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The effects of stocking Atlantic salmon, *Salmo salar*, in a Norwegian regulated river

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Abstract Stocking is undertaken in the River Suldalslågen, western Norway, to compensate for an estimated annual loss of 20 000 Atlantic salmon smolts, *Salmo salar* L., caused by regulating the river for hydropower production. The annual contribution to angling catches from stocked hatchery fish varied from 7 to 334 kg, or < 15% of the total number caught. Between 160 000 and 250 000 one-summer old fish were stocked, but only between 6 and 10 (< 0.005%) were recaptured as adults in the river. Recaptured stocked fish never exceeded 0.03% by number, despite smolts dominating the stocking material in recent years. It is not certain whether the slight increase in catches comes in addition to or at the expense of natural reproduction. In most years more adults were used as parent stock than were caught as offspring. The lack of positive response to stocking is possibly due to lesser age, smaller size and later migration of hatchery smolts, and that seawater tolerance of hatchery smolts is poorly developed, all factors increasing mortality at sea.

KEYWORDS: Atlantic salmon, presmolt, regulated river, stocking, yield.

Introduction

In Norway, fish stocking is a widely used strategy to mitigate negative environmental impacts on recruitment or to increase fish production and yield. The main species stocked are brown trout, *Salmo trutta* L., and Atlantic salmon, *Salmo salar* L. (Saltveit 1998; Fjellheim & Johnsen 2001). When the aim has been to mitigate against encroachments or to recover populations, stocking can be a cost-effective method (Aprahamian, Martin Smith, McGinnity, McKelvey & Taylor 2003). However, despite extensive stocking of different stages of young fish for decades, populations of Atlantic salmon have continued to decline in Norway (Fjellheim & Johnsen 2001). Although smolts are stocked in some rivers, most of the fish stocked are fry and fingerlings (Fjellheim & Johnsen 2001). Stocking fry or parr is only necessary and effective when natural reproduction is negatively affected (Cowx 1994; Saltveit 1998). As stocked smolts immediately leave the river, stocking smolts can be effective, as these fish are produced beyond the natural carrying capacity of the river (Russell 1994; McGinnity, Prodöhl, ÓMaoiléidigh, Hynes, Cotter, Baker, O'Hea & Ferguson 2004), assuming that an excess of spawners is used as parental fish. In Norway, brown trout and Atlantic salmon are also often stocked in unimpacted reaches or above the natural anadromous reach to increase production (Fjellheim & Johnsen 2001). However, this strategy is not necessarily environmentally acceptable as it may impact wild stocks (Cowx 1998) or populations of other species.

Despite extensive stocking of parr in rivers, little knowledge exists on its effects and its usefulness (Potter & Russell 1994; Russell 1994; Saltveit 1998; Fjellheim & Johnsen 2001). Atlantic salmon has a life history involving several years both in rivers and at sea, and thus long-term monitoring is needed to elucidate the effects of stocking. Most rivers subjected to long-term studies on the outcome of stocking programmes in Norway are heavily regulated (Fjellheim & Johnsen 2001). More knowledge exists on survival at sea from stocking wild and hatchery-reared of Atlantic salmon smolts, with regard to origin (Hansen & Jonsson 1989a), rearing facilities (Virtanen, Söderholm-Tana, Soivio, Forsman & Muona 1991), and time of release (Hansen & Jonsson 1989b).

As in most stocking regimes in Norway, there has been no evaluation of the need for stocking in the regulated River Suldalslågen. Stocking on a regular basis started in 1989 to compensate for an estimated loss of 20 000 smolts, mainly due to stranding.

