Output 8: Learning resources for Fish Biology and Life Cycles compilations

Introduction

The learning resources in this guide have been designed to support 'short episodes' of focussed learning' on a specific topic within the Fish Biology and Life Cycles compilations section following the Recognition of Prior Learning (RPL) using the multiple-choice question sets.

The multiple-choice questions and learning resources have been designed to satisfy the level of knowledge and understanding prescribed by the Scottish Aquaculture MA level 2 (husbandry operative)

The RPL/APL system is designed for experienced work-based learners with some knowledge, as well as knowledge gaps who wish to 'fast track the assessment and accreditation of their knowledge.

(See spread sheet guide to Scottish Optimal RPL and follow up through guided self-study learning)

Recommended pedagogy for RPL/APL

Step 1- Undertake multiple choice questions for the section

Step 2 Automated RPL to determine which questions have not been answered correctly in full

Step 3 (a) Automated documentation and QA of correct responses for submission for accreditation of specific knowledge

Step 3 (b) Self -study guided by the RPL results and feed back

Step 4 Second Multiple Choice (MC) with alternative question (same topics and level) or complete alternative approved summative assessment leading to accreditation.

(Note: Alternative MC questions will need to be developed by the VET user as only one set is available from the optimal project.)

Using these resources

The multiple-Choice questions can be presented by response tools via hand-held devices or presented within a Virtual Learning Environment, which is the recommended method for independent work-based learners.

A well designed VLE with high level assessment functionality and grade book will allow the full automation potential of the system to be gained, as well as

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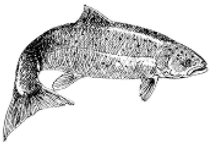
B1 **Fish Biology and Life Cycles**



Alevin and swim up fry

When salmonid eggs hatch the young fish are known as **alevins**. They are translucent with a bulbous orange yolk sac attached to the underside of their body. When viewed through a binocular microscope, as the heart pumps blood around the alevin the blood vessels are clearly visible.

What environmental conditions do the yolk sac fry (alevins) require?

A shoal of Pacific salmon moving upstream to find a suitable gravel substrate for a spawning redd

The female adult salmon selects the location of their **spawning redd** where the substrate gravel is of the correct to size to form a stable matrix for egg incubation. A well sited redd ensures a good stable flow of well oxygenated water through the eggs and newly hatched alevins. It is safe from scouring by winter floods and out of sight from predators. The eggs lie in the gravel throughout the winter, as the embryos within develop.

What happens after the eggs hatch?

whether in the wild or in a hatchery, following successful incubation of viable eyed eggs, yolk sac fry (alevins) emerge. They need to remain undisturbed in complete darkness and in close contact with gravel surfaces for security. They are totally dependent on the yolk sac reserves during this stage for all nutrients needed for growth. If disturbed, they will move away from the light, metabolising the yolk sac as an energy source, resulting in smaller, weaker fry that may struggle to start feeding. Therefore, they are programmed to remain passive and inactive in the gravel, conserving valuable energy.

What happens after the yolk sac has been used up?

In the wild when their yolk sac is nearly fully absorbed, approximately 12 weeks after hatching, the alevins start to show a behavioural change. They move from the riverbed gravel red, or in a hatchery situation the base of the hatching baskets and rise to the water surface to gulp air and inflate their swim bladders. By gaining neutral buoyancy, it is easier to swim and hold their position in fast flowing streams and once their yolk reserves are completely

These healthy Atlantic Salmon alevins have large yolk reserves to sustain them depleted, they are ready to capture and ingest food. This critical period is referred to as **"swim-up"** and exposes the young fish in the wild to predators for the first time.

The skin adopts a darker pigmentation as body markings appear and the tails and fins become more defined. At this stage they resemble miniature versions of the adults, swimming in an upright position and are called **'fry'**.

B2 **Fish Biology and Lifecycles**

Salmon smolt

Atlantic salmon are **anadromous**, which means they live in both freshwater and sea water at different stages of their lifecycle. Therefore, they must go through several physiological transformations to cope with changes in the salinity of their aquatic environment. Atlantic salmon parr become smolts to prepare for their first major migration, taking them from the river of their birth to the rich feeding grounds in the North Atlantic. Most return to their river of birth and die after spawning. There are however exceptions, and some fish will make their way downstream to the sea and after regaining condition, mature and return to spawn for a second time. Pacific salmon species all die after spawning and the nutrients released from decomposition are essential to recharging the aquatic ecosystem.

Salmon smolts migrating downstream to the North Atlantic feeding grounds

When does the first physiological change occur?

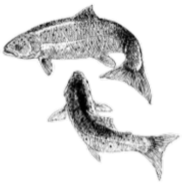
Up to and including the parr stage, the juvenile salmon feed and grow in a freshwater nursery stream. After one or two years, at between 30-60 Grams, depending on the food supply, the parr transforms in to a smolt. The 'smolification' process is triggered by changing photoperiod (increasing day length in the spring), to prepare the young salmon for their journey downstream. During this period smolts change in external appearance to become a streamlined silvery fish. Internally, their bodies are physiologically adapting to cope with the saline marine environment.

What is the nature of this physiological change?

The transformation from a parr to a smolt is one that very few fish undertake. It enables the fish to regulate, maintain and stabilise their internal salt concentrations through a physiological process called **'osmoregulation'**. Entering water of a higher salinity causes the fish to dehydrate due to the loss of water by **osmosis** to the external environment (dehydration). In response they need to drink water to rehydrate. During smoltification, chloride cells develop in the gills providing the capacity to secrete the excess salts that result from drinking sea water, thereby maintaining the correct balance of body salts internally.

Once the smolts move from freshwater to saltwater they will remain in estuary and inshore areas until their body has fully adapted to the marine environment. Once smoltification has been fully completed the fish can osmoregulate effectively in full strength sea water (35ppt) and is ready to migrate to the open ocean feeding grounds.

B3 **Fish Biology and Lifecycles**



Salmon eyed ova

When Atlantic salmon lay and fertilise their eggs in a gravel **redd** (nest) the female will cover the eggs to protect them from predators and the environment. At this stage the eggs are known as '**green' eggs**, delicate and susceptible to mortality caused by movement or exposure to strong light. This can be very problematic in an aquatic environment which can be unstable and unpredictable when floods and spate conditions prevail. The female will have constructed the redd to withstand anything but the worst conditions, whilst ensuring an adequate flow of well oxygenated water through the eggs.

Pacific salmon female cutting a redd in suitable gravel, with an accompanying male waiting to fertilise the eggs

How long does it take for the egg to become eyed after fertilisation?

