Output 1:
First Aquaculture Test Pilot (Norway)

Version: Final

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ASK for Best Practice

This document may be updated if needed and changed without notice.

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Content

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Summary

The application of 'case based' learning is a central strategy within the 'Ask for Good Practice pilots in Norway and Iceland, supported by multi-media resources. Work based learners are encouraged to study background learning material before addressing farm-based production challenges within case-based learning exercises.

A deeper understanding of the Atlantic Salmon's lifecycle, anatomy, and physiology help to underpin the learner's appreciation of aquaculture techniques, equipment, and processes.

These flexible learning resources focus on areas of the curriculum where resources for supporting work-based learners were previously less well developed in Norway and Iceland or are required at a higher EQF level, such as salmon anatomy and physiology.

Learning resources have been developed to support three Units:

- Atlantic salmon life cycles
- Salmon anatomy and physiology
- Salmon hatchery operations

They have been presented in a way that allows for customisation by VET practitioners. Unfortunately, due to Covid travel restrictions it was not possible to access farms to gather the images and video specified. However, these can be added by VET practitioners, which in some cases provides opportunities for customisation to suit the facilities used by work-based learners.

The resources represent a step towards the development of more sophisticated 'e learning' approaches in the future, by a team with specialist instructional design, multimedia production and IT skills, supported by well-designed story boards.

The 'Articulate creative' notes contained within these story boards are a rudimentary interim first stage of instructional design which can be built on by e learning development teams. In the short term, the resources can be disaggregated and presented on a Learning Management System as they stand, in a non-interactive interactive format.

Ask for learning resources

Atlantic salmon Lifecycle

These learning resources have been designed to support ‘short episodes’ of focussed learning’ on specific topics within the Fish Biology and Behaviour Unit (EQF Level 4) Each episode has a title and number that relates to multiple-choice question banks designed to support the Recognition of Prior Learning (RPL) or formative assessment.

The learner will be prepared for the following Learning Outcomes with the Fish Biology and Behaviour Unit, delivered in the context of the Atlantic salmon life cycle.

1. Describe the normal and abnormal behaviour of specific fish species with reference to their tolerance limits.
2. Describe the feeding behaviour specific fish species with reference to their metabolism.

The resources focus on the freshwater and marine phases of the Atlantic salmon’s life cycle, including their journey from the nursery stream as smolts to the Atlantic Ocean, and return as mature adults for spawning. The aim is to provide learners with an understanding of the environmental requirements and behaviour of the fish at each lifecycle stage, that can be applied to Salmon Hatchery Operations.

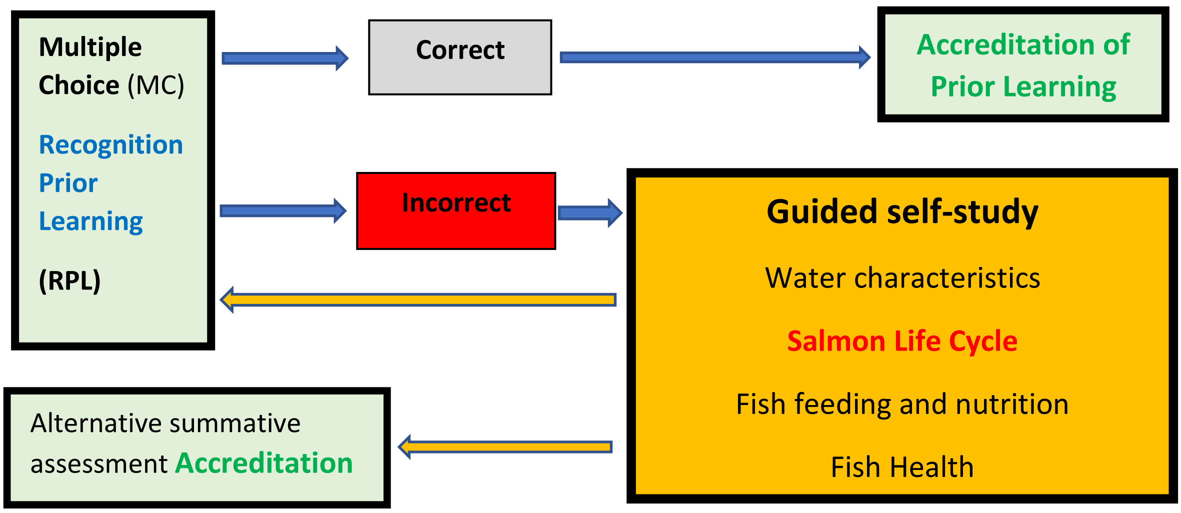
The resources can be used to support the following RPL led process for the development of underpinning knowledge:

Step 1- Undertake multiple choice questions for the section

Step 2 Automated RPL analysis determines which questions have not been answered correctly in full. This can be linked to an accreditation process through consultation with the national VET Awarding body

Step 3 Self-study, guided by the RPL results and feedback (See next page for details)

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



Graphic to illustrate recommended RPL/APL pedagogy

Self-study (navigating Ask for learning materials and external resources)

The learning experience is designed to be interactive and gives the learner control of their learning, starting with the 'Recognition of Prior Learning' (RPL)

Icons within the learning system can be used to flag components and activities to the learner...

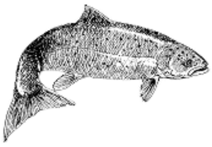
Blue font signifies **mandatory**

Activity	Purpose	Icon
What do you know already? RPL/APL	Mandatory assessment of the learner's current knowledge. Can lead to accreditation for some Units (APL)	Finger raised to a thinking face
Main content	Text and image, providing context and more topic details	No icon needed
Key characteristics	Summary points expanded on in the main content (Mandatory knowledge to be assessed)	A key
Relevance to salmon husbandry	Short insert to make the topic relevant to the fish farming, with hyperlinks to web links.	Stylised graphic (salmon in a net)
Watch this**....**	Selected Youtube or home-produced instructional video	Film reel graphic
....now have a go	Learning activity- may be a calculation or other activity, or formative assessment following a learning episode.	Graphic of tutor pointing to learners
...**the scientists say**	Interesting insights and debates from the scientific community	Mad professor talking head

Navigation to information within the PSA and the web

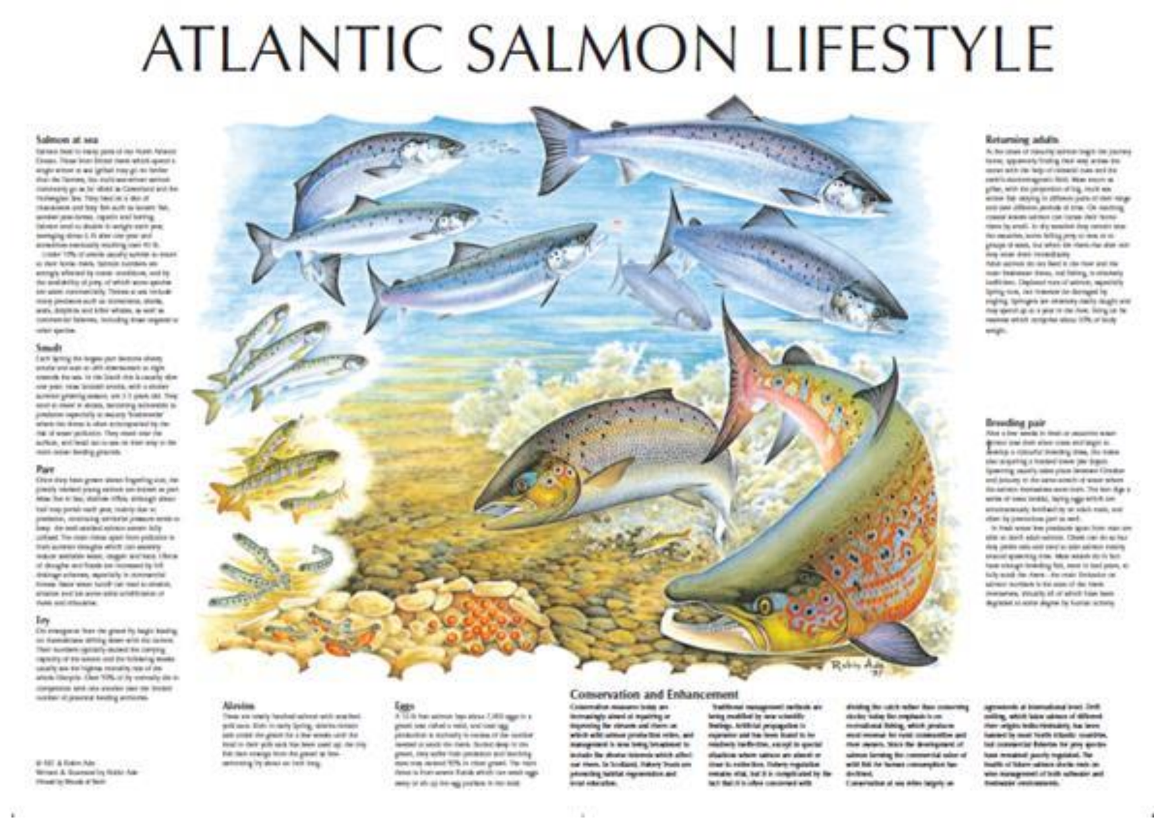
Colour code	Hyperlink
Green font	Links to a section of material in another episode in the same Unit or another Unit within the PSA, making related information more readily available. Navigation back must be easy to keep learners 'on-task'
Blue font	Links to an interim summary definition box and then for a full expansion and data set but ensuring easy navigation back to the main study material.

ASLC 1 **Atlantic salmon lifecycle**



Atlantic salmon classification and introduction

The Atlantic salmon (Salmo salar) is found in the north Atlantic Ocean, rivers that flow into the north Atlantic and, due to human introduction, in the north Pacific Ocean. The species is anadromous with a relatively complex life history, that begins with sexually mature adults spawning in freshwater



Articulate creative: *Salmon lifecycle made interactive, lined to a single sentence and episodes in this Unit (This image is provided as a guide only - no IPR)*

streams in the late autumn.

Once the resulting ova hatch in the early spring, the young eventually emerge from their spawning redds to start feeding and remain in fresh water for two or three years.

When the fish are about 15 cm in length, the young salmon (smolts) begin their migration to the north Atlantic, where they grow rapidly for one to three years, before returning to their nursery streams as adults to spawn and thereby complete their lifecycle.

What is the scientific classification of the Atlantic salmon?

Atlantic salmon belong to the class Teleostei, popularly referred to as the bony fish (teleosts) and sub class-Actinopterygii, the ray-finned fishes, which make up 96% of all existing species of fish. This diverse taxonomic group of fish have skeletons primarily composed of bone tissue, as opposed to cartilage.

Salmon is the common name for several species of ray-finned fish in the family Salmonidae, native to tributaries of the North Atlantic (genus Salmo) and Pacific Ocean (genus Oncorhynchus). The Atlantic salmon's full scientific name is Salmon salar. Other fish in the same family (Salmonidae) include trout, char, grayling, and whitefish, and they all share the distinguishing family feature of a seemingly functionless fleshy adipose fin.

Articulate creative: Salmon family tree graphic (non-interactive) to show the Atlantic salmon and other Salmonidae in relation to other teleosts

What is the global distribution of the Atlantic salmon?

Since the mid-19th century, numerous attempts have been made to restore or enhance populations of the Atlantic salmon within its natural range, and to establish the species in other parts of the

Global distribution of the Atlantic Salmon

Articulate creative: Produce a clean, better-quality Atlantic salmon distribution map.

(a) Differentiate native stocks from introduced stocks with colour differentiation. Have a drop-down paragraph on the status of the wild salmon and farmed salmon in each country (to be developed) and which appears on hovering... (b) Indicate those countries farming Atlantic salmon using a different colour notation and a drop-down box giving statistics on the scale of the industry and output in each country.

world. Despite multiple efforts, their introduction and naturalisation has been limited to eastern North America, Argentina, and New Zealand. The main constraints influencing their distribution and the naturalisation of populations are water temperature and the availability of suitable spawning and nursery sites. Salmon farming has been established in many countries, and some have a native wild stock of Atlantic salmon threatened by fish farming and other human activities.

How are Atlantic Salmon exploited globally?

The species is of great significance to several sectors of the economy. Commercial exploitation of the species in coastal and offshore waters is viewed internationally as a factor of increased importance in the regulation of river spawning runs.

Atlantic Salmon Fishing Cains River New Brunswick – By James Mann

In the past Atlantic salmon were plentiful, and sustainable small-scale artisanal fisheries were commonplace in north Atlantic seaboard coastal communities, netting Atlantic salmon for human consumption. Once the fish's feeding grounds were discovered around Greenland and the Faroe Islands in the 1950s, the stocks came under intense fishing pressure from many miles of drift nets and their conservation became urgent. Subsequently, many commercial net fisheries were bought out and closed to help more fish return to the rivers and breed, to the benefit of salmon populations and sport fishery interests. In 1990 a North Atlantic Salmon Fund (NASF) was established by a pioneering Icelander the late Orri Vigfusson, who was the first to take the threat of the drift net fishery seriously and raise international awareness and support for the conservation effort he led.

The Atlantic salmon is an iconic sport fish, revered by discerning anglers who long for the opportunity to catch what many consider to be the 'king of fish'. Professionally managed fisheries in Norway, Iceland, Russia and parts of Scotland and Ireland command high fees, making the species a significant contributor to the rural economy in those countries where wild stocks still thrive today.

In some countries, most notably, Scotland, Ireland and to some extent Norway, the stocks have been under great pressure latterly, despite the reduction of the commercial net fishery. Whilst many believe that there are a range of influential factors including global warming, many fear that intensive cage farming in the vicinity of wild stocks is a major contributory cause, and a precautionary approach by the regulators is restricting industry expansion in many countries.

Atlantic salmon fish farm, Vestmanna, Streymoy, Faroe Islands – Erik Christensen

The potential impacts of conventional salmon marine cage culture are:

- difficulties in controlling sea lice, which damage wild stocks, and lead to lower farmed fish welfare standards,

- containment failures which can lead to farmed fish escapees and the genetic dilution of wild stocks, and
- seabed pollution resulting from waste deposition under the cages.

How can aquaculture help the wild Atlantic salmon to recover and thrive once more?

RAS based salmon production has no impact on Atlantic salmon wild stocks or on the natural aquatic environments where the fish live. By increasing the proportion of salmon produced by RAS, the many environmental conflicts holding the salmon farming industry back, can be entirely avoided.

When powered by renewable energy sources, RAS production is carbon neutral and provides high quality sea food to global markets whilst addressing the animal welfare concerns that arise with conventional salmon farming.

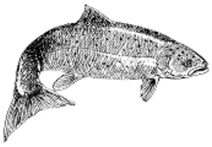
Ultimately, RAS production this will increase the availability of farmed salmon globally through the strategic development of production facilities, whilst aiding the survival of the wild Atlantic salmon currently under threat.

In addition, marine cage farming technology is developing. Larger cages are being anchored further offshore where wastes are more dispersed and less able to impact on sensitive coastal habitats. The recycling of water within cage systems is also under development and has the potential to further reduce waste and sea lice burdens in the future.

Key characteristics from the Atlantic salmon overview:

- A member of the ray-finned fishes within the teleost and a member of the Salmonidae (salmon family) all species of which have an adipose fin.
- Anadromous, migrating to the north Atlantic to feed and back to freshwater to breed.
- Distribution limited to the north Atlantic region and several other countries where the species has been successfully naturalised.
- Globally economically significant species for human consumption (commercial fishery and aquaculture) and sport (angling)
- Wild stocks under threat from the ongoing commercial fishery, aquaculture, global warming, and land uses that harm salmon nurseries.
- RAS based salmon production eliminates the potential environmental conflicts that conventional cage-based production can cause

ASLC 2 Atlantic salmon lifecycle



Navigation and migration

Atlantic salmon (and most of the Pacific salmon species) perform some of the most impressive migrations known in the animal kingdom. They travel from freshwater to the sea to feed, and when mature, return to the river and nursery stream where they were born to spawn. This behaviour is called 'anadromous'.

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

Some fish species are 'catadromous', migrating to freshwater to feed and grow, before eventually returning to the sea as mature adults to spawn. The European eel is an example, reproducing in the Southern Atlantic Sargasso, with young returning as elvers (glass eels) to freshwater to feed. Unlike land-based animals or birds, fish are not thought to use visual indicators, such as landmarks, to assist their navigation during migration. Incidentally, there is some evidence that not all birds and animals rely solely on visual indicators either.

Atlantic salmon 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 fully acclimatised, they start their migration to the rich feeding grounds in the North Atlantic. Recent research shows that they use the Earth's magnetic field as a navigational tool, like their Pacific cousins. That ability is not lost through several generations of fish even after being transplanted into a land-locked lake. Research findings suggest that farmed Atlantic salmon may be able to navigate and invade new habitats if they escape containment.

After 1-4 years when the young fish have grown into adults, the earth's magnetic field guides them back to the coastline where the river they originate from discharges.

Key characteristics of salmon migration

- Anadromous species, migrating to the sea to feed and back to freshwater to spawn.
- Navigate using the earth's magnetic fields to find the right area of coastline
- Use their olfactory organ (sense of smell) to find their birth river.
- Photoperiod triggers the physiological preparation and change from parr to smolt in preparation for seaward migration
- Salmon can complete their entire lifecycle in freshwater and when 'landlocked' they do not migrate

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

How do salmon find their own river and nursery stream?

Once the right area of coastline has been located, their sense of smell controls the rest of their journey. By the time smolts leave their river their olfactory organ has detected 'and logged' its unique 'chemical odour'. This 'imprint' is retained into adulthood and allows the salmon to locate their river of birth when returning to freshwater.

Why do salmon normally return to the precise river of their birth to spawn?

By doing so, the mature adults enter nursery stream habitat proven suitable, since they were able to survive and thrive there during their own freshwater phase. As a result, each population of salmon running each river system represents a genetically distinct gene pool, having evolved over many years to suits the specific conditions.

