Knowledge document trout
*Salmo trutta* (English translation)
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The trout shows a great flexibility in adaptation to different environments and circumstances, as can be seen from its adaptations to non-migratory and migratory lifestyles. *Salmo trutta* has two main ways of life, called Sea Trout and Brown trout. Brown trout lives its entire life in fresh water and stays (apart from little local migrations) in its water of origin. Sea trout is an anadromous species. Its adult life is spend in the sea, and only for reproduction it migrates into the river. Sea trout juveniles live their first years in the river, after which they swim to sea. Furthermore, in other countries (e.g. Ireland) a third form exists. Lake trout (*Salmo trutta lacustris*) is also an anadromous form, which migrates within lakes and rivers. These strategies seem to have been developed to achieve an optimum fitness.

The original range of the sea trout is Europe and parts of Eurasia. Trout seems to be somewhat less critical of its environment than for example salmon, and as a consequence the species has not so strong deteriorated as many salmon populations have. Improving and strengthening sea trout populations can piggyback in the context of salmon recovery programs. Nevertheless, in many countries the sea trout and brown trout populations declined sharply between the 18th and 20th century in most rivers of Europe (in many cases this lead towards regional extinction). The main causes are destruction of spawning and rearing habitat, water pollution, over fishing and an increasing number of morphological man-made adaptations in the river itself, including installation of migration barriers (such as dams and hydropower).

In many countries (including Canada and the U.S.) the trout has been (re) introduced. The fish has some economic importance. For restoration and preservation purposes, trout needs availability of sufficient spawning and rearing habitat. Sea trout needs to migrate from the sea to the spawning grounds and vice versa. And therefore Sea trout needs progressive fresh-salt transitions and good water quality. Fisheries management is important as well, since mortalities from by catch must be sufficiently small for rehabilitation of the species.

To improve trout populations, additional studies on the possibilities of migration, habitat research and genetic research is needed.
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# Introduction

## 1.1 Motivation

This knowledge document is part of a series on many Dutch fish species, made by Sportvisserij Nederland (see page 74). The series is written in Dutch. This trout document was translated in English, financed by the Living North Sea program and Sportvisserij Nederland.

These knowledge documents are meant to improve the accessibility to available knowledge in literature, and to enhance the appreciation and management of these fish species.

## 1.2 Management status

According to Dutch law, the trout is described and treated as two separate fish species (fisheries law – Visserijwet and Red list - Rode lijst), namely sea trout and brown trout.

**Sea trout**

Native fishes and cyclostomes are species that only complete some parts of their live cycle within Dutch territory. Trout (and salmon) reproduce higher upstream in the river Rhine and Meuse, but are nevertheless considered native species. The species is mentioned in the Dutch Fisheries Law (Visserijwet), under minimum sizes and closed seasons 1985. In an amendment of 3 April 2000 (Wijzigingsbesluit Reglement minimummaten en gesloten tijden 1985 (bescherming zalm en zeeforel)) it has been decided to close captures of salmon and sea trout the whole year round, for the inland waters and the 12 mile zone along the Dutch coast.

According to the Dutch Red list (Rode lijst, de Nie & Van Ommering, 1998, 2004) sea trout is considered a vulnerable species in the Netherlands. Meaning that the species is not capable of fulfilling its own live cycle within the basins of rivers Rhine and Meuse. On EU-level sea trout has no extra protected state.

The Benelux ordination 96-5 (Ordination for free migration of fish species within the hydrographical basins of the countries in the Benelux [May 1996] gives regulations about free migration of salmon in the basis of the river Meuse. Recovery of salmon populations will in many cases also enhance the recovery of sea trout populations.

According to EU guidelines there is a ban on catches between 12 and 200 miles from the shore.

**Salmo trutta** is not named on the IUCN list (the World Conservation Union).

**Brown trout**

Brown trout is considered a native fish species in the Netherlands. According to the Dutch Red List (Rode lijst), brown trout is extinct from
the Netherlands. Nevertheless, the fish is not mentioned in any of the Dutch Nature protection laws (Flora- en faunawet or the Habitatrichtlijn).

Such as it is, brown trout is described in the Fisheries Law (Visserijwet), under the regulation of minimum sizes and closed seasons 1985. The species has a closed season from 1 October till 31 March. A minimum size of 25 cm is at hand.

1.3 Described species

Sea trout and brown trout are separate forms of one species, *Salmo trutta*. This knowledge document describes both forms separately when needed. Another third form occurs, lake trout. Because this form doesn’t occur in the Netherlands, it hasn’t been described in this document.

Due to regional differences genetically qualities and specific adaptations of trout, the fish differ in behaviour. This document will focus on some of these variations. Adaptations of trout seems to be dictated by parameters like temperatures, river lengths, and such. For example, within arctic regions (e.g. Norway) parrs (juveniles) will stay for six years within the fresh river water. Within the river Rhine this is approximately two years. An important difference between Scandinavian rivers and the river Rhine is their length. Furthermore, Scandinavian rivers are more or less pristine, compared to the highly morphologically changed Rhine river system.

1.4 Method

The knowledge summarised in this document was mainly based on literature study. The ASFA (Aquatic Sciences and Fisheries Abstracts) files were searched with key words, as well as our own library (which is specialized in fish species). Furthermore the author used general literature, grey literature (reports) and information on the internet.

Main sources for general ecological information were the standard works of Mills (1970) and Elliott (1994). The author adopted information into chapters Management and Knowledge gaps from an earlier study on trout (Laak, 2002a,b).

The attached glossary describes some technical terms, used in this document.
2 Systematics and external characteristics

2.1 Systematics

The trout is a salmonid species. Even before the Pliocene (5.2–1.64 million years ago) salmonids were considered a separate group. Fossils have been found which indicate a subdivision into various genera in those days. It is assumed that a fossil, named *Eosalmo driftwoodensis*, which lived 35 million years before, was the forefather of the salmonides (Watson, 1999; Mills, 1989).

Salmonids are classified in the class Teleostei (recent true cartilaginous fishes). Teleostei are classified as a subclass of the Actinopterigii, ray-finned fishes. Ray-finned fish constitutes of one of the groups of the class of the Osteichtyes (bony fishes in the broad sense) within the super class of the Gnathostomata (vertebrate with jaw) (Berg, 1948).

The salmon order (Salmoniformes) distinguishes at least 3 suborders: Salmonoidei, Galaxioidei, and Rectropina. The suborder Salmonoidei includes the families Salmonidae, Osmeridae, Plecoglossidae, and Salangidae. The Salmonidae family has at least one subfamily: Salmonidae. The Salmonidae family, jointly with the families of the Coregonidae (whitefish type), Osmeridae (smelt family), and Esocidae (pike type), Salvinidae (arctic trout), Umbridae (mud minnows), and Thymallidae (graylings) represent the order of the Salmoniformes (salmonoids).

**Table 2.1** Table: Classification Salmonides

<table>
<thead>
<tr>
<th>Kingdom: Animalia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phylum: Chordata</td>
</tr>
<tr>
<td>Subphylum: Vertebrata</td>
</tr>
<tr>
<td>Superclass: Osteichtyes</td>
</tr>
<tr>
<td>Class: Actinopterygii</td>
</tr>
<tr>
<td>Subclass: Neopterygii</td>
</tr>
<tr>
<td>Infraclass: Teleostei</td>
</tr>
<tr>
<td>Superorder: Ostariophysi</td>
</tr>
<tr>
<td>Order: Salmoniformes (Salmon-like)</td>
</tr>
<tr>
<td>Family: Salmonidae (Salmon)</td>
</tr>
<tr>
<td>Subfamily: Salmoninae (Salmon and trout)</td>
</tr>
<tr>
<td>Genus: Salmo</td>
</tr>
<tr>
<td>Species: Salmo trutta</td>
</tr>
</tbody>
</table>

Sea trout and brown trout are considered to be the migrating and non-migrating specimen (resident or stationary) of the same species, *Salmo trutta*.
Salmonides are characterised by the presence of an adipose fin. The salmonides only occur in the Northern Hemisphere. Most species are anadromous (migrating to the sea). Many species die after spawning.

The taxonomic systematic of salmonides remains unclear (Crisp, 1993). Maitland & Campbell (1992) consider Graylings and Whitefish as separate families. Wheeler (1992) considers these families as genera of the suborder Salmonidei. The subfamily Salmoninae includes at least the genera Salmon, Oncorhynchus, Salvelinus, Hucho, Salmothymus, and Brachymystax (please refer to Table 2.1).

The naming of salmonides was reason for many discussions in the past. This is not surprisingly. Salmonides show many different stages during their life cycle, as well as behaviour variations, pertaining to the anadromous lifestyle of these species. The presence of various salmonid species in the drainage basin of a river will also contribute to the lack of clarity. Some authors from the 17th and 18th century gave the separate life stages ('parr', smolts, kelts) of the salmonides a specific Latin generic name or referred to the subspecies variety (varietas) or form (forma). It is noteworthy that many researchers in those days were familiar with the phenomenon precocious male. This phenomenon is expected to have also contributed to the name confusion. For sea trout, no indications have been found in literature that precocious are female. Köck (1995) provides a consideration of the naming of the salmonides by systematics around 1850-1900. It is not uncommon that a systematic at the beginning of 1800 gives three totally different classifications of the salmonid family during its lifecycle. Research implemented by - among others - Menzies (1931), Jones (1959), and Mills (1970) created more clarity with regard to the naming and the salmonid way of life (Mills, 1989).

Sea trout and brown trout are considered to be the migrating and non-migrating (resident or stationary) specimens of the same species, *Salmo trutta*. In the past these specimens were often distinguished as *Salmo trutta trutta* (sea trout) and *Salmo trutta fario* (brown trout). It is known that sea trout migrate between the freshwater nursery area and the sea/ocean, whereas the brown trout (note: brown trout is *Salvelinus* species) stays in the freshwater throughout its life. Some sea trout are known to opt for an intermediary strategy (estuary). These fish do not migrate to the sea, but do remain in brackish water for quite some time. In England these trout are also referred to as slob. Based on the age determinations by scale reading in the Netherlands, it is now assumed that this form also occurs in the Rhine and/or Meuse system (De Laak, 2001).

It also appeared that only few migrating specimen remain in the lakes. In Ireland trout living in lakes are often distinguished by their length, which in itself depends on the food specialisation Three specimen can be distinguished:

- Sonaghan. These are fish living in the open water and which feed on zooplankton and midges, which they pick up from the water surface;
Gillaro. These fish feed on larger invertebrates such as snails, caddis larvae and shrimps (Mysis species); Ferox. These fish become piscivore if they grow large enough to eat bass, arctic tout and trout. The ferox can grow into the largest of the three specimens.

The specimens can be distinguished among themselves on the basis of their appearance, they have a different spawning habitat and crossbreeding among the different specimen has never or nearly ever been registered (Ferguson, 1981). Since these specimen do not occur in the Netherlands, this report does not include any or nearly no information on this type of trout.

In recent centuries dozens of alleged subspecies have been described. In and around the Adriatic coast several relict trout populations, such as marble trout and Salmo plathycephalus are found as well. The Salmo (Plathysalmo) plathycephalus, (Behnke, 1968; In: Sušnik, et al., 2004) is found in Turkey. Resulting from phylogenetic research it was established that this species is closely related to sea trout, and the species is not classified as a separate species, but as a species belonging to the Salmo trutta complex. Due to isolation and specific habitat this fish species was required to adapt, which resulted in a special morphology. A number of authors does consider the marble/soca trout (Salmo trutta marmoratus, Cuvier 1817) as a separate species (Sušnik, et al., 2004). Trout is a fish species which adapts to the current circumstances, even more so than the salmon does. Several authors therefore use the term Salmo trutta complex.

Future genetic research will need to provide more clarity on the origin and the degree of kinship of the different stocks. However, based on the different research techniques used, it is not always possible to compare the genetic research results.

The terminology related to the various salmonid life stages in this report is – as much as possible - in compliance with the terminology used by Allen & Ritter (1977) (please refer to § 3.5) and the naming of the life stages are explained in a glossary.

2.2 External characteristics

The Salmoniformes (salmon) families distinguish themselves from most other fish species due to the presence of an adipose fin. Salmonides do not have gill rakes and the adipose fin is situated before the pelvic fin. The outer end of the jaw continues until under the eye. The jaw has small, but well-developed teeth. Apart from these distinguishing characteristics, the determination of the separate species is quite complex. Salmonides have different forms during the separate life stages (fresh, smolt, saline). During spawning, these fish also have a different colour, and for the males, the shape of the body, specifically the head, changes significantly.

Meristic characteristics of the trout: Dorsal fin rays: 12-14 (10-15); Anal fin rays (including soft fin rays): 10-12 (9-14); Vertebrae: (57-59),
number of scale along the lateral line: 110-130. (Nijssen and de Groot, 1987, in brackets: Froese and Pauly, 2004). A sea trout has four branchial arches, and each branchial arch has 13 to 25 branchiospines (Hochleitner, 2001). The tail fin is slightly forked to straight. In the Netherlands, the species salmon, sea trout / brown trout and rainbow trout occur. Determination of these species is expected to cause problems.

Brown trout has more colours than seat trout, however the appearance within one single river may also vary significantly. A brown trout has a somewhat yellow to brown colour, the belly is white to – occasionally – black, and shows red or brown spots on the side. The chromatophores (pigment cells) enable the trout to adjust its colour to the environment (Mills, 1970).

*Nursing stage*

The fertilised eggs are placed in what is referred to as redds. After the eggs hatched, the larvae (alevins) remain in the spawning bed until their yolk sac is digested.

Eggs and fry (Photograph: Sportvisserij Nederland)

Free swimming sea trout without the yolk sac in the freshwater stage are referred to as fry or ‘parr’. Sea trout parrs can be recognised by their dark oval spots on both sides of the fish, at the height of the lateral line. The fin, and specifically the pelvic fins, of sea trout parrs are smaller and often more red/orange in colour then those of salmon parrs.
### Smolt stage
Parrs change internally as well as externally during smoltification. The most important external change is visible due to the fact that guanine is made within the scales. This gives the smolt a silver like appearance.

### Sea or adult stage
During the sea stage, sea trout have a silver colour with a brown shade above the lateral line. The upper jaw extends beyond the eye. Above and below the lateral line, small black spots are visible. The tail root is thicker than for the salmon and the tail fin is less wide. The tail fin is slightly concave, meaning that the fin is not clearly forked, but has a slightly deep indentation.
Colours of the mating season
Internal and external changes of the fish occur during migration. The most noteworthy change relates to the development of a kype (hook or basket) of the male trout on their lower jaw (denture). The kype or hook falls into a cleft in the upper jaw (pre-maxilla). Furthermore, male trout are darker in colour than during the sea stage and have red to brownish spots on the opercuum (gill cover) and sides. Female trout are darker in colour as well.
2.3 Recognition and determination

This section includes a table in which the most important determination characteristics of salmon and sea trout are specified. A trout will not easily be mistaken for another fish species, for it can easily be recognised by its adipose fin. However, trout is often confused with Atlantic salmon. Pacific salmons can be distinguished from salmon and trout since the pacific salmon have black spots on the dorsal and tail fins.

