Literature survey into the possibility of restocking the River Rhine and its tributaries with Atlantic salmon (Salmo salar).

Dr. S.J. de Groot

NETHERLANDS INSTITUTE FOR FISHERY INVESTIGATIONS (RIVO)
Haringkade 1 - P.O. Box 68 - 1970 AB IJmuiden - The Netherlands
Tel +31 2550 64646

Publications and reports vol. 1989-11 of the project "Ecological Rehabilitation of the river Rhine".

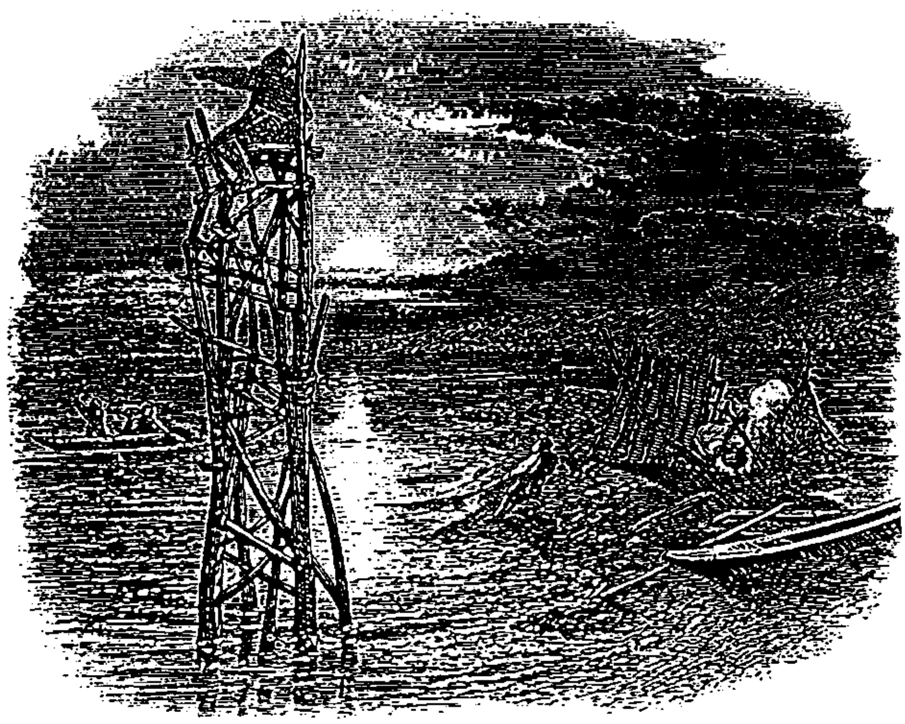
Participating institutes:

On behalf of the Ministry of Transport and Public Works:
Institute for Inland Water Management and Waste Water Treatment (DBW/RIZA), P.o.box 17, NL 8200 AA Lelystad.

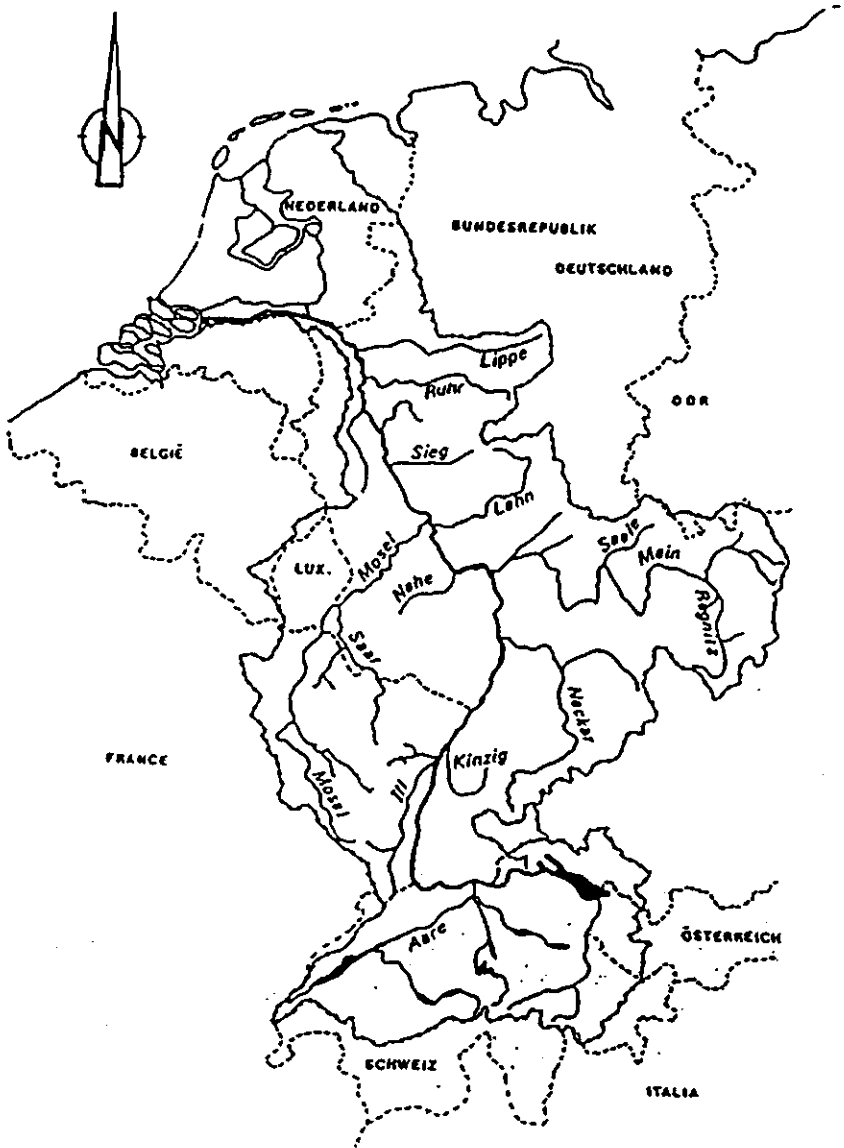
On behalf of the Ministry of Housing, Physical Planning and the Environment:
National Institute for Public Health and Environmental Protection (RIVM), P.o.box 1, NL-3720 BA Bilthoven.

On behalf of the Ministry of Agriculture and Fisheries:
Netherlands Institute for Fishery Investigations (RIVO), P.o.box 68, NL-1970 AB IJmuiden.

Report (RIVO): MO 88-205/89.2
Date of publication: April 1989



SALMON-WATCHER'S TOWER ON THE RHINE.



Rhine basin: 185,000 km², incl. 25,000 km² in the Netherlands

Length of the river:	Konstanz-Lobith	862 km
	Lobith-Kampen*	133 km
	Lobith-Hagestein	84 km
	Lobith-Vuren	89 km
	Vuren-Hook of Holland	79 km

Average discharge** : 2,200 m³/s

Highest discharge recorded : 13,000 m³/s (1926)

Lowest discharge recorded : 620 m³/s (1947; open river)
575 m³/s (1929; river frozen over)

---

* Including 8.6 km of meandering river bed straightened by hydraulic engineering works.

** Based on data collected over the period 1901-1975 at the Lobith measuring station.

Contents:

Foreword

This report contains the findings of a literature survey into the possibility of restocking the Rhine and its tributaries with the atlantic salmon. It principally deals with the possibility of reintroducing salmon into the Rhine basin.
The report has been prepared as part of a joint study undertaken by the Institute for Inland Water Management (DBW) of the Dutch Department of Public Works (Rijkswaterstaat) in Lelystad and the Netherlands Institute for Fishery Investigations (RIVO) in IJmuiden. .

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

IJmuiden, 5 April 1989.

S.J. de Groot.

List of abbreviations

A	=	Anal fin
D	=	Dorsal fin
DAFS	=	Department of Agriculture and Fisheries, Scotland
DBW	=	Institute of Inland Water Management (of RWS)
EC	=	European Community
EIFAC	=	European Inland Fisheries Advisory Commission
ICES	=	International Council for the Exploration of the Sea
IFREMER	=	Institut français de recherche pour l'exploitation de la mer
IMP	=	Multi-year Plan of RWS
LL	=	Scales along the lateral line
MO	=	Environmental Research Department (of RIVO)
NASCO	=	North Atlantic Salmon Conservation Organisation
RIVO	=	Netherlands Institute for Fishery Investigations
RIZA	=	State Institute for Waste Water Management
RWS	=	Dutch Department of Public Works (Rijkswaterstaat)

SUMMARY

The Atlantic salmon (Salmo salar L.), which is an anadromous migratory fish that reaches maturity at sea and returns to spawn in fresh water, was once of major importance to the fishing industry along the River Rhine. Salmon can return to their natal streams to spawn after only spending a single winter at sea. Such fish usually begin their ascent of the river system between June and August, while salmon that have been at sea for two winters tend to re-enter fresh water somewhat earlier in the year, between May and July. Those salmon that have spent even longer periods at sea are likely to delay their return until September or October.
The transition to fresh water is greatly facilitated if the temperature difference between the river and the sea is small. After entering the river system, salmon generally swim upstream for several kilometres and wait for a period of time, which may be a matter of hours or even as long as two months. They select a part of the river where the current is minimal and remain almost stationary to acclimatise. This allows them to reorientate and provides an opportunity for certain physiological changes to take place. Although the salmon's ability to recognise characteristic smells in the river is considered to be essential for locating the spawning grounds, other factors are thought to assist in the general recognition process.
While ascending the river, salmon only swim at night and therefore seek shelter during the day. This contrasts with their behaviour at sea where salmon also remain active during the day.

After reaching the spawning grounds, salmon lay their eggs in clear cool water (2-6°C) and bury them in gravel. In the case of the Rhine, the traditional spawning grounds lie outside the Dutch territory in the river's many tributaries in Germany, France and Switzerland. After about 110 days, larvae emerge from the eggs and disperse. Good salmon rivers contain upwards of 20 larvae per 100 m^2. Less well-populated streams have about 5 larvae per 100 m^2.
By dispersing in this way, salmon larvae make the best use of the limited food resources available and eventually develop into fully adapted freshwater fish. At this stage of their life cycle, salmon are known as parr. After remaining in the nursery area for 1, 2 or 3 years, most parr undergo a further transformation into smolts, which forces them to leave their natal streams for the sea. However, a certain number of male parr remain behind eventually becoming sexually mature without undergoing smolting.

Smolts usually swim downstream to the sea in March and April. Unlike parr, which are only active at night, smolts also travel during the day. Several factors have been put forward to explain why smolts decide to migrate to the sea. These include the higher discharge rates that occur in Spring, the corresponding reduction in pheromone levels, as well as the action of light and temperature changes. On encountering brackish water, smolts undergo further physiological changes to prepare them for the marine environment. Where the transition from fresh water to sea water is rather abrupt, the pockets of fresh water that are normally found in estuaries can facilitate the process of adaptation. Evidence has also emerged to suggest that the time of year at which such changes take place is quite critical.

Up to about forty years ago, when salmon still populated the Rhine, they would swim down the river and enter the North Sea via outlets along the Dutch coast. After drifting along with the residual currents, they eventually headed in a northwesterly direction towards the seas between Greenland and Iceland. This type of behaviour is typical of the post-smolt phase, in which salmon attempt to conserve their energy reserves and maximise their growth rates. Depending on the prevailing conditions, Atlantic salmon will stay in the seas around Greenland for 1, 2 or more years before returning to their spawning grounds. Their physiological condition is thought to be one of the key factors which determine when they decide to return.

The importance of salmon fishing along the Rhine is discussed in detail in this report by reviewing the Dutch and German salmon catches over the periods 1863-1957 and 1875-1950, respectively. Even up to the end of the last century, it was not uncommon for Dutch and German fishermen to land 100,000 salmon a year. However, factors such as the increased use of locks and weirs along the Rhine, coupled with the 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 suggests that the decline in the salmon population could already have started before official records began.

Under normal circumstances, the probability that an egg develops into a mature salmon which returns to its natal stream to spawn is rather small. Moreover, the chance of this happening has become even more remote due to actions taken by man. Natural mortality rates vary considerably depending on the particular stage in the life cycle. On average, 78% of the eggs are fertilised, but only about 0.5 to 1% of the fertilised eggs develop into smolts that eventually reach the sea. About 80% of the post-smolt salmon die within the first 9 months at sea. Subsequently, the mortality rate reduces to 1% a month. However, these figures do not include any of the losses that occur due to fishing. Norwegian sources claim that some 25% of the fish returning to the spawning grounds via the Faeroe Islands are caught. Comparable statistics for the North Sea are not available, but estimates suggest that the percentage could be as high as 50%. Added to this, 5% of the salmon die during their ascent up river.

Although the degree of scatter in the data and uncertainties in the assumptions preclude the possibility of drawing firm conclusions about the survival rate of salmon, these figures do 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:

a. the closure of two of the major migration routes to the sea (Haringvliet and Zuiderzee);
b. morphological changes in the river;
c. chemical and thermal pollution;
d. the loss of accessible spawning and nursery areas of the required quality;
e. 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. Although many of the conditions necessary to ensure the success of such a scheme are known, other factors may prove to be of more importance in the longer term. It is therefore recommended that restocking operations in the spawning grounds and nursery areas be carried out over a number of years (extending over at least three generations of salmon). Moreover, the number of salmon released must be large enough so that the reproductive cycle is not affected by the sex ratio. Furthermore, restocking operations should be conducted in a number of tributaries of the Rhine in order to provide a broad basis for the reintroduction programme. Not only must the water quality in the spawning and nursery areas meet the required standards, but these criteria should to a large extend also apply along the full length of the main watercourse downstream of these areas. This is especially important as salmon depend on their sense of smell to find their way back to the spawning grounds on their return from the sea. Care should be taken to ensure that possible predators such as trout should be removed from the areas where the young salmon are released. Attention should also be focused on ensuring that there are sufficient places for salmon to rest along the main course of the river when they return from the sea. In addition, legal protection should be sought for the salmon along inland waterways to increase the chance of the restocking programme succeeding. Finally, it should be emphasised that such operations should be supported by further research in order to assess the impact of all the relevant factors and conditions.

1. ECOLOGY

Atlantic salmon - Salmo salar Linnaeus, 1758; French - Saumon atlantique; German - Lachs

Distinguishing characteristics: D 12-16; A 10-13; LL 114-130. Maximum length 1.5 m. Protected species under the terms of the Fisheries Act up to a length of 40 cm. Bluish-green back, silver-coloured sides, white stomach. Body covered with widely dispersed dark spots, mainly above the lateral line. Different markings and colourings are observed during the breeding season and on young salmon. On the inside of the first gill-arch 17-24 thin gill-rakers are found. Upper jaw hardly projects beyond the back rim of the eyes. Slender caudal root; 10-14 scales between the adipose fin and the lateral line. Front part of the vomer does not bear teeth. (Table 1.1) (Nijssen & de Groot, 1982).

1.1 Life cycle (Figs. 1.1, 1.2)

The life cycle of the salmon consists of a number of phases, each varying in length depending on the prevailing conditions. Salmon typically spend part of their lives in fresh water and part in the sea. The eggs are deposited in rapidly flowing mountain streams on a bed of gravel mixed with a number of larger stones. This normally occurs at the end of November or in December. The fertilised eggs are buried by the female. A sexually mature female salmon can produce 10-20,000 eggs, or 1200-2000 eggs per kilogramme body weight. The eggs are relatively large (3-6 mm) and have a pale orangy-red colour. Fertilisation takes place as soon as the eggs have been laid. To facilitate this, the male salmon remains close to the female during egg laying.
At a temperature of 4°C, the fertilised eggs hatch in about 110 days, which is equivalent to an incubation rate of 440 days/degree. After two months, the young fish are visible inside the egg. The young larvae that emerge from the eggs are known as alevins. For the first 6-7 weeks, alevins live off food that is stored in the yolk sac. After the food reserves in the relatively large yolk sacs have been used up, the larvae have to find their own food in the form of zooplankton and insect larvae. Provided that alevins grow up in an environment where there are few stimuli that require them to move, they can make optimum use of their yolk sacs. Throughout their initial growth phase, young salmon maintain close contact with the river bed. At this stage of their development, salmon are restricted to a two-dimensional environment, in contrast to young trout, which move freely through the entire water column, therefore occupying a three-dimensional territory. In this context, territory is defined as an exclusive space that can be actively defended and where essential foodstuffs can be found (Wankowski & Thorpe,
1979 a).

The first one or two years of a salmon's life are usually spent close to the spawning ground. During this period, the salmon behaves as a fully adapted non-migratory freshwater fish. At this stage, salmon (parr) feed on copepods, phyllopods, amphipods and caddis-flies (small crustaceans and insects, particularly mosquito larvae). Their diet does not, however, include the plankton found in rivers and streams (Hoek, 1902). During their life in fresh water, salmon select food particles with a maximum width of 2.2-2.6% of their body length.

After one year, parr will normally measure 10-15 cm long and vary in colour from dark green to yellowish-brown. The dark markings by which parr are usually recognised have generally become quite distinct at this stage. From this time onwards, parr are sensitive to factors such as temperature, water level, the position of the moon and pheromone levels, which may influence them to leave their natal streams. Hormonal changes are thought to induce an urge to migrate to the sea at high water in springtime. The accompanying transformation from parr to smolt is generally referred to as "smolting", or "smoltification" in American publications.
The hormone secreted by the thyroid gland, thyroxine (and T4 in particular), is known to play a significant role in this respect.

However, the temperature of the water and changes in the amount of light (possibly registered by the light-sensitive pineal organ) are also thought to be contributory factors. The typical markings associated with the parr begin to disappear as the salmon gradually enters a new phase of its life, that of a migratory freshwater fish. The preference of young salmon for relatively dark, sheltered spots during the day, only becoming active at night is typical of the behaviour exhibited up to the smolting stage.

During the transition from parr to smolt a pre-smolt phase can also be identified, in which the dark markings associated with the parr begin to recede, whilst the body of the fish takes on a more intense silver colour. The characteristic markings of the parr first begin to disappear below the lateral line, followed by the areas behind the head and caudal root, with the central part of the body being the last to change. The smolt is easily recognisable by its silver-coloured body and greenish to bluish-green back. The tail fin of the smolt has a more pronounced fork shape than that of the parr.

The first smolts tend to leave the river in May and June and enter the sea. As a result of hormonal changes in the juvenile salmon, the parr is transformed from an active freshwater fish that can survive in rapidly flowing water into a more docile fish that is less well equipped to resist the forces of the current. According to Thorpe & Morgan (1978), the "migrating" smolt is simply released into the sea in this condition. However, such an explanation ignores the fact that smolts are able to withdraw from the main flow stream, if necessary.

During this period of its life cycle, the juvenile salmon is most active at night and requires a water temperature of at least 10°C. When migrating, American salmon (coho) average speeds of 56 km/day in rivers flowing at 24 km/day. The salmon parr that remain behind in the upper reaches of the river can reach lengths of between 25-28 cm at the end of the second summer. Males in this group can become sexually mature by the autumn without ever having migrated to the sea. It is thought that salmon parr must reach a certain minimum length before they undergo the transformation to smolt. Consequently, a number of the 2-year-old parr travel down river in the autumn to enter the sea as smolts. The only fish that remain behind are males which can subsequently develop into 3-year-old smolts. The percentage of 1, 2 and 3-year-old smolts in a river system can differ from year to year and can also vary within a given river system.

Salmon that migrate downstream as smolts after one year generally weigh 20-50 grammes and measure 10-18 cm in length. Estimates differ as to how long smolts remain in coastal waters before entering the ocean proper.
Smolts are likely to enter the sea directly in rivers without a pronounced estuary, particularly at the ebb tide. In spite of the absence of an estuary in such rivers, fresh water is gradually mixed with salt water, which limits the abruptness of the transition from fresh water to sea water.
However, smolts are also able to remain relatively inactive at the mouth of rivers for substantial periods of time, if necessary (Huntsman & Hoar, 1939). On average, smolts tend to leave rivers within the month. Cave (1985) postulated that smolts move out to sea when the temperature in the river exceeds 10°C.

On the other hand, temperature variations have been shown to delay the migration by up to 40 days, which can result in the most opportune time to enter the sea being missed. This can have serious implications for the survival rate of juvenile salmon that have reached the post-smolt stage. Thorpe (1988 a) has also pointed out how important it is to have the correct sea temperature when the smolts are ready to leave the river.
If temperatures are abnormally low, the young fish are likely to grow less rapidly making them more susceptible to predators. However, at the present time, little concrete information is available about the precise conditions under which smolts enter the sea.

It is thought that the reason why young salmon migrate towards the sea and undergo the transformation to migrating smolts is probably related to local conditions and seasonal influences on the food supply (Thorpe, 1988 b).

In general, little is known about the post-smolt stage of the life cycle, but evidence is available to suggest that the mortality rate is high, particularly in areas where seagulls and cod are known to be active (Hansen & Bielby, 1988). The effect of the coastal fishing industry in the Netherlands on the mortality of post-smolt salmon is difficult to estimate, as no data are available on the presence of young salmon in coastal waters. This primarily results from the fact that in the past, influences such as mortality factors were largely discounted when assessing populations of a particular species of fish. Unfortunately, by the time such ideas began to gain acceptance in fishing circles in the 1940s, the salmon had largely disappeared from the area and it was no longer possible to study these aspects in detail.

The third part of the life cycle of the salmon begins once the smolt enters the sea, where it becomes a fully adapted saltwater fish. Since smolts are relatively small and are generally not able to store much energy (migration may be initiated by lack of food) they tend to use as little of their reserves as possible in swimming out to sea.
Once in the sea, the feeding pattern of the salmon changes. It moves with the prevailing current consuming large quantities of food. In fact, only by remaining in the sea the salmon can obtain sufficient food to sustain further growth. The large distances travelled by young salmon to their new habitat near Greenland under the action of the currents provide ample opportunity for feeding and further development. In this environment, salmon such as the Atlantic salmon (S. salar), which are normally found in American waters but spend their winters near Greenland, experience water temperatures of between -3°C and +8°C. The majority of Western European salmon migrate to an area near the southern part of Greenland as shown in Figure 1.3.

Most of the salmon that return to their natal streams stop feeding as they approach fresh water. Hoek has reported that traces of Clupeidae were found in the stomachs of salmon caught in the Biesbos after returning from the sea. This would appear to suggest that the salmon had consumed these fish just before entering the river system. However, it is thought that the majority of salmon cease feeding once they reach coastal waters. Fraser (1987) has estimated that two-thirds of returning salmon conform to this behaviour pattern. He showed that from the end of June to the beginning of July onwards, the stomachs of salmon caught in Scottish coastal waters were empty.

Salmon generally remain at sea for three or more years. After one year at sea, they have normally reached a length of 50-65 cm (1.5-3.5 kg). They develop further in the second year at the end of which salmon can weigh as much as 4-8 kg, measuring 70-90 cm in length. During this period at sea, the jaw mechanism is adapted to allow the salmon to feed on saltwater fish such as sand eel, herring, sprat, stickleback and capelin. Salmon that return after one year at sea are known as grilse. At the turn of the century, Dutch fishermen used to catch salmon along the entire German Bight as well as along the Dutch coast (see Hoek, 1916 - Part 2, Map Appendix B, catches 1907-1912).

The fourth stage of the life cycle of the salmon begins as the fish re-enters its natal stream. About 2-4% of the salmon that leave the river as smolts return after their migratory period at sea. The extremely high mortality rate is thought to be brought about by fishing practices and particularly the popularity of techniques such as gill nets, which are used around the Faeroe Islands and off the Norwegian coast.

Little is generally known about the factors that determine the salmon's ability to locate its natal stream. Recent research suggests that the temperature of the water is far more significant than had originally been thought.

Hawkins (1986; in preparation; private communication) has clearly shown the importance of the difference in temperature of river water and sea water in this context.
Salmon that return to their natal streams are more likely to re-enter the river system when the temperature difference or "thermal barrier" is relatively small. It has also been possible to correlate the size of the fish with the period when they return. One sea winter fish (grilse) return to the River Dee in Scotland in May-July, whereas two sea winter fish are more likely to be sighted during the period February-May. Fish that have been at sea for three winters generally return between January and April.

Tracking studies carried out with acoustic tags (sea) and radio transmitters (fresh water) have indicated that some grilse and salmon enter the river system immediately, while others remain at the mouth of the river for a certain period before travelling upstream. This complies with the hypothesis that the temperature difference between the sea and river must not be too great and that the fish have a prescribed "temperature window" for re-entering the freshwater environment. In winter, the water in the river is colder than in the sea, whereas in summer, the opposite is true. The larger salmon enter the river earlier in the season than grilse, which is probably due to differences in metabolism. Grilse are generally less hardy than multi sea winter fish.

Observations in the Dee have shown that after re-entering the river against the current at speeds averaging 5-6 km/day, salmon tend to pause in quiet pools for periods of up to two months before continuing the journey upstream.
Particularly significant is the fact that although salmon and grilse do not exhibit a strict day-time/nighttime rhythm in the sea, they quickly develop a pronounced pattern of this type within a few days of entering the river system.
During the run upstream, salmon and grilse take the opportunity to build up their strength in sheltered areas before tackling obstacles such as the more rapid currents that flow under bridges, where the river narrows.
In summer, it is often necessary for fish returning to the spawning grounds to wait in pools for considerable periods because of the drop in the water level that often occurs at this time of year. Only after the autumn rains have increased the depth of the river will the salmon resume their journey upstream.
It is thought that these enforced rest periods afford a useful opportunity for the salmon and grilse to reorientate themselves to the river habitat. Of particular importance in this context are the characteristic smells and recognisable visual signs associated with a given river.
Hawkins showed the significance of such factors in his tracking experiments with transmitters.
He was able to prove that certain fish which had ascended quite some distance along particular branches of the river, retraced their path before continuing along a different branch of the river.

The critical "temperature window" for salmon in northern territories is narrower than for those in the south. Moreover, if the temperature of the sea water and fresh water is outside the normal range this tends to reduce the degree of latitude in the effective "window" even more (Mills, 1989).
Observations have shown that after swimming a distance of 3-4 km up river and encountering water temperatures of about 20°C, Scottish salmon suspended their run upstream and waited until the temperature had dropped to about 12°C before continuing their journey.
It is thought that a combination of optical factors and the ability to recognise characteristic odours enables salmon and grilse to retrace the route they followed when leaving the spawning beds.
The smell profile of the natal stream or, in the case of restocking operations, the river system into which the young salmon have been released, plays a significant role in this context.
According to some authors, the smell profile is imprinted in the sensory system of the salmon when the young fish emerge from the eggs as larvae with accompanying yolk sacs.
Others suggest that the formative parr phase is of more importance, while certain scientists emphasise the role played by the initial part of the smolt phase.

All are, however, agreed that when a fish is to be released into a new river system, it will require to be immersed for a period of about ten days to reorientate its sense of smell before being set free. This ensures that the smell pattern is recorded in the brain of the fish as effectively as possible. Although some authors (for instance, Hasler, Brett and Groot) assume that the imprinting process is only concerned with a relatively short period of the salmon's life, Thorpe has pointed out that little is known about the precise timing and duration of the imprinting process. For example, the young of certain types of salmon (Pacific) are washed into the sea almost immediately (pink salmon), while other species remain in fresh water for a period of three years before entering the sea (sockeye salmon). Nevertheless, both types of salmon appear equally adroit at returning to their natal streams.

It is possible that the imprinting process involves recording a series of profiles that correspond to all the major environmental changes that are encountered as the young salmon travels down river. Typically this could consist of imprints of the gravel bed, where streams enter lakes, where rivers branch as well as salient features of the main flow stream. When mature fish re-enter their natal stream these imprints have to be accessed from the brain in reverse order to reach the desired destination (Harden Jones, 1968).

Pheromones are thought to be of fundamental importance to the imprinting process. These are chemical substances which are secreted by one individual to elicit a specific response from other individuals of the same species. Pheromones are mainly produced in the skin of the fish and have a range of functions. They can, for instance, be used to warn other fish if one of the group is injured (pheromones released from the wound), while other pheromones serve to attract similar fish allowing them to recognise each other.

