HABITAT AVAILABILITY AND CARRYING CAPACITY IN THE FRENCH PART OF THE RHINE FOR ATLANTIC SALMON (*Salmo Salar* L.)

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**ABSTRACT**

A survey of potential spawning grounds and rearing habitats for Atlantic salmon was conducted in the French part of the Rhine Basin in Alsace, using a macro-habitat description method. Aerial photography was used for the Rhine whereas tributaries were described from a canoe. 113 ha of rearing habitat and 6 ha of spawning grounds were recorded, of which about half were in the Ill catchment and half in the Old Rhine between France and Germany. Their carrying capacity was evaluated on the basis of stocking tests. Parr densities at the end of the summer ranged from 0 to 26 0+ parr per 100 m² of suitable habitat with unfed fry and from 5 to 70 with feeding fry (4-5 cm). The overall carrying capacity of the French part of the Rhine for Atlantic salmon is estimated at 344 100 yearling parr for the whole area. The carrying capacity would enable a production of 56 000 to 112 000 smolts, of which 70% are one year-old and 30% two-year-olds. Mortality through hydroelectric turbines during downstream migration was estimated at 20% of the smolt run. On a basis of a 2% return rate at the eventual stage of the reintroduction period, 900 to 1700 adults would return each year to the area. Recommendations are made to protect and restore vanishing running waters needed for salmonids.

**KEYWORDS**

Rhine, France, salmon, habitat survey, fry stocking, parr survey, smolt production.

**INTRODUCTION**

By the end of the 1950's salmon had become extinct in the Rhine Basin after almost a century of steady decline due to river alignment, channelling, dam construction and pollution (Groot, 1989; Roche, 1990). After years of heavy pollution in the 1960's and 1970's, signs of improvement became apparent in the early 1980's. This improvement was the result of continuous efforts in pollution control after the creation in 1967 of the International Commission for the Protection of the Rhine against Pollution. A severe spill by Sandoz in 1986 pressured the riparian states to take a more ambitious step in the initiation of the "Rhine Action Program". One of the goals of this plan is to reintroduce migratory species lost in the last 50 years, notably Atlantic salmon. Limited stocking attempts were carried out in France (1982-1986) and Switzerland (1984-). New efforts began in 1987 in the Meuse (Philippart *et al.*, 1988) and in the Sieg, a tributary of the Rhine in Germany (Schmidt, 1991), where the first returning salmon was caught in 1990 (Steinberg and Lubienicki, 1991). Preliminary studies were also started in Holland, Luxembourg, Germany, France, and Switzerland (Cazemier, 1991; Lauff, 1991; Pedroli *et al.*, 1991; Roche, 1991; Marmulla, 1992) with the support of the Sandoz Rhine Fund and state resources.
The study conducted in France by the Conseil Supérieur de la Pêche started in 1989 with the following guidelines:

- collection of historical data,
- survey of potential salmon habitats in Alsace with an estimate of their carrying capacity, and proposals for protection or restoration,
- inventory of the dams with an assessment of the fishways and proposals for new migration devices when necessary.

This paper focuses on the results of the habitat survey and puts forward an estimate of the possible salmon runs expected from a restoration effort in the French part of the River.

**METHODS**

**Freshwater habitat requirements of Atlantic Salmon**

Adult salmon returning from the sea need shallow running water with a substrate of well aerated gravel into which they can dig and deposit their eggs. They usually spawn in riffles, where gravel is clear of silting and can be moved easily with the help of the current. The vicinity of a pool provides a shelter where adult salmon stay before and after spawning (Fig. 1). Gravel size varies largely according to the river, but the percentage of sand should not exceed 15 to 20% of weight (Mills, 1989) since permeability of the substrate would become too low. After emerging from the gravel, the fry leave the redd to find feeding areas in the fast running water of a riffle. Stones help them stay in the current and prevent them from being seen by other fish.