What triggers salmon to migrate?

Juvenile Atlantic salmon in freshwater feed on aquatic insects and invertebrates for 2 -3 years before the physiological preparation for a life in the marine environment. The urge to migrate is triggered by photoperiod, more specifically, increasing day length in the spring.

The young salmon change to a silvery colour and the gill chloride cells required to cope with osmoregulation in the marine environment start to develop. They become known as smolts.

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

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

The urge to migrate is not synchronous within a salmon population and in some cases, salmon do not migrate at all. This can be due to a lack of sea access, but there are also populations with sea access that do not migrate. These non-migratory 'landlocked' salmon found in various lakes around the world are the exception rather than the norm.

When the young salmon (smolts) first enter the sea, they feed in local coastal areas, before migrating to their north Atlantic feeding grounds. Once here, they gain weight quickly by feeding on a natural diet of fish and crustaceans before maturing and returning to spawn, reliant on their remarkable navigational ability.

.... **the scientists say**

Navigation

https://www.ecomagazine.com/news/science/atlantic-salmon-use-magnetic-maps-to-navigate#:~:text=A%20new%20study%20shows%20that%20Atlantic%20salmon%20use,habitats%20if%20they%20escape%20their%20pens%2C%20researchers%20say.

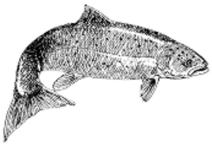
Relevance to salmon husbandry

The accuracy of the salmon's navigational ability has led to distinct 'gene pools' with stocks of wild fish adapted to the specific river system environment in which they have evolved.

Marine cage-based aquaculture has had problems with containment, leading to the accidental release of farm stocks of a different origin, selectively bred for a range of characteristics, such as fast growth and disease resistance. For example, Atlantic salmon originating in Norway and selectively bred for farming are commonly reared in Scotland. If they escape and run a nearby river they can breed with the wild stock. Scientists are concerned that the resulting 'genetic dilution' could reduce the wild salmons 'fitness for survival' and is one of the concerns raised by environmental lobbyists.

This potential impact of conventional cage-based salmon farming is eliminated by RAS based production.

ASLC 3 **Atlantic salmon lifecycle**



Growth and sexual maturation

The north Atlantic shelf abounds with an abundant natural food supply for the Atlantic salmon. Along with pelagic fish species, such as the Clupidae (herring family), crustaceans form an important part of the diet. Caretonoids synthesised by marine algae and ingested by crustacea are deposited in the muscle of salmon preying on them, giving the flesh its distinctive orange colour.

A wild salmon's muscle turns orange due to the deposition of carotenoids from marine crustacea

The salmon's growth rate is rapid and determined by the seasonal food supply and sea temperatures. Eventually, falling temperatures and more significantly reducing daylength acts on the endocrine system to trigger maturation and the urge to return to freshwater.

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

When does the salmon sexually mature?

Not all Atlantic salmon are ready to leave their marine feeding grounds at the same time. Some adults return to freshwater in the spring and summer months, which seems premature, as they do not ripen and spawn until the water temperature and daylength decreases further, later in the year.

The sexual organs can start to develop after one, two or several years of marine feeding, depending on nutritional, environmental and genetic factors. Some fish, known as a grilse, return to freshwater after one sea winter, whilst others may spend multiple winters at sea before returning as much bigger salmon.

Early sexual maturation is thought to be linked to fast growth and to some degree, genetically determined. Typically, faster-growing strains of farmed salmon have higher grilse rates compared to other strains.

Relevance to salmon husbandry

Early maturation of salmon in sea cages can be a problem as the 'organoleptic quality of the fillet declines and the fish loses value. Traditionally, the 'grilse' have been graded out for sale early by salmon farmers before sexual maturation is too advanced.

As there is a genetic component determining sexual maturation, molecular markers have been used by breeders to help selection of late maturation, so as the salmon can be kept in an immature state as they are grown and fattened for harvest.

What size can adult salmon reach?

Grilse mature after one year of sea feeding 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 feeding for longer at sea can be considerably larger.

The largest salmon, which are male, reach up to 30 Kg and tend to be multiple spawners. They return to the feeding grounds after spawning as 'kelts' to rebuild their muscle mass and energy reserves, before maturing and migrating to freshwater to spawn once more. Conversely, female salmon rarely reach more than 20 Kg in weight.

Does the adult salmon continue feeding when it returns to freshwater?

On leaving the marine environment the salmon stops feeding. This is thought to be a device to aid the survival of the species, by stopping the adults from predating their own progeny on return to freshwater.

Key characteristics of adult Atlantic salmon

- Salmon grow rapidly feeding on fish and crustacea on the north Atlantic shelf during their marine phase.
- Reducing water temperatures and day length trigger the release of pituitary hormone leading to sexual maturation
- Salmon that mature early after one sea winter are called grilse
- The Atlantic salmon can survive spawning and return to the sea as a kelt to mend, grow and return to spawn again.
- Salmon spawn in the winter so as the young hatch in the spring, when the natural food supply is increasing
- Precocious sexual maturation of salmon parr ensures that eggs can always be fertilised if adult males become scarce.
- On sexually maturing, the salmon's skin darkens, the female's abdomen swells, and the males develop a pronounced kype.

What role does the endocrine system play in maturation?

It is known that the sexual maturation of Atlantic salmon is controlled by environmental and physiological triggers that act on the endocrine system. Pituitary hormone is released and in turn regulates the release of sex hormones controlling gonad development and sexual maturation.

When do Atlantic salmon spawn?

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

Salmon leave the sea and enter freshwater at any time from the spring through to the autumn in readiness for their ascent to the spawning grounds.

Spawning occurs during the winter, generally November/December, although the precise timing will vary. The early runs of spring salmon are in freshwater for up to six months before spawning, sustained by their fat reserves.

Winter spawning ensures that the young fish hatch and emerge from the gravel during the spring, ready to feed, when natural food availability is rising.

Can salmon sexually mature without leaving freshwater?

Young salmon in the parr stage can become sexually mature, a phenomenon known as 'precocious sexual maturation'. The onset of maturation in precocious parr will be influenced by the same factors as adult fish, such as size, growth rate, water temperature and photoperiod. This evolutionary adaptation ensures eggs will always get fertilised, even in the event of a scarcity of mature males returning from the sea. Insert

Landlocked salmon complete their entire lifecycle in freshwater. This is a situation that the RAS salmon farmer can replicate, eliminating the need for saline conditions for spawning or grow-out.

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

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

Over the following weeks the 'secondary sex characteristics' of the male and female salmon become increasingly pronounced

As the females sexually mature, caretonoid pigments deposited in the flesh are mobilised and transported to the skin and eggs, which gives them their orange appearance. The carotenoids protect tissues from oxidative damage and helps regulate immune response. As pigments deposit in the skin and accumulate, the females become increasingly reddish brown in appearance.

When the female fully ripens its ovaries swell and the abdomen becomes very round and soft. When captured and gently held with the head down there will be obvious creasing around the protruding urino-genital pore. If fully mature, and gentle pressure is applied around the pore the eggs flow freely if the female. If the fish is unripe the abdominal area will still feel firm, and no eggs will be produced.

The males can become very dark as spawning time approaches, and they 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 to dominate a prime position for fertilising the eggs being released by spawning females.

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

When sexually mature ‘ripe’ males are captured and gentle pressure is applied near their vent, they will produce a white fluid called milt that contains the sperm.

ASLC 4 ***Atlantic salmon life cycle***

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 strategist of the fish world*

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 generally live in a stable environment, are late maturing, and reproduce multiple times during their life. They allocate a lot of energy to reproduction and invest a lot of time in ensuring the survival of the low numbers of offspring produced. This type of strategy is normally employed by larger organisms with longevity. Humans are the ultimate K strategists!

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

Organisms that are R strategists will produce large numbers of offspring with 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 as are many fish species.

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 have a single reproductive period annually.

Which 'non-salmonid' species exemplify R and K strategists?

R strategy

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

- 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:

- 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

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

Which breeding strategy do the salmonidae (salmon family) follow?

It could be argued that all salmonids, including Atlantic salmon 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.

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.

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

Atlantic salmon life cycle

Fish eggs and fecundity

There are a range of different spawning methods adopted by fish in both freshwater and the marine environment. This includes 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).

Atlantic salmon can produce 1,600 of freshly stripped eggs/Kg

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).

The strategy of each fish species in the table below illustrates the R and K norms and one 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 like birds ‘quantitatively’.

How much do fish eggs vary in size?

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.

A 'murmaids purse' with developing baby shark

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

The broad cast spawners tend to produce much larger numbers of small eggs, whereas the nest builder produces 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. In all cases mortality tends to be high in both eggs and young fish.

How often do fish 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.

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

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 hatchery practice, 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 low fecundity compared to the marine species (Atlantic Cod, Halibut and Sea Bass)

ASLC 6 ***Atlantic salmon life cycle***

Salmon spawning and egg fertilisation

Atlantic salmon deploy a 'K reproductive strategy', as they produce fewer eggs than many fish species and ensure they are protected during incubation. Some fish species have a higher fecundity than salmonids but provide no form of protection at any stage after spawning, effectively following the R reproductive strategy.

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

Salmon spawn in freshwater during the autumn/winter by burying their eggs in a gravel nest to protect them from predators and the environment. 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.

What conditions are needed for salmon redd construction?

The site selected for the redd must be free of sediment so the eggs cannot get smothered. The gravel must be the correct size to enable the fish to move and engineer it, but not too fine so as it can get impacted, impeding water flow. A reliable strong water flow is most essential for oxygenating eggs and alevins.

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

The redd must be well sited in a stable riverbed and 6-18 inches deep to protect incubating eggs and alevins from high water flows in flood and spate conditions.

How do the salmon spawn?

Once the female has excavated the redd it will move alongside an attendant mature male fish and prepare to lay its eggs. As the eggs are discharged by the females 'abdominal spasms', the male immediately releases milt (sperm) to fertilise them, soon after they leave the genital papillae. The female will then move upstream and with strong movements of her tail, displace gravel to cover and protect the eggs for incubation.

Key characteristics of salmon spawning and egg fertilisation

- Borderline K strategist, producing moderate quantities of eggs but protecting them within a gravel spawning redd.
- Spawn in the winter in gravel redds created by the female with tail movements (down draught).
- Spawning redds allow a water throughflow so as incubating eggs and alevins are well oxygenated.
- Eggs are fertilised by male sperm entering via the micropyle, which closes as water is absorbed and the egg hydrates and 'water hardens'.
- When first fertilised the 'green eggs' and are delicate and can be damaged by movement or light exposure.

Wild salmon eggs are fertilised in the water during spawning when contact is made between the ova released by the female and the milt (sperm) released by the male. For fertilisation to occur a sperm must enter the micropyle of the ova.

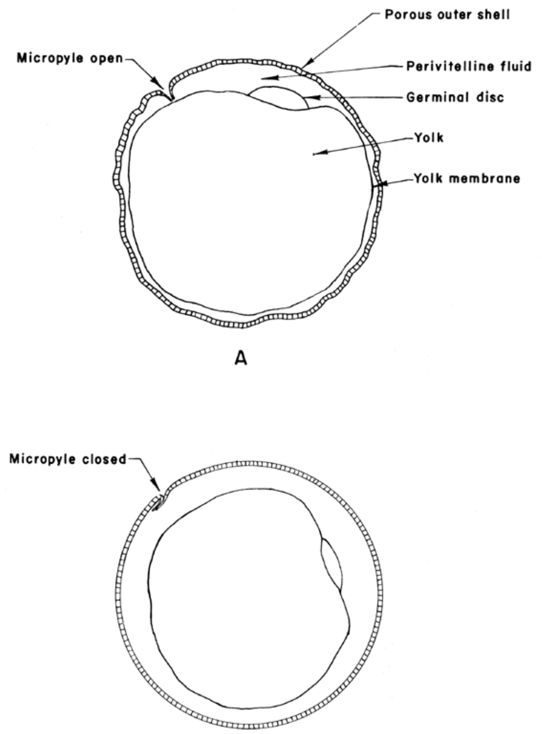


FIGURE 4. A, newly-taken trout egg, outer shell is not firm, egg feels soft and slightly adhesive; B, water-hardened trout egg, outer shell is drawn tight, micropyle is now closed, egg is firm and slick.

Salmon egg before and after water hardening

Egg shell: The outer shell of the egg which is porous

Perivitelline fluid: Forms within salmon eggs within 2 hours of fertilisation. It contains filamentous elaborations and provides several protective and regulative functions, including nutritive and preventing polyspermy.

Micropyle: An opening in the eggshell which allows the sperm to enter and fertilisation to take place. When water is added to the ova it hydrates and 'water hardens' eventually closing the micropyle. For successful fertilisation, the sperm must enter the egg before this happens.

Chorion (yolk membrane): Extracellular coat surrounding the fish egg and potential pathogen barrier.

Yolk: A complete nutrient source for the alevin once it hatches, which is contained within its yolk sac

Germinal disc: The germinal disc is a blastodisk when unfertilized, or blastoderm when fertilized. In fish eggs, cleavage occurs only in the blastodisc, a thin region of yolk-free cytoplasm at the animal cap of the egg

Articulate creative: Produce an interactive of two eggs (see above example) with drop down descriptions of each component. Show a sperm approaching the micropyle (A) and drop-down description when hovering... Show second image (B) of water hardened egg with micropyle closed. Graphics above can be used for reference only as PS have no IPR

Once immersed, water enters the ova via the micropyle and closes it off as it changes from its initial soft jelly like state and water hardens. The life span of the sperm starts to reduce once the milt is in contact with water.

The micropyle is located near the germinal disc in a newly ejected egg to ease the process of fertilisation. This bears no relation to the position of the germinal disc once the egg is water hardened. If an egg is turned until the germinal disc is at the side, the yolk soon rotates and carries the disc back to the top of the egg, irrespective of where the micropyle was positioned.

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

What happens to the eggs after fertilisation and water hardening?

The eggs when first fertilised, they are known as 'green' eggs, and are delicate and susceptible to mortality caused by movement or exposure to strong light. This can be problematic if the aquatic environment is unpredictable and prone to destabilising floods. 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. The eggs will remain in the redd overwinter until they hatch in the spring.

Relevance to salmon husbandry

The usual method of hatchery stripping, the ‘dry method’, does not precisely reflect natural spawning and fertilisation as the sexual products are not allowed to contact water.

This increases fertilisation rates. The ova are stripped from the female fish and are kept separate from sperm, water or other fluids, keeping the micropyle open.

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 brood-stock 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.

Atlantic salmon life cycle

Incubation of eggs and alevins

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 temperature dependant. In known water temperatures it can be predicted by calculating the 'Degree Days' of exposure.

For Atlantic Salmon it takes 220-250 Degree Days from fertilisation to the eyed egg stage and 440 Degree Days (in total) to hatch.

There is an upper lethal temperature of > 12 oC that salmon hatchery managers need to be aware of as increased mortality will occur if exceeded.

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

How can the Degree Day exposure be calculated?

Taking fertilisation to eyed egg as an example:

Time (days) x water temperature = Degree days

At a water temperature of 100C

- 22 days x 100C = 220-degree days
- At a water temperature of 50C50 days x 50C = 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 whether through a redd in the wild or hatching trays in a hatchery.

In many salmon nursery streams, 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.

Key characteristics of the incubation of eggs and alevins

- Egg development is determined by Degree Days (Time days X water temperature oC). It takes an egg 220-250 Degree Days to become eyed and 440 Degree Days to hatch.
- Green eggs are delicate whereas eyed eggs are robust and can be handled and the oxygen requirement of the egg increases as it develops.
- Eggs hatch by choriolytic enzymes released from the embryo's hatching glands softening the egg capsule.
- Alevins remain passive in the dark gravel matrix, consuming nutrients in their yolk sac
- When the yolk sac is fully absorbed, alevins gulp air to inflate their swim-bladder and are ready to feed as 'swim up fry'

Why is this stage called eyed egg?

When Atlantic salmon eggs are deposited in the redd they develop from 'green eggs' which are delicate, to become 'eyed-eggs' which are more robust and can be safely moved and handled.

As the name suggests the 'eyed' stage is apparent when two small black eyes are visible in the egg. 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.

How do salmon eggs hatch?

Egg hatch is initiated by the release of choriolytic enzymes from the hatching glands of the embryo into the Perivitelline fluid. The enzymes soften the zona radiata to allow the mechanical disruption of the egg capsule by the emerging alevin. Acidity resulting from acid rain and snow melts can disrupt hatching at pH 4. This impact can be compounded by metals released in these conditions, damaging young fish gills.

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

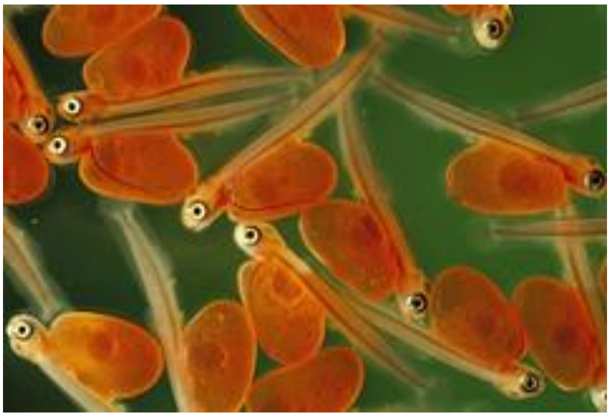
What happens after the eggs hatch?

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, the heart pumping and blood vessels are clearly visible.

They remain in the redd until they have absorbed their yolk sac. They must remain undisturbed in complete darkness and in close contact with gravel surfaces for security. During this stage, they are totally dependent on the yolk sac reserves 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 genetically pre-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 the yolk sac is nearly fully absorbed approximately 12 weeks after hatching, depending on water temperatures, and the alevin starts to show a behavioural change. They move from the riverbed gravel redd, or in a hatchery situation the base of the hatching baskets and rise to the water surface to gulp air and inflate their swim bladder, gaining neutral buoyancy. This makes it easier to swim and hold their position in fast flowing streams and once their yolk reserves are completely depleted, they are ready to capture and ingest prey.



