banned or allowed to a limited degree from 25 June onwards. Since 1997, the trap net fishery along the coast, where wild salmon rivers exist, opened on 19 June. In addition, few or no fishing restrictions were introduced outside rivers with reared stocks, these being called "terminal fishing areas" for reared fish.

Fishing in Swedish wild salmon rivers was restricted to angling in 1983. The restrictions were gradually extended, and in 1994, the entire river fisheries were banned completely. Limitations on angling had gradually been lifted during the latter half of the 1990s, but other types of river fishery are still prohibited.

In Finland, angling has been allowed in the rivers, subject to a closure of 1–2 days per week, enforced in the mid-1990s. Limited use of nets or weirs had been allowed before the 1990s, but net fishing has been largely prohibited since the mid-1990s and weirs are no longer permitted. In general, regulations for salmon fishery in the rivers have become gradually more restrictive during the 1980s and 1990s.

Development of M74 syndrome

Baltic salmon suffers from a syndrome termed M74, which may lead to the death of the majority of offspring at the

Table 2. Characterization of the rivers that were investigated (derived from various national sources). Area occupied by salmon or parr based on recent monitoring (mostly electrofishing). Fish ladders are present next to all migration obstacles.

	Simojoki	Tornionjoki	Kalixälven	Åbyälven	Ume/Vindelälven	Öreälven
Length (km)	175	520	330	110	320	110
Mean discharge (m^3s^{-1})	38	389	299	15	454/184	34
Catchment (km^2)	3160	40 010	18 130	1344	26 815	3029
Mean gradient (%)	0.10	0.09	0.14	0.32	0.11	0.16
Length occupied by salmon (km)[a]	110	850	500	40	300	60
Suitable parr habitat (ha)	255	5000	2500	80	1000	100
Migration obstacles in main stem	None	None	Natural	Man-made	Man-made	Two man-made
Distance from river mouth (km)			110	40	25	7 and 60

[a]Including tributaries.

late alevin stage (reviews by ICES, 1994; Karlsson and Karlström, 1994; Bengtsson *et al.*, 1999). The physiological mechanisms and factors inducing the M74 syndrome have not been resolved yet, but its occurrence is directly linked to a low thiamine content of salmon eggs (Bylund and Lerche, 1995; Amcoff *et al.*, 1998).

The mortality induced by M74 has been monitored in five to six rivers in the 1980s and in 11 to 13 rivers in the 1990s (ICES, 2001a, b). Although the measured variables have varied, they have exhibited roughly similar variation over time in most rivers (Vuorinen *et al.*, 1999): low mortality in the late 1980s, a steep increase during 1991–1992, persistent high mortality from 1992 until the mid-1990s and a decrease in the late 1990s. However, the level of mortality varies among rivers.

Detailed information for six rivers

Study area

Twelve of the 13 rivers still having wild salmon stocks in the Gulf of Bothnia are located in its northernmost part, the Bothnian Bay (Figure 1). Many regulated rivers that have lost their wild stocks are also located in the Bothnian Bay. About two million smolts are released annually in these rivers in compensation for the lost natural production.

The six rivers that were investigated (Simojoki, Tornionjoki, Kalixälven, Åbyälven, Ume/Vindelälven, Öreälven) are indicated in Figure 1. They cover the entire geographical range of all wild salmon rivers in the Bothnian Bay. The Tornionjoki, Kalixälven and Ume/Vindelälven are considerably larger than the other three rivers (Table 2) and have their headwaters in the subarctic mountain range of northern Scandinavia. The middle and lower reaches of these rivers, as well as the entire catchments of the three smaller rivers, are located in boreal coniferous forests with some moorland, bogs and agriculture areas. Ice covers the rivers during the winter months and the annual peak flood occurs during May–June, soon after the snow melts and the ice cover breaks up. Only minor anthropogenic disturbances may be seen in the water quality of the three larger rivers, but nutrients from agriculture and forestry, and also peat mining in the catchment of the Simojoki, have impaired the water quality of the three smaller rivers (IBSFC and HELCOM, 1999). Fluvial habitats suitable for salmon parr have been mapped and measured in each river (Table 2).

Hydroelectric power plant dams block three Swedish rivers, but fish ladders enable spawners to reach upstream spawning grounds. The power plant on the Ume/Vindelälven is located close to the sea and, hence, all the spawners have to pass a fish ladder (dating back to the 1930s) to reach their spawning grounds. Reproduction is restricted to the Vindelälven, a large tributary joining the Umeälven 8 km upstream of the power plant. Power plants are located in the middle reaches of the Åbyälven and Öreälven, where the fish ladders were built in 1996.

Records on M74 mortality are available from the Simojoki, Tornionjoki and Ume/Vindelälven (Table 3). Till 1994, mortality in the latter has been persistently higher than in the other two rivers.

Table 3. Mortality induced by the M74 syndrome (%) in three rivers by hatching year (Vuorinen *et al.*, 1999; ICES, 2001b).

Year	Simojoki	Tornionjoki	Ume/Vindelälven[a]
1985	–	–	40
1986	6[b]	–	20
1987	2[b]	–	25
1988	6[b]	5[b]	19
1989	3[b]	6[b]	16
1990	14[b]	1[b]	31
1991	4[b]	29[b]	45
1992	53[a]	70[b]	77
1993	74[a]	76[b]	88
1994	53[a]	89[a]	90
1995	92[a]	76[a]	69
1996	86[a]	–	78
1997	91[a]	–	37
1998	31[a]	25[a]	16
1999	59[a]	61[a]	53
2000	44[a]	34[a]	45
2001	41[a]	41[a]	39

[a]Proportion of females with offspring dying due to M74.
[b]Total mortality of offspring during the critical life stage.

River-specific management and enhancement programmes

Fishing of salmon were banned in 1994 in all the three rivers flowing through Swedish territory and again in the Åbyälven in 1998. Also, fishing was almost totally banned during 1996–1999 in the Ume/Vindelälven and Öreälven. Other regulations of river fishery have been less restrictive, such as the shortening of the fishing season in the Tornionjoki in the mid-1990s by an earlier start of the autumn-closed season.

In recent decades, stocking for enhancement purposes has been limited to four rivers (Table 4). Salmon native to each river were used for rearing. Released parr and smolts have been marked by removing the adipose fin before stocking in the Simojoki, Tornionjoki and Öreälven, while stocking material in the Ume/Vindelälven, as well as eggs and fry in all rivers, have not been marked. Stocking has been most intensive in the Tornionjoki, where almost three million eggs or fry, over seven million parr and about 0.7 million smolts have been released during the last two decades. However, relative to the area suitable for parr production, stocking has been most intensive in the Simojoki.

