Aquaculture and Fisheries Management 1992, **23**, 213–224

Decline and fall of the salmon fisheries in the Netherlands: is restocking the Rhine a reality?

S. J. DE GROOT *Netherlands Institute for ~~Fishery Investigations~~ Fisheries Research, IJmuiden, The Netherlands*

Abstract. The Atlantic salmon, *Salmo salar* L., was once of major importance to the fishing industry along the River Rhine. The paper discusses the Dutch and German salmon catches over the years 1863–1950. Even up to the end of the last century, it was not uncommon for Dutch and German fishermen to land 100000 salmon a year. However, factors such as the increased use of locks and weirs along the Rhine, coupled with growth in pollution, soon led to a rapid decline in numbers. By 1933, the salmon fishing industry in the Netherlands had virtually ceased to exist. Analysis of the available catch statistics suggest that the decline in the salmon population could have started before official records began.

Although the degree of scatter in the data and uncertainties in the assumptions preclude the possibility of drawing firm conclusions about the survivial rate of salmon, these figures illustrate how difficult it will be to maintain a stable population in the Rhine. Moreover, a number of changes have taken place since the heyday of salmon in western Europe, which could compound the problem. Of particular importance in the context of the Rhine are:

(1) the closure of two of the major migration routes to the sea (Haringvliet and Zuiderzee);
(2) morphological changes in the river;
(3) chemical and thermal pollution;
(4) the loss of accessible spawning and nursery areas of the required quality;
(5) the disappearance of salmon from other rivers that flow into the North Sea such as the Rivers Elbe, Weser and Ems. If salmon were only reintroduced into the Rhine, a certain proportion would probably stray and infiltrate these other rivers.

The fact that the impact of these changes is difficult to quantify increases the uncertainty associated with maintaining a stable stock of salmon in the Rhine.

History of the salmon fishing industry

The history of the Dutch fishing industry can be traced back to the oldest inhabitatns of the Netherlands, although it is difficult to specify exactly when salmon fishing began. The first written evidence to suggest that salmon were being caught in reasonable numbers dates back to 1100. However, proper statistics describing the number of salmon caught in the Netherlands at this time are not available. Similarly, few details are to be found about domestic consumption rates and the export trade.

The study made by Van der Woude (1988) about the history of the '*Noorderkwartier*' of the Netherlands provides an insight into the importance of salmon fishing in our country between 1650 and 1805. By comparing the taxes levied on the supply and sale of salmon, Van der Woude was able to draw conclusions about the number of salmon landed during this period and concluded that the variations in revenues were directly linked to variations in supply. He concluded that between 1650 and 1679, the number of salmon caught fell by more

Correspondence: Dr S.J. de Groot, Netherlands Institute for ~~Fishery Investigations~~ Fisheries Research, PO Box 68, 1970 AB IJmuiden, The Netherlands.

than one-third, with a similar decline in the period 1680–1699. In subsequent years, salmon catches appear to have remained fairly stable, at about one-third of the level attained in 1650. However, a decline in the annual salmon catch of 66% over a period of 50 years must be regarded as a fairly dramatic reduction.

Although there is evidence to suggest that freshwater fish formed a major food source in the first half of the 19th century, detailed information about river fisheries is generally scarce. In the second half of the 19th century, the effects of industrialization became increasingly apparent. Prosperity increased and improvements were observed in fishing techniques. However, the growing industrial importance of the major rivers changed the character of these waterways. As a result, salmon fishing steadily declined. In the Netherlands, the drop in catches was initially obscured by more efficient fishing methods, which gave the impression that the 'golden era' would continue for a considerable period of time. However, increases in Dutch salmon catches at the end of the 19th century merely mirrored the temporary revival in the total number of salmon caught in the Rhine basin. The effectiveness of seine nets used in the lower reaches of the Rhine played a significant role in this context, to the detriment of other fishing techniques practised upstream.

At the time, pressure was brought to bear, both nationally and internationally, to arrange a fairer distribution of the salmon found in the Rhine. However, the Salmon Convention drafted by the Rhine riparian states under the terms of the Mannheim Convention was narrowly rejected by the Dutch Parliament in 1870 but later ratified in 1886, the year in which recording of reliable national salmon statistics started. By that time, it had become increasingly clear that there were structural reasons for the decline in the salmon population.

At a national level, anxiety grew about maintaining salmon numbers, or in any event preventing further declines, resulting in a report which is still the most authoritative publication on the Dutch salmon fisheries (Anon 1916).

Among the important recommendations made by the commission were the suggestions 'to cooperate with the riparian countries upstream from the Dutch border; to preserve existing spawning beds and to rehabilitate former spawning grounds, wherever possible, in consultation with other riparian states; and to promote restocking of the Rhine to make good the damage likely to be caused by hydraulic engineering works and similar operations'.