These healthy Atlantic Salmon alevins have large yolk reserves to sustain them

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'.

..the science says

See incubation of salmon eggs and rearing of alevins: Natural temperature fluctuations and their influence on hatchery requirements - Autor M.G.Poxton

https://www.sciencedirect.com/science/article/abs/pii/0144860991900099

Relevance to salmon husbandry

On hatching the alevins are very delicate and must not be exposed to whilte light or subjected to changes in water quality. Red head lights are used to allow husbandry staff to work on the trays without stressing the stock.

By keeping them undisturbed in clean water under optimal flow rates, the nutrients and energy in the yolk sac are directed into growth of strong first feeding fry. When the majority have absorbed their yolk sac they are transferred to the first feeding tanks. Many hatcheries introduce substrate to allow those that have not completed absorption some habitat where they can quietly rest away from those that are ready to feed.

Atlantic salmon life cycle

Juvenile salmon (fry to parr)

Once they become mobile, the recently hatched salmon fry will start to move away from the area of their redd to find new territories with the correct flow rate to suit their swimming ability. The nature of the nursery stream substrate correlates with prevailing flow rates as high flows 'scour' stream beds expose the bed rock or leave a coarse 'cobble' substrate. Pebbly riffles with no boulders and substrate particle sizes of 16-64 mm are considered the ideal range for juvenile salmon under 7 cm and the young fish establish feeding stations where they can 'hold position'.

Key characteristics of salmon fry and parr

- Salmon fry establish feeding stations (territories) with the right flow rate and substrate according to their size.
- Salmon parr can occupy swifter flowing riffles than Brown trout, due to their streamlined shape and pectoral fins.
- Salmon feed on benthic invertebrates that live in the riffle, such as the nymphs and larvae of stonefly, mayfly and caddis.
- Salmon parr and Brown trout can be identified, based on their distinctive physical features and colouration.

Do juvenile Atlantic salmon compete with brown trout?

The salmon commonly share their nursery stream with their cousins, the Brown trout (Salmon trutta) as they have a similar general habitat and feed requirement. However, as the salmon grow they become are more streamlined and are assisted by large pectoral fins which they angle to help compress them to the substrate, and they occupy feeding stations in swift flowing 'riffles', that trout would struggle to occupy and defend. They prefer the deeper and swifter parts of the riffle by the time they reach 8-9 cm, with substrate particle size of >64 mm.

Most nursery streams and rivers are broken up into what is known as a riffle and pool structure. The riffles are faster flowing shallow areas found at the head and tail of a pool. The water flow reduces as it deepens on entering the pool and the aquatic benthic invertebrate community changes.

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

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 epiphytic (surface living) algae in the riffles, that many of the 'grazing' invertebrates thrive on.

In addition to a more diverse food supply, the riffles 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 separate and coexist, without either wasting energy competing for the same niche. The ideal Atlantic salmon habitat is swift flowing, with a stony substrate, providing a multitude of feeding stations and 'visual privacy' from their brethren, reducing territorial aggression. The Brown trout tend to fall back into the slower flowing sections, away from the salmon

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 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 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 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 the salmon transform morphologically and physiologically into smolts before migrating to the sea.

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

What do Atlantic salmon look like at the parr stage?

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

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

- 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?

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

- 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

How do juvenile Atlantic salmon and Brown trout differ?

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.

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.

Articulate creative: *Using owned digital images (1 salmon parr and one trout above and below) a comparative double image can be designed to illustrate the features that differentiate the two species during the freshwater phase.*

...the science says

Table1. Natural food fluctuations (% of total food intake) of different size classes of Atlantic salmon, *Salmo salar*

Type of food	Life stage/size class				
	Fry	Fingerling	Juvenile	Grower	Broodstock
Invertebrates	100	100	85	25	25
Fish			15	75	75

Source: Scott & Crossman (1973

Relevance to salmon husbandry

The juvenile salmon in the wild feed in the water column and look up for their food. They select bigger invertebrates as they grow, and their mouth gape increases to improve the energy efficiency of feeding. In a hatchery as the fish grow the fish farmer increases the pellet size as soon as possible to improve energy efficiency. Also, if there are too many small feed particles for the fish stock to capture before they sink to the bottom, the risk of feed waste increases.

The salmon are naturally territorial, and as they have no habitat to sperate them from each other, this can lead to aggression in the hatchery. If there is insufficient food the fish will bite each other's fins and gill covers, leading to serious physical damage if unchecked.

By feeding them to satiation and providing a constant supply of feed at very regular intervals, aggression in the hatchery can be reduced and the stock remain healthy and grow more quickly.

ASLC 9 **Atlantic salmon life cycle**

Smolt

Atlantic salmon are anadromous, which means they live in both freshwater and sea water at different stages of their lifecycle. Therefore, they face 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.

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, depending on the stream's natural productivity and fish stock densities, the parr transforms in to a smolt (between 30-60 Grams).

The 'smolification' process is triggered by changing photoperiod (increasing day length in the spring) and prepares the young salmon for their downstream journey. During this period smolts change their 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 parr to a smolt enables the fish to regulate their internal salt concentrations through a physiological process called 'osmoregulation'. Entering water of a higher salinity causes dehydration due to the loss of water by osmosis to the external environment (dehydration). In response the fish needs to drink water to rehydrate.

During smoltification, chloride cells develop in the gills providing the capacity to secrete excess salts that result from drinking sea water, thereby maintaining the correct balance of body salts internally.

Key characteristics

- Salmon parr can smoltify in preparation for migration after one- or two-years freshwater feeding.
- Smoltification is triggered by increasing day length (photoperiod).
- Smoltification changes the fish's appearance, becoming more streamlined and silver and they develop chloride secreting cells to aid osmoregulation
- Smolts migrate to sea in the spring and spend time in the '**brackish'** estuary waters to acclimatise before entering the ocean

When do the smolts migrate to the sea?

Typically, this is a spring event (March -May), but the precise timing can be dependent on water levels. If the downstream migration coincides with a drought and low water levels, it is possible for the fish to get held up or concentrated in deeper pools. Here they can become more prone to predation from piscivorous birds such as the Goosander which often predate the Scottish smolt run during dry springs.

Do the smolts head straight out to see as soon as they reach the coast?

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. Spending some time in the brackish estuarine waters helps the fish to fully complete smoltification, enabling them to osmoregulate effectively in full strength sea water (35ppt) when they eventually enter the open ocean and head for the north Atlantic feeding grounds.

Relevance to salmon husbandry

In most commercial salmon hatcheries light regimes are imposed over a 10–12-week period to manipulate photoperiod. By imposing a winter short day period for 5-6 weeks, followed by a summer long day period when the fish have reached a suitable size for transfer to grow out, the natural smoltification process can be controlled.

The development of smoltification is monitored in several ways:

- Observing changes in fin and body shape and colouration, including the tail fins which develop a black edge.
- Observing changes in behaviour, such as downstream swimming.
- Monitoring physiological changes such as ATPase levels which are indicative of advanced smoltification

This avoids fish being transferred to sea water that are not able to fully osmoregulate and may not survive transfer.

Ask for learning resources

Salmon anatomy and physiology

These learning resources have been designed to support 'short episodes' of focussed learning' on specific topics within the Fish Biology and Behaviour Unit (EQF Level 4). Each episode has a title and number that relates to multiple-choice question banks designed to support the Recognition of Prior Learning (RPL) or formative assessment.

The learner will be prepared for following Learning Outcomes with the Fish Biology and Behaviour Unit

1. Describe the external and internal anatomy of specific fish species and the visual signs of poor health.
2. Explain the functions and physiological role of the major organs of specific fish species

The resources focus on the Atlantic salmon and cover the identification of healthy external and internal features and their structure and function. The aim is to provide learners with enough information, insight and understanding of the basics of fish anatomy, so as they can identify the external and internal anatomical structures and know their basic function.

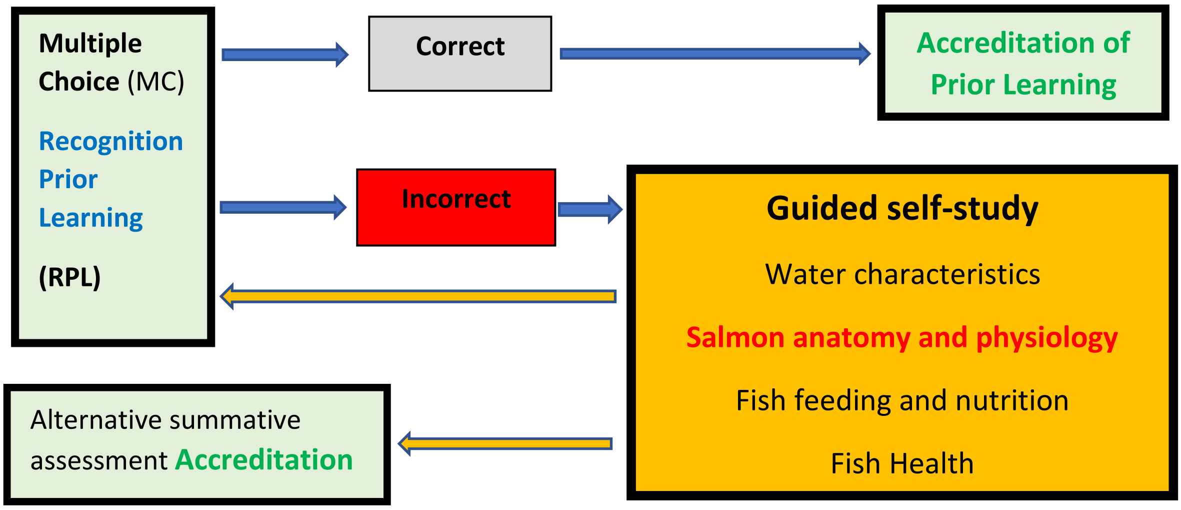
The resources can be used to support the following RPL led process for the development of underpinning knowledge:

Step 1- Undertake multiple choice questions for the section

Step 2 Automated RPL analysis determines which questions have not been answered correctly in full. This can be linked to an accreditation process through consultation with the national VET Awarding body

Step 3 Self-study, guided by the RPL results and feedback (See next page for details)

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



Graphic to illustrate recommended RPL/APL pedagogy

Self-study (navigating Ask for learning materials and external resources)

The learning experience is designed to be interactive and gives the learner control of their learning, starting with the 'Recognition of Prior Learning' (RPL)

Icons within the learning system can be used to flag components and activities to the learner...

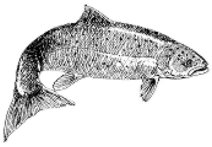
Blue font signifies **mandatory**

Activity	Purpose	Icon
What do you know already? RPL/APL	Mandatory assessment of the learner's current knowledge. Can lead to accreditation for some Units (APL)	Finger raised to a thinking face
Main content	Text and image, providing context and more topic details	No icon needed
Key characteristics	Summary points expanded on in the main content (Mandatory knowledge to be assessed)	A key
Relevance to salmon husbandry	Short insert to make the topic relevant to the fish farming, with hyperlinks to web links.	Stylised graphic (salmon in a net)
Watch this....	Selected Youtube or home-produced instructional video	Film reel graphic
....now have a go	Learning activity- may be a calculation or other activity, or formative assessment following a learning episode.	Graphic of tutor pointing to learners
...**the scientists say**	Interesting insights and debates from the scientific community	Mad professor talking head

Navigation to information within the PSA and the web

Colour code	Hyperlink
Green font	Links to a section of material in another episode in the same Unit or another Unit within the PSA, making related information more readily available. Navigation back must be easy to keep learners 'on-task'
Blue font	Links to an interim summary definition box and then for a full expansion and data set but ensuring easy navigation back to the main study material.

SAP 1 Salmon anatomy and physiology



Skin and scales

The salmon's skin and scales form an important protective physical barrier between the fish and its external aquatic environment. Despite being thin, salmon skin is resilient and surprisingly strong. Salmon leather developed in Scandinavia as a by-product from the salmon farming industry is in strong demand. The skin also contains **chromatophores** that control the salmon's colouration, which changes dramatically during its lifecycle. When transforming from parr to smolt the scales become far more reflective to suit an oceanic lifestyle, and change again as an adult during sexual maturation, darkening considerably.

The small-interlocked scales of salmonids form a tight physical barrier

What is the salmon's skin composed of?

The skin of a salmon is typical of most modern teleost (bony fish) species. It is composed of scales which provide a strong but flexible, protective outer layer, covered by an epidermis containing mucus glands. The scales are rooted in the deeper lying dermis. A subcutaneous layer lies between the dermis and underlying muscle blocks.

What is the function of fish skin?

Fish skin is multifunctional. It is well supplied with blood vessels and nerve endings and receives tactile, thermal, and pain stimuli. It also contains specialised sensory receptors in the **lateral line.** Some (non-salmonid) fish species, such as **Rock skippers**, breathe partly through the skin, by the exchange of oxygen and carbon dioxide between the surrounding water and numerous small blood vessels near the skin's surface. However, salmon do not share this capability and fully rely on their **gills** for breathing.

All modern teleost fish, including salmon are covered in scales, small rigid plates that grow out of the skin that can provide effective camouflage using reflection and colouration, as well as hydrodynamic advantages when swimming.

Key characteristics of salmon skin are:

- provides a strong physical protective barrier to the body, composed of dermis and epidermis, scales and mucus,
- forms a first line of defence against pathogens, aided by the mucus produced in the epidermis,
- determines the fish coloration due to chromatophores in the dermis and epidermis,
- becomes more 'reflective' during smolting to help camouflage from predation at sea, and
- helps to maintain the fish's osmotic balance.

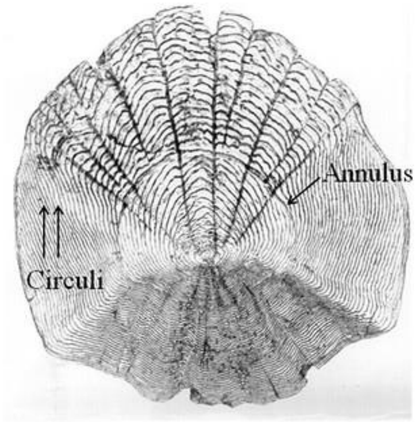
2.1 Structure of the salmon skin

Articulate creative: Link the definitions below to an interactive diagram of fish skin cross section so as they drop down when hovering on the name of each component. The diagram can be derived from those from the web (No IPR)

The **Dermis** of the skin is a deeper layer made up of connective **fibroblasts**, **collagen** and blood vessels, with scales lying in pockets and emerging from the connective tissue.

The **Epidermis** covers the scales of a fish with an epithelial layer of cells and contains the mucus glands and goblet cells producing the protective mucus.

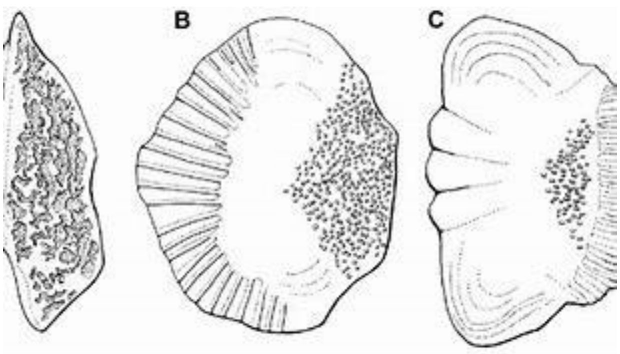
Mucous glands are extremely numerous in salmon skin offering protection from pathogens such as bacteria and helping to maintain osmotic balance. The mucus produced by 'goblet cells contains substances called **mucins** which rapidly form a gel on leaving the goblet cells and contacting water, to become viscous and elastic. It contains enzymes, antibodies, and salts and sloughs off periodically, removing any pathogenic bacteria that has attached to the fish's external surfaces.



Scale reading (Add own image)

Scales are thin, translucent, and often derived from bone in the deeper dermal layer. For most bony fish come in one of three designs with the cycloid or ctenoid by far the most common. The latter distinguished by serrations at the edges but lack the **enameloid** and **dentine** layers that typify the less common Ganoid scale type.

Salmon (along with the carp family) have cycloid scales and Circuli are laid down as the fish grows. Periods of slower growth in the winter clearly show on the scale as Annulus. The distance between each, increases with growth rate, making it possible to read a wild salmon's age and to determine how many years it spent in freshwater before **smolting** and heading out to marine feeding grounds, where its growth accelerates.



A. Ganoid B. Cycloid (Salmon) C. Ctenoid

Articulate creative: Produce diagram of the three scale types. Drop down the following descriptions as each scale is 'hovered'.

- cycloid as is the case for salmon (and carp) with a smooth outer edge,
- ctenoid scales which have small teeth (such as the perch) and
- ganoid scales which are covered in enamel like dentine and often have a serrated edge (such as sturgeons and garfish)

2.2 Skin colouration

Chromatophores (pigment cells) colour the dermal and epidermal layers. The world's diverse fish species exhibit an almost limitless range of colours that can be controlled to varying degrees, allowing then to blend closely with their surroundings and stay hidden from predators. Salmon change colour markedly during their lifecycle to suit each aquatic environment.

How do chromatophores work?

Melanophores (black pigment cells) occur universally in fishes and are often juxtaposed with other pigment cells called 'erythrophores' (yellow, orange, and red pigment cells) and 'iridocytes', bearing the silvery or white pigment guanine. Pigment cell combinations are limitless and provide an endless range of colour variations seen in fishes globally.

Salmon, along with many other bony fish can change their colour to some degree, by movement of pigment within the chromatophores. The release and retraction of pigment can improve camouflage and help the blend into its environment. This colour change process is controlled by the **endocrine system**. Melanotropin (melanocyte-stimulating hormone, or MSH) secreted by the pituitary regulates the star-shaped cells (melanophores) that contain large amounts of the dark pigment (melanin). When the salmon smoltifies in preparation for its seaward journey its fins darken due to melanin release and its flanks become silver in appearance due to the retraction of melanin and an increase in iridocytes. With a much more reflective, silvery

Relevance to salmon husbandry...

