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Effects of marine survival, precocity and other life history traits on the cost-benefit of stocking salmon in the Baltic Sea

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ABSTRACT

Cost-benefit analysis was applied to estimate the economic consequences of precocious maturation among hatchery-reared Atlantic salmon (*Salmo salar*) sea-ranched in the Baltic Sea. Data on the rearing and release costs, fishing costs, catch benefits, catch size, catch age and survival of previously immature and mature salmon in Carlin-tagged groups released into the Gulf of Finland in 1981–2005 were used in the analysis. Previously immature and precociously mature salmon differed in their marine growth, survival, sea age at maturity and migration behaviour. Precocity reduced the net present value (NPV) of the releases due to the lower catch age and marine survival of the previously mature compared to the immature salmon. Assuming that all the salmon were harvested by professional fishermen, the estimated NPV for the whole study period 1981–2005 was positive at a discount rate of 0.04 and a producer price of 5.2 euros/kg or over. During the period of lower survival in the late 1990s and later, the NPV was, however, negative for all assumed producer prices of capture salmon in the professional fishery, i.e. prices between 4.2 and 9.2 euros/kg. The NPV only turned positive if the value of the catch was assumed to be the estimated value of the recreational fishery catch, i.e. 21 euros/kg. The results suggest that if the catch age and marine survival of salmon do not markedly increase from their present low levels, there will be practically no potential to render the NPV positive in the professional fishery by introducing novel breeding practices capable of reducing parr maturation rates. A shift in the fishery from commercial to recreational fishing could to some extent increase the NPV of salmon releases.

1. Introduction

The precocity, i.e. early sexual maturation, of male Atlantic salmon (*Salmo salar*) as parr before sea migration is a common phenomenon in stocks of both the Baltic Sea and the Atlantic Ocean (Leyzerovich, 1973; Myers et al., 1986; Lundqvist and Friberg, 1982). However, female salmon and a proportion of males undergo parr-smolt transformation before their first maturation and migrate to the sea to feed before spawning as anadromous adults (Lundqvist et al., 1988; Jonsson et al., 1998; Hansen et al., 1989). Precocity is controlled by both genetic and environmental factors (Lundqvist et al., 1986; Myers et al., 1986; Berglund et al., 1991; Fleming and Einum, 1997), and the trait is stock-specific and displays considerable annual variation. Parr maturation enhances the overlap between generations and thus maintains genetic variability, especially in small populations (Saunders and Schom, 1985; Saura et al., 2008). In sea ranching, maturation as parr has been regarded as a potential problem, as it may reduce the survival rates of the released fish and thus the economic output of ranching (Myers, 1984; Lundqvist et al., 1988, 1994).

The growth rate differs between maturing and immature salmon parr before their potential smolt age under controlled hatchery conditions (Rowe and Thorpe, 1990a; Whalen and Parrish, 1999). Two-year-old immature reared smolts are usually larger than precociously mature reared males of the same age (Lundqvist et al., 1988, 1994). Tagging experiments with hatchery-reared smolts suggest that the return rate and survival of precociously mature males is significantly lower than that of immature smolts (Lundqvist et al., 1988; Vehanen et al., 1993; McKinnell and Lundqvist, 2000). The initial size difference may partly explain the lower return rate of mature males, because recapture rates generally tend to increase with increasing release size of the reared fish (Salminen et al., 1995; Jokikokko et al., 2006; Kallio-Nyberg et al., 2009). However, the survival of precociously mature parr may also be lower due to a weaker ability to acclimatize to sea water (Lundqvist et al., 1986; Berglund et al., 1992).

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The marine survival of both wild and hatchery-reared Atlantic salmon has markedly decreased during the last 10–15 years for both the Atlantic and Baltic stocks (Jonsson and Jonsson, 2004; Kallio-Nyberg et al., 2006, 2009; Friedland et al., 2009). According to Jyräsalo and Ollikainen (2005), the costs of salmon releases have exceeded the net benefits to the commercial salmon fishery, for instance in the Gulf of Finland. In the Baltic Sea, the trend towards declining survival has primarily been attributed to variable and presently unfavourable marine conditions (Kallio-Nyberg et al., 2006, 2009), whereas the potential role of hatchery smolt quality has remained generally unclear. For example, the steadily increasing average size of hatchery smolts was not found to significantly compensate for the generally decreasing survival trend (Kallio-Nyberg et al., 2009). Nor was the trend significantly affected by variable parr maturation rates among the released fish (Kallio-Nyberg et al., 2009). The parr maturation rate may, however, affect the annual yield of the fishery, not only through post-smolt mortality, but also through potential changes in other important life-history traits such as marine growth, migratory distance and sea-age at maturity.

In this article we examine the effect of differences in growth, survival and migration between immature and precociously mature male smolts at sea, and evaluate the economic consequences of precocity in the sea-ranching programme of the Gulf of Finland using the cost-benefit approach (Boardman et al., 2006). The net present value (NPV) of precociously mature (male) and immature smolt (male and female) groups is compared by taking into account the release costs, fishing costs and catch benefits in applying cost-benefit analysis. The focus of the analysis is the professional fishery, which accounts for most of the catch produced by the smolt releases (WGBAST, 2009), but the benefits of the recreational fishery are also considered.