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However, stranding was only a problem between 1981 and 1985 (Saltveit & Bremnes 2004). Young-of-the year (YoY) densities increased from 1986 to 1993, indicating increased natural reproduction (Saltveit & Bremnes 2004). However, high mortality in the first year of life for naturally reproduced juvenile Atlantic salmon in Suldalslågen indicated limitations to survival during the first winter or the following spring/summer (Saltveit & Bremnes 2004). During winter, juvenile fish have access to a smaller wetted area because of lower regulated flows. The limiting factor for fish production in the river was therefore unknown when the stocking programme was implemented. It was assumed that stocking parr in the River Suldalslågen would not increase the yield, but stocking smolts could, as the natural reproduction seemed higher than the rivers carrying capacity. This paper examines the efficacy of stocking to compensate for the flow regulation, and attempts to elucidate the limiting factors on success of stocking to ascertain whether the option should exercised in the future.

Materials and methods

Study site

The 22-km long, River Suldalslågen, western Norway, has a catchment area of about 1000 km^2. It runs from Lake Suldalsvatn (65 m a.s.l. and 29 km^2 in surface area), to the inner part of the Ryfylkefjord. Anadromous fish are found along its entire length. The dominant fish species are Atlantic salmon and brown trout. Suldalslågen is relatively warm during winter compared with most Norwegian rivers, with temperature between 1 and 3 °C, but temperatures between May and October seldom exceed 10–12 °C.

A hydropower scheme was implemented in 1980 involving water transfer from Lake Suldalsvatn to a power station with outlet to an adjacent fjord. This power station did not have any major impact on adult salmon returning to the river (Thorstad, Økland, Johnsen & Næsje 2003). The flow in Suldalslågen is reduced throughout the year; from 15 December to 1 May, the minimum flow released into Suldalslågen is 12 m^{3}s^{-1}. In a short period after 1 May, the flow is increased to more than 100 m^{3}s^{-1} to secure smolt emigration. From mid May to 1 October the minimum flow in the river is 60–70 m^{3}s^{-1}, but it is gradually reduced to the winter minimum flow. Since 1998 the river has been through a 6-year test period with two different flow regimes. During the first 3 years flow was as described above, afterwards a regime with two small emigration flows not exceeding 60–70 m^{3}s^{-1}at the beginning of May, then 40 m^{3}s^{-1} until 15 July, was followed by a return to the previous regime.

Stocking strategy

The original plan was to stock 12 000 2-year-old Atlantic salmon smolts, and 100 000 YoY parr in the tributaries and 50 000 YoY parr in Lake Suldalsvatn annually. These sites lacked or had a limited natural reproduction. Some of the tributaries were affected by acidification, or could be dry for parts of the year. From 1992, most of the YoY parr were stocked within the main river. Further, more fish than required have been stocked, and the stocking strategy (the period for stocking, sites and the material) was changed (Table 1) to mainly stocking smolts in the fjord. All hatchery fish were marked by adipose fin removal. The parental fish were wild salmon taken from the River Suldalslågen.

Sampling

Migrating wild and stocked Atlantic salmon smolts were collected in a smolt trap (Garnås & Hesthagen 1986), operated from a bridge situated 1 km above the river mouth. A 12-m long bag with equal parts of 21, 16 and 10 mm mesh size from the opening, was mounted on a 1.5 × 1.5 m frame. The trap was set in the evening and emptied in the morning. The trap was in operation from April to mid-June. All fish caught were dead and were immediately frozen for further analysis. Smolts were measured (nearest mm) and weighed (0.1 g), and scales and otoliths were removed for ageing.

River catch

Information on river catches of wild and stocked salmon was taken from official statistics collected by the River Owner's Association, which also collected scales, and data on length, weight and sex of the adult fish. The anglers were asked to note if the fish were fin clipped or had characteristics of escapees from fish farms. Escapees could also be separated from wild fish by scale readings. A small proportion of the catch consisted of strays, smolts stocked in other rivers or directly into the sea. In 1993 and 1994, yield (kg of stocked fish) was estimated based on mean weight of the total catch. Subsequently, the weights of stocked fish and wild fish were separated.