The 'green' eggs will incubate in the redd before reaching the 'eyed' stage of development. The time to reach this stage is not fixed but is temperature dependant. It can be predicted by applying **'Degree Days'**, if the water temperature regime is known.

The developing eye of the embryo is clearly visible in these eyed ova being held in an aquarium to observe development

For Atlantic Salmon it takes 220-250 Degree Days from fertilisation to the eyed egg stage.

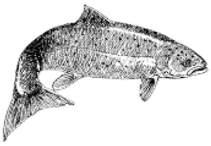
For example - this would be equivalent to 44-50 days if the water temperature was a constant 5 Degrees Centigrade and 22-25 days if the temperature was 10 Degrees Centigrade.

In most salmon nurseries, as the temperature is low in the winter and starts to increase towards the early spring, the time duration will fall between these two extremes.

Why is this stage called eyed egg?

As the name suggests the ‘eyed’ stage is apparent when two small black eyes are visible in the egg. The eggs become a bit more robust and as egg development continues the alevin and anatomical features such as the backbone can be observed. Movement inside the eggs will become more pronounced as the time for hatching draws nearer.

B4 **Fish Biology and Life Cycles**



Salmon parr

The newly hatched salmon fry will start to move away from the area near the redd they emerged from to find new territories with the correct flow rate to suit their body length and swimming ability. Once a territory has been established, they will defend this area and their feed stations. The juvenile salmon commonly share their nursery stream with Brown trout (Salmon trutta) as they have the same general habitat and feed requirements.

Do juvenile Atlantic salmon compete with brown trout?

The salmon are more streamlined and assisted by large pectoral fins which they angle to help compress them to the substrate, they tend to occupy feeding stations in the relatively swift flowing 'riffles', that trout would struggle to occupy and defend.

The external features of an Atlantic Salmon parr are distinctive on this specimen

What do Atlantic salmon look like at the parr stage?

The Atlantic Salmon parr and trout are easily confused as they live in the same zones in the upper reaches of the river system.

In the parr stage the following features are key to identifying the difference between an Atlantic salmon parr and a Brown trout parr.

- More streamlined shape
- Deeply forked caudal fin (tail)
- Longer pectoral fins
- Smaller mouth (maxilla) doesn't extend behind the centre of the eye
- One large spot on the operculum (gill cover) though can be up to four
- Well defined parr (finger) marks

What do Brown trout look like compared to salmon?

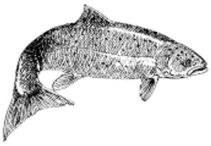
- Rounder body shape
- Blunt squared off caudal fin (tail) with little or no fork
- Shorter pectoral fins
- Longer mouth (maxilla) that extends back beyond the centre of the eye
- Orange spot on the adipose fin
- Large and more distinctive spots on the flanks

The external features that typify Brown Trout are evident on this specimen

How easy is it in practice to tell a juvenile Atlantic salmon parr from a brown trout?

By carefully comparing the fish in the top and bottom pictures with reference to the check list of distinguishing features they are easy to distinguish. Not all the features are so obvious when carrying out identification so care should be taken to ensure more than one feature is checked to obtain a correct identification.

B6 **Fish Biology and Life Cycles**



Adult Atlantic salmon

The Atlantic salmon grows rapidly to become a mature adult during the marine feeding stage as the north Atlantic shelf feeding grounds are rich in suitable fish prey. Crustaceans also form an important part of the diet and turn the flesh orange due to the deposition of **caretonoid** pigments found in the crustacea. These are naturally occurring substances synthesised by marine algae and consumed by crustacea, before becoming deposited in the flesh of the salmon when consumed.

A wild salmons muscle turns orange due to the deposition of carotenoids from marine crustacea

How long does the adult salmon feed and grow at sea?

At the end of the marine feeding phase the salmon is a streamlined silver scaled fish with a large, powerful muscle mass and fat deposits to sustain it on the journey back to freshwater.

The sexual organs can develop after one, two or several years of sea feeding, depending on nutritional, environmental and genetic factors. Those fish that mature after one year of sea feeding are known as **grilse** and can vary in size from 0.8-4 Kg.

The two sea winter Atlantic salmon tend to run from 3.6Kg to 5.4 Kg and those that have a longer sea feeding phase can be considerably larger. The very largest are the males which can reach 30 Kg but tend to be multiple spawners. They have returned to their feeding grounds after spawning to rebuild muscle mass and can reach exceptional sizes. The females rarely reach more than 20 Kg.

On leaving the marine environment and returning to freshwater to breed the salmon stops feeding. This is probably a device that has evolved to aid the survival of the species, by stopping the adults from predating their own progeny on return to freshwater.

What does a sexually mature Atlantic salmon look like?

The salmon that leaves the sea and enters freshwater from any time from the spring through to the autumn in readiness for the ascent to the spawning grounds. Spring run salmon are in freshwater for up to six months before spawning, and their fat reserves sustain them during this long period of fasting.

The fish retains a its silver marine feeding phase appearance for several days on entering freshwater before the shine gradually diminishes.

What happens to the salmon's appearance as they sexually mature?

The mature male Atlantic salmon develops a 'hooked kype' that inserts into a recess in the upper jaw

Over the coming weeks as the female Atlantic salmon sexually matures, the caretonoid pigments deposited in the flesh are mobilised and transported to the eggs. This turns them orange.

Some pigments are deposited in the skin giving the fish a darker, slightly red appearance.

The males can become very dark due to the deposition of caretonoids and develop a pronounced lower jaw extension which is curved and armed with teeth.

This secondary sexual characteristic immediately distinguishes males from females and is called a 'kype'. It is a very distinctive feature used to fight other males on the spawning redds at breeding time in order to dominate a prime position for fertilising the eggs being released by spawning females.

B7 **Fish Biology and Lifecycles**

Fish reproductive strategies

In biological and ecological terms, the long-term survival and reproductive strategies of a fish species will depend on several factors but ultimately comes down to whether they need to produce a small number of large high-quality offspring, or a large quantity of small lower quality offspring. The nature of the environment is the main determinant of strategy, although other factors have a significant influence.

What are reproductive strategies?

Animal and plant reproductive strategies have evolved to successfully produce offspring and ensure the survival of their species. A reproductive strategy determines how a species diverts energy into producing viable offspring and whether additional energy is used to care for the offspring.

*A small number of **e**ggs hatch in the mother's oviduct making sharks the ultimate K strategy example*

There are two diametrically opposed reproductive strategies that can be adopted:

- **K strategy** – relies on producing a small number of high-quality offspring

Organisms that are K strategists will have low numbers of offspring but will invest a lot of time in ensuring the survival of the offspring they produce. This type of strategy is normally employed by larger organisms that have long life spans. Humans are a very good example of K strategists!