All the rivers have been used for log driving, which peaked during the first decades after the Second World War. The rivers were largely excavated for this purpose with the exception of the main stems of the two largest rivers (Tornionjoki, Kalixälven), which reduced river habitats suitable for salmon parr (Karlström, 1977). Log driving ceased by the late 1970s, and subsequently river channels have been restored at least partially. A fish ladder was built in 1980 at Jokkfallet in the Kalixälven, which had been a partial natural obstacle to salmon migration.

Monitoring methods

We utilized all the existing riverine monitoring data of the six stocks comprising catch statistics, counts of adults, scale samples, electrofishing and smolt counts, with a varying repertoire of methods by river. The results were updated until 2000 or 2001, depending on the method. Regretfully, counts of both smolts and spawning migrants are not available for any river. Moreover, it is of course uncertain as to what extent the catch reflects absolute abundance, the ultimate variable of interest.

Because of the sporadic nature of river fishing and poaching, catch records do not normally cover all the salmon caught. In the Simojoki, catches have not been recorded every year, and the recent ban on salmon fishery in Swedish rivers has truncated these time series.

A total count of spawning migrants is available for the Ume/Vindelälven. In the Öreälven, a partial count of migrants was organized till the year 2000 by installing a trap at a dam, but under high-water conditions, some fish might have managed to pass the dam freely. Information has been regularly collected during 1986–1999. Partial counting has also been carried out at the fish ladder in the Kalixälven during 1980–1983 and 1990–2001.

Table 4. Stocking data (in ’000; EF, eggs and fry; P, parr; S, smolt) for four rivers, 1980–2000 (Kalixälven and Åbyälven, no stocking during this period).

	Simojoki		Tornionjoki			Ume/Vindelälven			Öreälven		
Year	P	S	EF	P	S	EF	P	S	EF	P	S
1980	0	1	0	164	10	0	0	0	0	10	0
1981	0	1	0	100	6	0	0	0	0	14	0
1982	0	1	0	216	10	0	0	0	0	0	2
1983	0	0	0	201	49	0	100	0	0	30	0
1984	14	0	0	215	56	0	12	0	0	6	0
1985	18	0	0	56	18	0	0	0	0	4	0
1986	16	0	40	300	9	0	0	0	0	0	0
1987	37	15	0	138	32	0	204	0	0	8	2
1988	57	15	30	99	19	0	25	4	0	0	1
1989	66	52	0	223	4	30	59	0	0	1	2
1990	68	26	4	275	86	25	17	12	0	0	0
1991	103	61	0	147	40	80	10	0	30	2	8
1992	72	4	642	539	15	0	0	0	0	0	0
1993	37	5	511	370	28	0	0	0	0	0	0
1994	174	15	443	799	23	0	0	0	0	5	0
1995	329	69	1300	731	62	314	29	0	0	6	0
1996	187	140	0	540	50	0	24	0	10	10	0
1997	178	143	0	609	16	0	3	0	14	25	0
1998	191	76	0	600	60	0	0	0	60	8	0
1999	260	67	0	607	61	0	0	0	20	31	0
2000	140	50	0	452	60	0	0	0	114	0	0
Total	1947	741	2970	7381	714	449	483	16	248	160	15

Size, sex and origin (wild or reared, based on the presence of the adipose fin) have usually been determined in conjunction with the counts. Grilse have been distinguished from multi-sea-winter (MSW) salmon based on size, and sex was distinguished based on external morphological characteristics. Scale samples have been collected from catches in the Tornionjoki to age the fish and to identify hatchery-reared smolts (Antere and Ikonen, 1983; Hiilivirta *et al.*, 1998). This method enables the identification of strayers from nearby compensatory releases from wild salmon, both of which have intact adipose fins.

Abundance of parr has been monitored annually in shallow fluvial habitats of all rivers during late summer and autumn by electrofishing with pulsating DC current, following methods of Junge and Libosvárský (1965) and Bohlin *et al.* (1989). Selection of sampling sites has not been random, especially in the largest rivers, because of methodical limitations to shallow (<1 m), mostly shoreline habitats. Selection criteria applied have been fairly similar in each river, allowing rough between-river comparisons. The data comprise over 70 000 parr caught at 2421 fished sites over 20 years. However, number of sites sampled varies temporally by river and among rivers. Catchability has been estimated on the basis of three successive removals if the total sample represented at least 50 individuals. In case of smaller catches or less than three removals, catchability has been estimated from pooled data consisting of sets with three successive removals (Bohlin *et al.*, 1989), representative of the nearest 5 years in the same river to take into account potential river-specific temporal trends. In the Åbyälven, Ume/Vindelälven and Öreälven, one estimate was derived across all the years because of scarcity of data. In the Tornionjoki, Finnish data from 1995 to 1997 and 1998 to 2000 were pooled separately to estimate catchability, because of marked changes in the field crew between these periods.

Smolt runs have been monitored in the Simojoki (1980–1981, 1984–2001) and Tornionjoki (1987, 1988, 1990–1994, 1996–2001) by partial trapping. Total run size has been estimated by mark-recapture methods (Youngs and Robson, 1978; Karlström and Byström, 1994; Mäntyniemi and Romakkaniemi, 2002). Prior to 1996, smolts in the Tornionjoki were trapped about 80 km upstream from the river mouth, while the trap has been located at the river mouth afterwards.

Monitoring results

Catches from the Tornionjoki have been largest, varying from 4 t in 1988 to 74 t in 1997, while catches from the two smallest rivers (Åbyälven, Öreälven) varied only from a few to some dozens of specimens (Table 5). In all the

Table 5. Recorded catches and counts of salmon by river, 1980–2001 (partial counts in Kalixälven and Öreälven; total count in Ume/Vindelälven).