Table 2.2 Characteristics of salmon and trout. (Based on the course Fish Species - OVB - 1985)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Salmon</th>
<th>Sea trout</th>
</tr>
</thead>
<tbody>
<tr>
<td>External</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of scales along the lateral line</td>
<td>109-120</td>
<td>120-130</td>
</tr>
<tr>
<td>Number of scales above the lateral line up to the adipose fin</td>
<td>10-13</td>
<td>14-17</td>
</tr>
<tr>
<td>Dorsal fin rays</td>
<td>10-12</td>
<td>12-14</td>
</tr>
<tr>
<td>Anal fin rays</td>
<td>8-11</td>
<td>10-12</td>
</tr>
<tr>
<td>Pelvic fin rays</td>
<td>9-10</td>
<td>9-10</td>
</tr>
<tr>
<td>Tail fin</td>
<td>Forked</td>
<td>Straight or slightly concave, at times convex</td>
</tr>
<tr>
<td>End of the mouth in relation to the eye</td>
<td>Straight under the eye</td>
<td>Extends beyond the eye</td>
</tr>
<tr>
<td>Basic tail root</td>
<td>Slim</td>
<td>Thick</td>
</tr>
<tr>
<td>Proportion of the body</td>
<td>Slimmer than the body of a sea trout</td>
<td>More heavy than salmon, when both have the same length</td>
</tr>
<tr>
<td>Head – body ratio</td>
<td>Smaller head than sea trout</td>
<td>Comparatively larger head</td>
</tr>
<tr>
<td>Colour during sea stage</td>
<td>Grey/silver with blue/green glow</td>
<td>Brown at the top (side)</td>
</tr>
<tr>
<td>Shape of the spots on the side</td>
<td>X-shaped</td>
<td>Spots, dots</td>
</tr>
<tr>
<td>Internal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vomer</td>
<td>Small teeth on the shaft</td>
<td>Small teeth on the shaft and head</td>
</tr>
<tr>
<td>Shape of the branchiospine (gill rake)</td>
<td>Slim</td>
<td>Blunt</td>
</tr>
<tr>
<td>Number of branchiospines (gill rakes)</td>
<td>15-20</td>
<td>14-17</td>
</tr>
<tr>
<td>Muscle tissue</td>
<td>Sturdy</td>
<td>Soft</td>
</tr>
</tbody>
</table>

At times it is difficult to distinguish salmon from sea trout. Determination can be hindered due to the fact that the fish is damaged or has been damaged in the past, resulting whereof several relatively simple characteristics (number of scale rows between adipose fin and lateral line) can no longer be determined. If the fish was damaged on the location of
the disappeared scales, new scales, referred to as regenerated scales, are
developed. These scales do not have a regular shape, and lack the age
related information up to the moment this new scale was developed.
Furthermore, hybrids (crossbreeding) between salmon and trout occurs as
well. Farmed fish have a different habitus (appearance) than fish grown
and developed naturally. Various phyla of sea trout are known. Sea trout
from Germany and Scotland were given different names when released in
North-America, and notwithstanding crossbreeding, they could even be
clearly distinguished several generations later. Elliott et al., (1992)
describes that genetic differences apply to sea trout appearing near the
British isles which flow into the Irish Sea and Atlantic Ocean.
3 Ecologic knowledge

3.1 Way of life

In principle trout is an anadromous fish species. The way of life shows many similarities to those of the salmon. Fish develop in fresh cold water of the upper course of rivers. After one (1) to six (6) years pre-smolts leave the freshwater in spring. These smolts quickly develop in the estuary or sea. Sea trout do not swim as far into the sea or ocean as the Atlantic salmon. After one (1) or three (3) years (seldom longer) in the sea, they return to the rivers to spawn in early winter. Part of the smolts return to the river in the autumn of the same year they migrated to the sea. Only a slight percentage of these fish participates in spawning. After spawning, part of the parents die, and another part of these fish (kelts) return to the sea to regain strength, and to possibly participate in the spawning migration once again. Kelts often hibernate in the river and migrate – jointly with the smolts – back to the sea. Trout usually spawn several times when they are sexually mature, though part of the trout die after the first spawning (Mills, 1970). The juveniles remain in streams near the spawning grounds. After this development stage, trout change in their appearance (this is referred to as smoltification) and migrate to the sea. A part of the population can complete their full lifecycle in freshwater, even if they have the possibility to migrate to the sea. This generally represents the trout lifecycle.

3.2 Geographic distribution

Salmonides only occur in the northern hemisphere. Most species are found in the cold Arctic areas, or in the higher mountain areas, such as the Alps. Trout appear throughout Europe, North Africa, Turkey and the western section of Asia (countries around the Caspian Sea, such as Iran). Sea trout do not appear in the Mediterranean, brown trout do appear in rivers discharging in the Mediterranean Sea (Mills, 1970; Elliott et al., 1994). Fishbase indicates that sea trout is indigenous in Afghanistan. Apart from Afghanistan, Watson (1999) also refers to the Aral Sea as the boundary of the eastern distribution. Mills (1970) also refer to Iraq and the northern slopes of the Himalaya as the eastern boundary of the distribution area. Brown trout occurs nearly on all locations where sea trout is found as well.

Since the Pleistocene trout developed in five (5) different regional areas in Europe. There has been no or nearly no exchange of trout between these areas, resulting whereof – on geographical level – five (5) allopatric areas apply as well.
Trout was introduced in many countries in the world, specifically in North-America and Australia. The English introduced trout in their former colonies such as New Zealand, Zimbabwe, Malawi, Lesotho, Kenya, Ethiopia, and even in the Falkland islands. Trout was also introduced in South-America. Various countries reported a negative effect of the introduction of trout (Mills, 1970; Watson, 1999).

### 3.2.1 Occurrence in the Netherlands

In the past, trout occurred in nearly all side-streams and tributaries of the river Meuse in Limburg (including the Voer, Geul, Roer, Swalm, and Niers). The presence in the Netherlands, but outside the province Limburg (the provinces Brabant, Gelderland, Overijssel, and Drenthe) is presumed to be largely the result of releases in the nineteenth century. In the sixties of the last century, brown trout still had self-preserving populations in streams in the province of Gelderland, such as the Hierdense beek and the streams in Renkum (including the Heelsumse beek). Due to waste water discharges and lowering of the groundwater level respectively, these stocks have subsequently disappeared. However, since 2005, brown trout of various ages have frequently been detected in the Heelsumse Beek once again. By means of the introduction of fry or eggs, brown trout is now also found in several of the streams in the Achterhoek and Kempen. It is quite complex to determine whether or not natural reproduction takes place here. Many Dutch district water boards have the objective to make it possible once again for fish to migrate from the sea or rivers to the streams. This enables sea trout to reach suitable spawning habitat in those streams. Time will tell whether this actually initiates new brown trout or sea trout populations.
3.3 Strategies

Trout can live and survive in a wide variety of circumstances. Through centuries, fish have adjusted to extreme situations. This is why seat trout has become a polymorphous species. The species has the ability to adjust its life cycle to sections of its life cycle.

Partial residency in freshwater and saline water is a life strategy. It limits the risks that a species becomes extinct in a river when a catastrophe occurs. In saline water the species finds a habitat in which it can grow quickly and therefore ensure a high reproduction rate. The investment in partially developing in sea are migration (energy loss) and the danger of predation. If these investments do not outweigh the reproduction success, the species will adjust its strategy. As such trout have developed many strategies and flexibilities to survive as best as possible. The species is capable of surviving in many different types of water, from small oligotrophic lakes high-up in the mountains, up to large rivers, where an anadromous life style is common. This is why in total up to 50 subspecies or varieties of this species have been described, which – in the end – have been reduced to one single species *Salmo trutta*. To indicate that the species is a polymorphous species, some authors use the term *Salmo trutta* complex.

Elliott *et al.*, (1994) described the four life cycles as follows:
1. Trout resides his/her entire life in the natal river;
2. The trout ‘parr’ migrates at an age of 1+ or 2+ to a main river and the adult fish only return to the natal river for spawning;
3. The trout ‘parr’ migrates at an age of 1+ to 3+ to a lake. The spawning population consists of iteroparous (spawning several times during their life) male and female from the lake, returning to their natal river for spawning. Part of the male ‘parrs’ do not migrate to the lake and become a sexually mature ‘parr’;
4. The ‘parr’ smoltificates and migrates to the estuary or to the sea and remains there to develop or grow. After one year or several years, the adult fish migrates to the spawning areas in the natal river to spawn.

The life strategies referred to above may occur in a trout population which live alongside one another in a river or lake. It is also possible that only part of the population selects a specific strategy. An example thereof is that female are more inclined than male to migrate to the nursery areas (sea or lake). Males are more inclined to remain in their natal river, and to become sexually mature at a small length. Recently it was described that sea trout in the Baltic Sea also spawn in water with a salt content of 4-5‰ (Klemetsen *et al.*, 2003). By means of laboratory tests researchers proved that based on the current salt content in Gotland, spawning does not contribute to the population. Apart from the more general biological phenomena, such as smoltification in the northern regions, several particular strategies or ecological differences are referred to (Klemetsen *et al.*, 2003).
Egg size
The eggs from resident trout are larger in size than the eggs from anadromous fish. The egg size largely determines the size of the alevin. The larger the alevin, the better the chance to survive the first months of their development stage. It appears that resident trout ensure that their offspring have an advantage over the anadromous trout with regard to the often extreme circumstances.

Growth of the ‘parr’ / Smoltification
‘Parr’ growth is strongly dependent on the circumstances. In some Norwegian rivers ‘parrs’ already smolitificate into a length from 6 to 8 cm in the autumn. The circumstances in the small rivers are not optimum for older parrs, at times even risky in relation to the possibility of falling dry or freezing up of the stream. In larger streams the parrs grow larger and reach an older age. The variance in age and length also increases in larger streams.

Migration/Anadromy
Completing the various life stages in various growing up areas is attractive at times. Due to the better growth circumstance the fish can grow bigger in a shorter time and thus ensure more offspring. It appears as if migrating to other nursery areas is more important to female fish species than it is to male fish species. Female fish are often larger (and therefore have larger and/or more eggs) and older when returning than male fish. It is not of importance for a male fish whether it’s size is 50 cm or 60 cm, for he is capable fertilising all eggs anyway. The average age of female fish at the time of the first spawning is higher than for male fish.

3.4 Migration
Trout are (partially) anadromous fish. This means they migrate from the sea to freshwater when they are in the adult stage. However, part of the population remains in freshwater or in the estuary area all their life. Trout show a vast variety of migration patterns in various rivers. Several studies in the United Kingdom and in Norway showed that trout usually remain very close to the coast. Post-smolts migrate in groups of the same species from the same natal river along the coast. Most fish do not migrate any further than 15 km, however some migrate more than 80 to 100 km. There is a difference between trout populations in different rivers with regard to how far they migrate into the sea/ocean. (Solomon, 1995). Migration to the most upstream located areas of a stream are of importance, since in case of drought or other unfavourable circumstances, trout must be able to migrate elsewhere. The most upstream located sections of the stream are of great value to trout as a nursery area. In general no other fish species occur in these areas. This is based on the unfavourable growth circumstances in combination with a (natural) migration obstacle (Klemetsen et. al., 2003).

Homing
Even in the Middle Ages some people recognised that salmonides have a “homing” instinct (Mills, 1989). During the sea stage Pacific and Atlantic
salmons migrate thousands of miles, and in the end, return to their natal river with exact precision. This phenomenon is referred to as homing. The definition of homing is: ‘salmonides returning to the natal river for spawning’. Homing therefore does not refer to fish that remain in a river (residents) to forage. It is a known fact that non-adult trout (grilse) at times migrate to a river to remain there for several weeks or months. These fish are referred to as “dummy runners”. Another phenomenon refers to ‘strayers’. Strayers are fish that migrate to a river which is not their natal river. Strayers can migrate far up a river, but based on their origin they do not belong to the original salmonid population of that river. It appears that the phenomenon dummy runners and strayers occurs more often with sea trout than it does for Atlantic salmon.

Many theories have been developed and tested to explain why salmonides can find their way back to their natal river. In the beginning of this century climatologic and physical factors were deemed to be the most important reasons. Factors such as temperature, development of the salt content, oxygen or CO$_2$ gradients in freshwater and in saline water, displacement based on geomagnetic fields in combination with a bi-coordinate system (‘map’), light intensity and light direction were deemed to be the most important factors for homing behaviour (Mills, 1993; Banks, 1969; Berg & Berg, 1987). However, physical-chemical parameters cannot be the only reason or stimulus for the migration of salmonides. If this would be the only stimuli, the fish would find it hard to choose from waters with the same physical-chemical characteristics. Furthermore, physical-chemical parameters are not sufficiently consistent for the time frame during which the fish leaves the river as a smolt and returns to the rivers (after 1 to 4 years) as an adult fish (Hasler 1958; In: Hoar & Randall, 1971).

As early as 1980 Buckland (in: Mills, 1989) suggested that salmon were guided by their olfactory sense to follow the scent of their natal river from the ocean. Trout also use their olfactory sense to find their natal river (Mills, 1970). The theory that salmonides use geomagnetic fields for orientation purposes was already confirmed by a study conducted by Moore et al. (1990; in Mills, 1993). Salmonides have magnetic crystals on their lateral line, which could provide a rough indication of the orientation of the earth magnetic field and their migration route.

The role of the olfactory sense of salmonides in actual situations has already been tested in coastal situations by Craigie (cited in Elliott et al., 1992). During this study the olfactory organ of fish was damaged. Various studies have been conducted whereby the olfactory organ of salmonides was cauterised, and the olfactory nerve was neurotomised (Stabell, 1984). Most of these studies show that the homing preciseness reduced significantly for treated fish. Cauterised fish had a better homing percentage than neurotomised fish. Olfaction is essential for coastal migration (e.g. _Alosa fallax_), chum salmon (_O. nerka_) and anadromous sea trout (_S. trutta_).

Orientation during the freshwater stage
Hasler and Wisby (1951) as well as Hasler (1954) have proven the importance of aromatic substances related to the orientation (olfactory hypothesis) of the fish and the dependency of an undamaged olfactory organ. Hasler (1966) refers to water plants and the mineral composition of the soil or substrate composition of the homing river, as a source of the olfactory substances.

Harden Jones (1968) states that salmon smolts pick up the scent they sense during their downstream migration and store this in their memory (sequential imprinting), or are genetically determined. The memory is used during the spawning migration (in the opposite direction so to speak) in order to return to the natal river. For this purpose region specific olfactory substances (general orientation sea and cost stage) as well as population specific orientation (tributary orientation) are used, but land markers and specific flow characteristics (in estuaries) can also be memorised.