2. Material and methods

2.1. The production and tagging of smolts

The Neva salmon smolts of this study originated from a hatchery brood stock reared at the Laukaa hatchery of the Finnish Game and Fisheries Research Institute (FGFRI). The on-rearing of the fish to 2-year-old smolts was carried out in several private hatcheries in Central Finland (Kallio-Nyberg et al., 2009). In the winter or spring months before release, the FGFRI fitted about 500–1000 juveniles per rearing group with Carlin tags. During tagging, the individual smolt length and maturation status of each fish was recorded. The fish with running milt were precociously mature males. In the analysis, the measured smolt lengths at tagging were used as “release lengths” without adjustment for potential growth between tagging and release, because the potential growth rate in winter months was assumed to be negligible due to the very low rearing temperatures (generally <2°C) (e.g. Virtanen, 1987). In 1981–2005, a total of 99 479 salmon were tagged, of which 85 067 (85.5%) were immature smolts and 14 412 (14.5%) precociously mature males (Table 1). The smolts were then released in April–May in three separate estuaries along the Finnish south coast between 24°N and 28°N in the Gulf of Finland (the estuaries of the Rivers Vantaanjoki, Porvoonjoki and Kymijoki) in 1981–2005 (Fig. 1). The tagged fish were released with non-tagged fish. Because the hatcheries and release places varied to some extent from year to year, the evaluated year effect on survival included both hatchery and release site effects. The Neva salmon were caught in the coastal waters mainly by trap nets and gill nets used by both recreational and professional fishermen, but a proportion of the salmon were also caught in offshore fishing (Salminen et al., 1995).

Table 1
The number (n) and recapture rate (%) of tagged immature salmon smolts and precocious males released in the Gulf of Finland in 1981–2005.

Year	Immature		Precocious	
	Smolts n	Recapture rate %	Males n	Recapture rate %
1981	995	17.2	4	25
1982	1995	20.8	3	0
1983	2727	9.6	76	6.2
1984	3554	9.8	90	5.6
1985	6910	15.8	536	9.2
1986	7404	17.5	852	14.4
1987	4192	15.2	751	11.2
1988	6631	14.6	327	6.2
1989	7801	16.4	600	14.3
1990	4705	10.0	2225	9.2
1991	3865	9.1	1083	8.0
1992	7519	11.9	1322	12.0
1993	1449	13.2	550	10.4
1994	1361	8.5	38	1.5
1995	3776	8.2	214	10.7
1996	1580	10.1	417	9.4
1997	811	3.1	187	2.1
1998	1146	3.1	852	3.9
1999	1747	1.3	252	2.0
2000	1235	2.0	765	1.7
2001	3453	1.1	546	0.9
2002	2487	0.5	451	0.9
2003	2167	0.7	827	0.7
2004	2174	0.6	821	0.6
2005	3376	0.2	621	0.1

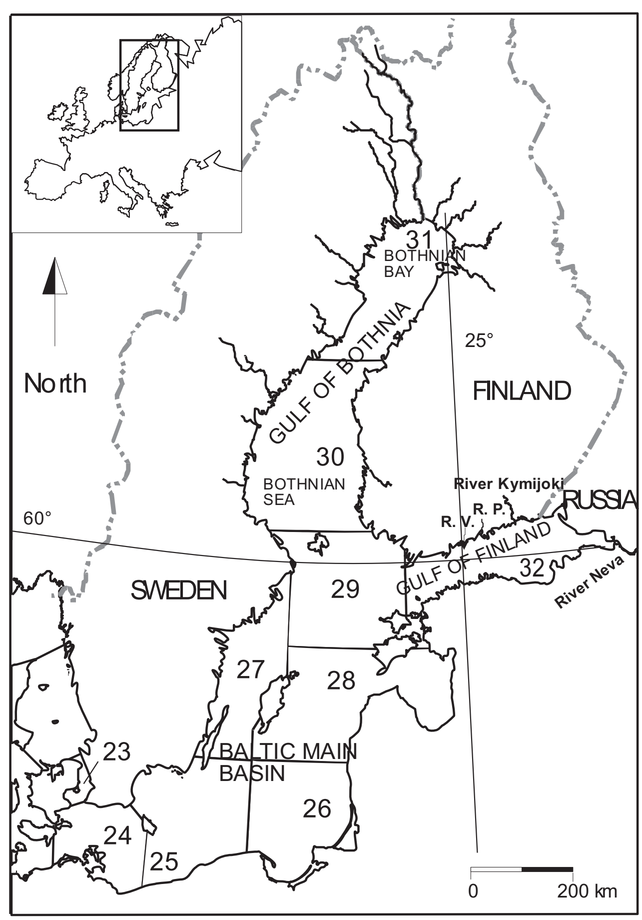

Fig. 1. A map of the Baltic Sea showing the sub-basins (Main Basin (= Baltic Proper), Gulf of Finland, Gulf of Bothnia, and some smaller sub-basins) and the location of the estuaries of Kymijoki, Porvoonjoki (R. P.) and Vantaanjoki (R. V.). The Neva salmon groups were released into the estuaries of these rivers or coastal waters. Southern Main Basin = sub-divisions 23–26; Northern Main Basin = sub-divisions 27–29.