Marine Survival of Atlantic Salmon in the Baltic Sea

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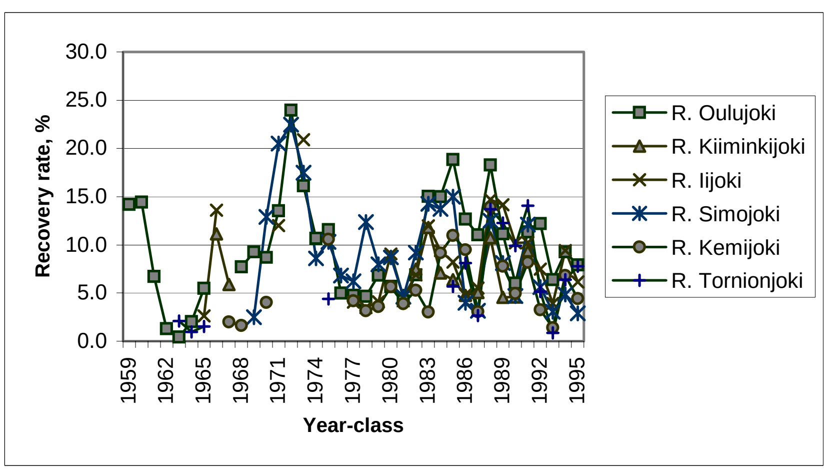
In the Baltic Sea, Atlantic salmon (*Salmo salar* L.) live in an environment very different from the oceanic conditions of the North Atlantic. As a brackish-water area, the Baltic Sea hosts a community where marine and freshwater organisms coexist. A general feature of the marine fish community is low in overall diversity. In the Main Basinprincipal southern feeding areas of Baltic salmon (Baltic Main Basin, Gulf of Finland) there are two significant marine prey fish species for young salmon to feed on during the first months of their migration in the open sea, the herring (*Clupea harengus* L.) and the sprat (*Sprattus sprattus* (L.)), and in the north (Bothnian Sea) only one, the herring (Salminen et al. 2001). Furthermore, the number and abundance of potential predators on young salmon is low in the open sea.

Located within the west-wind zone, the Baltic Sea is exposed to the cyclones from the west-southwest. Climatic variations, together with hydrological and hydrographic processes, strongly influence the temperature and ice conditions, the inflow of fresh water from rivers and the exchange of water with the North-Atlantic Ocean. These features have a significant controlling effect on different trophic levels and their processes, including the dynamics of the open-sea fish community. Human induced factors affecting the whole marine ecosystem of the Baltic include pollution and eutrophication. In the Baltic Sea, salmon live in a highly volatile environment.

Salmon populations of the Baltic Sea exhibit both long-term and short-term fluctuations (Svärdson 1955; Lindroth 1965; McKinnell, 1997; Niva 2001) (Fig. 1). Most authors agree that a substantial part of this variation arises from events during the smolt and post-smolt stages, but attempts to identify the ultimate factors causing early mortality have not been productive. Working hypotheses have linked variable survival to variable predation by marine mammals (review: Lindroth 1965), bird and fish predation (Lindroth 1955, 1965; Larsson and Larsson 1975; Lindroth 1977; Larsson 1985), starvation and disease (Österdahl 1965; Rahkonen et al.1997; Buchmann et al. 2001). No single dominant factor has yet to emerge suggesting that annual mortality levels are influenced by the interaction of a complex of different factors, whose relative importance is continuously changing.

Most of our knowledge on post-smolt mortality in the Baltic is based on tagging experiments using hatchery smolts, and may thus be biased by the study method itself and by hatchery practices affecting both smolt quality and the circumstances in which the fish encounter the marine habitat (release site and time). Specific tagging experiments have been carried out to identify the timing and duration of the critical period for survival (Lindroth 1977; Larsson 1985; Eriksson 1988, 1994; Salminen and Erkamo 1998) and the role of smolt quality and size (e.g. Lundqvist et al. 1988; Vehanen et al. 1993; Lundqvist et al. 1994). Long-term monitoring data have been used to search for synchronous trends in the recapture rates of different reared stocks (McKinnell 1997; Niva 2001) and for correlations between these and different environmental factors (Salminen et al. 1995). These experiments and analyses suggest that although the mortality rates of young salmon are highest during the first days and weeks of migration, the survival levels of hatchery fish are determined during a prolonged period in the marine habitat. Positive correlations between recapture rates, post-smolt growth, summer sea-surface temperatures and the availability of suitable prey fish suggest that the variability in

Fig. 1. Tag-recovery rates (Carlin tag) from releases of salmon smolts in different Finnish Rivers in smolt year-classes 1959–1995.