	Simojoki	Tornionjoki	Kalixälven		Åbyälven	Ume/Vindelälven		Öreälven	
Year	Catch (kg)	Catch (kg)	Catch (kg)	Count (N)	Catch (N)	Catch (N)	Count (N)	Catch (N)	Count (N)
1980		18 750	4663	80	–	–	1255	–	1
1981	200	6100	4175	161	–	–	638	–	8
1982	–	4500	1710	45	–	–	424	–	3
1983	50	8700	3753	890	–	–	403	–	7
1984	100	8700	2583	–	–	–	443	–	45
1985	–	5500	3775	–	–	–	904	–	57
1986	200	5100	2608	–	–	–	227	–	52
1987	–	4200	2155	–	–	284	246	8	74
1988	–	4000	3033	–	2	751	446	0	75
1989	–	9900	4153	–	6	677	598	1	29
1990	50	17 600	9460	639	14	2079	1572	23	106
1991	–	17 400	5708	437	40	525	356	20	76
1992	–	26 600	7198	656	20	840	354	0	188
1993	–	17 800	7420	567	30	1284	1663	24	195
1994	400	14 200[a]	0[b]	806	5[b]	847[c]	1309	10[b]	54
1995	1300	9000	3555	1282	8	747	1166	1	50
1996	2600	52 600	8713	3781	25	574[c]	1940	0[b]	70
1997	3900	74 300	10 162	5961	15	371[c]	1788	0[b]	147
1998	2800	49 500	5750	2459	0[b]	307[c]	1154	0[b]	71
1999	1880	24 000	4610	2044	10	315[c]	2212	0[b]	90
2000	1730	27 800	5008	2519	20	340	3367	10	–[d]
2001	2700	23 300	6738	9367	20	1000	5476	5	–

[a]No fishing allowed on tributaries flowing through Swedish territory.
[b]No fishing allowed (except for broodstock fishery in Öreälven).
[c]Fishing allowed only in Umeälven.
[d]No count because trap was destroyed by spring flood.

rivers, catches were low in the late 1980s and increased in the early 1990s. A second and higher peak was observed during 1996–1998 in the rivers without strengthened fishing restrictions (Simojoki, Tornionjoki, Kalixälven; Table 5), after which catches have declined again.

Annual counts of adults in the Ume/Vindelälven varied from 200 to 250 during 1986–1987 to over 5000 in 2001 (Table 5). In the Kalixälven, the lowest counts were recorded in the early 1980s and the highest counts in 2001. In the Öreälven, lowest number was also observed in the 1980s, but counts were highest in the early 1990s. Counts in all the rivers were also relatively high around 1996–1997.

Proportion of MSW spawners and sex ratio have varied considerably both among and within rivers (Figure 3). These two parameters are positively correlated because almost all female spawners are MSW fish. Common features in most rivers are larger proportions of grilse and males in the 1980s than in the late 1990s. Unlike other rivers, no clear trends in these variables exist for the Ume/Vindelälven. Grilse were also relatively abundant for 1–2 years during the turn of the period 1980s to the 1990s. The proportion of MSW (female) salmon has been high during the late 1990s, especially in the Tornionjoki. The earlier start of the autumn-closed season enforced in the mid-1990s might inflate the increase in proportion of MSW salmon in the catch samples from the Tornionjoki, because grilse ascend the river late, near the closing time of angling season (Kallio and Pruuki, 1987; Romakkaniemi *et al.*, 2000).

The catch samples from the Tornionjoki indicate that not only have 2SW salmon become more abundant among spawners, but also 3SW and even older fish account for a substantial part of recent spawning runs. In 1995–2000, the average proportion of 1SW, 2SW, 3SW, 4SW and repeat spawners accounted for 12, 52, 30, 0.4 and 6% of the catch samples, respectively. Also, the mean size has increased: the average weight ranged from 2 to 6 kg in the 1980s and from 6 to 9.5 kg since 1992. Both in 1996 and 1997, 83% of all aged fish in the catch samples collected from the Tornionjoki were hatched in 1991. In 1998 and 1999, 15 and 10%, respectively, represented repeat spawners having spent 2–7 years at sea after smolting. Of these, 81% were females and 73% were hatched in 1991.

Reared fish accounted for 8–35% of Tornionjoki salmon and for 7–96% of Öreälven salmon (Figure 4). In the Tornionjoki, the proportion of reared fish was highest in the late 1980s and increased again in the most recent 2–3 years. Strayers accounted for up to 20% in the late 1980s, but since the mid-1990s, they have been relatively rare. The proportion of reared salmon has on average been much higher in the Öreälven than in the Tornionjoki, but has been decreasing rapidly in the late 1980s and again in the late 1990s.

Average densities of wild parr (corrected for catchability; Table 6, Figure 5) at the sampling sites were commonly low in all the rivers in the 1980s and even virtually absent in the Öreälven. Around 1990, the parr densities increased, followed by a decline in the mid-1990s. According to age-0 parr data, 1989–1991 represent good hatch years in at least one of the rivers, while lower number of parr hatched in 1992–1993. A steep increase in age-0 parr densities (approximately by a factor of 10) occurred during the latter half of the 1990s in all rivers, particularly during 1996–1997, which was followed 1 year later by increases in age > 0 parr. During the last 2 years (1999 and 2000), age-0 parr were generally reduced, but were still higher than average.

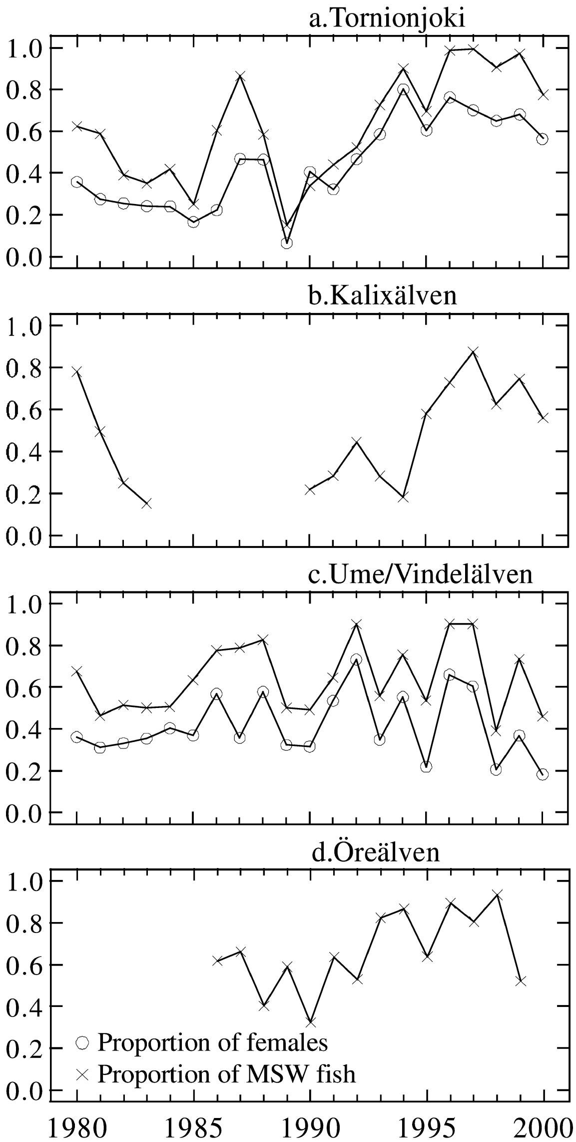

Figure 3. Fraction of MSW salmon and females in four rivers (a–d). Data for Tornionjoki originate from catch samples (N = 3940), data for other rivers are from fish counts.