The decision of the government in 1987 to lend its support to the proposed project entitled 'Ecological Rehabilitation of the River Rhine: a Proposal for a Netherlands Research Programme' following on from the 7th Ministerial Conference regarding the Pollution of the River Rhine, should be seen as a positive development, which underlines the renewed interest being shown in the fate of the salmon. Preventing the decline of salmon numbers is no longer an issue, as the main emphasis has shifted towards re-establishing the salmon in parts of the River Rhine.

Size of the salmon population in the Rhine

Due to the lack of data, it is impossible to give precise estimates of the numbers of salmon caught in the Dutch, German, French and Swiss sections of the Rhine basin on an annual basis. The most detailed historical records that were kept concern the salmon caught in the Dutch part of the Rhine. These data, which cover the period 1863–1957, have been summarized in Fig. 1. Kuhn (1976) prepared a similar overview for German salmon catches between 1875 and 1950. Combining both sets of data allows the total number of salmon caught in the Netherlands and Germany over this period to be calculated (Fig. 2).

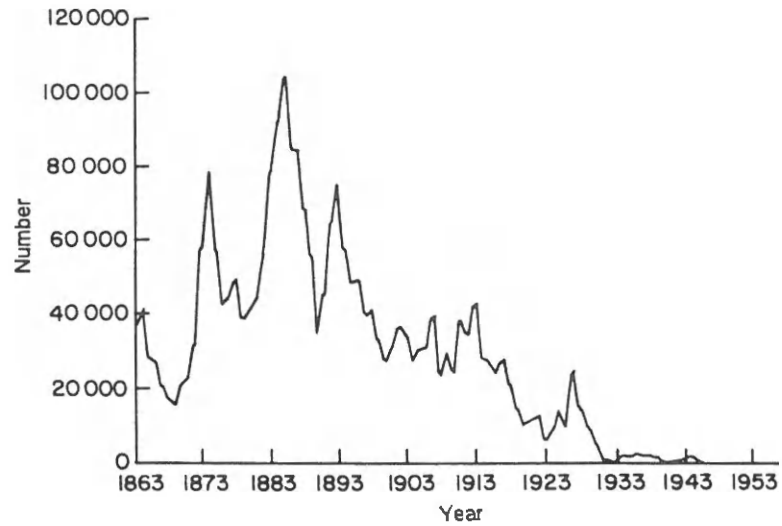

Figure 1. Dutch salmon catches 1863–1957 (source: RIVO data).

From the turn of the century onwards, Dutch salmon catches began to drop significantly, a trend which is also mirrored in German statistics for the same period. As a result, seine nets, which were shown to be so successful in the past, were not used after 1932.

The end of the 1920s witness a major decline in salmon catches in the Rhine. In subsequent years, the number of salmon landed in the Dutch section was stabilized at about 1000–2000 fish a year, up to 1944. However, these figures would probably have been higher had organized salmon fishing not ceased in Dutch waters in 1933. This also explains why salmon catches along the German section of the Rhine increased in rlative terms, which enabled the German salmon fishing industry to continue much longer. In 1945, the number of salmon caught in the Netherlands declined even further, to only a few hundred a year on average.

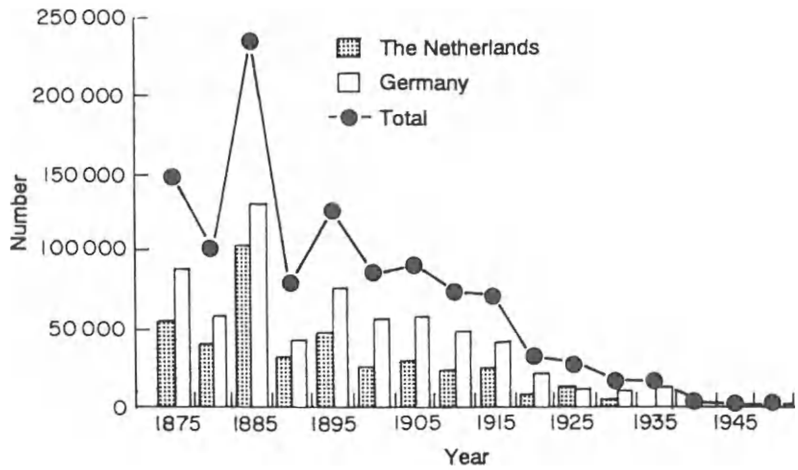

Figure 2. Dutch and German salmon catches 1875–1950 (source: RIVO data, Kuhn, 1976).