K strategist generally live in a stable environment, are relatively large, late maturing and allocate a lot of energy to reproduction. They have low numbers of offspring with longevity and reproduce multiple times during their life.

- **R strategy** – relies on producing a large quantity of offspring

Organisms that are R strategists will produce large numbers of offspring with very little or no parental care provided to ensure survival. This type of strategy will usually result in high mortality among the offspring, compensated by the large numbers produced to ensure the species survival. insects are good examples of R strategists.

Fish that are R strategists generally live in an unstable environment such as the open sea, are very fecund (produce lots of eggs) and allocate limited energy to reproduction. They mature early with short life spans and a single reproductive period annually.

Different fish species have a range of reproductive behaviours and approaches to protecting their eggs and young, which can include nest building, mouth brooding and mass spawning.

It might be expected that all fish would fall into the R strategy due to the unstable and unpredictable aquatic environment in which most live, where rapid reproduction is important.

These koi carp are a highly fecund freshwater species (Cyprinus carpio) typifying the 'R- strategy'

However, there are some fish which produce relatively low numbers of offspring and take more care of the young they produce. They can be considered K strategists, or even somewhere in between R and K.

Which breeding strategy do the salmonids follow?

It could be argued that all salmonids, including Atlantic salmon and Rainbow trout, are R strategists as they provide no parental care other than building a nest (redd) into which they will lay and fertilise their eggs. After the eggs are covered over with gravel they are left to the mercy of predators and the changing aquatic environment.

Like Atlantic Salmon, these Rainbow trout are closer to the K than the R strategy as they build spawning redds

However, by building a nest to protect the eggs and newly hatched young (alevins) they are providing an element of care and so are borderline K strategists.

Species such as the 'three spine sticklebacks' are nest builders that aggressively defend their nest until the eggs have hatched and the young are ready to leave.

Whereas as the Nile tilapia, a mouthbrooder, will pick the eggs from the nest and retain them in their mouth until they hatch. Both fish species in this case are K strategists, as compared to other less protective species.

Fish species such as the Atlantic cod and the herring are clearly R strategists as they produce large quantities of eggs that once fertilised are left to the mercy of predators and the unstable aquatic environment. The species in both cases only survive due to the large numbers of eggs produced, to counteract the low survival rate of each batch.

Which species exemplify R and K strategists?

R strategy

Some of the fish species which are considered R strategists include:

The Nile Tilapia is a mouth brooder that can produce and incubate many small batches of eggs annually

- Herring – large numbers of eggs adhered to substrate
- Halibut – large numbers of eggs dispersed into the sea as free floating
- Atlantic cod - large numbers of eggs dispersed into the sea as free floating
- Common carp – large numbers of eggs adhered to vegetation

K strategy

Some of the fish species which could be considered closer to K strategists include:

- Atlantic salmon – eggs buried in a nest in the gravel of the riverbed
- Nile tilapia – mouth brooders that hold the eggs and young in their mouth until big enough to fend for themselves
- Three spine stickleback – builds a nest to protect the eggs and young until big enough to fend for themselves

B9 **Fish Biology and Lifecycles**

Fish eggs

There is a range different spawning method adopted by fish in both freshwater and the marine environment. These can include spawning in nests, broadcasting free floating eggs, sticking eggs to substrate and vegetation, mouth brooding and giving birth to live young. In most species sexually mature adults will produce large numbers of eggs, which can vary from a few hundred to hundreds of thousands. (See table below).

A 1 Kg Rainbow trout produced 2,000 of these freshly stripped eggs

However, there are R strategists (large numbers of eggs and no parental care) and K strategists (relatively lower numbers of eggs or young and some degree of parental care). This is relative within **telosts,** (bony fish) as compared to other K strategists in the animal kingdom such as birds or mammals, all fish classified as K strategists appear to have many eggs.

The strategy of each fish species in the table below illustrates the R and K norms and the exception to the norm (K+).

Fish species	Spawning method	Average number of eggs laid
Atlantic salmon (K)	Gravel nest	1,600 eggs/Kg
Common Carp (R)	Adhesive to substrate	150,000 eggs/Kg
Sea Bass (R)	Free floating	250,000-500,000 eggs/Kg
Atlantic cod (R)	Free floating	250,000-500,000 eggs/Kg
Halibut (R)	Free floating	100,000 eggs/Kg (X3)
Nile tilapia (K)	Mouth brooder	250-500 eggs/female/month
Lumpfish (K)	Nest and adhesive to substrate	50,000-15000 per female
Herring (R)	Adhesive to substrate	200,000 /large female
Rainbow trout (K)	Gravel nest	2,000 /Kg
Tope (K+)	Live bearers	20 pups every 2 years

Table: Comparative fish fecundity (R and K strategists)

The Tope which is a member of the shark family is an exception and a live bearer (viviparous). From the age of 10 years old, females produce 20 live young (15" long) once every 2 years. They are the clearest example of K strategists and very similar to birds 'quantitatively'.

How much does the size of fish eggs vary?

The size of eggs produced varies between species. For example, common carp eggs average 1-2mm diameter, whereas Atlantic salmon eggs average 3-8mm diameter. The spawning method adopted by fish will usually give an indication of the number and size of eggs produced.

Many large shark eggs are incubated internally

Most fish will spawn into the external aquatic environment, with some broadcasting their eggs and sperm freely into the water where they float and drift on the surface currents, while others will construct a nest into which they will deposit the eggs and sperm.

The broad cast spawner tends to produce much larger numbers of small eggs, whereas the nest builders will produce lower numbers of eggs which tend to be larger in size. The fish that produce sticky eggs that adhere to a substrate produce large numbers of small eggs as they are more vulnerable to predation than those deposited in a nest. It is important to note that in all cases mortality tends to be high in both eggs and young fish.

How often do egg producers spawn?

Many species of fish only spawn once a year in the appropriate season, with some species such as the salmonids being autumn/winter spawners, and others such as Common carp and Atlantic Sea Bass spawning in the spring.

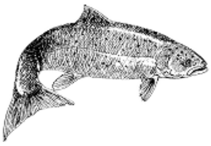
Others can spawn several times a year or produce eggs continuously, as is the case for the Nile Tilapia.

Although producing 100,000 eggs per Kg of female, the Halibut can spawn several times a year, increasing its fecundity to match the Atlantic Cod.