The number of adults from each year's stocking, recaptured by anglers in the river during the period 1992–2002, was estimated using catch statistics and by backcalculation from scales. Samples do not exist for

Table 1. Site of stocking and number of Atlantic salmon of different category stocked in the River Suldalslågen from 1985 to 2003

	River Suldalslågen			Lake Suldalsvatn	Tributary streams		Sea
Year	Start-fed parr	YoY parr	Smolt	YoY parr	Start-fed parr	YoY parr	Smolt
1985	500		6000		89 500	15 000	
1986	122 500		4109				
1987			3884				
1988			21 862	7507	14 355		
1989	10 000		15 000	21 400	95 000	1000	
1990		10 000		9000	33 000		
1991	2870	20 515		69 250	54 100	15 840	
1992	1020	131 870		47 270		74 660	
1993		153 540		52 400	30 000	68 015	
1994		133 450		25 940	5400	55 500	
1995		163 375					
1996		14 000	5000	90 000		8000	10 000
1997			53 296	31 910		6500	18 182
1998		45 620	29 880				15 000
1999		56 600	50 300				15 000
2000		54 930	50 150			3200	
2001		20 600	47 100				30 000
2002		12 540					50 000
2003							80 000

YoY, young-of-the year.

all fish caught in 1993, 2000 and 2001 and backcalculation from these years gives only gives minimum estimates. As smolts were stocked as 1+, it was impossible to separate those stocked as 1+ smolt from those from the same generation stocked as YoY parr in the river. All recaptures are therefore related to year they hatched and not to the year stocked.

Differences in year fish lengths (total length) and smolt age were tested by *t*-tests.

Results

River catch

Atlantic salmon catches from the River Suldalslågen exhibit large annual variations, but with a gradual increase in river catches from 1981 to 1992, followed by a dramatic decline in 1993. In this year only 1275 kg were caught, which was the lowest river catch since 1978/1979. Angling catches remained low and even declined further in the following years. Yield remains low, but a slight increase is apparent in recent years.

Stocked Atlantic salmon constituted a very small part of anglers' catches, varying from 6.8 kg in 1996 to 334 kg in 2003. The largest share was in 1993 and 2001–2003, which are the only years when the number of stocked fish exceeded 10% of the total numbers caught (Table 2).

Table 2. Numbers of Atlantic salmon descending from natural reproduction (Wild) and from stocking (Stocked) in anglers' catches from River Suldalslågen

Year	Wild	Stocked	Total number	Stocked (%)
1993	43	10	53	18.9
1994	130	9	139	6.5
1995	198	10	208	4.8
1996	48	3	51	5.9
1997	158	7	165	4.2
1998	103	3	106	2.8
1999	209	6	215	2.7
2000	410	35	445	7.9
2001	190	29	219	13.4
2002	239	40	279	14.3
2003	412	54	466	11.6

Catches related to number stocked

Of fish stocked between 1992 and 1999, only between six and 31 were recaptured annually as adults (Table 3). Recaptures from the high number of fish stocked as YoY parr between 1992 and 1995 were minimal, only 0.005% of the number stocked (Table 3). After 1995, smolts were stocked in increasing numbers (Table 1), but recaptures remained low. Only 17 fish of the total number stocked in 1996 and 1997 were caught as adults in the river, while the stocking in 1998 gave 31 adult

Table 3. The relationship between the number of fish stocked different years either as young-of-the year (YoY) parr or as smolt and their recapture in terms of numbers and percentage of those stocked. The table also gives the number of female and male parental fish used to produce the given number of stocked fish. The results in the table is based on back calculations from scales

	Number of parental fish		Number stocked		Recaptured	
Year	male	female	YoY	Smolt*	Number	%
1992	30	49	253 800		7	0.003
1993	20	38	273 955		10	0.004
1994	5	24	188 950		6	0.003
1995	11	19	163 375	15 000	8	0.005
1996	14	31	112 000	71478	17	0.009
1997	5	10	38 410	44 880	17	0.020
1998	14	15	45 620	65 300	31	0.028
1999	10	14	56 600	50 150	22	0.021
2000	12	15	57 130	77 100	15	0.011
2001	8	17	20 600	50 000	1	
2002	7	15	12 540	80 000	0	

*Number is shown for the year they hatched.

salmon or 0.034% of the number stocked (Table 3). To date, fish stocked in 1999 and 2000 have given rise to 22 and 15 adult recaptured fish, respectively.