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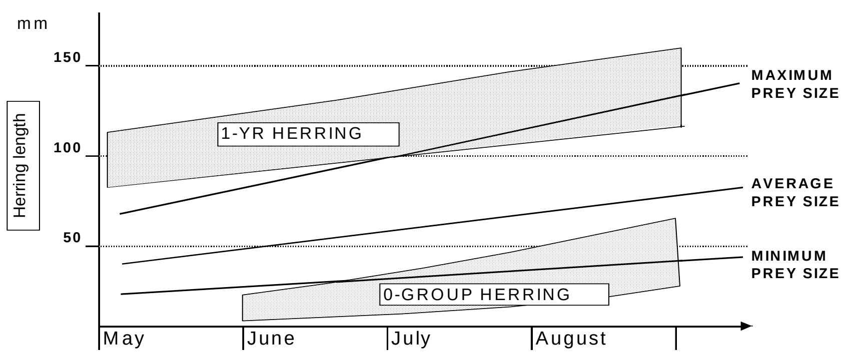
survival is mainly due to variable marine conditions affecting post-smolt growth rates, and thus, the vulnerability of the fish to some size dependent source(s) of mortality.

Tagging experiments have further indicated that in ranched Baltic salmon, the mean survival rates markedly increase (Virtanen et al. 1991; Vehanen et al. 1993; Lundqvist et al. 1994) while the annual variation in survival decreases with increasing smolt size (Salminen et al. 1995; Salminen 1996). In the long-migrating northern salmon stocks, smolt size also influences the distribution of feeding migrants between the northern and southern feeding areas (Salminen et al. 1994; Kallio-Nyberg et al. 1999). Small smolts tend to migrate further south than larger ones.

The higher and less variable survival of larger smolts may be due to their lower initial vulnerability to predation, further reduced by their rapid size increment at sea, which is probably attributed to better foraging opportunities. In the Bothnian Sea, large smolts are able to feed on 1-year old herring shortly after sea entrance while small smolts either have to postpone their shift to piscivory (the only option for an introduced, short-migrating ranching stock) until young-of-the-year herring become available later in the summer (Fig. 2), or to migrate further (an option for the local long-migrating stocks) (Salminen et al. 2001). Smaller, slow-growing individuals are subjected to a wider range of potential sources of mortality for an extended period of time. After an entire year of migration in the Bothnian Sea, the smallest smolts of the short-migrating ranching stock are still smaller than the largest ones at release (Salminen 1997).

Fig. 2. Schematic diagram showing the prey size preference of average salmon post-smolts (size at release 160 mm, average growth rates) during the first months after release in the Bothnian Sea, versus the available size distribution of the principal prey fish, the herring (based on data in Salminen et al. 2001).



Despite large seasonal and annual variability in the physical and biological features of the Baltic Sea, average post-smolt survival rates of salmon seem to be higher in this volatile environment than in the Atlantic Ocean (e.g. Ìsaksson 1994). This may be due to the lower salinity barrier, facilitating the migration of salmon smolts through the estuaries, where predators are usually abundant. On the other hand, the low salinity barrier may also give the managers of hatchery programs more freedom to manipulate smolt quality (e.g. size), despite possible associated deficiencies in smolt status. Overall predation levels on young salmon may also be lower in the Baltic compared to the Atlantic.

Are salmon different in the Baltic Sea compared to the Atlantic? The Baltic salmon provides two pieces of evidence of its genetic adaptation to freshwater or brackish water conditions. First, it has genetic resistance to *Gyrodactylus salaris* Malmberg, a freshwater ectoparasite that is fatal to the North Atlantic stocks of salmon (Bagge et al. 1990). The second piece of evidence of adaptive genetic divergence between Baltic and oceanic salmon is the short feeding migration, which is probably common for all eastern and southern stocks of Baltic salmon, though properly documented only for the River Neva salmon (Kallio-Nyberg and Ikonen 1992). Both these adaptations may partly reflect the dichotomous origin of Baltic salmon: after the last glacial period salmon probably colonized the Baltic Sea from two different directions, from the Atlantic Ocean and from the eastern ice-lakes (Koljonen et al. 1999).

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