While similar signals are seen in all the rivers, parr densities in the Öreälven have remained exceptionally low. Densities of reared parr (Table 6, Figure 5) have been fairly constant, or have even declined, and bear little relationship

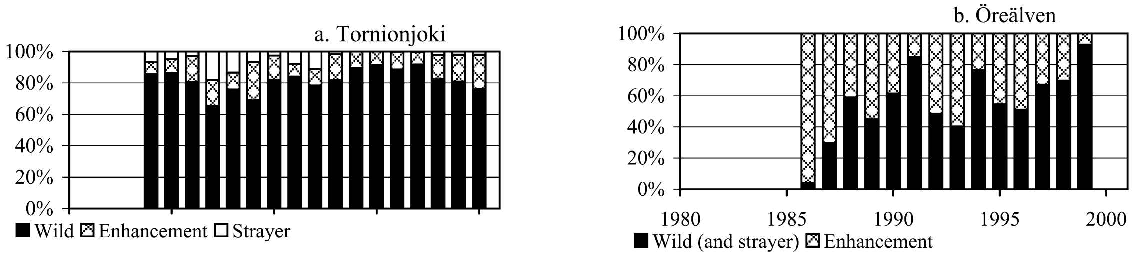

Figure 4. Fraction of wild and reared adult salmon (enhancement and strayers) in two rivers: (a) Tornionjoki (N = 3037) and (b) Öreälven (N = 899). Strayers were not identified in the Öreälven data and are included among wild salmon.

with the number stocked (Table 4), which show increases in the Simojoki and Tornionjoki. While reared parr were more abundant than the wild parr till the early 1990s, their number was exceeded by wild parr during the last 5 years.

Since 1980, natural reproduction in the Simojoki yielded 1000–60 000 wild smolts with highest number observed in the most recent years (Figure 6). Smolts of reared origin predominated in most years and peaked around 1996. Also in the Tornionjoki, the lowest number of wild smolts (50 000–70 000) was observed in the late 1980s, as well as during 1996–1997, and the highest number (500 000–600 000) was observed in the most recent years. Wild fish often accounted for about half of the abundance in the Tornionjoki, i.e. a much lower proportion than found in the catch samples of ascending salmon (Figure 4).

Discussion

The decline in the wild salmon stocks in the Gulf of Bothnia that started after the Second World War and was halted in the 1980s, has been a consequence of recruitment overfishing (Karlsson and Karlström, 1994). The fishing restrictions enforced till this time have not been able to improve the wild stocks, although they may have somewhat reduced the pressure on the stocks during their struggle against total extinction.

Parr densities in most rivers (Tornionjoki, Kalixälven, Ume/Vindelälven, Öreälven) indicate that the number of spawners reached their lowest level during the first years of the 1980s. The only exception is the Simojoki, where the lowest depression seemed to be reached around 1985. However, the more complete time series of catches (Tornionjoki, Kalixälven) and adult counts (Ume/Vindelälven) indicate that the number of spawners was lowest during 1986–1988, while only counts in the Öreälven indicate lowest number for the early 1980s. Although low in number, spawners during 1986–1988 were relatively old and largely females, at least in some rivers (Figure 3). Romakkaniemi *et al.* (1995a) have suggested, based on the product of sex ratio and weight-at-age, that the reproductive capacity of a 3SW Baltic salmon is 30 times higher than for a grilse and three times higher than for a 2SW salmon.

A revival in the stocks has been detected by the end of the 1980s (Jutila, 1992; Pruuki, 1993a; Karlsson and Karlström, 1994). The increase began with strong grilse runs in 1989 and 1990. Kuikka (1991) observed an exceptionally high early marine survival of smolts of the 1988 run in the Baltic Sea, which led to an increased number of maturing salmon at sea. The simultaneous decline in the offshore fishery and the early timing of the spawning runs during 1989–1992 could have led to higher escapement from offshore and coastal fisheries (Karlsson and Karlström, 1994; Karlsson *et al.*, 1994). Also, mean size-at-age among spawners started to increase in the late 1980s (Karlsson and Karlström, 1994), leading to a higher spawning biomass.

Spawning runs mostly remained at a higher level during the early 1990s, but parr densities declined again. The lowest number of age-0 parr was observed during 1992–1994, and in many rivers the hatching years of 1995 and 1996 were also fairly poor. This may be explained by the outbreak of the M74 syndrome. M74 mortality peaked

Table 6. Estimated average parr densities ($\hat{N}$ per 100 m^2) by period and by river (W 0, wild age-0; W > 0, wild age > 0; R, reared).

	1980–1985			1986–1990			1991–1995			1996–2000		
	W 0	W > 0	R	W 0	W > 0	R	W 0	W > 0	R	W 0	W > 0	R
Simojoki	1.53	2.43	3.60	2.02	1.52	5.79	1.56	1.25	8.22	13.06	7.34	5.47
Tornionjoki	0.06	0.27	3.83	0.57	1.01	2.63	0.86	1.81	2.11	7.16	5.97	2.90
Kalixälven	0.30	2.30	0.00	1.89	4.47	0.00	2.00	3.97	0.00	13.94	10.20	0.00
Åbyälven	–	–	–	1.21	1.53	0.00	2.78	3.66	0.00	8.66	6.29	0.00
Ume/Vindelälven	0.27	1.15	0.81	0.83	1.69	2.78	0.74	0.87	0.14	7.20	7.06	0.21
Öreälven	0.00	0.01	2.05	0.01	0.00	0.00	0.06	0.11	0.27	0.81	0.44	0.15
Average (all rivers)	0.43	1.23	2.57	1.09	1.70	2.80	1.33	1.95	2.68	8.47	6.22	2.18

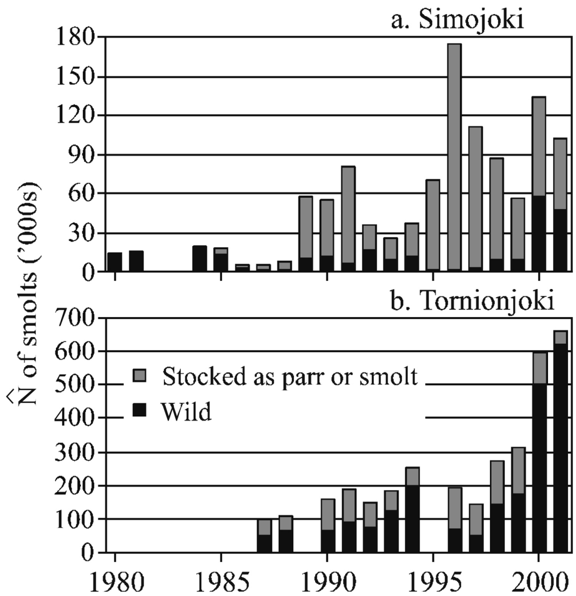

Figure 6. Annual smolt runs ('000s) in (a) Simojoki and (b) Tornionjoki based on smolt trapping with mark-recapture experiments (redrawn after ICES, 2002).

during these years, when 70–90% of the offspring from broodfish died during the first weeks after hatching. The reduction in wild parr densities was of similar magnitude.