In general, more females from the wild stock are used each year as parental fish than are recaptured as adult fish from their offspring (Table 3). For example, in 1993, 38 females were used to produce 273 955 YoY parr, and from these only 10 were recaptured as adults within the river. However, the gains have been slightly better in later years, and in 1998 and 1999, 31 and 22 adult salmon were recaptured after release of stocked fish bred from 15 and 14 female fish, respectively.

Sea and smolt age of adult fish

Adult fish of both wild and stocked origin had sea ages of 1–5 years (Fig. 1). A small difference in sea age composition was found between wild and stocked in 1993, 1994 and 1995. After 1999, wild salmon dominated the catches of one sea winter fish, while two and three winter fish dominated the catches of stocked fish (Fig. 1). This could be due to catch restrictions, as wild salmon larger than 75 cm had to be released after having been registered, but without scale samples.

There were large differences between wild and stocked fish in the time spent as juveniles in the river. Adult salmon from natural reproduction generally smoltify as 3- and 4-year olds, while salmon from stocking were 1 or 2-year old as smolt (Fig. 1).

Smolt migration

In 1993, most of the smolts (75%) were hatchery fish, but from 1994 to 1998, hatchery and wild fish contributed equally to smolt numbers (Fig. 2). From 2000 there was a statistical significant ($r^2 = 0.995$; $P = 0.0001$) increase in the number of wild smolts leaving the river. Throughout the whole period there is a statistically significant decline ($r^2 = 0.585$; $P = 0.004$) in the number of stocked smolts leaving the river because the number of fish stocked has been gradually reduced until they were no longer stocked in 2003 (Table 1).

Hatchery smolts migrated later than wild smolts. In some years, the difference between the time when 50% and 75% of the smolts had migrated could be between 15 and 30 days. In later years, the difference decreased to about a week or less.

Smolt age and size

Stocked smolts had a relatively low mean smolt age, varying between 1.4 and 1.9 years (Fig. 3), and < 10% of the stocked smolts caught in the trap were older than 2 years, except in 1996, when 20% were older than 2 years. Wild smolts were in general older ($P < 0.05$), with a mean age between 2.8 and 3.7 years (Fig. 3). During the years of study there was a significant ($r^2 = 0{,}729$; $P = 0.0004$) reduction in mean age of wild smolts.

Prior to 1997, stocked fish smoltified at a smaller size ($P < 0.05$) than wild smolts (Fig. 3). In 1997, the mean length of hatchery smolts increased, but they were still smaller than wild smolts. From 1998 to 2001, hatchery smolts were significantly longer ($P < 0.05$) than wild smolts, because a larger number of the hatchery fish were stocked as smolts in the river instead of as YoY parr (see Table 1). A decline in the mean length of wild smolts was apparent from 1998 because of smoltification at a lower age and thus smaller size (Fig. 3). In 2004, however, the mean size of wild smolts again increased, being significantly larger ($P < 0.05$) than in the period 1999–2003.

