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Cost–benefit analysis of Atlantic salmon smolt releases in relation to life-history variation

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ABSTRACT

Cost–benefit analysis was applied to estimate the net present value (NPV) of Atlantic salmon (*Salmo salar*, Carl Linnaeus) hatchery smolt releases and the spatial distribution of the present value of benefit [PV(B)] in the Baltic Sea. The benefit was assessed for the commercial fishery and separately from hatchery-reared and wild smolts. Data on Carlin tagging and on the proportions of individual salmon stocks in the commercial catches were used. The NPV of hatchery smolt releases appeared to be negative with current rearing costs and the range of applied discount rates (2–4%), and especially with the currently low overall survival of salmon smolts in the sea (<2%). A 5% recapture rate had been needed for a positive outcome. The PV(B) of wild salmon smolts was higher than that of reared salmon smolts due to their larger catch size and higher recapture rate. Both wild and reared salmon mostly benefited the fishermen operating in the Baltic Main Basin, while few fish and minor revenues were left for the coastal and river fisheries in the Bothnian Bay. Six salmon stocks, three wild and three reared, originating from the Bothnian Bay accounted for 60% of the total Atlantic salmon catch in the Baltic Sea. The current economical benefits from hatchery smolt releases to professional fishermen barely overcome the costs they cause to rearing and releasing counterparties.

1. Introduction

The Atlantic salmon (*Salmo salar*, Carl Linnaeus) living in the Baltic Sea is the only fish species within the advisory system of the International Council for the Exploration of the Sea (ICES) whose recruitment is largely under human control, because of extensive releasing programmes. During the last ten years, for instance, hatchery-reared salmon have accounted for 60–70% of the estimated 7 million smolts (2- to 3-year-old salmon, ready to begin sea life) annually entering the Baltic Sea (WGBAST, 2011). The goal of stocking has been to compensate for the lost natural smolt production (Lindroth, 1984) and to support the weak wild stocks (Jutila et al., 2003a; Romakkaniemi et al., 2003). The largest producers of hatchery smolts have been Sweden (proportion in 2010: 0.39) and Finland (0.31), i.e. the countries with the largest losses to the original natural smolt production. Most of the releases (approximately 65%) have been carried out in the northern part of the Baltic Sea, the Gulf of Bothnia (WGBAST, 2011). The releases are mainly based on legal obligations, set for the power plant companies responsible for the damming of salmon rivers. Some release programmes, however, may be regarded as voluntary sea-ranching, aimed at the support of local salmon fisheries (Eriksson and Eriksson, 1993; Salminen et al., 1995, 2007). The releases benefit fishermen, their only costs being fishing costs.

In the 1980s and at the beginning of the 1990s, up to 9 out of 10 salmon captured in the Baltic Sea had been reared. Since then, the proportion of reared fish has decreased, and in the 2000s wild fish formed the clear majority of the catch (Koljonen, 2006; WGBAST, 2011). This marked change may be attributed to the partial recovery of natural smolt production (Jutila et al., 2003a; Romakkaniemi et al., 2003), and to the relatively stronger decrease in the survival rate of reared smolts than that of wild smolts (Michielsens et al., 2006; Kallio-Nyberg et al., 2006, 2011b; WGBAST, 2011). The estimated annual natural Atlantic smolt production was 2.0–2.5 million smolts in the 2000s, and the northern, Bothnian Bay (Fig. 1) salmon stocks have accounted about 80% of this (WGBAST, 2011). Because the salmon of the Bothnian Bay migrate to feed in the Baltic Main Basin (Kallio-Nyberg et al., 1999; Jutila et al., 2003b), and the natural smolt production and number of reared smolts released in the Main Basin are low, the majority of the salmon catch in the Baltic Sea is based on smolt production in the Bothnian Bay (WGBAST, 2011).

Besides its contribution to fisheries, the hatchery rearing of smolts has also provided an important means to preserve the genetic diversity of salmon stocks that have lost their natural spawning grounds (Koljonen et al., 2002). Currently, 15 of

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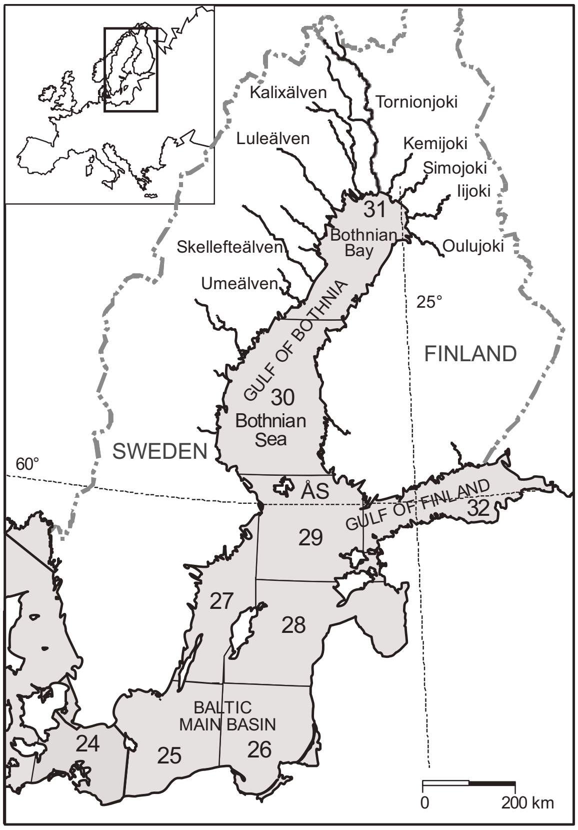