**Fig. 1 Pool - riffle sequence used by salmon for spawning**

**Habitat survey**

In order to calculate the total area of suitable salmon habitat, rivers were surveyed according to a macro-habitat method (Baglinière and Champigneulle, 1986; Malavoi, 1989; Haury et al., 1991). Homogeneous sections of river (rapids, riffles, runs, pools and flats; see table 1), were observed and noted on 1:25000 maps enlarged to 1:6250. Determination of the macro-habitat categories was done from a canoe moving downstream, and from aerial photographs (Rhine only), a method used in former studies (Gayou, 1986; Côté et al., 1987; Philippart et al., 1988).
TABLE 1. Characteristics of the macro-habitats as defined in the habitat survey

<table>
<thead>
<tr>
<th>Type</th>
<th>Current velocity (m/s)</th>
<th>Depth (m)</th>
<th>Surface aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid</td>
<td>&gt; 0.8</td>
<td>&lt; 0.6</td>
<td>very turbulent</td>
</tr>
<tr>
<td>Riffle</td>
<td>0.5 - 0.8</td>
<td>&lt; 0.6</td>
<td>turbulent</td>
</tr>
<tr>
<td>Shallow run</td>
<td>0.2 - 0.5</td>
<td>&lt; 0.6</td>
<td>fairly smooth</td>
</tr>
<tr>
<td>Deep run</td>
<td>0.2 - 0.5</td>
<td>&gt; 0.6</td>
<td>fairly smooth</td>
</tr>
<tr>
<td>Pool</td>
<td>&lt; 0.2</td>
<td>&gt; 0.6</td>
<td>quiet</td>
</tr>
<tr>
<td>Flat (glide)</td>
<td>&lt; 0.2</td>
<td>&lt; 0.6</td>
<td>quiet</td>
</tr>
</tbody>
</table>

Rapids and riffles are considered the most suitable for salmon fry and parr, especially during the growing season (Mills, 1989). The surface of these only were used in estimating the total area of potential rearing habitats. Some parr are also found in runs, but their density is usually low. Possible spawning sites were defined as the combination of pool and a riffle and their surface was estimated on the basis that the ten upper meters of the riffle would be used for spawning (5 m in small tributaries). Stream-bed composition was analysed in a few potential spawning sites. Samples were taken with a square frame (0.1 m²) equipped with a fine net (0.3 mm) used for macrobenthos sampling. Sediment from the upper 20 cm layer was moved downstream into the net, allowing the collection of most particles of sand.

**Carrying capacity**

The carrying capacity of the rearing habitats was estimated with the help of electro-fishing surveys in sections of streams stocked with salmon fry of French and Scottish origins. Stocking occurred between February and July at densities of 40 to 110 per 100 m² of rearing habitat. Seven sites in three streams were surveyed in 1991 and 17 sites in five streams in 1992. Salmon parr densities were estimated with the Carle and Strub method (1978). A mean 0+ parr density was calculated for each type of river; Old Rhine, Vosges streams and ground-fed streams, and then multiplied by the corresponding areas to obtain the overall carrying capacity. The parr carrying capacity was then used to predict the potential smolt production, using growth data from the stocking tests (smolt age) and data from literature (winter survival of parr).

**Adult runs**

A projection of the potential returning adult population was made on the basis of a return rate of smolts surviving after the passage through all the hydroelectric plants. Mortality from turbines was estimated according to the type of turbine. Return rates to the first dam and to the spawning areas were estimated from the range of figures available in literature and from estimates of expected migration difficulties specific to the Rhine Basin.

**RESULTS**

**Salmon habitat**

The Old Rhine, a 52-kilometer stretch of the Rhine parallel to the Grand Canal d'Alsace, contains about half of the potential salmon habitat with 64 hectares of rearing habitat and 2.5 ha of spawning grounds (Fig. 2). This stretch, common to France and Germany, is located approximately 800 kilometers from the sea. Other potential salmon habitats are found in the Ill Basin with 49 ha of rearing habitat and 3.5 ha of spawning grounds. Most of the sites of the Ill Basin are located in tributaries in the Vosges Mountains, especially in the Bruche, and a few sites are found in ground-fed streams of the Alsatian Plain. These production areas are between 740 km to more than 850 km away from the sea. The few potential habitats found in the Moder and its tributaries are of poor quality due to excess of silt, sand and pollutants. The Lauter has some juvenile habitat but reproduction may not be successful in the lower stretch because of the large amount of sand in the substrate (20%). For this reason, habitats in these two rivers were not taken into account in this study. Sediment analysis in the Old Rhine and the Bruche show adequate substrate composition with a sand content of less than 10%. Other Ill tributaries flowing from the Vosges have substrates similar to that of the Bruche and were thus not analysed.
Carrying capacity