Fish that return in the spring or summer after one year at sea (about two years old) are known as grilse or in the context of the Rhine basin, "Jacob's salmon". The latter name is particularly associated with salmon of 61-67 cm in length and is derived from St. Jacob's day, celebrated on the 25th of July.
In the past, many fish returned to the Rhine in June, July and August with numbers gradually decreasing towards the autumn. Most of the fish returning to the Rhine were male (85%). Salmon that remained at sea for another year (83-91 cm, 7.5 kg, > 3 years old) normally returned in the period May-July. The common parlance on the Rhine for such fish was "small summer salmon". Although these fish were not sexually mature when entering the Rhine, they had generally reached this stage by the time they arrived in Germany. Salmon that remained at sea even longer ascended the Rhine in September and October. These became known as "winter salmon" (103-115 cm, 5-15 kg), a term which was used until 1 April the following year. From May onwards, fish of this size were referred to as "large summer salmon". Such fish were rich in fat, but not yet sexually mature. Salmon and grilse are known to stop feeding during the river phase as they rely primarily on their reserves of fat. The "winter salmon" in the Rhine, for instance, had to be able to live off such reserves from the time of entering the Rhine basin to that of leaving the river approximately 14 months later, as well as being in good enough condition for spawning a year after entering the river.

Studies in Canada have shown that salmon that had to ascend a 660-mile-long river to reach their spawning beds, were only just able to spawn before dying. The female fish had used up 96% of their fat reserves and 53% of their protein reserves.

Most salmon die after spawning or on their way back to sea. At this stage, the fish are known as kelts. The majority of kelts that survive the journey back to sea are females. Once at sea, kelts start to feed again and, under favourable conditions, can complete a further migratory cycle. In the Rhine, kelts were usually caught in April.

1.2 Spawning grounds (Figs. 1.4, 1.5, Table 1.2)

The productivity of salmon rivers is determined by several factors, with the availability of spawning beds being of special importance. Spawning grounds are generally found in the upper reaches of rivers and their suitability varies from location to location within a specific river system. Efforts to trace the brooks and streams in Germany where salmon used to spawn have been hampered by a lack of sufficient information on this subject in the Netherlands. With current records, it is unlikely that a complete inventory could be made of the streams which would be suitable for spawning and to what extent others could be brought up to the required standard. This problem is compounded by the fact that information from German sources is of such a general nature, being subdivided into regions like "Voralpen", "Black Forest", "Vosges" and "Ardennes - Eifel - Hunsrück", as to be of little practical value.

At the beginning of the spawning season, the female salmon hollows out a small nest pit in the gravel known as a redd. Initially, trial redds are made by the grilse or small salmon in gravel beds of some 60 cm deep.
When digging a redd, salmon generally choose sites where the water is relatively shallow (40-60 cm deep).
Spawning can take place in water depths of between 15-120 cm, provided that the flow velocity is > 40 cm/s. However, the temperature of the water must also be below 14.4°C. Among the sites commonly chosen by salmon for constructing redds are places where the current accelerates such as at the head of rapids, where currents converge or where a current is deflected by an obstacle (e.g. a large stone).
Extremely fast flowing water is avoided as the bed material in such places is unlikely to have the correct balance of fine gravel and sand.
If the current is too swift, deposits of fine gravel are washed away. In contrast, too weak a current has the disadvantage that the gravel becomes clogged with excessive amounts of fine material.

Since the female salmon digs the redd in relatively firm bed material, it can sometimes take a week before the work is completed. The dimensions of redds vary with the size of the fish ranging from 20 cm deep and 50 cm in diameter to 30 or more cm deep and up to 1 m in diameter.
The female constructs an egg-pocket at the bottom of the pit, which consists of a number of larger stones from which all the finer material has been washed away. As such, the egg-pocket represents the cleanest part of the redd.

During foreplay, the adult salmon retire to pools that are to be found on either side of the gravel bed. Although the female spends several hours in the redd, the eggs are fertilised in a matter of seconds. Egg deposition can take place once every seven hours in clusters of 100-1000. In the wild, at least 78% of the eggs are fertilised by the male, which compares with figures of 98% obtained under laboratory conditions.

After spawning, the female covers the eggs with fine gravel from the upstream part of the redd. This action also tends to wash the gravel, removing any detritus, silt and mud that are present. A completed redd has the form of a low mound in which the eggs are covered with a layer of gravel of 40-60 cm thick.

The position of the redd, in relation to adjacent pools both upstream and downstream of the mound, coupled with the loose packing of the gravel bed ensures that the eggs and larvae have access to an adequate supply of oxygen-rich water and that excretion products are removed. Having the correct particle size distribution in the gravel that makes up the redd is a key element of the design. It is impossible to construct a redd in closely-packed bed material, whereas material that is loosely compacted frequently becomes blocked in a short period of time.

After a few weeks, the only signs that remain of the spawning operations are the mounds of somewhat "cleaner" gravel at the bottom of the river.

At the present time, scientists are unable to provide a complete explanation of how alevin find their way into the open water from under the gravel. However, it is known that, depending on the conditions, a certain proportion of the larvae will be lost at this stage. For instance, extremely swift currents can remove the tops of redds, which increases the number of larvae in the river in comparison with situations where the flow is less rapid and the amount of material removed is substantially lower.

French research has shown that alevins are mainly active during the first three hours after sunset, which may be linked to the dispersion mechanism in which the water level, temperature and the amount of light in relation to the position of the moon, could play a key role.

Under extreme environmental conditions, such as the partial drying out of river beds, salmon may be forced to hybridise with
trout. The highest percentage of naturally occurring hybrids was found in Spanish rivers. Garcia de Leaniz and Verspoor (1988) reported a figure of 7.7% as opposed to an average rate of 2.3%

1.3 Nursery areas

Alevins emerge from the eggs measuring about one cm in length. Their movements are initially restricted by the presence of a large yolk sac which makes them vulnerable to predators. Once the yolk sac has been used up, alevins feed on insect larvae. However, whilst in the larval phase, alevins are also regarded as a source of food by water insects that inhabit the same environment. Alevins continue to grow throughout the spring approximately reaching the length of a finger in the month of May. From this point onwards, the young salmon is generally referred to as a parr. In addition to man, the major predators of the parr are trout, pike, chub, perch, eel, cormorants, ducks, swans and herons.

When salmon were common in the Rhine, parr that had transformed to smolts could migrate to the open sea via the Zuiderzee (the former Lake IJsselmeer).
However, if salmon were to be reintroduced in the Netherlands they would not only have to contend with the presence of the IJsselmeer, the lake formed after the Zuiderzee was closed off, but also have to contend with a new predator, the pikeperch, which did not exist in the heyday of Rhine salmon.
It is questionable how smolts would find their way to the sea in periods when water is not withdrawn from the lake IJsselmeer and even if this were to be the case, how they would manage to recognise the water course again. The large numbers of eel, perch and of pikeperch in particular would represent a significant threat to the young salmon in the Rhine. Similar considerations led the British authorities to investigate the possibility of removing all the glass eel from the mouths of the major UK salmon rivers. In Ireland, a constant vigil is maintained for pike.
Evidence of the effect of predators on salmon is available from observations with larvae. It has been shown that 11% of salmon larvae are likely to be eaten in 24 hours by perch. Although the validity of using free swimming larvae for such tests could be questioned, the results indicate the seriousness of predatory attacks on salmon.

Salmon parr typically feed throughout the year with a peak in April and May. If the stomachs of parr are found to be empty this is more likely to be a reflection of the fact that food is in short supply in the river than a loss of appetite.
Parr tend to consume small amounts of food at night, with very little nutrition being taken during periods of bright sunlight or high temperatures.

Milner (1982) reported that a prerequisite for the presence of salmonids in a water course was a sufficient degree of protection. First-year salmon living in streams with a depth of 10-15 cm hide behind pebbles of between 1.6 and 6.4 cm, while fish older than one year (8-9 cm long) are more likely to be found in water of at least 30 cm deep and to seek shelter behind stones of 25.6 cm. Protection of this type safeguards the salmon from predators and from being moved along by the current, as well as providing a degree of cover which effectively reduces the size of territory required.

The need for protection in the river is strongly dependent on the speed of the current. It has been shown that young salmon move closer to the river bed if the current increases from 10 to 30 cm/s. In addition, young salmon are known to prefer different flow velocities depending on the time of day, seasonal influences and species-related variations.

Milner (1982) has devised a method of assessing the suitability of salmonid streams by awarding points on the basis of the length of the river over which a number of juvenile (0+) salmonids occur for a given amount of biomass expressed as grammes/100 m^2. Milner's scale varies from grade 5 (i.e. $\leq$ 20% of the river has $\geq$ 4.7 salmonids/100 m and $\leq$ 130 g/100 m of biomass) to grade 1 (i.e. $\geq$ 80% of the river has $\geq$ 19.9 salmonids /100 m and $\geq$ 841 g/100 m of biomass).

Smolts are known to consume large quantities of food on the journey downstream towards the sea. In swift currents, smolts float with their tails pointing forwards, while in water flowing at speeds of less than 1.5 km/h they tend to swim in a normal manner with the current. In the vicinity of turbine-entry ducts, where high flow velocities are common, smolts are frequently sucked in tail first.

Tests have shown that the GH hormone levels in smolts decreased in March-April before these fish were transferred to the sea. At the same time, significant increases were observed in thyroxine concentrations (T3 and T4). The smolts' transition from fresh water to salt water was accompanied by rises in blood pressure, pH and lactate levels. Such changes were observed to proceed far slower in parr that were transferred to a saltwater environment than in the case of smolts.
Another effect of the thyroid hormone is that it influences phototaxis. Non-migratory fish tend to remain in shaded areas during the day, while migratory fish seek the open water. In addition, fish with high levels of thyroxine are more likely to swim in shoals (coho salmon). Such behaviour can be regarded as offering better protection against predators. It is thought that the thyroid hormone is instrumental in this behaviour, although it is possible that genetic factors could also play a role.
Coho salmon (smolts) originating from the upper reaches of long rivers migrate downstream at a faster rate than those maturing in the lower reaches of rivers. Respective speeds of 20 km/h and 8 km/h are typical of these two groups of smolt. This has implications for the likelihood of catching such fish with particular types of fishing gear.

Changes have also been observed in the fatty acid composition of smolts before they enter salt water. Such changes were found to be independent of temperature.
In general, the fatty acid content of the parr is greater than that of the smolt, but the smolt has more unsaturated fatty acids, as opposed to the parr's greater proportion of saturated fatty acids.

Evidence is available to suggest that the more silver-coloured a smolt is before it migrates to sea, the more likely it is to be able to adapt quickly to the saltwater environment (hypoosmoregulation) and hence to survive. Experiments in America with coho salmon tagged with coded wires have shown that far larger numbers of smolts that moved out to sea just after the new moon, around the time of the spring equinox, subsequently returned to the river as mature fish. Of these smolts 4.8% returned compared with the normal figure of 2%.

French researchers in Brittany (Baglinière c.s., 1987) have shown that young salmon are subjected to rather extreme and variable climatic conditions during their early stages of development. It was found that the water temperature in this region varied from 6°C-20°C and that the rainfall ranged from 485-1100 mm/year with a peak in winter. It should be noted, however, that all the rivers studied in this project were relatively short (60-75 km).

1.4 Population dynamics and production

Studies have shown that the population densities of parr in rivers can vary from 0-24 (0+) parr/100 m^2 and 0-7.4 (1+) parr/100 m^2.
Parr normally inhabit areas where the current exceeds 40 cm/s and the water depth is less than 40 cm. The 0+ age group have an affinity for water depths of 23 cm and a current of 60 cm/s, whereas parr in the 1+ age group generally prefer deeper water and a coarser type of bed sediment. Typical size ranges for the two age groups are 79-101 mm long (0+) and 134-154 mm long (1+). The corresponding population density of smolts in salmon rivers is estimated to be 1.9-5.1 smolts/100 m^2.

Calculations of the effective productivity of salmon rivers can be made according to the assumption proposed by R.E. Foerster for sockeye salmon.

> Assume 1000 adult salmon ascend a river, 500 of which are male and 500 are female. Each female would be expected to lay 4000 eggs (Netboy, 1980). If 5% of the adult salmon are assumed to be lost during the journey upstream, this would imply that 1,900,000 eggs would be produced during spawning. Now, if 50% of the eggs are lost, 950,000 eggs would be left from which a similar number of alevin would be expected to emerge. If it is assumed that 75% of the alevins either fail to emerge from the gravel in the redd or are lost during migration downstream, 237,000 larvae would remain. If 97% of the larvae die, 7000 smolts would subsequently reach the sea.

In assessing the survival rates of salmon, Mills (1989) based his estimates on an initial population of 5000 eggs. From the 4700 larvae that emerged, 360 remained at the end of the first year. Some 256 of these subsequently developed into parr: 140 parr (1+ year old), 77 parr (2+ years old) and 39 parr (3+ years old). In conclusion, he assumed that 1% of the eggs finally developed into smolts. Prior to this, Dunkley (1988) estimated the survival rate of North Esk salmon to be 0.5%.

In reviewing Norwegian salmon stocks, Hansen and Bielby (1988) calculated that for a hypothetical 3214 smolts leaving the River Imsa in 1981, only 778 would remain after the first year with some 2436 of the fish being lost in Norwegian waters. Subsequently, 578 would attempt to return to Norwegian coastal waters, but with the prevailing mortality rate, 23 would probably die. Of the 555 fish expected to return successfully, 448 would be caught by fishermen, 66 grilse would reach their natal streams and 1 would die of natural causes. In addition, from the 200 fish to remain at sea, 23 would be expected to die, leaving 177 to be caught by sea fishermen. Assuming a natural mortality of 5 and 45 fish to be caught at sea, 127 fish would remain to enter Norwegian coastal waters. If 118 of these were caught, this would imply that 9 salmon, which had remained at sea for 2 years, would reach the Imsa. In total, from the original 3214 smolts, 75 fish would return.

In reviewing the information on salmon previously caught in the Rhine, it has not proved possible to establish clear length/weight relationships. The data available are either given in terms of "weights" or "numbers caught" (see, for example Fig. 2.4). Many factors are known to affect length/weight ratios, which change continuously throughout the life cycle of the salmon. The availability of food and the sex of the salmon are known to be of importance in this context. Growth and the onset of sexual maturity are in fact two contrasting factors: salmon are likely to grow rapidly with an abundance of food but mature sexually somewhat later because of the reduced need to reproduce.

2. HISTORY OF THE SALMON FISHING INDUSTRY UP TO 1940

The history of the Dutch fishing industry can be traced back to the oldest inhabitants 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. At that time, Dutch fishermen sold the salmon caught in the Rhine in Koblenz. Records show that in subsequent years, the number of documents relating to the salmon and shad trade increased rapidly. This was accompanied by a growth in the associated legal procedures and the amount of money levied in tolls. 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" (Northern quarter) of the Netherlands provides a useful insight into the importance of salmon fishing in the Netherlands between 1650 and 1805. Throughout this period, a tax system involving the payment of every "ninth penny" was in force. 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. After considering various options, he could only explain the fall in tax revenues that occurred by assuming variations in the supply of salmon. He concluded that between 1650 and 1679, the number of salmon caught fell by more 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, the loss of two-thirds of the annual salmon catch over a period of 50 years must be regarded as a fairly dramatic reduction.
These findings illustrate the type of important biological information concerning salmon in the Rhine that may be hidden in official archives.

The first reliable records about salmon catches in the Netherlands began to be kept in 1798. The Geertruidenberg fish market recorded the number of salmon that were sold there from 1798-1810. Figures varied from 3555 in 1810 to 18,415 in 1799.

Although there is evidence to suggest that freshwater fish formed a major source of food in the first half of the 19th century, detailed information about river fisheries is generally scarce. However, it is known that the salmon fisheries, and particularly those on the Rhine, were the only ones whose influence extended beyond the immediate locality. Evidence suggests that salmon fishing was an important trade at the time, with its own processing industry in the form of salmon smokehouses.
In the second half of the 19th century, the effects of industrialisation became increasingly apparent. Prosperity increased and improvements were observed in fishing techniques, as well as in marketing and organisational aspects. However, the growing industrial importance of the major rivers drastically changed the character of these waterways. As a result, salmon fishing steadily declined. In the Netherlands, the drop in the number of 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 in upstream areas.

At the time, pressure was brought to bear, both nationally and internationally, to arrange a fairer distribution of the salmon found in the Rhine.
Although the Salmon Convention that was drafted by the Rhine riparian states under the terms of the Mannheim Convention was narrowly rejected by the Dutch Lower House in 1870, this was also the year in which reliable national statistics regarding the supply of salmon started to be kept. The Salmon Convention was eventually ratified by the Dutch Parliament in 1886.

By that time, it had become increasingly clear that there were structural reasons for the decline in the salmon population.
Many possible explanations for the reduction in salmon numbers were put forward, such as the river straightening operations that had been started along the Upper Rhine in 1817. Bertram (1873) remarked that Dutch salmon had a different taste from Scottish salmon and was regarded as being "too oily and too rich" by salmon connoisseurs. This may well have been the first indication of the effects of pollution, but in those days this was not recognised as such.

At a national level, anxiety grew about maintaining salmon numbers, or in any event preventing further drastic declines. A Government Commission was formed by order of Royal Decree No. 23 to "investigate possible ways of promoting the presence of salmon in Dutch rivers, to issue a report on this subject and to make recommendations about whether it would be desirable to introduce young salmon in the lower reaches of the Rhine for this purpose".
The subsequent report, which was issued in two parts, has remained the most authoritative work on Dutch salmon fisheries ever published. Being the first report of its type, it provides a complete summary of all aspects of salmon biology, fishing and the problems associated with restocking the Rhine. Moreover, it contains a detailed review of the activities that were thought to have an impact upon the ecosystem of the Rhine as well as contemporary ideas on how to prevent further declines in the salmon population and the possibilities for improving the situation. The first part of the report deals with political and administrative aspects, including the situation in neighbouring countries. The second part contains detailed technical papers written by recognised experts who sat on the Government Commission e.g. Dr. P.P.C. Hoek, Prof. H.F. Nierstrasz and Mr. A.A. Nengerman. Furthermore, the full version of the Salmon Convention as ratified on 21 July 1886 and other relevant regulations were included in the second part of the report.

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".

In 1922, the Inspector of Fisheries and P. van Brakel collaborated in writing a report for the Fisheries Division of the Ministry of Agriculture, Trade and Industry entitled "Improving the salmon and shad populations in our rivers" (Anon., 1922). This report updated the early work of the Government Commission on Salmon by including more recent statistics. However, in spite of the measures introduced, the decline of the salmon population continued unrelentingly until salmon became practically extinct in the Netherlands at the end of the 1940s.

The decision of the government 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.

Although the depth of information regarding salmon fishing on the Rhine is not ideal, even less is known about conditions on the River Maas.
Nengerman, Lonkhuyzen and Brouwer (1918) published some data on this subject, whilst preserving the confidential nature of their sources. The information obtained from salmon fishermen operating in the upper reaches of the river system, concerned catches landed along the Maas from Eijsden to the mouth of the Nieuwe Maas.
One of the sources was able to supply information collected over the period 1886-1917 (Table 2.1).

These data are of particular interest since the Maas used to join the Rhine at two places, east and west of the Bommeler Waard, although nowadays it enters the Rhine at the stretch of water known as the River Amer at the confluence with the River Bergse Maas.

In the past, salmon used to reach the Bergse Maas by first entering the river system via the sea inlets at Goedereede and Brouwershaven and then swim along the Haringvliet and the Volkerak into the Hollands Diep and the Amer. Since the Rivers Maas and Waal were completely separated in 1904, the Bergse Maas became the only route via which salmon reached the stretches of the Maas flowing through provinces Brabant, Limburg and through Belgium. Before this time, when the Upper Merwede and the Upper Maas were still joined, salmon could use a more northerly route to reach the Maas.

Unfortunately, no attempts were made in the past to establish the relative proportions of salmon returning to the River Nieuwe Merwede as opposed to the Maas. In contrast to the records kept about Rhine salmon, detailed statistics of the salmon fisheries in the Maas are not available. However, evidence has been found to suggest that from about 1909, the salmon catches around Maastricht had begun to decline. The situation is further complicated by the fact that many of the salmon from this area were sold in Belgium and that fishermen were rather secretive about the actual numbers of salmon caught for fear of having to pay more for the right to fish on the river. According to Hoek, none of the tributaries of the Maas in the Netherlands was particularly suitable for salmon. As a result, the salmon fishing industry along the Maas in Brabant and Limburg never developed to a significant extent.

Although similar problems are encountered when trying to trace information about the Belgian salmon industry centred on the Maas, it is generally agreed to have been of greater importance than its Dutch equivalent. A Belgian fishmonger is on record as having purchased 258 salmon caught in the River Ourthe near the Tilff weir in 1885. The average number of fish caught per year along this stretch of the river was 110 (amounting to 1433 over 13 years). Examination of the monthly catch statistics shows that more fish were caught in October, when the fertile fish moved upstream to spawn, as well as in May, which coincided with the arrival of the summer salmon. However, the salmon fisheries along the Maas soon went into rapid decline due to the construction of weirs and other river channel works.

2.1 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 summarised in Table 2.2 and Figure 2.1. Kuhn (1976) prepared a similar overview for German salmon catches between 1875 and 1950 (Figure 2.2). Combining both sets of data allows the total number of salmon caught in the Netherlands and Germany over this period to be calculated (Figure 2.3), which can be used as a fairly representative basis for estimating the effective size of the salmon population in the Rhine. This information can be contrasted with Neresheimer's statement in his authoritative work "Handbuch der Binnenfischerei Mitteleuropas" (edited by Demoll & Maier, 1939) that:

> "Nach den langjährigen Statistiken entfallen vom Gesamtertrage wenigstens 80% auf Holland, je 10% auf die preussische Strecke des Mittel- und Unterrheins und auf die übrigen beteiligten Staaten."

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 had proved to be so successful in the past, were no longer used after 1932. The rise in the Dutch share of salmon catches from the Rhine at the end of the last century was largely achieved at the cost of the German fishing industry. From the 1930s onwards, the situation was reversed with German fishermen increasing their share of a rapidly dwindling catch at the expense of their Dutch counterparts.

In order to compensate for the decline in the salmon population in the Rhine, experiments began as early as 1861 with releasing salmon fry into the wild which had been reared under controlled conditions. These activities assumed greater importance after the ratification of the Salmon Convention in 1886. Enormous numbers of young salmon were released into the Rhine at the end of the 19th and beginning of the 20th centuries. Restocking operations in Switzerland and Germany between 1879 and 1912, to which the Netherlands also 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.

Opinions were divided as to the effectiveness of such operations as a means of increasing salmon stocks in the Rhine. In July 1887, for instance, Von Behr, the president of the "Fischerei-Verein" (German Fisheries Association), supported by Haack, the managing director of the famous fish farm at Hunningen, and Professor Nitsche (Tharand) made the following comments about such schemes:

1. "In our opinion, the policy of introducing salmon fry into the Lower Rhine, in the absence of suitable natural spawning grounds, which has up to now been pursued by the Netherlands, cannot be regarded as an efficient way of augmenting salmon stocks nor can the method of restocking the river with one-year old salmon that have been reared in hatcheries be considered to be worthwhile.

2. The German Fisheries Association (Fischerei-Verein) should attempt to persuade the Dutch authorities that it would be more effective for them to support a joint scheme to introduce fry into the Upper Rhine. Should this not prove possible, consideration should be given to shifting the restocking activities to the tributaries of the Lower Rhine, with particular emphasis being placed on the section of the river system flowing through Luxemburg. It is felt that the River Ruhr merits special attention in this context."

The difficulty that the two sides had in reaching agreement about such matters is illustrated by the amusing reply Professor Nitsche gave to an open letter written by the Dutch Professor Hubrecht. Professor Nitsche expressed his scepticism about the arguments raised by Hubrecht against the practicality of the proposals of the 1887 Freiburg conference. Professor Nitsche commented that he now had a clearer understanding of the differences that existed between the Dutch and German approaches to solving the problem of declining salmon numbers. He went on to suggest that the Dutch view with respect to restocking personified by Professor Hubrecht could best be characterised by the motto: "Ars naturae Magistra". Nitsche felt that this was a truly noble saying, worthy of a people who prided themselves on living on land reclaimed from the sea. However, Professor Nitsche was quick to point out that the original motto, Natura Artis Magistra, which was often quoted in Holland, had more inherent appeal to him than any corrupted version.

In spite of these arguments, there existed a considerable body of opinion in the Netherlands in favour of releasing juvenile salmon reared in hatcheries into Dutch waters, even though such young fish were not normally found in the Netherlands.
It appeared that national pride took precedence over common sense. In addition to pursuing an active policy of restocking Dutch rivers, the Netherlands also increasingly participated in fishery rehabilitation activities in other countries.

At the beginning of the century, the Netherlands payed 25-30% of the costs of such international initiatives, increasing its sponsorship to over 50% during World War I (1914-1918). By 1923, the Netherlands was contributing 70-80% of the total costs involved. The Netherlands continued to support such activities up to 1940 meeting between 60-80% of the annual costs. The willingness of the Dutch authorities to fund such a large part of the restocking operations in the Rhine was probably based on the belief that their share of the salmon catch amounted to 80%. The divisions that existed between the individual German states at this time meant that statistics for the country as a whole were not compiled. As a consequence, the Dutch accepted the validity of German claims. While it was clear that Dutch fishermen certainly caught more salmon than any of the individual German states, it has only recently been possible to make a true comparison with the total German catch thanks to the pioneering work of Kuhn (1976).

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 about the effect of restocking operations on salmon catches concluded that although it could not be ruled out that over the last twenty years, the salmon population in the Rhine had become increasingly dependent on restocking operations, no clear statistical evidence could be found to support such a link from the available data.

The fact that catches declined exceedingly rapidly from 1945 onwards after restocking operations had practically ceased could not be assumed to be a direct consequence of the change in policy. On the contrary, as was pointed out in the 1947 report "a definite link between the two events could only be established if all restocking activities were to be discontinued for a few more years. However, it should be realised that pursuing such a course of action involves the risk that by the time the necessary evidence has been collected the remaining salmon population will no longer be viable."

History has proved that these words were truly prophetic. Subsequent analyses have shown the positive effect that restocking the Rhine had on retarding the decline in salmon numbers. Kuhn (1976) endorsed this conclusion:

> "Wenn auch ein direkter Zusammenhang zwischen Brutaussetzung und Lachsfang nicht zu erkennen war, so läst die drei Jahrzente überspannende Kurve mit nur relativ rücklaufiger Tendenz doch darauf schliessen, das die künstliche Lachszucht lange Zeit über zur Erhaltung der Salmenfischerei im Rhein beitrug".

Nevertheless, he had to concede: "Eine Aufrechterhaltung der Lachsfischerei war allerdings auch mit Hilfe der Lachszucht nicht mehr möglich."

2.2 Variations in the number of salmon caught

The fluctuations in annual salmon catches clearly show that certain years were more successful for spawning than others. However, the size of the catch in any one year cannot simply be related to the productivity of the river in a given year. A high or low yield from the spawning grounds only becomes noticeable when the young salmon return to their natal streams from the sea. This is complicated by the fact that just as young salmon can re-enter the river system to spawn after having been at sea for 1, 2 or 3 years, smolts may not leave their natal streams directly and can remain for up to three years before migrating.

Drawing conclusions about the productivity of the Rhine in a given year is made more difficult by virtue of the fact that for most of the period for which records were kept, the salmon population was in decline.

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 realised that the size of their catches was decreasing rapidly. This could have led to too drastic a reduction in the fishing capacity. On the other hand, before fishermen decided to discontinue their operations, many would have tried to maximise their catch by all available means. The skill of the individual fisherman may also have played a part in this context.

Annual fluctuations in the salmon population can best be quantified by comparing statistics of the number of salmon caught year by year. In addition, weight data can be used to give a reasonable indication of the onset of certain trends. A comparison between the weight and number of salmon caught over the period 1893-1918 is shown in Figure 2.4. 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. When, for instance, large numbers of grilse were caught, fishermen could generally expect a ready supply of small summer salmon. This is illustrated in Figure 2.5 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 1898 and 1919 is given Figure 2.6. In addition to annual variations in salmon catches, a marked difference can be seen within a particular year. Figure 2.7 shows the average monthly catch over the period 1911-1918. In the Netherlands, the most important months for the salmon fishermen were March to July, often with some continuation into August.

It is also possible to discern daily variations in the salmon catch due to the work of Nengerman c.s. (1918), who published the results of a confidential survey of salmon fishermen working on the Rhine, Waal and Merwede. An overview of the salmon catches of ten fishermen that participated in the survey is given in Table 2.3 for the period 1865-1917. One of these fishermen, No. 7, supplied detailed information about the number of salmon he had caught per day between 1912 and 1917 (Table 2.4). Examination of these records clearly shows the effect of the ban on fishing imposed on Sundays. By Monday, salmon ascending the river system had had sufficient time to reach the fishing grounds, which explains why the highest catches were recorded on this day, whereas the average catch had dropped to 1.3 salmon/day on Saturdays after five consecutive days of uninterrupted fishing.