Conversely, although only capable of producing 250-500 eggs in a batch, if robbed of their eggs, as is standard practice in a hatchery, a female Nile Tilapia can produce 1 batch per month. This is equivalent to 3,000-6,000 eggs a year, which is still a very low fecundity compared to the marine species (Atlantic Cod, Halibut and Sea Bass)

Carp (Cyprinus carpio) broadcast sticky eggs on to vegetation whilst vigorously spawning once a year

B13 **Fish Biology and Life Cycles**



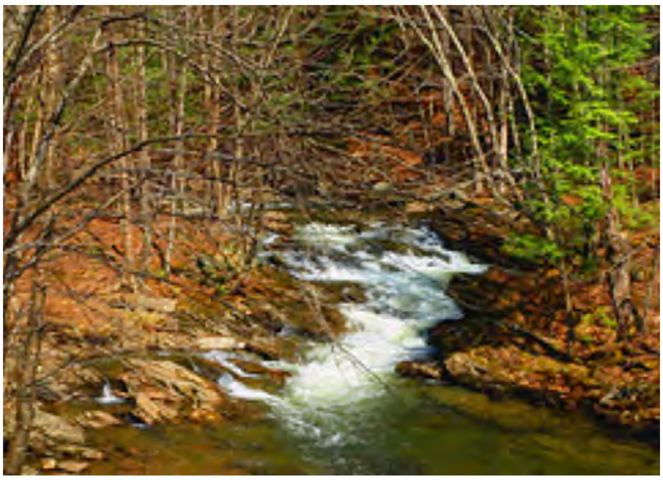
Salmon migration

Atlantic salmon (and most of the Pacific salmon species) perform some of the most impressive migrations known in the animal kingdom. Atlantic salmon will migrate from freshwater to the sea, and when they feel the urge, they will return to the river of their birth and usually the nursery stream where they were born. This migratory behaviour from freshwater to the sea and back to freshwater to spawn is called **'anadromous'**. There are fish species such as the European eel which do the opposite. They reproduce in the Southern Atlantic Sargasso and migrate to freshwater to feed and grow, before eventually returning to the sea to spawn. This behaviour is called **'catadromous'**.

The salmon's athleticism enables them to overcome most natural obstacles driven by the urge to return to freshwater to spawn

What triggers salmon to migrate?

Juveniles Atlantic salmon during their freshwater upbringing feed on aquatic insects and invertebrates for 2 -3 years before the change physiologically in preparation for a life in the marine environment. The urge to migrate to the sea is triggered by **photoperiod**, more specifically, increasing day length in the spring. The young salmon change to a silvery colour and are known as smolts. The gill chloride cells required to cope with the osmoregulation challenges they will encounter when entering the marine environment will also start to develop.



The increasing day length in April and May triggers some of the parr to smolt and head downstream

The urge to migrate does not happen to

all young salmon at the same time and in some cases, salmon may not migrate at all. This can be due to a lack of sea access. However, there are populations that have sea access but do not migrate. Non migratory salmon are called landlocked and exist in various lakes around the world, although they tend to be the exception rather than the norm.

How quickly do Atlantic salmon in a hatchery become smolts?

Prawns, form a large part of the Atlantic salmon's marine diet

In the past, many Atlantic salmon smolt producers have used intensive feeding and photoperiod to trigger early **smoltification** in order to control the timing of transfer to sea and/or shorten the production cycle.

Other than the influence of photoperiod in the wild, it is not fully understood what triggers the urge to migrate. But when they do, it is for the purpose of reaching better feeding grounds on the North Atlantic shelf, where they can gain weight quickly by feeding on fish and crustaceans before returning to spawn. When the young Atlantic salmon first migrate, they will feed in the coastal areas initially before migrating further afield to feeding grounds near Iceland and Greenland.

B14 **Fish Biology and Lifecycles**

Osmoregulation

In any aquatic environment, freshwater or marine, few fish have a bodily fluid concentration that matches the aquatic environment in which they live. Consequently, fish are subjected to a physical process that could upset their biological system due to the movement of fluids and dissolved materials (normally salts). The physiological process taking place is called '**osmosis'**.

What is Osmosis?

Osmosis is defined as "*the movement of water from a solution containing a lower concentration of dissolved materials through a semi permeable membrane to a higher concentration solution"*. This process is continual within the fish and the main areas for osmotic exchange are the skin, gills and gut lining. The process that has evolved to cope with this phenomenon is called 'osmoregulation'.

How does a fish osmoregulate in freshwater?

The effects of osmosis are as follows; in freshwater the salt balance in the fish is higher than its external environment and so excess water enters the fish as a result of osmosis. The kidney in freshwater fish will remove and discharges the excess water as dilute urine. As the fish loses salts in its bodily fluids as a result of osmosis, they are regained by specialist chloride cells in the fish's gill.

The smolt's chloride secreting cells need to develop before approaching the estuary

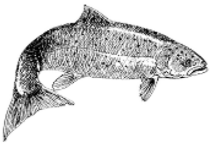
What happens when a fish moves from fresh to saltwater?

When a fish moves from freshwater to saltwater it must prepare and adapt to cope with the increase in salinity. The process of osmoregulation in freshwater is reversed, as fish will drink constantly to regain water lost by osmosis to prevent dehydration and an increase in the concentration of their bodily fluids. Any excess salts brought in with the saltwater are discharged by the chloride cells on the gill and removed by the kidney and excreted as concentrated urine.

How do anadromous fish such as Atlantic Salmon prepare for migration to the sea?

Prior to moving from fresh to saltwater the juvenile salmon must undergo smolitification, which leads to the development of chloride secreting cells in the gill that can pump salt out as opposed to bring it in, as required in freshwater. The kidney must also reduce its urine production to counteract the loss of water to the external environment.

B15 **Fish Biology and Life Cycles**



Salmon homing instinct

In the animal kingdom there are many examples of great migrations, but the migration of some fish species is among the most fascinating. Unlike land-based animals or birds, fish do not have visual indicators such as landmarks to assist. Although there is evidence to demonstrate that not all birds and animals rely solely on visual indicators either. It is believed that fish can navigate using other means such as the earth's magnetic field. Atlantic and Pacific salmons are among the fish species that are thought to use earth's magnetic field like a compass.

The salmon is thought to navigate using the earth's magnetic field

How do salmon navigate?

When young Atlantic salmon leave their nursery stream and eventually reach the marine environment, initially they feed close to the coast whilst fully adjusting to the more saline conditions. Once ready they start their migration to rich feeding grounds in the North Atlantic near Iceland and Greenland. This journey is believed to be completed using magnetic fields to enable the fish to navigate.