Parr. Experiments in salmon stocking with both unfed and feeding fry (4-5 cm) were done in 1991 and 1992. Stocking unfed fry in February and March led to 0+ parr densities in mid-September between 0 and 7/100 m² (11 sites) except for one site (26/100 m²) downstream of a domestic effluent (table 2). Stocking feeding fry between May and July led to 0+ parr densities between 22 and 70/100 m² (11 sites) except for one site in a ground fed stream whose habitat does not appear much suitable for salmon (5/100 m²). The highest parr densities were observed in the Bruche, the largest tributary of the Ill river. Survival of feeding fry was estimated between 20 and 80% whereas survival of unfed fry ranged from 0 to 50%, apparently strongly related to availability of food in the river at the time of stocking. Fry stocked in early February in the Bruche had a 0-3% survival rate except for one site (50%) where a domestic effluent locally boomed the trophic chain. Fry released a month later had a survival rate twice higher (3-6%). Because of the difficulty of stocking at the right time, the results obtained with unfed fry were not used for the calculation of the carrying capacity. Using mean parr densities (or single values) obtained with feeding fry in four main types of streams (Old Rhine, small and medium size Vosges streams, ground-fed), the underyearling parr carrying capacity would be 166 400 in the Old Rhine, 176 700 in the Vosges streams and 1000 in the ground-fed streams of the plain. The total carrying capacity of the 113 ha is 344 100 parr, thus a mean parr density of about 30/100 m².

| TABLE 2. Densities of salmon parr per 100 m² (number of sites in parentheses) and carrying capacity |
|---|---|---|---|---|
| **Stream** | **1991** | **1992** | **Mean or single value** | **Area of this type of stream (100 m² units)** | **0+ parr carrying capacity** |
| **Unfed fry** | | | | | |
| Old Rhine fry | | | | | |
| Bruche | 5-6 (2) | 0-26 (7) | 4.4 | 6400 | 166400 |
| Ground-fed stream | 7 (1) | 3 (1) | - | 3800 | 159600 |
| Lauter | - | - | - | 900 | 17100 |
| **Feeding fry** | | | | | |
| Old Rhine fry | | | | | |
| Bruche (Vosges, med.) | 42-50 (2) | 25-27 (2) | 26 | 6400 | 166400 |
| Weiss (Vosges, small) | 19 (1) | 27-70 (5) | 42 | 3800 | 159600 |
| Ground-fed stream | - | 5 (1) | 5 | 200 | 1000 |
| Lauter | 22 (1) | - | - | - | - |
| **Total** | | | | 11300 | 344100 |
The average length of parr in September in the Bruche was 12 cm with unfed fry, 10.9 cm with feeding fry stocked in May and 10.1 cm when stocked at the end of June. Parr were slightly smaller in the Old Rhine where growth was affected by high summer temperatures: 10.6 cm with unfed parr and 9.6 cm with feeding fry stocked at the end of June.