Spawning runs increased again in all the rivers that were investigated around 1996. Spawning runs commonly peaked in 1997, and densities of age-0 parr peaked in 1998. Catches in rivers without further restrictions on fishing and run counts typically increased two- to five-fold in 2 years time (1995–1997). From the mid-1990s until the end of the decade, parr densities rose roughly five-fold in the Öreälven and Åbyälven and at least 10-fold in the other rivers (Figure 5). The typical smolting age is 2 or 3 years in the Simojoki and 3 years in the Tornionjoki (Jutila and Pruuki, 1988; Jokikokko and Jutila, 1998). Thus, parr belonging to the strongest year-classes smolted mostly in 2000 and 2001 in these rivers. In these years, wild smolt abundance rose close to the potential level previously estimated for these rivers (ICES, 2001b). Currently, concern is being expressed about the uncertainty associated with estimates of smolt production capacity and its probable underestimation, particularly for the largest Baltic rivers (ICES, 2001b, 2002).

Catch samples from the Tornionjoki show that the year-class that hatched in 1991 was predominant among the spawners during 1996–1998. The age at spawning is about the same among Bothnian Bay stocks, i.e. commonly 5–6

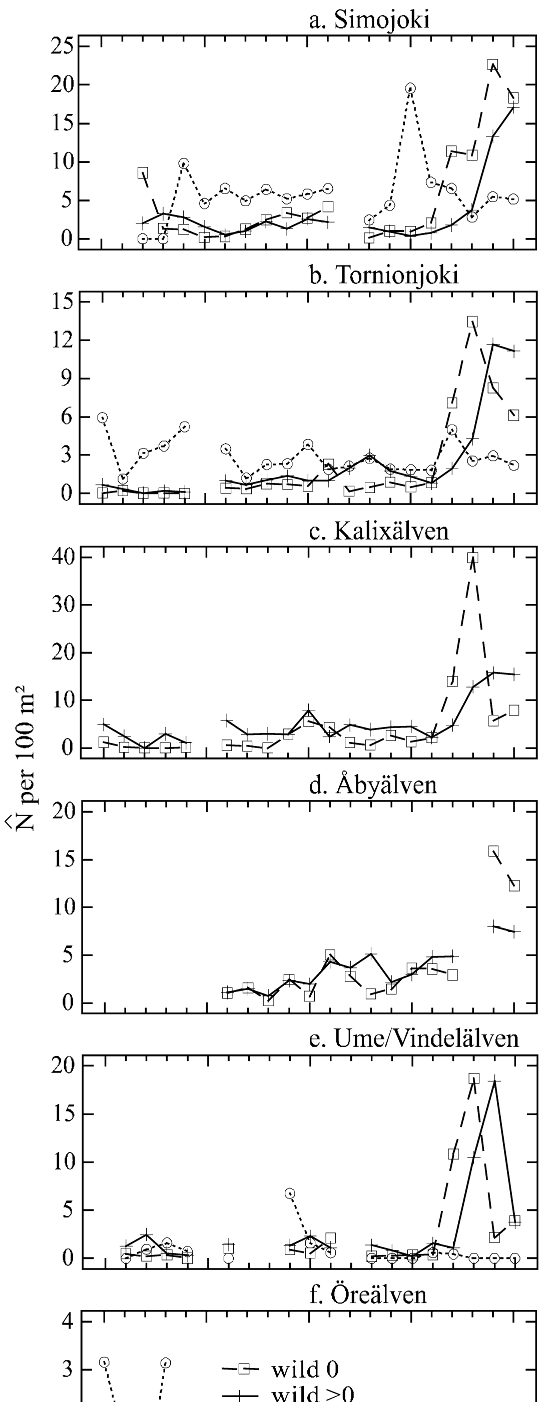

Figure 5. Average parr densities (N̂ per 100 m^2) by river (a–f) and category: wild age-0, wild age > 0 and reared (mostly of age > 0). Reared parr had adipose fin removed, except in the Ume/Vindelälven, where all parr caught in stocking areas were regarded as reared.

years for first-time spawners (Alm, 1934; Järvi, 1938). This suggests that offspring from spawners of the first increase dominated the spawners during the second increase also in the other rivers.

As the abundant year-classes hatched around 1990 grew up at sea, further fishing restrictions were implemented. The TAC was reduced by 37%, from 1993 to 1997, and Finland strengthened restrictions on coastal fishery starting in 1996. Fortunately, M74 mortality also showed the first signs of a reduction among fry hatched in 1997 (Table 3; ICES, 2001b), and thereafter mortality has been much reduced. This reduction in M74 mortality may have allowed an even steeper increase in parr densities than might be accounted for by the increase observed in spawning runs. Nevertheless, the large proportion of female spawners and the high proportion of MSW salmon guaranteed a high reproductive capacity. Thus, several factors were acting in the same direction, with similar effects, but much stronger, as in the late 1980s. Also, the fishing restrictions enforced during this period had been more severe than the previous years.

During the last few years, the number of spawners has decreased in most rivers. This may well have been caused by poor year-classes smolted during 1996–1998 as a consequence of the high M74 mortality in the early 1990s. Up to 15% of the Tornionjoki spawners sampled were spawning for the second or the third time during these years, indicating that spawning mortality has been low and that exploitation rate at sea has been modest. Most repeat spawners were females hatched in 1991. The high proportion of repeat spawners could reflect a situation, where a dominant old year-class disappears from the population, while the just maturing year-classes are much weaker.