In order to rehabilitate the Rhine salmon population, experiments began as early as 1861 by releasing salmon fry which had been reared under controlled conditions. These activities assumed greater importance after the ratification of the Salmon Convention in 1886. Enormous numbers of fry and parr were released into the Rhine at the end of the 19th and the beginning of the 20th centuries. Restocking operations in Switzerland and Germany between 1879 and 1912, to which the Netherlands contributed, involved about 160 million young salmon. In addition, about 13 million young salmon were released into the Rhine in the Netherlands over the period 1861–1897.

Throughout the period that restocking operations were carried out in earnest, most observers were convinced of the positive effect of this policy. It was felt that without such action the decline in salmon numbers would have been even more rapid. However, in 1947, a report on the effect of restocking operations on salmon catches concluded that no clear statistical evidence could be found to support such a link from the available data.

Variations in the number of salmon caught

The fluctuations in annual salmon catches clearly show that certain years were more successful than others. In fact, data in terms of smolt production are lacking, hence it is not possible to correlate the catch of Rhine salmon with the stocks. In addition, the introduction of improved fishing techniques could have led to temporary increases in the number of salmon caught.

The overall picture could also have been distorted by fishermen deciding to stop fishing once they realized that the size of their catches was decreasing rapidly. This could have led to too drastic a reduction in the fishing effort. On the other hand, before fishermen decided to discontinue their operations, many would have tried to maximize their catch by all available means. The skill of the individual fisherman may also have to be taken into account.

A comparison between the weight and number of salmon caught over the period 1893–1918 is shown in Fig. 3. If a subdivision is made on the basis of whether the salmon caught ascending the river were grilse, small summer salmon, or large winter or summer salmon, it becomes far easier to distinguish a particularly productive year. The grilse (or 'Jacob's salmon', St Jacob's day — 25 July) returned in the spring and summer (length 61–67 cm). Their numbers decreased towards the autumn. The 2-sea-winter salmon (length 83–91 cm) returned in May–July. They were referred to as 'small summer salmon'. These fish were not sexually mature when entering the Rhine, but they generally reached this stage by the time they arrived in German waters. Multi-sea-winter salmon ascended the Rhine in September and October, and were referred to as 'winter salmon' till 1 April (length 103–115 cm). From May onwards, fish of this size were referred to as 'large summer salmon'. When, for instance, large numbers of grilse were caught, fishermen could generally expect a ready supply of small summer salmon. As an example, Fig. 4 is given, in which the relative proportions of the different categories of salmon caught are given in relation to the total number of salmon landed that year for the period 1903–1919. Specific information about the number of grilse and small summer salmon caught between 1989 and 1919 is given in Fig. 5. In addition to annual variations in salmon catches, a marked difference can be seen within a particular year. Figure 6 shows the average monthly catch over the period 1911–1918. In the Netherlands, the most important months for the salmon fishermen were March to August.

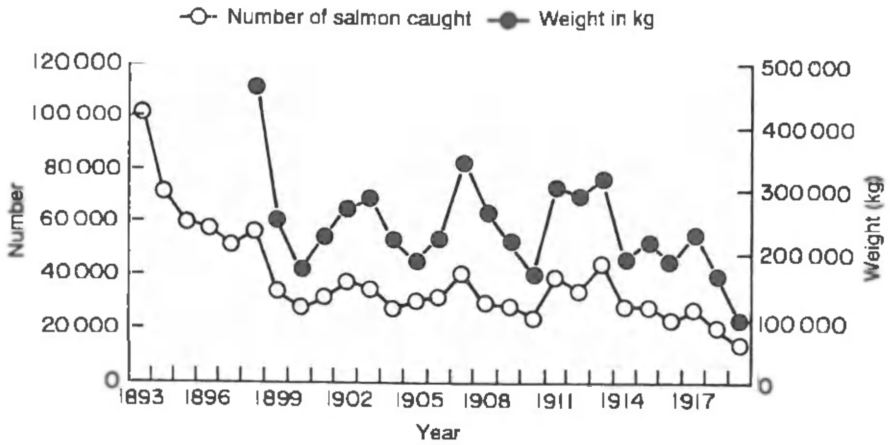

Figure 3. The weight and number of salmon caught over the period 1893–1919 (source: RIVO data).

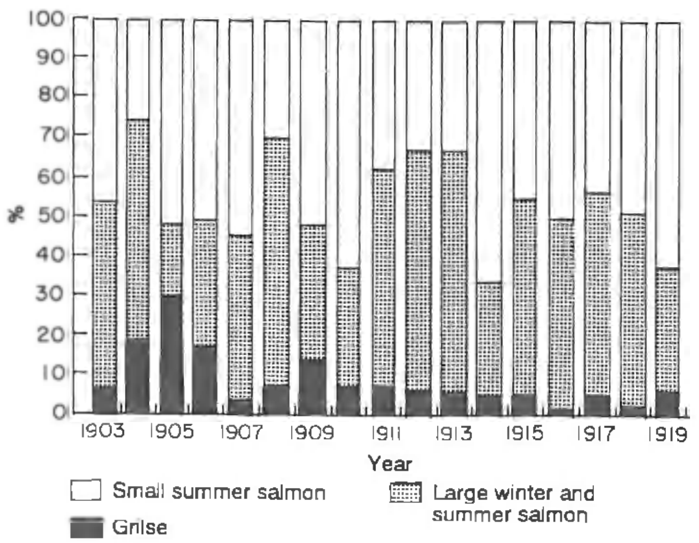

Figure 4. Proportion of the various types of salmon sold over the period 1903–1919 (source: RIVO data).