Smolts. Considering that most 0+ parr were longer than 10 cm in September it was assumed that the majority of the juveniles would migrate to sea as smolts after one year in freshwater (Elson, 1957). Growth results and observation of 1+ parr in the 1992 surveys suggest that a proportion of 70% 1+ smolts and 30% 2+ smolts should be chosen for further calculation of smolt production before more precise data are available. Given a 41% winter survival rate for 0+ parr (cold winter) and a 32% winter survival rate for 1+ parr (Baglinière et al., 1992), the survival rate from 0+ parr to smolt would be 32.64% (0.7*0.41 + 0.3*0.41*0.32). The smolt production from 30 parr/100 m² would be ten smolts/100 m², i.e. nine one-year-olds plus one two-year-old per 100 m². The proportion of sexually mature male parr should be considered since their mortality rate is higher than that of immature parr, but none was observed in September. Also predation by cormorant (Phalacrocorax carbo) may be high in the rearing habitats of the Old Rhine where a fast growing population has been observed since 1984 (Morel, 1992). Considering that these mortality factors might significantly reduce the smolt production (Mills, 1989), and that stocking with feeding parr might overestimate what would happen with natural ova deposition, the production of 10 smolts/100 m² was thought to be a maximum. A minimum was set at half this value, thus a range of 5 to 10 smolts/100 m², which means that the survival rate from parr to smolt of 32.64% cited above would become a range of 16.32% - 32.64%. These survival rates were used for the calculation of the smolt production per area on the basis of their carrying capacity (table 3).

Losses from hydroelectric power plants

Rhine. The hydroelectric plants in the Rhine have 5 m diameter Kaplan turbines with slow rotation which would cause limited losses, estimated at around 5% per dam (Larinier, pers. com.). However, the entire smolt production of the Old Rhine will pass through six sequential turbines with few salmon escaping in the spillways. Since Rhine flooding generally occurs from May to July and the smolts usually migrate from mid-March to mid-May, there are few chances of overflow at the spillway to attract and lead the fish in that direction. The total estimated loss would thus be 26.5% of the original smolt production (table 3).

III. Few hydro-electric facilities are still used in the III Basin. Most of them were abandoned in the middle of this century. Five plants are still in use, two of which may cease operation in the near future. Losses from these turbines have been estimated between 9 and 13% per station using the method described by Larinier and Dartiguelongue (1989). Downstream migration facilities constructed at the remaining working plants would significantly reduce future losses. However, a fair number of smolts could escape since flows are usually higher than the capacity of the plants during the downstream migration period. Therefore, the basis chosen for loss estimation in the III Basin is also 5% per dam. The remaining smolt production of the III catchment would be of 24 600 to 59 300 fish, thus a total loss of 15% including losses at the lowermost dam in the Rhine at Iffezheim. Out of 56 200 to 112 400 smolts, 45 200 to 89 500 would survive passage through all the dams while migrating downstream, amounting to a total loss of 20% for the whole area.

Returning adults

In short salmon with wild populations, smolt to adult return rates of 5 to 10% are common. In the case of the Rhine this percentage will be affected by negative factors such as the length of the freshwater migration, riverside power station intake screens (Weibel, 1991), engineering work at the mouth of the river (Cazemier, 1991) and a long salt water stage. The return rate to the Iffezheim dam area, at a distance of 690 km from the sea, is therefore estimated at 2%. It should be noted that during the reintroduction period it might be as low as 1% and would increase only slowly as natural selection favours survival in freshwater and at sea. On this basis, the eventual adult salmon run originating from the French part of the Rhine would be of 900 to 1700 adults returning to the Iffezheim dam. The number reaching spawning areas at the appropriate time would be less due to delay at fish migration facilities, periodic pollution barriers, fishing, and poaching. With the hypothesis that 50% of the salmon would be lost for reproduction in the Old Rhine and in the farther reaches of the III Basin (a loss of 5 to 7% per dam) the return rate to the spawning grounds would be between 1 and 2% (table 3) which means about 600 to 1100 salmon available for reproduction.
TABLE 3. Potential salmon habitat in Alsace and estimates of their carrying capacity, potential smolt production and possible eventual adult runs