At the turn of the millennium, the first indications of another increase show up in the number of adult counts. The high abundance of parr should have led to increased number of smolts since 2000, which is supported by counts in the Simojoki and Tornionjoki (Figure 6). Smolt runs may have increased already since 1999 in the southernmost rivers, where smolt age is lower (Alm, 1934). It may well be that the all-time high adult counts in the Kalixälven and Ume/Vindelälven in 2001 represent the first spawning migrants from these large smolt runs.

The broad similarities in the development of salmon stocks across the Gulf of Bothnia point towards common regulating factors. The existence of both short- and long-term synchronous historic trends in abundance of Baltic salmon stocks is well-known (Järvi, 1938, 1948; Lindroth, 1965; McKinnell and Karlström, 1999). Most observations on this phenomenon are from the 19th and early 20th centuries, when sea fishing was less intensive, which suggests that it is of non-anthropogenic origin (Hagman and Kukkamäki, 1938). However, McKinnell and Karlström (1999) also found strong correlations in population development among rivers in the Gulf of Bothnia during the period of extensive sea fishing.

According to the evidence presented in this study, a combination of both anthropogenic and non-anthropogenic factors operating at a large scale may explain the recent developments. Possible central non-anthropogenic factors are the early marine survival of smolts, timing of the spawning migration and M74 mortality, which have also been suggested by Kuikka (1991), Pruuki (1993b), Karlsson *et al.* (1994) and Karlsson and Karlström (1994). With respect to anthropogenic factors, changes in offshore and coastal fisheries are consistent with changes in river abundance. Elimination of the White Zone and low market price of salmon in the late 1980s (Karlsson and Karlström, 1994), together with the introduction of TACs and their gradual reduction in the 1990s, appear to have led to a gradual decline in fishing effort and an associated decline in offshore fishing mortality. Before 1996, the coastal fishery intercepted at least part of the increased number of spawning migrants that survived the offshore fishery. However, the sudden introduction of an early season ban on Finnish coastal fishery in 1996 should have contributed to a further reduction in total marine fishing mortality among wild migrants.

Figure 7 qualitatively summarizes the factors that we considered to be most important in affecting the development of these salmon stocks. Despite first signs of a reduction in offshore and coastal fishing mortalities during the late 1980s, the figure emphasizes the especially favourable natural conditions for survival at that time: high post-smolt survival (1) contributed to all-time high catches around 1990 and, simultaneously, increased number of fish survived to spawn as a consequence of early timing of the spawning runs (2). In contrast, no extraordinary natural conditions can be brought out to explain the second rise in abundance in the late 1990s, but the likely role of the prolonged early-season ban (3), coinciding with

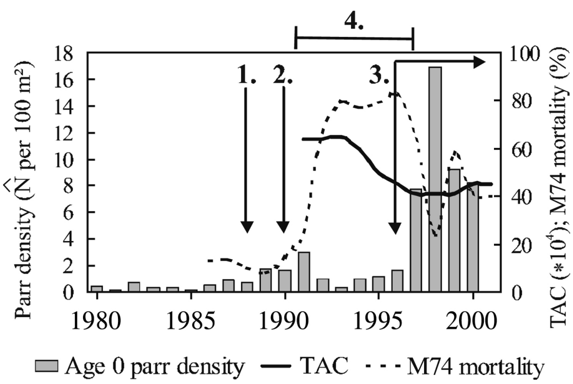

Figure 7. Annual average density of wild age-0 parr across all the rivers that were investigated in relation to time series of TAC, M74 mortality and other factors (1, high survival of post-smolts; 2, early timing of spawning runs; 3, delayed opening dates for coastal fishery; 4, abundance cycle with length of one salmon generation) that are likely to have controlled abundance of wild salmon in Gulf of Bothnia rivers.

the maturation of fish hatched during the first rise (4, length of salmon generation), are emphasized. Although the stepwise-strengthened management regulations appear to offer the best explanation for the upward trend in abundance during the 1990s, the M74 syndrome has counteracted its effects, particularly during the early 1990s. Still, a quantitative reconstruction of the stock history at different life stages and of the factors of interest, seem to be required to test this hypothesis.

The widely observed downward trend among North Atlantic salmon stocks during the past decades (ICES, 2001b; DFO, 2002) also indicates that large-scale factors play a key role in controlling their abundance. However, in contrast to the Baltic stocks, even total closures of some marine fisheries in the northwest Atlantic have not been able to reverse the trends, pointing towards a dominant role of variation in (natural) marine survival (DFO, 2002).

Although covariation in salmon abundance among rivers is evident, there are also differences. Fishing regulations, stocking and other enhancement programmes have specific effects on the stock in each river. Regulations related to coastal fisheries close to river mouths can be regarded as intermediate between river-specific and general management measures because salmon in these areas are neither totally mixed nor do they represent a single stock (Romakkaniemi *et al.*, 1995b). Partial mixing of stocks might extend even up to the lower parts of the rivers, as indicated by the large proportion of strayers in the Tornionjoki in the late 1980s (Figure 4). There has been a large annual compensatory stocking of smolts at the mouth of the regulated River Kemijoki, just 20 km off from the Tornionjoki, and the stocking volume peaked in the late 1980s. This in combination with a low abundance of wild Tornionjoki salmon could explain the high proportion of strayers in the late 1980s.

In the Åbyälven, Ume/Vindelälven and Öreälven, the increase in number of spawners during the late 1980s was stronger than in the other rivers, while the increase in the late 1990s was less pronounced. A possible explanation might be that salmon from these rivers do not migrate the same distance along the Finnish coast and head off earlier, so that the coastal regulations by Finland have had less effect. The extended fishing restrictions in 1996 and thereafter appear to have increased, especially, the number of spawners entering the Simojoki, Tornionjoki and Kalixälven, suggesting that the intensive fishery on the Finnish coast exploited these stocks in particular.

Another river-specific phenomenon is the variation in overall parr density. Since the mid-1980s, parr density in the Kalixälven has been about two times higher than the average of over all rivers (Table 6). Wild parr densities have been among highest also in the Simojoki. In contrast, parr densities in the Öreälven have remained generally 10–20 times lower than in the other rivers. These differences cannot be easily explained either by management-driven or other obvious factors.