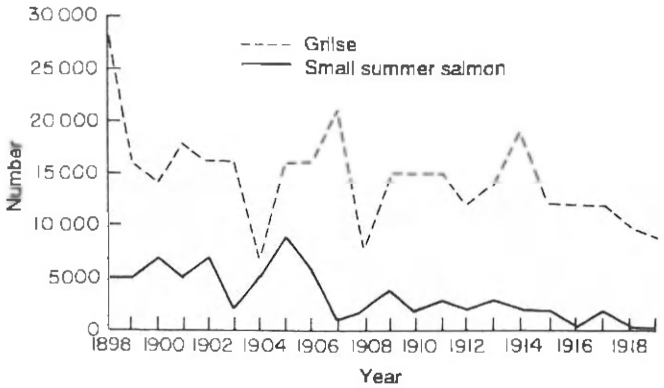

Figure 5. Number of salmon sold over the period 1898–1919 (source: RIVO data).

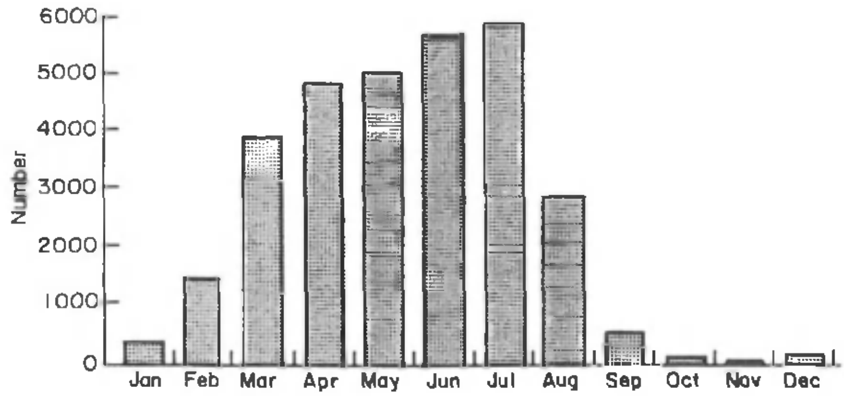

Figure 6. Monthly supply of salmon, 1911–1918 (source: RIVO data).

The effect of human intervention

Hoek (1901) displayed insight when summarizing the effects human intervention had had on the Rhine in his report entitled 'The State of the Dutch Sea Fisheries in 1900':

'The deline in the fishing industry over recent years has been brought about by a number of factors such as hydraulic engineering projects required for regulating the water discharge and improving navigability, the pollution . . . Man, in his efforts to control nature, must accept responsibility for allowing the Rhine to degenerate . . . into something approaching a discharge channel closed in between steep straight banks and dredged to the required depth for shipping purposes.'

Channelization and flood control

Since the Rhine is basically a glacier stream the river receives an important supply of water during the summer months. As a consequence, the difference between high and low water levels in the Rhine is less marked than in a river fed by rainwater such as the Maas. This feature makes the Rhine particularly attractive to shipping. The move towards greater industrialization in the 19th centory led to extensive hydraulic engineering works. This involved deepening the navigation channel and, where necessary, constructing weirs and locks. The fact that canalization of the Rhine proceeded at a more rapid pace than, for instance, that of the Maas, reinforced the natural superiority of the Rhine as a major inland shipping route. In order to comply with increasing demands attention was also focused on the tributaries of the Rhine. In the report of the Government Commission on Salmon, Hoek (1916a) reviewed the condition of the main tributaries of the Rhine in Switzerland and Germany with particular reference to the salmon fisheries.

Although efforts to improve the flow of the Rhine are often associated with the last hundred years, a considerable amount of work had been carried out before this time, primarily to safeguard towns and villages from flooding (Van der Ven 1976). In the Middle Ages, for instance, rerouting the course of the river caused several villages along the upper reaches of the Rhine that were originally on the left bank to 'shift' to the right bank or vice versa.

Improving the navigability of the river involved dredging out excess deposits in shallow areas and systematically reducing the width of the river bed. Along the Waal, for instance, the 18 shallows and islands that existed in 1850 were linked with the bank and the river water redirected along the main flow channel. Along the upper reaches of the Rhine ('Alt-Rheine'), many of the side branches were removed to improve the flow conditions.