<table>
<thead>
<tr>
<th>Production area</th>
<th>Lower III: Bruche</th>
<th>Middle III: Other tributaries incl. ground-fed</th>
<th>Old Rhine</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spawning area (hectares)</td>
<td>1.8</td>
<td>1.7</td>
<td>2.5</td>
<td>6</td>
</tr>
<tr>
<td>Rearing area (hectares)</td>
<td>25</td>
<td>24</td>
<td>64</td>
<td>113</td>
</tr>
<tr>
<td>Parr density per 100 m²</td>
<td>42</td>
<td>5-42</td>
<td>26</td>
<td>30</td>
</tr>
<tr>
<td>Carrying capacity of 0+ parr</td>
<td>105 000</td>
<td>72 700</td>
<td>166 400</td>
<td>344 100</td>
</tr>
<tr>
<td>Annual smolt production (16.3 - 32.6% survival)</td>
<td>17 200-34 300</td>
<td>11 900-23 700</td>
<td>22 200-54 300</td>
<td>56 200-112 400</td>
</tr>
<tr>
<td>Smolt run downstream Iffezheim</td>
<td>16 100-32 200 (94%)</td>
<td>8500-17 100 (72%)</td>
<td>20 100-40 200 (74%)</td>
<td>45 200-89 500 (80%)</td>
</tr>
<tr>
<td>Adult run up to Iffezheim</td>
<td>320-640 (2%)</td>
<td>170-340 (2%)</td>
<td>400-800 (2%)</td>
<td>890-1780 (2%)</td>
</tr>
<tr>
<td>Adults at spawning grounds</td>
<td>290-580 (1.8%)</td>
<td>90-170 (1%)</td>
<td>200-400 (1%)</td>
<td>580-1150 (1.3%)</td>
</tr>
</tbody>
</table>

DISCUSSION

Although in the past the Rhine itself provided most of the salmon habitat in the area, the tributaries now represent the best chance for resettlement of anadromous salmonids, because of significant changes to the original Rhine bed in the last century, notably channelling and dam construction. The remaining suitable habitats in the Old Rhine will not be available to reproduction without the construction of efficient fish migration facilities at seven large hydro-electric dams. A temporary alternative would be the transportation of trapped adults from one of the first dams to the spawning grounds, as has been done successfully in other rehabilitation programs, notably in Canada (Côté and Beaulieu, 1987). In the short-term this would be an effective means to improve the number of salmon in the spawning grounds, as it would limit the losses during upstream migration, and increase their chances of reaching the spawning grounds before the end of their maturation.

The III river Basin is the largest and most adequate tributary where salmon could reproduce in the French part of the Rhine Basin. It is far easier to reach than the Old Rhine, with only one large dam in the main bed between the estuary of the Rhine and the mouth of the III. Salmon vanished from the III at the beginning of the century because of hydroelectric development and pollution, mainly related to industrialisation of the Vosges valleys. The main branch of this river was probably used by salmon for spawning in the past, but the result of eventual reproduction there is now questionable, due to changes in agricultural practices and high domestic discharge which have led to silting and poor water quality. Most spawning grounds in this basin are located in tributaries of the left bank flowing from the Vosges, with a great deal of salmon habitat in the larger ones. Despite gradual improvement, water quality is still not at best overall (the Giessen, Fecht, and Thur lack acceptable water quality) and the lower stretches suffer from low summer flows due to infiltration and water abstraction. Ground-fed streams feeding the III and the Rhine in the Alsatian Plain are also partly salmonid waters with some suitable salmon habitat, most of them threatened by eutrophication due to intensive agricultural practices.

The evaluation of smolt production by means of parr densities estimated by electro-fishing surveys at the end of the summer is a widely used management method (Bagliniere and Champigneulle, 1986; Caron and Ouellet, 1987; Mills, 1989; Kennedy and Crozier, 1991). Stocking of eggs or unfed fry was first thought to be the most appropriate for this estimate but proved difficult to do well, at the right place and at the right time, as variation in results with unfed fry shows. This was due in particular to the difficulty of finding the right synchronism between the development of the fry under hatchery conditions and the development of invertebrates in the stream stocked. Parr densities obtained with feeding fry were more representative of the quality of the habitat for
Atlantic salmon being especially related to current velocity and depth, size of the substrate, and abundance of predators, with less dependence on stocking conditions. The mean parr density observed (30/100 m²) is near the lowest mean densities of wild populations in Ireland, Scotland or Wales, and close to the upper mean in England (Kennedy, 1988). Other types of habitat than rapids and riffles were not electro-fished since parr densities there are expected to be very low (Baglinière and Champigneulle, 1986). However, the carrying capacity of runs might not be negligible and should be estimated in further work, because quite large areas of this type of habitat are available.