Nursery streams have a unique odour, allowing salmon to 'home in' using their olfactory organ (sense of smell)

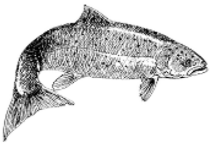
After 1-4 years when the young fish have grown into adults, they will feel an urge to return to freshwater to breed. Again, it is assumed that the salmon use the earth's magnetic field to find their way back to the river they originated from. This form of navigation will get them close to the right area of coastline.

How do they find the right river system?

Thereafter, it is believed that olfactory organ starts to take over and the salmon uses their sense of smell to locate the specific river system from which they came. When the young salmon leave the river system of their birth it is believes that a unique chemical imprint of that river system is left with the young fish and retained into adulthood.

Some scientists wonder why salmon have evolved the ability to return to where they were born. The answer could be as simple as ensuring adults enter nursery stream habitat that has been proven suitable, as they survived there as a young fish

B16 **Fish Biology and Life Cycles**



Male salmon sexual maturation

Whether Atlantic salmon breeding adults are from wild stock or aquaculture breeding stocks, the physical characteristics that are apparent when the fish are sexually mature will be the same.

In aquaculture sexually mature adult fish used for breeding are collectively known as brood-stock. In the past brood-stock of most fish species were obtained through the capture of wild adult fish. Today there are specialist brood-stock farms that produce eggs and juvenile stock for most species and through selective breeding, improve the characteristics of the stock for aquaculture.

Some sectors must rely on the capture of juveniles from wild stocks such as the European eel, which no one has managed to spawn in captivity. Consequently, eel farmers are dependent on migratory juveniles (known as elvers or glass eels) captured from river systems and returning to freshwater for their growth and feeding phase.

How are Atlantic salmon brood-stock produced and held?

Atlantic salmon brood-stock are usually grown on in sea cages until they are ready to mature. There is an increasing interest in the land-based production of brood-stock including the use of landlocked adults that have spent most of their life in freshwater. When combined with kelt reconditioning programmes, this can have the benefit of being able to use brood-stock multiple times. (Kelts are adult brood-stock that have already spawned and are in an exhausted state and need to restart feeding to regain full condition.)

Atlantic salmon brood stock originating from wild stock have been selectively bred and grown on held in marine cages

The fish selected as brood-stock are chosen for traits that are desirable to the fish farmer, including:

- Fast growth
- Disease resistance
- Good body conformation (shape)
- Improved egg production (size and fecundity)
- Brood-stock recognition

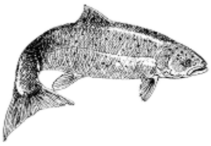
Atlantic salmon brood-stock males and females are easy to differentiate from each other when they are sexually mature, but not so easy up until that point as both sexes look quite similar until the differing 'secondary sex characteristics' start to develop.

What are the male characteristics?

Sexually mature male Atlantic salmon are much darker in appearance than the females. The males have an elongated head with a large hook on the lower jaw, known as a kype. If sexually mature 'ripe' males are captured and gentle pressure is applied near their vent, they will produce a white fluid that contains the sperm. This fluid is called milt.

Male Atlantic salmon just starting to darken and show early signs of sexual maturation. The 'kype' is not prominent but starting to develop its characteristic hooked shape.

B17 **Fish Biology and Life Cycles**



Female salmon sexual maturation

Whether Atlantic salmon breeding adults are from wild stock or aquaculture breeding stocks, the physical characteristics that are apparent when the fish are sexually mature will be the same.

In aquaculture sexually mature adult fish used for breeding are collectively known as brood-stock. In the past brood-stock of most fish species were obtained through the capture of wild adult fish. Today there are specialist brood-stock farms that produce eggs and juvenile stock for most species and through selective breeding, improve the characteristics of the stock for aquaculture.

The 'urino genital pore' is clearly extended on this ripe female as its eggs are gently stripped into the bowl

Some sectors must rely on the capture of juveniles from wild stocks such as the European eel, which no one has managed to spawn in captivity. Therefore, eel farmers are dependent on migratory juveniles (called elvers or glass eels) captured from river systems and returning to freshwater to for their growth and feeding phase.

How are Atlantic salmon brood-stock produced and held?

Atlantic salmon brood-stock are usually grown on in sea cages until they are ready to mature. There is an increasing interest in the land-based production of brood-stock including the use of landlocked adults that have spent most of their life in freshwater. When combined with kelt reconditioning programmes, this can have the benefit of being able to use brood-stock multiple times (Kelts are adult brood-stock that have already spawned and are in an exhausted state and need to restart feeding to regain full condition.)

The fish selected as brood-stock are chosen for traits that are desirable to the fish farmer, including:

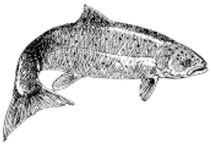
- Fast growth
- Disease resistance
- Good body conformation (shape)
- Improved egg production (size and fecundity)
- Brood-stock recognition

Atlantic salmon brood-stock males and females are easy to differentiate from each other when they are sexually mature, but not so easy up until that point as both sexes look similar until the differing 'secondary sex characteristics' start to develop.

Female characteristics

Sexually mature female Atlantic salmon have a dark colouration (not as dark as the males) with a very round and soft abdomen. The **urino-genital pore** (vent or papilla) will protrude. If the females are captured and gently held with the head down there will be obvious creasing around the urino-genital pore. If gentle pressure is applied around the pore the orange coloured translucent eggs will flow freely if the female is fully mature. If the fish is unripe the abdominal area will still feel firm and no eggs will be produced.