Discussion

The results from River Suldalslågen are in line with general impression of stocking YoY fish in Norwegian rivers; it does not lead to increased yield. Among the reasons are probably the performance of hatchery fish, their interactions and competition with wild fish when increasing fish densities beyond the carrying capacity of the river and by taking brood stock material from

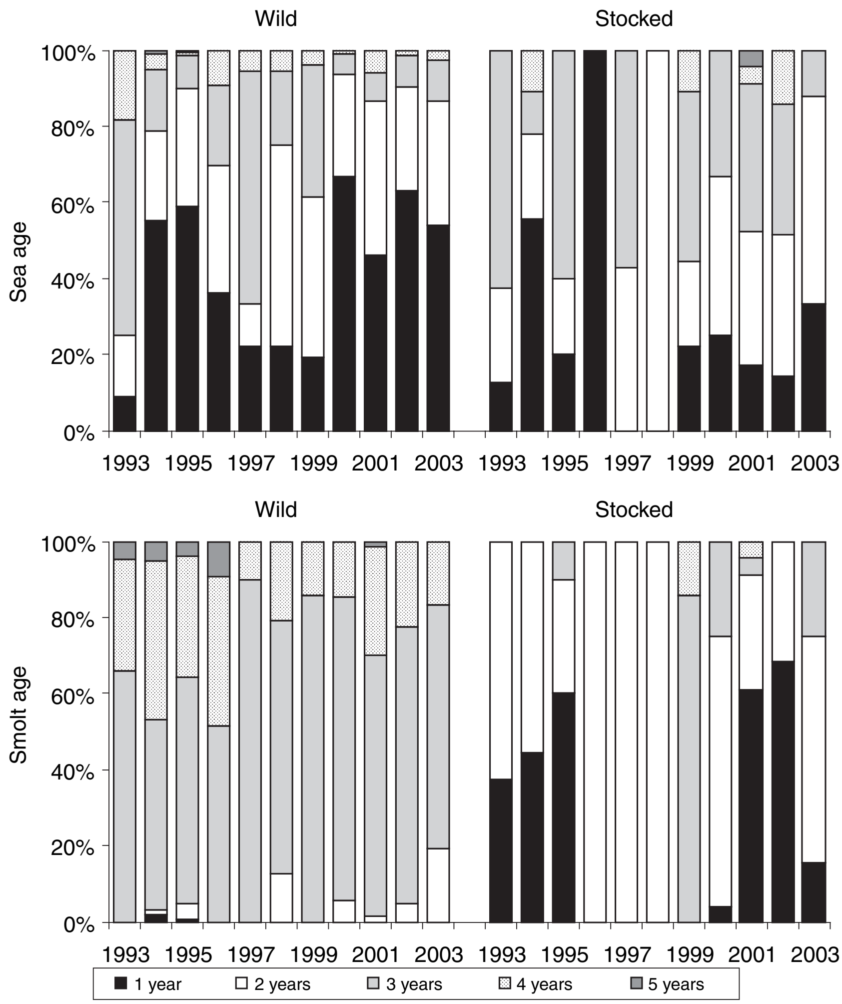

Figure 1. Sea age and smolt age frequency distribution in hatchery and natural reproduced adult Atlantic salmon in the angling catch in the River Suldalslågen during the period 1993–2003.

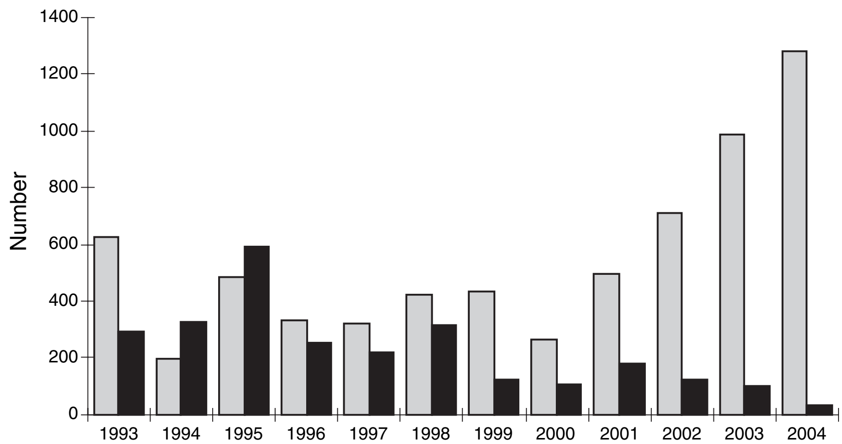

Figure 2. Total annual catches of wild (grey bar) and hatchery smolt (black bar) in the smolt trap in Suldalslågen from 1993 to 2004.