After 1940, many of the sandbanks in the River Rhine disappeared as a result of deepening and maintenance work on the river. Sand extraction was also practised at this time. Although the use of large seine nets was no longer allowed on Dutch rivers, smaller nets of this type and bag nets were still employed. In spite of the fact that German fishermen had modified their bag nets to catch eels rather than salmon a large number of juvenile salmon were still caught and destroyed. The movements of salmon in the German and Swiss parts of the Rhine became more restricted due to the construction of locks and weirs in the upper reaches of the river.

The extent of the hydraulic engineering works carried out along the tributaries of the Rhine continued to gather pace around this time. As a consequence, the Neckar, Main and Ruhr became practically inaccessible to salmon. The construction of locks and weirs along the Mosel, which started after World War II, effectively eliminated another important spawning area for salmon. The proliferation of structures of this type along the Rhine has meant that, even under the most favourable circumstances, salmon would only be able to ascend the river as far as Karlsruhe.

Nowadays, it is not only the presence of locks and weirs along the Rhine that are preventing the return of salmon. The condition of the many streams and rivulets that traditionally formed the spawning grounds for these fish has also changes. Moreover, simply restoring a few tributaries of the Rhine — which is suggested by certain parties as a potential solution — would not guarantee the return of the salmon on a permanent basis, as a variety of habitats will be required.

An alternative method that has been put forward for restoring salmon stocks in the main rivers in the Netherlands is to release young fish into the upper reaches of the Maas. However, the practicality of such a scheme can also be questioned since the Maas has even more locks and weirs than the Rhine (van Drimmelen 1987).

Closing off the delta and the cosntruction of weirs

Although fish ladders and passes have been incorporated in all the weirs (often linked to hydro-electric power stations) and sills in the Rhine from Basel to Strasbourg, these have had little effect. Fish experience great difficulty in negotiating weirs even if they are equipped with such aids. The greater the number of weirs that are constructed along a stretch of river, the more restricted the waterway becomes for fish. Since the natural spawning grounds of the salmon are located in the upper reaches of the Rhine tributaries and the connected streams, the positioning of weirs downstream of this area has had a major effect on the decline and the ultimate demise of the salmon.

The closure of the sea inlets in the south-western part of the Netherlands represents a new hazard for salmon and other migratory freshwater fish. At present, fish entering the Western and Eastern Scheldt from the sea cannot reach the Rhine directly. Not only is Lake Grevelingen closed off, but the Haringvliet locks represent a further impediment to the free movement of fish.

At present, the Nieuwe Waterweg offers the only open link with the sea in the Netherlands. However, the intensity of shipping along this route could prove to be disadvantageous to salmon. Since the construction of the '*Afsluitdijk*' (Barrier Dam), which closed off the Zuiderzee, salmon have been prevented from using their traditional route to re-enter the Rhine via the River IJssel. Moreover, access to the North Sea Canal via the IJmuiden locks cannot be regarded as a viable alternative for salmon and salmonids.

Sand and gravel extraction

Sand and gravel extraction activities in Dutch rivers are not thought to have had a serious impact on salmon stocks, mainly because salmon only passed through the Netherlands either en route to the sea as smolts or kelts, or in ascending the river as grilse, 2- or multi-sea-winter salmon. However, on such journeys, salmon would have had to swim through turbid waters, carrying considerable amounts of suspended sediment when in the vicinity of extraction works. In contrast, the salmon fishing industry encountered serious difficulties because of such activities. Fishermen using large seine nets (either from the bank, pivots in the flow or rafts anchored above sand banks) experienced particular problems in attaching their nets to the river bed due to removal of sand.

Sand and gravel extraction operations in the smaller German rivers and streams will have had a much more dramatic effect on the salmon population since these areas were used as spawning grounds. The gravel beds would no longer have been suitable for spawning purposes due to an increase in silt levels in the river and sedimentation of the redds.

In addition, fish fry are known to be more sensitive than adult fish to polluted silt (fine sediment). It is therefore recommended that sand and gravel extraction activities be prohibited in streams that are identified as potential spawning grounds for salmonids or which already contain such fish (e.g. trout).

Waste water discharges

As early as the beginning of this century, discharges of polluted waste water were identified as one of the possible reasons for the decline in the salmon population in the Rhine (Hoek 1916b). Hoek was convinced that the Rhine as a large fast-flowing river would have had an inherent capacity to 'clean itself'. Although large quantities of waste water were discharged into the Rhine, he pointed out that after relatively short distances, the effects were hardly noticeable due to ample dilution in the flow stream, rapidly restoring the clarity of the water. Hoek concluded: 'Although the effects of local pollution on the salmon population of the Rhine should not be ignored, care should be taken not to overestimate the extent of the damage caused.'