**Genetics component**

More recent studies indicated that the homing behaviour is also determined – to a lesser or greater extent - by a genetic component (Stabell, 1984; Hansen et al., 1993; Nielsen, 1998). Researchers arrived at this conclusion due to the fact that many studies indicated that the homing success rate of farmed fish (fish released as a juvenile fish into the river system) is lower than for naturally grown salmonides, whereas survival at sea is the same for both groups. Which part of the population migrates is genetically determined. However, it is also determined by other factors, mainly those which determine the growth factor. River length is an important aspect, as well as whether there are lentic areas (lakes) representing a higher risk on predation. Migration means taking risk, since moving increases the risk on predation. It also means loss of energy (the fish must return as well). In the end, migration must have a positive result. In trout populations residing in large rivers, migrations applies as well, however, this refers to relatively limited distances only, specifically when this includes lakes of wider, deeper sections which represent a better chance of survival during the winter (Olsson & Greenberg, 2004).

After a few days of acclimatisation brown trout easily survive in seawater for a duration of five (5) months. This was one of the first indications that sea trout and brown trout are the same species (Elliott et al., 1992).

Berg and Berg (1987) found a minimum straying percentage of 15.5% for (sea) trout. The straying percentage of sea trout kelts (approximately 1400 fish have been marked) in the study conducted by Jensen (1968) is zero. This indicates that reconditioning of kelts for the recovery of salmonid populations could be of significant importance.

From research conducted in English rivers it appears that sea trout migrate up the river throughout the year. The most downstream migrating adult fish are registered in May in the south of England. In the north of England the large downstream migration peak could also be in
October. In general ‘Finnock’ (sexually mature and immature) arrive later than adult fish (Elliott et al., 1992).

It appears as if sea trout does not or nearly not take in any food during the spawning migration in freshwater. Only 2% of the 150 researched fish had food in their stomach, including salmonid eggs, trout and salmon parr and macro invertebrates (Elliott et al., 1992).

Brown trout is loyal to the site or location. Depending on the individual, only minor relocations apply. Some individuals hardly relocate (9 metres as a maximum), whereas others may relocate over a distance of up to 80 metres. The migration is highly variable and can take place throughout the day, or concentrated during part of the day, during the night or during dusk or dawn. The individual activities do not always relate to the ‘drift rate’ of the food. This is due to the fact that trout can also use different food resources (benthic food or piscivore) or because individuals have developed as specialist for a specific food item (Giroux et al., 2000).

3.5 Reproduction

3.5.1 Spawning behaviour and fertilisation

At the end of the autumn, specimen ready for spawning have gathered in pools. Females are the first to arrive at the spawning areas in November and December. A spawning area or site is referred to as ‘redd’ and the location of these ‘redds’ is usually at the end of a pool, where the water depth reduces and the flow rate increases. A ‘redd’ contains various packages of eggs.

Elliott (1992; 1994) describes the behaviour of sea trout during spawning on the basis of previously published literature.

1. The female explores the gravel bed and attempts to make a (shallow) hole several times.
2. Several males fight each other during this time. One of the males appears to be dominant and hits the female.
3. The female concentrates on deepening the spawning bed. The males chases imposing males and intruding females away.
4. As soon as the spawning bed has reached a depth of 5 up to 15 cm as a maximum, the female will lay down in the bed. The male accompanies her and pushed his entire body against hers. Soft and hard roe and milt (eggs and sperm) will simultaneously be released if the fish are in the spawning bed. During the release of the gonadal secretion, both fish have their mouth open. Both male and female trout quiver when releasing hard and soft roe.
5. Next, the female swims a bit further upstream of the ‘redd’, and she covers the eggs within minutes, by tail movements.
6. These steps can be repeated several times, the female will not release all eggs at once.

Spawning behaviour therefore highly resembles that of the salmon, except that female trout also show quiver behaviour. (Jones, 1959).
Trout female leave the ‘redd’ after spawning, sometimes they spawn again upstream of the spawning bed. Male trout do remain near the ‘redd’, hoping to spawn with other trout females. Spawning takes place as from a water temperature of 6 °C. A significant part of the trout population spawns several times during their life cycle (‘repeat spawners’). The share of these ‘repeat spawners’ varied from nearly 0 to 70% in 29 Norwegian rivers. The percentage shows a positive correlation with the river length and the average discharge, however not with regard to the degree of latitude (Elliott et al., 1992). Trout spawning in lakes is only incidental.

Anadromous trout can also spawn with resident trout. The offspring of these crossbreeding’s cannot be distinguished on the basis of external characteristics, however biochemical differences have been found (Elliott et al., 1992).

The spawning area of salmon and trout can overlap. This can result in hybrids (please refer to § 3.9 for further information).

3.5.2 Gender ratio at reproduction

Various studies indicated that females occur approximately three times as often as males in the smolt stage (Elliott et al., 1992).

Sea trout in Wales indicated a higher share of females than males, being 1.28 females per male (Solomon, 1995). With regard to the ‘finnock’ share of the population, this is 1.83 (1.8 for another river) for adult fish the share of females -when compared to males- represented in the population is 2.74 (1.97 in another river). In the rivers Tyne and Tees a higher share of females is registered as well (1.64, 2.77 respectively). For several other English rivers the ratio of the ‘whitling’ share of the population is described: 1.71:1 (female : male), and 3.83 for the elder fish in the population. With regard to ‘kelts’ the ratio female : male is even 8.7:1 in a specific river (Solomon, 1995). A higher share of females indicates that the mortality rate for males is higher if the fish remain at sea for a longer period of time (Solomon, 1995). This is described for salmon populations as well. The cause of the phenomenon is unknown.

3.5.3 Spawning grounds/habitat

Trout spawning grounds are located in the river upper courses. For the Rhine these are tributaries such as the Ruhr, Sieg, Ill, Ahr, Mosel up to streams in Switzerland. Sea trout is less picky than salmon when selecting ‘redds’. Crisp and Carling (1989; cited in Elliott et al., 1992) stated the following determination of a ‘redd’:

- In general the percentage of fine sediment (<1 mm diameter) in the spawning area was < 15%. If the sand percentage was 40%, the hatch percentage of the eggs was only 4%. Peat up to 40 volume percent of the spawning bed had little effect on the hatch percentage.
- The flow rate was higher than 15 cm/s, but is less than twice the female length.
- The depth of the water at the location of the spawning bed is deeper than the body height of the fish migrating after spawning, in general
approximately 0.2 times the fish length. Spawning beds are found in water with a depth of 15 cm to 90 cm. The optimum is around 30 cm.

- The ‘redd’ must have a specific porosity (degree in which water flows through the gravel).
- Most eggs are densely packed in egg packages. A small proportion of the eggs are widely spread over the ‘redd’.

The relation between the gravel size in which salmonides can spawn is 

\[ P = 0.5L + 4.6 \]  

(\( P = \) median gravel size in mm and \( L = \) fish length in cm).

However, trout also spawn on a spawning bed with a much smaller diameter. The indicators for spawning on a certain location are complex to determine. Aspects such as groundwater flows, spawning bed porosity, oxygen degree, do not always appear to be the condition (trigger), because spawning also takes place on locations not suited for spawning (Elliott et al., 1992).

Literature for spawning bed specifications of brown trout is not available. Brown trout spawns in low land streams, but also often of sandy grounds. It is important that the substrate flows through sufficiently with oxygen rich seepage water. Streams in the Netherlands which comply with these conditions, are the streams Hierdense beek and Keersop (personal remark F. Moquette).

### 3.5.4 Gonades and fertilisation

Solomon (1995) indicates various relations related to fertilisation. Fertilisation of living fish can be determined by collecting eggs. For dead fish, the eggs can be removed from the abdomen. Both methods provide a different result due to the fact that eggs remain in the abdomen when collecting eggs from live fish. The following relation applies as an average in relation to collecting eggs from dead and live fish: 

\[ \log N = 2.338 \times \log L - 2.958 \]  

(L is length, \( N \) is the number of eggs). The study also concluded that the fecundity of fish, that smoltified as a smolt at the age of three, is lower per cm of body length than that of a fish who smoltified at an age of two year. Fish that spawned before, have a slightly lower (not significant) fecundity. For larger fish and for those that spawned before, more eggs remain in the abdomen than applicable to younger fish.

Elliott et al. (1992) refer to a ‘finnock’ 481 up to 2405 eggs for 4 SW fish. Fish with a length of 35 cm produce approximately 750 eggs. Seat trout from the Irish Sea with a length of 50 cm produce 2700 eggs, and fish from the Atlantic Sea with the same length produce approximately 2000 eggs.

Brown trout females can be sexually mature at a length of 15 cm. They produce approximately 100 eggs (Elliott, 1994).

### 3.5.5 Duration of the reproductive life stage

Part of the fish that spawned return to the sea and can once again participate in spawning. In general this relates to 10 to 40% of these fish, however, this can increase up to 70% in short Norwegian rivers. Elliott et al. (1992) state that the survival percentage of kelts at sea is 29 to 40%. Part of this population will therefore spawn several times. It has been
reported that sea trout participated in spawning up to 12 times (Solomon, 1995).

### 3.6 Ontogenesis

Table 3.3 represents an overview of the terminology of the different life stages of the Atlantic salmon. This classification is also used to distinguish the separate life stages of (sea) trout (Elliott et al., 1994). The stages ‘smolt’ and ‘1-4 sea winter’ are not used for brown trout. The term ‘fingerling’ is often used, which in general refers to the life stage between ‘fry’ and ‘parr’. ‘Fingerlings’ do not yet have the characteristic brown spots on the lateral line. However, the life stage ‘fingerling’ is an important stage in the development of the young trout. During this stage the young fish starts to feed exogenous and starts to show species-specific behaviour such as territory drive.

Literature often uses the terms ‘grilse’, ‘whitling’ and ‘finnock’. These are used for age classification per region, and ‘grilse’ in North-America is a 1SW fish, while in England it is a fish which migrates to the river, after one summer.

The terms ‘whitling’ and ‘finnock’ (or ‘peal’, ‘sewin’ or ‘sprods’) are used in Wales and Scotland for a sea trout which is still at sea during the summer of its first year (Solomon, 1995). According to Mills (1970) ‘sewin’ sea trout live at the west side of the English isles, and ‘finnock’ is trout living at the eastern side.

Sea trout migrating and remaining in the estuary for a longer period of time, but that do not migrate to the sea, are referred to as ‘slob’ in England.

#### Table 3.3 Summary of the various life stages of the Atlantic salmon (based on Alan & Ritter, 1977)

<table>
<thead>
<tr>
<th>Stage</th>
<th>Term</th>
<th>Definition/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Egg</td>
<td>Egg produced by an adult female salmon up to fertilisation</td>
</tr>
<tr>
<td>2</td>
<td>Green egg</td>
<td>Fertilised egg up to the egg-up stage</td>
</tr>
<tr>
<td>3</td>
<td>Eye-up</td>
<td>Stage during which black eye spots of the embryo become visible until the egg is hatched</td>
</tr>
<tr>
<td>4</td>
<td>Alevin</td>
<td>Stage as from hatching of the egg-up stage to the end of the dependency of the yolk sac</td>
</tr>
<tr>
<td>5</td>
<td>Brood/Fry</td>
<td>Stage of independence of the yolk sac as a primary food source, via emergence / dispersion from nest (redd) to free-swimming</td>
</tr>
<tr>
<td>6</td>
<td>Parr</td>
<td>Stage of free-swimming up to smolt migration:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0+ = parr less than 1 year old</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1+ = parr 1 year or older, &lt; 2 years old</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2+ = parr 2 years or older, &lt; 3 years of age, etc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>♀ parr = mature male parr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silver parr = pre-smolt = migrating downstream, partial silver coloured parr, preceding the smolt migration</td>
</tr>
<tr>
<td>7</td>
<td>Smolt</td>
<td>Full silver coloured, young salmon migrating to sea</td>
</tr>
</tbody>
</table>
| 8     | Post-smolt   | Stage from the transition to the sea, up to the quick growth stage at the end of the first sea winter (pre-grilse = post-smolt that returns to the
<table>
<thead>
<tr>
<th>Stage as from the quick growth stage up to the end of the first sea winter</th>
<th>freshwater for reproduction, in the year of the smolt migration)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Salmon</td>
</tr>
<tr>
<td>(a)</td>
<td>1-SW-salmon</td>
</tr>
<tr>
<td>(b)</td>
<td>2-SW-salmon</td>
</tr>
<tr>
<td>(c)</td>
<td>3-SW-salmon</td>
</tr>
<tr>
<td>(d)</td>
<td>4-SW-salmon</td>
</tr>
<tr>
<td>(e)</td>
<td>Previous spawning salmon</td>
</tr>
<tr>
<td>10</td>
<td>kelt</td>
</tr>
</tbody>
</table>

'Sricks' are male Pacific salmons that participate in spawning as early as after one summer (6 months). 'Hooknose' are male Pacific salmons that participate in spawning after 18 months. The year in which they become sexually mature, depends on their length. Larger smolts will quickly be sexually mature ('Jack' tactic), in general smaller smolts remain at sea for a period of one year ('Hooknose' strategy). These are different reproduction strategies which may take place within a sea trout population (Elliott et al., 1994).

### 3.6.2 Egg stage

Trout is a litho-phile species, whereby the eggs and breed are hidden in the substrate (nests or redds). These redds are not guarded. The reproduction behaviour of the species is targeted at optimising the circumstances for the eggs, embryos and alevins respectively, in and around the spawning bed. The most important variables referred to are: water depth, flow rate, permeability of the substrate, type of substrate (granulate size; granulate distribution), water temperature, oxygen content and pH value. The oxygen content of the water plays a more important role related to the survival percentage than the water temperature. Eggs require a high amount of oxygen as they become mouldy if the oxygen content is too low. This could occur if the redd has a high fine sand content. The water temperature is the determining factor for the development or hatching rate of the eggs. Sea trout eggs can develop between <1.4 and 16 ºC, however, above 9 ºC the mortality increases quickly. Sea trout eggs require a slightly lower average daily temperature than salmon eggs. It is shown that eggs which develop at a lower temperature, produce a bigger size alevins ('fry'). At water temperatures of 5 ºC, the eggs hatch after 90 days, at a temperature of 3 ºC, eggs will hatch after 102 days (Watson, 1999). Mills (1970) refers to comparative values for the hatching of eggs, whereas Elliott (1994) refers to 444 day degrees for the hatching of eggs. Eggs can be hidden at a limited depth of (4 cm) up to more than 20 cm in the gravel. In rivers with a stony substrate, there is a relationship between the length of the fish and the depth into which the eggs can be hidden.
In these rivers the relationship is referred to as \( y \) (depth) = 0.262* fish length + 2.4. In rivers with a lime substrate, no clear relationship between both parameters can be determined. This is because a special type of cement substrate is common in many lime rivers (Elliott et al., 1992).