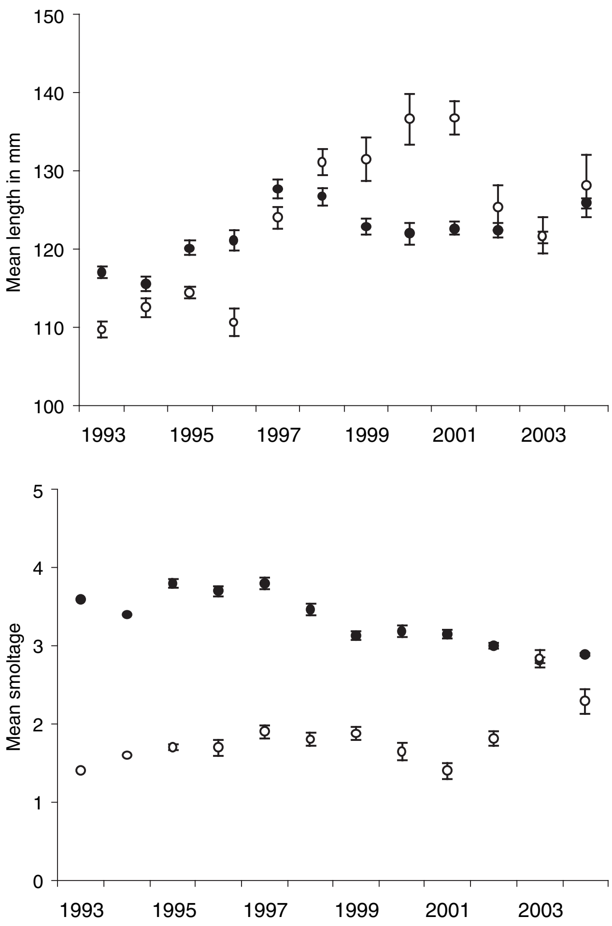

Figure 3. Mean size and mean smolt age of wild smolt (●) and hatchery smolt (○) caught in the smolt trap in Suldalslågen during 1993–2004. Deviation from the mean is given as 95% CI.

an already limited spawning population (Saltveit 1993, 1998; Fjellheim, Raddum & Barlaup 1995; Fjellheim, Raddum & Barlaup 1998/reviewed in Fjellheim & Johnsen 2001; Sægrov, Hellen, Jensen, Barlaup & Johnsen 2000/reviewed in Fjellheim & Johnsen 2001; Einum & Fleming 2001; Borgstrøm, Skaala & Aastveit 2002). Removal of spawners, depleting natural reproduction, was probably the reason for lack of success when stocking Atlantic salmon in the River Lærdalselva (Saltveit 1993, 1998) and anadromous brown trout in the River Teigdalselva, where between 30% and 36% of a marginal population of mature females were removed (Fjellheim *et al.* 1995; Fjellheim & Johnsen 2001). No evaluations of the tolerance of a spawning population to removal of broodstock to produce stocked fish exists for Norwegian rivers and probably not elsewhere. In Suldalslågen the size of the spawning population declined in 1992 (source: Statistics Norway and Suldal River Owner Association), but is still used for broodstock material. In most years between 1977 and 2003, natural recruitment in Suldalslågen has been below the carrying capacity of the river due to a low number of eggs spawned per m^2 (S.J. Saltveit, unpublished data).