2.3 Distribution of salmon in the Dutch part of the Rhine basin

According to Hoek (1916), comparable numbers of salmon returned to each of the three main outlets of the Rhine: the rivers Nieuwe Maas, Oude Maas and Nieuwe Merwede. Just upstream from the sea inlets, bag and stake nets were commonly used to catch salmon. Most of the nets were positioned in areas such as the Haringvliet, Goereese Gat (from the Hoornse Hoofden to the sea), Beningen, Botlek, Brielse Maas, Scheur and Nieuwe Waterweg. The number of stake nets used in these waters had reached 108 in 1914, dropping to 95 in 1919, whereas a similar trend was apparent for the number of bag or fyke nets (1914: 304 and 1919: 290). For information such as a detailed description of the different types of fishing gear employed around the turn of the century, the Fisheries Acts in force at that time and the regulations regarding inland water fisheries, reference is made to the Bulletins and Reports of the Fisheries Inspectorate No. 1 (1912), which also contain illustrations of the most important types of commercial freshwater fish.

Information relating to the use of seine nets is given in a report by Hoek (1916, Report of the Government Commission on Salmon, Part I, Appendix V), in which the position of such nets in the Dutch part of the Rhine basin is indicated. Seine nets were operated from a fixed pivot at five locations along the Nieuwe Maas, Oude Maas and Nieuwe Merwede.

This allowed salmon to be caught throughout the period from mid-March to mid-August.

Large numbers of salmon were also caught all along the Rhine up to the German border using fishing boats equipped with drift nets. An indication of the scale of these activities is given in the following statistics: in 1919, 40 fishing boats operated along the stretches of water including the Nieuwe Maas, Scheur, Nieuwe Waterweg, Oude Maas, Brielse Maas and Upper Oude Maas; 58 on the Upper Merwede, Nieuwe Merwede, Hollands Diep (up to the Moerdijk Bridge) and the Amer; 28 along the Bergse Maas; 26 on the Nieuwe Maas, Lek and Upper Merwede; 21 on the Lower Rhine and Lek from Pannerden up to Vianen; and 56 along the Rhine and Waal from Loevestein to the German border.

Before the large-scale use of seine nets, which were introduced along the lower reaches of the river in about 1850, the salmon fishing industry was mainly centred on the upper reaches of the Rhine. An overview of the salmon catches at various points along the river network between 1870-1919 is given in Table 2.5. Throughout this period, the fishing industry along the Maas was highly localised and of little importance in national terms.

2.4 The effect of human intervention

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

> "The decline 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 caused by cities, factories and the mining industry as well as shipping movements and the fishing industry itself. Man, in his efforts to control nature, must accept responsibility for allowing the Rhine - and to an even greater extent other West European rivers - to degenerate from a large natural watercourse with small islands, shallows, meandering sections, ox-bow lakes and creeks, its pure clear water supporting a wealth of flora and fauna, representing a veritable el dorado for spawning fish, into something approaching a discharge channel closed in between steep straight banks and dredged to the required depth for shipping purposes. Whereas in the past, salmon ascending the river system to breed had access to all the tributaries in the upper reaches of the Rhine, nowadays, the building of weirs for wood mills and other industrial purposes has greatly reduced the opportunities for them to reach their natural spawning grounds."

More recently, this subject has also been considered by Swales (1983). In addition to summarising the problems associated with "improving" rivers and how to deal with the negative aspects of such operations, this work contains a large number of useful references for further study. Many of Swales suggestions, which are discussed below, are particularly relevant to the German section of the Rhine.

From a hydraulic engineering point of view, an ideal river is one which is characterised by a straight uniform channel of trapezoidal cross-section to minimise the flow resistance, with river banks that are kept clear of trees and bushes to allow easier access for excavating equipment and to reduce the danger of flow being impeded by trees falling into the river. To further improve navigability, aquatic plants, large stones and branches should be removed and flood embankments provided on both sides of the river to contain high flows.

In contrast, the fishery biologist is primarily interested in producing the type of environmental conditions which are favourable to the survival and growth of plants and animals. For instance, a diversity of habitat is necessary to promote a rich and varied fish community.
Moreover, abundant cover and shelter should be provided to ensure sufficient shade and concealment from predators.
In addition, adequate water depth and flow are important as are water quality, ample food supplies, and suitable spawning and nursery areas.
The creation of such conditions is essential if abundant fish stocks and other aquatic life forms are to be preserved.

Hydraulic engineering works that are intended to improve either the navigability of rivers or facilitate land drainage schemes frequently involve operations such as dredging, widening, deepening and straightening the river as well as aquatic weed control, bank-side weed control and the removal of obstructions.

These operations can seriously affect the environment and can have a specific impact on fisheries as illustrated below:

1. shortening a river can reduce the number of fish and the amount of biomass present;
2. destabilising and reducing the variety of habitats can disturb ecological communities resulting in major decreases in diversity, stability and abundance;

3. disrupting and modifying natural flow regimes can cause less tolerant species with a preference for certain flow patterns to disappear. Migratory movements of anadromous species may be disrupted. Moreover, large variations between maximum and minimum flow conditions can result in increased mortality;
4. destroying the existing pattern of pools and riffles in the bed can lessen community diversity due to a reduction in the variety of habitats. The loss of gravel riffles eliminates spawning beds and natural benthic insect life;
5. increasing silt levels can increase turbidity which will interfere with fish feeding, movements and behaviour patterns. Suspended sediments are known to damage gill membranes, impeding respiration with lethal or sublethal effects.
   River bed sedimentation tends to blanket spawning beds and so reduces the survival of eggs and fry. In addition, benthic insect life can be impaired, which affects fish feeding and growth;
6. removing shelter may disturb the normal predator-prey balance, increasing stress levels in fish communities. As a result, fish behaviour patterns, orientation and movements are affected;
7. clearing bank-side vegetation can increase insolation, leading to higher water temperatures. In turn, this can result in cold-water species being replaced by warm-water species;
8. removing aquatic vegetation may lessen recruitment in weed-spawning species. Furthermore, loss of invertebrate organisms can affect fish feeding and growth. Reducing the amount of weed cover may disturb the predator-prey balance, increasing the stress level within the community;
9. changing the water chemistry through dredging and land run-off can impair the quality of the water, leading to sublethal and lethal effects.

Although changes to rivers cannot always be avoided, measures can often be introduced that can lead to partial or complete recovery of the natural habitat after river channel works have been carried out.

2.4.1.Fishery restoration through habitat improvement.

Fisheries damaged by river channel works will recover in time but this can take anything up to fifty years or more. The natural recovery process depends to a large extent on how quickly natural river features return such as the pool-riffle pattern which is needed for fish to survive.

1. Recreating a pool-riffle pattern

   The combined effects of river dredging, widening and straightening almost invariably destroy the natural alternating pattern of deep pools and shallow riffles. This is especially serious as the relatively sediment-free gravel beds found in such areas provide ideal spawning grounds. The shallow turbulent waters of riffles offer a high degree of protection from predators and allow fish to feed undisturbed.

   River beds can often be restored by constructing low dams which impound the flow. Deep pools are formed at the base of these dams as a result of erosion, while downstream a riffle pattern develops where the eroded material is redeposited. The reduced flow velocities upstream the dam allows suspended sediments to settle out. For best results, a series of low dams should be positioned along the river at intervals of 5-7 times the channel width. These underwater dams are usually constructed with rocks and boulders, reinforced if necessary with poles and gabions. The current can also be deflected by using groynes positioned in the river at an angle of 45°. The main effect of such current deflectors is to increase the flow velocity and promote erosion of the river bed.

2. Restoring a meandering flow pattern

Straightening a river invariably reduces the length of the watercourse and with it the river's capacity to support fish life. Since a straightened river travels a shorter distance for the same drop in height, channel gradient and hence current velocity are increased. By reintroducing bends into the river, much of the old flow pattern can be restored and the channel gradient reduced.

3. Replacing areas with shelter and cover

Bank regrading works which produce uniform 45° slopes remove much of the overhanging bank vegetation. Replanting with shrubs and trees can have a positive effect, but usually requires some time before natural cover levels are completely restored. In the meantime, artificial bank cover devices such as planks of wood combined with a current deflector positioned on the opposite bank at an angle of 45°, can be very effective in creating a sheltered pool particularly along the outside of a bend in a river.
In rivers where many of the aquatic plants etc. have been removed, rocks and boulders can be dumped in the water to provide fish with additional shelter and cover. Under certain circumstances, securing branches in the river bed can also prove to be effective. Moreover, the development of artificial "seagrass" (plastic lamellae) promises to offer an extremely fast solution for reintroducing shelter and cover in a river.

4. Bank revegetation

Planting trees along the sides of a river stabilises the banks, while organic matter from the branches and leaves enriches the water phase.

5. Bank stabilisation

Channel widening works often result in increased turbidity due to the higher erosion rates that occur on newly formed denuded banks. Artificial bank protection in the form of a revetment can considerably reduce turbidity levels in the water.

6. Providing temporary shelter

The provision of small inlets along the river is invaluable for migrating fish, such as salmonids, which usually travel at night and require shade and protection during the day.

7. Restoring spawning and nursery areas.

As the replacement of gravel spawning beds can be a costly operation, the use of structures, such as those described in 1. above, to promote the washing out of deposited sediments is to be preferred in areas where gravel is present in the river bed.

2.4.2 Channelisation and flood control.

Since the Rhine is basically a glacier stream, the upper reaches of which are fed by melting snow and ice, 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 industrialisation in the 19th century led to extensive hydraulic engineering works being carried out along the Rhine to improve the navigability of the river for shipping. This involved deepening the navigation channel and, where necessary, constructing weirs and locks. The fact that canalisation 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 from shipping companies and industry at large, attention was also focused on the tributaries of the Rhine. In the report of the Government Commission on Salmon, Hoek (1916) reviewed the condition of the main tributaries of the Rhine in Switzerland and Germany, with particular reference to the salmon fisheries. A summary of his findings is given below.

In Switzerland, the flow of water along the River Thur (below the Schaffhausen waterfall, which forms a natural barrier to salmon) has been partially corrected making it unsuitable for salmon. Various weirs have been constructed along the River Wutach, thereby closing off the river to salmon. The River Aare, which used to be an important salmon river, has been completely closed off by weirs. The presence of many weirs along the River Reuss has impeded the movement of salmon. Regulating the flow of the River Limmat has totally destroyed its importance as a salmon river.
In Germany, the River Wiese, which represents an important source of water to industry, has many weirs, effectively closing it off to salmon. Although the lower section of the River Elz (and the Dreisam) has been completely canalised, salmon were still observed in 1914. In addition, the River Kinzig was still a major salmon river in 1914. Since most of the River Ill has been made navigable by introducing a large number of weirs, it is no longer important as a salmon river. Correcting the flow of the River Rench has destroyed its importance as a salmon river. Although the River Neckar has not been canalised, regulating the flow along this river in 1914 has limited the number of salmon to be found there. Canalising the River Main by introducing a large number of weirs has effectively closed this river off to salmon.
Partial regulation of the flow along the River Nahe has meant that fewer salmon returned to this river.
Although large parts of the River Lahn were canalised in 1914, the tributaries of this river, the rivers Sauer, Kill, Salm, Ruhwer and the Dhron still contained salmon.
The River Sieg (and River Agger), has been made navigable from Siegburg onwards with the construction of various weirs, but still supported a large salmon population. The presence of 10 weirs and locks in the lower section of the River Ruhr has virtually closed off this waterway to ascending salmon. The River Lippe, with 12 weirs in the lower section, can also be considered to be effectively closed off to ascending salmon.

A complete overview of the hydrography of the German section of the Rhine, together with relevant legislative and hydraulic engineering aspects was published by the Grand Duchy of Baden in 1889 (Anon., 1889).

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. 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.
The Rhine became the focus of international attention in 1849 when an engineering commission travelled along the river.

This visit greatly stimulated Dutch interest in engineering works to improve the Rhine, sentiments which were reinforced by the Mannheim Convention of 1869. In 1914, depth requirements were introduced along the Rhine, specifying a minimum depth of 3 m from the sea to Cologne, 2 m from Cologne to Mannheim and 1.6 m from Mannheim to Basel. 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. The extent of typical river corrections is shown in Figure 2.8, where the old and new situations at Plittersdorf are compared. Information about the effect of river deepening in the Waal, Lower Rhine and Lek from the end of the last century up to 1939 is given in Tables 2.6 and 2.7.

2.4.3 Closing off the delta and the construction 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. A fish ladder is a poor substitute for a free-flowing river without obstructions. Moreover, non-migratory fish (sedentary fish) such as pike, bream and tench are almost totally unable to negotiate fish traps. Kuhn (1976) has reported that a maximum of 30 to 40 fish used a particular fish ladder (Kulturwehr Breisach) of which the majority were eel.

Fehlmann (1926) concluded in his study entitled "Die Ursachen des Rückganges der Lachsfischerei im Hochrhein": "Im ganzen ist somit unzweifelhaft klar, dass das Ausbleiben der Lachse im obern Teil des Hochrheines einzig und allein verschuldet ist durch die Rheinkraftwerke und es ist nicht zu verstehen, wie von gewisser Seite die Schuld immer wieder auf den Lachsfang der Holländer zu schieben versucht wird."

2.4.4 Sand and gravel winning.

Sand and gravel winning 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, summer or 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 sand having been removed.

Sand and gravel winning 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. Dredging activities to remove sand or gravel, or deepen channels are known to have a marked effect on the current velocity. Removing major gravel beds where the salmon deposited their eggs in redds, would have changed the flow velocities in these parts of the river, which would either have caused silting up of the gravel bed or removal of the finer gravel particles. Either way, the gravel bed would no longer have been suitable for spawning purposes. Moreover, an increase in silt levels in the river could have led to the redds being covered over with sediment which would have affected the exchange of oxygen and excretion products with the surroundings, seriously harming the eggs.

In addition, fish larvae are known to be more sensitive than adult fish to polluted silt (fine sediment). Dredging operations could also have diminished the little food that was available to the salmon (small crustaceans and insect larvae that are to be found in clear shallow streams). It is therefore recommended that sand and gravel winning activities be prohibited in streams that are identified as potential spawning grounds for salmonids or which already contain such fish (e.g. trout).

2.4.5 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. Mention has already been made of the fact that by about 1872, a difference in taste had been detected between Scottish and Rhine salmon, with the latter being classified as too oily. Hoek (1916 b) was only able to explain this in rather general terms by stating: "The contamination of rivers with sewage from large cities and with effluent from factories and mines seems to be having a negative effect on salmon numbers. However, it is difficult to quantify the extent of the damage such pollution causes to a particular river system such as the Rhine."

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 - dilution in the flow stream rapidly restoring the clarity of the water phase. Hoek argued that the fact that the salmon population had declined rapidly in the Ruhr, which was heavily polluted, could be attributed to the river having been made inaccessible to salmon because of the large number of weirs that had been constructed there. The Lahn and Main were also thought to be similar cases in point. He supported this argument by suggesting that salmon entering the river system would continue their ascent upstream rather than returning to sea if they encountered polluted water.
However, polluted water must have had an impact on parr and smolts in Hoek's day, even though large numbers of salmon were not found dead in the river nor were the effects recorded in the scientific literature.
At the time, it was assumed that salmon were able to swim through heavily polluted areas relatively quickly.

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." In spite of Hoek's reassuring words, it is rather surprising that he was unaware of the events taking place in England at the time. Archibald Young in "The Salmon Fisheries" published in 1877 had already pointed out the serious consequences of pollution caused by the industrial revolution in 21 salmon rivers in the UK (source: Netboy, 1980).

Further evidence of the general attitude towards pollution in Hoek's day is to be found in a letter (dated October 18th, 1918) written by F.C. Liebert, director of the Netherlands Institute for Hydrographic Fishery Investigations in Den Helder. This letter, which is part of the RIVO archives, was written in response to an incident in which fish were found dead in water smelling of carbolic acid near Woudrichem (10 March 1917). One of the salmon found dead at Gorinchem retained a pronounced carbolic acid smell even after a steam distillation had been performed.
The analysis techniques available at the time were unable to show any evidence of pollution and the death was ascribed to mould, which was found to be present in large quantities in the river.
Although Liebert referred to the ability of the river to "clean itself" under most circumstances, he pointed out: "Pollution reduces the natural resistance of fish to infectious diseases such as furunculosis in salmon and Lepidorthosis contagiosa in white fish ... ". However, he went on to say: "I regard it as highly improbable that young salmon migrating to the sea for the first time in spring, when the water level in the river is at its highest, will be much affected by pollution."

Some ten years later, Redeke was requested by the ICES to summarise the impact of river pollution on fisheries in response to the growing recognition that the presence of contaminants was affecting fish mortality. Redeke (1927) gives an extensive review of the subject, including more than 150 references. He pointed out that certain types of fish, such as salmon and trout, were more sensitive to pollutants than, for instance, carp, eel and tench. These problems were found to be exacerbated by low water levels in summer, particularly in smaller streams. The relatively high concentrations of oxygen-consuming and toxic substances occurring during this season were thought to be primarily responsible for the increased mortality rates. Toxic substances were considered to be more serious than shortages or the complete absence of oxygen as a proportion of the fish could escape such gradual effects by swimming to cleaner water. In general, it can be said that by 1927 domestic and industrial waste water 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.

2.4.6 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.

One of the ways in which the fishing industry aggravated the decline in salmon stocks was by catchinglarge numbers of sexually mature fish and kelts returning to the sea after spawning. In addition, a significant proportion of undersized fish were removed from the river. All of these effects had been documented by Hoek (1916 b) in his report to the Government Commission on Salmon. Catching undersized salmon 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. Between 1907 and 1912, 787 salmon were landed by trawlers from the North Sea at IJmuiden.
The number of salmon caught at sea was generally thought to increase in July reaching a peak in August before reducing to practically zero in the following months. Although Hoek was unable to explain this phenomenon at the time, it was believed that the catch figures were distorted by the inclusion of sea trout. An overview of the salmon landed at IJmuiden over the period 1907-1912 is given is Table 2.8.

2.5 Developments in Western Europe and the N.E. Atlantic

The practice of referring to salmon as either Canadian, Norwegian, Irish, Scottish, Spanish etc. would tend to suggest that each represents a specific "race" or stock of Atlantic salmon. Fish originating from a particular river (e.g. the Rhine) or even from a certain fish farm are sometimes characterised as belonging to a given "race" or stock.

A.G. Huntsman, the famous Canadian salmon biologist, who is noted for his work in the first four decades of this century, has concluded: "There is no definite clarification of the meaning of the word "race" as applied to salmon". Although it can be justified to use the above-mentioned classification in compiling fishery statistics, often in relation to resource management, there are less compelling scientific grounds for making such a distinction.

In biological terms, a race or stock of a species means a population which differs genetically from other populations of the same species (Wilkins, 1985).
Many of the differences observed in salmon from various rivers, for example in terms of growth statistics, can be traced to the quality of their environment and their habitat. Since spawning takes place between fish of the same population and not between salmon from another group, it is, however, possible to make a distinction on the basis of the gene pool or genetic makeup of a given population (stock). The shape, behaviour and physiology of an organism are genetically determined (genotype).
On the other hand, the life cycle of each individual fish, the amount and type of food it eats, its age and sex, the temperatures and salinity levels to which it is exposed, and environmental factors all affect its appearance.

The sum of the characteristics manifested by an organism is known as its phenotype. Even though the phenotypes of salmon may differ this does not necessarily imply that their genotypes are different. By making use of a technique known as electrophoresis, it is now possible to study differences in genotypes in relation to specific proteins. This allows a differentiation to be made between various populations of salmon. For instance, Atlantic salmon can be subdivided into a North American and European race.
Neither of these stocks are truly homogeneous, but consist of a number of subraces. Three clear genetically different substocks have been identified amongst European salmon: the Celtic, Boreal and the Baltic races. The largest genetic difference exist between the North American and European stocks. In terms of European salmon, the Baltic race differs most from salmon originating from Atlantic rivers, and Irish salmon (Celtic race) differ significantly from Norwegian salmon (Boreal race).

Genetic differences can also be found between salmon inhabiting different river systems within the same area. Even though the genetic variations in such cases are not as large as those used to distinguish between the main stocks of salmon, the fact that such differences exist questions the validity of the assumption that salmon interbreed and as such are an extremely homogeneous species of fish. On the contrary, the salmon's ability to adapt to different environmental conditions is one of the characteristics that has underpinned its success in evolutionary terms. The facility with which salmon can change from migratory to non-migratory behaviour, to survive in areas with a clear day/night periodicity or those with 24-hour daylight or darkness, as well as adapting to short or long river systems etc. is fundamental to the salmon's survival. As J.E. Thorpe once said: "Atlantic salmon are opportunistic generalists and show a wide variation in life history patterns".

These facts should be borne in mind when studying the various salmon populations currently found in the waters of the North East Atlantic. At present, natural salmon populations are under threat and are having to be supplemented by stock reared in hatcheries. The likely effects of this and other actions are discussed in Chapter 4.

2.5.1 Germany.

The history of the salmon in German waters has already been discussed in detail and is closely linked to that of salmon in the Netherlands. The English poet Coleridge expressed his thoughts on the subject after a visit to the Rhine in the following way:

> The River Rhine it is well known
> Both wash your city of Cologne.
> But tell me, nymphs, what power divine
> Shall henceforth wash the River Rhine.

An overview of German salmon statistics for the period 1875-1950 is given in Figure 2.2. Although salmon were released along most of the upper reaches of the German part of the Rhine (and at the beginning of the century also in Switzerland), the Prussian section is of special interest as it is currently being examined as a restocking point within the framework of the "Rhine Action Programme". In the past, sexually mature fish used to be caught in the rivers Mosel, Sieg, Ahr and Dhün in the closed season (the autumn) and the fertilised eggs hatched at a fish farm near Trier in the Aveler Valley. Other smaller hatcheries were also used such as Wolg-Burgen (Mosel), Schumacher-Kruft (Eifel) and Lohansen-Schreck (Siegkreis). In addition, the Boldt and Schmidt fish farms at Minden a/d Sauer produced special fry and young salmon for the Netherlands. Table 2.9 shows the number of mature fertile salmon that needed to be caught to be able to release the numbers of young salmon into the Mosel and Sieg over the period 1891-1933 given in Table 2.10. In spite of the fact that experts such as the Swiss Fehlmann (1926) clearly indicated that channelisation and flood control measures introduced in the German section of the Rhine were mainly responsible for the drastic reduction in the salmon population, the German authorities were loath to accept these arguments. They stuck steadfastly to their view that the Dutch fishing industry was responsible for these developments as typified by Neresheimer's statement in the "Handbuch der Binnenfischerei" (1939), in which he claims that Dutch fishermen caught 80% of the salmon taken from the Rhine:

> "Dass danach die übrigen Partner mit Neid auf die Niederländer blicken, und sie beschuldigen, for die Fortpflanzung nicht genug übrig zu lassen, ist verständlich. Anderseits ist es menschlich begreiflich, dass die verwöhnten Holländer der Ansicht zuneigen, zum Fangen seien sie da, die Oberlieger aber dazu, die Erhaltung der Bestände und die künstliche Zucht zu betreiben, oder wenigstens die dort ankommenden Fische ruhig ablaichen zu lassen. Sie beklagen daher sowohl die Verbauung, Verunreiniging usw., die Faktoren, die der Nachzucht selbstverständlich grossen Abbruch tun, als auch den Umstand, dass die Fischer von Luxemburg aufwärts sich nicht mit den abgelachten "Hengsten" begnügen, sondern auch Salme fangen wollen, wodurch dann freilich auch die Nachzucht vermindert wird."

Hoek published a report on observations and research into the life cycle of the salmon in the Upper Mosel area. He confirmed the hypothesis that young salmon in fast-flowing streams did not feed on floating plankton, but rather lived on larvae and insects found under stones.
The rivers Weser and Elbe were also important salmon rivers at one time, but have since declined. No detailed statistics are available for the Weser - information which also eluded Hoek at the beginning of the century. However, Busch c.s. (1988) did indicate that the last salmon was caught in the Weser in 1910. At the turn of the century, the average catch from the Elbe amounted to 3875 salmon (Hoek, 1916 c).

In spite of the steady increase in the number of international meetings, conferences and declarations from the European Parliament, pollution in the Rhine has only decreased slightly. To reduce the levels of contamination to those known to have existed in 1885, when salmon numbers started to decline, would be an extremely difficult if not impossible task to achieve.

Analysing the effect such pollution levels had on salmon stocks is made more difficult because of the absence of meaningful statistics about salmon catches in preceding years. In addition, all the changes that have taken place in the Rhine basin including the climatic shifts in northwest Europe would also have to be assessed before a dynamic population analysis could be undertaken. An investigation of this type is being performed for Scottish rivers by Professor A.D. Hawkins (Aberdeen). By utilising data from 1750 to the present day, he has been able to show that similar variations in salmon numbers have manifested themselves in various river systems. Apart from climatic changes and the introduction of certain types of fishing gear, it is apparent that the construction of weirs and dams has had a serious impact on the decline of salmon catches (private communication). It is hoped that the results of this type of research will allow meaningful conclusions to be drawn about how best to improve existing salmon stocks and rehabilitate former salmon rivers, as well as enabling the feasibility of such actions to be studied in detail (see Section 5.2.a).

2.5.2 The United Kingdom and Ireland.

In contrast to Rhine salmon, British salmon inhabit relatively short rivers. In Scotland and eastern England, the Boreal stock is most prevalent, whereas in Wales and southern England, salmon of the Celtic race are to be found. In the past, salmon in the Thames would swim 320 km upstream to spawn (the longest distance covered by fish ascending a river system in the United Kingdom).
Salmon return to British rivers throughout the year. The majority of salmon re-entering the relatively short rivers on the west coast do so during Summer and Autumn, while on the east coast, Spring and Winter are the more common periods for fish to return to their spawning grounds.
Figure 2.9 gives an overview of the main British salmon rivers, which can still be accessed by salmon over practically their entire lengths.

In Ireland and the United Kingdom, the effect that water pollution can have on salmon stocks was appreciated far sooner than in the rest of Europe. An act was introduced in 1466 to prohibit leather tanners and glove makers from washing their leather in the River Liffey (Dublin). Moreover, A. Young commented in his book "The salmon fisheries", published in 1877, that twenty-one rivers in the United Kingdom were already severely polluted. He listed the probable causes of contamination as: waste water discharges (9), fine sediment from potteries (3), mining (11), paper mills (3), wool dyeing (2), chemical discharges (5) and tanning (3).
Furthermore, the construction of weirs for water mills and industrial use are thought to have significantly exacerbated the decline of salmon numbers.
River channel works also destroyed important spawning grounds.
In 1940, the level of pollutants in surface waters was so bad that dark smelly water with a high silt content pervaded the delta areas of many rivers, moving backwards and forwards with the tide.
As Netboy pointed out in 1980 the conditions made it practically impossible for fish to ascend the river system and for smolts to make their way to the open sea. At present, a great deal of attention is being paid to resolving the pollution problems in the Thames estuary, with the intention of creating the conditions necessary for salmon and trout to return.

2.5.3 France.

During the last decades, Atlantic salmon have practically disappeared from most of the main rivers in France: the rivers Meuse, Mosel, Seine, Loire, Dordogne and Garonne.
In spite of the fact that at the turn of the century it had been suggested that the French revolution might have been responsible for the decline in salmon numbers, the building of dams along these rivers would seem to be a more likely explanation. Following the revolution in 1789, the laws introduced to protect the salmon by the "Ancien Régime" were abolished and salmon fishing became unrestricted. At present, some two hundred years later, rehabilitation and restocking activities are receiving a great deal of attention in France (Thibault, 1987) (Figure 2.10).