The egg hatch percentage is also influenced by a low pH value. A pH lower than 3.5 was lethal for all sea trout eggs within 10 days. A pH value of 4.5 resulted in good survival, however this value in the presence of metal (e.g. Al) could have lethal effects. Even with higher pH values (>6.5) the egg and alevin mortality increases if for example iron is present. However, the presence of calcium and sodium is essential for egg hatching. Both elements also influence the alevin survival (Klemetsen et al., 2003).

Larger sea trout produce larger eggs, as is applicable to salmon. For smaller fish an egg weight of 110 mg is stated, whereas eggs of larger fish weigh approximately 170 mg (Elliott et al., 1992). The size of the eggs is 4 to 5 millimetre and they are yellow or orange in colour.

No literature was found related to the specific details of the egg stage of brown trout. It is likely that the stages of both species are very similar.

### 3.6.3 Embryonal and larva stage

This stage represents the time between the eye-up stage and the ‘parr’ stage. During the embryonic stage, the egg strongly depends on a proper oxygen provision. Specifically decomposition products such as ammonia, must be discharged from the spawning bed. This is where the importance of the oxygen percentage of the water in the spawning bed as well as the circulation thereof are of importance. Another influence is the spatial distribution of the eggs/alevins in the spawning bed.

After hatching of the eggs, the ‘alevins’ remain in the redd for a period of 5 to 6 weeks (or approximately 400 day degrees, before they leave the redd. When the larvae leave the redd, their length equals approximately 20 mm. The larvae or alevins will seek protection between the gravel in the redd as soon as they are disturbed. After several days of active foraging, the alevins will spread out and will search for food at some distance from one another. This is the first sign of territory demarcation (Elliott, 1994). Larger ‘alevins’ are more dominant and will occupy the best locations for foraging and protection. The remaining larvae migrate downstream at the beginning of the night, mainly if high water level and draught applies. If they cannot find a territory, they will die due to lack of food. The mortality rate as from leaving the gravel up to the ‘parr’ stage could be > 90%, however this strongly depends on the density. Next, the population is limited due to factors such as predation.

Brown trout could occur in acid as well as in basic water. Due to the lack of predation in acid water by whitefish (apart from pike) and only limited competition of whitefish, the survival rate in quite acid waters is rather high.

The growth rate is negatively correlated to the population density within a river system. Practice indicates that physical factors such as temperature and shelter influence the growth rate as well. The maximum growth rate
is realised at a temperature of 12 °C. Growth is mainly realised during spring and autumn (Elliott et al., 1992).

### 3.6.4 Juvenile stage

This stage includes the ‘parr’ stage up to the pre-‘smolt’ stage. For the young trout parr it is most important to obtain a suitable territory. A trout parr is highly aggressive. The size of the territory is 0.05 to 0.5 m$^2$ (Elliott et al., 1992). Furthermore the ‘parr’ has a home range (living area), which varies from 15 to 30 m$^2$. Depending on the density of the ‘parr’, the home range may vary (Hesthagen, 1990). In the first three to four months trout density is determined by density depending factors. These factors only determine the density of the fry or brood at a certain initial value. These initials values will not be reached if extreme circumstances apply, such as high discharges, which washout the eggs and ‘parrs’. Salmon parrs are trout competitors with regard to space and food. If both species occur, a shift in habitat occurs. Salmon is most often observed in quick flowing parts (often shallow), whereas trout can be found in the more quiet and deeper areas of pool-riffle sequences or along the riverbank. Trout parr requires shelter (most often in stream cover). Salmon parr can better sustain in a flow than sea trout, since salmon have larger pelvic fins, with which they press themselves against the riverbed. The salmon parr pelvic fin is approximately 50% larger than trout parr pelvic fins. Due to turbulence of this shallow quick flowing water the salmon parr has adequate protection against predation (Karlström, 1969).

Trout parrs have homing behaviour. During experiments, approximately 70% of the brown trout caught (as from 2 to 9 years old) were re-caught at the catch site. Approximately 20% was found 25 meters upstream, and 10% was found within 25 meters downstream. If higher parr densities applies, the percentage of re-caught fish reduced (Hesthagen, 1990).

Smolt production is also an important characteristic for the value of a river for salmonides. In several English rivers smolt production is at a level of 15 to 20 trout smolt per 100 m$^2$. In Denmark the smolt density is determined to be 4 individuals per 100 m$^2$ (Elliott et al., 1992). Elliott (1994) indicates a range in the production, being from 0.14 to 54.7 gram per m$^2$ per year. In dry years (such as 1984, 1985) the production is low. However, a dry year does not necessarily mean a year with a low production.

More interactions between the environment and the organism determine when smoltification takes place. Factors which are of influence are: growth (and growth-related factors), internal clock (circannual rhythm), and some environmental parameters. Prior to the start of the smoltification, the parr must have reached a certain length. Based on growth-related factors (temperature, photoperiod, competition and food) and the internal clock (partially genetically determined) the body will start to create certain hormones at a certain time (GH, Cortisol, T4, Insulin). These hormones cause physiological and morphologic changes. The physiologic changes could include an increased salt tolerance and a
changed metabolism. The metabolism is mainly focused on growth in length (B type growth; Elliott et al., 1992) than on creation of fat of gonad development. The increase in the growth of length is between 19 to 72% for parr that start to smoltify. The morphologic changes are the changes of the fish in a typical more slender smolt specimen and the production of guanine, which give smolt a silver-like appearance. Next, due to hormonal influences, the behaviour of the fish changes as well. The pre-smolt no longer has an aggressive behaviour and gathers into a school (NRC, 2004, Elliott et al., 1992). The environmental parameters, which in the end initiate the smolt run are temperature, discharge and the factor related thereto, being the flow rate. “The first spate (increase discharge) in May takes the smolts away” (Jones, 1959).

The increase of the growth in length is more important than obtaining a minimum length. This is the reason why at times younger parr smoltify earlier and at a smaller length than older and longer parr in the same river system. (Elliott et al., 1992). The food intake of parr ready for smoltification is 4 times as high than the food intake of resident parrs, whereas pre-smolts allocate more energy to growth instead of to storing more energy reserves (Klemetsen et al., 2003).

The age on which parr smoltify is partially also depending on the degree of latitude. In northern areas parr smoltify at the age of 4 to 7 years, which is caused by the average lower temperature (Klemetsen et al., 2003). In England MSA (Mean Smolt Ages) with an age of 2 to 3,5 years were identified (Solomon, 1995). In the Netherlands the age of approximately 500 sea trout caught off the coast was determined as well. Of these fish, the average MSA is 2.0 year. With regard to sea trout, studies in the Netherlands indicate the following: 9% smoltify after one single freshwater year; 81% after two freshwater years, and 10% after three freshwater years (de Laak & Vriese, 2001). For brown trout this process of smoltification does not apply.

3.6.5 Precocious males

‘Precocious males’ are sexually mature male trout that do not migrate to the sea. As applicable to Atlantic salmon, precocious males also occur in trout. The males often participate in spawning and they can be attacked and wounded by larger males. The percentage of precocious parr varies between 18 and 57% in two Swedish rivers (6-60 % for nine Norwegian rivers). The percentage varies strongly, and appeared to be related to growth rate. In years with a high growth rate, more precocious males occur. On average these parr are larger than parr which smolitificate at a later stage. During the years it has become evident that there is no correlation between the rivers, probably because the growth rate can differ strongly between two rivers in one year. In rivers in Norway with a low growth rate and high parr ages, few precocious males were found. A small percentage (approx. 1 to 2%) of the precocious parr still try to smoltify. These parr have lost their osmo-regulatory capacity and were not capable of withstanding the transition from freshwater to saline water (Elliott et al., 1992; 1994).
3.6.6 **Adult stage**

Sexual maturity of sea trout depends on the growth rate, which in turn depends on the temperature and the availability of food in the sea. For salmon the relationship between the NAOI (North Atlantic Oscillation Index) is a good prediction for the age of being sexually mature. For sea trout no literature was found in which this was studied. However, it is only logical that a similar relationship will partially apply to sea trout as well. Resident trout can already become sexually mature after 1 year (1+ fish), at a length of 15 cm, however, in general resident fish become sexually mature in the second or third year.

**Mature brown trout in the Achterhoekse beek (Photograph: Sportvisserij Nederland)**

**Mature sea trout (Photograph: Sportvisserij Nederland)**
3.6.7 **Life expectancy**

Sea trout will live in freshwater for the duration of 1 up to 5 years, and 6 months up to 5 years in saline water. Depending on the ages residing in freshwater and in saline water, the minimum life expectancy of sea trout is 1.5 year as a minimum and 10 years as a maximum. Literature often refers to ages of 9 and 10 years. At times older ages are referred to in relation to brown trout. Occasionally Canada reports ages of 13 years, whereas in accordance with Nall (1931: In Klemetsen *et al.*, 2003) the eldest brown trout found in England was 18 years of age. The majority of brown and sea trout will not have a life span exceeding 3 to 6 years. In England trout resides in freshwater in various rivers, for a period of 2 years on average (Elliott *et al.*, 1992; 1994).

3.7 **Growth, length and weight**

3.7.1 **Increase in length**

Sea trout parr growth depends on density and is mainly determined by the temperature and the size of the eggs and alevins. Length growth of pre-smolt trout in the freshwater stage was determined for several English rivers, and the percentage of smolt of different age classifications is as follows (Solomon, 1995):

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Share (%)</td>
<td>2 (0.2)</td>
<td>74.9 (79,0)</td>
<td>22.0 (19,6)</td>
<td>1.1 (1.2)</td>
</tr>
<tr>
<td>Length</td>
<td>13.8</td>
<td>17.0</td>
<td>18.2</td>
<td>21.7</td>
</tr>
</tbody>
</table>

The percentages in accordance with Nall (1931: In Solomon, 1995) are indicated between brackets. In the study implemented by Nall in English rivers, a small percentage of S1 and S5 fish were found. In the Dutch study for which smolts were caught off the coast, the smolt length indicated to be between 15 and 35 cm, with an average of approximately 27 cm (Vriese & Wiegerinck, 1991). The age of these smolts was not determined.

Growth at sea is highly variable. Solomon (1995) summarised the age and length of trout in 20 different English rivers. The length of the separate years is specified in the following table.
### Table 3.5

**Growth of sea trout in English rivers (according to Solomon, 1995) and the growth of sea trout in the Netherlands (de Laak & Vriese, 2001).**

<table>
<thead>
<tr>
<th></th>
<th>+</th>
<th>1+</th>
<th>2+</th>
<th>3+</th>
</tr>
</thead>
<tbody>
<tr>
<td>England (min. and max.)</td>
<td>27-39</td>
<td>36-55</td>
<td>37-68</td>
<td>56-74</td>
</tr>
<tr>
<td>The Netherlands (average)</td>
<td>45</td>
<td>50</td>
<td>65</td>
<td>79</td>
</tr>
</tbody>
</table>

A range is indicated for trout, at the age of 4 a weight of 20 gram for food-deprived streams up to a weight of 1 kilo in quick growing piscivorous anadromous population. For trout in food-deprived lakes, a piscivorous fish at 4 years of age has a length of 17.5 cm, whereas a fish of 9 years of age has a length of 36 cm (Klemetsen et al., 2003).

Brown trout growth in England is as follows: after 1 year: 4.2 to 9.1 cm; after 2 years: 11.7 to 23.1 cm; after 3 years 18.9 to 36.1 cm, and in the fourth year a length of 23.5 up to a maximum of 43.1 cm is reached (Mills, 1970).

#### 3.7.2 Maximum length and weight

The maximum length of sea trout is 140 cm (Froese & Pauly, 2004). According to Froese & Pauly (2004) the maximum reported weight of sea trout is 50 kg. In general the reported weight of sexually mature sea trout is from 5 up to 10 kg, at a length of 80 to 100 cm. Depending on the growth circumstances, brown trout can reach a length from 20 up to 50 cm. Outliers of a length up to 80-100 cm are reported at times as well (Froese & Pauly, 2004). The reported maximum weight for brown trout is 20 kg (Froese, R. and D. Pauly. Editors. 2012.FishBase).

#### 3.7.3 Length—weight ratio

In various studies the weight for sea trout was determined. In some studies the data is presented as a length-weight ratio. This report limits itself by only stating the length-weight ratio related to sea trout caught before the Dutch coast in the years between 1996 and 2000. The length-weight ratio for these sea trout is calculated as follows: $G=a*(TL)^b$, whereby $a = 0.003106$ and $b = 3.3157$ ($r^2 = 0.9624$). 644 fish with a length between 39.0 cm TL and 80.1 cm TL have been weighed (Klein Breteler & de Laak, 2003). The length-weight ratio for ‘fry’ and ‘parr’ is known at Sportvisserij Nederland, these have not been included in the diagram. The distribution of the weight is included in Figure 3.2.
Figuur 3.2  Length-weight ratio – sea trout. Vertical: weight in grams (Gewicht in grammen). Horizontal: Total Length (Totaallengte). For comparison the length-weight ratio of salmon is indicated in the table as a dotted line.

Please note that the maximum trout length is 120 cm. No individual length-weight data is available of fish with a length of more than 100 cm, which is why it is not realistic to include this data in the diagram.

Figur 3.3  Length-weight ratio – brown trout. For comparison the length-weight ratio of sea trout is indicated in the table as a dotted line.
The length-weight ratio of sea trout is valid as from 39 cm. Figuur 3.3 illustrates that the length-weight ratio between the migrating and resident population in the scope 39-50 cm hardly differ.

3.8 Food

Mills (1970) described brown trout as a generalist with regard to its foraging behaviour, whereas other authors refer to trout as being an opportunist (Klemetsen et al., 2003). Benthic fauna, drift food in the centre water layers as well as food from the surface is eaten. The diet varies between the habitat, season, fish size and age (Klemetsen et al., 2003). On individual level a fish can (temporary) be a specialist. Brown trout mainly eat invertebrates. During the winter season this mainly refers to benthic fauna and in spring/summer this is supplemented by hatching insects and terrestrial fauna. On occasion trout (sea trout and brown trout) eat other fish species, and is at times an important predator of young salmon.

The composition of the food package can vary strongly between sites and years (Elliott et al., et al, 1992). Parrs are selective with regard to the size of the food particles. A parr mainly eats the larger particles. Parrs with a length of 25 cm mainly eat terrestrial and aquatic insects of the groups Ephemeroptera (mayflies), Trichoptera (caddis), and Plecoptera (stoneflies). Larger fish (brown trout) can subsequently switch to fish or become specialists for example with regard to larger (terrestrial or aquatic) insects (Giroux et al., 2000).