Farmers understand skin integrity is a central factor and indicator for animal health and welfare within intensive salmon production systems

The salmon's skin is its first line of defence against infectious disease and all measures are taken to avoid physical damage, scale loss and mucus removal due to contact with abrasive surfaces.

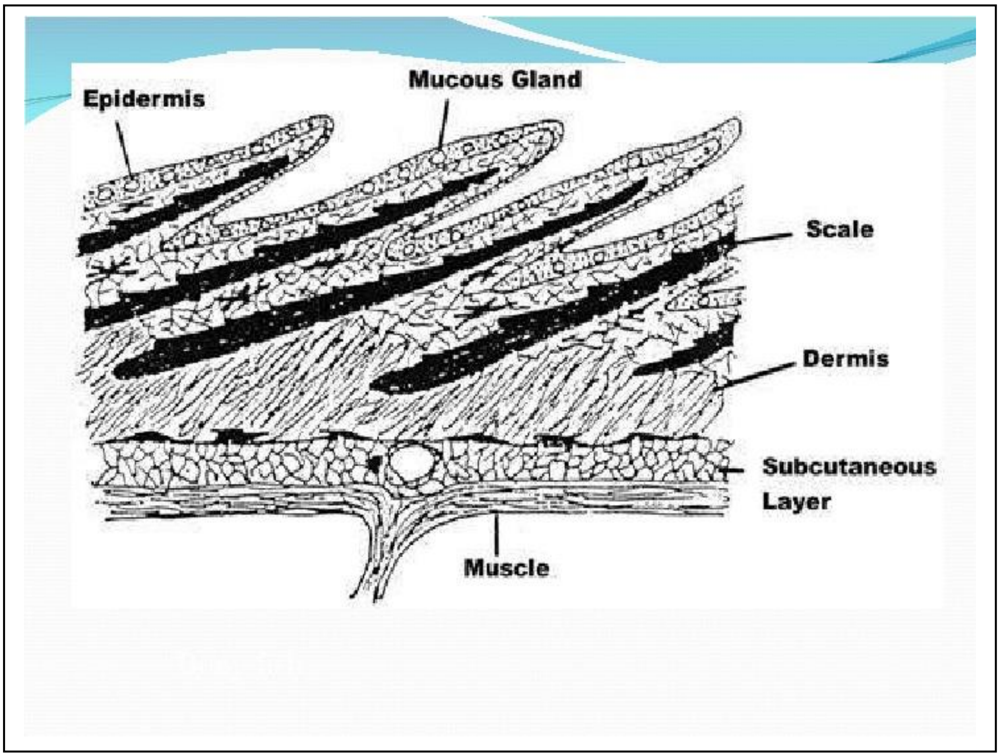
The stress of capturing, counting, grading and moving fish is reduced by reducing crowding, restricting the quantity of fish hand-netted and through the use of fish pumps and counting systems that eliminate the netting and handling of fish altogether.

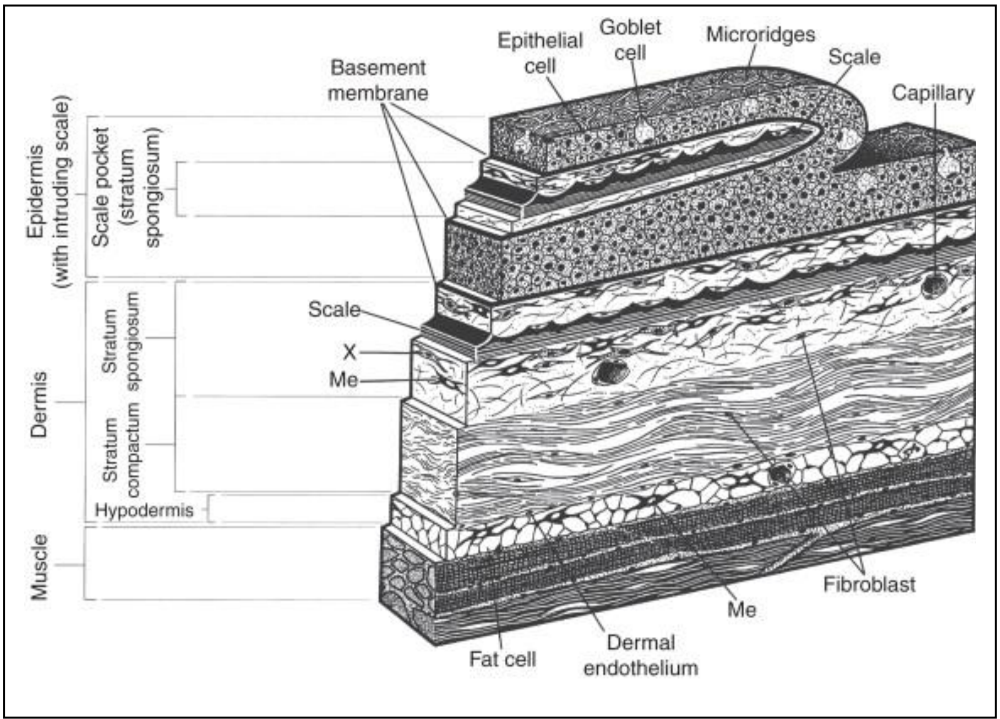
Skin colour can change due to long-lasting crowding events, acting as a qualitative stress indicator.

..**the scientists say**

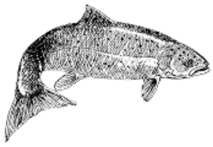
Scientists investigated skin development and its immune status in healthy Norwegian Atlantic salmon reared in two different systems, a traditional open net-pen system, and a semi-closed containment system. Freshwater smolts were compared to post-smolts after 1 and 4 months in seawater. Growth performance, when adjusted for temperature, was equal between the systems. Skin analyses, including epidermis and dermis, showed that mucus cell numbers and thickness increased in pace with the growth and time post seawater transfer. Gene expression changes suggested similar processes with development of connective tissue, formation of extracellular matrix and augmented **cutaneous secretion**, changes in mucus protein composition and overall increased immune activity related to gradually enforced protection against pathogens. Results suggest a gradual morphological development in skin with a delayed recovery of immune functions Post Smolt Transfer. It is possible that Atlantic salmon could experience increased susceptibility to infectious agents and risk of diseases during the first post-smolt period. The paper is available here: https://www.nature.com/articles/s41598-018-27818-y Article on scales, at https://en.wikipedia.org/wiki/Fish_scale surface due to the reflectiveness created by guanine and hypoxanthine crystal, consistent with most pelagic ocean living fish species, it is less visible to predators, when viewed from the side.

Articulate creative: Create an interactive diagram of the skin, so as the function of each component (described above) drops down with a text description when hovering over the component's name. Refer to diagrams below from the web (No IPR)





SAP 2 **Salmon anatomy and physiology**



Fins

Fish fins vary in their size, shape, structure, and location on the body, according to their function. Some of the fins are paired and most are supported by fin rays (bony structures), but each fin type will perform the same function. Some fins have a single, unique function, others perform a shared function, and one appears to have no function at all!

All the Atlantic Salmon's fins can be controlled, moved, and folded, apart from the adipose fin, which is functionless, and unique to the salmon family (Salmonidae). A fin will often function simultaneously with other fins, enabling the fish to move, control its direction, or maintain its position in the water column.

3.1 Fin function

Dorsal fin

Dorsal fins - the number and location of dorsal fins varies between different fish species, but its function remains the same. The Atlantic salmon's dorsal fin has fin rays and is located on the back of the fish. Its main function is to prevent rolling and yawning and help the fish to maintain an upright position when swimming.

Pectoral fins – the pectoral fins have fin rays which are paired and are located close to the head in all fish species, including the salmon. They have a wide range of movements, like the pelvic fins, including turning right and left, braking and can raise and lower the fish in the water column.

Anal fin

Pelvic fins – the pelvic fins have fin rays which are paired and not always located in the same area of the body in all fish species. For example, in salmonids they are in the abdominal area, whereas in freshwater perch, for example, they are located closer to the head near the pectoral fins. They have a wide range of movements, like the pectoral fins, including turning right and left, braking, and raising and lowering the fish in the water column.

Anal fins – the anal fin has fin rays and is located immediately behind the vent in all fish. Like most fish the salmon has one anal fin, but some marine species such as Atlantic cod will have up to three anal fins. The main function of the anal fin is like that of the dorsal fin, to prevent rolling and yawing and help the fish to maintain an upright position when swimming.

Key characteristics of salmon fins are:

- Most fins have a function, whether specific or shared with other fins.
- The adipose fin is functionless and unique to the salmon family (salmonids).
- All except the adipose have integral fin rays (bones), that are moved and flexed, enabling fins to perform their function.
- Paired fins (pectoral and pelvic) help to break, turn, and position the fish in the water column.
- Single fins (dorsal and anal) are used to help prevent 'yawing and rolling' and keep the fish upright.
- The caudal fin is essential for locomotion (forward movement), by converting 'muscular energy' into propulsion

Caudal fin (tail)

Caudal (tail) fin – the caudal fin has fin rays and is located at the rear end of all fish species and is attached to the caudal peduncle. This is a single fin with a main function of providing propulsion for forward motion.

Adipose fin – the adipose fin is a small fatty fin with no fin rays, found only in salmonid species e.g. salmon and trout. It appears to have no real function.

Note about caudal fin above

This is a fin in poor condition, indicative of some intensively farmed salmonids. It may need to be replaced with an image of a caudal fin in better condition.

Articulate creative

Add diagram or central fish feature and provide the narrative on 'function' as a drop down when each feature is pointed at. (See External Features interactive fish on Power point and story board for example of how to do this)

3.2 Fin condition

Fin damage is an acknowledged welfare threat as living tissue (epithelium) is compromised. All types of fin damage can lead to haemorrhaging within or from the tissue of the fin. The fins also possess nociceptors (pain receptors) and active fin damage can be a route for pathogenic infection. It has been classified in different ways; erosion, splitting and thickening including malformed fins.

What determines farmed salmon's fin condition?

Images of fin condition linked to scoring system

Articulate creative: Create a carousel of images with a drop-down comment and fin health score to reflect the scoring system and its application

The fin condition of farmed salmonids is dependent on many factors, including the stocking density, type of holding facility (surface material), feeding regime and water quality. The effects of fin damage can also differ according to the life stage of the salmon. For example, in parr, the loss of pectoral fins can reduce their station-holding capacity and in smolts and post smolts, active fin damage can subject the fish to osmotic duress.

Fin condition can be scored, to introduce objectivity to the use of fins as health and welfare indicators.

...**the scientists say**

Fin condition, amongst a host of other anatomical and physiological factors, provides a strong indication of the health status of farmed salmonids.

This is fully covered in 'Welfare Indicators for farmed Atlantic salmon: tools for assessing fish welfare'

https://nofima.no/wp-content/uploads/2018/11/FISHWELL-Welfare-indicators-for-farmed-Atlantic-salmon-November-2018.pdf

A poster of morphological fish welfare indicators are available as a result of the work above on the development of Welfare indicators

https://nofima.no/wp-content/uploads/2018/11/FISHWELL-OWI-poster-v1.1.pdf

Relevance to salmon husbandry:

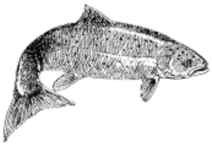
Wild Atlantic salmon normally have undamaged fins with clean edges during both the freshwater and marine feeding phase. This is a sign of good health.

In a fish farm, bacteria can more readily attack and erode fins so as they become 'ragged' in appearance. Severe fin erosion, often called 'fin rot', is a sign of disease caused by **gram-negative bacteria** such as Vibrio, Pseudomonas and Aeromonas. It can be transmitted to other fish through physical contact, so is made worse by crowding.

The farmer must monitor fin condition and respond to fin erosion by reducing stock densities and/or improving water quality. In some cases, disease treatments will be required.

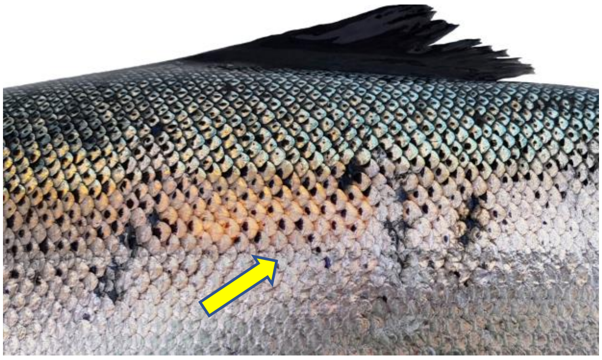
Fish Health and Welfare

SAP 3 **Salmon anatomy and physiology**



Lateral line

The lateral line is sometimes referred to as a fishes sixth sense. Whilst not a prominent external feature, the lateral line is visible to the naked eye and appears as a line of pores in the scales and runs the full length of the fish from behind the operculum (gill cover) to the caudal peduncle (wrist of the tail).



Atlantic salmon lateral line

Structurally, the lateral line is a hollow fluid-filled tube with pressure sensitive canals used to detect vibrations and small changes in water pressure. It has several important functions. First and foremost, it can allow the fish to detect dangers that may not be immediately visible and helps the fish to swim and maintain its position in the water, even if blind.

Does the lateral line have any other functions?

Lateral lines also serve an important role in the schooling behaviour of some species, as well as body orientation and the avoidance of predators, as individual fish can twist and turn synchronously as a shoal when under threat.

Key characteristics of the Atlantic salmon's lateral line

- Visible to the naked eye as a series of pores
- Each pore leads to a hollow fluid filled tube with pressure sensitive canals open to the aquatic environment
- Helps body orientation, the avoidance of predators and prey detection

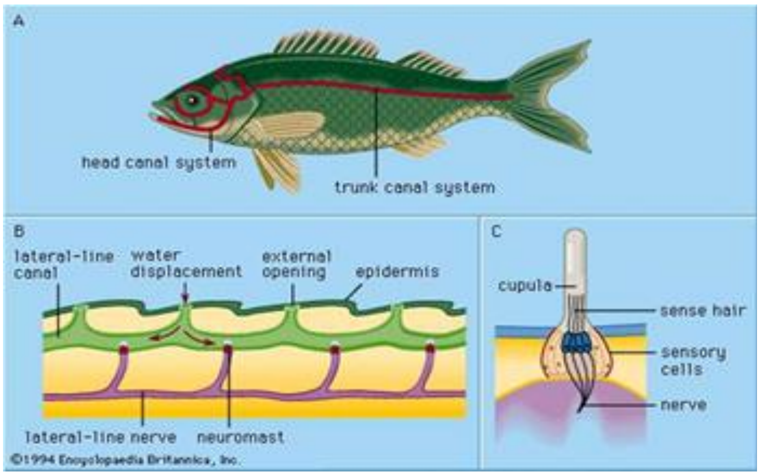
As a predatory species, the salmon will use their lateral lines to detect water displaced by fleeing prey, helping them to target their attack.

In some non -salmon species, the receptive organs of the lateral line have been modified to function as 'electroreceptors', which are organs used to detect electrical impulses.

Relevance to salmon husbandry

Due to their sensitive lateral line, farmed salmon can become stressed if there is excessive noise and vibration near to the holding units.

Farmed salmonids may not be so fit for survival as compared to their wild counterparts. This is of little to no importance for fish being reared for the table but is a concern for those rearing salmonids for wild fishery stock enhancement purposes. **See what the scientists say**



Lateral line nervous system

How does the lateral line function?

Water displacement is sensed by the ‘sense hair’ which is connected to **neuromasts** in the lateral line nerve

Articulate creative: Produce simple diagram with arrows interactive on hovering to show water displacement leading to detection by sense hair. Make sense ‘hair light up’ Note PSA has no IPR on this diagram

...the scientists say

Results of salmonid research to date suggest that hatchery rearing significantly impairs the motor and sensory systems of fish. Scientists at the University of Washington wanted to know whether hatchery and wild-reared juvenile steelhead developed **morphological** defects in lateral line structure, **otolith** composition, and brain weight.

They found wild juveniles possessed:

- significantly more superficial lateral line neuromasts than hatchery-reared juveniles.
- normal, **aragonite**-containing otoliths

Note for drop down: Aragonite is a carbonate mineral, one of the three most common naturally occurring crystal forms of calcium carbonate, CaCO3 (the other forms being the minerals calcite and vaterite). It is formed by biological and physical processes, including precipitation from the ocean and freshwater environments.

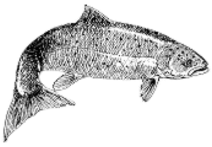
Whereas hatchery-reared juveniles possessed a high proportion of crystallized (vaterite) otoliths which is a condition that has been associated with reduced auditory sensitivity (i.e. poorer hearing) in hatchery-reared Chinook salmon in the past.

Lastly, and consistent with the findings of other studies to date, wild juvenile steelhead had significantly larger brains than fish reared in a hatchery.

This suggests hatchery-reared juveniles have reduced sensitivity to biologically important hydrodynamic and acoustic signals from predators and food sources. It may also reduce their ability to sense physical non-biological factors, such as flow and current speed.

The paper is here: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0059162

SAP 4 Salmon anatomy and physiology



Nares and the olfactory organ

In common with most fish, the Atlantic salmon has two nares (nostrils) located at the front of the skull. They are not connected to their respiratory system, but are blind ended sacs lined with sensory nerves which allow the olfactory organ to detect low concentrations of chemicals in the water. For some bottom feeding species such as eels and catfish, their sense of smell is more important than sight for food detection and well developed. Their olfactory organ provides the ability to find food.

Nares

Do the nares serve any other important functions in salmonids?

Although salmonids are primarily visual feeders, their nares and olfactory organ are particularly important. On returning from the north Atlantic feeding grounds and traveling the coastline, they can sense the unique chemical odour of the river they originate from. In the closing stages of the journey, they can usually recognise their own **nursery stream** where they grew in to parr after hatching and emerging from the **spawning redds**.