2.6 Salmon stocks at the end of the 19th century

At the turn of the century, the Dutch salmon fishing industry landed on average about 27,600 fish a year, while German fishermen caught some 60,000 fish a year. Although at that time, the proportions were assumed to be 80% for the Netherlands, 10% for Germany and 10% for the other Rhine riparian states (based on incorrect German statistics), a 30% : 60% : 10% split appears to have been closer to the truth (see Table 2.2 and Figure 2.2), putting the total salmon catch at 100,000 per year. The increased use of seine nets in the second half of the 19th century is thought to have greatly enhanced the size of the Dutch catch. This trend started with the introduction of seine nets along the lower Rhine at "de Merode" on the Nieuwe Maas in 1848. In subsequent years, further seine nets were positioned along the Rhine: "Oranje Nassau" at Pernis in 1852; "Klein Profijt I" (Oude Maas) in 1862; "Noordewal" (Nieuwe Merwede) in 1869; "Prins Hendrik" (Nieuwe Maas) in 1875; "Klein Profijt II" (Oude Maas) in 1875; "Zuidwal" (Nieuwe Merwede) in 1887 and at Dubbeldam in the Nieuwe Merwede in 1900. The increased deployment of such efficient gear caused considerable concern in Germany and among Dutch fishermen operating in more upstream areas. The fact that certain Dutch fishermen were catching more salmon was thought by many at that time to have contributed to the decline of the salmon population. The absence of meaningful statistics from Germany where the relatively small independent states did not appear to compile and exchange data on a regular basis, meant that it was difficult to discount such claims. Although it is quite possible that the salmon population in the Rhine was larger in previous centuries, clear evidence to support this is difficult to obtain. In 1885, the salmon catch is thought to have reached record levels (250,000), which compares with the 150,000 caught in 1875 when combined Dutch-German records first began.

By 1900, it had already become apparent that salmon stocks were on the decline (Hoek, 1891, 1899a, b), which had led to widespread disquiet. This is evidenced by the moves to undertake restocking operations in the Upper Rhine from 1871 onwards, as well as the unsuccessful rehabilitation efforts in the Netherlands around this time. In spite of the fact that the effectiveness of such measures were never fully established, it seems reasonable to assume that the rate of decline was reduced to a certain extent. Nevertheless, it did not prove possible to stabilise the salmon population at an acceptable level.

Experience from other European countries (France, UK) has shown that a number of factors are likely to have caused the decline. The impact of these effects is so severe that even on an individual basis several of them could have decimated large parts of the salmon population. The major threat to salmon in the Rhine at the beginning of the century came from the building of weirs and locks, which effectively blocked off the spawning grounds to fish ascending the river. At each lock or weir, a proportion of the salmon was prevented from continuing their journey upstream. The presence of a series of locks was therefore sufficient to stop the movement of salmon up river almost completely - a fact that was not sufficiently understood at the time. The need to construct more locks and weirs along the Rhine resulted from greater industrial growth and was primarily intended to improve the navigability of the river so as to facilitate the transport of goods and raw materials, and as a means of generating hydro-electric power.

Since the Rhine is basically a glacier stream and carries much more water throughout the year than, for instance, a river exclusively fed by rainwater, the original effects of pollution from urban and industrial waste water were less noticeable than in other water courses. Around 1900, developments of this type did not give rise for concern although the seeds were being sown for future pollution problems. The levels of industrial contaminants in English rivers played a much more significant role in the decline of the salmon population at the end of the century than was the case in the Netherlands. Notwithstanding this, the construction of locks and weirs was also thought to have contributed to the reduction of salmon stocks in the UK.

The increase in shipping along the Rhine restricted the activities of the fishing industry, which, on the face of it, helped to preserve salmon stocks. On the other hand, oil spillages from ships tended to negate such benefits. Even though the fishing industry had a serious effect on the salmon population in the Rhine, the economics of such operations dictate that they could not be responsible for eradicating the species. Estimates vary as to the percentage of fish caught in relation to the total salmon stock. On the basis of data collected for other species of fish, it may be assumed that 30-40% of the salmon were removed by fishermen. However, care should be exercised in using these figures to assess population numbers as has been pointed out by Shearer (1988a).

3. DEVELOPMENTS SINCE 1940

3.1 Size of the population

The end of the 1920s witnessed a major decline in salmon catches in the Rhine. In subsequent years, the number of salmon landed in the Dutch section stabilised at about 1000-2000 fish a year, up to 1944. However, these figures would probably have been higher had organised salmon fishing activities not ceased in Dutch waters in 1933. This also explains why salmon catches along the German section of the Rhine increased in relative terms, which enabled the German salmon fishing industry to continue much longer (see Figure 2.3). In 1945, the number of salmon caught in the Netherlands declined even further, to only a few hundred a year on average. However, 1949 proved to be an exceptional year, in which 900 salmon were landed (See Table 2.2).
An overview of the salmon catches in the Netherlands between 1940-1947 is given in Table 3.1, with a subdivision on the basis of length.

Two salmon that were part of Swedish sea-ranching experiments found their way into Dutch waters in 1969 and 1971. They had been released as smolts and had reached lengths of 65 and 85 cm respectively. The first fish was found dead in the IJsselmeer, while the other salmon became caught up in a sluice in the Maas (Larsson, 1984; private communication). It is clear that these fish managed to enter Dutch waters from the sea, but had not been able to survive. The same can also be said of a salmon caught in a bag net in the lake IJsselmeer in 1984 (Cazemier, 1986).

3.2 Production of smolts or juvenile fish

Little is known about the population densities of young salmon in given sections of the Rhine. During monitoring operations involving "schokkers" (small commercial fishing boats) carried out in May 1951, a total of 231 young salmon (8-27 cm) and 638 sea trout were caught descending the river at Pannerden and along the Waal near the Pannerden Canal (by Zwemstra), at the Millingsche Waal (by Sepers) and at the Waal near Erlekom (by Udo) (see Table 3.2).

3.3 Fluctuations in numbers

The reason for the serious decline of the Rhine salmon population in the 1920s referred to earlier has never been satisfactorily explained. Various authors have attributed this to either a major reduction in the number of salmon hatched that year, high mortality rates among these fish, or an increase in the number of salmon caught at sea. It was certainly not due to a drop in the number of young fish reared in hatcheries as such operations continued unabated throughout this period. Although the effects of a particularly weak batch of fish from a certain part of the Rhine may in the past have been obscured by more resilient batches from other parts of the river, the loss of many of the spawning grounds during the period under discussion meant that such losses could no longer be compensated for. This would also explain the limited impact of releasing young salmon in the upper reaches of the Rhine.

3.4 Channel works and the construction of weirs and locks

After 1940, many of the sandbanks in the River Rhine disappeared as a result of deepening and normalisation work on the river. Sand winning 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 eel rather than salmon (so-called Durchschlupfvorrichtungen), a large number of undersized 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. Work started on the Kembs lock downstream from Basel around 1930. This was followed by the construction of the lateral canal through the Alsace region after World War II, which improved the access to shipping as well as aiding the production of hydro-electricity. As a result of these operations, the entire upper Rhine and its tributaries effectively became closed off to migratory fish.

The extent of the hydraulic engineering works carried out along the tributaries of the Rhine (see Sections 2.4.1 and 2.4.2) 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 the Second World War, 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 the salmon. The condition of the many streams and rivulets that traditionally formed the spawning grounds for these fish has also changed. 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 (see Section 3.3).

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. In the Netherlands alone there are locks at Grave, Linne, Roermond, Belfeld and Sambeek (which date back from the period 1918-1929). In addition, in thr same river the locks at the Juliana Canal, Borgharen and Lith would also present major obstacles to salmon. The Maas (Meuse) basin in Belgium and France is almost completely controlled by locks (Van Drimmelen, 1987). Although the 16 locks built along the Belgian section of the river from 1923 to 1987 all have fish ladders, this hardly seems to have improved the accessibility of the river to fish (Philippart c.s., 1988).

The fact that salmon fishing along the River Maas never reached the levels attributed to the Rhine also suggests that this environment is less suitable for salmon. In this context, it would therefore be of interest to investigate why the upper reaches of the Maas were more favoured by trout (both migratory and non-migratory subspecies) than by salmon. A possible explanation for this difference in behaviour is that salmon rely on their sense of smell to find their way back to the spawning grounds, whereas trout need not. Coupled with this, the fact that salmon are more susceptible to pollutants could be of importance.

Despite the large amount of research that has been conducted into the effectiveness of fish passes or ladders on such rivers, many different types still proliferate. It is known that the materials used to construct these facilities are extremely important in determining success rates. For instance, concrete fish ladders installed in Scotland initially proved to be unsatisfactory. It was only after leaching had taken place over several years that the number of salmon using these ladders began to increase. In contrast, wooden fish ladders are known to be more effective than those made of concrete. J.E. Thorpe (DAFS, Pitlochry, Scotland) has even gone so far as to describe fish traps as "monuments of failure".

Mills and Graesser (1981) have recorded the number of salmon that managed to negotiate the Kilmorack and Aigas fish ladders in the dams at the hydro-electric power station along the river Beauly in Scotland.
Between 1965 and 1979, 5 - 14,000 salmon used the fish ladders each year.

Detailed analysis of the statistics showed that 8% of the fish failed to negotiate the second 19-metre-high fish ladder (standard deviation 1-16%).

The closure of the sea inlets in the southwest 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 Lake Grevelingen is closed off, but the Haringvliet Locks represent a further impediment to the free movement of fish.
Observations about the ability of fish to negotiate such obstacles are rather fragmented and are insufficient to allow meaningful conclusions to be drawn.
Moreover, it is unclear as to whether salmon are able to swim upstream against discharges from locks of this type. 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. Use of this waterway would bring with it the risk of becoming trapped in the Amsterdam canal system, in the IJsselmeer or in the Amsterdam-Rhine Canal, where the current is minimal.

3.5 Additional factors likely to limit the size of salmon stocks

Apart from the destruction and blocking off of spawning grounds in the Rhine, which have resulted from hydraulic engineering works, water pollution has increasingly become a factor likely to hamper the return of the salmon. Rather than investigating the water quality in all the streams and rivers that eventually flow into the Rhine to check their suitability, it would seem more sensible to assess the latest information about the minimum water quality standards required for salmon and trout.

3.5.1 Minimum water quality standards for salmon and trout.

The most important reports of recent times regarding water quality requirements for salmon and trout are those of Solbe (1988) published by the Atlantic Salmon Trust. The criteria put forward by Solbe are, as far as possible compared in the following section with relevant EC Directives containing compulsory limits and target values for salmonids (where available) and with the basic water quality standards laid down in the Multi-year Plan (IMP) for Water 1980-1984 (Ministry of Transport and Public Works).
Reference is also made to a report compiled by the Department of Fisheries entitled "A Contribution to the Development of National and Regional Water Quality Plans" (Feith, 1982). This paper sets out the views of the Ministry of Agriculture and Fisheries in these matters.

In discussing water quality standards for salmon and trout, a distinction can be made between those conditions that are necessary for such fish to survive those thateffectively preclude the presence of salmon and trout.

<u>Oxygen content</u>

Although salmon require oxygen to survive, their oxygen demand does not remain constant throughout their lives. As a general rule, it can be said that the heavier the fish, the smaller the relative oxygen requirement on a weight basis. A nominal 1 kg of salmon comprising 10 fish would need 200 mg/O/hour at 10°C, while a single fish weighing 1 kg would have an oxygen demand of 160 mg/O/hour at the same temperature. If the nominal 1 kg of salmon consisted of 100 fish, the oxygen requirement would be about 300 mg/O/hour.
Moreover, the oxygen demand from salmon fry and parr is even higher.

For salmonids to survive, an oxygen content of 9 mg/litre (50th percentile) and 5 mg/litre (5th percentile) is required. In this context, 5 mg/litre O_2 must be seen as an absolute minimum level. These values are in broad agreement with EC Directives for salmonids based on EIFAC proposals. In comparison, the value of 5 mg/litre put forward in the IMP is far less stringent. For hardier species of fish (non-salmonids), oxygen contents of 5-2 mg/litre are considered to be sufficient.

Temperature

Since fish are cold-blooded animals, their body temperature is largely a function of the surrounding water temperature. This is especially important since body temperature determines the speed of embryonic development, growth and oxygen consumption. For these reasons, the water temperature in salmon spawning grounds must be low.
The optimum temperature for embryonic development of trout, for instance, is 2-6°C. Furthermore, it is generally agreed that the water temperature in such areas should never exceed 10°C and that 21.5°C is the upper temperature limit for juvenile and adult salmon in fresh water. To facilitate the transition of smolts to a seawater environment, water temperatures of 5-16°C are considered to be ideal (G. Boeuf, IFREMER, private communication). For this reason, smolts descending the river late in the season often encounter problems as the temperature of the water is too high. Conversely, the water temperature also plays an important role when salmon return from the sea and re-enter the river system en route to their spawning grounds (see Section 1.1). Ideally, the notional "temperature window" i.e. the difference in temperature between the river water and the sea, should be as small as possible. Sudden increases in the water temperature of rivers have been known to interrupt the ascent of salmon upstream, which has only been resumed after the temperature has fallen to acceptable levels.

During their life cycle, salmon normally experience temperatures ranging from several degrees above 0°C up to 21.5°C. Bouck (1977) has commented on the impact of higher water temperatures in rivers such as the Columbia river in Canada. At 10°C, sockeye salmon lose 7.5% of their fat reserves, whereas at 16.5°C, 12% of their stored fat is lost. These statistics represent a considerable weight loss for the fishing industry, equivalent to 4,400 less fish on a catch of 100,000. In addition, the quality of salmon obtained is impaired at higher temperatures, which has further financial implications.
At temperatures as high as 26-27°C, salmon are unable to survive and die immediately.

In the event of the rehabilitation of the Rhine as a salmon river, it is not expected that problems will be encountered by larger salmon having to swim through areas where cooling water is discharged, provided that the discharge temperature remains within the prescribed limits. However, the importance of water temperature in determining the physiology and behaviour of fish should not be underestimated as temperature rises can reduce fat reserves considerably.
Although this could restrict the salmon's ability to return to the spawning grounds, the fact that the full length of the river (up to Schaffhausen) will never be used for this purpose is perhaps a fortunate development. Moreover, discharges of cooling water are unlikely to occur in those parts of the river where alevin would emerge from the eggs and fry develop.

Oil

Oil is a serious pollutant for salmon since it is pervasive and can remain on the river bed for a considerable period of time. EC Directives prohibit the formation of oil films on the surface of salmon waters, as these could affect the health of fish and ultimately their flavour. In addition, oil is likely to impair the sense of smell of salmon, which could have implications for their direction finding.

Detergents

Detergents can affect salmonids and other fish in several ways such as:
- reducing their ability to extract oxygen from the air;
- destroying their sense of smell. Bardach c.s. (1965, 1967) and Holl c.s (1965, 1970) pointed out that detergents could seriously impair the taste and smell epithelium of fish that otherwise showed now outward signs of exposure.

Tests have shown that 0.5 ppm concentrations of both hard and soft detergents (branched-chain alkyl benzene sulphonates (ABS) and non-branched alkyl benzene sulphonates (LAS)) can cause the principal sensors responsible for taste and smell to come loose in their beakers and buds. After 24 days, the taste and smell buds of 50% of the fish used in these experiments had been eroded.

In view of the fact that salmon depend on their sense of smell 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 how these chemicals affect the sense of smell of salmon and trout. Publications by Bardach, Holl and their co-workers contain recommendations for the directions such studies should take.

The water quality in the Dutch part of the Rhine is regularly monitored by DBW/RIZA. Broekhoven (1987) has prepared a complete overview of the condition of the water in the Dutch section of the Rhine and of the relevant developments that have taken place. In recent years, a number of improvements have occurred in the Rhine with regard to oxygen content, the presence of heavy metals and certain organic micropollutants. However, discharges of chlorides, ammonium compounds, phosphates, PAHs, PCBs, chlorinated hydrocarbons (particularly gamma HCH) and cholinesterase blockers still remain unacceptably high. New standards were proposed at the ministerial conference held on 1 October 1987 and attended by all Rhine riparian states. However, Broekhoven has concluded that a further reduction in pollution levels is required before the Rhine water system will improve substantially.

Low concentrations of pollutants such as PCBs (10-100 µg/l (ppb)) are known to impair the ability of young salmon to avoid predators and seek shelter (Anderson, 1971). The ability of salmon to return to fresh water has also been shown to be affected by subacute amounts of DDT (Anderson & Elson, 1971). In tests with a control group of salmon, it was found that the rate of return among fish that had undergone exposure to such toxins wasreduced by half.

The Association of Rhine and Maas Water Supply Companies (RIWA) regularly investigated the effects of river water on the growth of rainbow trout. In their report on chronic toxicity and trout, Van der Gaag and Schellart (1984) produced evidence to show that in the winter of 1981-1982, water from the River Lek retarded the growth of trout.
The fatty tissue of fish raised in this type of water contained higher concentrations of chlorinated hydrocarbons than the control sample. These fish were also found to have enlarged livers and kidneys and to have a lower hematocrit level than the control group.

Furthermore, the mortality rate of trout embryos exposed to water from the Lek was higher than in the control population.
However, when compared with the findings of similar studies performed in 1974 and 1977, an overall improvement was noted.

In 1986, van der Gaag c.s. published the results of a study into the chronic toxicity of water taken from the Maas. The effects observed on adult rainbow trout and their eggs were in good agreement with the findings of the previous study on water taken from the Lek. Not only was evidence found of reduced growth levels and enlargement of the livers and kidneys, but it was also demonstrated that the fish suffered from anaemia and accumulations of chlorinated hydrocarbons in the fatty tissue.
The International Convention on the Protection of the River Rhine against Chemical Pollution (IRC) at Koblenz annually publishes tables containing the chemical characteristics of samples of Rhine water taken from the following measuring stations: Rekingen, Village-Neuf, Seltz, Koblenz-/Rhein, Koblenz/Mosel, Bimmen/Lobith, Hagestein, Vuren and Kampen (Anon. 1987).

The ICES working group "Introduction and Transfers", which met at the NASCO headquarters in Edinburgh in June 1988, considered that it was premature to adopt a policy of cleaning the salmon spawning grounds in the Rhine and introducing improvements such as fish ladders and creating artificial spawning beds, before it had been demonstrated that salmon can survive in the Rhine in the longer term. Sightings of an occasional salmon in the Rhine are an insufficient basis on which to judge the likely success of such a project. Comparisons with the (sea) trout are also inappropriate because of the differences between the two species: salmon rely on their sense of smell to return to their spawning grounds, whereas trout have other options at their disposal.

4. FUTURE PERSPECTIVE

4.1 Increasing existing salmon stocks and further rehabilitation measures

As an "opportunistic generalist", the salmon has earned a reputation for adapting to the different environments it encounters throughout its life cycle. For instance, salmon are able to modify their behaviour patterns from a 12 to a 24 hour cycle and can also adjust to the length of a given river when returning to spawn. Such characteristics are part of the genetic makeup of the salmon, which allows it to transform from a resident freshwater fish into a migratory fish that, after a period at sea, returns to its natal stream to spawn.

In spite of this versatility, the condition of salmon stocks in the Eastern Atlantic salmon grounds is poor. The wild salmon has already disappeared from much of the area extending from Norway down to Spain. These developments contrast sharply with the success of commercially reared salmon, particularly in Norway and Scotland. However, rearing salmon away from their natural environment as a cultivated species raises a number of issues since such fish begin to lose many of the characteristics associated with wild salmon. This trend is further reinforced by the selective breeding practices that are employed in fish farms. Preference is given to encouraging traits, such as rapid growth and fatter bellies, which result in more meat and are therefore of greater commercial interest. Factors such as shifts in the mating season, which allow longer production periods at the nursery and better resistance to the many diseases that may occur in the hatchery are also favoured. However, blocking out the immune system of cells due to vaccination can increase the susceptibility of salmon to other diseases and epidemics. Fish in hatcheries also tend to lose their ability to find their own food as they are artificially fed to obtain optimum yields.

Commercial salmon farming such as that currently practised in Norway where the ratio of wild salmon to artificially reared fish is now almost 1:100, poses a considerable threat to natural salmon stocks. At present, almost 1000 tonnes of wild salmon are caught in Norwegian waters per annum, which compares with 95,000 tonnes reared in hatcheries, a figure which is expected to rise to 130,000 tonnes in the near future. It is feared that interbreeding with salmon that escape from hatcheries will weaken the wild population significantly. Salmon raised in hatcheries do not return to their natal streams, but tend to choose rivers for spawning at random (Hansen et al, 1987).
Geneticists in Scotland have shown that of some 1000 fish caught in a single river almost all of them had originated from the same parents, which were subsequently traced to a Norwegian fish farm (A.F. Youngson, DAFS, private communication).

Blaxter (1970) observed reduced sensory powers in salmon raised in hatcheries, which he attributed to them being deprived of the required information at the larval stage.
Although this phenomenon has parallels throughout the animal kingdom, it manifests itself strongly in fish. Hansen (private communication) referred to a series of experiments in the lakes connected with the River Imsa (near Stavanger, Norway) that clearly showed the effect artificial breeding practices have on the survival rate of salmon. All the fish that leave the lake system via the River Imsa, are caught in a fish trap monitored by the Norwegian Direktoratet for Naturforvaltning. After the fish have been measured and tagged they are released again into the river. As part of the investigation, some 3000 salmon parr reared in hatcheries were introduced into the lake system and their movements traced. It was found that 75% of the "wild" fish left the lake system as smolts to travel to the sea, whereas the corresponding figure for salmon reared in nurseries was only 35%. After having been at sea for a year, 16.8% of the wild salmon re-entered the river, with only 0.3% of the artificially reared salmon returning. In the following year, the figures were 6.6% and 1.0% respectively (Hansen, 1987; and Hansen, private communication).

Fishing methods can also affect the genetic makeup of salmon stocks. Hansen (1988) has suggested that as a result of this, salmon are entering rivers later in the season.

The fact that salmon reared in hatcheries are less able to survive in the wild is acknowledged by the managers of Norwegian fish farms. They were therefore surprised that German buyers intending to release young salmon as part of restocking operations wanted to buy Norwegian eggs for this purpose (information received at a Norwegian fish farm).

From the early 1970s onwards, plans have been developed to address the problems of diminishing salmon stocks in Canada, the United States, Great Britain, France, West Germany, Belgium and the Netherlands. Such initiatives have formed part of more comprehensive policies aimed at improving the condition of river systems in general.

Mills (1987) has recorded the number of salmon caught in the UK, Ireland and Canada between 1900 and 1945 in addition to reviewing the average numbers of salmon caught in these countries and Iceland over the period 1960-1981. Political pressure in these countries has resulted in various schemes aimed at restoring or reintroducing salmon stocks. These have not only involved government and semi-government institutions, but also companies and private citizens.

In England, for instance, steps were taken as early as 1955 to reintroduce salmon into the River Thames. Of particular importance in this context, was the long overdue clean-up of the heavily polluted Thames estuary. As a consequence, many species of fish that had been absent from this part of the river for many years began to return (Dart, 1979).
To investigate the viability of restocking the Thames with salmon, parr were released at various locations on a regular basis. After an initial batch of 50,000 parr, it was decided to release sufficient numbers over a seven year period so as to have at least 20,000 smolts swimming down river to the sea each year. Gouch (1983) reported that in practice, many more salmon were released into the Thames than were strictly necessary to meet the original target. Records kept by Bulleid (1983) showed that of 5000 smolts released with clipped adipose fins 70 returned as grilse, amounting to 1.4 % of the original stock. In spite of this success, it has not yet proved possible to establish a stable salmon population in the Thames that is able to survive without being supplemented by restocking operations. The presence of weirs along the river is thought to prevent many of the salmon from reaching the upstream spawning grounds even though a number of fish ladders have been provided.

Of late, a great deal of attention has also been focused on the condition of the dwindling salmon population in the Belgian Meuse. A small group of researchers regularly publish articles at conferences and symposia on this subject.
Papers by Philippart, Descy and Micha in the proceedings of the colloquium on the "Réintroduction du Saumon atlantique dans la bassin de la Meuse" (1985) provide a useful inside into salmon stocks in Belgium. This collection also contains a paper by Lecuyer on the reintroduction of salmon into French rivers.
In Belgium, it is generally agreed that the presence of a large number of weirs along the Meuse is preventing salmon from reaching the upstream spawning grounds. The availability of fish ladders or fish sluices does not appear to have helped much in this respect. Deelder (1958) has concluded, among others, that although the latter are to be preferred, such structures nevertheless hinder the passage of salmon ascending the river.

A growing interest in river restoration programmes and restocking streams that used to be inhabited by salmon has also been evident in France. The decline or disappearance of salmon stocks in this country has mainly been attributed to the presence of locks and weirs. Cuinat (1987,1988) has reported on improvements made in the Loire-Allier river system. In 1979, some ten dams were adapted so as to allow salmon to negotiate these barriers more easily.

As a result, a small yet viable salmon population has managed to establish itself in the river, such that fish larvae from this area are being used for rearing and restocking purposes. To facilitate the rehabilitation of the river system, gravel extraction has been suspended and fishing prohibited along large sections of the river. However, in spite of these efforts, the restocking process is proceeding more slowly than originally anticipated. For the viability of this scheme, it is important that the eggs of "native" salmon should yield more fish larvae than those imported from Scotland. Moreover, the quality of the eggs is fundamental to the success of operations of this type. Key factors in this respect are parentage (wild rather than artificially reared salmon), race (Boreal or Celtic salmon) and the stress level experienced by the salmon in captivity prior to and during spawning. However, much of the progress achieved to date is being threatened by plans to construct more dams along the Loire-Allier river system.
Luquet c.s. (1987) has reviewed the attempts that have been made to restock another part of the Loire, the river Gartempe, since 1981. The Loire-Vienne-Creuse-Gartempe river system has an overall length of 4500 km, with the Gartempe extending over 200 km. Fish ladders were constructed at the six dams which form the greatest obstacles to fish. A lack of sufficient funds prevented all the dams along the Gartempe from being modified in this way. To date, up to 220,000 alevins and 15,7000 smolts of Scottish origin have been released into these waters. It is worth noting in this context that Luquet regards the eggs obtained from salmon in the Allier, which started to become available in 1986/87, as being more suitable for this purpose. Whether the modifications made to the dams have been successful will only become clear in 1990, when the first salmon are expected to return. Hawkins (DAFS, Scotland) in a private communication has observed that smolts of Scottish origin released in Spain have not returned to spawn, whereas those of Spanish origin released at the same time, have returned. It is thought that the Scottish salmon have either been lost at sea or have entered other river systems.

Arrignon (1988) has summarised the catches in the River Loire over recent years. On average, 6000-8000 kg are landed each year. Pustelnik c.s. (1987) has described the rehabilitation of the Dordogne, which was once an important salmon river, but became inaccessible to salmon due to the presence of dams. Prior to the restocking operations, catch statistics were reviewed, which showed that the river was once capable of producing 12 tonnes of salmon per annum. The fish caught varied in length from 0.6 to 1.0 m and typically weighed 8-10 kg. The number of alevins released into the River Dordogne increased from 17,000 in 1978 to 97,000 in 1984. The survival rate of the fish released is still causing concern. This has been attributed to the quality of the artificially reared fish and a number of other factors. It has been estimated that the spawning areas (9 ha) and the nursery area (142 ha) could eventually support 600,000 young salmon, of which 13,000 could be expected to return as adult fish from the sea to spawn.

Dumas and Casabon (1987) have outlined the improvements that are being made to the River Nivelle in the Pyrenees to mitigate the effects of weirs. In spite of the fact that the rivers in Brittany are among the best salmon rivers in France, stocks in streams such as the River Elorn have had to be supplemented with artificially reared salmon (Prouzet, 1983).

Richard (1988) has discussed the improvements that were made to the 175 km long River Orne in Normandy, which was populated by salmon until 1935. The demise of the salmon stock in this river was mainly due to the building of hydro-electric power stations. However, now that water from the river is being used to supplement drinking supplies and the accessibility has been improved by constructing fish passes, it is expected that salmon numbers will increase. Restocking operations began in 1980 and as a result, 5.2% of the smolts returned as adult fish in 1984. Moreover, of the 200,000 alevins released in 1984, several hundred returned in 1986 and 1987. The plan currently being followed envisages releasing 100,000-150,000 4-6 month old salmon each year over the period 1989 to 1993.

On balance, it is expected that French rivers where the water quality has not been substantially affected and where the salmon population has disappeared as a result of the construction of dams and weirs have a good chance of being successfully rehabilitated. However, the provision of facilities such as fish passes (sluices, ladders and lifts) is extremely expensive and the recovery process, which has many pitfalls, is often extremely slow. The eggs and larvae obtained from indigenous populations are more suitable for releasing into a river than material imported from elsewhere. Guyomard (1987) has argued that the salmon populations to be found in French rivers are not significantly different in a genetic sense as they are all closely related to the Celtic salmon (Wilkins, 1985). This may well explain the success already achieved with restocking operations in France. In addition, a number of the smaller rivers in Brittany and Normandy, and parts of the Loire are still able to support indigenous salmon populations.