From a study conducted over a period of several years it became clear that of the total of 2400 trout caught, 347 brown trout (14.5%) appeared to have eaten fish. Piscivorous brown trout can eat prey up to approximately 1/3 of their own size. Smaller prey such as common minnows are often swallowed with the tail first, other than larger prey fish such as arctic trout. The majority of the trout in this study had 1 prey fish in their stomach, whereas one trout had 16 prey fish in the stomach (L’Abée-Lund et al., 1996).

During the sea stage, post-smolts mainly eat species such as Rait’s sand eel (*Ammodytes marinus*) and the greater sand eel (*Hyperolus lanceolatus*) and *Atherina* (sand smelt). Older sea trout mainly eat Polychaeta (bristle worms such as: *Eunereis longissima*) and sprat (*Sprattus sprattus*). Less frequent are stickleback species. Sometimes herring (*Clupea harengus*) is referred as an important prey fish, however it is unclear whether a confusion with sprat occurs. In estuary areas *Amphipods* and insects could also be an important component of their diet. Empty stomachs are mostly detected in November and December. The largest quantity of food is consumed at the beginning of the summer, mainly from the centre water layers or from the surface. This is mostly done at night. In winter and in spring mainly benthic food is consumed during sunset and sunrise (Mills, 1970).
3.9 Survival percentages in different life stages

In general the survival from egg to fry is quite high and often is 94% according to Mills (1970). The survival of free-swimming larvae up to the ‘parr’ stage is highly variable and is determined by circumstances such as the availability of food, temperature, predators and flow rate.

The survival percentages at sea vary strongly. For smolts a percentage of 37% is referred to, and 56-68 % for adult fish in Norway. In Ireland the percentages calculated for small fish are 23% survival for males, and 29% for females, and 15% (male) and 31% (female) respectively for larger fish. Survival percentages for a period of 15 years, being as from 5.8 up to 15.1% for two South England populations were found, and 24% for a North England population (Elliott, 1994).

The survival of smolt up to the return to freshwater was determined on various occasions during the study conducted by Solomon (1995). The survival is approximately in the order of 1% (0.8 – 1.5%). Elliott et al. (1992) reports much higher survival percentages, as from 1.3% up to 15.1% (for finnock 9.1% up to 43.4 %).

Also for kelts a strongly varying survival percentage is found: 40.5% for an Irish population, 25.7% for an English population and 16-21% for a Scottish population (Elliott, 1994).

3.10 Population dynamics

3.10.1 Minimum population growth

Literature provided nearly no data regarding the minimum population size. In a stream in Denmark it is estimated that a minimum population size of anadromous trout of approximately 300 fish must exist (Hansen et al., 2002).

3.10.2 Population structure

Many studies have been conducted with regard to the structure of trout populations in England and Scandinavia. The trout population structure can vary significantly and strongly depends on the life strategy of the subpopulations. According to Elliott et al., (1994) four basis specimen or types occur (please refer to § 3.3). The non-migrating specimen has a rather simple population structure of juvenile fish, aged 2 or 3 years old, and a cohort of sexually mature fish in the age of 2 or 3 years up to approximately 10 years of age. If migrating trout occur, the population structure becomes more complex, since these subpopulations could also occur in the same river. From a study conducted in England and Wales it is illustrated that - what is referred to as - ‘whitling’ or ‘finnock’ (mostly male; Elliott, 1994) return to their natal river when they have reached a length of 25 up to 40 cm. This cohort of fish represents a percentage of the returning population of 2.7 to 97.6%. The highest percentage is found...
in short rivers. However, from this cohort of fish, only 14-31% is actively involved in spawning.

Fish from various year classes which return to their natal river in the same year, ensure that the spawning success is maximum. Should circumstances apply resulting whereof a year class is not or barely not represented, other year classes can absorb this. By crossing fish from different year classes it is prevented that year classes become genetically isolated. Fish from specific year classes could be reproduced by a limited number of parent fishes if they return in the same year (Elliott, 1994).

Table 3.6 indicates that trout have a very complex population structure, whereby fish of different freshwater ages can also enter at different seawater ages, meaning that fish that only stayed in the freshwater for 1 year, can enter as 1SW, 2SW or even as an older fish, which applies to fish that remained in freshwater for 2 years as well. As such a large number of combination of freshwater and saline water ages may occur.

<table>
<thead>
<tr>
<th>Post-smolt age</th>
<th>Sexually mature as 0+ growth season</th>
<th>Sexually mature as 1+</th>
<th>Sexually mature as 2+</th>
<th>Sexually mature as &gt;2+</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quantity</td>
<td>Length</td>
<td>Quantity</td>
<td>Length</td>
</tr>
<tr>
<td>0</td>
<td>434</td>
<td>34.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>28</td>
<td>45.6</td>
<td>935</td>
<td>47.7</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>58.5</td>
<td>116</td>
<td>60.5</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>21</td>
<td>67.8</td>
</tr>
<tr>
<td>&gt;3</td>
<td></td>
<td></td>
<td>6</td>
<td>76.5-88.5</td>
</tr>
</tbody>
</table>

Around 1930 (Nall, in Solomon, 1995) it was determined that in the same rivers in Wales 89% of the fish started migrating as 2SW and 11% as 3SW. Of all rivers included in the study conducted by Solomon (1995), the percentage of 1SW fish was 44% (46.9 cm), 36% as 2SW fish (62.4 cm), and 20% as 3SW fish. Both studies concluded that the average length of the separate age classifications is larger than those reported in Scottish rivers.

Studies on the age structure should only be used with caution. This is because of the fact that the trout population at for example estuary sites can differ significantly from the age structure at spawning grounds. As such it is know that with regard to sea trout, mainly the whitting or finnock at times remain in the estuary for a longer period of time. This estuary is not explicitly the estuary of the natal river of this specific fish. Furthermore sea trout also migrate to a river which is not their natal river, these fish are referred to as strayers. These facts could cause important differences related to the population structure at the coast, and the population structure of fish that actually participate in spawning.

The percentage of fish that previously participated in the spawning is 5-69% of the population participating in the spawning (27 rivers in Norway).
Fish can participate up to 12 times in spawning (Solomon, 1995). Elliott (1994) reported 5 to 8 years as a spreading of the ages on which brown trout participate in spawning in several studies in England.

### 3.10.3 Genetic aspects

A sedentary population of trout (brown trout) does not lose its competence to return to the sea after a long-lasting isolation. Furthermore sea trout and brown trout crossbreed as well, which refers to a species with the same genetic characteristics. However, trout do have a wide array of external characteristics related to region, which could refer to genetic differences between the different areas. To what extent these actually refer to genetic differences, or whether these refer to adjustment to the environment, is not clear.

The number of chromosomes of a diploid cells of a trout is 80 (Froese & Pauly, 2004).

Trout has a population doubling time of 1.4 up to 4.4 year (Froese & Pauly 2004).

### 3.10.4 Hybridisation

The spawning area of salmon and sea trout can overlap, which could result in hybrids. In general salmon spawn in more shallow and more quick flowing sections of a tributary. These sections are often located at a higher location (and/or are located further upstream). By closing off these spawning habitats, for example by means of dams or by destruction of the habitat, salmon is forced to spawn on lower positioned sites. This increases the chance or risk on hybridisation. For that matter, hybridisation also occurs in a natural stock of sea trout and salmon (<0.5%, Elliott et al., 1992). Nyman (1970) also concludes that the percentage of hybrids among natural, undisturbed circumstances is low. During a study of 4431 salmons in England and the British isles, 0.3-0.4% appeared to be hybrid (Payne et al., 1971, Payne et al., 1972). In some rivers, such as the river Tweed and the river Tay, the percentage of hybrids is higher. In Elliott et al. (1992) percentages between 0 and 31% are reported.

In Newfoundland, where sea trout was introduced at the end of 1800, the percentage of hybrids appeared to be 0.9% (Verspoor, 1988). The author reports that due to the study method used (limited number of sample sites), the percentage of hybrids could be underestimated. Verspoor states that the high percentage of hybrids in Newfoundland, compared to the data from England (0.3-0.4%) and Sweden is based on the fact that sea trout is not an indigenous fish species.

Depending on the study method used, the percentages of hybrids may differ. Some researchers base the percentage of hybrids on the shape of the scales. More modern techniques base the percentage on a electrophoresis or mitochondrial DNA analysis. The presence of various salmon species increases the possibility of hybrids. It could be that the length of the river also plays a role. Jordan & Verspoor (1993) provide a summary of previous results from studies related to hybridisation percentages. This shows that the percentage varies between 0 and
22.8%, however, the percentage of hybrids in river systems in England is around 1 to 2%. The river Tweed indicated the highest percentages (3.4%). Hybrids have a better growth than the parent animals and a better resistance against diseases. Salmon and trout hybrids are fertile and can be backcrossed with salmon and sea trout (Mills, 1970).

In general more hybrids occur if the natural habitat is disturbed resulting from the building of dams or, as in this case, the introduction of a fish species.

3.11 Parasites / diseases

During the freshwater stage, mainly brown trout are at times vulnerable to external parasites Argulus (carp louse) and Piscicola (leech) and the gill parasites Gyrodactylus and Discocotyle. In some countries outbreaks of Diphyllolothrium sp. were reported. This worm causes a high level of mortality in the larval stage. The intermediate hosts are snails and birds. Another parasite with the same intermediate hosts is the worm Diplostomum, this worm causes a cloudy cornea and swollen eyes. Myxosoma cerebralis (protozo) causes the whirling disease. At first the disease was only known at fish farms, but now this disease occurs in natural populations in Scotland as well (Mills, 1970).

Just as salmon, sea trout is vulnerable to the harmful effect of Aeromonas sp., which causes the disease furunculosis. In fish farms this bacteria causes a reduction of growth due to internal and external bleedings. The disease occurs in natural populations as well, which is possibly increased due to the presence of fish farms. This disease if often followed by mould damage, such as Saprolegnia.

By farming fish in rivers, fjords and at sea, the pressure of infection of specific parasites and diseases increased. This pressure of infections refers to many diseases, however, mostly to the sea louse Lepeophtheirus salmonis, which presents a huge problem for trout smolts migrating to the sea. As the infection intensity exceeds more than 30 sea louses per post-smolt, and the larvae reach the pre-adult stage, a serious weakening of the post-smolts can be registered and mortality of Atlantic salmon can be expected (Grimnes & Jakobsen, 1996). Adult fish returning to the spawning areas can be exposed to a serious infection, however the sea louse cannot survive in freshwater. Caligus elongatus is also referred to as sea louse, but occurs less often and is smaller than the Lepeophtheirus salmonis. The Lepeophtheirus salmonis causes changes (apoptosis and necrosis) of the epidermis and mucous membrane of all salmonides. In a test, changes in the skin and gill tissue in which the louse itself was not present, were registered. The gill tissue became thicker due to intercellular swellings and more leukocytes occurred. The gill Na+/K+-ATPase activity increases and as such also the number of Cl- ions in the plasma. An increase in stress was registered. The infection was administered by mean of 3, 6, and 10 lice per salmon. Since this is only a moderate infection, a considerable negative impact of sea lice damage may be expected under natural circumstances (Nolan et al., 1999). Due to
the disturbed Cl− household the post-smolts also have problems with the osmoregulation. Seat trout population of Irish and Scottish waters have suffered greatly from the harmful effect of the salmon louse, originating from aquacultures around 1970 up to 1980 (Solomon, 1995), please refer to §6.1.5 as well.

Lepeoptheirus salmonis —the tails are the eggs of the copepode (Photograph: Sportvisserij Nederland)

3.12 Predators

Trout parrs and smolts are eaten by otters, cormorants, whitefish and pike. Specifically pike smaller than 40 cm is at times a food competitor for the brown trout; next pikes could specialise on salmonides. A study at an Irish lake proved that 2/3 of the present pikes had a diet of salmonides only (Mills, 1970). In Olsson & Greenberg (2004) the burbot and pike are referred to as brown trout predators. Limited data on predators of trout in the smolt and sea stage was found. It is assumed that during these stages, trout has the same predators as salmon. During the downstream migration, the smolt is additionally vulnerable for predation by large fish of prey (pike, pike perch, trout, and asp) and cormorants. In the estuary, smolt is vulnerable to predation by sea-gulls, terns, cormorants, cod, whiting, and pollack. Seals can predate on smolts as well as adult trout in the estuary.
4 Requirements related to the habitat and the environment

4.1 General

Quak (1989) developed a HIS (Habitat Suitability) model for trout. This HSI model is based on data from North-American literature (Raleigh, 1986). The HSI model is focused on resident trout. To what extent the model can and may be used for the European situation is not clear.

Due to the fact that sea trout has an anadromous lifestyle, the fish remains in various habitats during its life cycle, and sea trout has different requirements of its environment in all these stages of life. It would be too detailed to gather all required parameters for all life stages. Specifically since sea trout does not develop in all life stages in the Netherlands. The required parameters for brown trout are unknown for the situation in the Netherlands. For reference, the English or German literature could be used. This would also be too farfetched to investigate all within the scope of this knowledge document.

4.2 Water temperature

Sea trout occurs in moderate areas. The eggs can develop well between 0 and 16 °C, however, above 9 °C the mortality rate increases quickly. Sea trout can survive maximum temperatures of 25 up to 30 °C if the fish is accustomed to these temperatures. For the juvenile stage the maximum values are approximately 5 degrees lower (Mills, 1970). The minimum temperature is approximately 0 °C. At this temperature a high mortality rate in natural situations is expected. The temperature which causes an optimum growth in freshwater is between 12 and 19 °C. Smolts are more vulnerable to higher temperatures than parrs. The survival of smolts reduces at temperatures above 22 °C (Alabaster, 1967).

In a study related to the values of pools for the survival of brown trout during dry periods it was illustrated that mortality started to occur at 24.7 °C, and at 29.7 °C all fish died. Depending on the shape and temperature / oxygen content, pools are often a shelter for brown trout in times of extreme draught (Elliott, 2000). The stress reaction accelerates at an increased water temperature. The parameter temperature has a high number of interactions with other parameters such as food availability.

4.3 Oxygen content

Trout are reported to have a high stress reaction at a low oxygen content. The sensitivity for a low oxygen content is different for the various stages
of life of trout. Eggs require a minimum oxygen content of 1 mg/l at an adequately high flow rate to survive, however, at a level of less than 5 mg/l the development of the eggs stops already. At 3 mg/l oxygen, mortality occurs for trout parrs. Up to 10 mg/l a growth reduction is expected. Contents of >10 mg/l appear to be optimal. However, this depends on the temperature. In the summer, sea trout parrs avoid waters with an oxygen content of 5 mg/l or lower (Elliott et al., 1992).