Key characteristics of the Atlantic salmon's nares

- Nares connect to the olfactory organs to provide a sense of 'smell'
- Water moving in and out of the olfactory pit, allowing the ciliated epithelium to detect low concentrations of chemicals
- Olfactory senses enable the adult salmon to navigate back to its nursery stream.

What do the olfactory organs look like?

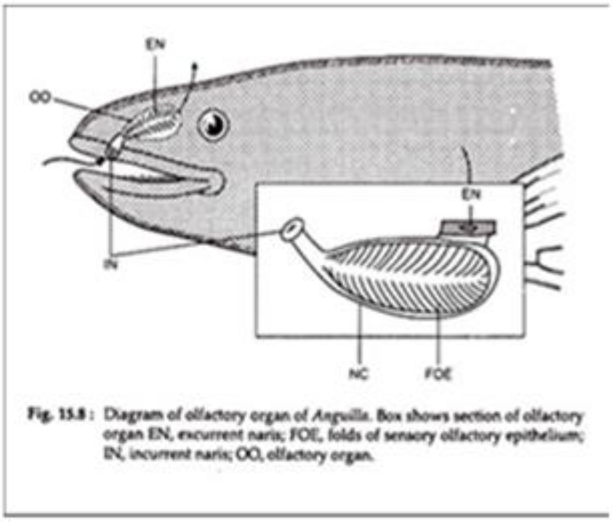
Fish olfactory organs are pouch-like structures that the water can move in and out of. The 'olfactory pit' is lined internally with **ciliated epithelium** projected in multi-folded olfactory rosette of receptor cells. The cilia of the olfactory pit drive the water and odours are perceived when the dissolved chemicals contact the **olfactory rosette**. Olfactory stimuli are conveyed to the olfactory lobe of the brain via the first cranial nerve, the olfactory nerve.

Relevance to salmon husbandry

Salmon have an incredible sense of smell which is mainly used for navigation. They can detect chemicals (such as amino acids) in the water released from fish feed and this contributes towards their perception of feed palatability.

However, the salmon is primarily a visual feeder and intercepts feed whilst it is in the water column and does not rely on this form of feed detection in the way bottom feeding fish such as carp and catfish do.

Articulate creative: Produce interactive diagram of fish to show olfactory organ with epithelium. Show two direction water flow with arrows that appear with a drop down note on hovering to emphasis the two directions of water flow. (No IPR on image of eel below)



The ciliated epithelium in the olfactory pit detects chemicals

...the scientists say

Recent scientific studies (2018) in America at the University of Washington have shown that exposure to pollutants can interfere with the salmon's sense of smell.

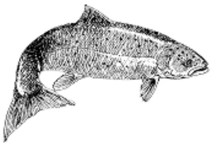
The research team wanted to test whether the 'fear response' of juvenile coho salmon that normally depend on their sense of smell to alert them to predators, changed with increasing carbon dioxide. Puget Sound's waters are expected to absorb more CO2 as atmospheric carbon dioxide increases, contributing to ocean acidification.

The research team set up tanks of saltwater with three different pH levels: today's current average Puget Sound pH, the predicted average 50 years from now, and the predicted average 100 years in the future. They exposed juvenile Coho salmon to these three different pH levels for two weeks.

After two weeks, the team ran a series of behavioural and neural tests to see whether the fishes' sense of smell was affected. Fish were placed in a holding tank and exposed to the smell of salmon skin extract, which indicates a predator attack and usually prompts the fish to hide or swim away. Fish that were in water with current CO2 levels responded normally to the offending odour, but the fish from tanks with higher CO2 levels didn't seem to mind or detect the smell, indicating a much higher vulnerability to predation.

https://www.technologynetworks.com/applied-sciences/news/salmons-critical-sense-of-smell-in-danger-313229

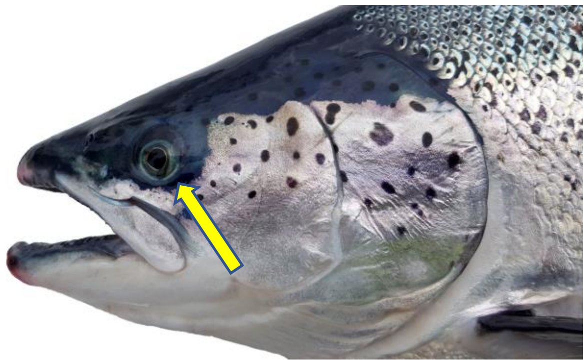
SAP 5 **Salmon anatomy and physiology**



Eyes and photoreception

The eyes of the Atlantic salmon are located on the side of the head which gives each eye an independent and wide angled field of view. Some of the more predatory species have a limited amount of binocular vision due to a slightly more forward placement of the eyes which allows them to work together in judging distance when attacking prey.

The structure of the eye in salmonids is basically the same as a mammalian eye, although the iris is fixed and so has no influence in regulating the amount of light entering the eye. In most mammals the **iris** controls the diameter and size of the pupil and thus the amount of light entering the eye to the retina.



Eyes

How does the salmon focus?

In salmonids focus is maintained by moving the lens close to and further away from the **retina**, whereas in mammals focus is achieved by changing the shape of the lens in the eye.

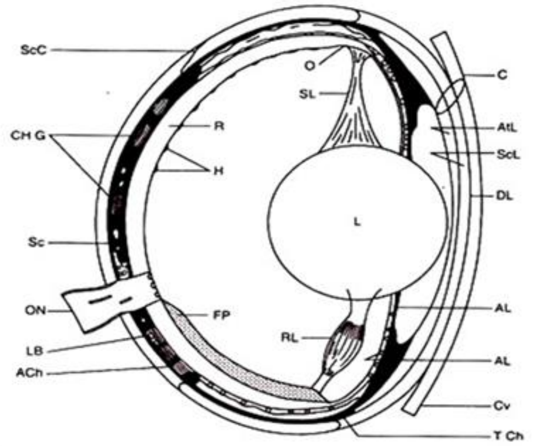
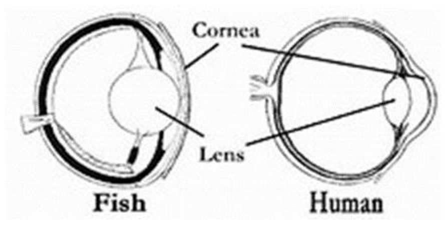


Fig. 15.1 : Diagram of the eye of a teleost fish. ACh, argentea of choroid; AtL, autochthonous layer; AI, argentea of iris; AL, annular ligament; C, cornea; ChG, choroid gland; Cv, conjunctiva; DL, dermal layer, FP, falciform process; H, hyaloid or vitreal vessels; L, lens; LB, lentiform body; O, ora; ON, optic nerve; R, retina; RL, retractor lentis; Sc, sclera; ScC, scleral cartilage; ScL, scleral layer, SL, suspensory ligament; TCh, tensor chorioide.

Articulate creative: Interactive diagram comparing fish-eye function to mammalian eye to illustrate how fish move their lens to focus (Images from web as ref below. No IPR). Show light entering and missing the retina, on hovering with the lens, show it moving back and the light rays focussing (salmon) or being flattened (human)

Images for reference (No IPR)



What is the effect of turbidity on the salmon's ability to detect prey?

Turbidity has both positive and negative effects on prey detection, by increasing or diminishing the contrast between prey and background due to the scattering of light. The positive effect of turbidity on prey contrast depends on the optical scattering properties of suspended particles and the visual sensitivity of the predator. The Atlantic salmon is a visual feeder that can detect and capture prey items in moderately turbid waters when the light conditions are conducive.

Can salmon see colour?

Fish, including the salmon, have the necessary elements of the nervous system to enable colour vision. This relies on detectors called cones in the retina in the back of the eye which transmit signals to the brain for interpretation. We have three different kinds of cones in our eyes, called red, green, and blue that make human color vision possible. Conversely, fish have four kinds of cones that make them sensitive to ultraviolet wavelengths of light as well as the red, green, and blue that we are sensitive to. Ultraviolet vision is sometimes only used during a part of the life cycle. For example, research has shown that juvenile brown trout live in shallow water where they use ultraviolet vision to enhance their ability to detect zooplankton. As they get older, they move to deeper waters where there is little ultraviolet light as it cannot penetrate the water column. The closely related Atlantic salmon share this characteristic.

6.1 Pineal gland

It is possible to manipulate fish development by subjecting them photoperiod regimes designed to speed up or slow down normal physiological development determined by seasonal changes in day light hours, such as sexual maturation and smolting in the Atlantic salmon. As the eye is light sensitive and controls vision, it would be logical to assume that **photoperiodicity** is totally dependent on eye function. However, it is the pineal gland that is in control, a small structure located deep within the human brain, but in fish found directly under the skull. Its primary function is the nightly release of melatonin, a hormone which inhibits melanin formation and is thought to help regulate the reproductive cycle. However, although the human pineal gland detects daylight via the eyes, in teleost fish the pineal gland is a directly photosensory organ that contains photoreceptor cells, similar to those of the retina. It conveys photoperiod information to the brain via neural pathways and by release of indoleamines, primarily melatonin, into the circulation system.

Key characteristics of a salmon's eye and photoreception

- The salmon's eye has an iris that is fixed and cannot regulate the amount of light entering, unlike the mammalian eye.
- The lens of a salmon is spherical and rigid and cannot change its shape to focus, unlike the mammalian eye.
- The salmon can focus clearly by moving its spherical lens backwards and forwards from the retina.
- The salmon have four kinds of cones in the retina and can detect ultraviolet as well as red, green, and blue.
- The pineal gland at the base of the skull is directly photosensitive and controls photoperiodicity

...the Scientists say.....

In rivers, flecks of mud and algae shift the underwater light away from the clear blue of the ocean and towards the red end of the spectrum. The salmon compensate for this via a simple biochemical switch in their retinas which gradually enhances their ability to see infrared light. The salmon effectively transform their eyes into night-vision goggles, so they can see further into the murky water

This trick revolves around a pair of molecules that form the building blocks of all animal eyes: a protein called an opsin and a partner chemical called a chromophore. They combine, forming a visual pigment. When light hits the pigment, the chromophore absorbs its energy and rapidly snaps into a different shape. Its contortions force its opsin partner to transform, too and a series of chemical reactions are triggered that end in an electrical signal traveling to the brain.

For a comprehensive summary of fish vision visit Wikipedia: https://en.wikipedia.org/wiki/Vision_in_fishes

For a comprehensive insight to the role and function of the light sensitive pineal organ of teleost fish

https://link.springer.com/article/10.1023/A:1018483627058

Relevance to Salmon husbandry...

Salmon have good eyesight and as typical predators rely on visual feeding. **Water turbidity** can inhibit feeding activity, and adjustments to daily feed inputs sometimes must be made until better water clarity returns.

As juvenile salmon feed visually during daylight hours light, 24-hour day light regimes are used in hatcheries to maximise feed intake and growth rate during the early freshwater phase.

During grow out in marine pens, the salmon remains sensitive to light levels. As is common with many predators it often feeds more actively at dawn and dusk, reflecting the salmon's natural feeding behaviour. Artificial light regimes have been applied successfully during grow out in marine cages, to increase daily feed intake.

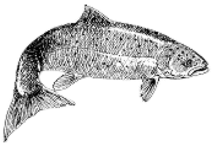
Smoltification is controlled by photoperiod regimes and can be accelerated or delayed to control the precise timing of when the salmon enter grow out. It is the light sensitive pineal gland as opposed to the eyes that is solely responsible for **photoperiodicity**.

SAP 6 **Gills**

Resource needs

Sub sections (summarised)	Resources
Introduction	**Image:** Looking down the mouth the salmon to see the gill arches
	Image: Salmon gill, looking in from operculum to the rakers and showing all gill arches
	Image: Close up of salmon gill rakers (could be comparative to other fish gill rakers, such as the herring as a plankton feeder
	Histological image: Taste buds
	Histological image: Mucus cells
	Image: Single salmon gill removed (to show gill rakers and lamellae)
	Macro Image: Blood rich gill
	Short video: Operculum beating in different states. At rest, when exercised and when stressed to show increased ventilation
	Image: Close up of primary and secondary Gill lamellae
	Histological image: **G**ill lamellae to show single layer epithelium
	Articulate creative: Histological Image branchial epithelium with over lay arrows and highlights to show CO2 leaving, the NH3 acidic boundary layer and NH3 leaving
	Articulate creative: The multifunctional gill- Annotated image or diagram of a salmon gill to be developed to Illustrate the full range of gill function, with drop down text (point and click)
	Articulate creative: Gill histology to highlight ionocytes and mucus goblet cells in situ reproduce a colour coded graphic like this one. The role of each cell type could be described with drop down text
	Articulate creative 1: Fish gas exchange function graphic- Make all arrows appear when the learner hovers over the gills and the bottom right-hand graphic pop up

SAP 6 **Salmon anatomy and physiology**



Gills

Image: Looking down the mouth of the salmon to see the gill arches

The gills are formed from a curved gill arch composed of bony elements which support the primary lamellae and project across the **pharyngeal** opening and is well supplied with blood from the afferent branchial artery entering the gill arch.

The gill has a much more diverse role to play than simply providing a mechanism for absorbing oxygen from the water and expelling carbon dioxide. It is a complex multi-functional organ. It is the main site for gas exchange, ion regulation, acid base regulation and nitrogenous waste excretion and central to vital processes such as metabolism, growth, and exercise. It also enables the fish to deal with common environmental challenges, including, low oxygen, elevated levels of carbon dioxide and ammonia, and changes to salinity and temperature.

Delicate gill lamellae are protected by an operculum

The gill supports feed detection and capture, assisted by gill rakers which are modified according to the preferred diet and feeding habits of different fish species.

Image: Salmon gill, looking in from operculum to the rakers and showing all gill arches

They vary in length and number and are prolific in filter feeders, acting as a sieve to remove edible **plankton.** As a typical carnivore, the salmon has a relatively small number of short, teeth like gill rakers which prevent relatively large food particles from exiting the spaces between the gill arches.

Image: Taste buds (histological)

Flask shaped multicellular tastebuds are distributed in the epithelium of the gill arch region.

There are two distinct types of cells, sensory and supporting, helping fish to sense the nature of food particles contained in the water flowing through the gill during ventilation. Their distribution and density differ considerably when comparing fish species inhabiting different water bodies.

Image: Close up of salmon gill rakers (could be comparative to other fish gill rakers, such as the herring a plankton feeder

The epithelium covering all components of fish gills contains mucous cells. Alongside other functions, they help stop particulate matter from covering the epithelium, enabling the taste buds to function effectively, so as the chemical nature of food passing through the gill can be sensed.

Image of mucus cells (Histological)

Insert Single salmon gill removed (to show gill rakers and lamellae)

How are the delicate gills protected?

The gills are filled with blood vessels, which gives them their bright red colour.

Image to show blood rich gill

They are located close to the head and lie behind and to the side of the mouth cavity. In most fish, including the salmon a tough plate like cover called the operculum provides physical protection. The operculum's movements work like a pump, synchronised with mouth movements and constantly bringing water across the surfaces of the gill lamellae. This is known as 'active' ventilation which occurs at low water flow rates and is an energy consuming process. When water flow rates increase to a certain level the salmon switches from 'active' to 'ram' ventilation, whereby it opens its mouth and allows the water to flow over the gill lamellae, which takes less energy, as the swimming muscles take over. The change of ventilation mechanism was thought to be controlled by 'mechanoreceptors' until more recently, when research on rainbow trout indicated that a drop in water oxygen tension was the main trigger. Norwegian research on salmon in sea cages showed that fish of 63 cm average length switched from 'active' to 'ram' ventilation when current velocities increased to 65 cm/sec, approximately equivalent to 1 body length per second, and on doing so, consumed 10% less oxygen. When fish are challenged aerobically due to low oxygen concentrations, they will often switch from 'active' to 'ram' ventilation, to get more water flowing over the lamellae. This can be indicative of stress.

Insert short video: Operculum beating in different states. At rest, when exercised and when stressed to show increased ventilation and the switch to ram ventilation

Library

Flag for supervisors: An accessible and comprehensive description of the structure and function of fish gills: https://www.yourarticlelibrary.com/fish/anatomy-and-physiology/structure-of-gills-in-fishes-with-diagram/88222

Flag for Managers and specialists: Comprehensive high level scientific account of fish gill physiology and function https://journals.physiology.org/doi/pdf/10.1152/physrev.00050.2003

Flag for supervisors: An assortment of papers from a Gill Health Workshop: http://aquacultureassociation.ca/wp-content/uploads/bsk-pdf-manager/2018/06/Bulletin-2018-2.pdf

7.1 The multifunctional gill

Gas Exchange

The multifunctional gill- Articulate creative:
Annotated image or diagram of a salmon gill to be developed to Illustrate the full range of gill function, with drop down text (point and click)

- **Gas exchange**
- **Gill mucus sells**
- **Ammonia and carbon dioxide excretion**
- **Ion regulation**
- **Acid base regulation**

Gill lamellae increase the surface area in contact with the environment to maximize gas exchange between the water and the blood (both to attain oxygen and to expel carbon dioxide). Fish gills have two types of lamellae, primary and secondary. The primary gill lamellae (also called gill filaments) extend from the gill arch, and the secondary gill lamellae extend from the primary gill lamellae.

Image of primary and secondary Gill lamellae

The lamellar epithelium is only one cell layer thick and believed to be the primary site of gas exchange. Various studies have shown a correlation between lamellar surface area and respiratory needs, with **pelagic** higher than **benthic** fish species for both parameters.