With the exception of the Simojoki, rivers without enhancement stocking exhibit higher prevailing wild parr densities than those with stocking programmes. However, this should not be taken as an indication of a negative impact of stocking, because stocking programmes are commonly directed towards rivers with poor natural production. Also, rivers have exhibited similar fluctuations in the abundance of wild salmon, independent of the fact whether stocking occurred. Numerous stocked juveniles survived, as can be deduced from the smolt counts (Figure 6). In the Tornionjoki, reared fish often made up about half of the smolt population, but only 10–20% of the ascending spawning migrants (Figure 4). This indicates that marine survival of reared fish is much lower than that of wild fish. In the Öreälven and Simojoki, reared fish often accounted for a large proportion of the spawning migrants, and even predominated in some periods. Nevertheless, abundance dynamics of wild salmon in these rivers were not markedly different from those in rivers without stocking programmes. Overall, it is difficult to point out either the positive or the negative effects of enhancement stocking on the wild salmon population. Although stocking may successfully introduce salmon beyond its earlier range of distribution (O'Connell and Bourgeois, 1987; Bourgeois, 1998), hard evidence that release programmes lead to improved production, is lacking (Fleming and Petersson, 2001). However, the revival of salmon in the Öreälven after a period of particularly low abundance throughout the 1980s suggests that the two-decade stocking programme may have contributed to the resilience of this stock. The extinction of wild stocks in the Pyhäjoki and Kiiminkijoki since the 1960s exemplifies the fatal collapses to which less vital Baltic stocks have been prone. Timely established brood stocks and rearing programmes could have saved at least part of the genetic diversity and used in specially designed rebuilding programmes.

The number of years during which the river fishery was banned varied among the four Swedish rivers, with the regime having been most restrictive in the Öreälven and least restrictive in the Kalixälven. In contrast, rod-fishing pressure has increased in the Simojoki and Tornionjoki since the mid-1990s. The recent increase in wild parr densities in the latter two rivers has been as steep as in the others, suggesting that under the circumstances, the river fishery has not had major effects on the spawning stocks. Overall, the data do not reveal distinct effects of river-specific management regimes.

To summarize, we have documented a rapid recovery in the wild salmon stocks of the northern Baltic Sea in recent years, apparently a rare event these days. Appropriate management of the salmon fishery in the Baltic Sea appears to have created the necessary conditions for the recovery, but good timing of favourable natural factors, acting also on larger scales, has facilitated the positive development. As our attention has been focussed on order-of-magnitude differences, the relatively low resolution of our analyses may well explain the lack of indications of the effects of local factors. Nevertheless, the results indicate that existing local management schemes would not have been effective by themselves to induce stock recoveries under the prevailing circumstances. However, causes and effects remain hypothetical and call for more rigorous analyses and further testing.

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References

Alm, G. 1934. Salmon in the Baltic precincts. Rapports et Procès-verbaux des Réunions du Conseil International pour l'Exploration de la Mer, 92. 63 pp.

Amcoff, P., Börjeson, H., Lindeberg, J., and Norrgren, L. 1998. Thiamine concentrations in feral Baltic salmon exhibiting the M74 syndrome. *In* Symposium 21, pp. 82–89. Ed. by G. McDonald, J. D. Fitzsimons, and D. C. Honeyfield, American Fisheries Society, Bethesda.

Anon. 1951. Report of the Migratory Fish Committee. Svenska Vattenkraftföreningens Publikationer, 423, 8. 308 pp. (In Swedish).

Antere, I., and Ikonen, E. 1983. A method for distinguishing wild salmon from those originating from fish farms on the basis of scale structure. ICES CM 1983/M: 26. 7 pp.

Bengtsson, B.-E., Hill, C., Bergman, Å., Brandt, I., Johansson, N., Magnhagen, C., Södergren, S., and Thulin, J. 1999. Reproductive disturbances in Baltic fish: a synopsis of the FiRe project. Ambio, 28: 2–8.

Bohlin, T., Hamrin, S., Heggeberget, T., Rasmunssen, G., and Saltveit, S. J. 1989. Electrofishing-theory and practice with special emphasis on salmonids. Hydrobiologia, 173: 9–43.

Bourgeois, C. E. 1998. Assessment of the introduction of Atlantic salmon, *Salmo salar*, into the Rocky River. *In* Stocking and Introduction of Fish, pp. 225–233. Ed. by I. G. Cowx, Fishing News Books, Oxford.

Bylund, G., and Lerche, O. 1995. Thiamine therapy of M74 affected fry of Atlantic salmon *Salmo salar*. Bulletin of the European Association of Fish Pathologists, 15: 93–97.

Carlin, B. 1969. Salmon tagging experiments. Swedish Salmon Research Institute Report, 3: 8–13.

Christensen, O., Eriksson, C., and Ikonen, E. 1994. History of the Baltic salmon, fisheries and management. ICES Cooperative Research Report, 197: 23–39.

Christensen, O., and Larsson, P.-O. 1979. Review of Baltic salmon research. ICES Cooperative Research Report, 89. 124 pp.

DFO 2002. Atlantic Salmon Maritime Provinces overview for 2001. DFO Science Stock Status Report D3–14. 43 pp.

Fleming, I. A., and Petersson, E. 2001. The ability of released, hatchery salmonids to breed and contribute to the natural productivity of wild populations. Nordic Journal of Freshwater Research, 75: 71–98.

Hagman, N., and Kukkamäki, T. J. 1938. The variations in the catch of salmon and the water levels of the rivers. Annales Zoological Societatis Zoologicæ–Botanicæ Fennicæ Vanamo, 5: 1–43.

Hiilivirta, P., Ikonen, E., and Lappalainen, J. 1998. Comparison of two methods for distinguishing wild from hatchery-reared salmon (*Salmo salar* Linnaeus, 1758) in the Baltic Sea. ICES Journal of Marine Science, 55: 981–986.

Hurme, S. 1962. The Baltic rivers in Finland supporting migratory fish species. Maataloushallituksen kalataloudellisen tutkimustoimiston monistettuja julkaisuja, 24: 1–198 (in Finnish).

IBSFC, and HELCOM 1999. Baltic Salmon Rivers – status in the late 1990s as reported by the countries in the Baltic Region. The Swedish Environmental Protection Agency, the Swedish National Board of Fisheries. 69 pp.

ICES 1989. Report of the Baltic Salmon and Trout Assessment Working Group. ICES CM 1989/Assess: 16. 83 pp.

ICES 1994. Report of the study group on occurrence of M-74 in fish stocks. ICES CM 1994/ENV: 9. 24 pp.

ICES 2001a. Report of the Baltic Salmon and Trout Assessment Working Group. ICES CM 2001/AFCM: 14. 131 pp.

ICES 2001b. Report of the ICES Advisory Committee on Fishery Management, 2001. ICES Cooperative Research Report, 246. 895 pp.

ICES 2002. Report of the Baltic Salmon and Trout Assessment Working Group. ICES CM 2002/AFCM: 13. 216 pp.