4.4 PH-value

Trout can survive low pH values. Problems start to occur at a pH value of 3.5 up to 4.0 due to the disturbed osmoregulation. At high Ca\(^{2+}\) values in acid water (3.5-4.0) more trout can survive. Fish originating from fish farms have a lower survival rate than fish maturing in streams (Elliott et al., 1992). The optimum pH trajectory for growth is between 6.8 and 7.8 (Mills, 1970).

4.5 Transparency and light

Trout require light during foraging. If the deeper water in lakes is more clear, it will be explored. At times, trout forage at night for benthic food. However, literature does not indicate which requirements apply to trout with regard to the view (Raleigh et al, 1986).

4.6 Salinity

Recent studies described that sea trout also spawn in the Baltic Sea in waters with a salt content of 4-5‰ (Klemetsen et al., 2003). Researchers used laboratory tests to prove that with the current salt content in Gotland, spawning does not contribute to the population. The eggs or larvae are thus not resistant against these salt contents.

Juvenile stages of sea trout are less resistant against high salt content, however after a period of customisation, they can survive well in the saline water. Brown trout can also survive in saline water after a period of customisation. When trout parr is suddenly moved to saline water, the parr (13-15 cm TL) does have a reduced maximum swimming speed (\(U_{\text{burst}}\)) for a duration of two days (Pedersen & Malte, 2004). Adult trout are well resistant against high salt contents.

4.7 Flow rate /tide difference

It is important for eggs that the flow rates are not too high for if this happens the eggs will washout. However, the flow rate must be quick enough to remove waste product from the gravel bed, and to ensure a proper provision of oxygen. The flow rate in the spawning bed can deviate significantly from the flow rate measured just above the spawning bed.
Studies revealed that for young sea trout fry in nursery channels the washout is lowest at 25 cm/s. At a level of more than 25 cm/s the washout increases. At a length of 4 to 5 cm, a flow rate of more than 50 cm/s is tolerated. At lower temperatures the preference for a high flow rate reduces. At an increase of the water temperature of 7 degrees, results in an increase of 5 cm/s for the critical flow rate (= flow rate at which fish washout). In general it can be stated that the flow rate for spawning, the egg stage and fry stage must be in between 20 and 80 cm/s in the main stream. High discharges, but draught as well are of a significant influence on the survival of eggs and fry.

4.8 **Water depth**

Spawning beds are found at a water depth of 15 up to 90 cm. Fry or 0+ parr is hardly ever found in water deeper than 50 cm (Elliott et al., 1992). Specifically sections with in-stream cover of for example emergent vegetation is preferred (Elliott et al., 1992). Parrs older than one (1) year have a preference for a water depth of 75 up to 150 cm. For the adult brown trout a water depth of >15 cm and a flow rate at the head of the fish of < 15 cm/s is required for an optimal peaceful habitat.

In streams in which salmon and sea trout fry both occur, sea trout parrs have a preference for a water depth of 20-30 cm, whereas the young salmon occurs at a depth of 90 cm (Elliott et al., 1992). The preferred water depth is influenced by temperature, flow rate and the presence of shelter. If temperature reduces, the tendency is that salmon and sea trout fry seek shelter more often.

4.9 **Soil substrate**

For the substrate at the spawning grounds a range of 1 up to 7 cm diameter is the optimum. The percentage of sand in the spawning bed must preferably be lower than 5%.

4.10 **Vegetation**

Trout do not require vegetation for growth. Vegetation and vegetation debris are also not required during other life stages. Vegetation in a stream could indicate a higher production and resulting thereof, a high density of trout parrs and adult fish. The density of juvenile and adult fish however depends on the percentage of shadow, hollow banks and in stream cover, such as water plants.

4.11 **Water quality**

Trout show a high stress reaction when increased levels of ammonia and CO₂ g apply. The presence of aluminium in acid water have a negative influence on growth and survival (Elliott et al., 1992).
Trout is vulnerable to a range of contaminations caused by pesticides. Contaminations influence all life stages of salmonides.

Mills (1989) provides a subdivision of toxic chemicals in acids and bases; - metals; - phenols (including phenol) and cyanides, and the pesticide group. Next, oil, oxidation of organic substances, suspended solid substances, city waste water, industry, farms or fish farms, radio-active substances and ferriferous water (mining) is in some cases toxic for salmon and other fish species. Also some authors (Watt et al., 1983) report acid rain to possibly be toxic. The effects of acid rain are mainly reported from northern regions, with a natural lower pH value of the water and appear to be of little relevance to the Dutch situation, due to the relative high pH value of the Rhine water.

Copper and zinc damage the gill of fish, phosphor causes haemolyse (disintegrating of corpuscles) and a quick death. The toxicity of substances depends among others on the decomposition and hardness of the water. Ammonia oxidizes quickly, but phenols and some pesticides are persistent. The toxicity of metals among others depends on the pH value and water hardness. A lethal dose for copper is 48µg/l, for zinc this is 600µg/l at a water hardness of 20mg/l. The effects of contamination can be additive (Mills, 1989). Brown (1969; cited in van Brummelen, 1990) indicates as LC50 value for ammonia, phenol and zinc (as Zn^{2+}) the following values for farmed rainbow trout: 35.0, 8.0, and 4.0 mg/l. The pesticide Diazinon has a negative impact on the homing behaviour, and alarm pheromone production against predators have been registered for chinook salmon at concentrations registered in the field (Scholz et al., 2000).

Even at low values of toxic or caustic substances, the fish can suffer indirect damage due to an increased risk on, for example, fungus infections.

Van Brummelen (1990) stated in 1990 that a number of substances in the water of the river Rhine, temporarily (on annual basis, but locally as well) exceed the threshold values. This is mainly applicable in industrial and residential areas. This refers to the substances tetrachloroethylene, copper, zinc, anionic detergents, chloroform, cadmium, chromium, nickel and lead. The author states that the spawning migration of anadromous fish in the Rhine can be hindered by these substances. It is unclear what the effect is on the population level (Van Brummelen, 1990). Since 1990, the water quality of the Rhine has improved, even though some substances can still occur in too high concentrations.

Thermo pollution can be seen as a contamination and it is known that migration is postponed or disturbed by high water temperatures.

For a variety of contaminations (sub)lethal values for salmonides are determined, specifically in the young life stages (Kamphuis & Nijdam, 1993).
4.12 **Spatial requirements**

The density of juvenile fish highly depends on the spatial structure of a stream and river section. However, this is a very complex problem. Not only are the individual parameters of importance for the fish, they also influence one another. For example, if the temperature reduces, the optimum for flow rate is different as well. Apart from the parameters soil substrate/vegetation/depth, the parameters pools, shelter and overshadowing are important as well. A shelter in a river section of approximately 35% in summer is optimal. The shelter serves the purpose for avoiding predators and to rest. In winter trout parrs require deeper sections to survive.

In winter the adult brown trout require a hibernation area such as a ‘pool’. The percentage of the spawning area in a river section must be approximately 5%. This means that many pool-riffle sequences must be applicable.

4.13 **Migration**

The migration of sea trout in the Dutch lower estuary region is described by de Vaate and Breukelaar (2001). This reveals that of the 582 sea trout equipped with a transponder (lifetime 4 year) along the coast, 202 were registered in the Netherlands. The most important entering points are de Nieuwe Waterweg, de Afsluitdijk and het Haringvliet. The average travel speed in upstream direction was 21.8 km per day. 6 fish (1%) migrated twice in Dutch rivers and went to spawning grounds in Germany. Of the 202 fish that migrated to the Netherlands, 93 fish in Germany were registered. Statements are made with respect to the choice of migration route through the Netherlands in relation to the discharge and temperature (bij de Vaate and Breukelaar, 2001).

Brown trout has a high degree of site loyalty and only migrates at low temperatures in the winter (<4ºC) to pools (Mills, 1970). Brown trout migrate by approximately 1 km per day during the upstream migration. After spawning, brown trout migrates back to the lakes at a speed of 2.3 km per day.(Rustadbakken et al, 2004).
Trout spawning and nursery site in Scotland (Photograph: Sportvisserij Nederland)
5 Fisheries

Professional fisheries sector
Sea trout has been important in fisheries of saline water and freshwater up to after the second World War. Currently a total fishing ban for salmon and sea trout applies to the freshwater and the 12 mile zone off the coast. Notwithstanding this fact, salmon and sea trout are regularly caught by professional and recreational fishermen.

Recreational fisheries sector
Brown trout and sea trout are attractive fish species for angling. In some closed off previous estuaries, trout is released specifically for recreational fishing (Raat, 2003). In closed off waters in the Netherlands, such as sand extraction pits sea trout and brown trout are occasionally released. Brown trout is also released in several streams in the south or east of the country. Specific assessments of the releases are not implemented. The released trout is often bought from fish farms abroad. These trout are probably not genetically the same as the trout which were present originally.
In England, Germany and Scandinavia trout is an important species for recreational fishing as well.
6 Threats

The sea trout population has long been under pressure, as is applicable to salmon. However, it is not clear to what extent the trout stock of the anadromous population has reduced. The resident population in the Netherlands has reduced, and according to the Red List, the resident population has disappeared from the Netherlands, even though (brown) trout do occur in streams resulting from releases. Trout as well as salmon have a complex life cycle and lifestyle. This is why it is not surprising that many threats exist and various factors resulted in the decline of both species.

To which extent the (anadromous) trout stock has actually reduced is a question. Catch statistics show that significant fluctuations with regard to quantities per year exist. Next, it is unclear whether the professional fisheries explicitly distinguished between salmon and sea trout (De Groot, 1990), please refer to the diagram below.

![Catch statistics in the Netherlands related to (sea)trout in 1889-1986](image)

Possibly, sea trout (salmon trout) were considered less valuable fish and were mainly traded without being auctioned. This certainly applies to the period before 1920 (de Groot, 1991).

6.1 Fisheries

Since ancient times fishing or angling for salmon and trout takes place. In the early prehistory, spears and fishing nets, made from treebranches were used, in the Middle Ages woven nets made from willow branches were used and at the end of 1800 large mechanised cotton seine nets were used during the spawning migration. However, around 1900 salmon and trout were seen less in the river Rhine and fisheries also disappeared. Sea trout catches did not reduce, contrary to the dramatic decline of
salmon catches. It is likely that sea trout is less critical than salmon with regard to the water quality and spawning areas.

In the days that salmon catches were still good, sea trout was caught as well

Since the seventies of the last century, various organisations bought out commercial fisheries in international waters. The fisheries were bought out by national authorities or by organisations such as NASCO and NASF. At present most fisheries have been bought out. It mainly involved what is referred to as high-sea fisheries with among others long-lines and other catching gear on the traditional feeding grounds of the Atlantic salmon. It is plausible that poaching still occurs. Due to the buying out of these fisheries, a quick recovery of wild salmon and trout populations was expected, however, this recovery did not take place (WWF, 2001).

6.2 Water pollution

Rhine
Since the industrialisation, water pollution of the Rhine, but also from – for example – the Thames increased rapidly. After 1900 the presence of salmon in the Rhine quickly declined. The taste of the salmon predominantly resembled phenol (disinfectant). Water pollution, river normalisation and constructing dams took their toll. At the beginning of 1900 immense fish mortality occurred downstream of the German Rhine, which was uncommon for these times. This was probably due to the massive discharges of organic material from potato and sugar beet by factories. Redeke (1927) states that fish mortality has become a common phenomenon and blames this on the poor water quality. Only 25 years earlier Hoek stated that damage due to contamination or pollution could easily be overestimated. In 1877 serious impacts on fisheries resulting from contaminations in 21 rivers were reported in England. As early as in the 14th century it was forbidden in England to discharge waste material from
tanneries directly into the river. However, it is remarkable that the Rhine states did not succeed in recognising this threat.

With regard to water pollution Reekens reports the following: "In a postscript with the Meuse report of Dr. Hoek it is reported that in 1911 several dead and nearly dead salmon were found in the Meuse near the city of Maastricht, which – resulting from the research initiated by Dr. Redeke - appeared to have suffered from a type of furunculosis, known in Baden for trout and in England for salmon. Dr. Hoek assumes that the disease is related to the pollution, to which the river Meuse and some of the related estuaries in Belgium are exposed to."

Not only the Meuse suffered from contamination. Many streams in the province of Limburg suffered from its use as public sewer, onto which household and industrial waste water could be discharged at will. With regard to the river Roer, Reekens (1916) states: "It appears to be known from the river Roer that in the past it was visited by salmon, which was ended due to the contamination of the river by a variety of factories."

### 6.3 Morphologic changes in the habitat

Resulting from various interferences in rivers, such as gravel and sand extraction, and at times dredging of shallow sections of the rivers, or simply due to silting up of gravel grounds, coinciding with a reduction of the flow rate (for example due to hydrologic activities), the embankment and strengthening of banks and canalisation, caused the disappearance of a large proportion of the Atlantic salmon spawning grounds and habitat. Mainly the construction of dams in the centre and upper courses, for example for the generation of hydropower energy caused the disappearances of several hundreds of hectare spawning grounds and habitats in the Rhine system. These interferences are applicable to Scandinavian countries as well, often even on a much larger scale.

**Rhine**

 Significant hydraulic engineering projects have been implemented in the Rhine since 1812. These projects had the objective to improve safety, improve shipping routes, improve drinking water production, and the generation of energy. Resulting from these projects flow patterns disappeared or changed, shallow areas disappeared resulting from the extraction of gravel and sand, dead estuaries or adjacent flowing channels were closed off fully, flow accelerations discontinued due to the widening of river beds, rocks disappeared, bends were cut off and pool/riffles (sections with flow accelerations, alternating with deeper and slower flowing sections) disappeared. Resulting from the implementation of these hydraulic engineering project, the length of the river Rhine reduced by approximately 15% since these days (Holl, 1999). The changes in the flow patterns also create changes in interfaces with water of a different composition. The hydraulic engineering projects increased the depth of the rivers Waal, Rhine and Lek by 0.4 meters up to 2.6 meters during the period from 1891 up to 1934 (de Groot, 1989). For safety reasons various openings to the sea were closed off in the Netherlands (the
closing off of the Zuiderzee (1932), and resulting from the February calamity in 1953, several tidal inlets in the province of Zeeland were permanently closed off (Haringvliet, Volkerak, Oosterschelde). In 1970 three dams were constructed in the Nederrijn/Lek (Driel, Amerongen, and Hagestein) in order to regulate the flow through the IJssel. These canalisation and standardisation works resulted in a huge degradation of the habitat.

Standardisation works were also conducted at the rivers Waal, Lek, and IJssel. The flow profile was embedded in a summer and winter profile. Islands and sand banks were linked at the shore by changing the course of the river. In 1850, the Waal still included 18 shallows and islands. The summer profile of the large rivers in the Netherlands currently represents a deepened river. The flow rate in the main flow is guaranteed by groyns (cribs), resulting that sand can no longer deposit. During high water the river can flood into the floodplains. The width of the floodplains is limited by the winter dikes.