In the United States and Canada, various improvements have been made to river systems to encourage salmon to return. Jones (1983, 1988) has discussed the measures introduced along the River Connecticut, while Frenette c.s. (1988) has reported on the Jacques-Cartier river.

In summary, it can be said that a considerable body of knowledge exists regarding the rehabilitation of salmon stocks in certain rivers. However, it remains to be seen whether this information can be directly related to the situation pertaining in the Rhine. The multiplicity of factors that led to the reduction and eventual demise of salmon stocks in the Rhine would need to be analysed on an individual basis for each stream, rivulet, tributary and identifiable main section of the river. Moreover, even if such a study were to be restricted to those parts of the Rhine and its tributaries where only minor difficulties are expected to be encountered in allowing the water to flow without impediments through weirs, sluices and hydro-electric power stations, this would still entail a considerable amount of work.

The most urgent questions that need to be addressed are: How large are the available spawning grounds? Is the bed material in these stream suitable and not silted up? Are the water quality and temperature adequate? What are the dangers that will confront young salmon developing in these areas? Is sufficient cover and shelter available and do such streams provide an adequate supply of food? Where and under what conditions is waste water discharged into streams in the vicinity? Do these waste discharges contain substances harmful to salmon and other fish? Have fish passes been provided in the river? How effective are they? Have these been built primarily as hydraulic engineering structures and not adapted to the needs of the salmon? Are there sufficient places where fish can rest and do these offer adequate protection? Is the salmon protected by law and are these measures enforced? Is it possible for salmon to return to the Rhine after a period at sea or will the Dutch coastal waters and estuaries prove to be too great an obstacle? The latter question still requires further research to be carried out into the conditions salmon encounter in Dutch coastal waters and the North Sea in general. Furthermore, assessments need to be made of the impact coastal fishing operations could have on post-smolts, grilse and older salmon.

4.2 Accessibility of the Rhine for fish returning to spawn

Since the natural salmon population in the Rhine has disappeared, it will not be possible to re-establish such stocks by simply releasing young salmon into the river. In order to build up a viable population, it is necessary for adult salmon to return to spawn in the streams in which they were released. It is expected that the Nieuwe Waterweg and, to a lesser extent the Haringvliet, will form the main routes for salmon re-entering the Rhine from the sea. The fact that the discharge sluices of the Afsluitdijk are only open for part of the time will considerably reduce the effectiveness of the IJsselmeer as a means of re-entering the Rhine system. In spite of the fact that a certain number of returning salmon will probably be able to negotiate IJmuiden locks, it is doubtful whether these fish will ever reach the Rhine via this route.

The absence of a significant current in the Amsterdam-Rhine Canal will deter such fish and may well cause them to head for the Lake Markermeer.

Although it is clear that salmon are driven by an instinctive urge to return to the river in which they matured as freshwater fish (parent stream theory) only a small proportion of them actually manages to do so. This is complicated by the fact that some fish stray and infiltrate other river systems. However, experiments into the movements of salmon have shown that fish that have spawned in a given river definitely return to this stream if they spawn a second time. This is in agreement with the view that adult salmon reared from eggs do not return to the river from which their parents originate, but to the stream in which they matured as freshwater fish. Nevertheless, each established salmon river has an indigenous population which is able to maintain itself.

At present, it is not possible to draw meaningful conclusions as to the size of the salmon population that the Rhine can sustain. Experience gained with rehabilitation operations in the Thames has shown that even though all the salmon cannot reach the spawning grounds they are still returning in significant numbers. At the same time this also demonstrates the dependence of such schemes on regular restocking activities.

4.3 Expected dispersion within the Rhine basin

The dispersion pattern of migratory freshwater fish in a given river system depends on many factors. Fish can descend the river either in an active or passive manner, but are always required to make a positive effort when ascending the flow stream. Both young and adult fish tend to travel at night, but if turbidity levels are high they may also continue their journey by day.
During their run upstream, salmon stop off at points in the river where the currents are low, such as behind rocks or in deep pools. Pools of this type are especially important as they allow travelling salmon to regain their strength after exerting themselves in the rapidly flowing water (Jones 1959). Hawkins and Smith (1986) have fitted radio transmitters to salmon and in this way were able to measure the average distance travelled by salmon per day. They concluded that salmon could average 10 km a day but recorded data ranging from 2-22 km/day.
Speeds of 0.2 - 0.3 m/s were observed, which, when expressed in body length (BL) seconds, ranged from 0.24 to 0.74 with an average of 0.3 BL seconds. Data collected from a number of American and Russian rivers show salmon travelling at speeds of 4-4.3 km/day, but figures of 12 km/day are not unknown.

Several factors control when fish begin the journey upstream. Not only are physiological factors such as the levels of thyroxine and corticosteroid in the blood important, but external stimuli such as water flows, light levels and temperature also play a key role. Environmental aspects of this type are especially significant as they can affect the orientation of the fish and control the intensity of movement.
Moreover, magnetic data and astrological parameters are thought to be used by salmon when crossing large stretches of water. On the journey upstream, the current is a major source of directional information. However, parameters such as the unique smell profile of the river also play a role. In addition, population-specific characteristics can be important if these are activated by environmental stimuli e.g. the effect of the current on the behaviour of emerging larvae, which determines the distribution over the nursery area. Changes in the response to different factors can occur within a few generations as a result of selective pressures. The significance of this is that a habitat is found that allows the various functions such as survival, growth and reproduction to be optimised in spite of large differences in time and place (Northcote, 1984).

Research by Hawkins (see Section 1.1) has revealed that salmon like to rest in calm water for various periods of time depending on the prevailing conditions.

Channelisation work in the Rhine has meant that many of the banks and islands have been removed to improve the navigability of the waterway. Dead branches of the river have been closed to ensure sufficient flow rates and to prevent silting up. To facilitate the return of the salmon it is essential that an adequate number of resting places be created in both the Dutch and German parts of the Rhine. It is important to note that salmon used to spend up to fourteen months in the Rhine when journeying to and from the spawning grounds. This emphasises the importance of creating the right conditions to enable salmon to return.

5. ASSESSMENT OF FUTURE PROSPECTS

5.1 Feasibility of restocking operations

At present, salmon stocks in the entire eastern Atlantic are declining, even though a number of excellent salmon rivers are still to be found in 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) (see Section 1.3), it is possible to calculate the required nursery area for 0+ salmon assuming a mortality rate of 6% at the transition from fertilised eggs to larvae (Mills, 1989). It transpires that for a population of 15,000 salmon, an area of 760 km of the lowest category of biomass (≤ 130 g/100 m biomass) would be sufficient or 190 km of the highest category (≥ 841 g/100 m biomass).

Whether these conditions can be achieved in the upper reaches of the Rhine remains to be seen. In the near future, the Loire-Allier system, which has a combined nursery/fishing area of 109,930 km, may be capable of sustaining a similar size of salmon population to that predicted for the Rhine. The actual spawning grounds in the Loire are probably not much larger than those likely to be available in the Rhine. How realistic it is to expect that the annual catch in the Loire can be more than quadrupled from its current size of 1000 fish or 6-8 tonnes is still a matter for debate. One essential difference that should be borne in mind when comparing the two rivers, is that the Loire is still inhabited by salmon, whereas the Rhine is not. Even though the main reason for the 70 year decline and eventual demise of salmon in the Rhine - the closure of rivers or sections of rivers by dams and weirs - is quite apparent, little is known about the others factors that contributed to this decline.

The likely survival rate of salmon in the Rhine can be estimated on the basis of information found in the literature (Hansen & Bielby, 1988; Harden Jones, 1968; Lassen c.s., 1988; Foerster in Netboy, 1980). However, 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 two 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 two 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 fertilisation rate of 78% (2,695,680 fertilised eggs) and a mortality rate up to the smolt stage of 99%, 26,957 smolts could be produced. As 80% of the post-smolts die during the first nine months at sea, 5391 young salmon would be expected to reach Greenland. Assuming the mortality rate after the first nine months at sea to be 1% and losses of 25% and 50% to occur due to fishing near the Faeroe Islands and in the North Sea respectively then of the 75% of the fish that are expected to return after one winter at sea (4043 grilse), 889 would be successful (3154 lost), whereas of the remaining 25% that stay at sea for another year (1348 two sea winter fish) 162 would be expected to reach the mouth of the river (1186 are lost). Together this would amount to a total of 1051.

Although the mortality rate in the river will probably be of the order of 5%, it is impossible to estimate 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 Esk (Dunkeld, 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 their 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 two 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 entering 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. The salmon population in the south of Norway is currently being seriously affected by acid rain. In spite of the fact that lime has been added to the water as a temporary measure, many of the lakes and rivers have lost their fish stocks and are now dying. It is, however, difficult to assess at this stage how detrimental acid rain will be to salmonids in the Rhine.

Thomessen and Døving (1980), and Royce-Malmgren and Watson (1987) have suggested that acid rain affects the sense of smell of salmonids. Low pH levels prevent such fish from detecting the characteristic smells on which their homing instinct is based. Furthermore, Skogheim c.s. (1985) has pointed out that fish exposed to acidic water saturated with aluminium (pH 5.17-5.53) died en masse.

Piggins (1982) has indicated that the number of smolts that survive the sea phase and return to spawn has been decreasing over the last 12 years. In addition, he observed that the increase in the number of smolts released was not directly proportional to the number of fish that returned to the river.

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. Damage to the smell and taste epithelium is known to be caused at detergent levels as low as 0.5 mg/l.

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

The fact that salmon that were released as young fish are returning to the Thames indicates that a great deal can be achieved with restocking operations. However, there is often a negative side to such success. The return of the salmon has meant that sport fishing, which used to provide enjoyment to many along the Thames, now needs to be strictly controlled and administered. The salmon has therefore impoverished the recreational value of the river to a certain extent. Nevertheless, the entire clean-up operation has had a positive effect since it has meant that more species of fish have now returned to the Thames as well as the salmon. The success of other schemes to reintroduce salmon has also been widely reported in the literature.
Examples are the introduction of Atlantic salmon in the rivers that flow into the Pacific and the transfer of coho salmon from their original Pacific territory to Maine (USA). The salmon production of Chile is extremely high and this country has the potential of eventually surpassing Norway in this field. At the beginning of this century, salmon were also introduced in New Zealand. Although it was at first thought that this scheme had failed, evidence is now available to confirm that they have established themselves in other rivers in the area. On the other hand, releases of chinook salmon in the Barents Sea and the White Sea (USSR) have not proved successful. Moreover, the rearing of coho salmon (net cultures) has not yielded the expected results in spite of the fact that a proportion of the salmon reached a marketable size.
Even in the most favourable circumstances, if salmon were encouraged to return to Dutch waters, it would still not be feasible for professional salmon fishing with stake nets to be revived. Nowadays, the frequency of shipping movements and the deepening of the river bed preclude such activities. It is feared that should salmon be reintroduced in the upper reaches of the Rhine on too small a scale, the effects of poor years (or inadequate releases) will dominate to such an extent that a newly established population will not be able to survive, as evidenced by the results of similar schemes in France.

It should, however, be possible for river systems on both sides of the main stream to be recolonised by salmon and hence increase the size of the spawning grounds.
By the end of the 1920s, access in the Rhine had become so restricted that poor breeding years could no longer be compensated for. Simply correcting for deficiencies of this type by releasing more fish is not a practical proposition. 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. The large numbers of wheels on poles that are currently found in the Netherlands have not been able to enhance the stork population and have only proved to be a rather striking reminder of the failure of this initiative.

If it is finally decided to release young fish into the Rhine, it is recommended that parr be used as these fish will 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. In this context, advice should be sought from authorities that are specifically involved in nature management. In Norway, such expertise is available at the Direktoratet for Naturforvaltning in Trondheim, which has its own monitoring stations and fish farms for restocking operations with wild salmon.

In order to increase the chance of success of these activities, it is advisable to obtain salmon from as many different sources as possible. Consideration should be given to obtaining Scottish salmon from the Tweed or salmon from the English river Tees.

If it is decided to include Norwegian salmon as well, preference should be given to fish that enter the river relatively late in the season, such as would be the case with salmon from the river Alta. In general, the numbers of fish selected for restocking purposes should be large and the releases should continue over many years. Introducing small numbers of fish is of little practical value as most of the male salmon will then stay behind in the area where the fish are released and mature as "precocious males". As a result, too few female salmon will return from the sea to allow successful reproduction. Problems of this type have occurred, for example, when fish were introduced into the St. Lawrence in Canada.

It is further recommended that trout stocks be eliminated in the streams and rivers where the salmon are to be released. Especially in cases where the salmon population has to be built up from scratch and the new releases are not meant to supplement a stock under threat, the presence of predators such as trout can cause considerable harm. Once the salmon population has established itself, trout can be allowed to return to the river and a natural equilibrium should develop between the two species.

It is extremely important to determine the most opportune period for the transition from parr to smolt, especially as the time frame within which this change occurs it rather limited.
In Brittany (Celtic population), the period in question is from the end of March to the beginning of May, while in the south of Norway, this takes place in the months of May and June. At present, there is insufficient knowledge available about the timing of the smolting process that is likely to apply in the Netherlands, but such information could be obtained from IFREMER-Brest; the Freshwater Fisheries Laboratory, Pitlochry, Scotland; and the Directorate for Nature Management in Trondheim. Further data on the smolting process is to be found in the journal Aquaculture, which has published a series of special reports on the subject.

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. In addition, continuous monitoring would be needed to assess the impact that substances which have not been included in the directives have on fish stocks.
Finally, it can be concluded that establishing a natural population of salmon in the Rhine without outside help will certainly not be realised 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.

5.2 Recommendations for further study

a. <u>A reassessment of the salmon stock in the Rhine based on historical data</u>

In the past, detailed investigations were conducted into the salmon stocks in the Rhine, particularly during the period when the population began to decline (1885-1920). In spite of much scientific and political debate, salmon have completely disappeared from the Rhine. Nevertheless, the effect of releasing young fish into the various tributaries of the river has never been thoroughly evaluated. It is therefore extremely difficult to assess what the likely impact of reintroducing salmon will be. In setting up such a project, careful consideration will need to be given to the many pitfalls and obstacles that are likely to be encountered. Various parameters can be derived from rivers that are still able to support a salmon population, which can provide useful guidance for such schemes. However, the genetic differences between salmon from various river systems or even within a given river system make it extremely difficult to determine how useful this information will ultimately be. In addition, the precise reasons for the disappearance of salmon from the Rhine (pollution-channelisation-fishing) have never been fully evaluated and ranked, which makes it all the more urgent that the variation in salmon stocks in the Rhine be studied as a function of time.

The present literature survey has succeeded in drawing attention to a number of aspects, but a great deal of the information contained in old documents still needs to be processed using modern quantitative methods. It is likely that many useful data about the Rhine salmon population can be extracted from the archives. Of particular importance in this context are the records kept by government, provincial or local authorities as well as private collections and fishing museums (see, for instance, van der Woude, 1988).

Reprocessing historical data could be especially helpful in clarifying why salmon disappeared from the Rhine and could yield valuable lessons for a future restocking programme. A comparable study has been started at the Marine Laboratory (DAFS) in Aberdeen with the aim of extracting information that will be useful to rehabilitating salmon rivers.

The value of such investigations is currently recognised by the authorities responsible for managing salmon stocks in Great Britain, France and Norway, as they have realised that fluctuations in various river systems often coincided with one another.
It has been shown, for instance, that the effects of weirs and artificial lakes can be traced back from historical records and that methods can be found to improve the situation (Hansen, 1986 and Shearer, 1988b).
The use of historical data to evaluate salmon catches in former salmon rivers or rivers where the stock is under threat has also been favourably received in Canada (Bielak & Power, 1987). The feasibility of mounting a project of this type is currently being studied in the Netherlands.

b. Fundamental research into the functioning and efficiency of fish passes

The majority of fish ladders, fish sluices etc. that have been constructed to date have achieved limited success. It is questionable in how far the behaviour of fish and the use that they make of such facilities have been considered when designing these structures. In view of the poor results obtained, it would seem worthwhile examining whether better alternatives could not be found. If a series of fish sluices and fish ladders is positioned in a river, experience has shown that this effectively prevents access to the upper reaches of the watercourse. It is therefore recommended that a study be undertaken to discover how many fish of a particular species actually make use of facilities of this type. Considering the fact that the number of sluices, locks and weirs along the Rhine will always be relatively high in comparison with other rivers and that inaccessibility is thought to have been one of the key factors in the disappearance of salmon, research of this type is essential.

c. The effect of detergents on the smell and taste senses of migratory fish

Although detergents are degradable and can be broken down, they are still present in the Rhine in large quantities. Bardach and Holl c.s. have shown that detergent concentrations of as little as 0.5 mg/l caused the smell and taste buds of fish to erode in 4 days. Since migrating salmon are likely to take at least 40 days (10 km/day) to reach the spawning grounds, their sense of smell will probably be seriously impaired. A combination of behavioural, electrophysiological and histological research should be able to provide information about the magnitude of such effects.

6. REFERENCES

Anon., 1889. Der Rheinstrom und seine wichtigsten Nebenflüsse von den Quellen bis zum Austritt des Stromes aus den Deutschen Reich. Eine hydrografische, wasserwirtschaftliche und wasserrechtlige Darstellung mit vorzugsweise eingehender Behandlung des Deutschen Stromgebietes. Im auftrag der Rheinstromverhältnisse, herausgegeben von den Centralbureau für Meteorologie und Hydrografie im Grossherzogthum Baden. Mit 9 Übersichts-Karten und Profilen nebst einer Stromkarte des Rheines in 16 Blättern. Berlin, Ernst und Korn, p.359.

Anon., 1912. De visscherijwet en haar uitvoeringsvoorschriften met overzicht; benevens enkele bepalingen uit andere wetten en reglementen voor de visscherij van belang. Meded. Versl. Visserijinspectie No. 1:1-273.

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

Anon., 1920. Jaarverslag der Visscherijinspectie 1919, IV. Verslag betreffende den staat der binnenvisscherij. Meded. Versl. Visscherijinspectie No. 28: 1-145.

Anon., 1922. De verbetering van de zalm- en elftstand in onze rivieren. The Hague, Gebroeders van Cleef, pp.1-63.

Anon., 1983. Action COST 47-Mariculture - Rapport Final, 1980-1983. Final report COST Project 46/4 on ocean ranching of Atlantic salmon pp. 16-91. C.C.E.-COST, Brussels, 1-94.

Anon., 1987. De zalm. Een beknopt historisch en biologisch beeld. OVB-Nieuwegein, I-VI, 1-42 (mimeo).

Anon., 1987. Internationale Commissie ter Bescherming van de Rijn tegen Verontreiniging. Tabellenboek - Meetresultaten van het fysisch-chemisch onderzoek van het Rijnwater - 1986. Koblenz. IKSRV.

Anderson, J.M., 1971. Sublethal effects and changes in ecosystems. Assessment of the effects of pollutants on physiology and behaviour. Proc. R. Soc. B 177: 307-320.

Anderson, J.M. & P.F. Elson, 1971. Effect on adult returns of exposure of native wild smolt to sublethal DDT. ICES C.M. 1971/M:7 AnaCat. fish. comm.

Arrignon, J., 1988. Fish and their environment in large Europea river ecosystems, The Loire. Sciences de l'Eau 7(1): 21-34.

Baglinière, J.L, P. Prouzet, J.P. Porcher, A. Nilhouarn & G. Maisse, 1987. Caractéristiques générales des populations de saumon atlantique (Salmo salar L.) des rivières du Massif armoricain. In: M. Thibault & R. Billard eds. Restauration des rivières à saumons. INRA, Paris, pp. 23-37.

Bardach, J.E. & J. Case, 1965 Sensory capabilities of the modified fins of squirrel hake (Urophycis chuss) and searobins (Prionotus carolinus and P. evolans). Copeia 1965 (2): 194-206.

Bardach, J.E., M. Fujiya & A. Holl, 1965. Detergents: effects on the chemical senses of the fish Ictalurus natalis (le Sueur). Science, 148 (3677): 1605-1607.

Bardach, J.E., M. Fujiya & A. Holl, 1967. Investigations of external chemoreceptors of fishes. In: Olfaction and Taste II, Proc. Second Int. Symp. held in Tokyo, Sept. 1965. ed. T. Hayaski, Oxford, London - Pergamon Press pp. 647-665.

Bern, H.A. & C.V.W. Mahnken ed., 1982. Salmonid smoltification. Proc. Symp. La Jolla, California, USA, 29 June to 1 July 1981. Aquaculture, 298: 1-270.

Bertram, J.G., 1873. The harvest of the sea, including sketches of fisheries and fisher folk, 3rd edition. London, John Murray, pp. 1-340 (p. 44).

Bielak, A.T. & G Power, 1987. Utilisation des données historiques pour évaluer les stocks de saumon atlantique: exemples de quelques rivières du Canada. In: Restauration des rivières à saumons. eds. M. Thibault & R. Billard, Paris INRA, 103-113.

Blaxter, J.H.S., 1970. Sensory deprivation and sensory input in rearing experiments. Helgoländer wiss. Meeresunters., 20: 642-654.

Bouck, G.R. 1977. The importance of water quality to Columbia River Salmon and Steelhead. In. Proc. Symp. held in Vancouver, Washington. March 5-6, 1976- Columbia River Salmon and Steelhead. ed. E. Schwiebert. Amer. Fish Soc. Spec. Publ. 10: 149-154.

Broekhoven, A.L.M. van, 1987. De Rijn in Nederland. Toestand en ontwikkelingen anno 1987. RWS/Dienst Binnenwateren/RIZA, Arnhem - D.B.W./RIZA nota 87.061, p. 56.

Bulleid, M.J., 1983. The river Thames salmon rehabilitation experiment. Proc. Inst. Fish Managem., 14th Annual Study Course, pp. 14-27.

Busch, D., U. Haesloop, H.J. Scheffel, M. Schirmer, 1988. Fish and their environment in large European river systems. The river Weser, FRG. Sciences de l'Eau, 7(1): 75-94.

Cave, J.D., 1985. The effects of the Kielder scheme on fisheries. J. Fish. Biol., 27 (Suppl. A.): 109-121.

Cavitte, J.P., J.P. Andrieu, A. Bruzy, P. Beaudelin, Ph. Derenne & F. Gayou, 1987. Programme de restauration du saumon atlantique (Salmo salar) dans le bassin de la Garonne. In: Restauration des rivières à saumons. eds. M. Thibault & R. Billard, Paris, INRA, 377-386

Cazemier, W.G., 1986. Salmoniden in Nederland. Uit: De zalm weer terug in de Maas? Combinatie Juliana, pp. 1-8.

Cuinat, R. & P. Bomassi, 1987. Evolution de la situation pour le saumon du bassin Loire - Allier, de 1979 à 1985. In: Restauration des rivières à saumon. eds. M. Thibault & R. Billard. Paris, INRA, 39-51.

Cuinat, R., 1988. Atlantic salmon in an extensive French river system: the Loire - Allier. In: Atlantic salmon: planning for the future. eds. D. Mills & D. Piggins. London, Croom Helm, pp. 389-399.

Dart, M.C. 1979. The recovery of the river Thames. Proc. Inst. Fish Managem. Annual Study Course, 18-20th Sept. 1979. Nottingham Univ. pp. 48-62.

Deelder, C.L., 1958 Modern fish passes in the Netherlands. Progr. Fish-Cult., October 1958, 151-154.

Deelder, C.L. & D.E. van Drimmelen, 1959. The decline of the fish stocks in the Netherlands sections of the rivers Rhine and Meuse. Athens Proc. I.U.C.N. Tech. Meeting 4: 185-190.

Desey, J.P., 1985. Qualité des eaux de la Meuse: évaluation en vue de la réintroduction du saumon atlantique dans le bassin mosan. Comple-rendu du Colloque "Réintroduction du Saumon atlantique dans le bassin de la Meuse". Ville de Namur, pp. 49-67.

Drimmelen, D.E. van, 1987. Schets van de Nederlandse rivier- en binnenvisserij tot het midden van de 20ste eeuw. Nieuwegein, Organisatie ter Verbetering van de Binnenvisserij, pp. 1-128.

Dumas, J. & J. Casanbon, 1987. Connaissance et restauration de la population de saumon atlantique (Salmo salar L.) de la Nivelle (Pyrénées atlantiques). In: Restauration des rivières à saumons. eds. M. Thibault & R. Billard, Paris, INRA, 332-230.

Dunkley, D., 1988. Stock and recruitment in North Esk salmon - the fate of fish derived from a single brood year. The salmon Hut, 20: 55-59.

Eriksson, C., M.P. Ferranti & P.O. Larsson, 1982. Sea ranching of Atlantic salmon. COST 46/4 workshop, Lisbon, 26-29 October 1982. C.E.C., Brussels, pp. 1-152.

Fehlmann, W., 1926. Die Ursachen des Rückganges der Lachsfischerei im Hochrhein. Beilage zum Jahresbericht der Kantonsschule Schaffhausen auf Frühjahr 1926, Schaffhausen, Buchdruckerei Meier und Cie, p. 112.

Feith, A.F., 1982. Visstand, visserij en waterkwalitiet. Bijdrage ten behoeve van het opstellen van rijks- en provinciale waterkwaliteitsplannen. Documentatierapport 24 (1982), Directie van de Visserijen, The Hague, 60 pp.

Fraser, P.J. 1987. Atlantic salmon. Salmo salar L., feed in Scottish coastal waters. Aquaculture and Fish. Managem., 18:243-247.

Frenette, M., P. Dulude & M. Beaurivage, 1988. The restoration of the Jacques-Cartier: a major challenge and a collective pride. In: Atlantic salmon: planning for the future. eds. D. Mills & D. Piggins. London, Croom Helm, pp. 400-414.

Gaag, M.A. van der, & J.A. Schellart, 1984. Toxicologisch onderzoek: chronische toxiciteit voor forellen, Ei-larvaal onderzoek, Mutageniteitsonderzoek. In: De samenstelling van het Rijnwater in 1982 en 1983. Rapport van de Werkgroep Waterkwaliteit - Redactie A.P. Meijers, RIWA-Amsterdam, November 1984, pp. 123-133.

Gaag, M.A. van der, A.C. Hoekstra & L.W.C.A. van Breemen, 1986. Toxicologisch onderzoek: chronische toxiciteit voor forellen, Mutagene activiteit. In: De Samenstelling van het Maaswater in 1983 en 1984. Rapport van de Werkgroep Waterkwaliteit - RIWA-Amsterdam, June 1986, pp. 169-174.

Garcia de Leaniz, C. & E. Verspoor, 1988. Hybridisation between Atlantic salmon (Salmo salar) and Brown Trout (Salmo trutta) in northern Spain. ICES C.M. 1988/M:20 AnaCat Comm. 8 pp.

Cough, P.J., 1983. Juvenile salmon production in the Thames catchment. Proc. Inst. Fish Managem. 14th Annual Study Course, pp. 151-161.

Groot, S.J. de, 1988. Een eeuw visserijonderzoek in Nederland 1888-1988. IJmuiden, RIVO pp. 1-252.

Guyomard, R., 1987. Différenciation génétique des populations de saumon atlantique: revue et interprétation des données é lectrophonetiques et quantitatives. In: Restauration des rivières à saumons. eds. Thibault & R. Billard Paris, INRA, pp. 297-308.

Hansen, L.P., 1986. The data on salmon catches available for analysis in Norway. In: D. Jenkins & W.M. Shearer. The Status of the Atlantic salmon in Scotland. ITE Symposium No. 15. Institute of Terrestrial Ecology, 79-83.

Hansen,. L.P., 1987. Growth, migration and survival of lake reared juvenile anadromous Atlantic salmon Salmo salar L. Fauna norv. Ser. A., 8: 29-34.

Hansen, L.P., 1988. Status of exploitation of Atlantic salmon in Norway. In: Atlantic Salmon: planning for the future. eds. D. Mills & D. Piggins. London, Croom Helm, pp. 143-161.

Hansen, L.P. & G.H. Bielby, 1988. Salmon Trust, Pitlochry, Scotland, pp. 1-29.

Hansen, L.P., C.Clarke, R.L. Saunders & J.E. Thorpe ed., 1989. Salmonid Smoltification III. Proc. Workshop Univ. of Trondheim, 27 June to 1 July, 1988. Aquaculture.

