Historical decline of Atlantic salmon in NW-Europe

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Abstract
Analysis of zoo-archaeological and historical data of Atlantic salmon stock development shows a remarkable decline from the Middle Ages onwards. Apparently, the species encountered great difficulties in successfully reproducing from that time on. The most probable cause for this decline are thousands of watermills built in the tributaries of Europe's large rivers from the Early Middle Ages on. These watermills both blocked upstream migration and made spawning sites unsuitable for successful reproduction. In order to restore viable Salmon populations in Europe's large rivers, far more attention has to be paid to rehabilitation of lower order streams.

Introduction
The Atlantic salmon (*Salmo salar*) has become the symbol of ecological degradation of river systems in NW-Europe, especially for the rivers Rhine and Meuse. Traditionally, the main reasons for degradation are believed to be intensive fisheries, pollution and especially river regulation, particularly in the 19th and 20th century. According to Hoffmann (1996), however, it is unjust common thought that the Rhine and its major tributaries had only suffered little before 19th and 20th century canalizing and embanking. Our hypothesis is that this is also the case for Atlantic salmon and that watermills in lower order streams are historically important stressors by blocking upstream migration and altering favorable reproduction conditions.

Method
We studied developments in Atlantic salmon stocks by means of Dutch zoo-archaeological data (Bone-info; www.archis.nl) and historical publications containing time series on fishery taxes and market prices. In the zoo-archaeological approach we compared the number of sites in the Netherlands with salmon remains with the number of sites containing Pike (Esox lucius) remains in five periods. Due to the fact that salmon bones contain higher levels of fat that turn into fatty acids after decay and subsequently dissolve the rest of the bones, their remains decay quicker than that of Pike. If actual stocks of both species would remain stable over time, one would therefore expect an increase in the ratio between the number of sites with remains of Atlantic salmon and those with Pike remains. Historical time series were based on: Halard (1982): 1260-1410, Van der Woude (1988): 1650-1800, Martens (1992): 1798-1827 and De Nie (1997): 1885-1939. These time series were indexed in order to be able to compare and link series of different origin. In case data was lacking over specific periods of time, developments were extrapolated by fitting a trend line (Eqn. 1; with c being a constant).

$$\frac{1}{\sqrt{c * time}} \qquad (1)$$

Data from developments in watermill construction in the Rhine and Meuse catchment areas were obtained from *www.molendatabase.com*. Furthermore, we derived data from Domesday Book (Williams and Martin, 2004), a survey of rural estates in 11th century England and compared these data with present-day distribution of Salmon in the UK.

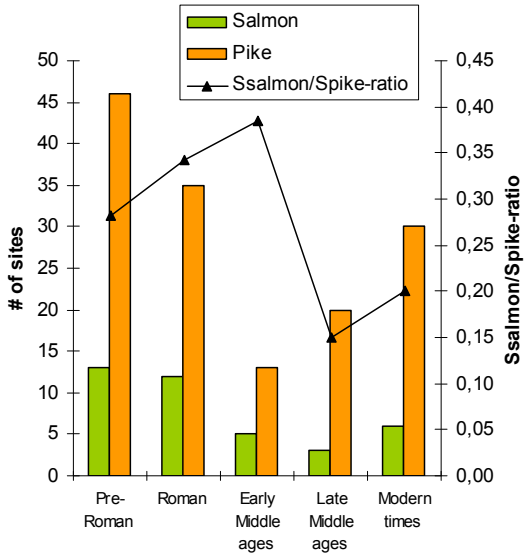

Figure 1: Number of sites with zoo-archaeological records of Salmon (Ssalmon) and Pike (Spike) in the Netherlands and the ratio between them over five periods of ca 500 years each.