Limiting factors or bottlenecks for fish production in general are not well documented (Cowx 1994). A positive effect from stocking can only be achieved if natural reproduction in the river is below carrying capacity, and only if a surplus of spawners is used for production of stocked fish (Saltveit 1998; Aprahamian *et al.* 2003). As rivers are highly dynamic systems, carrying capacity will vary both in time and space, dependent upon nature of the habitat, food availability, temperature and flow regime (Armstrong, Kemp, Kennedy, Ladle & Milner 2003). This variation will be especially large in regulated rivers, which may not regain the same population size as previously. Attempts to increase densities beyond the carrying capacity without other measures are therefore likely to fail (Cowx 1994; Russell 1994; Aprahamian *et al.* 2003).

The lack of capacity to accommodate stocking resulted in catastrophic consequences, both for the stocked and the wild juvenile fish in two Norwegian regulated rivers, leaving a smaller population of both stocked and wild fish the following spring (Fjellheim *et al.* 1995; Fjellheim *et al.* 1998/reviewed in Fjellheim & Johnsen 2001; Sægrov *et al.* 2000/reviewed in Fjellheim & Johnsen 2001). Only 1% of stocked brown trout in the River Øriselva, western Norway, survived until smolt size, a survival rate three to six times lower than wild fish (Borgstrøm *et al.* 2002). In the River Imsa, western Norway, it was postulated that the production of adults could be enhanced by increasing the recruitment rate, i.e. by improving survival through increased carrying capacity and reducing the effects of factors limiting life history within the river (Jonsson, Jonsson & Hansen 1998).

Carried out correctly and used for the right purpose, stocking can be more efficient at producing returning adults than natural spawning (Marshall, Farmer & Cutting 1994; Aprahamian *et al.* 2003). When the limiting factor is known, stocking may give positive results, as seen from the equal output of smolt and adult return from native and ranched native salmon stocked in an Irish river system (McGinnity *et al.* 2004), and documented when re-establishing stocks in rivers affected by pollution (Russell 1994; see also Aprahamian *et al.* 2003; Hesthagen & Larsen 2003; Milner, Russell, Aprahamian, Inverarity, Shelly & Rippon 2004).

Despite giving rise to just as many migrating smolts as natural reproduction, the smolts descending from start fed and summer-old YoY hatchery fish gave < 15% of the salmon catches in the River Suldalslågen, indicating a far higher mortality at sea for hatchery smolts. The slightly higher proportion of hatchery fish in the catches since 1999 could be due to an increase in the number of smolts stocked, both in the river and at sea. About 50% of the catches in 2000 could be related to smolt stocking in the sea in the Sandsfjord system, while only a single salmon in 2001 and five fish in 2002 could be related with certainty to stocking at sea. In some years, catches of strays (Carlin tagged fish stocked elsewhere) outnumbered catches of stocked fish. Reduced marine survival also occurred in stocked Pacific salmonids (Reisenbichler & Rubin 1999).

A smaller size, younger age and later migration to sea, are all traits of the stocked smolts likely to increase mortality of hatchery fish at sea (Rosseland 1979; Hansen & Jonsson 1989a,b; O'Connell & Ash 1993; Klemetsen, Amundsen, Dempson, Jonsson, Jonsson, O'Connell & Mortensen 2003). The rearing conditions are also different from the natural environment and in addition, the density of fish is many thousands of times higher, decreasing the ability of hatchery fish to compete and survive in natural environments (Einum & Fleming 2001). The results from Suldalslågen are a strong indication of the benefits in improving conditions for natural reproduction, as wild smolts have a far higher probability of survival at sea.