Hansen, L.P., R.A. Lund & K. Hindar, 1987. Possible interaction between wild and reared Atlantic salmon in Norway. ICES C.M. 1987/M:14 AnaCat, 18 pp.

Hawkins, A.D., 1986. A wild salmon chase. Progress Report, May 1986, The Atlantic Salmon Trust (Pitlochry), pp 21-24.

Hawkins, A.D. (in preparation). Factors affecting the timing of entry and upstream movement of Atlantic salmon in the Aberdeenshire Dee. In: Proc. Second Int. Symp. on Salmon and Trout Migratory Behaviour, Trondheim, June 1987 (eds. E.L. Brannon & B. Jonsson).

Hawkins, A.D.& G.W. Smith, 1986. Radio-tracking observations on Atlantic salmon ascending the Aberdeenshire Dee. Dept. Agr. Fish Scotland, Scot. Fish. Res. Rep. No. 3611-24.

Hawkins, A.D.& J. Webb, 1988. Research programme on salmon movements, 1988. Progress Report, December 1988, The Atlantic Salmon Trust (Pitlochry), pp. 7-9.

Herbert, D.W.M. & J.C. Merkens, 1961. The effect of suspended mineral solids on the survival of trout. Int. J. Air Wat. Poll., 5(1): 46-55.

Herbert, D.W.M., J.S. Alabaster, M.C. Dart & R. Lloyd, 1961. The effect of china-clay wastes on trout streams. Int. J. Air Wat. Poll., 5(1): 56-74.

Hoek, P.P.C., 1891. De zalm op onze rivieren. Voordracht gehouden door, ... op uitnodiging van de Vereeniging ter Bevordering der Zoetwatervisscherij in Nederland, te Rotterdam, op 1 December 1891. Leiden, E.J. Brill, pp. 1-36.

Hoek, P.P.C., 1894. Rapport over statistische en biologische onderzoekingen, ingesteld met behulp van in Nederland gevangen zalmen. Bijlage IV in Versl. Staat Ned. Zeevisch., 1893: 249-396 + platen 1-7.

Hoek, P.P.C., 1895. Statistische und biologische Untersuchungen an in den Niederlanden gefangenen Lachsen Z. Fish. 3: 1-57.

Hoek, P.P.C., 1898. Over Winter- en Zomerzalmen. Meded. Vissch.,5: 77-80.

Hoek, P.P.C., 1899a. Zalmbeschouwingen. Meded. Vissch., 6: 26-30; 41-45.

Hoek, P.P.C., 1899b. De slechte zalmvangsten van de laatsten tijd. Meded. Vissch., 6: 93-96.

Hoek, P.P.C., 1900. De kunstmatige teelt en de zalmvangst. Meded. Vissch., 7: 161-166.

Hoek, P.P.C., 1902. Verslag omtrent waarnemingen en onderzoekingen, op de levenswijze van de zalm in het Boven Moeselgebied betrekking hebbende, ingesteld Augustus-November 1900. Verslag Staat Ned. Vissch. 1901, 76-83 (also published in 1901 in: Meded. Viscch., 8: 81-86; 99-103).

Hoek, P.P.C., 1909. Over den groei van den zalm in de eerste levensjaren. Meded. Vissch., 16: 91-110; 123-129; 148-154.

Hoek, P.P.C., 1911. De Jacobszalmen van de afgelopen zomer. Meded. Vissch., 18: 204-206.

Hoek, P.P.C., 1911. De "Winterzalmen"-verwarring. Meded. Vissch., 18: 91-94.

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

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

Hoek, P.P.C., 1916 (c). Rapport van subcommissie B van de Staatscommissie voor het zalmvraagstuk over den toestand der zalmvisscherij op de andere rivieren (niet Rijn en Maas)in het buitenland. In: Verslag van de Staatscommissie voor het zalmvraagstuk, Part II: 117-156.

Holl, A., 1965. Vital staining by trypan blue: its selectivity for olfactory receptor cells of the brown trout bullhead, Ictalurus natalis. Stain Technology, 40 (5): 269-273.

Holl, A., E. Schulte & W. Meinel, 1970. Funktionelle Morphologie des Geruchsorgans und Histologie der Kopfanhänge der Nasenmuräne Rhinomuraena ambonensis (Teleostei, Anguilliformes). Helgoländer wiss. Meeresunters. 21: 103-125.

Huntsman, A.G. & W.S. Hoar, 1939. Resistance of Atlantic salmon to sea water. J. Fish. Res. Bd. Can., 4(5): 409-411.

Hvidsten, N.A. & L.P. Hansen, 1988. Increased recapture rate of adult Atlantic salmon, Salmo salar L., stocked as smolts at high water discharge. J. Fish Biol., 32: 153-154.

Jones, F.R. Harden, 1968. Fish migration. Chapter 4 - Salmon and Trout. London, Edward Arnold (Publishers) Ltd., 42-68.

Jones, J.W., 1959. The salmon. New Naturalist Series M 16. London, Collins, I-VI, 1-192. In: Atlantic salmon: planning for the future. eds. D. Mills & D. Piggins. London, Croom Helm, pp. 415-426.

Jones, R.A. 1983. The restoration of Atlantic salmon in the Connecticut river. Proc. Inst. Fish Managem. 14th Annual Study Course, pp. 9-13.

Jones, R.A. 1988. Atlantic salmon restoration in the Connecticut river.

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

Larsson, P.O. 1984. Remote straying of salmon (Salmo salar L.) from the Swedish west coast and possible effects on sea ranching operations. Aquaculture 38: 83-87.

Lassen, H.J. Mø/ller & L.P. Hansen, 1988. Simulating North Atlantic Salmon marine life history. ICES C.M.1988/M: 18 (AnaCat Fish. Comm.) 12 pp.

Lecuyer, P., 1985. Technique de réintroduction du saumon Atlantique. Compterendu du Colloque "Réintroduction du saumon Atlantique dans le bassin de la Meuse", Ville de Namur, 105-110.

Lonkhuyzen, J.P. van & H. Vonk, 1920. Rapport over de zalmvisscherij op de benedenrivieren en Zuid-Hollandsche Stroomen in Nederland. Arnhem Boek-, Courant- en Handelsdrukkerij, October 1920, p. 15.

Luquet, J.F., J.F. Glomeau, B. Lafosse, J. Lanneau & J. Sabra, 1987. Opération de réintroduction du saumon atlantique dans le Gartempe. In: Restauration des rivières à saumons. eds. M. Thibault & R. Billard. INRA, Paris, pp. 335-344.

Marty, C. & E. Beall, 1987. Rhythmes journaliers et saisonniers de dévalaison d'alevins de saumon atlantique à l'émergence. In: M. Thibault & R. Billard eds. Restauration des rivières à saumons. INRA, Paris, pp. 283-290.

Menzies, W.J.M., 1949. The stock of salmon.Its migration, preservation and improvement. Buckland lectures for 1947, London, Edward Arnold and Co., 1-96.

Micha, J.C., 1985. Obstacles physiques à la remontée du saumon atlantique dans le bassin mosan en Belgique. Compterendu du Colloque "Réintroduction du Saumon atlantique dans le bassin de la Meuse". Ville de Namur, pp. 69-101.

Mills, D.H., 1987. Atlantic salmon management. In: Developments in Fisheries Research in Scotland. Eds. R. Bailey and B.B. Parrish. Fishing News Books, Farnham, pp. 207-219.

Mills, D., 1989. Ecology and management of Atlantic salmon. London, Chapman and Hall. 351 pp.

Mills, D. & N. Graesser, 1981 The salmon rivers of Scotland. The Beauly. London, Cassell 339 pp. See especially pp. 119-121, Table 11.

Milner, N.J., 1982. Habitat evaluation in salmonid streams. Proc. Inst. Fish Managem., 13th Annual Study Course, pp. 47-72.

Nengerman, A.A., J.P. van Lonkhuyzen & A.B. Brouwer, 1918. Rapport over de zalmvisscherij op de rivieren in Nederland. Deventer, Druk van H.W. Velders, December 1918, p. 20.

Neresheimer, E., 1939. Die Lachsartigen. In: Handbuch der Binnenfischerei Mitteleuropas - R. Demoll & H.N. Maier (eds.). Stuttgart, E. Schweizerbartsche Verlagsbuchhandlung, Bd III: 219-370.

Netboy, A., 1980. Salmon, the world's most harassed fish. London, André Deutsch, 1-304.

Nijssen, H. & S.J. de Groot, 1987. De vissen van Nederland. Natuurh. Bibl. K.N.N.V. No. 43, 1-224.

Northcote, T.G. 1984. Mechanisms of fish migration in rivers. In: Mechanisms of Migration in Fishes. Eds. J.D. McCleave, G.P. Arnold, J.J. Dodson & W.H. Neill. New York, London, Plenum Press, 317-355.

Parrish, B.B. & Sv. Aa Horsted ed., 1980. ICES/ICNAF joint investigation on North Atlantic salmon. Rapp. Réun. Cons. perm. int. Explor. Mer, 176: 1-146.

Phillipart, J.C., 1985. Histoire des Salmonidés migrateurs Saumon de l'Atlantique et truite de mer dans le bassin de la Meuse. Compterendu du Colloque "Réintroduction du saumon Atlantique dans le bassin de la Meuse", Ville de Namur, pp. 5-47.

Phillipart, J.C., 1987. Histoire de l'extinction et problématique de la restauration des Salmonids migrateurs dans la Meuse. In: Restauration des rivières à saumons. M. Thibault & R. Billard eds. INRA, Paris, pp. 125-137.

Phillipart, J.C., A. Gillet & J.C. Micha, 1988. Fish and their environment in large European river ecosystems. The river Meuse. Sciences de l'Eau, 7(1): 115-154.

Piggins, D.J., 1982. Census work on runs of migratory fish in Ireland. Proc. Inst. Fish. Managem., 13th Annual Study Course, 35-45.

Prouzet, P., 1983. Salmon rehabilitation and management on the river Elorn, northern Brittany, France. Proc. Inst. Fish. Managem., 13th Annual Study Course, 2-43.

Pustelnik, G., M. Roguet, C. Tinel, J. Soumastre, R. Roux & F. Simonet, 1987. Historique, cartographie écologique de la rivière Dordogne et évaluation de son potentiel d'accueil pour le saumon atlantique. In: Restauration des rivières à saumons. eds. M. Thibault & R. Billard, Paris INRA, 53-64.

Redeke, H.C., 1927. River pollution and fisheries. Rapp. P. Réun. Cons. perm. int. Explor. Mer, 43: 1-50.

Richard, A., 1988. The stock restoration of Orne river migratory salmonids (Low Normandy-France) EIFAC-Symp. on Management Schemes for Inland Fisheries, Göteborg, Sweden, 31 May-7 June 1988 (mimeo), p.8 + ills.

Royce-Malmgren, Ch. & W.H. Watson, 1987. Modification of olfactory-related behaviour in juvenile Atlantic salmon by changes in pH. J. Chem. Ecol., 13(3): 533-546.

Sedgwick, S.D., 1988. Salmon farming handbook. Farnham, Surrey, England, Fishing News Books Ltd., p. 207.

Shearer, W.M., 1988a. Relating catch records to stocks. In: Atlantic Salmon: planning for the future. Eds. D. Mills & D. Piggins. London, Croom Helm, pp. 256-274.

Shearer, W.M., 1988b. Long term fluctuations in the timing and abundance of salmon catches in Scotland. ICES C.M. 1988/M: 21 AnaCat. Fish Comm. 9 pp.

Skogheim, O.K., B.O. Rosseland & I.H. Sevaldrud, 1985. Deaths of spawners of Atlantic salmon, Salmo salar L., in the river Ogna, Southwest Norway, caused by acidified aluminium-rich water. Rep. Inst. Freshw. Res. Drottningholm 61: 195-202.

Solbe, J., 1988. Water quality for salmon and trout. Atlantic Salmon Trust, May 1988, 72 pp.

Sower, S.A. & R.N. Iwamoto, 1984. Salmonid Reproduction. Proc. Int. Symp. 31 October to 2 November. Aquaculture 43: 1-356.

Swales, S., 1982. Restoration of fish habitat in channelised rivers. Proc. Int. Fish Managem. 13th Annual Study Course, pp. 73-90.

Thibault, M., 1987. Eléments de la problématique du saumon atlantique en France. In: Restauration des rivières à saumons. M. Thibault & R. Billard eds. INRA, Paris, pp. 413-425.

Thibault, M. & R. Billard, 1987. La restauration des rivières à saumons. Hydrobiologie et Aquaculture, Paris, INRA, pp1-445.

Thommessen, G. & K.B. Dø/ving, 1983. Detection of a blocking effect of low pH in the trout olfactory organ. In: K.B. Dølving (ed.). Chemoreception in studies of Marine Pollution. Reports from a workshop at Oslo, July 13 and 14, 1980. pp. 44-48.

Thorpe, J.E., H.A. Bern, R.L.Saunders & A. Soivio, 1985. Salmonid Smoltification II. Proc. Workshop Univ. Stirling, Scotland, 3-6 July 1984. Aquaculture, 45: 1-404.

Thorpe, J.E., 1988a. Salmon enhancement: stock discreteness and choice of material for stocking. In: Atlantic salmon: planning for the future, eds. D. Mills & D. Piggins, pp. 373-388 (especially p. 380).

Thorpe, J.E., 1988b. Salmon migration. Sci. Prog. Oxf., 72: 345-370.

Thorpe, J.E. & R.I.G. Morgan, 1978. Periodicity in Atlantic Salmon, Salmo salar L., smolt migration. J. Fish. Biol., 12: 541-548.

Verhey, C.J. (ed.), 1961. De Biesbosch, land van het levende water. Chapter 8: De vissen en de visvangst, pp. 139-164, 149-254. Zutphen, W.J. Thieme & Cie. N.V.

Verslag van den Staat der Nederlandse Zeevisserijen (Reports on the State of the Dutch Sea-Fishing Industry):
1882 (1883): 57-58; 1883 (1884): 64-65;
1886 (1887): 65-76; 1887 (1888): 79-84;
1888 (1889): 61-66; 1889 (1890): 72-79;
1892 (1893): 131-132; 1893 (1894): 127;
1894 (1895): 50-51; 1895 (1896): 99-100;
1896 (1897): 51-53; 1897 (1898): 50;
1910 (1911): 199-200; 1915 (1916): 34-58;
1917 (1918): 48-52.

Vibert, R., 1950. Recherches sur le saumon de l'Adour (Salmo salar, L) (Ages, Croissance, Cycle génétique, Races) 1942-1948. Annls Stn. Centre Hydrobiol. appl. III: 27-149.

Wankowski, J.W.J. & J.E. Thorpe, 1979a. Spatial distribution and feeding in Atlantic salmon, Salmo salar L., juveniles. J. Fish. Biol. 14, 239-248.

Wankowski, J.W.J. & J.E. Thorpe, 1979b. The role of food particle size in growth of juvenile Atlantic salmon (Salmo salar L.). J. Fish. Biol. 14, 351-370.

White, H.C., 1942. Atlantic salmon redds and artificial spawning beds. J. Fish Res. Bd. Can. 6(1): 37-44.

Wilkins, N.P., 1985. Salmon stocks: a genetic perspective. Atlantic Salmon Trust, Pitlochry, Scotland pp. 1-30.

Woude, A.M. van der, 1988. De contractfase van de seculaire trend in het Noorderkwartier nader beschouwd. Bijdr. Med. Gesch. Ned., 103: 373-398.

Scientific names	*Salmo salar*	*Oncorhynchus masu*	*O. tshawytscha*	*O. gorbuscha*	*O. nerka*	*O. keta*	*O. kisutch*
Common names	Atlantic salmon	Cherry	Chinook, King, Spring, Quinnat, Tyee	Pink, Hump-backed, Humpy	Sockeye, Red, Blue-back	Chum, Dog	Coho, Silver
Length of fresh-water life	1–4 yrs.	1 yr.	few days to 2 yrs.	few days	few days to 3 yrs.	few days	1–2 yrs.
Length of ocean life	1–4 yrs.	1–2 yrs.	1–5 yrs.	16–20 mos.	½–4 yrs.	½–4 yrs.	½–1½ yrs.
Average length at maturity	30 in.	NA	36 in.	20 in.	23 in.	25 in.	24 in.
Range of length at maturity	22–38 in.	NA	16–60 in.	14–30 in.	15–33 in.	17–38 in.	17–36 in.
Average weight at maturity	10½ lb.	9 lb.	22 lb.	3–4 lb.	6–8 lb.	8–9 lb.	10 lb.
Range of weight at maturity	5½–25 lb.†	8–20 lb.	2½–125 lb.	1½–12 lb.	2–12 lb.	3–45 lb.	1½–30 lb.
Principal spawning months	Nov.–Jan.	NA	Aug.–Sept.	July–Sept.	July–Sept.	Sept.–Nov.	Sept.–Dec.
Fecundity of female (average no. of eggs)	600–800 per lb. of weight	NA	5,000	2,000	4,000	3,000	3,500

NA – not available † Record sport catch 70 lb. and net catch 103 lb.

Table 1.1 Biological characteristics of the salmon. (source: Netboy, 1980)

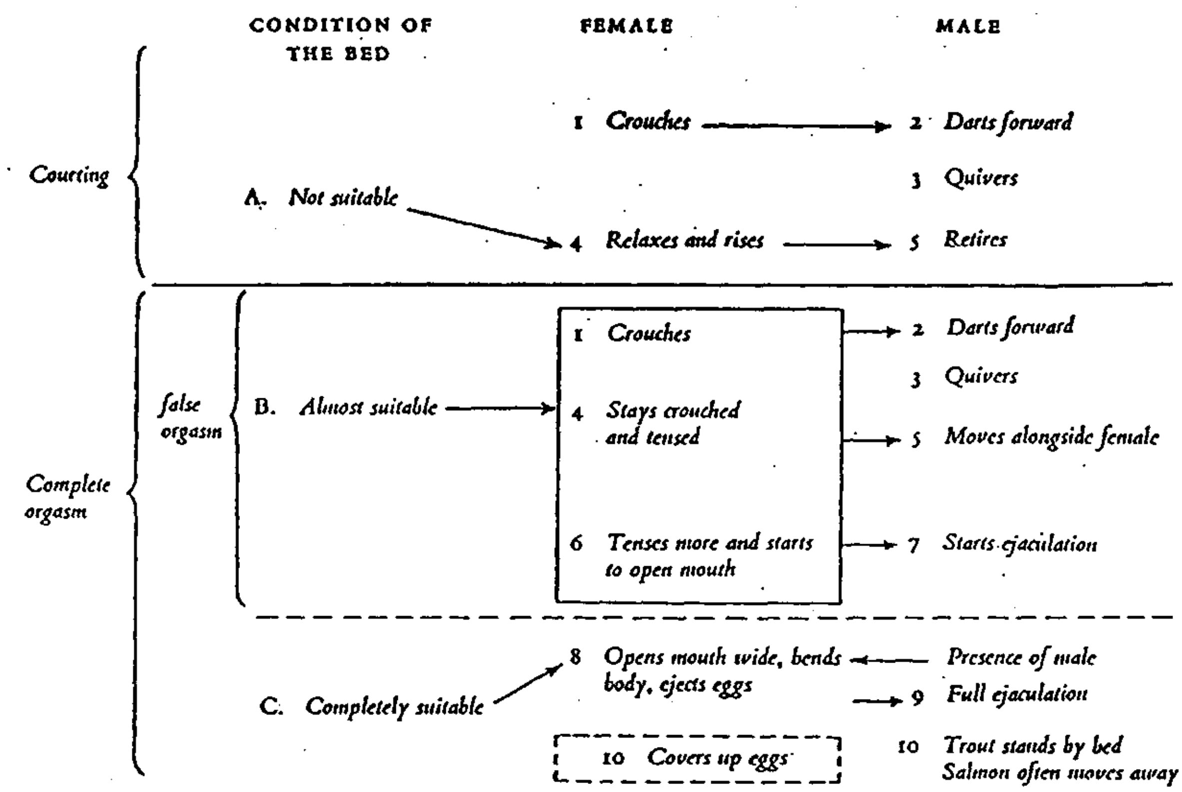


Table 1.2 Spawning behaviour of the salmon.
(source: Jones, 1959)

Year	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9
1886							18		
1887							21		
1888							28		
1889							14		
1890							22		
1891							30		
1892							8		
1893							13		
1894							19		
1895							25		
1896							6		
1897							12		
1898							18		
1899							14		
1900							24		
1901							16	7	
1902							5		
1903							8		
1904							2	13	
1905							40	45	
1906							38	32	
1907							40	20	
1908							37	33	
1909							40	8	
1910		10					47	5	
1911		31					80	39	421
1912	33	16					690	3	339
1913	14	1	1			1	27	30	780
1914	3	3	0	1	2	0	18	29	353
1915	0	0	6	3	3	1	20	14	317
1916	0	0	0	3	1	0	8	0	0
1917	0	0	1	2	0	1	7	0	0
Total	50	61	8	9	6	3	765	278	2211

Table 2.1 Catches landed by salmon fishermen at specific points along the Maas between Eijsden and the Nieuwe Maasmond.

The stretches of water referred to in the table have been numbered sequentially from Eijsden up to the Amer.
(source: Nengerman c.s., 1918)

jaar	stuks	jaar	stuks	jaar	stuks
1863[1>]	35350	1895	48486	1927	25565
1864	41800	1896	49470	1928	14854
1865	28500	1897	39850	1929	9658
1866	27500	1898	41633	1933	5987
1867	20900	1899	33454	1931	1268
1868	17430	1900	27598	1932	1079
1869	15500	1901	31891	1933	611
1870[2>]	21600	1902	37336	1934	2642
1871	23142	1903	34686	1935	2300
1872	32015	1904	27541	1936	2868
1873	58255	1905	3098	1937	2311
1874	79107	1906	31564	1938	1920
1875	56852	1907	40544	1939	2016
1876	42383	1908	23557	1940	982
1877	44300	1909	29657	1941	1169
1878	49649	1910	24447	1942	1200
1879	38807	1911	39376	1943	1913
1880[3>]	41736	1912	34580	1944	2315
1881	44376	1913	43594	1945	456
1882	55079	1914	28298	1946	230
1883	78609	1915	27425	1947[4>]	233
1884	92116	1916	24161	1948	347
1885	104422	1917	28346	1949	900
1886	84230	1918	21032	1950	327
1887	84509	1919	14559	1951	94
1888	68048	1920	10307	1952	53
1889	56144	1921	12039	1953	29
1890	34555	1922	13480	1954	27
1891	46091	1923	6520	1955	17
1892	65481	1924	9111	1956	2
1893	75175	1925	14586	1957	2
1894	57458	1926	9670		

Table 2.2 Estimate of the total Dutch salmon supply over the period 1863-1957, based on information from Kralingse Veer from 1863-1879 and on total supply figures from 1880-1957.
(source: RIVO data)

N.B. jaar — year
stuks — number

1> Figures taken from ten Houten & Co. pamphlet, 1903, detailing the catches landed at Kralingse Veer 1863-1869 (as referred to in the Report of the Government Commission on Salmon, 1916).
2> Figures taken from the Report of the Government Commission on Salmon (1916), detailing the catches landed at Kralingse Veer, 1870-1879.
3> Source: RIVO data, 1880-1948.
4> Source: Deelder & Van Drimmelen, 1959.

Year	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10
1865/66						35				
1867		10				97				
1868		37				95				
1869		42				57				
1870		49				52				
1871		19				40				
1872		56				79				
1873		93				81				
1874		77				113				
1875		48				141				
1876		17				93				428
1877		44				109				
1878		59				104				680
1879		40				57				253
1880		51				88				927
1881		53				29				2261
1882		35				62				1315
1883		60				126				1948
1884		20				62				3332
1885		17				33				6026
1886		42				40				4353
1887		29				200				3735
1888		53				68				2384
1889		47				22				2595
1890		32				21				2024
1891		25				19				1401
1892		37				6				1735
1893		24	878			14				1977
1894		82	832			6				2033
1895		59	428							1418
1896		92	590							1588
1897		115	884							2388
1898	614	142	744	276						1818
1899	261	37	338	214						1277
1900	191	38	268	119				649		1130
1901	204	81	351	106				824		1613
1902	274	76	312	61				518		2275
1903	290	68	245					894		2025
1904	111	30	120							1332
1905	196	38	333		60					2338
1906	117	63	294		50					1307
1907	158	102	295		40					1756
1908	259	94	283		38					1021
1909	139	76	229		40					945
1910	202	86	331		60					214
1911	474	153	181		55					475
1912	450	140	302		58		94			759
1913	656	185	490		60		406		270	1308
1914	247	89	324		55	4	147		362	704
1915		101	101		65	5	231		799	1160
1916		33	3		22	4	315		877	876
1917					16	2	384		870	746
Total	4843	3096	9156	776	619	1964	1577	2885	3178	69880

Table 2.3 Catches landed by salmon fishermen at specific points along the Rivers Rhine, Waal and Merwede up to and including Gorinchem.