Some 10 years later, Redeke (1927) was requested by the International Council for the Exploration of the Sea to summarize the impact of river pollution on fisheries. In general, it can be said that by 1927 domestic and industrial waste waters were considered to pose a far greater threat to the fish population than had been thought possible less than 25 years before. The number of incidents where large numbers of fish were found to be dead had increased dramatically. However, it was often difficult or even impossible to give precise explanations for such events, in spite of the fact that a large number of potential causes could be identified.

Detergents can affect salmonids and other fish in several ways, such as reducing their ability to extract oxygen and destroying their sense of smell (Bardach & Case 1965; Holl 1965; Bardach, Fujiya & Holl 1965, 1967; Holl, Schulte & Meinel 1970).

In view of the fact that salmon depend on their olfactory sense to find their natal streams, any deterioration of their sensory organs can have disastrous consequences for this group of fish. Should the sensory organs of salmon be affected in this way, returning fish will tend to take the widest branch of the river where it divides. This could pose special problems if rivers such as the rivers Sieg and Agger, in the centre of Germany, were to be restocked, as the presence of detergents could cause the fish to travel in the wrong direction. Impairment or complete loss of the sense of smell in smolts may seriously endanger their chances of surviving at sea as well as affecting their ability to find their natal streams when they return as adult salmon. The large quantities of detergents that are released into the Rhine with domestic waste water mean that research is urgently needed to investigate more specifically whether or not these chemicals affect the sense of smell of salmon and trout.

The impact of the fishing industry on salmon stocks

With the advantage of hindsight it can clearly be said that the fishing industry has had a negative effect on salmon stocks in the Rhine. However, in the final analysis, economic forces dictate that the fishing industry cannot fish a particular species to extinction. The loss of income as the size of the catch declines brings such activities to a natural end, as was the case with the Rhine. The Dutch salmon fishing industry effectively ceased to exist after 1933 and that of the Germans after 1950.

Catching salmon below the minimum legal size was prevalent in the entire Rhine basin. This was mainly attributed to the widespread use of 'framed bag nets' in the Netherlands and in the downstream areas of the Rhine in Germany. The introduction of set times for the use of framed bag nets and prohibiting the use of seine nets at night and on Sundays did, however, prove to be effective in limiting the damage caused. In order to compensate for the lack of sexually mature fish in the river, and hence the decline in the number of young salmon, restocking operations were undertaken, particularly after 1892 (Hoek 1898).

Although detailed statistics about the precise number of salmon caught at sea are not available, it is known that in relative terms the catches were not large. The number of salmon caught at sea was generally thought to increase in July, reaching a peak in August before declining to practically zero in the following months.

Feasibility of restocking operations

At present, salmon catches in the entire eastern Atlantic are declining, even though a number of excellent salmon rivers are still to be found in countries around or near the North Sea such as France, Norway, Scotland and Ireland. The salmon population in Spain is rapidly disappearing and even if attempts to halt the decline are successful, the purity of the original species will have been affected by interbreeding with 'foreign' salmon. Experience from France and Spain has shown that eggs recovered from indigenous fish are more suitable for rearing and eventual release than imported eggs from Scotland and Norway. It is therefore clear that restocking the tributaries of the Rhine will be a slow and arduous process.

At the turn of the century, the nursery grounds for salmon in the Rhine extended over 159 540 km (excluding the Netherlands). Current estimates suggest that at best about 9000 km or about 5% of the original area could be used for such purposes in Germany in the near future. This includes those parts of the river already inhabited by trout. In 1900, 100 000 salmon were caught in the Rhine, which would translate to a maximum of about 5000 salmon on the basis of the potential area now available. Assuming that one-third of the salmon produced were caught by fishermen, this would suggest that the Rhine could support a maximum of 15 000 adult fish. However, this estimate does not take account of the changes that have taken place since 1900 in the water quality of the Rhine, fishing practices and the increase in the number of weirs and dams.

Using the method proposed by Milner (1983), it is possible to calculate the required nursery area for 0+ salmon assuming a mortality rate of 6% at the transition from fertilized eggs to larvae (Mills 1989). It transpires that for a population of 15 000 salmon, an area of 760 km^2 of the lowest category of biomass ($\leq 130\,g/100\,m^2$ biomass) would be sufficient or 190 km of the highest category ($\geq 841\,g/100\,m^2$ biomass). Whether these conditions can be achieved in the upper reaches of the Rhine remains to be seen.