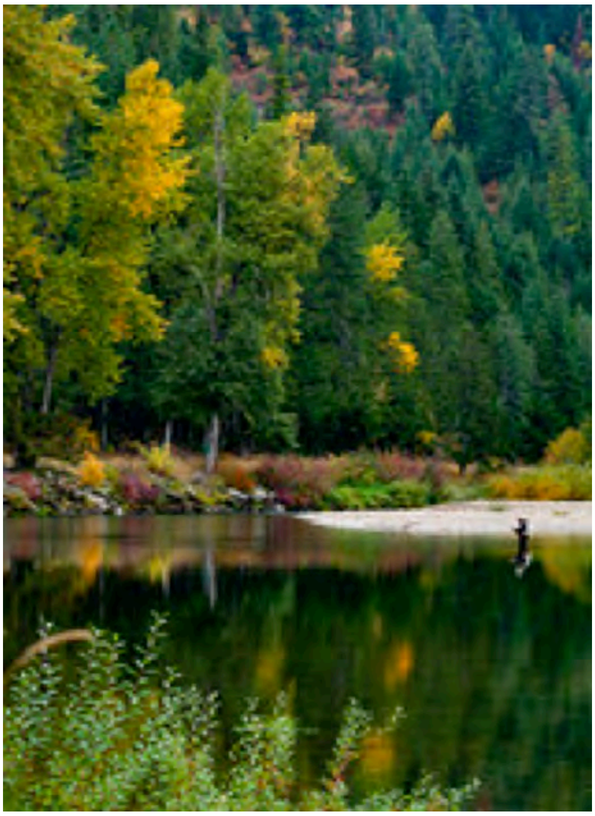
B18 **Fish Biology and Life Cycles**



Salmon sexual maturation environmental triggers

Once juvenile Atlantic salmon have spent their early years in freshwater they will start to change and prepare for migration to the marine environment. Before this occurs, the juvenile fish will undergo a physiological transformation to prepare them for life in the marine environment. The marine migration will take the salmon to feeding grounds where they will grow rapidly, preparing the adult for return to freshwater to breed.

It is known that the sexual maturation of Atlantic salmon is influenced by environmental and physiological triggers that are intrinsically linked. The environmental factors initiate the **endocrine system** and the release of **pituitary hormone** that regulates the release **sex hormones** controlling gonad development. These appear to be the main cues and the normal chain of events steering the fish physiologically towards sexual maturation.



Reducing day light hours and falling temperatures are the two main environmental triggers for sexual maturation in the autumn

In the wild, Atlantic salmon will return to the rivers of their birth to prepare for spawning during the winter, generally around November/December, although the timing will vary. This reproductive strategy is not exclusive to Atlantic salmon and is likely to be an evolutionary adaptation to ensure young fish hatch and emerge from the gravel during the spring when food availability is improving.

The physiological factors influencing sexual maturation in Atlantic salmon are linked to growth, including body mass, growth rate, fat reserves, and general condition factor. However, those physiological factors are influenced by external environmental factors, particularly water temperature and photoperiod (day length).

The sexual maturation of Atlantic salmon is not exclusive to adult fish. Young salmon in the parr stage can also become sexually mature a phenomenon known as 'precocious parr'. The onset of maturity in precocious parr will be influenced by the same factors as adult fish, such as; size, growth rate, water temperature and photoperiod. It is thought this evolutionary adaptation ensures eggs will always get fertilised, even in the event of a scarcity of mature males returning from the sea.

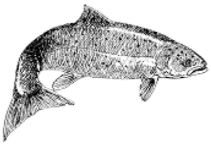
As the fish grow and develop in the marine environment, they will experience seasonal changes such as increasing and decreasing temperature and daylength and at a stage when the fish is sufficiently physiologically developed to breed an urge in the fish to return to freshwater will be triggered.

The Pacific salmon migrate to freshwater in response to the same environmental triggers as Atlantic salmon

Although some adult fish seemingly return to freshwater prematurely in the spring and summer months, they will not fully mature until the water temperature and daylength start to decrease.

Not all Atlantic salmon will get this migratory urge at the same time. Some fish return to freshwater after one sea winter, known as a grilse, while others may spend multiple winters at sea before returning to spawn as much bigger fish. It is thought the reason some fish sexually mature early and return as grilse is linked to increased water temperatures, ultimately resulting in faster growth.

B19 **Fish Biology and Life Cycles**

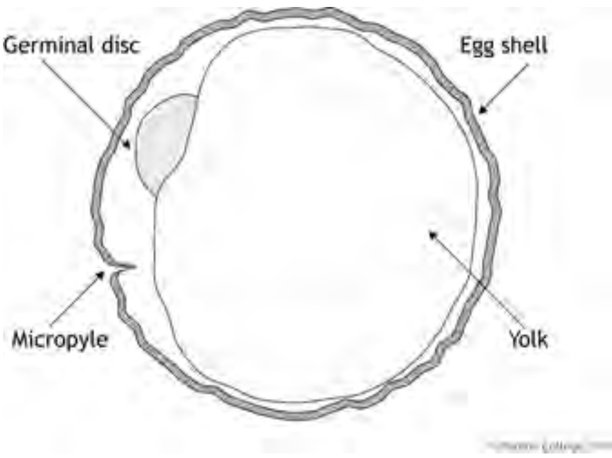


Salmon egg fertilisation

The fertilisation process for Atlantic salmon ova begins before the ova (eggs) and milt (sperm) are mixed. The ova are stripped from the female fish and are kept separate from any sperm, water or other fluids. This is important because there is a small opening in each ovum called a **micropyle** (see diagram below) which allows the sperm to enter and fertilisation to take place. If any fluids or water is added to the ova the micropyle will close, causing problems when milt (sperm) is added, as it will not be able to access the egg and the ova will be unfertilised.

All salmonid egg stripping teams need to be well prepared when preparing ova and milt for 'dry fertilisation'

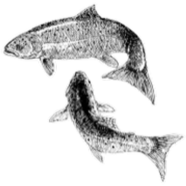
This method of stripping and fertilisation is commonly called the **'Dry method'**. The same applies to milt when it is in contact with water or ovarian fluid, the sperm will activate so it is important this is also kept separate until required.



When the ova and milt have been stripped from the broodstock they can be gently mixed in a container or bowl using a finger. The ovarian fluid will activate the sperm which will actively swim using their tails, and fertilisation occurs almost immediately.

Fertilisation occurs when a sperm has entered the micropyle of the ova. It is important that water is not added to the ova and milt mixture immediately as the water will reduce the life span of the sperm and cause the micropyle to close and the ova will **water harden**. Water hardening is a process where the ova takes in water through the micropyle and closes off. The ova in this process will go from a soft jelly feel to hardened when touched.

B20 **Fish Biology and Lifecycles**



Salmon egg incubation

Atlantic salmon spawn in freshwater during the autumn/winter by burying their eggs in a gravel nest. This nest is known as a **'redd'** which is a depression in the gravel stream bed cut out by the female fish. The female uses her tail to create a down draught which loosens the gravel downstream of the depression. The site selected for the redd must be free of sediment so the eggs cannot get smothered, with gravel of the correct size to enable the fish to engineer it, but not too fine to impede water flow.

A clean gravel redd allows water through flow essential for successful incubation

An adequate water flow will oxygenate the eggs and alevins. The gravel nest must also be stable to protect incubating eggs and alevins from high water flows in spate conditions. Once the female has excavated the redd she will prepare to lay her eggs alongside a male fish.