The stretches of water referred to in the table have been numbered sequentially from the German border up to Gorinchem.
(source: Nengerman c.s., 1918)

1912

						Total
M.		5	5	6	4	20
T.		7	5	4	3	19
W		6	8	2	2	18
T		4	7	0	1	12
F.	4	8	1	1	1	15
S	4	5	1	0	0	10

1913

																						totaal
M.	5	7	1	3	7	17	7	0	3	0	0	15	4	9	3	7	2	4	2	0	7	103
T.	0	5	6	5	2	11	3	0	2	5	0	6	2	13	2	3	3	5	0	8	0	81
W	10	3	7	0	7	0	4	0	4	0	9	2	4	11	1	4	7	3	0	6	0	82
T	9	7	10	0	5	1	0	4	4	0	7	6	7	1	2	2	3	2	0	2	0	72
F.	0	5	12	0	8	2	0	1	4	0	5	5	2	6	0	0	0	0	0	0	0	50
S	6	0	3	0	6	2	0	3	4	0	0	0	4	0	0	0	0	0	0	0	0	28

1914

									totaal
M.	1	2	2	0	4	6	9	9	33
T.	3	5	3	0	5	5	10	6	37
W	2	3	1	1	2	4	6	1	20
T	0	6	0	3	1	0	2	0	12
F.	3	10	0	2	4	10	0	0	29
S	4	3	0	3	0	6	0	0	16

1915

																		totaal
M.		2	8	6	9	7	3	10	3	2	2	13	11	4	7	1	8	96
T.		2	4	4	6	9	3	0	5	1	1	6	4	1	3	0	5	54
W	4	2	0	4	2	0	3	5	5	3	0	2	3	0	0	0	0	33
T	0	1	0	0	8	5	2	2	1	2	0	0	1	0	0	0	0	22
F.	1	2	0	1	3	5	1	1	0	0	0	0	0	0	0	0	0	14
S	0	2	5	0	0	2	0	3	0	0	0	0	0	0	0	0	0	12

1916

																						totaal
M.	0	1	6	4	0	0	4	7	0	2	11	9	17	11	21	1	6	17	2	11	2	132
T.	1	0	11	0	0	1	6	8	0	3	5	1	1	4	7	3	5	2	0	8	0	66
W	0	0	3	0	3	2	2	2	0	2	1	0	4	7	6	2	2	0	0	4	0	40
T	0	2	4	0	0	1	2	0	3	2	3	2	2	3	0	4	0	0	0	1	0	29
F.	0	2	0	0	2	0	1	0	2	0	5	2	1	3	0	4	1	1	0	0	0	24
S	0	3	0	0	0	0	7	0	1	3	1	1	0	3	5	0	0	0	0	0	0	24

1917

																							totaal
M.	1	4	0	5	2	3	8	6	11	1	7	9	8	2	5	17	10	5	12	1	6	4	127
T.	0	6	0	1	0	3	11	5	6	1	7	3	1	1	8	8	2	2	8	0	2	4	79
W	0	1	6	4	0	3	6	0	13	1	2	0	0	0	2	3	0	2	0	0	3	8	54
T	3	1	0	3	0	4	3	3	3	0	3	0	3	1	2	2	9	3	6	1	0	0	50
F.	3	2	3	1	0	0	4	2	4	3	2	0	1	0	3	3	9	1	0	0	0	0	41
S	5	1	3	2	1	1	2	1	4	2	1	0	0	0	0	1	7	0	1	0	0	0	33

Summary 1912 - 1917 :

	Totaal	Per day
93 *Mondays*	511 Salmon	± 5.5 Zalmen
93 *Tuesdays*	336	± 3.6 Zalmen
94 *Wednesdays*	237	± 2.5 Zalmen
94 *Thursdays*	197	± 2.1 Zalmen
95 *Fridays*	173	± 1.8 Zalmen
96 *Saturdays*	123	± 1.3 Zalmen

Table 2.4 The daily catch of Fisherman No. 7 on the River Waal (1912-1917).
(source: Nengerman c.s., 1918)

YEARS	Ammerstol.	Dordrecht	Gorinchem	Hardinxveld	Kralingse Veer	Krimpen a.d. Lek	Rotterdam	Woudrichem	Other landing points	Total
1919	948	–	41	479	11 110	5	11	1 052	913	14 559
1918	1 321	1	79	909	14 111	27	21	4 095	468	21 032
1917	1 964	11	702	1 547	18 526	62	46	3 093	2 395	28 346
1916	1 917	7	795	4 318	16 128	30	24	2 128	1 814	24 161
1915	1 908	67	1 083	1 346	20 004	99	–	3 017	1 912	29 439
1914	1 152	165	673	764	22 500	67	–	3 044	526	28 891
1913	2 744	122	1 274	2 539	30 212	170	–	6 703	1 634	45 398
1912	3 007	90	723	1 358	26 230	164	–	3 172	345	34 925
1911	2 881	89	475	2 624	28 801	120	–	4 506	288	39 664
1910	1 470	128	192	990	19 768	62	–	1 899	394	24 842
1909	1 871	204	927	1 894	22 982	58	–	1 179	229	29 286
1908	2 551	233	1 019	2 248	21 923	136	–	1 593	283	29 840
1907	3 219	510	1 785	2 835	31 075	98	–	1 120	295	40 839
1906	2 507	192	1 297	1 483	25 175	86	–	810	294	31 858
1905	2 015	272	2 333	2 446	23 384	27	–	531	333	31 314
1904	2 166	140	1 425	1 233	20 802	35	–	1 775	120	27 661
1903	3 183	153	2 006	1 424	26 650	100	–	1 270	245	34 931
1902	3 160	97	2 263	1 481	29 412	96	–	930	312	37 648
1901	2 653	122	1 597	1 248	25 789	107	–	482	351	32 242
1900	3 051	189	1 113	1 077	21 551	–	–	617	268	27 866
1899	3 414	636	1 275	973	25 920	–	–	1 236	338	33 782
1898	4 554	2 197	1 819	3 657	41 622	–	–	1 985	744	56 578
1897	4 853	3 281	2 388	2 180	38 034	–	–	684	884	52 307
1896	3 845	1 204	1 588	1 885	48 264	–	–	470	590	57 846
1895	4 663	1 391	1 418	2 699	48 201	–	–	976	428	59 938
1894	6 201	1 637	2 033	3 868	55 599	–	–	1 228	882	71 398
1893	7 537	3 040	1 980	9 370	74 278	–	–	3 799	878	100 882
1892	8 639	–	1 735	–	64 686	–	–	–	–	– –
1891	6 774	–	1 401	–	44 643	–	–	–	–	– –
1890	3 530	–	1 242	–	33 886	–	–	–	–	– –
1889	6 830	–	2 606	–	54 015	–	–	–	–	– –
1888	6 833	–	2 393	–	66 248	–	–	–	–	– –
1887	7 474	–	3 761	–	84 500	–	–	–	–	– –
1886	5 736	–	4 353	–	83 991	–	–	–	–	– –
1885	6 523	–	6 026	–	103 650	–	–	–	–	– –
1884	10 002	–	3 332	–	1) 91 878	–	–	–	–	– –
1883	9 593	–	1 959	–	1) 78 609	–	–	–	–	– –
1882	5 907	–	1 315	–	1) 55 079	–	–	–	–	– –
1881	4 065	–	2 261	–	1) 44 376	–	–	–	–	– –
1880	3 184	–	927	–	1) 41 737	–	–	–	–	– –
1879	3 600	–	253	–	1) 38 914	–	–	–	–	– –
1878	4 337	–	680	–	1) 49 691	–	–	–	–	– –
1877	–	–	428	–	1) 44 580	–	–	–	–	– –
1876	–	–	546	–	1) 42 293	–	–	–	–	– –
1875	–	–	–	–	1) 56 436	–	–	–	–	– –
1874	–	–	–	–	1) 77 070	–	–	–	–	– –
1873	–	–	–	–	1) 58 384	–	–	–	–	– –
1872	–	–	–	–	1) 32 228	–	–	–	–	– –
1871	–	–	–	–	1) 23 209	–	–	–	–	– –
1870	–	–	–	–	1) 21 687	–	–	–	–	– –

Table 2.5 Number of salmon landed from Dutch fisheries during the period 1870-1919 at various sites around the country.

	Height of the river bed relative to A.O.D.*		Water level relative to A.O.D. at a discharge rate of 787 m³/sec				Depth of the river (m)				Deepening of the river since 1900 (m)	
monitoring periods	1900	1934	1895-1900		1930-1933		1900		1939			
Hulhuizen	+ 6,20	+ 4,80	+ 8,65		+ 8,30		2,45		3,50		1,05	
Nijmegen	+ 4,90	+ 3,40	+ 7,28		- 6,70		2,25		3,30		1,05	
Dodewaard	+ 2,05	+ 1,30	+ 5,05		+ 4,70		3,00		3,40		0,40	
Tiel	+ 0,65	- 0,40	+ 3,60		+ 2,95		2,95		3,35		0,40	
St. Andries	+ 0,05	- 2,30	+ 2,45		+ 1,70		2,40		4,00		1,60	
			high water level	low water level	high water level	low water level	high water level	low water level	high water level	low water level	*high water mark*	*low water mark*
Zaltbommel	- 1,70	- 3,20	+1,70	+1,70	+1,65	+0,70	3,40	3,40	4,75	3,80	1,35	0,40
Herwijnen	- 1,80	- 4,10	+1,35	+0,80	+1,20	+0,15	3,15	2,60	5,30	4,25	2,15	1,65
Gorinchem	- 2,50	- 5,00	+2,15	+0,10	+1,10	-0,35	3,65	2,60	6,10	4,75	2,45	2,15

Table 2.6 Deepening of the River Waal since 1900 (source: RIVO data)

* Amsterdam Ordnance Datum - mean sea level as defined for Amsterdam

	Height of the river bed relative to A.O.D.*		Water level relative to A.O.D. at a discharge rate of 280 m^3/sec		Depth of the river (m)		Deepening of the river since 1891 (m)
Monitoring periods	1891	1934	1891-1895	1930-1935	1891	1934	
Arnhem	+ 5.40	+ 4.00	+ 8.00	+ 7.75	2.60	3.75	1.15
Wijk bij Duurstede	+ 0.60	- 0.40	+ 3.50	+ 2.50	2.90	1.90	-
Culemborg	0	- 1.60	+ 2.45	+ 1.25	2.45	2.85	0.40
Vreeswijk	- 1.50	- 3.05	+ 1.55	+ 0.55	3.05	3.60	0.55
Beneden-Lek (130 km from Lobith)	- 3.65	- 6.25	- 0.55	- 0.55	3.10	5.70	2.60

Table 2.7 Deepening of the Rivers Nederrijn and Lek since 1891. (source: RIVO data)

* Amsterdam Ordnance Datum - mean sea level as defined for Amsterdam

	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL NUMBER
20-24	-	-	-	-	-	-	1	1	-	-	-	-	2
25-29	-	-	-	-	-	-	2	2	-	1	-	-	5
30-34	-	-	-	-	1	1	2	2	5	3	1	-	15
35-39	2	1	-	1	2	7	5	1	3	-	-	-	22
40-44	-	-	-	-	8	14	10	11	3	-	-	-	46
45-49	-	-	-	2	6	29	35	40	9	2	2	-	125
50-54	-	-	-	1	7	13	24	63	18	8	1	-	135
55-59	-	-	1	1	8	16	30	47	9	4	1	2	119
60-64	-	-	1	-	16	17	30	46	4	6	-	1	121
65-69	2	1	-	4	10	8	29	45	4	3	1	-	107
70-74	-	-	-	4	3	3	16	14	6	3	-	-	49
75-79	-	-	-	1	2	2	7	9	-	1	-	-	22
80 and over	-	2	4	1	2	3	3	4	-	-	-	-	19
Total	4	4	6	15	65	113	194	285	61	31	6	3	1) 787

Table 2.8 Catches of salmon landed from the sea at IJmuiden (1907-1912).

1897/98	1 140	1926/27	148
1898/99	1 241	1927/28	442
1899/1900	1 464	1928/29	225
1900/01	878	1929/30	135
1901/02	737	1930/31	507
1902/03	569	1931/32	468
1903/04	495	1932/33	332
1904/05	777		
1905/06	1 072		
1906/07	984		
1907/08	992		
1908/09	1 258		
1909/10	1 129		
1910/11	1 577		
1911/12	766		
1912/13	730		
1913/14	847		
1914/15	937		
1915/16	969		

Table 2.9 The number of spawning salmon caught in the Rivers Mosel, Sieg, Ahr and Dühn, 1897-1916 and 1926-1933. (source: RIVO data)

Year	Sieg	Mosel	Other rivers	Total
1891	191 702	320 929		512 631
1892	102 200	1 215 200		1 317 400
1893	254 000	1 601 000	12 000	1 867 000
1894	250 000	2 108 000	47 000	2 405 000
1895	236 625	1 786 000	35 000	2 057 625
1896	168 700	2 355 000	45 000	2 568 700
1897	70 000	1 090 600	47 000	1 207 600
1898	318 250	2 533 000	20 000	2 871 250
1899	123 000	3 181 000	--	3 304 000
1900	105 000	2696 000	--	2 801 000
1901	12 000	3 161 000	--	3 173 000
1902	25 000	2 427 000	--	2 452 000
1903	109 500	1 851 400	--	1 960 900
1904	271 000	2 559 000	--	2 830 000
1905	195 000	2 492 000	--	2 687 000
1906	407 000	1 300 000	--	1 707 000
1907	411 000	1 400 000	--	1 811 000
1908	700 000	1 363 000	--	2 063 000
1909	800 000	1 300 000	--	2 100 000
1910	--	1 300 000	--	1 300 000
1911	--	1 265 000	--	1 265 000
1912	--	1 702 000	--	1 702 000
1913	--	1 206 000	--	1 206 000
1914	--	1 139 000	--	1 139 000
1915	--	1 202 000	--	1 202 000
1916	--	1 346 000	--	1 346 000
1917	--	1 340 000	--	1 340 000
1918	--	1 148 000	--	1 148 000
1919	--	1 050 000	--	1 050 000
1920	--	783 000	--	783 000
1921	--	540 000	--	540 000
1922	--	114 000	--	114 000
1923	--	382 000	--	382 000
1924	--	50 000	--	50 000
1925	--	69 000	--	69 000
1926	--	66 500	--	66 500
1927	20 500	728 200	--	748 700
1928	15 000	782 100	--	797 100
1929	--	523 400	--	523 400
1930	--	383 300	--	383 300
1931	22 500	742 500	138 000	903 000
1932	--	927 134	6 000	933 134
1933	20 000	483 700	--	503 700

Table 2.10 Overview of the number of juvenile salmon released in the Rivers Mosel and Sieg.
1. produced from 20 mature fish, 15 males, 5 females
2. produced from 6 mature fish, 3 males, 3 females.

Table 3.1 Salmon catches in the Dutch part of the Rhine, 1940-1947. (source: RIVO data)

Year	Large winter and large summer salmon		Small summer salmon		Grilse		Total
	Number	%	Number	%	Number	%	
1940	212	22	730	74	40	4	982
1941	370	32	754	64	45	4	1169
1942	604	50	401	34	195	16	1200
1943	351	18	1314	69	248	13	1913
1944	428	19	1813	78	74	3	2315
1945	88	19	357	78	11	3	456
1946	150	65	73	32	7	3	230
1947*	96	45	85	39	35	16	216

* up to November (Statistics not reliable after 1 July)

Table 3.2 Length and frequence of salmonids caught in the River Waal and the Pannerden Canal, May 1951.
Catches of the Fisheries Inspectorate, assisted by Mrs. Zweinstra, Sepers and Udo (professional fishermen).
(source: RIVO data)

Length in cm	Total number of salmon	Total number of sea trout	Total
6	-	2	2
7	-	-	-
8	2	-	2
9	7	-	7
10	34	4	38
11	28	4	32
12	48	7	55
13	31	12	43
14	25	31	56
15	24	54	78
16	9	76	85
17	7	106	113
18	9	83	92
19	1	54	55
20	4	80	84
21	1	30	31
22	-	44	44
23	-	18	18
24	-	21	21
25	1	5	6
26	-	3	3
27	-	2	2
28	-	-	-
29	-	1	1
30	-	1	1
Totaal	231	638	869

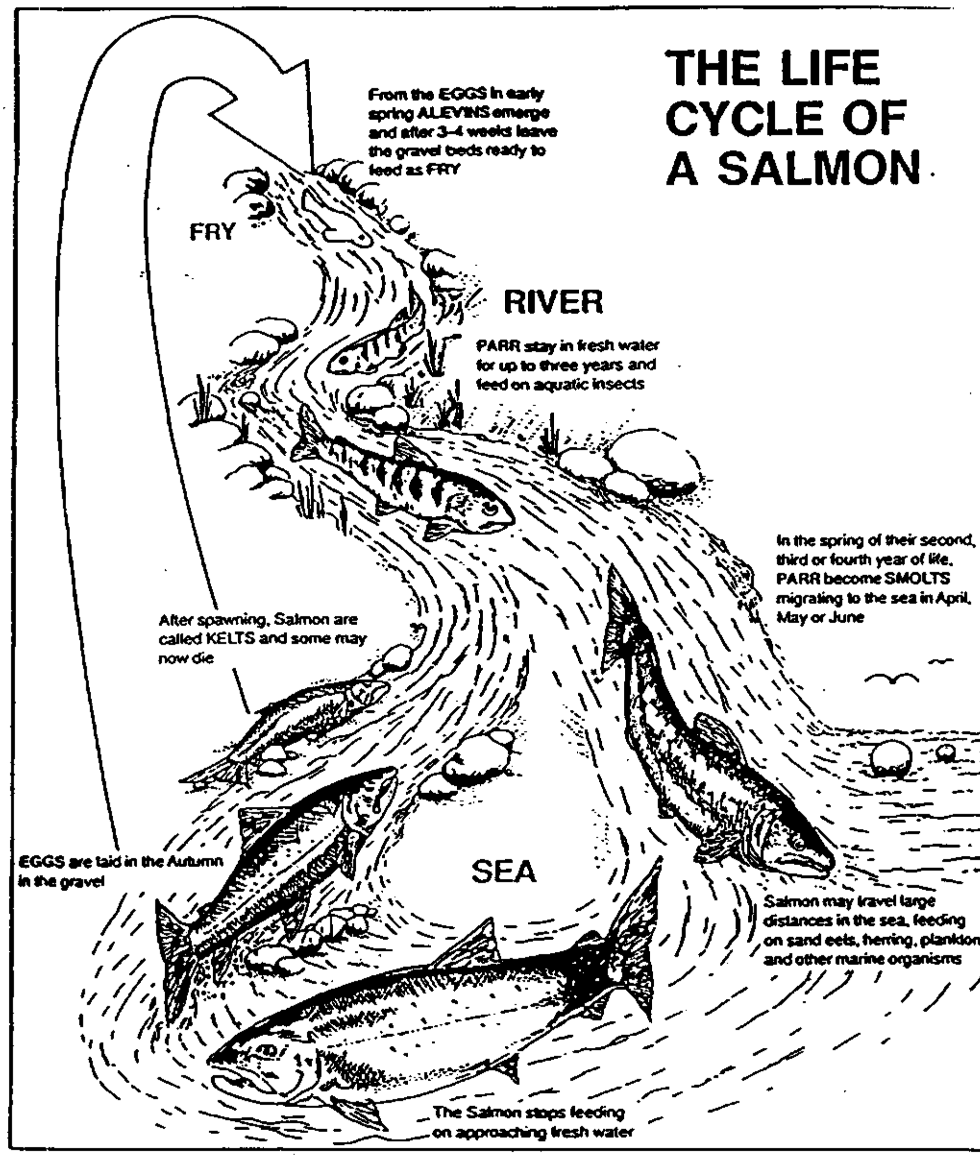


Fig. 1.1 The life cycle of a salmon.
(source: Welsh Water's Fisheries and Conservation News, 1988, No. 6)

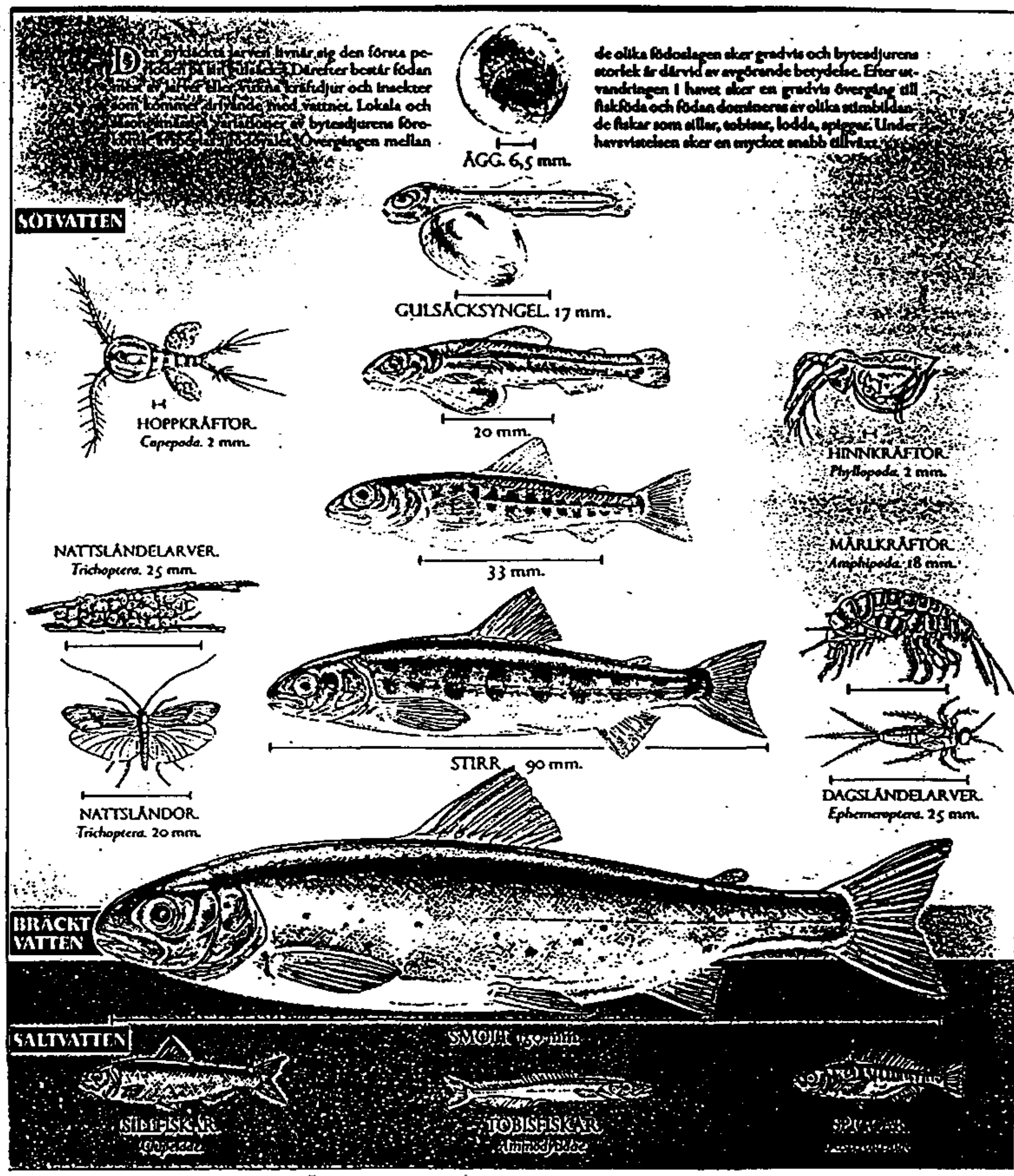
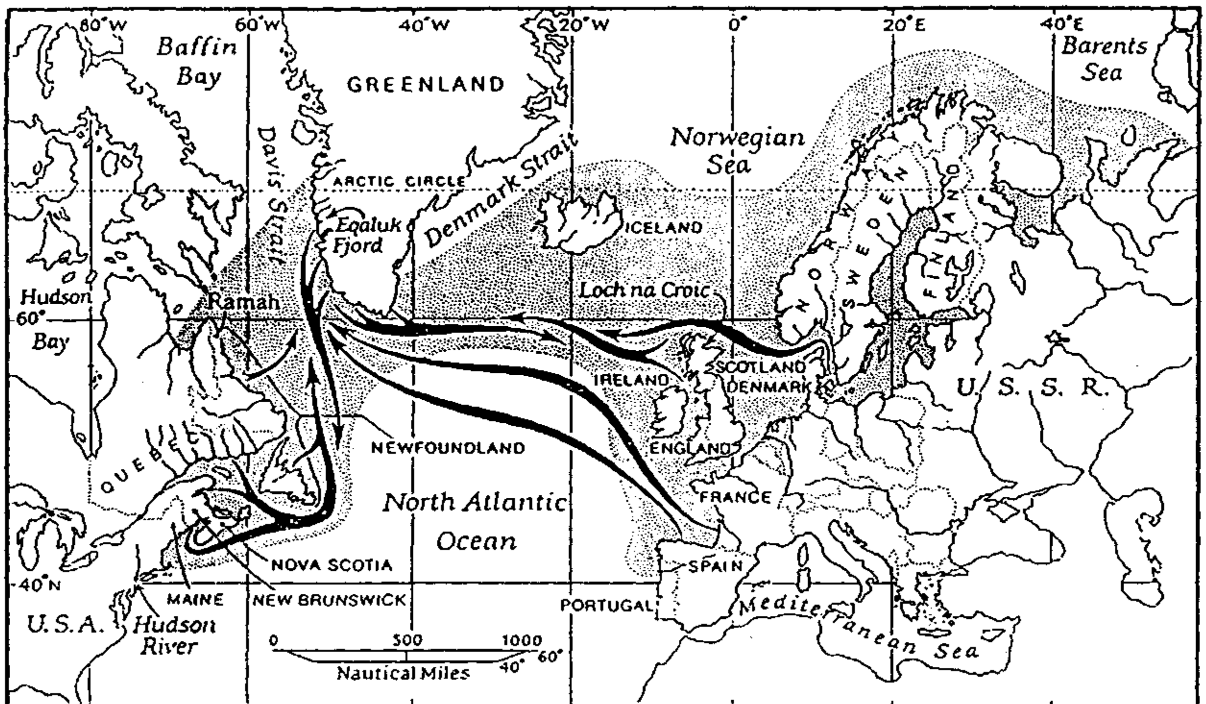
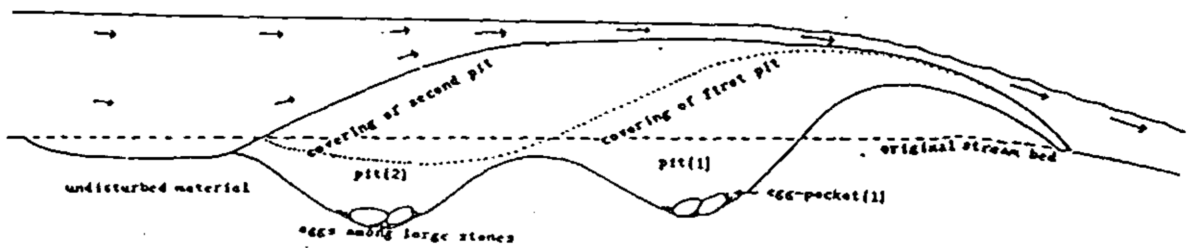


Fig. 1.2 The development of the salmon.
(source: Lackamin poster, Sweden)



Oceanic Migrations of the Atlantic Salmon of Europe and North America.

Fig. 1.3 Oceanic migration routes of the Atlantic salmon of Europe and North America.
(source: Netboy, 1980)



Vertical longitudinal section of salmon redd at head of rapids with two egg pockets. Arrows indicate current. Interrupted line—original stream bed; dotted line—stream bed after first pit is covered; continuous line—stream bed after second pit is covered.