Notwithstanding, it is sheer speculation that the likely survival rate of salmon in the Rhine can be estimated on the basis of information found in the literature (Harden Jones 1968; Foerster in Netboy 1980; Hansen & Bielby 1988; Lassen, Moller & Hansen 1988). Furthermore, it is difficult to predict the precise number of salmon that will be able to negotiate sluices, weirs and fish passes during their run upstream. Assuming that 1050 salmon ascend the river to spawn (one-fifteenth of the number of salmon that the Rhine is likely to support) and that the mortality rate on the journey is 5% then 1000 sexually mature fish would be expected to reach the spawning grounds. Moreover, if 75% are grilse or one-sea-winter salmon (male:female ratio 2:1, average weight 3 kg and capable of producing 1600 eggs/kg), whereas the remaining 25% are 2-sea-winter salmon (male:female ratio 1:3, average weight 7·5 kg and capable of producing 1600 eggs/kg), the 250 female grilse would be expected to produce 1 200 000 eggs, while the 188 2-winter salmon would be expected to produce 2 256 000 eggs. This would amount to a grand total of 3 456 000 eggs.

Assuming a fertilization rate of 78% (2 695 680 fertilized eggs) and a mortality rate up to the smolt stage of 99%, 26 957 smolt could be produced. As 80% of the post-smolts die during the first 9 months at sea, 5391 young salmon would be expected to reach Greenland. Assuming the mortality rate after the first months at sea to be 0·1% and losses of 25% and 50% to occur due to fishing near the Faroe Islands and in the North Sea (assumption) respectively then of the 75% of the fish that are expected to return after one winter at sea (4043 grilse), 1478 would be successful (2565 lost), whereas of the remaining 25% that stay at sea for another year (1348 2-sea-winter fish) 442 would be expected to reach the mouth of the river (906 are lost). Together this would amount to a total of 1920.

Although the mortality rate in the river will probably be of the order of 5%, it is impossible to predict how many fish will be deterred by the presence of hydraulic engineering structures in the Haringvliet and Hollands Diep. The importance of such assumptions is further underlined when considering the sensitivity of the analysis to the survival rate of fish reaching the smolt phase. A figure of 1% has been included in the calculation presented above, which results in a balanced system, whereas a value of 0·5% as reported for the River North Esk (Dunkley 1988) would mean that the system would be out of balance.

An alternative calculation method could also be applied, based on the assumption that a maximum of 3·5% of the young salmon that descend the river eventually find theyr way back to their natal streams. The remaining fish would either be lost or enter other rivers. If 1050 salmon ascended the river to spawn, this would mean that 943 grilse and 2-winter salmon would return, all of which presupposes that the hydraulic engineering structures in the Haringvliet and the Hollands Diep do not affect the salmon enterin the river system.

It is clear from these figures that for this scenario to succeed the deficiency in salmon numbers must be made up by fish that stray or infiltrate from other rivers. In practice, the discrepancy is likely to be even larger because of the effects of pollution.

It is not clear whether certain smells that are characteristic of the spawning grounds are still discernible as such by salmon that have passed through rivers rich in detergents.

A further complication in the context of the Rhine is that none of the rivers in the vicinity can serve as alternative entry points for salmon returning from sea. Rivers such as the Ems, Weser and Elbe, which once used to have relatively small salmon populations compared with the Rhine, cannot yet be regarded as true salmon rivers.

The latter also applies to the Maas and River Scheldt. Consequently, factors such as straying and infiltration, which play an important role in population other rivers, are likely to be of little significance in the Rhine basin.

It should be possible, however, for river systems on both sides of the main stream to be recolonized by salmon and hence increase the size of the spawning grounds. It is therefore essential that a wealth of spawning streams be made available for salmon in the Rhine. However, creating the right conditions is no guarantee of success.

If it is finally decided to release young fish into the Rhine, it is recommended that parr be used as these fish leave the river of their own accord, depending on their physiological state. Releasing smolts is not considered to be a tenable option in view of the length of the river and the reduced opportunities that would exist for the characteristics of the surrounding river to be imprinted on the fish. The eggs and larvae that are to be used should be taken from wild fish and not from fish farms that are principally concerned with the commercial aspects of salmon production.

If the Rhine is to be rehabilitated as a salmon river, it is essential that the water quality of the river should meet the requirements for salmon rivers as laid down in the relevant EC Directives.

Finally, it can be concluded that establishing a natural population of salmon in the Rhine without outside help will certainly not be realized within the foreseeable future (10–20 years). After all, the Rhine is one of the most polluted rivers in Europe and it suffers from the added disadvantage that it has a large number of locks and weirs that restrict the access to fish.

Acknowledgments

The present paper is based on a report prepared by the author in the framework of the project Ecological Rehabilitation of the River Rhine (Publs. Reps. 11-1989). The project is a joint effort of the Department of Public Works and Transport; of Agriculture, Nature Management and Fisheries; of Housing, Physical Planning and the Environment. The report was a joint study undertaken by the Institute for Inland Water Management (DBW) in Lelystad and the Netherlands Institute for Fishery Investigations (RIVO).