A smolt production of 5 to 10 per 100 m² is in the range of what is recorded in other river systems, mostly from 2 to 12 (Mills, 1989) with a higher value of 10-22 given by Egglishaw (1970). Symons (1979) gives a range between 4.7 and 10.2, the highest for rivers where smolitification mostly occurs in the second spring. This range was used by Gayou (1986) to estimate the potential smolt production in the Garonne and the upper and lower were also used in two estimates in the Rhine-Meuse system; one by Philippart et al. (1988) for the Meuse (10/100 m²), the other by Lauf (1992) for tributaries of the Mosel in Luxembourg (5/100 m²).

The knowledge of the smolt production in a river where a salmon population is established is a useful management tool to predict adult runs, provided that mean adult return rates and proportion of one, two, and three sea-winter salmon are known from previous studies. Computerised models were developed for this purpose in recent years (US Fish and Wildlife Service, 1989; Caron and Le Bel, 1991). Projection of possible adult runs are more theoretical and of limited value in the case of a river where salmon got extinct, due to the lack of specific biological knowledge. However, it seemed useful to put forward a realistic range of population size, first to help define the objectives and priorities of the restoration project, second to answer the legitimate questions of financial support groups and agencies involved in the project. The smolt to adult return rate of the present estimate is about half the one chosen for the Meuse (4%; Philippart et al., 1988) or for estimates in the River Thames (5%; Thames Migratory Committee, 1977). It is closer to what was thought for the Garonne and the Dordogne Basin (1.4% to 2%; Gayou, 1986 and Pustelnik et al., 1987) or for the Connecticut River (1.2-3%; Stolte, 1982; 1.6%; US Fish and Wildlife Service, 1989). Again it should be noted that returns will be much lower in the early years of a re-introduction program, as was shown in some of the cited projects (Gough, 1986; Jones, 1988).

CONCLUSION

The goal of this study was to quantify what potential spawning and rearing areas still exist in the French part of the Rhine, and to what extent a salmon population could be restored. It was shown by means of field surveys and literature study that potential salmon habitats are mostly located in Ill tributaries and in the Old Rhine, and could hold about 3.500.000 parr. Rapid growth of the juveniles enables a great deal of them to migrate to sea as 1+ smolts, with a fairly high smolt production as a result, estimated between 56.000 and 112.000 fish. In the hypothesis of a 2% return rate to the lowermost dam at Iffezheim located 690 km from the sea, 900 to 1700 adult salmon originating from the Ill Basin and the Old Rhine should be able to return to this point every year. The Bruche, a main tributary of the Ill with little dam obstruction and best habitat, would be able to hold a self-sustaining population of 300 to 600 salmon.

Protection of stream bed and riverside vegetation in recorded habitat by legislation means is a necessity prior to restoration efforts, since many of the surveyed streams are threatened by human encroachment, such as river engineering to ensure protection of new housing development, industrial sites or unadapted crops in the flood plains. Recent legislation tools now exist in France and should be used, despite long procedures and resistance of short-term interest groups.

Other potential salmon habitats have deteriorated, either from river engineering, silting, excess of sand, water abstraction, water warming, eutrophication or pollution. They were thus not recorded in this study. Improvement of the water quality is planned in most cases, since pollution has been a major concern for fishery managers and the general public for the last two decades. Meanwhile, efforts for habitat restoration have been scarce and restoration of river beds and banks now has to be undertaken. Fish habitat in straightened and oversize stretches of rivers can be improved by recreating pools and providing shelters such as boulders, tree trunks or bank cover. Old dams whose economic or hydraulic use is not clearly established should be removed from the stream bed or broken, in order to favour natural cleaning of the gravel by floods. Apart from gaining spawning and nursery habitat for salmonids it will also reduce water warming and help fish migration. Silting could be greatly reduced by preventing soil and bank erosion, which means in most cases replanting a strip of permanent vegetation along river banks and favouring pastures versus intensive agriculture in flood plains.
AKNOWLEDGMENTS

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