During the last years of stocking in Suldalslågen, YoY were stocked earlier in the year, mid August, and at a smaller size, 5–7 cm, compared with previously; 8–10 cm fish stocked in September. This may be one reason for a slightly higher catch of hatchery fish, as it may have improved smolt quality through a slightly longer duration in the river before smoltification and led to a migration period more similar to wild smolt. One summer old parr gave fewer migrating smolts than 1-year-old parr stocked in a Finnish river (Jokikokko & Jutila 2004), which could be expected from the time spent in the river. The catch of adults in the river were very small, because of high exploitation rate in the Baltic Sea. However, the return results of stocked salmon were usually lower than wild fish (Jutila, Jokikokko & Julkunen 2003). Improvements in recapture rate in the River Tyne, England, were attributed to stocking larger parr, which improved freshwater survival (Russell 1994), as was the case with a release of larger Baltic salmon smolts into the River Umeå or Baltic Sea (Lundqvist, McKinnell, Fängstam & Berglund 1994; McKinnell & Lundqvist 2000).

The reason for a lower number of migrating smolts from hatchery fish in Suldalslågen is that fewer fish were stocked in the years up to 2003 when stocking was terminated. The lower mean age of wild smolts explained the increase in number of wild smolt migrating in recent years. The reduced flow in Suldalslågen from 2001 onwards gave a higher water temperature, increased juvenile fish growth and increased smolt production, as fewer years were spent in the river (S.J. Saltveit, unpublished data). Time will show if this will increase the number of adult fish from natural reproduction returning to the river, as it may result in complex interrelated adjustments throughout the life cycle (Milner, Elliott, Armstrong, Gardiner, Welton & Ladle 2003).

The stocking of Atlantic salmon as parr in the River Suldalslågen did not come up to the expectations of compensating for loss in fish production due to the regulation and giving an increase in yield of adult fish. However, nor did the stocking of smolts. Of the 5000 Carlin tagged smolts stocked each year in the river between 1996 and 1999, only two fish (0.02%) were caught by anglers in the river (C.R. Jensen, unpublished data). Also smolts (Carlin tagged) towed in net cages from the river mouth to the open sea or stocked in the river mouth had a low recapture rate compared with other Norwegian rivers, only 0.7–0.1% respectively (R. Strand, unpublished data).

For wild smolts from a large sized salmon river such as Suldalslågen, a 2–5% survival at sea is expected (L.P. Hansen, personal communication). However, wild smolts have a 50% higher survival rate at sea compared with hatchery smolts as well as being less prone to straying (Jonsson, Jonsson & Hansen 1991; Quinn 1993; Jutila *et al.* 2003). Given this survival rate for stocked smolts from Suldalslågen, the stocking of 50 000 smolt should alone result in at least 250 adults in the catch (see Saltveit 1998). Hvidsten, Heggberget & Hansen (1994) found the straying in hatchery smolts was between 14% and 19%. This is rather low and therefore does not explain the large differences in the catches of adult fish coming from the hatcheries and those from natural reproduction. The production of wild smolts was estimated to be between 31 500 and 51 000 smolts based on mark/recapture studies (Saltveit & Bremnes 2004), a number contributing to more than 85% of the river catch. A similar or even larger number of smolts were stocked. Smolts from the hatchery never developed seawater tolerance (shown experimentally) and suffered high mortality during the whole smolt migration period (Finstad, Kroglund, Hartvigsen, Teien, Rosseland & Salbu 1999; Flodmark, Schjolden & Poléo 2003), explaining the low return.

In relation to the high number of fish stocked in Suldalslågen, the gain is extremely low and more parental fish were used to produce hatchery fish than are recaptured as adult fish from their offspring. The exploitation rate in the river is estimated to 40–50% of the returning stock (see Saltveit 1998), indicating a small contribution from the stocked fish to the spawning population. It is also not certain whether the slight increase in catch in Suldalslågen was in addition to, or at the expense of, natural reproduction (see also Russell 1994). Stocking is based on wild parental fish taken from the river and these will not be available for natural reproduction and can thus lead to fewer natural smolts. It would also have been appropriate to know the carrying capacity and bottlenecks for fish production before the implementation of stocking in the river, objectives imperative to any stocking programme or effective managements of stocks (Cowx 1994; Aprahamian *et al.* 2003; Solomon, Mawle & Duncan 2003).

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