Histological image of gill lamellae to show single layer epithelium

In addition, fish, including the salmon, use 'counter current flow' to maximize the intake of oxygen that can diffuse through the gill. They do this by moving deoxygenated blood through the gill in one direction while oxygenated water moves through the gill in the opposite direction. This mechanism maintains the concentration gradient, thus preventing the respective oxygen levels from reaching an equilibrium and increasing the efficiency of the **diffusion** process. The muscles on the sides of the pharynx push the oxygen-depleted water out the gill openings. **Hyperlink to counterflow diagram**

Gill mucus cells

Image of goblet cells, or link to below image of gill histology

These gland cells are present throughout the epithelium, including the gill arch, gill filament and secondary lamellae, they secrete mucus (a glycoprotein). This can be acidic or neutral, despite being secreted by the same cells, suggesting that the cells can undergo transformation. The functions of mucus cells are as follows:

- Protective
- Reduce friction
- Anti-pathogen
- Help in ionic exchange
- Help in gas and water exchange

They are typical **goblet cells**, unicellular and may be oval or pear shaped, with a nucleus lying at the bottom of the cell and a neck which opens outside the epithelium.

Ammonia and carbon dioxide excretion

In well-aerated water, the obligatorily high gill ventilation rates allow metabolically generated CO_2 to readily leave through the gill without a substantial build up in the tissues, as may happen in air-breathing vertebrates. Accordingly, the **blood bicarbonate concentration** of fishes is low, coupled with a low steady-state **$PaCO_2$**. This minimizes the fish's ability to shed **buffered metabolic acid** via hyperventilation, as occurs in mammals, and reduces the buffering capacity during **metabolic acid-base disturbances**.

Histological Image branchial epithelium

Articulate: over lay arrows and highlights to show CO_2 leaving, the NH_3 acidic boundary layer and NH_3 leaving

In fresh-water fishes, ammonia (NH_3) is excreted across the branchial epithelium via passive NH_3 diffusion. This NH_3 is subsequently trapped as an acidic boundary layer lying next to the gill, which maintains a blood-to-gill water NH_3 partial pressure gradient, easing the release of NH_3. Although widely researched, many questions regarding the mechanism(s) of ammonia excretion across fish gills remain unresolved. There is believed to be a linkage between CO_2 and ammonia excretion, and the likelihood that **proton (H^+)-ATPases** are present in freshwater fish gills to drive active transport processes across the membrane.

Acid base regulation

The gills play an important role in regulating the pH of the blood, known as acid-base regulation. In vertebrates, including fish, the process is linked to carbon dioxide (CO_2) excretion through the reversible hydration/dehydration reactions of CO_2 and the acid–base equivalents, protons (H^+) and bicarbonate (HCO_3). This can be shown as $CO_2 + H_2O \leftrightarrow H^+ + HCO_3$.

Histological image

Trout gills with ionocytes

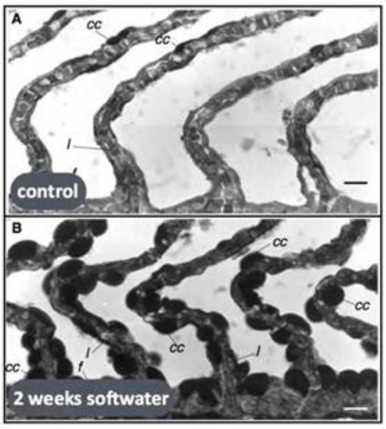


Figure 8
Light micrographs of trout gills (f = filament, l = lamella) in (A) control conditions and (B) following two weeks of exposure to ion-poor water (modified from Greco et al., 1995). Ionocytes (labeled CC) are larger and more numerous in ion-poor water.

In fish, however, **acid–base regulation** is also coupled to ionic regulation because acid–base compensation relies primarily on the direct transfer of H^+ and HCO_3^- across the gill in exchange for Na^+ and Cl^-, respectively. This makes the regulation of NaCl movement across the gill critical to maintaining both the ionic and osmotic balance in fish. A vital participant in all three processes is **carbonic anhydrase, the zinc metalloenzyme** that catalyses the above reversible hydration/dehydration reactions of CO_2, making it critical to CO_2 excretion, ionic regulation, and acid–base balance.

Active ion transport

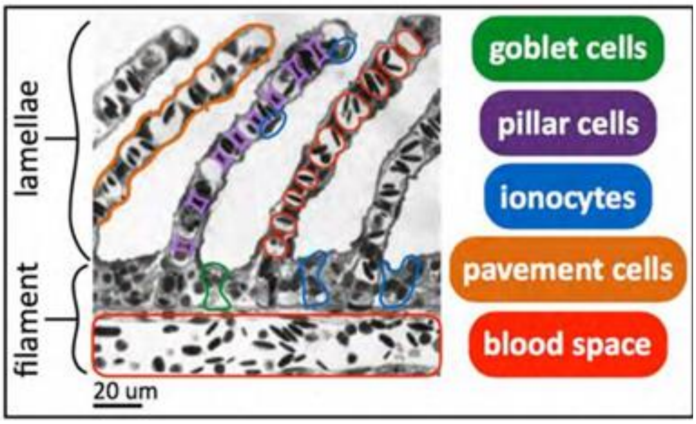
Active ion transport involves the expenditure of metabolic energy to move solutes against **concentration gradients**.

Specialised gill chloride cells are responsible for the active transport of Sodium (Na) and Chloride (Cl) salts into the fish when living in freshwater, and out of the fish when living in seawater. This process is central to **osmoregulation**.

They are known as ionocytes, because they help in the ionic regulation in the **euryhaline** and **stenohaline** fishes. They are provided with many mitochondria located in the gill epithelium to provide the metabolic energy required to power the process.

In ion poor water the ionocytes need to worker harder at actively transporting ions into the fish and develop as a result

Gill histology **Articulate creative:** reproduce a colour coded graphic like this one. The role of each cell type could be described with drop down text



Articulate creative: Link to trout gill graphic to illustrate active ion transport

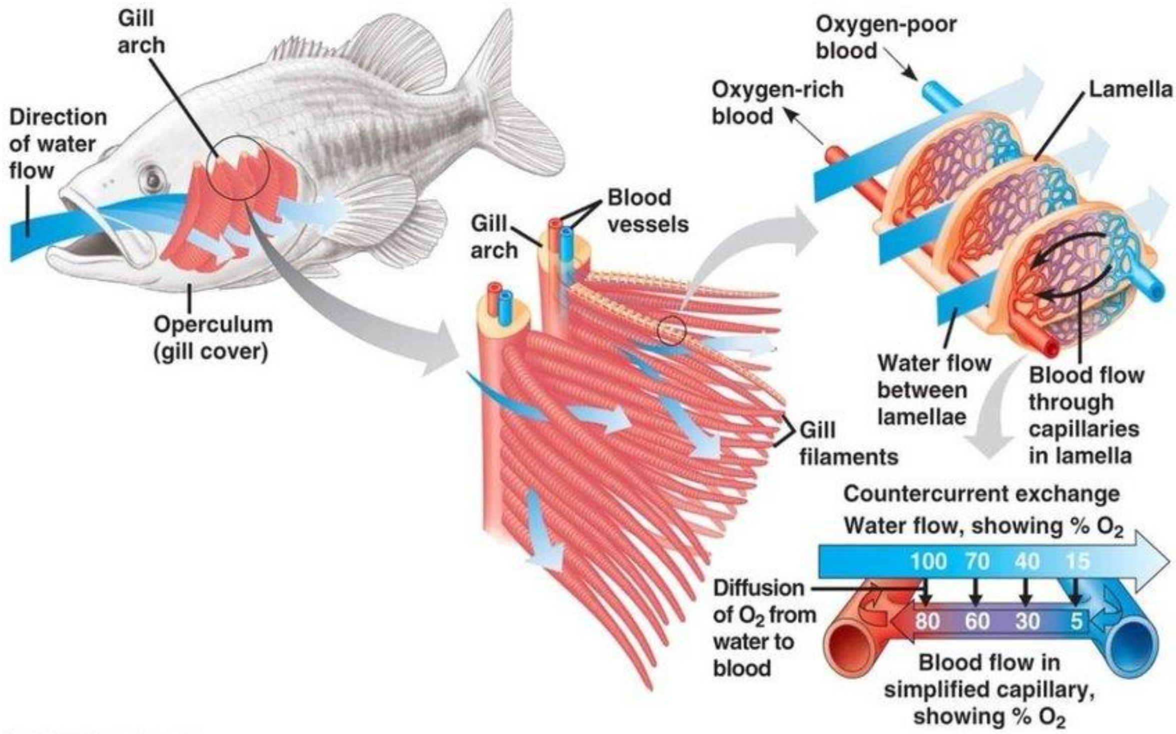
Relevance to salmon husbandry:

1) The blood rich tissues of the delicate gill lamellae are prime sites for attack by parasites and other pathogens. Therefore, monitoring and maintaining healthy gills is a health management priority for salmon farmers.

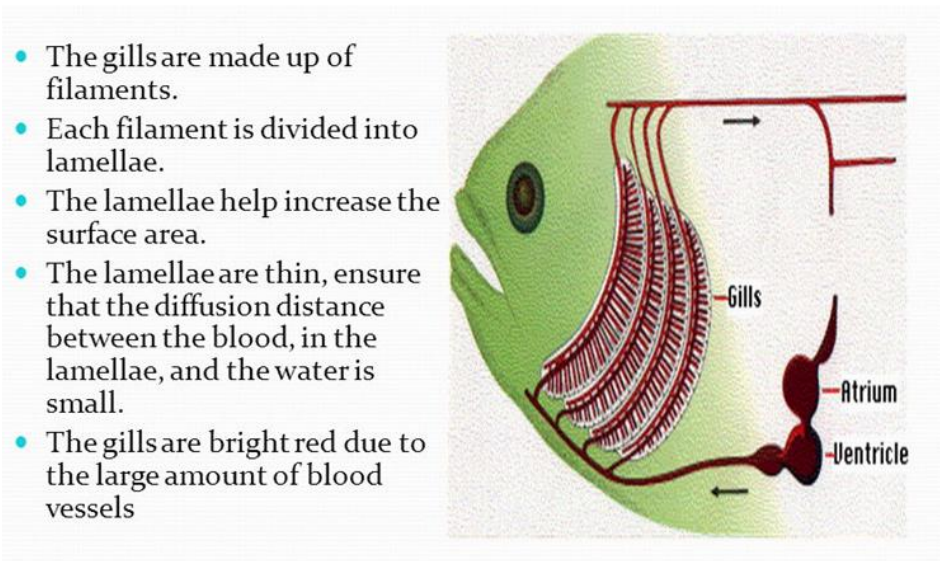
2) Monitoring and maintaining the water quality in the rearing environment is important to gill health management. There are several dangers:
   - Suspended particulates in the water can be abrasive,
   - Exposure to high levels of ammonia leads to the thickening of lamellae membranes, reducing their oxygen transfer efficiency and
   - an increase in organic substances encourages the growth of pathogenic bacteria than can attack the gills

3) An increased ventilation rate is visible to the observant salmon farmer, and indicative of stress. All salmon farmers should remain aware of operculum ventilation rates and responsive whenever they are heightened, and remove the cause of **stress**

Fish health and welfare



Articulate creative 1: Create a salmon version of the above graphic. Make all arrows appear when the learner hovers over the gills and the bottom right-hand graphic pop up



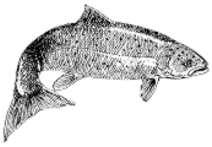
Alternative articulate creative 2: An alternative simpler graphic that could be re-recreated as a salmon head, so as when hovering over the ventricle, it pulses, and the blood vessels to the gill turn blue to represent deoxygenated blood and then turn red as they leave the gill, oxygenated.

The notation above can then drop down in a box accompanied by an anatomical image

Key characteristics of the salmon's gill:

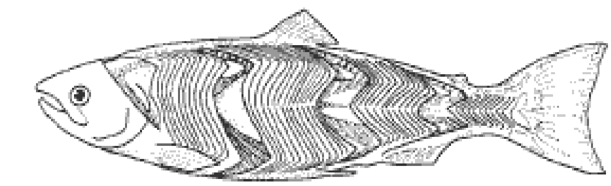
- The operculum (gill cover) physically protects the delicate gills and ventilates them
- Each gill arch has two rows (hemibranchs) of gill filaments
- Each gill filament has many secondary lamellae one cell thick and a large surface-area for the diffusion of gases including dissolved oxygen
- Gills have a good blood supply to maintain the concentration gradient needed for the diffusion of dissolved gases
- Metabolic wastes, ammonia and carbon dioxide are both directly excreted by the gills
- Mucus produced by mucus cells protects the gill epithelium
- Chloride cells in the gill epithelium are responsible for the active transport of sodium and chloride salts, central to osmoregulation.
- The gills play an important role in regulating the pH of the blood, known as acid-base regulation.

SAP 7 Salmon anatomy and physiology



Muscular system and locomotion

The salmon is a fish species revered the world over for its athleticism. It has the stamina to swim huge distances from its nursery stream to the north Atlantic feeding grounds, and back again. It also has the speed and acceleration to catch prey, avoid predators, and leap up water falls on its journey back to freshwater as a mature adult. The fish is well equipped, being **fusiform** (streamlined) and muscular, with two types of muscle fibre, one designed for stamina and the other for short bursts of speed.



Side muscles in a bony fish

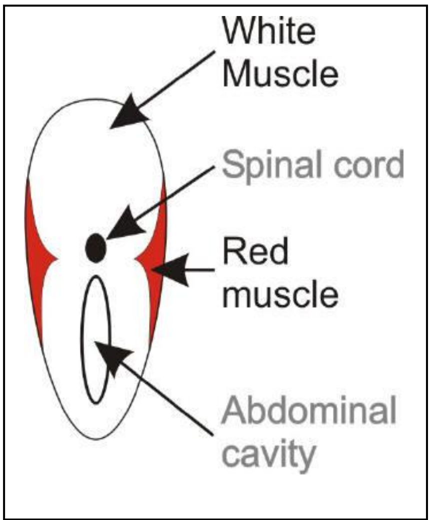
Salmon are normally swimming against a current, whether a stream flow during the freshwater phase as a juvenile (parr) or an oceanic current during the adult marine feeding phase. Physical activity helps the growth of lean muscle and improves the texture and sensory qualities of the fish when consumed.

Articulate creative: Recreate the image above (non-interactive) to show “W” shaped muscle blocks. Add labels plus definitions below on drop down (**myomeres** blocks of muscle cells are separated into "flakes" by connective tissue. **Myosepta** connective tissue (See diagram at end of episode where ‘myotome’ and ‘myocommata’, are alternative terms used)

7.1 Salmon muscle composition

There are two main muscle types, white and red which differ physiologically and functionally. Most fish have predominantly white muscle, but the muscle of some fishes, such as **scombroids** and salmonids, ranges from pink to dark red. At the cellular level, actin and myosin are two types of proteins present in the muscle cells of all vertebrates, including fish. Actin makes thin and short filaments in the myofibrils while myosin makes thick and long filaments. Both types of protein filaments are responsible for muscle contraction and movements. They interact with each other and aid in muscle contractions.

Articulate creative: Create interactive version of diagram opposite with drop down named components with information below for the 2 muscle types



Red muscle: During swimming, the longitudinal red muscles found as a thin dark strip under the **lateral line** are contracting. They are **aerobic** and need oxygen, which is supplied by myoglobin. Red muscles are used for sustained activity, such as cruising at slow speeds on ocean migrations.

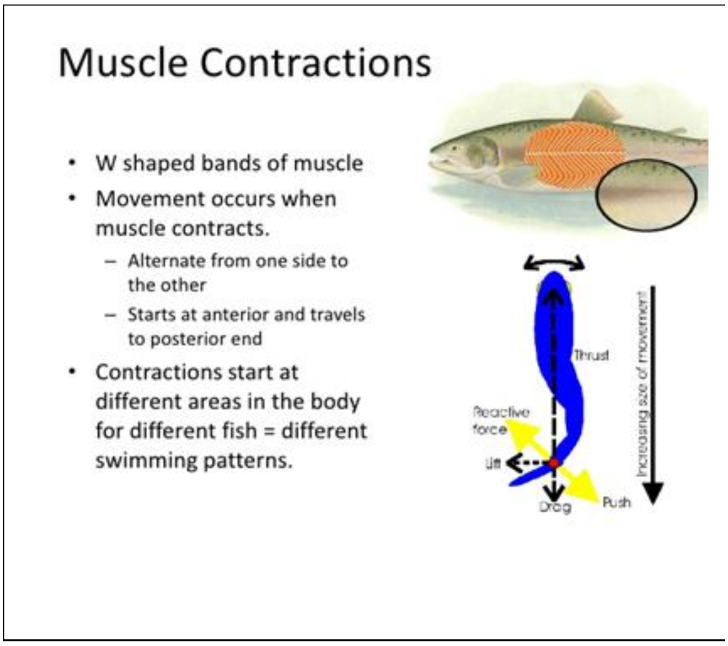
White muscle: Obliquely oriented white muscle forms most of the muscle mass. The white muscle is **anaerobic** which means it does not need oxygen. White muscles are used for bursts of activity, such as jumping waterfalls or acceleration when catching prey or fleeing a predator.

Salmon muscle structures (detail)

Articulate creative: Produce interactive labelled image, incorporating the labels in the example from the web below, that appear on hovering over the cross-section image... Use hotspots

Why are the muscle groups "W" shaped?

The blocks of **myomeres**, running from the head to tail, separated by connective tissue called **myosepta,** apparent as a "W" shaped segmentation of the salmon's muscle. This is typical of many animals that utilize **undulatory locomotion**, and this type of muscle configuration provides a 'gearing' advantage, best explained by the **scientists**!



Salmon swimming action

8.2 Salmon swimming action

Salmon swim by exerting force against the surrounding water. This is achieved by the fish contracting muscles on either side of its body to generate waves of 'flexion' that travel the length of the body from nose to tail, generally getting larger as they go along.