Fig. 1. Map of the Baltic Sea showing the Atlantic salmon feeding area, ICES subdivisions (25–32), and the locations of the rivers from which the individual salmon stocks were included in the analysis.

the 32 genetically distinct Baltic salmon stocks are solely sustained by hatchery operations (Koljonen, 2006). The strategies applied to preserve these stocks and their genes range from the generations-long maintenance of hatchery brood stocks and milt banks (store of frozen milt, Finland) to the annual capture and stripping of hatchery-reared spawners returning to their stocking sites (WGBAST, 2011).

Hatchery rearing and stocking also have inevitable drawbacks (e.g. Machado-Schiaffino et al., 2007). In the Baltic Sea, hatchery releases of salmon have been blamed for maintaining fishing (mortalities) at such a high level that it has largely been impossible to sustain the weakened wild stocks, as the massive stockings maintain the profitability of the intensive fishery, consequently resulting in continuous fishery pressure on the weak stocks. The capability of long-term hatchery rearing to preserve the original genetic structures and life-history traits of the salmon stocks has also been analysed for both qualitative and quantitative traits, and some changes are known to occur (Kallio-Nyberg and Koljonen, 1997; Säisä et al., 2003; Vainikka et al., 2010). From the perspective of enhancing natural production or for the reintroduction of lost stocks, the stockings have not been efficient, and they have also been unable to protect particularly the weakest salmon populations from overharvesting (Jokikokko and Jutila, 2005).

It has been difficult to combine all the objectives set for present day salmon stock management. The goal on one hand is to provide large catches for the offshore fishery in order to gain benefits from the releases, and on the other to regulate the fishery on the basis of the production of the weak wild stock, which restricts full utilization of the released resources. In addition, the goal has been to transfer fishing pressure from the offshore to coastal and river fishery, thereby allowing the wild fish come closer to their home rivers and spawning sites, which would allow more tailored fishing regulation for each river stock. Since the 1990s, the distribution of salmon catches between Baltic Sea countries has been regulated by the principle of relative stability, referring to the partitioning of the annual total allowable catch (TAC) by a permanent allocation key (WGBAST, 2011). In recent years, high agreed TACs together with low post-smolt survival have resulted in very few salmon returning to their natal rivers or stocking sites through the competing sequential fisheries in the Baltic Sea (Laukkanen, 2001; Jutila et al., 2003a).

The annual losses to natural smolt production due to the damming of salmon rivers of the Bothnian Bay have been estimated to be about 1.1 million smolts on the Finnish side (Kemijoki, Iijoki and Oulujoki Rivers) and 1.0 million smolts on the Swedish side (Luleälven, Skellefteälven, Umeälven Rivers). The present compensation releases in these six Bothnian Bay rivers, totalling about 2.1 million smolts, are intended to cover the losses to natural smolt production (WGBAST, 2011).

The costs and benefits of Atlantic salmon smolt releases and supportive breeding have previously been assessed for some individual rivers in Sweden and Spain and for the eastern Baltic Sea, Gulf of Finland (Lundqvist et al., 1994; Kallio-Nyberg et al., 2011a; Horreo et al., 2012). In this study we carried out a cost–benefit analysis (Boardman et al., 2006) of the large-scale smolt releases in the northern Baltic Sea, in the Bothnian Bay. We also examined the effect of fish growth, age at capture, recapture rate and feeding migration distance on the benefits to fishermen and the distribution of the benefits among the fishing areas.

We determined the net present value (NPV), present value of benefits [PV(B)] and present value of costs [PV(C)] of smolt releases in euros. The NPV of the smolt groups was evaluated with the aid of cost–benefit analysis by taking into account the stocking costs, including rearing and releasing costs (applies only reared smolts, as no costs are related to natural reproduction), fishing costs and catch benefits. We also compared the spatial distribution of the benefits of smolt releases with the respective distribution of the benefits of wild smolt production originating from the same area. Furthermore, we explored the proportions of wild and reared Bothnian Bay salmon in catches (WGBAST, 2011). Our aim was to connect the economic analysis of smolt releases in the Bothnian Bay with the biological variables of the Atlantic salmon stocks and then provide a new perspective for the management and conservation of the wild salmon stocks.

2. Material and methods

2.1. Tagging data of Simojoki salmon

Estimates for the life-history traits for both reared and wild salmon were calculated from tagging data (individual Carlin tags, returned by fishermen with catch information) for wild and reared River Simojoki salmon (Fig. 1). The variables included in the analysis were: smolt size (measured at tagging), recapture catch size, recapture rate (the proportion of tagged smolts recaptured and reported, describing the survival of the fish), sea age of the fish in years at recapture, and the site of recapture for both hatchery-reared and wild salmon. The tagging data for the 2000–2007 smolt cohorts were used. In total, 8273 reared and 6791 wild smolts were tagged and released in the River Simojoki during this period (Kallio-Nyberg et al., 2011b).

2.2. Background information

The River Simojoki (65°38′ 25°00′ E) flows into the Bothnian Bay in the north-eastern part of the Baltic Sea (Fig. 1). The river supports