Due to strongly increased shipping, it has become more complex to distinguish the water originating from the various side streams or rivers and these interfaces (thermoclines and rheoclines) cannot (well) be distinguished. Another aspect which could postpone or disturb the migration of salmonides is pollution (thermopollution).

Meuse
Analogous to the events taken place in the Rhine, large-scale changes applied to the Meuse drainage basin as well.

One of the first large changes in the Meuse was the closing off of the Schanse Gat in 1856. In former days, the St. Andries canal provided an open connection between the Meuse and the Waal. When this connection was closed off, the only remaining open connection between both rivers was at Woudrichem. Another important change was the construction of the Bergse Maas during 1887-1904. Resulting thereof the estuary of the Meuse was relocated and the connection at Woudrichem was closed off. This opened a direct access to the upper course, via the Hollands Diep and the Amer.

6.4 Migration barriers

Rhine
For the hydro-electric power stations, dams were also built in the main stream in order to create a fall. As early as in 1895 a hydro-electric power station was built in the main stream of the Rhine near Rheinfelden. Around 1930 the High Rhine was no longer accessible as from Basel. Notwithstanding the fact that some dams (including Kembs) were provided with fish passages, these should not be indicated as efficient passages. Shortly after World War II, the Grand Canal d’Alsace (lateral canal through the Elzas) on French/German territory was completed. This canal was fully built from concrete. At the end of World War II the canalisation of the Moezel was completed as well. Several other estuaries were completely closed off from the Rhine around 1800. It should be taken into consideration that in the upstream sections, dams had already
been built, including water mills for saw millers/millers, which resulted in the loss of spawning and nursery sites.

Various rivers connections have been implemented in the Netherlands as well. The first adjustment date back to approximately 1200 aD. In 1851 the canal the Nieuwe Merwede was dug to guarantee an adequate discharge of water from the Rhine into the Hollandsch Diep. Next, and again to guarantee adequate water discharge from Rhine water, the Nieuwe Waterweg was dug in 1866-1872. In 1856 the Schansegat, being the connection between the Waal and Meuse was closed off. However a connection between the Meuse and Waal remained at Well and Woudrichem. In 1887 the Bergsche Maas was dug and the connection between Well and Woudrichem was provided by a dam including a shipping lock. The Meuse flows – via the Amer – into the Hollandsch Diep. Resulting from the storm and floods in the province of Zeeland in 1953, a number of tidal inlets was closed off by means of dikes or dams. One of the most famous dams are in the Haringvliet. The construction of these measures to protect against high water (Deltaplan) indicated the end of a free migration between freshwater and saline water for various fish species.

The Haringvlietdam is a migration barrier for various fish species

Meuse
In 1875 dams were already constructed in the Meuse just above the city of Liège. Hoek reports the following in this regard: "On French territory, the Meuse now has 19 dams, over a length of 95 km. In Belgium, just above the city of Liège, 21 dams were built and another 2 between Liège and Visé." Furthermore, Hoek reports that no salmons have been reported since the dams above Liège have been built (in 1875). Dams in the Meuse
In Belgium have been subjected to numerous modifications. In the middle of the last century 24 dams were situated on Belgium territory, 15 in the Meuse between the Dutch border and Namur and 9 between Namur and the French border. In order to allow passage for large ships on the Meuse up to Namur, the first 15 dams have been replaced by 7 larger dams (mostly on different locations) and the soil was dredged up to a depth of 5 meters. The situation between Namur and the French border remained relatively unchanged; old dams were replaced by new dams. Moreover, in the drainage basin of the Meuse in France, large acreages of forest disappeared.

In the Dutch section of the Meuse, dams were built at Linne (1925), Roermond (1925), Belfeld (1928), Sambeek (1928), and Grave (1928) in the years 1918-1929, followed by the construction of the Julianakanaal (1929), the dam at Borgharen (1928), and the Lateraalkanaal Linne-Buggenum (1970). Downstream from Grave, the Meuse was standardised. And the last dam, at Lith, was constructed in 1936. Resulting thereof the interest of the Meuse as a shipping river increased. The perspectives for draining large areas for agricultural purposes in the province of Noord-Brabant improved significantly.

Fish passage in the river Meuse. The fish trap is positioned between the dam (left) and the shipping lock (right). Photograph: Sportvisserij Nederland.

In those days it was assumed that the effects on the salmon (and trout) stock could be overcome by including fish ladders in the dams, according to the system designed by the Belgium engineer G. Denil, which was referred to as the "échelle à amortiseurs". The dam at Grave was provided with one single Denil-fishway, the dams at Linne, Roermond, Belfeld, Sambeek, Borgharen, and Lith were provided with two Denil-fishways.
(Heermans, 1988). The experiences with these fish ways were not positive.
Currently the Meuse has 7 dams on Dutch territory in the trajectory Lith-Borgharen. Six of these dams are provided with a fishway or fish ladder. At Borgharen (most upstream weir in the Netherlands) a fish passage was opened in 2008. On the Meuse, two hydro-electric power stations are situated at Lith and Linne, and more hydro-electric power stations are planned at Grave, Belfeld, Sambeek and Borgharen.

At the end of the 20th century a High Water Action Plan was formulated. The cause for this plan was a number of near flooding’s of the Rhine in 1993 and 1995. In this plan the Rhine is given more space due to widening and excavation of the foreland, repositioning of dikes and the connection of branches of the old meanders (IRC, 2004). These and other measures appear to have been successful, in the Sieg (within the framework of the salmon project an important Rhine estuary) more sea trout is caught, even though the annual catches fluctuate strongly.

### 6.5 Aquaculture

In general it can be stated that human interference causes trout to experience a higher stress level than in natural systems which are not influenced by humans. Human interference here is referred to as interference in the broadest sense of the word, meaning the construction of dams, contamination or pollution and aquaculture.

According to some authors, farmed salmon and crossings with sea trout represent a new biological group (entity), named *Salmo domesticus*. This salmon threatens the wild salmon and trout by their ecological and genetic input in the original area of distribution.

Keeping salmonides and fighting diseases in the aquaculture could also have a direct or indirect effect on passing trout. By farming fish (salmons) in rivers, fjords and at sea, the infection pressure of specific parasites or diseases increased. The increase of the infection pressure relates to many diseases, but specifically the sea louse *Lepeophtheirus salmonis* represents a huge problem for trout *smolts* migrating to the sea.
Salmon with Lepeoptheirus salmonis (Photograph: Sportvisserij Nederland)

The sea trout population of the Irish and Scottish waters have suffered significantly from the damage due to salmon louse, originating from aquacultures as from approximately 1970 up to 1980 (Solomon, 1995).

Due to the aquaculture in nets, other problems such as eutrophication occurred, which in itself caused further unexpected problems. One of the results from waste and decomposition products is the fact that the sediment is enriched, whereas it can become oxygen deficient. This will change the composition of the invertebrates for the advantage of – for example - tubifex-type of specimen and worms. These invertebrates are a host for a.o. myxozoa. *M. cerebralis* causes the whirling disease which results in a high mortality rate among rainbow trout populations in Colorado.
7 Gaps in knowledge

Since ancient times, salmonides have been a source of mysteries and myths. It is likely that of no other fish species than salmon so much information is known. However, a scientist describes: *In spite of some information on distribution and timing, our knowledge of salmon in the sea is dominated not by what we know but by what we do not know....* (Dempson et al., 1986)

It is a fact that up to approximately 1960 little to nothing was known about the sea stage, but there still is relatively little known about the freshwater stage as well.

Much is unknown with regard to salmon population management. Some projects are successful whilst they require relatively minor efforts, other recovery programmes indicate no success, not even after a period of 10 or many more years.

Notwithstanding the fact that much was done for salmon recovery in the Rhine river system, which initially appeared to be successful, (mainly the Sieg), salmon catches reduced (2004-2005) once again. Of the less critical species sea trout, catches even reduced dramatically. In 2007 salmon catches are once again on level, but sea trout catches are marginal.

7.1 Fisheries

Currently, fisheries no longer appear to present a threat for the recovery of salmon stock. At the end of the seventies of the last century, authorities, including NASCO bought out fisheries on the ocean. A fishing ban applies to the inland waterways in the Netherlands, and to a 12 mile zone off the coast. EU regulations prohibit catches in a zone from 12 up to 200 mile off the coast. Notwithstanding these fishing ban measures, no recovery of salmon stock followed. The question to be asked is how effective these fishing bans – and the risk of being caught – actually are. It could be that a high mortality rate of smolts and juveniles in the IJsselmeer and coastal areas occurs due to gill net fisheries. This is investigated at this time.

7.2 Water pollution

Since 1970 the pollution of the rivers in Western Europe reduced, partially thanks to the Rhine Action Plan (RAP). The Rhine water quality is no longer a limiting factor for fish.

However, with regard to micro-pollution, this could be a different story. New substances are added, and more information on existing substances becomes available, such as information on the effects of chlorinated hydrocarbons (such as PCBs) and hormone disrupting substances (EDCs).
In recent years the effects from Endocrine Disruptive Chemicals (EDCs) are of increased interest. EDCs are also known as Hormone Active Agents (HAAs). These substances disguise or increase the hormone balance. Hormones regulate growth and development, the metabolism, physical adjustments to a changing environment, reproduction, behaviour and the parr-smolt transformation (NRC, 2004). Substances with characteristics similar to those of EDC could be hormones from waste water, but also a specific softeners in plastic or TBT, an anti-fouling substance (paint) for boats. These substances could have a wide variety of effects on hormonal processes, however, the most well-known effect is the oestrogen effect of certain chemicals on the sexual development of young fish. Due to these substances, male fish develop female gonades. The fact that this could have a major impact on fertility should not come as a surprise.

Trout is also sensitive to minor concentrations of contaminants (such as pesticides, oil and copper) in the water (please also refer to section 4.11). To what extent these could hinder a possible recovery of trout is unknown.

7.3 Spawning and nursing areas

It was proven by a number of recovery programmes and researches that it is a must to create a recovery of spawning and nursery areas (habitats). In North-America and Scotland only the recovery of spawning and nursery areas resulted in the recovery of salmon and trout stock. At present closed off spawning and nursery areas are reopened or rehabilitated as part of the Rhine Action Plan. Another action taken is to reconnect old distributaries, etc. Most of these projects are implemented in Germany. However, the mere recovery of spawning and nursery areas in the Rhine river system does not appear to result in the recovery of trout stock. It could be that the spawning and nursery grounds lack quality due to the sand load (quantity of sand present in a stream due to erosion) in a stream or river.

Within the Netherlands the efforts to improve the spawning and nursery grounds for resident trout are limited.

Furthermore, the value of the IJsselmeer and the estuary as a nursery area for trout is unknown. Trout is caught regularly in the IJsselmeer, but it is unknown to what extent the IJsselmeer and the estuary is of value as a nursery area.

7.4 Survival of various life stages

The survival of trout in the various life stages is extremely low. Specifically the survival in the marine or sea stage is very low. This requires further research.
7.5 Migration

Trout migrate over long distances and are capable to overcome natural hindrances by means of their jumping and swimming abilities. Migration does not only include upstream migration, but also downstream migration.

**Upstream migration**

The construction of fish passages has a significant effect as a recovery measure in the salmon recovery programmes. The effectiveness of the fish ladder depends on the type of fish ladder and the design. Next, local circumstances play a role, such as discharge characteristics, etc. It is clear that if several fish ladders must be passed, fewer fish will be successful in reaching their final destination. Specifically if a passage involving several fish ladders must be passed, part of the fish will not arrive at the spawning grounds in time.

With regard to the upstream migration, trout experience problems when entering the freshwater at the Afsluitdijk and the Haringvliet. Also in the Dutch section, salmonides experience problems (dams and branches) while migrating to Germany. Telemetric research related to sea trout and salmon provided insight into these issues. In order to reduce the problems, it is proposed to use de Kier at the Haringvlietdam (please refer to § 8.2).

Nowadays the only free access is via the Nieuwe Waterweg, the river Waal to Germany.

Also in Belgium a study was conducted with regard to the functionality of fish ladders. However, this study was limited, due to the fact that it was determined only which fish species and the number of fish passed the ladder. From Germany only limited fish passage research data is known, such as data related to the Sieg. Proper data regarding the efficiency of various fish passages is lacking. The best manner for fish passages is to remove the dams. However, this is often not realistic due to safety and economic interests.

**Downstream migration**

Downstream migration has been given attention in recent years. Fish can pass dams in downstream direction, without being damaged due to the difference in height. However, due to the disorientation, fish are an easy prey for predators such as pike, pike perch, asp and fish eating birds (cormorants). At hydro-electric power stations this disorientation plays an even bigger role. Due to the differences in pressure and the brief changes in speed fish clearly become disoriented. Furthermore, direct and indirect mortality at hydro-electric power stations occurs due to mechanical damages and pressure differences. The degree of damage depends on the height of the fall, the type of turbine (size, number of blades and rotation speed) used, and the fish species and the length of the fish. Little to no information on direct or indirect mortality for fish passing the rivers Rhine and Meuse are available.

With regard to the downstream migration in the Rhine, *smolts*, originating from the nursery areas downstream of Iffezheim, need to pass relatively
few obstacles. The Sieg is therefore an important tributary for salmon recovery.

If the fish migrate via the route Waal or IJssel, no dams hinder the downstream migration. However, if they migrate via the Beneden-Rijn and the Lek, the fish must pass 3 dams (of which two include a hydro-electric power station). If the fish migrate via the IJssel, they end up in the IJsselmeer. It is unknown what the value of the IJsselmeer is for smolts (trout). Catch reports of the RIZA rare fish catches often state that smolts are caught in the fykes positioned in the IJsselmeer. The situation on the Meuse is significantly worse than the river Rhine for upstream and downstream migrating fish.

Damage to young salmon near a hydro-electric power station (Photograph: J. Schneider)

7.6 Genetics

During the last decades, many studies have been conducted with regard to the genetic difference between trout stock. This information can be used for the management of trout stock. These studies initiated a high level of discussion. Proving genetic differences between stocks is rather complex. This will be explained by the following example. Some species know little genetic differentiation, even if large geographic areas are involved. Even if strict isolation applies, it will take a long time before genetic differences will appear in a large stock. Issues such as generation intervals play a role in this respect. The genetic difference of frog populations among themselves in our cold and chilly country is much larger than the genetic differences between a herring from the North Sea and a herring from Labrador. In a large stock, only little genetic flow
(effective migration of genetic information) applies. If a congener from a different geographic area is introduced to a small stock, and this specimen successfully participates in spawning, this will have a considerable effect on the genetic information of the entire stock. This introduction could even result in outbreeding depression (genetic decline of local adjustments) and resulting thereof, a lower fitness. The genetic composition of an entire species is the gene pool. Sub stocks have all the characteristics of the gene pool and are just a subset of this gene pool. If a population or stock only has a subset of this gene pool, this stock is often unique (highly differentiated). The loss of this sub stock (subset of genes) is then a loss of a section of the gene pool of the species.