The **vector forces** exerted on the water by such motion cancel out laterally but generate a net force backwards which in turn pushes the fish forward through the water. The salmon generate thrust using the lateral movements of their body and caudal fin. Conversely, many other species move mainly using their median and paired fins

Articulate creative: Produce annotation of fish swimming, with reference to graphic (bold blue) Make fish 'flex' and move forward, showing vector forces in action

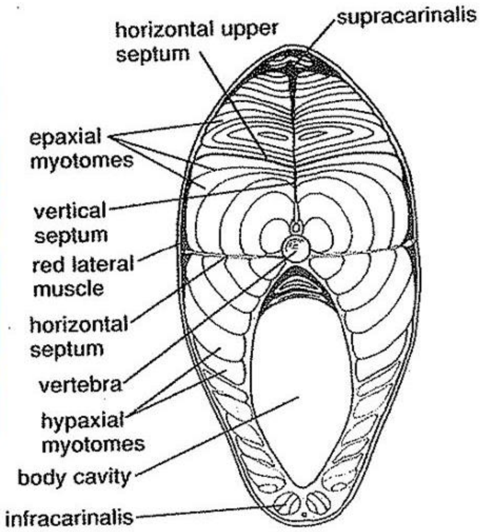
Key characteristics

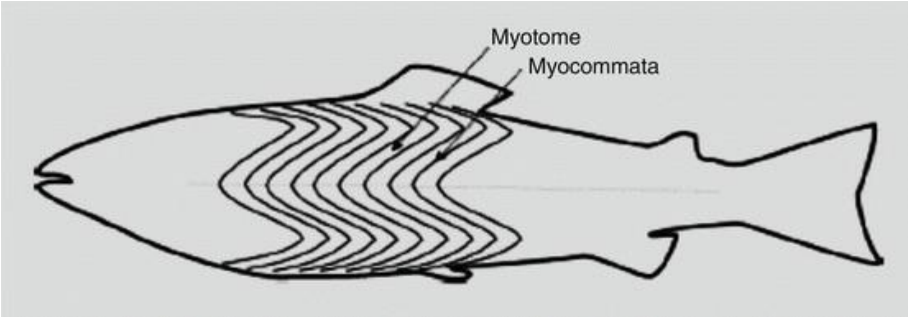
- Salmon have both red and white muscle fibres.
- Red muscle is aerobic and used for sustained swimming (stamina).
- White muscle is anaerobic and used to generate short duration bursts of speed (acceleration).
- "W" shaped muscle blocks (myomeres) are separated by connective tissue (myosepta) and can create 'waves of flexion'
- By generating body flexion and using its caudal fin, the salmon can create vector forces and forward thrust.

Relevance to salmon husbandry

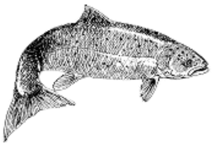
The texture of the flesh is important to the sensory qualities of a farmed salmon when it reaches its destination, as a meal on the consumer's plate!

Therefore, the flow rates in salmon holding units are set to ensure that the salmon gets sufficient exercise to develop muscle texture but does not waste metabolic energy holding its position in a current that is too strong.



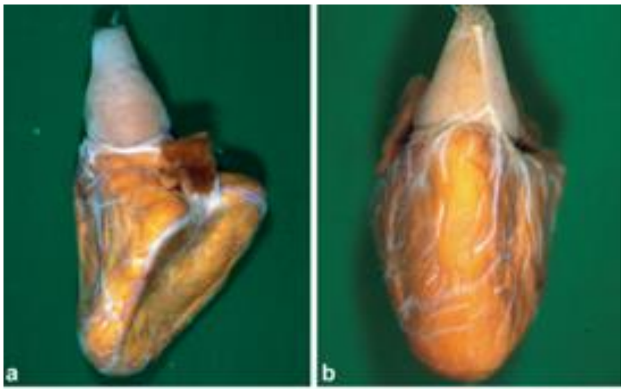

Myotome
Myocommata

SAP 9 **Salmon anatomy and physiology**



Heart and circulatory system

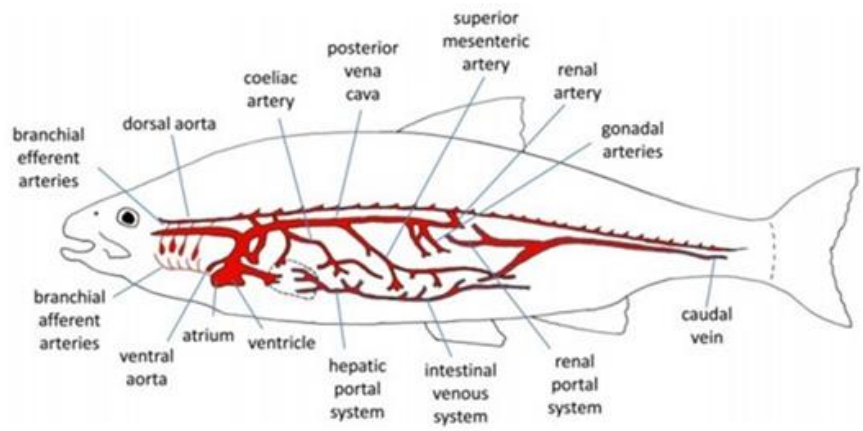
As in other vertebrates, the circulatory system of fish is comprised of both static and dynamic components. The **blood** is dynamic, with all its constituent parts flowing continuously around the fish's body. The veins and arteries leading to and from the heart and the capillaries that connect them are all static.



Fish heart, dorsal and lateral view

Articulate creative: Create hotspot areas on the image of a salmon heart opposite, which when pointed at cause the name of the chamber to appear and a thick red line to appear around its boundary - Note, no IPR for this image, so may need to create our own, or a diagram.

The heart is constructed of four chambers, but unlike mammals they are not all muscular. They do not form a single organ but sit one behind the other and are normally found below the pharynx and immediately behind the gills.

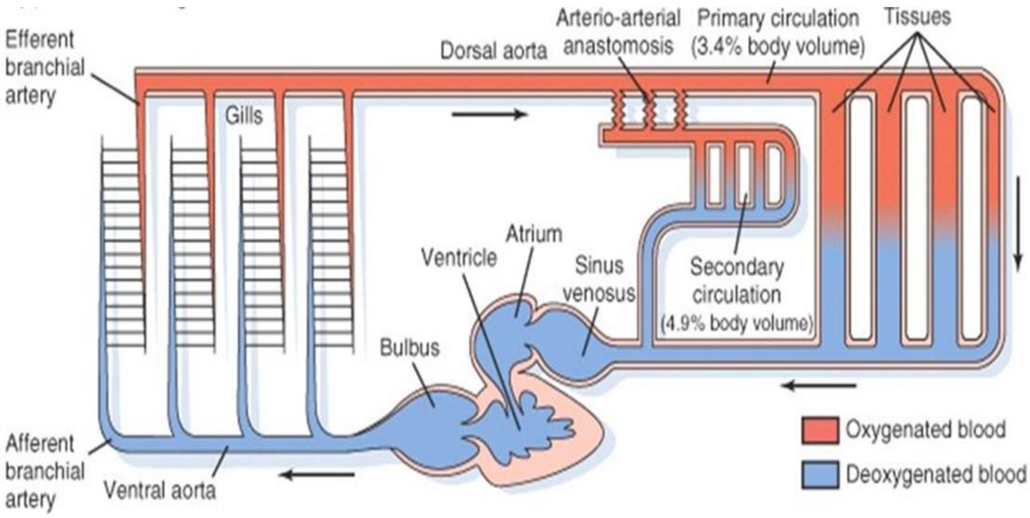


Salmon circulatory system

Articulate creative: Create a similar diagram - High light blood vessels that take oxygenated blood to organs in red and the veins returning blood to the heart in blue when hovering

8.1 Single cycle circulatory system

Fish have less blood per gram of body weight than mammals, normally between 3% and 8% of body weight. It is pumped in a single circuit through the capillaries of the gills to be re-oxygenated, before flowing to the body tissue capillaries where it is used for **respiration**. This is known as a 'single cycle closed-loop circulatory system'.



Sinus venosus. The first chamber and preliminary collecting chamber. In **teleosts** it is filled from two major veins called the **hepatic veins** and the left and right branches of the Curvierian ducts which in turn collect blood from the paired (left and right) lateral veins the inferior jugulars, the anterior cardinals and the posterior cardinals.

Atrium. The blood flows into the atrium from the sinus venosus. The atrium is the largest of the chambers and only weakly muscular, pushing the blood with weak contractions.

Ventricle. The ventricle is the only muscular chamber, nearly as large as the atrium it is the work horse of the heart, its contractions drive the blood around the body.

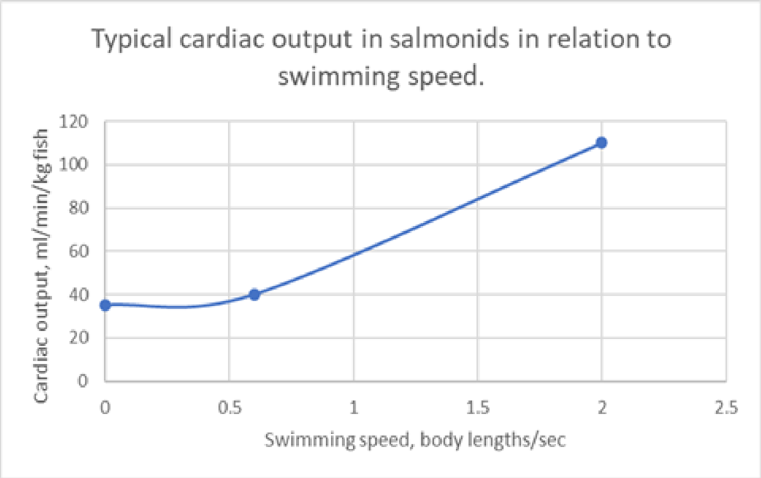
Bulbus arteriosus. The last chamber of the fish heart is called the bulbus arteriosus. This is elastic and works to reduce the pulsed nature of the blood leaving the ventricle giving it a more even, constant flow.

Key characteristics

- The four chambers of a salmon's heart are not all muscular and do not form a single organ
- Blood is received by the Sinus venosus, filled by the hepatic and other veins.
- Blood is pumped by the ventricle to the gills for re-oxygenation and on to the tissues of the body within a single cycle close loop system
- The heart resting rate resembles that of mammals and increases under exercise to similar levels

Articulate creative: Present the 4 descriptions of heart components above as text dropping down from a schematic diagram like the one above, when hovered over. (Note-No IPR for this image)

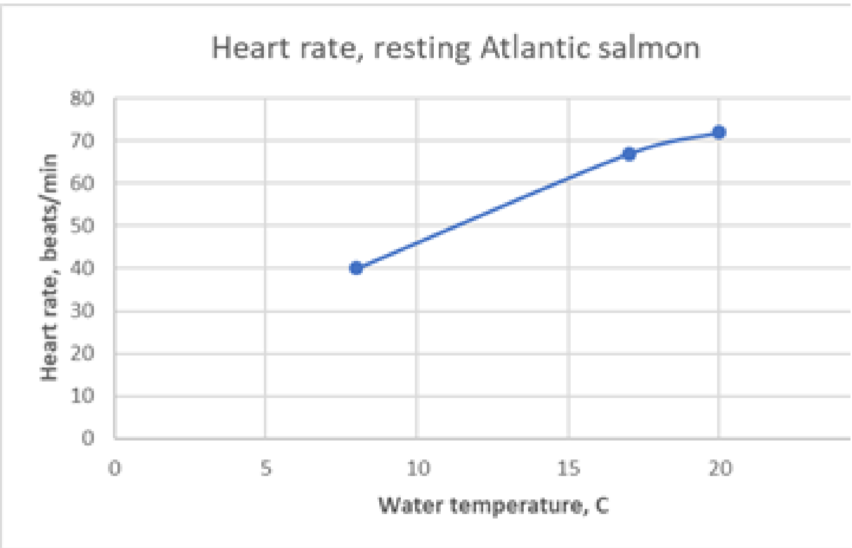
On clicking the ventricle it will contract and the blood light up red and blue as above and arrows appear to indicate the direction of blood flow. The red will light up first, synchronous with the red box, then the blue synchronous with the blue box



How does the cardiovascular output of a salmon compare to humans?

The resting heart rate in salmon resembles mammals, ranging from 40 to 90 but increases with water temperature.

As water temperature increases from 8oC to 20oC, the heart rate rises from 40 to 70 beats per minute



During exercise, the heart rate increases and can reach 150 to 200 beats per minute (bpm).

Relevance to salmon husbandry

Exercise increases heart rate and energy consumption, and the fish farmer needs to set the flow rates to provide the optimum level of exercise for fish feeding, growth, and muscle texture. Sub optimal Dissolved Oxygen would cause a compensatory increase in heart rate and should be avoided, for many reasons.

the Scientists say...

This research illustrates how salmon (chinook, in this case) can regulate their cardio-vascular system in response to physiological challenges (exercise, in this case).

As more oxygen is required for metabolic energy by swimming muscles, blood flow to the gut is cut (A) by an increase in resistance to blood flow in the visceral organs (B), and blood pressure and heart rate rises (C and D).

Similar changes would result from other challenges such as low Dissolved Oxygen (DO) as and when required.

Graphs need to be simplified

122 H. THORARENSEN AND OTHERS

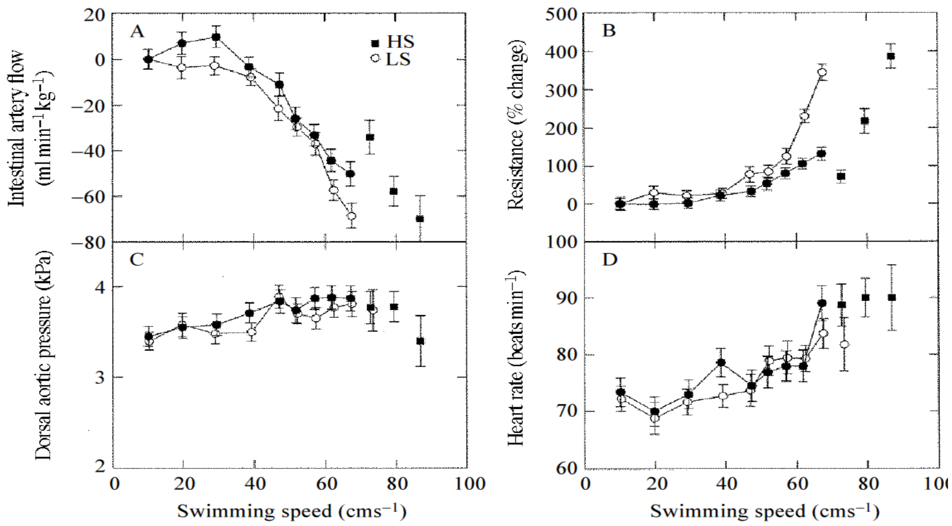
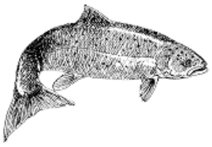


Fig. 2. Cardiovascular changes during exercise in chinook salmon, swimming with a DA cannula and a Doppler flow probe on the intestinal artery. Bars show ± S.E.M., N=10 for each group of fish shown connected with a line. Individual points represent mean values for 2–3 fish of the group that swam faster than the remainder. (A) Blood flow in the intestinal artery, expressed as the percentage change from the resting level. There is significant difference between groups (P<0.0003) and significant changes in both groups as swimming speed increases (P<0.0001). (B) Relative resistance of the splanchnic vascular bed. Resistance increases significantly with swimming speed in both groups (P<0.0001). (C) Pressure in the dorsal aorta. The results for the two groups are not significantly different and there are no significant changes with swimming speed. (D) Heart rate shows a significant increase with swimming speed (P<0.0001), but heart rate in the two groups was not significantly different.

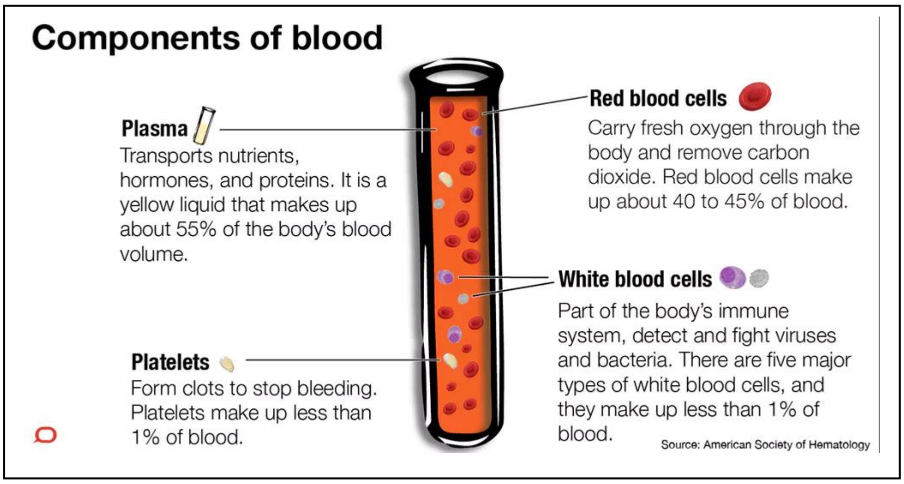
SAP 10 **Salmon anatomy and physiology**



Blood

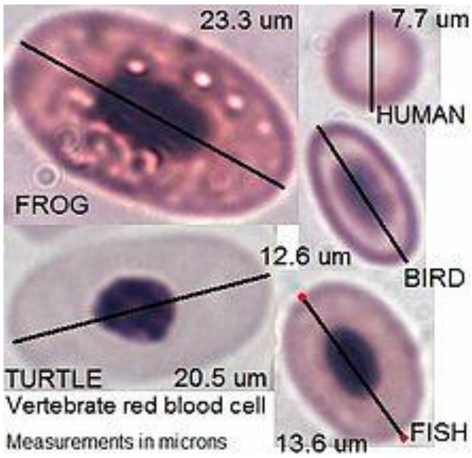
Fish have less blood per gram of body weight than mammals, normally equivalent to between 3% and 8% of a fish's body weight. Salmonids have a blood volume equivalent to approximately 4% of body weight. The blood serves a major function in transporting hormones and carries nutrients from the gut to the tissues and waste products from the tissues to the gills and kidneys for excretion.