Ikonen, E., and Kallio-Nyberg, I. 1993. The origin and timing of the coastal return migration of salmon (*Salmo salar*) in the Gulf of Bothnia. ICES CM 1993/M: 34. 9 pp.

Järvi, T. H. 1938. Fluctuations in the Baltic stock of salmon. Rapports et Procès-verbaux des Réunions du Conseil International pour l'Exploration de la Mer, 106. 114 pp.

Järvi, T. H. 1948. On the periodicity of salmon reproduction in the northern Baltic area and its causes. Rapports et Procès-verbaux des Réunions du Conseil International pour l'Exploration de la Mer, 119. 131 pp.

Jokikokko, E., and Jutila, J. 1998. The effects of stocking with salmon parr, *Salmo salar*, on the smolt production in the River Simojoki, northern Finland. *In* Stocking and Introduction of Fish, pp. 35–45. Ed. by I. G. Cowx, Fishing News Books, Oxford.

Junge, C. O., and Libosvárský, J. 1965. Effect of size selectivity on population estimates based on successive removals with electric fishing gear. Zoologicke Listy, 14: 171–178.

Jutila, E. 1992. Report on the management, catches and smolt production of the salmon stock in the Simojoki river. ICES CM 1992/M: 11. 14 pp.

Jutila, E., and Pruuki, V. 1988. The enhancement of the salmon stocks in the Simojoki and Tornionjoki rivers by stocking parr in the rapids. Aqua Fennica, 18: 93–99.

Kallio, I., and Pruuki, V. 1987. The diversity and seasonal spawning migration of salmon (*Salmo salar* L.) in the River Tornionjoki. Proceedings of the World Symposium on Selection, Hybridization and Genetic Engineering in Aquaculture, 1: 166–176.

Karlström, Ö. 1977. Habitat selection and population densities of salmon (*Salmo salar* L.) and trout (*Salmo trutta* L.) parr in Swedish rivers with some reference to human activities. Ph.D. thesis, Acta Universitas Upsaliensis 404. 12 pp.

Karlström, Ö. 1995. Salmon parr (*Salmo salar* L.) production and spawning stocks in Baltic salmon rivers in northern Sweden 1976–94. ICES CM 1995/M: 23. 15 pp.

Karlström, Ö., and Byström, P. 1994. Estimates of the smolt run in the River Torneälv 1987–1993. ICES CM 1994/M: 19. 18 pp.

Karlsson, L., and Karlström, Ö. 1994. The Baltic salmon (*Salmo salar* L.): its history, present situation and future. Dana, 10: 61–85.

Karlsson, L., Karlström, Ö., and Hasselborg, T. 1994. Timing of the Baltic salmon run in the Gulf of Bothnia – influence of environmental factors on annual variation. ICES CM 1994/M: 17. 15 pp.

Kaukoranta, M., Koljonen, M.-L., Koskiniemi, J., Pennanen, J., and Tammi, J. 2000. Atlas of Finnish fishes. Finnish Game and Fisheries Research Institute. 40 pp.

Kuikka, S. 1991. Effects of some external factors on the predictability and production capacity of Baltic salmon stocks. ICES CM 1991/M: 29. 21 pp.

Lindroth, A. 1965. The Baltic salmon stock. Its natural and artificial regulation. Mitteilungen, Internationale Vereinigung für Theoretische und Angewante Limnologie, 13: 163–192.

Malmgren, A. J. 1884. The migration of the salmon (*Salmo salar* L.) in the Baltic. Bulletin of the United States Fish Commission, 4: 322–328.

Mäntyniemi, S., and Romakkaniemi, A. 2002. Bayesian mark-recapture estimation with an application to a salmonid smolt population. Canadian Journal of Fisheries and Aquatic Sciences, 59: 1748–1758.

McKinnell, S., and Karlström, Ö. 1999. Spatial and temporal covariation in the recruitment and abundance of Atlantic salmon populations in the Baltic Sea. ICES Journal of Marine Science, 56: 433–443.

McKinnell, S., Lundqvist, H., and Johansson, H. 1994. Biological characteristics of the upstream migration of naturally and hatchery-reared Baltic salmon, *Salmo salar* L. Aquaculture and Fisheries Management, 25(suppl. 2): 45–63.

O'Connell, M. F., and Bourgeois, C. E. 1987. Atlantic salmon enhancement in the Exploits River, Newfoundland, 1957–1984. North American Journal of Fisheries Management, 7: 207–214.

Parrish, D. L., Behnke, R. J., Gephard, S. R., McCormick, S. D., and Reeves, G. H. 1998. Why aren't there more Atlantic salmon (*Salmo salar*)? Canadian Journal of Fisheries and Aquatic Sciences, 55(suppl. 1): 281–287.

Pruuki, V. 1993a. Changes in the status of the salmon stock in the river Tornionjoki. ICES CM 1993/M: 51. 6 pp. + figures.

Pruuki, V. 1993. Salmon stocks and salmon catches in the Gulf of Bothnia. Aqua Fennica, 23(2): 227–233.

Romakkaniemi, A., Karlsson, L., and Karlström, Ö. 1995a. Wild Baltic salmon stocks: fecundity and biological reference points concerning their status. ICES CM 1995/M: 28. 11 pp.

Romakkaniemi, A., Lilja, J., Nykänen, M., Marjomäki, T.M., and Jurvelius, J. 2000. Spawning run of Atlantic Salmon (*Salmo salar*) in the River Tornionjoki monitored by horizontal split-beam echosounding. Aquatic Living Resources, 13: 349–354.

Romakkaniemi, A., Pakarinen, T., and Ikonen, E. 1995b. Spatial stock composition of salmon on the basis of tag returns in the northern Bothnian Bay fishery. ICES CM 1995/M: 27. 11 pp.

Vuorinen, P. J., Paasivirta, J., Keinänen, M., Vartiainen, T., and Parmanne, R. 1999. Organochlorines and thiamine in salmon (*Salmo salar* L.) and prey species, Baltic herring (*Clupea harengus* L.) and sprat (*Sprattus sprattus* L.), in connection with the M74 syndrome. ICES CM 1999/U: 12. 16 pp.

Westerberg, H., Sturlaugson, J., Ikonen, E., and Karlsson, L. 1999. Data storage tag study of salmon (*Salmo salar*) migration in the Baltic: behaviour and the migration route as reconstructed from SST data. ICES CM 1999/AA: 06. 18 pp.

Youngs, W. D., and Robson, D. S. 1978. Estimation of population number and mortality rates. *In* IBP Handbook No. 3, 3rd edition pp. 137–164. Ed. by T. Bagenal. Blackwell, Oxford.