Fig. 1.4 The spawning bed of the salmon.
(source: White, 1942)

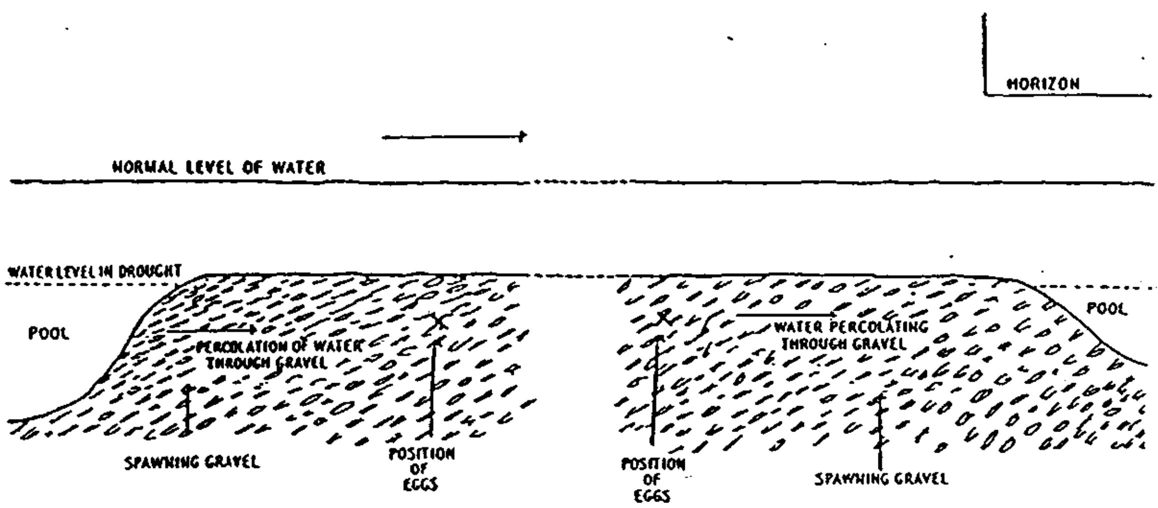


Fig. 1.5 The spawning bed of the salmon.
(source: Jones, 1959)

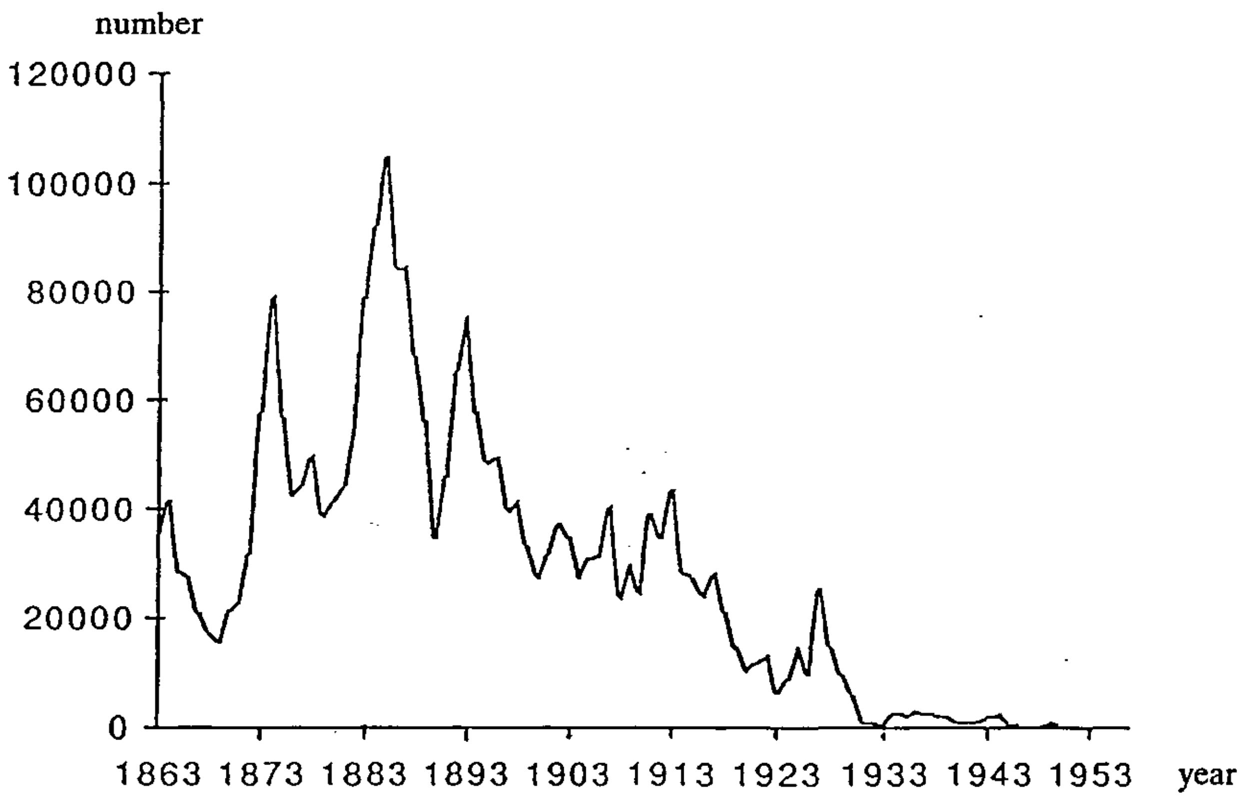


Fig. 2.1 Dutch salmon catches 1863-1957.
(source: RIVO data)

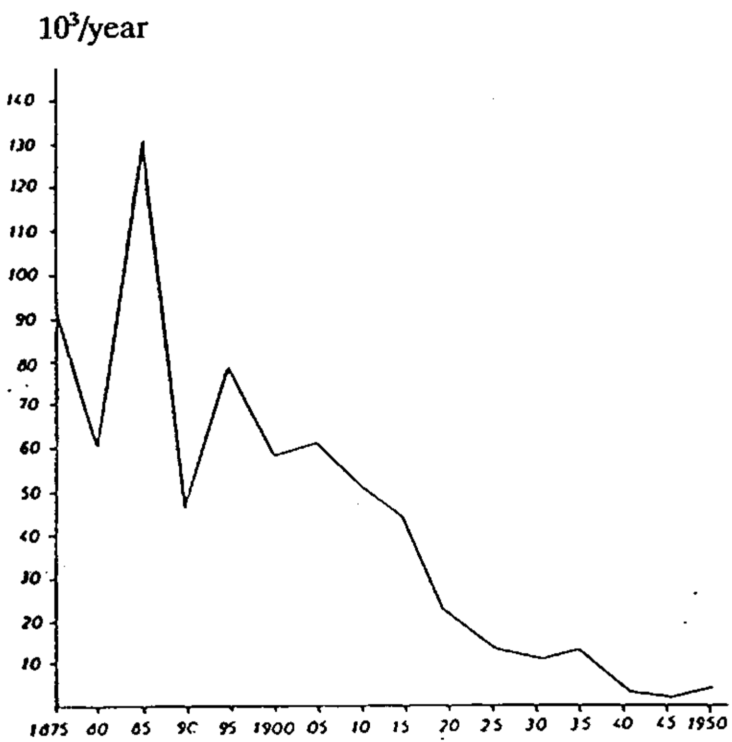


Fig. 2.2 German salmon catches 1875-1950.
(source: Kuhn, 1976)

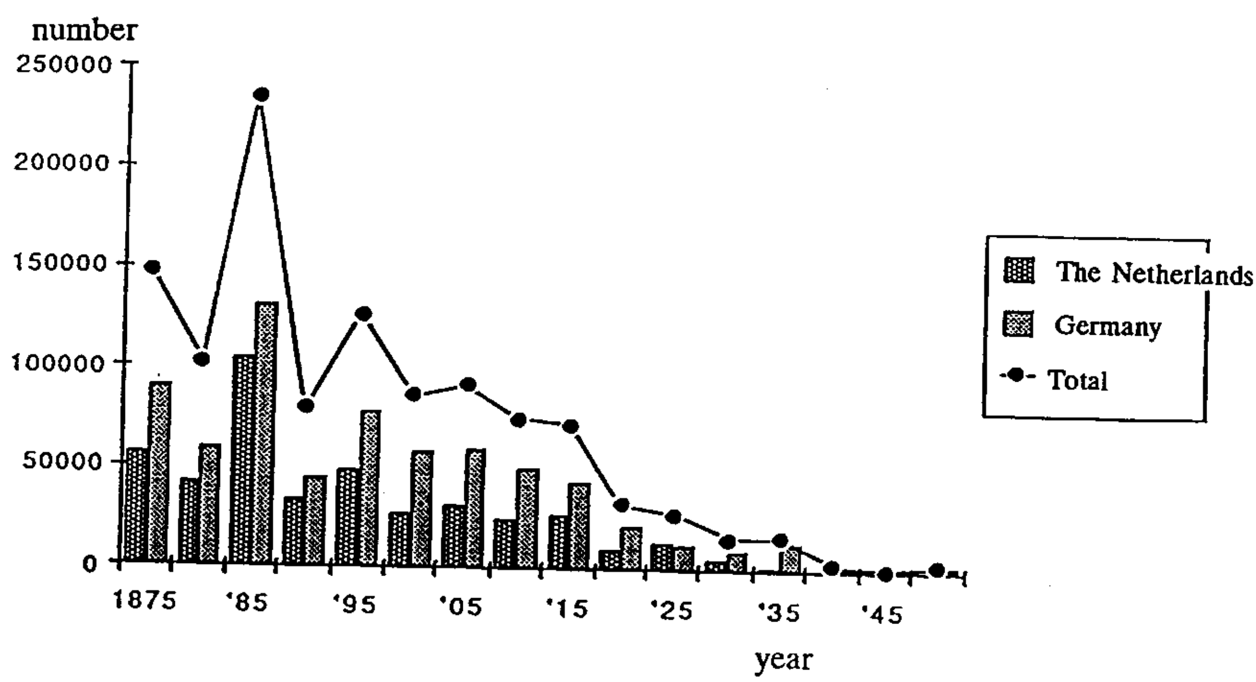


Fig. 2.3 Dutch and German salmon catches 1875-1950.
(source: RIVO data, Kuhn, 1976)

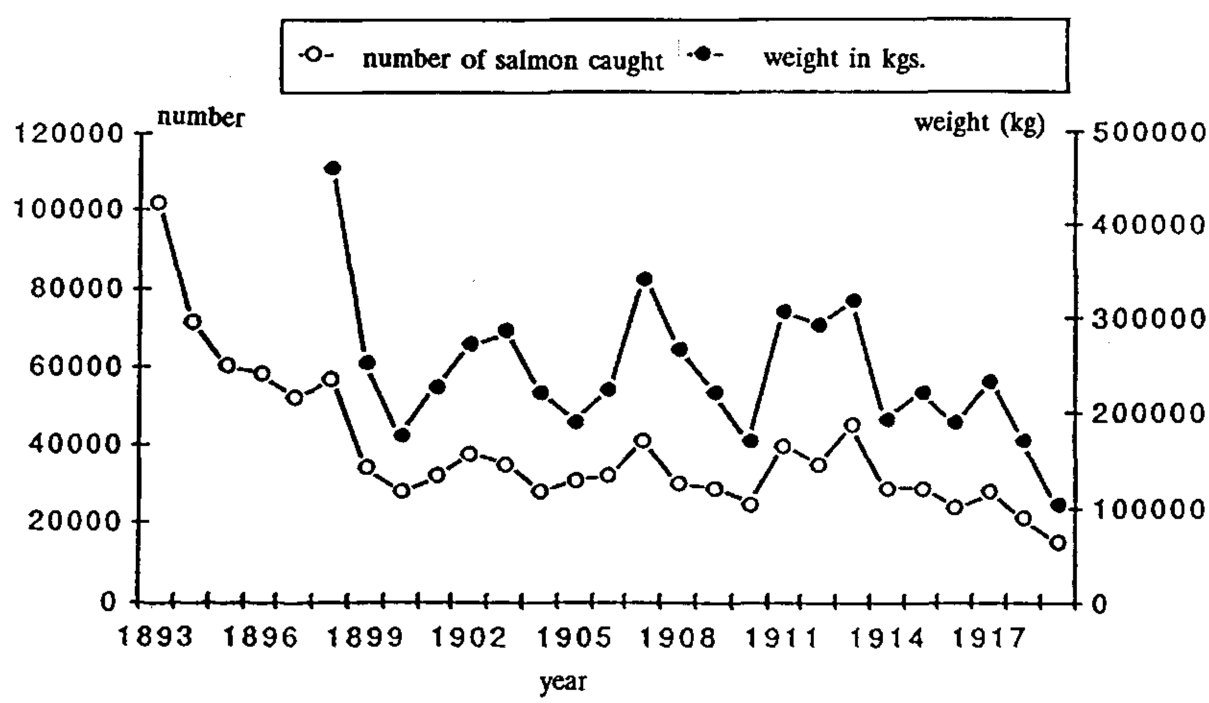


Fig. 2.4 The weight and number of salmon caught over the period 1893-1919. (source: RIVO data)

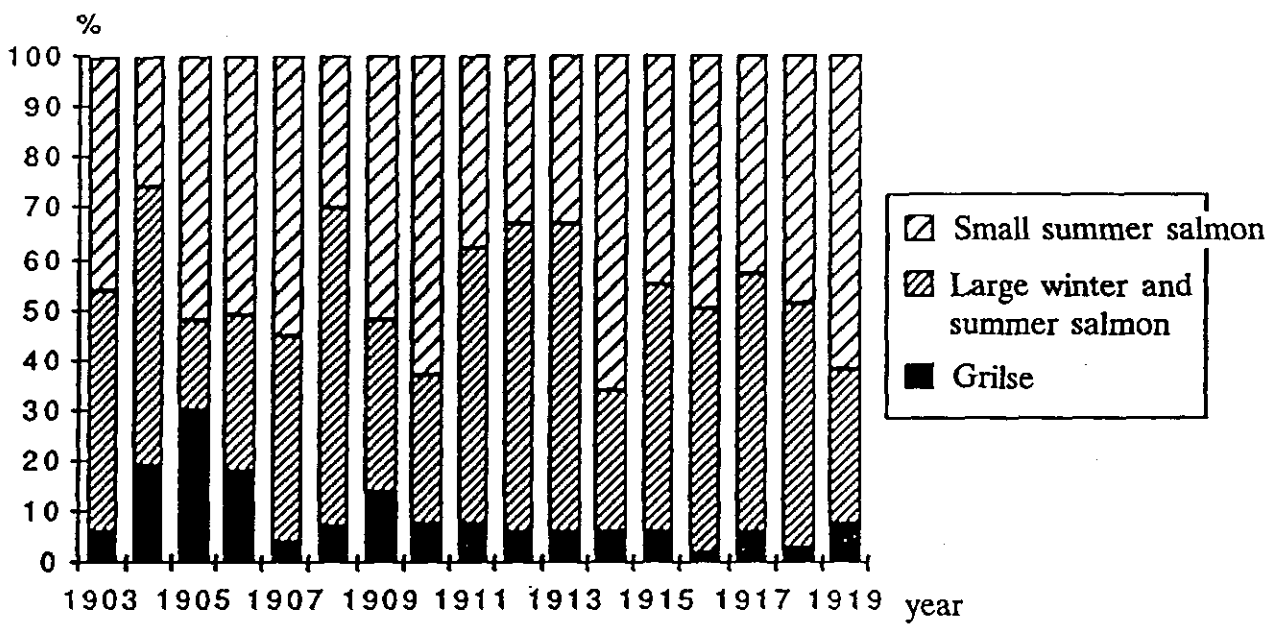


Fig. 2.5 Proportion of the various types of salmon sold over the period 1903-1919.
(source: RIVO data)

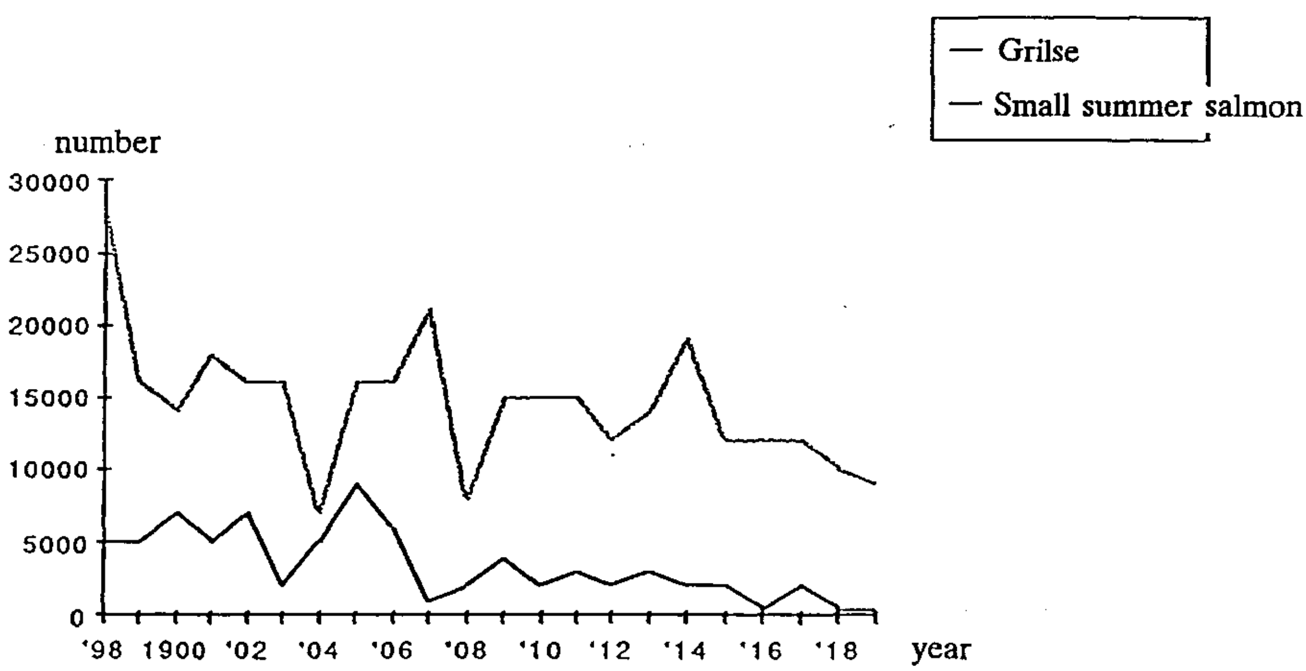


Fig. 2.6 Numbers of salmon sold over the period 1898-1919. (source: RIVO data)

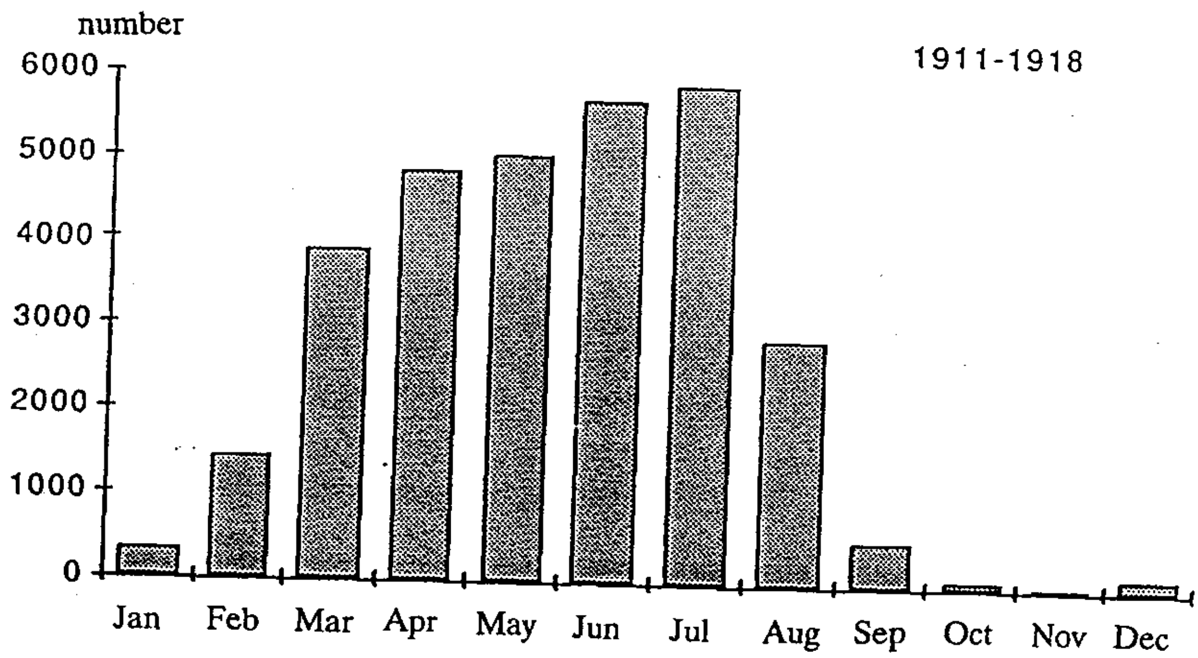


Fig. 2.7 Monthly supply of salmon, 1911-1918.
(source: RIVO data)

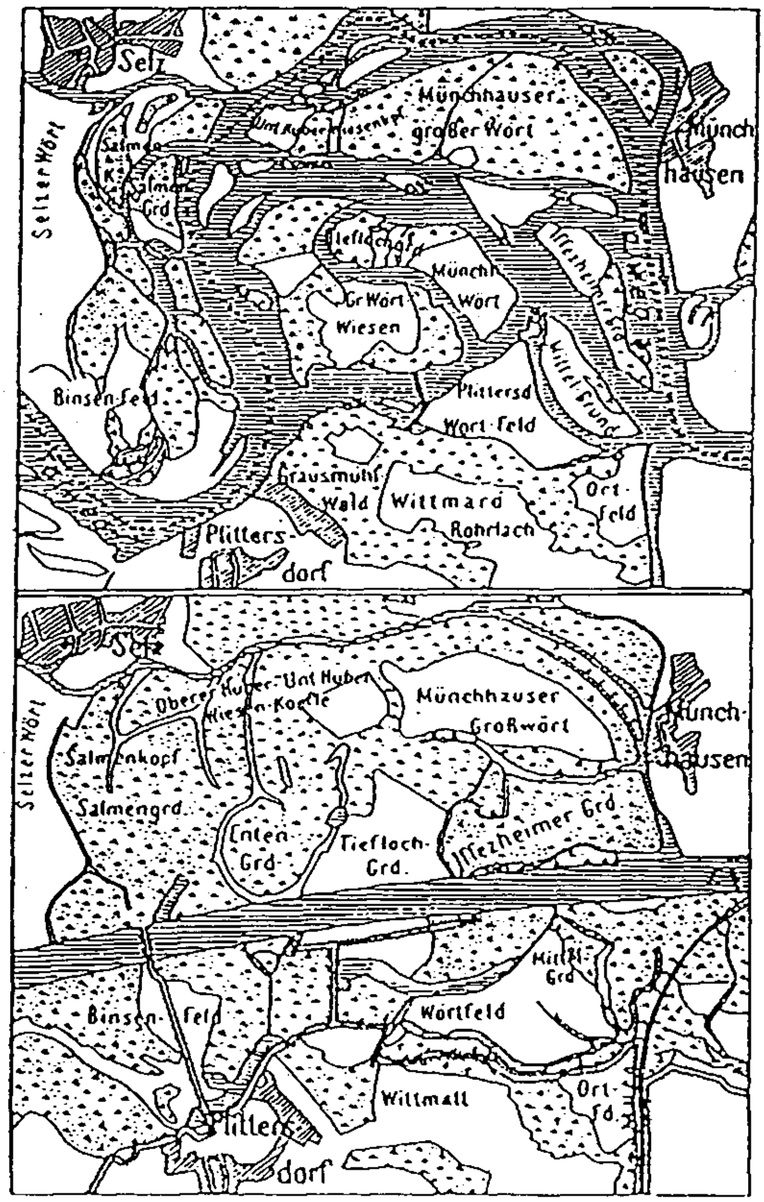


Fig. 2.8 Straightening of the River Rhine at Plittersdorf. (source: Kuhn, 1976)

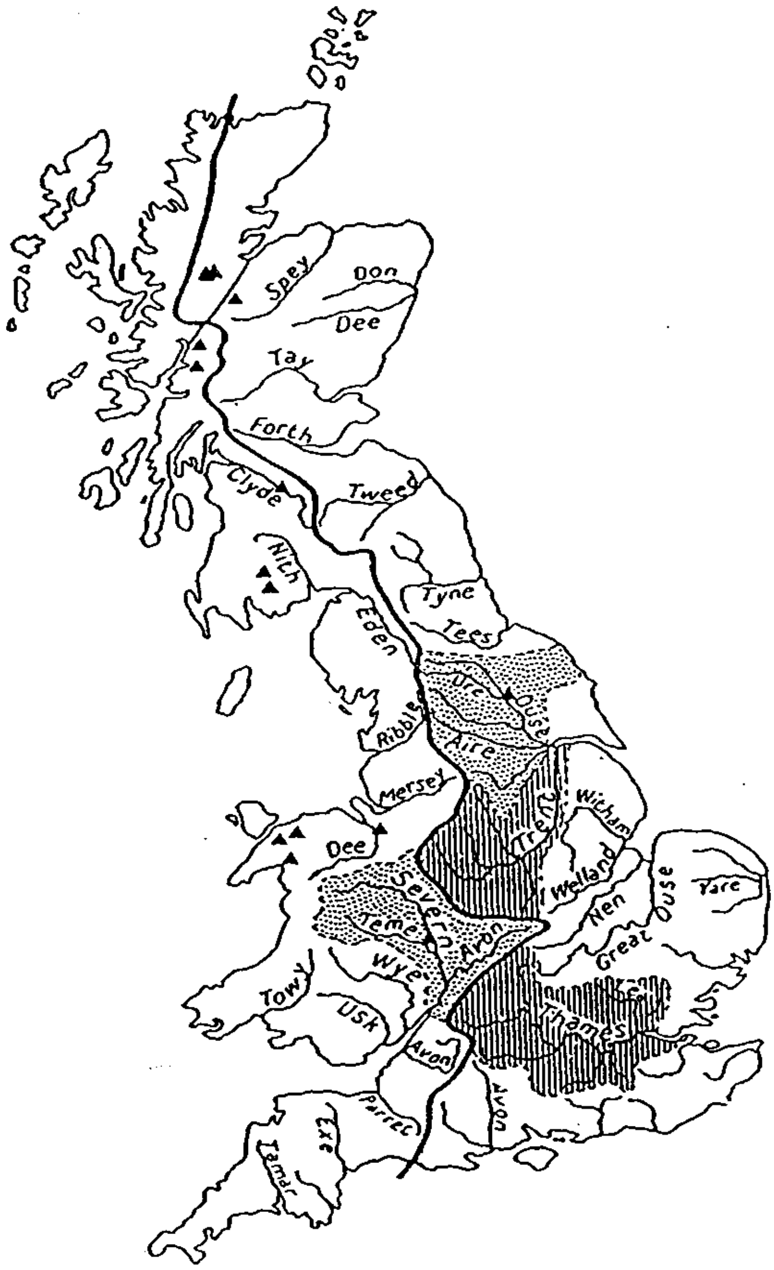
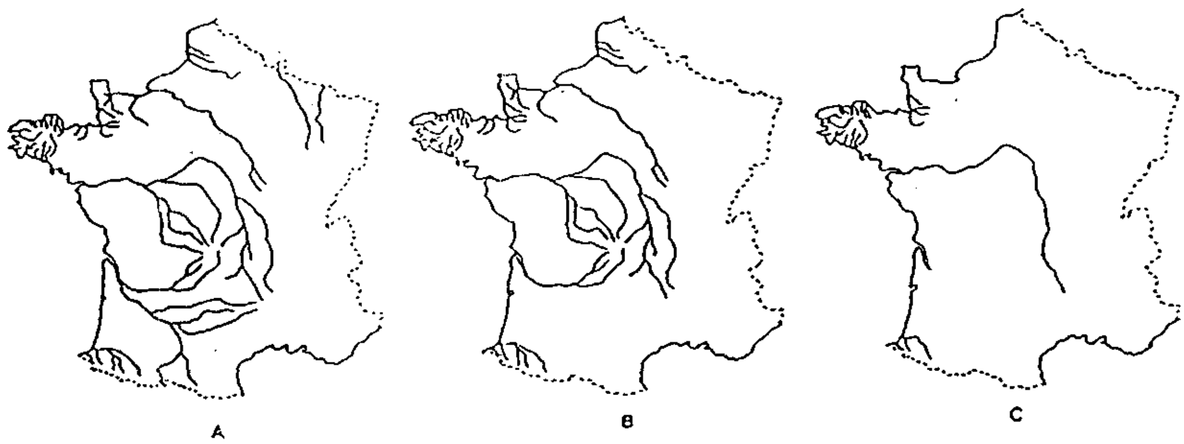


Fig. 2.9 British Salmon rivers.
(source: Netboy, 1980)

a)



b)

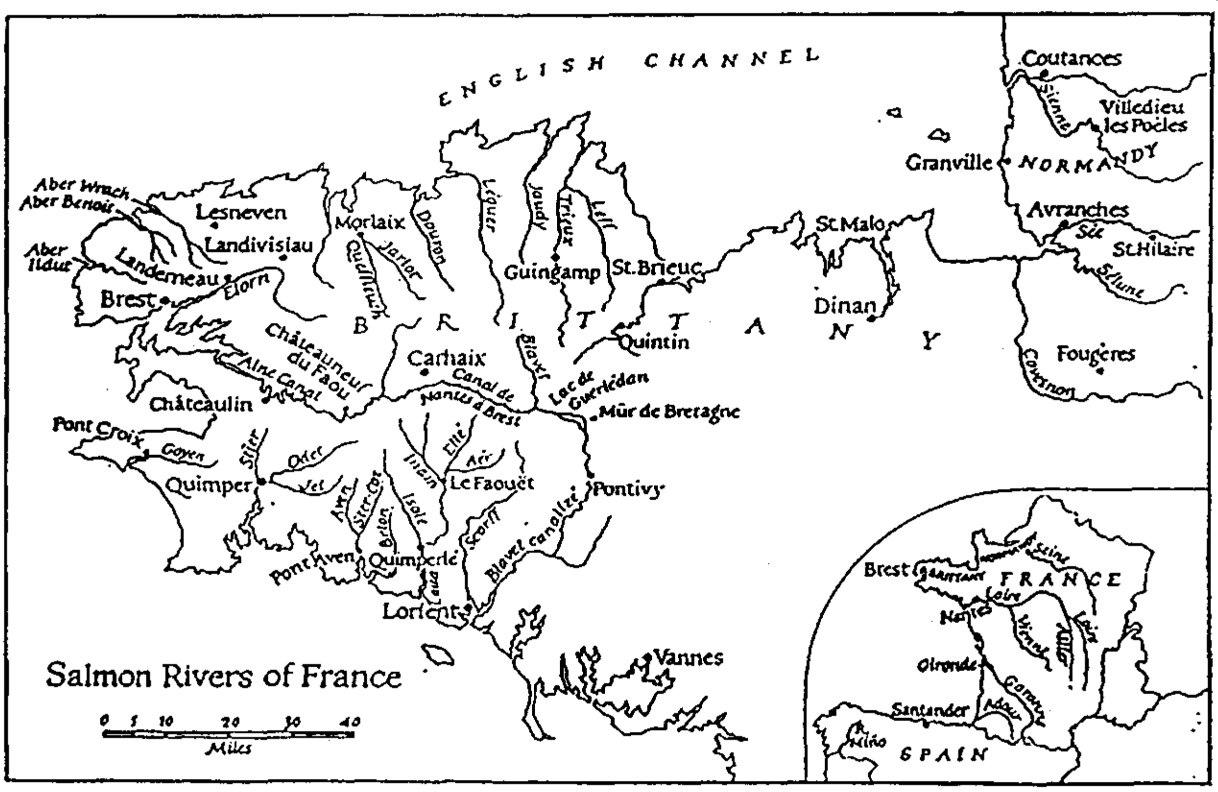


Fig. 2.10 a) Salmon rivers of France:
A - mid 18th cent.
B - end 19th cent.
C - end 20th cent.
(source: Thibault, 1987)
b) Salmon rivers of Brittany, circa 1980.
(source: Netboy, 1980)