When the eggs are discharged the male will release milt (sperm) immediately fertilising the eggs. The female will then move upstream and again use her tail to move gravel over the eggs to cover and protect them. The eggs will remain in the redd overwinter until they hatch, normally in the spring.

When the eggs will hatch is temperature dependant and can be anticipated using 'Degree-days'.

An example, Atlantic salmon eggs will take approximately 440-degree days to hatch which means at a water temperature of 10^{0}C the eggs would hatch in 440degree days/10^{0}C = 44 days.

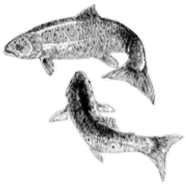
Once the eggs have hatched the juvenile salmon known as alevins at this stage will remain in the redd until they have absorbed their yolk sac.

Once they have almost fully absorbed the yolk sac the alevins will emerge from the gravel and rise to the water surface to gulp air to inflate the swim bladder.

Egg and alevin development to become actively feeding 'swim up fry' is temperature dependent

The alevins are now at the stage to start first feeding and are known as 'swim up' fry.

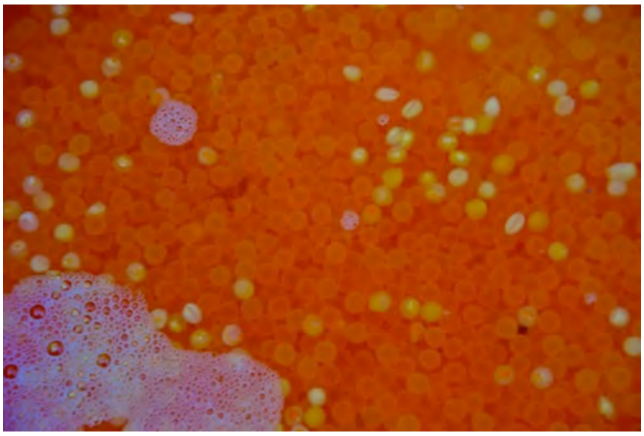
B21 **Fish Biology and Lifecycles**



Salmon egg development

There are many environmental factors that will influence the development and survival of salmonid eggs but the one which has the most influence on the development of Atlantic salmon eggs is water temperature.

Water temperature will influence the rate at which the eggs develop and hatch e.g. if it is cold it will take longer to hatch. However, the opposite is also true in that if it gets too warm then the rate of development will accelerate but there is an upper lethal temperature of > 12^{0}C, where increased mortality will occur.



A rupture of the yolk membrane during the early stages of development kills eggs and they turn white

When Atlantic salmon eggs (ova) are deposited in the redd they develop from what is known as 'green eggs' which are delicate, to become 'eyed-eggs' which are more robust.

The rate of ova development is temperature dependant and can be anticipated using 'Degree days' if the daily temperatures can be predicted with reasonable accuracy.

To understand the application of degree days, consider the following requirements for Atlantic Salmon:

- 220-250 Degree- days from fertilisation to eyed egg
- 440 Degree-days from fertilisation to hatch

These salmon eggs would require 440 degree-days exposure from fertilisation to hatch

How is the Degree day exposure calculated?

Taking fertilisation to hatch as an example:

Time (days) x water temperature = Degree days

At a water temperature of 10^{0}C

- 22 days x 10^{0}C = 220-degree days

At a water temperature of 5^{0}C

- 50 days x 5^0C = 250-degree days

Therefore, depending on the daily water temperatures salmon eggs can take from 22- 50 days to reach the eyed stage from fertilisation. It should be noted that the oxygen requirement of the ova will increase as the embryo develops, emphasising the importance of a constant flow of water through the redd.

Consider this more complex scenario:

The water temperature is anticipated to be 5^0C for 30 days, followed by 7^0C for 30 days followed by 10^0C for the duration.

How many days will it take from fertilisation to hatch?

Answer:

- 5X30 =150 Degree-days
- 7X30 = 210 Degree- days

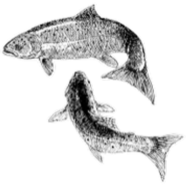
Total Degree-day exposure + 150+210 = 360

Therefore, the eggs will have passed the eyed stage and there will be 80 Degree-days exposure remaining until hatch

- At 10^0C this will take 8 more days

Therefore, the time in days from fertilisation to hatch is 30+30+8 = **68 days**

B25 **Fish Biology and Lifecycles**



Juvenile salmon habitat

Most nursery streams and rivers are broken up into what is known as a riffle and pool sequence. The riffles are faster flowing shallow areas found at the head of a pool. The water flow reduces as it deepens on entering the pool and the aquatic invertebrate populations tend to be different when comparing samples from a riffle and pool.

This stretch is dominated by riffle habitat that salmon could more easily occupy

This is due to;

- different substrates resulting from sand and silt deposition as flow rates reduce,
- differences in dissolved oxygen levels with the riffles being oxygen rich and
- the abundance of aquatic plant life in the riffles, especially epiphytic (surface living) algae that many of the 'grazing' invertebrates thrive on.

In addition to a more diverse food supply, the riffle areas contain gravel and small rocks/boulders that provide habitat and shelter for juvenile salmonids. The existence of these two habitats (riffle and pool) in proximity, enables Brown trout and Atlantic salmon juveniles (parr) to sperate and coexist, without wasting too much energy battling for the same **niche**. The ideal Atlantic salmon habitat has a stoney substrate, as this provides the small fish a multitude of feeding stations offering 'visual privacy' from other salmonids, reducing territorial aggression.

What is the salmons natural food supply in freshwater?

The tail of the pool has a similar flow and substrate type to the pool-head, and this also provides ideal salmon habitat. The salmon fry feed on aquatic insects and crustacea of an increasing particle size as they grow up to become parr. The fish quickly learn to recognise and select prey of an appropriate particle size to match their 'mouth gape'.

Stonefly nymphs are a major part of the salmon's diet as they live on stone surfaces in the riffles

The invertebrate population here tends to be dominated by stonefly and mayfly nymphs, as well as caddis larvae and shrimps, which are all well adapted to cope with the fast flows. The nymphs cope by 'clinging on the rock surfaces with their claws, the caddis due their cases made of stone providing ballast and the shrimps through their swimming ability and being able to squeeze between rocks. So, they either 'cling' anchor or hide. However, when any of these creatures get dislodged and enter the drift, they immediately become available to feeding salmon and trout of an appropriate size. As they grow, larger prey can be consumed, and following 1 – 3 years of freshwater growth they smoltify before migrating to the sea.

There are noticeable physical differences between Atlantic salmon and Brown trout. Atlantic salmon juveniles are more streamlined and have larger pectoral fins which they can angle to use the river flow to help compress them to the substrate.