Results and discussion
Analysis of the zoo-archaeological data (Fig. 1) shows that during the transition from the Early to the Late Middle Ages a decrease in the Salmon-Pike ratio occurs, indicating a major decrease in Atlantic salmons stocks during this period.
From Fig. 2 it becomes also apparent that salmon decline in NW-Europe started well before the great river regulation works in the 19th and 20th century. By the beginning of the

18th century Atlantic salmon stocks were already decimated. At the same time watermills (in this case in the lower order streams of the Rhine and Meuse catchment areas) were on the increase, thus blocking large parts of the upstream spawning areas of salmon and altering favorable conditions for spawning and nursery.

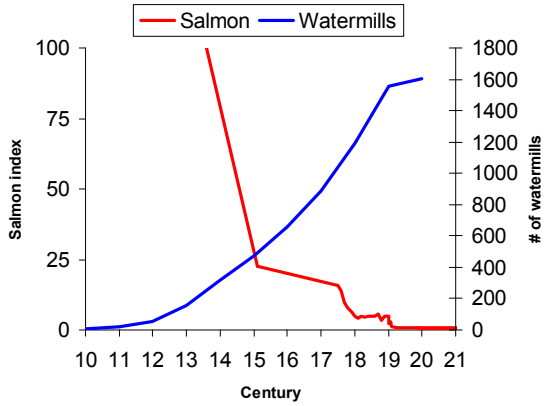

Figure 2: Decline of Atlantic salmon in NW-Europe (indexed; 1360=100%; left y-axis) and increase of watermills in the catchment areas of Rhine and Meuse (right y-axis).

In Domesday Book (Williams and Martin, 2004) over 6000 watermills are reported to be existing in 11th century England. These watermills were not evenly distributed over England. Especially in the north- and southwest watermills were far more scarce. In the present day distribution of Salmon in the UK (Fig. 3), this historical distribution of watermills is still visible: Salmon and watermills seem to exclude one another. This appears to be the case already in medieval times since the five locations for which Salmon is mentioned in Domesday Book are all situated in the peripheral regions where watermills were scarce or absent.

Conclusions

Our research confirms Hoffmann's statement that river systems in NW-Europe were already severely ecologically affected in the Middle Ages. The construction of watermills in lower order streams appears to have had a major impact on Atlantic salmon stocks (and probably also on other aquatic organisms). In order to restore salmon stocks and the complete river ecosystem in general, much more attentions has to be paid to lower order streams, a task – given the immense magnitude of historical alterations – that will not prove to be easy.

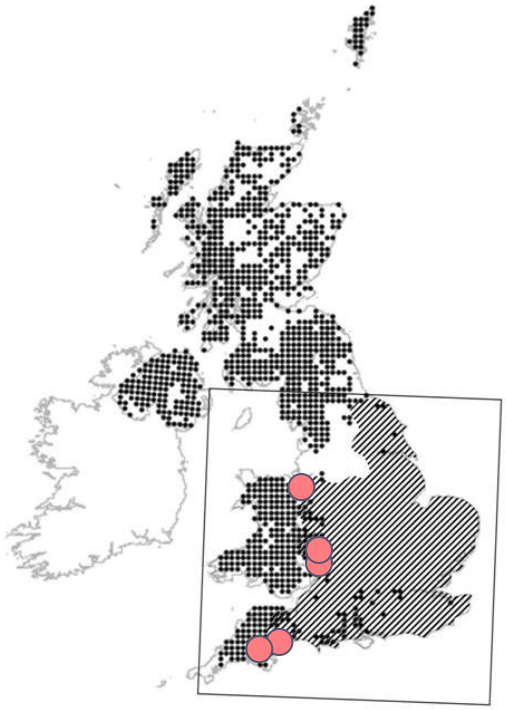

Figure 3: Present day distribution of Atlantic salmon in the UK (black dots) and main area of watermill distribution in the 11th century (shaded area). The box indicates the area referred to in Domesday Book (with the exception of the larger part of Wales). The pink dots refer to reports of Salmon in Domesday Book.

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