Special thanks are due to a number of researchers who have contributed to this study, in particular Dr L.P. Hansen (Trondheim), Professor A.D. Hawkins (Aberdeen), Dr D.H. Mills (Edinburgh), Dr J.E. Thorpe (Pitlochry) and Mr A. Bij de Vaate (Lelystad).

References

Anon. (1916) Verslag van de Staatscommissie voor het zalmvraagstuk, met bijlagen. Part I: 1–91, Part II: 1–271. Algemene Landsdrukkerij, Hague.

Bardach J.E. & Case J. (1965) Sensory capabilities of the modified fins of squirrel hake (*Urophycis chuss*) and searobins (*Prionotus carolinus* and *P. evolans*). *Copeia* **1965**, 194–206.

Bardach J.E., Fujiya, M. & Holl A. (1965) Detergents: effects on the chemical senses of the fish *Ictalurus natalis* (le Sueur). *Science* **148**, 1605–1607.

Bardach J.E., Fujiya M. & Holl A. (1967) Investigations of external chemoreceptors of fishes. In: Olfaction and Taste II. Proceedings of the Second International Symposium held in Tokyo, September 1965 (ed. by T. Hayaski), pp. 647–665. Pergammon Press, Oxford.

van Drimmelen D.E. (1987) Schets van de Nederlandse rivier- en binnenvisserij tot het midden van de 20ste eeuw. Organisatie ter Verbetering van de Binnenvisserij, Nieuwegein.

Dunkley D. (1988) Stock and recruitment in North Esk salmon — the fate of fish derived from a single brood year. *The Salmon Net* **20**, 55–59.

Hansen L.P. & Bielby G.H. (1988) *Salmon in Norway*. Atlantic Salmon Trust, Pitlochry, Scotland.

Harden Jones F.R. (1968) Salmon and trout. In: *Fish Migration* (ed. by ???) pp. 42–68. Edward Arnold (Publishers) Ltd, London.

Hoek P.P.C. (1898) Over Winter- en Zomerzalmen. *Mededeelingen over Visscherij* **5**, 77–80.

Hoek P.P.C. (1901) Verslag van den Staat der Nederlandsche Zeevisscherijen over 1900. F. *Zalmvisscherij en daaraan verwante visscherijen*, p. 117.

Hoek P.P.C. (1916a) Rapport over de betekenis der zalmvisscherij op de Mass (met bijlage). In: Verslag van de Staatscommissie voor het zalmvraagstuk. Part II: 159–172.

Hoek P.P.C. (1916b) Rapport over den Rijn als zalmrivier. In: Verslag van de Staatscommissie voor het zalmvraagstuk. Part II: 173–238.

Holl A. (1965) Vital staining by trypan blue: its selectivity for olfactory receptor cells of the brown trout bullhead, *Ictalurus natalis*. *Stain Technology* **40**, 269–273.

Holl A., Schulte E. & Meinel W. (1970) Funktionelle Morphologie des Geruchsorgans und Histologie der Kopfanhänge der Nasenmuräne Rhinomuraena ambonensis (Teleostei, Anguilliformes). *Helgoländer wissenschaftliche Meeresuntersuchungen* **21**, 103–125.

Kuhn G. (1976) Die Fischerei am Oberrhein Geschichtliche Entwicklung und gegenwärtiger Stand. *Hohenheimer Arbeiten, Heft* **83**, pp. 1–193. Verlag Eugen Ulmer, Stuttgart.

Lassen H.J., Møller J. & Hansen L.P. (1988) Simulating North Atlantic Salmon marine life history. International Council for the Exploration of the Sea. C.M 1988/M: 18. 12 pp.

Mills D. (1989) *Ecology and Management of Atlantic Salmon*. Chapman and Hall, London.

Mills D. & Graesser N. (1981) *The Salmon Rivers of Scotland*. (See especially pp. 119–121, Table II). Cassell, London.

Milner N.J. (1982) Habitat evaluation in salmonid streams. Proceedings of the Institute of Fisheries Management. 13th Annual Study Cource, pp. 47–72.

Netboy A. (1980) *Salmon, the World's Most Harassed Fish*. André Deutsch, London. 1–304.

Redeke H.C. (1927) River pollution and fisheries. *Rapports et Proces-Verbaux des Réunions des Conseil Permanent International pour l'Exploration de la Mer* **43**, 1–50.

van der Woude A.M. (1988) De contractfase van de seculaire trend in het Noorderkwartier nader beschouwd. *Bijdragen en mededelingen betreffende de geschiedenis der Nederlanden* **103**, 373–398.

van de Ven G.P. (1976) Aan de wieg van de Rijkswaterstaat. Zutphen. De Walburg Pers 438 pp.