Genetic research indicated that morphologic, behavioural or geographic difference are more often caused by environmental influences (foraging circumstances / growth possibilities, degree of latitude, length of the river) and that fish, notwithstanding their deviating shape or behaviour, are closely related. The question which then quickly follows is whether an isolated population should be preserved. If the population is a unique subset of the gene pool, preservation appears to be required. (Rymann, no year, Quinn, 2000).

7.7 Further knowledge gaps

**Shipping**
The effect of shipping on the salmonid migration is unknown. Unfavourable effects are to be expected due to the sound of ship engines and the propeller shaft and influencing of river flow patterns. Trout use the river as a migration route and rest in deeper pools during their journey. Due to canalisation, such pools disappeared from the main stream. Combined with the higher turbulence in the main stream caused by shipping, this could present problems during the upstream migration. Ship engines produce very low (< 25 Hz), medium frequencies, as well as extreme high frequencies (> 20kHz). This also generates underwater sound levels as from 120 up to 150 dB (diesel, low speed) and 130-158 dB for petrol engines (260 HP, 2000 rpm). Fish such as roaches and rudds show escape behaviour at sound levels as from 120 - 125 dB. Unfavourable influences created by the flow pattern due to ship engines are to be expected. Two-stroke engines also influence the water quality due to their oil contamination.

**Global warming**
Relative small changes of the ocean water temperature have significant effects on the salmon stock. The disappearance of glaciers in the Alps (some researchers expect the glaciers to disappear within 50 years), will have impressive consequences for the Rhine flow characteristics. Moreover, other different characteristics (of which the most important are the temperature and oxygen content) will be influenced in an indirect manner.

Further reasons
Further reason for the disappearance of salmon in the river Rhine could include the following:

- Sand and gravel extraction from the Rhine and tributaries in Germany.
- Fish migration hindrances (dams). Furthermore, fish passages do not function 100%.
- Effects of hydro-electric power stations on the downstream migration of *smolts* and *kelts*.
- Effects of the closing off of tidal inlets and the migration of *smolts* to the sea. Possibly *smolts* have more trouble adjusting to the acute transition from freshwater to saline water. This issue is mainly applicable in the Netherlands.
- Effects of cooling water discharges.
- Changes of the trophic degree, changes in the fish stock (predation at downstream migration of *smolts*, possibly interfere with the return of salmon).
8 Management

8.1 General

Much experience regarding sea trout and brown trout management was acquired on international level. In general sea trout benefits from the salmon recovery programmes. In various programmes it is noted that it is important to know where the bottlenecks related to the production are, and to first focus on these aspects. If not, the risk exists that manipulation without result will be applicable. A thorough analysis must reveal what the actual limitations of the habitat are, after which result-oriented adjustments can be implemented. The effects must be assessed on population level.

Various authors also refer to the fact that a proper estimation of the effects of the measures cannot yet be calculated in methods. This is mainly based on the complexity of the interaction between anadromous and resident trout, and the interactions with salmon and/or other fish species and predators. Next, interactions can only be related if the effects of an interaction have been determined for an adequate period of time. At times a specific (habitat) research is limited to 1 or 2 years. Various authors refer to the fact that this is actually a too short period to visualise the effects and influences in a proper manner.

The Netherlands has little to no experience with trout population management.

8.2 Current projects

No specific projects focused on the recovery or return of seat trout or brown trout exist in the Netherlands. In de Achterhoek (in the province of Gelderland) projects have been implemented within the scope of the salmon recovery programmes, whereby salmon and sea trout have been released (Semmekrot & Quak, 1991). The results indicate that only few nursery sites are present in the streams in the Achterhoek, and that resulting from migration hindrances, no autonomous self-sustaining population of sea trout can exist (Semmekrot, 1992).

In the Netherlands a study was conducted with regard to the migration of sea trout within the Netherlands (bij de Vaate and Breukelaar, 2001). The main specifics of the results of this study have been described in § 4.13.

Resulting from this study the zero situation prior to de Kier was determined. The migration moments of sea trout at the Haringvlietdam will be registered for a period of 3 years preceding the introduction of a modified discharge management. After the introduction of a modified discharge management (Kier), monitoring for a period of 3 years will once
again apply. The results of the study are an indication of the effects on the migration of salmonides following a modified discharge management (for further information in Dutch, please also refer to www.haringvlietsluizen.nl).

No specific recovery programmes have been developed for seat trout, due to the fact that it is expected that sea trout also profits from the measures taken within the framework of the salmon recovery programmes in the Rhine and Meuse.
## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alevin</td>
<td>Yolk sac larva.</td>
</tr>
<tr>
<td>Anadromous</td>
<td>Fish species migrating to the sea, and returning to freshwater as an adult specimen for spawning.</td>
</tr>
<tr>
<td>B-type growth</td>
<td>Phenomenon of increased growth of pre-smolts in spring.</td>
</tr>
<tr>
<td>Yolk sac larva (embryo)</td>
<td>The young fish that, immediately following hatching, lives on the nutriment from the yolk sac.</td>
</tr>
<tr>
<td>Dummy runner</td>
<td>Fish entering the drainage basin of the natal river, without spawning migration behaviour. Not to be confused with a strayer.</td>
</tr>
<tr>
<td>One-sea-winter fish (1SW)</td>
<td>Fish returning for spawning, after remaining at sea for one single winter.</td>
</tr>
<tr>
<td>Entrapment</td>
<td>Locked in situation of eggs and yolk sac larvae due to the density of the gravel bed.</td>
</tr>
<tr>
<td>Estuary</td>
<td>Intertidal zone between freshwater and saline water.</td>
</tr>
<tr>
<td>Phenotypical</td>
<td>External appearance.</td>
</tr>
<tr>
<td>Pheromone hypothesis</td>
<td>The hypothesis that salmonides are guided by sex hormones released by juvenile fish for their orientation.</td>
</tr>
<tr>
<td>Phototaxis</td>
<td>Behaviour caused by the sensitivity to light. Positive phototaxis means that the fish will swim to the light.</td>
</tr>
<tr>
<td>Fingerling</td>
<td>The stage as from the yolk sac up to leaving the spawning bed (+/- 3 cm). Term is not used in Allen &amp; Ritter, 1975.</td>
</tr>
<tr>
<td>Finnock</td>
<td>Fish that remained at sea during one single summer, and are caught in autumn in the estuary or freshwater. Also referred to as: grilse, herling, whitling. Only a small percentage of these fish spawn. The term is not used by Allen &amp; Ritter, 1975.</td>
</tr>
<tr>
<td>Fry</td>
<td>Stage of independence of the yolk sac up to the distribution of the fish leaving the redd. Free swimming larvae.</td>
</tr>
<tr>
<td>Genetic flow</td>
<td>The extent to which the genetic characteristics disappeared or are preserved within a population.</td>
</tr>
<tr>
<td>Grilse</td>
<td>A sea-winter salmon that returns to freshwater, in general for spawning. Term is not used by Allen &amp; Ritter, 1975.</td>
</tr>
<tr>
<td>GSI</td>
<td>Gonado-somatic index – ration between the gonado weight and the weight of the entire fish body.</td>
</tr>
<tr>
<td>Homing</td>
<td>Salmonides migrating back to the natal river for spawning.</td>
</tr>
<tr>
<td>Homestone</td>
<td>Favourite parr spot, in general near/behind a stone or branch.</td>
</tr>
<tr>
<td>Homing river/natal river</td>
<td>River of birth of the fish.</td>
</tr>
<tr>
<td>Hybrid</td>
<td>Product of a crossing between two species (F1).</td>
</tr>
<tr>
<td>Intergravel flow</td>
<td>Flow of the water through the gravel of the gravel bed. Discharges waste materials and introduces oxygen.</td>
</tr>
<tr>
<td>Interspecific competition</td>
<td>Competition related to food and territory between species.</td>
</tr>
<tr>
<td>Intraspecific competition</td>
<td>Competition related to food and territory between the same kind of fish.</td>
</tr>
<tr>
<td>Iterparus</td>
<td>Spawning on various occasions during the lifecycle.</td>
</tr>
<tr>
<td>Juvenile</td>
<td>Immature stage (opposite of adult)</td>
</tr>
<tr>
<td>Kelt</td>
<td>A fish returning to the ocean after spawning</td>
</tr>
<tr>
<td>Land-locked</td>
<td>Population which cannot reach the sea resulting from natural causes or human interference. Not to be confused with non-migrating species or (sub) populations.</td>
</tr>
</tbody>
</table>

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<table>
<thead>
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<tbody>
<tr>
<td>Multi Sea Winter fish (MSW)</td>
<td>Fish which remained at sea for the duration of two winters or more, before migrating to freshwater.</td>
</tr>
<tr>
<td>Olfactory hypothesis</td>
<td>The hypothesis that salmonides are guided by aromatic substances in the water as a source for orientation.</td>
</tr>
<tr>
<td>Osmoregulation</td>
<td>Regulation of the osmosis process; exchange of dissolved substances and water between the inner part of the fish and its environment.</td>
</tr>
<tr>
<td>Parr</td>
<td>Stage from distribution from the redd up to the downstream migration as smolt.</td>
</tr>
<tr>
<td>Premature alevins</td>
<td>Phenomenon that eggs hatch too early due to environmental circumstances.</td>
</tr>
<tr>
<td>Pre-smolt</td>
<td>First stage of change from parr to smolt.</td>
</tr>
<tr>
<td>Repeated or previous spawners</td>
<td>Salmon that participate in spawning more often than once are referred to as repeated or previous spawners.</td>
</tr>
<tr>
<td>Post-smolt, sea trout</td>
<td>Stage of leaving the river as smolt up to A) Entering freshwater in the year of smoltification, and B) End of the first winter year, if during the year of smoltification no return to freshwater applied.</td>
</tr>
<tr>
<td>Post-smolt, salmon</td>
<td>Stage of leaving the river up to the beginning of the transition of winter bands on the scale.</td>
</tr>
<tr>
<td>Polymorphism</td>
<td>Different species or stocks with phenotypical differences, with the ability to crossbreed.</td>
</tr>
<tr>
<td>Precocious male parr</td>
<td>Phenomenon that parrs do not smoltify but remain in their natal river. Fish become sexually mature and can participate in spawning. Is – at times- also registered in females.</td>
</tr>
<tr>
<td>Previous spawner</td>
<td>Fish which spawned before and return to the river, also referred to as kelt. According to Allan &amp; Ritter (1977) this is an incorrect term.</td>
</tr>
<tr>
<td>Pools</td>
<td>Deeper sections of the river where the flow rate is lower and turbulence is less. Opposite of riffles.</td>
</tr>
<tr>
<td>Polymorphism</td>
<td>Please refer to sympatric populations</td>
</tr>
<tr>
<td>Redd</td>
<td>Position in the gravel bed in which the eggs are laid (nest).</td>
</tr>
<tr>
<td>Rheocline</td>
<td>Transition layer between a strong and milder flow.</td>
</tr>
<tr>
<td>Rheotaxis</td>
<td>Behaviour caused by the vulnerability for currents. Positive rheotaxis means that the fish prefers to swim against the current.</td>
</tr>
<tr>
<td>Broad navigation</td>
<td>Broad migration by salmonides from the ocean up to the sea/coast, for which the fish also uses terrestrial magnetism and the position of the sun.</td>
</tr>
<tr>
<td>Salmonides</td>
<td>Family name for species in the family of salmon.</td>
</tr>
<tr>
<td>Semelparus</td>
<td>Participating in spawning only once during the lifetime.</td>
</tr>
<tr>
<td>Smolt</td>
<td>Juvenile stage during the downstream migration.</td>
</tr>
<tr>
<td>Smoltification</td>
<td>Transition from parr to smolt; adjustment for the migration to the sea and living at sea.</td>
</tr>
<tr>
<td>Straying, strayers</td>
<td>Fish entering a drainage basin, which is not their natal river or the location of their release.</td>
</tr>
<tr>
<td>Sympatric populations</td>
<td>Group of fish in a (sub)population with specific characteristics (morphology and population characteristics) and genetic differences. They can crossbreed, but will not act accordingly in a natural situation, due to for example, the distance.</td>
</tr>
<tr>
<td>Telemetrics</td>
<td>&quot;Remote measuring&quot; Telemetrics is used for behavioural studies, to perform observations by means of (radio) transmitters and receivers.</td>
</tr>
<tr>
<td>Thermocline</td>
<td>Transition layer between the water layers with different temperatures.</td>
</tr>
<tr>
<td>Two sea-winter fish (2SW)</td>
<td>Fish which remained at sea for two winter.</td>
</tr>
<tr>
<td>Whitling</td>
<td>Refer to the term Finnock. Term is not used in Allen &amp; Ritter, 1975</td>
</tr>
</tbody>
</table>
Literature


Karlström, Ö., 1969. Habitat selection and population densities of Salmon (Salmo salar L) and Trout (Salmo trutta L) parr in Swedish rivers with some reference to human activities. Doctoraal dissertatie. Institute of Zoology, Uppsala University, 12 may 1977.


Ryman, z. j. Genetic population structure. Division of Population Genetics Stockholm University, Stockholm, Sweden.


Other publications in this series are (in Dutch):

01. Kennisdocument grote modderkruiper, *Misgurnus fossilis* (Linnaeus, 1758)
02. Kennisdocument Atlantische steur, *Acipenser sturio* (Linnaeus, 1758)
03. Kennisdocument gestippelde alver, *Alburnoides bipunctatus* (Bloch, 1782)
04. Kennisdocument sneep, *Chondrostoma nasus* (Linnaeus, 1758)
05. Kennisdocument pos, *Gymnocephalus cernuus* (Linnaeus, 1758)
06. Kennisdocument Atlantische zalm, *Salmo salar* (Linnaeus, 1758)
07. Kennisdocument forel, *Salmo trutta* (Linnaeus, 1758)
08. Kennisdocument vlagzalm, *Thymallus thymallus* (Linnaeus, 1758)
09. Kennisdocument rivierdonderpad, *Cottus gobio* (Linnaeus, 1758)
10. Kennisdocument riviergrondel, *Gobio gobio* (Linnaeus, 1758)
11. Kennisdocument Europese aal of paling, *Anguilla anguilla* (Linnaeus, 1758)
15. Kennisdocument bittervoorn, *Rhodeus amarus* (Pallas, 1776)
17. Kennisdocument diklipharder, *Chelon labrosus* (Risso, 1827)
18. Kennisdocument haring, *Clupea harengus harengus* (Linnaeus, 1758)
20. Kennisdocument ,winde *Leuciscus idus* (Linnaeus, 1758)
22. Kennisdocument karper, *Cyprinus carpio* (Linnaeus, 1758)

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