The large pectoral fins are very prominent on this Atlantic salmon parr

These prominent external features, particularly the large pectoral fins, make them better suited to life in faster shallow water. Consequently, more salmon juveniles tend to occupy the shallow riffles of a river or stream than brown trout of a similar size.

However, electro-surveys of the fish population show that the riffle areas are not always exclusively occupied by Atlantic salmon juveniles as the stronger trout can sometimes carve out and defend a feeding station.

Therefore, fishery managers must always identify their catch carefully when conducting nursery stream fish population surveys. Correct identification techniques should always be employed to ensure there no assumptions are made and the survey information gathered is accurate.

B26 **Fish Biology and Lifecycles**

Osmosis

In any aquatic environment, freshwater or marine, there are very few fish that have a body fluid concentration (mostly salts) that is the same as the aquatic environment in which they live. Freshwater fish have body fluids that are of a lower concentration than the external aquatic environment. For marine fish the situation is the reverse.

For freshwater fish this phenomenon leads to water intake through the skin, gills and gut lining which are semi-permeable, lowering the concentration of the bodily fluids. Without intervention, water ingress would continue until the internal concentration of concentration the surrounding freshwater environment. The fish would simply fill up with water, if they had no means of regulation, which would be fatal.

For a marine fish, the marine environment is of a higher slat concentration that the internal bod fluids of the fish. Consequently, water leaves the fish via the same semi-permeable membranes and without intervention it would dehydrates.

The physiological process causing water ingress and dehydration to challenge freshwater and marine fish species respectively, is called osmosis.

What is Osmosis?

Osmosis is defined as "*the movement of water from a solution containing a lower concentration of dissolved materials through a semi permeable membrane to a solution with higher concentration of dissolved materials*".

How do fish cope with osmosis?

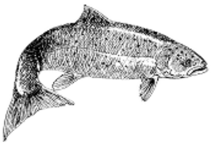
Fish must maintain their bodily fluid concentration they are to maintain normal physiological functions. The do this through osmo-regulation.

The kidneys of freshwater fish excrete vast quantities of dilute urine to expel excess water ingress, and 'gill chloride' cells help to retain salts that would otherwise get excreted.

Marine fish drink water to replace the loss to dehydration and the gill chloride cells work in reverse by excreting excess salts in the sea water the fish is drinking.

Via these two mechanisms, the fish can maintain a stable internal salt balance.

B27 **Fish Biology and Life Cycles**



Salmon osmoregulation in freshwater

In any aquatic environment, freshwater or marine, there are very few fish that have a body fluid concentration (mostly salts) that matches the aquatic environment they live in. Freshwater fish have body fluids that are of a lower concentration than the external aquatic environment. For marine fish the situation is the reverse.

The physiological process causing water ingress and dehydration to challenge freshwater and marine fish species respectively, is called osmosis.

What is Osmosis?

Osmosis is defined as "*the movement of water from a solution containing a lower concentration of dissolved materials through a semi permeable membrane to a solution with higher concentration of dissolved materials*".

How does this effect Atlantic Salmon during the freshwater phase?

For freshwater fish osmosis leads to water intake through the skin, gills and gut lining which are semi-permeable membranes, lowering the concentration of the bodily fluids. Without intervention, water ingress would continue until the internal concentration of concentration the surrounding freshwater environment. The fish would simply fill up with water, if they had no means of regulation, which would be fatal.

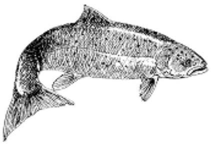
The salmon parr's kidney works hard during the freshwater phase, to expel excess water intake

To counteract the water ingress due to osmosis the fish has two physiological devices:

- For the kidney to produce lots of dilute urine as means expelling the excess water and counteracting the dilution of body fluids.
- Chloride cells in the gill which help to retain salts, counteracting their dilution.

These two mechanisms are enough for the fish to osmo-regulate and maintain a stable and normal body salt concentrations

B28 **Fish Biology and Life Cycles**



Salmon osmoregulation during the marine phase

In any aquatic environment, freshwater or marine, there are very few fish that have a body fluid concentration (mostly salts) that matches the aquatic environment in which they live. Freshwater fish have body fluids that are of a lower concentration than the external aquatic environment. For marine fish the situation is the reverse.

The physiological process causing water ingress and dehydration to challenge freshwater and marine fish species respectively, is called **osmosis**.

What is Osmosis?

Osmosis is defined as "*the movement of water from a solution containing a lower concentration of dissolved materials through a semi permeable membrane to a solution with higher concentration of dissolved materials*".

How does this effect Atlantic Salmon during the marine phase?

For a marine fish, the marine environment is of a higher salt concentration that the internal body fluids of the fish. Consequently, water leaves the fish via semi-permeable membranes and without intervention, the fish would dehydrate.

Therefore, due to the Atlantic salmon's anadromous lifecycle the parr need to prepare physiologically for their downstream migration to more saline waters. During its freshwater life, the kidneys have been excreting vast quantities of dilute urine to expel excess water ingress. In addition, the 'gill chloride' cells help to retain salts that would otherwise get excreted in the urine.

Chloride secreting cells in the salmon gill lamellae help to stabilise internal salts during the marine phase.

Before the fish enters freshwater, it must smoltify, effectively putting all its freshwater osmoregulatory mechanisms into a reverse gear! The fish becomes streamlined and silver often with a black edge to the caudal fin (tail). But more importantly, it is the unseen internal changes which will secure the salmon's survival.

This physiological transformation enables the salmon to cope with increasingly saline waters as it moves down stream into the 'brackish estuary' and after a period of a few days to fully acclimatise, makes it out to the north Atlantic feeding grounds and full strength sea water (35 ppt salinity)

The process of osmoregulation is the reverse of that adopted in freshwater. The fish drinks constantly to regain water lost by osmosis and to prevent dehydration. However, as it is drinking saline water, the build-up of ingested salts must be counteracted to stabilise body fluids at a normal concentration. This is done in two ways:

The kidney (dark organ under the vertebrae) produces low volumes of concentrated urine to expel salts and conserve water

- Chloride secretion cells in the gill lamellae reverse their function, and instead of conserving salt, as they were in freshwater, after smoltification they can excrete and expel excess salts.

- The kidney stops producing urine in vast quantities as that would intensify the dehydration and produces small quantities of concentrated urine in order to expel more salts from the system.

After the marine feeding phase is complete, in preparation for re-entry to freshwater as a mature breeding adult the entire physiological process must be reversed once more, back into the freshwater osmo-regulatory mode!