Fish blood consists of plasma, platelets and two types of blood cells transported around the body. Plasma is basically composed of water containing a variety of dissolved ions (Na+, Ca2+, K+, Cl-) and small organic molecules such as urea, sugars, amino acids, and fatty acids.



The blood clotting (coagulation) mechanism involves activation, adhesion, and aggregation of platelets. The deposition and maturation of fibrin, a **non-globular protein** formed by the action of the protease thrombin on fibrinogen, which causes it to polymerize is also instrumental in the clotting process.

Articulate creative: Convert image to represent blood composition, including Erythrocytes and all 5 leucocytes described below. Create drop down descriptions when hovering



Articulate creative:

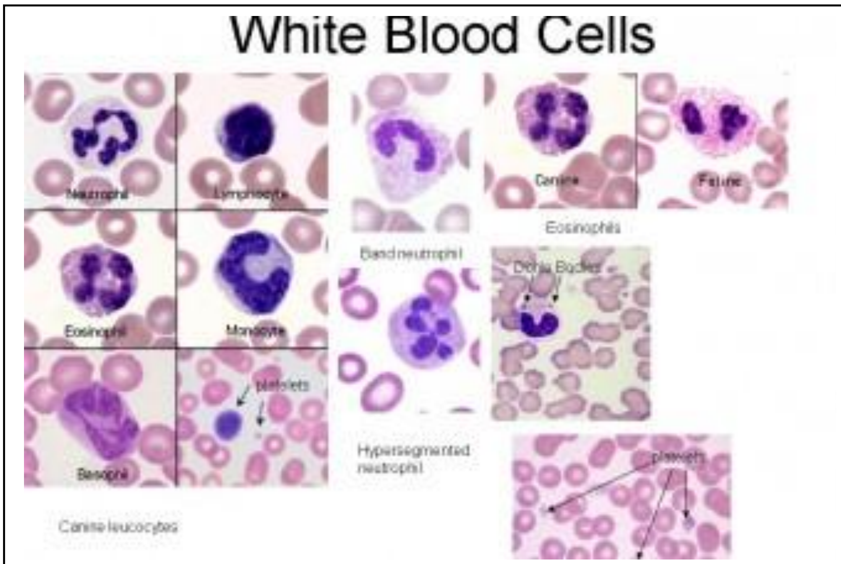
Make an interactive image that asks the learner to select the human RBC to highlight its non-nucleated nature compared to the fish RBC

Might be possible to source copyright free digital images for this job. (MH to check)

Blood cells come in two types: Erythrocytes, also known as red blood cells (RBC's), and Leucocytes.

9.1 Gas transportation

Erythrocytes are by far the most common cells found in the blood plasma and transport gases around the body. They **collect oxygen at the gills** and carry it to all the body's cells whilst collecting excreted carbon dioxide. Fish erythrocytes are nucleated, unlike human RBC's.



Fish have a full complement of cells related to immune function

Articulate creative:
Convert white blood cells image so as the names of the 5 types appear on hover with the descriptions below. (Need to source copyright free images of white blood cells MH)

The salmon's erythrocytes are full of haemoglobin and consequently red in colour, like our own and carry oxygen round the body. Fish have acutely pH-sensitive haemoglobin (Hb). A reduction in pH reduces both Hb-O2 affinity **(Bohr effect)** and carrying capacity **(Root effect).** This combined with a large arterial-venous pH change greatly enhances tissue oxygen delivery in teleosts.

Key characteristics of salmon blood are:

- The blood transports hormones and carries nutrients from the gut to the tissues and waste products from the tissues to the gills and kidneys for excretion.
- The blood plasma carries Erythrocytes (red blood cells) which transports oxygen around the body via haemoglobin molecules, giving the blood its red colour.
- The five cell types of Leucocytes (white blood cells) carried in the blood are an essential part of the fish defence mechanism against **pathogens.**
- Monocytes, one of the five white blood cells are macrophages and consume harmful invaders, such as bacteria and parasitic larvae
- The kidney and spleen are the main blood cell producing organs.
- The Bohr and Root effects lead to loading and offloading on O2 according to blood pH

9.2 Fighting infection

Leucocytes are a mixed collection of cells that are less common than erythrocytes and are not red because they do not contain haemoglobin. The five most important types are Granulocytes, Lymphocytes, Monocytes, Thrombocytes and Non-specific Cytotoxic Cells.

1) **Lymphocytes** are 4.5 to 12 microns in diameter and their job is to detect and mark foreign particles. More specifically, they mediate the activity of small molecules called antibodies that find and bind to foreign materials so that Monocytes can find them.

2) **Thrombocytes** are important in blood-clotting, helping to conserve resources, as they prevent blood loss in case of injury.

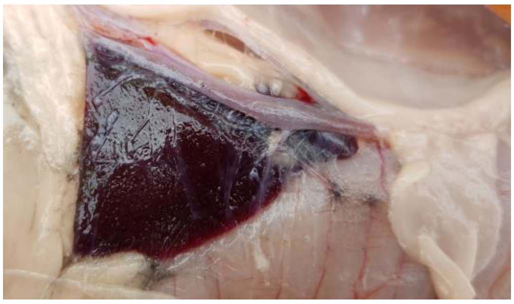
3) **Monocytes** (sometimes called Macrophages) are important in defence as they eat (phagocytize) anything they come across in the blood that might harm the fish such as bacteria, or parasite larvae.

4) **Granulocytes** are also active in defence as they specifically attack bacteria, but also have a role in controlling stress which is not fully understood and is being researched.

Relevance to salmon husbandry

White blood cells are a vital part of the salmon's immune system and are compromised if the fish is stressed, making it vulnerable to a range of infectious diseases. By reducing stress and maintaining high standards of husbandry the farmed salmon's immune system remains robust. **Fish Health and Welfare**

The salmon slaughter procedure can influence the residual blood in the fillet as measured by the number of blood spots and amount of haemoglobin. Trials showed that the amount of residual blood was influenced by anaesthetisation and killing procedures. Fish that were chilled alive and CO_2/O_2 anaesthetised then directly gutted had less residual blood in the fillet ($P < 0.05$), compared to the standard industrial procedure of gill cutting and bleeding before gutting. **Grow out** https://www.sciencedirect.com/science/article/abs/pii/S0044848606003140



Spleen-main red blood cell producing organ

5) **Non-specific Cytotoxic Cells** are another defence mechanism which specialises in attacking tumours and protozoan parasites.

9.3 Blood producing organs

The blood cells (both red and white) have a limited life span and so must be continuously recycled and replaced. There are several organs and tissues involved in the production of blood cells.

The primary blood cell producers are:

Spleen: recycles, produces, and stores blood for use in times of need e.g. bleeding due to injury

Kidney: produces red blood cells in the front region, while the rear kidney cleans the blood by removing nitrogenous waste to discharge as urine and has an important **osmoregulatory role**.

Heart: produces blood, but its primary role is to pump blood to gills and around the body.

Liver: will recycle and produce blood cells but this is not the **liver's primary function**.

.... the scientists say

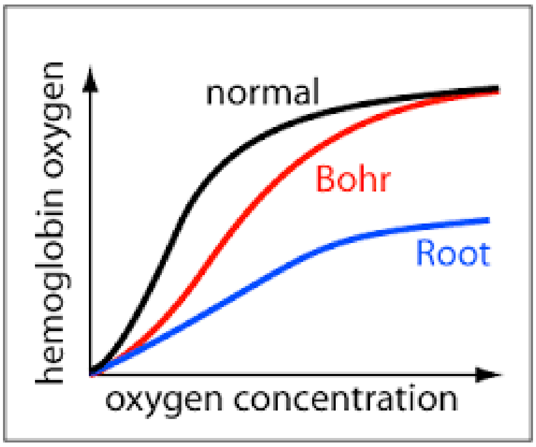
1) Bohr effect

The efficiency of oxygen transport by haemoglobin can be influenced by the environmental conditions. In 1904, Danish scientist Christian Bohr noticed that haemoglobin binds oxygen more tightly at high pH than it does at low pH. This phenomenon called the Bohr effect is a property of fish haemoglobins found in teleost species. It consists of a drastic reduction in haemoglobin O2 affinity, causing a decrease in the oxygen transportation capacity when pH decreases, and oxygen tensions are high.

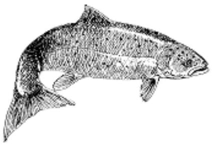
2) Root effect

The Root effect is a physiological phenomenon that occurs in fish haemoglobin, named after its discoverer R. W. Root. It is the phenomenon where an increased proton or carbon dioxide concentration (lower pH) lowers haemoglobin's affinity and carrying capacity for oxygen

Root and Bhor effect



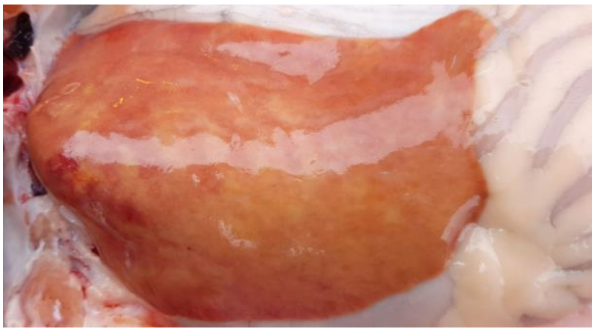
SAP 11 **Salmon anatomy and physiology**



Liver

The liver is an organ only found in vertebrates. It is a large red/brown coloured organ with a smooth surface found in the anterior (front) part of the body cavity.

As well as having a role in the destruction and recycling of old **blood** cells, the liver fulfils a diverse range of other functions, including cleansing metabolic wastes, nutrient storage and the manufacture of specific nutrients and digestive enzymes (bile).



Liver (paler in farmed than wild fish) *Add wild*

Bile contains biliverdin derived from the breakdown of haemoglobin which functions to **emulsify** dietary fats. The fullness of the **gall bladder and colour of bile** can indicate when a fish last fed.

What triggers the release of bile?

Cholecystokinin, a hormone secreted by cells in the duodenum, stimulates the release of bile into the intestine and the secretion of enzymes by the pancreas. Cholecystokinin also,

- stimulates the secretion of bile salts into the biliary system,
- stimulates the secretion of pancreatic enzymes,
- induces satiety (lack of hunger) and
- modulates hormones and **neuropeptides.**

A healthy fish liver in a wild fish appears dark in colour. Many intensively farmed fish, including Atlantic salmon, have high fat diets to spare protein in the diet for growth. So long as the diet is nutritionally well balanced, as most manufactured feeds are, normal liver function is not compromised.

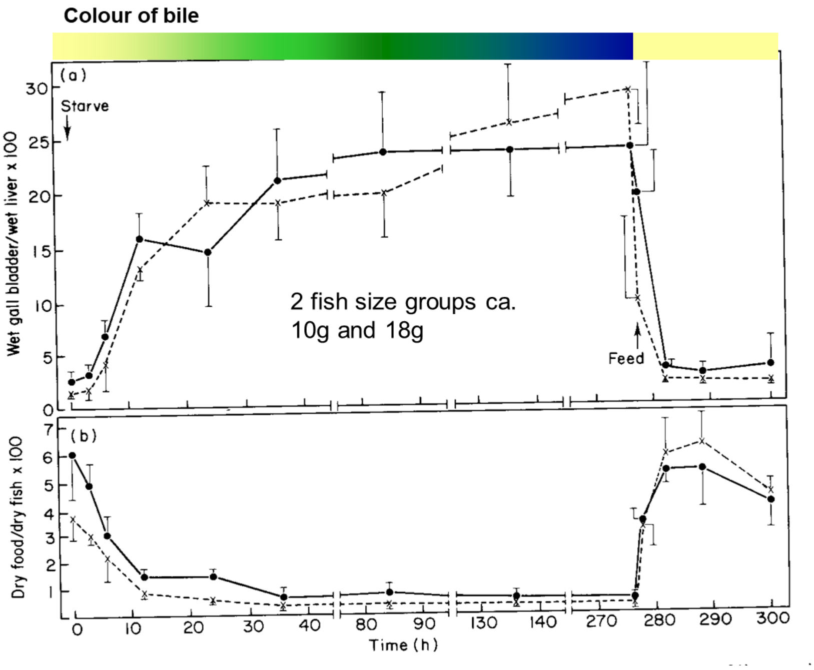
However, although the precise causes are not well understood, 'fatty liver' is a physiological or pathological phenomenon commonly seen in many species of farmed fish globally. Severe fatty liver in fish results in reduced growth and feed efficiency, impaired immune response and decreased nutritional quality and is a **non-infectious nutritional disease**. 'Fatty liver' is a rare condition within the salmon farming industry.

Key characteristics of the liver:

- Storage of nutrients such as vitamins, minerals, and glycogen (sugar) for use as an energy source.
- Synthesis of plasma proteins, such as albumin, and clotting factors
- Manufacture of the alkaline digestive juice bile (stored in the gall bladder)
- Removal of metabolic wastes and toxins from the blood.
- Metabolism of fats, proteins, and carbohydrates and enzyme activation

...**the science says**

1) The gall bladder and bile are an indicator of the level of recent feeding activity.
When stomach contents, especially fats and protein enter the duodenum, cholecystokinin is released from the duodenal mucosal cells to stimulate contraction of the gallbladder and relaxation of the sphincter of Oddi so that bile can enter the small intestine.
In fish that have recently fed, the gall bladder is very small and contains a pale straw-coloured bile. If the fish is starved and the gut contents fall, the gall bladder fills up to weight, approximately 20% of the liver weight by day 2. As the starvation period increases, the bile turns green, then blue by around day 5. When starved fish are re-fed, the gall bladder empties of bile about 6-8 hours after the meal as food reaches the mid-gut.



2) Liver as an environmental marker
The liver is very susceptible to contamination by organic and inorganic compounds that can accumulate over time and cause life-threatening conditions. Because of the liver's capacity for detoxification and storage of harmful components, it is often used as an environmental **biomarker**.
3) Fatty liver
The common occurrence of 'fatty liver' in intensively farmed fish globally is due to increasing hepatic triglyceride synthesis, which initially acts as a protective mechanism, to avoid **lipotoxicity** induced by high free fatty acids in circulation. Most instances of fatty liver are classified as "nutritional fatty liver" or "oxidative fatty liver" depending on whether the cause is nutrient imbalance or oxidative stress. One of the main factors in fatty livers is amino acid imbalance (methionine deficiency). In some aquaculture regions, water contaminants, especially heavy metals and persistent organic pollutants have been reported to contribute to the prevalence of fatty liver in farmed fish.

It is also noted that the tendency to deposit fat in the liver is influenced by fish species, gender, and the stage of development. For example, the fat content in the liver of young and /or female fishes is normally more sensitive to dietary energy content than that in the liver of older and /or male fishes.

Relevance to Salmon husbandry:

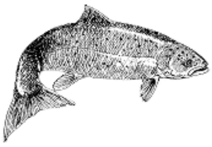
1) Nutritionally balanced diet

Feeding fish with optimal nutritionally balanced diets derived from fresh raw feed materials and maintaining a sustainable healthy aquatic environment prevents fatty liver problems from occurring.

2) Gall bladder and bile indicators

Examination of the gall bladder and bile can be useful during a post-mortem to determine how recently the fish last consumed any food. (**See the science says**)

SAP 12 Salmon anatomy and physiology



Swim bladder

Most fish species (but not all) possess a swim bladder which provides buoyancy and allows fish to adjust and maintain their position without actively swimming. The swim bladder is sensitive to water pressure, so the fish can constantly adjust as they move through the water column.

The swim bladder of the Atlantic salmon emerges during **embryogenesis** as a small mass of undifferentiated cells resting dorso-laterally on the posterior wall of the fore-gut. This mound of cells is proliferated from the narrow band of **mesoderm** which lies between the **epithelium** and the **serosa** of the alimentary canal and elongates slowly for 11 weeks. At the end of this time an **evagination** from the **lumen** of the right side of the oesophagus grows and becomes the **pneumatic duct**.

> **Key characteristics** of the salmon swim bladder
>
> - The swim bladder lies under the kidney in the form of a single sac.
> - The salmons swim bladder is connected to the gut via a 'pneumatic duct' which allows it to adjust buoyancy quickly.
> - By adjusting its swim bladder, the salmon can move within the water column more easily and save energy

The developing swim bladder elongates rapidly and reaches the posterior end of the body cavity at approximately the time when the young salmon emerge from the gravel.

What does the swim-bladder look like?

The swim bladder is generally a torpedo shaped structure that normally runs the length of the body cavity immediately beneath the kidney. It takes the form of a single sac as in salmonids, unlike cyprinid species which have a dual connected sac.

Swim Bladder

How does the swim-bladder function?

The swim bladder in most fish performs the same functions but there are two basic designs:

- Physostomous – connected to the gut allowing buoyancy to be adjusted quickly. Found in salmonids and cyprinids.

- Physoclistous – no connection to the gut and buoyancy is slowly adjusted through gasses being secreted from the circulatory system.
  Found in perch and seabass.

Do all species of fish have a swim-bladder?

Some fish that do not possess a swim bladder are bottom living species such as flatfish. Some active species such as sharks and tuna that lack a swim bladder must constantly swim and expend a lot more energy as a result.

Farmed salmon can experience ‘buoyancy disorders due to swim-bladder problems, where their balance and orientation is affected.

...the scientists say

Malformation of the swim bladder of farmed Atlantic salmon was reported as an increasing problem in Norwegian aquaculture. In affected fish, the swim-bladder is shortened and dilated, and the pneumatic duct opens at the normal point in the oesophagus but runs along the ventral side of the swim-bladder and enters the caudal pole of the organ. This contrasts with normal fish, where the pneumatic duct is short and enters the cranioventral part of the swim-bladder. The fish exhibit a characteristic behaviour suggesting that balance and buoyancy are altered. This malformation of the pneumatic duct may lead to altered filling of the swim-bladder, which in turn may cause the abnormal shape and size of the organ

https://www.researchgate.net/publication/250220756_Swimbladder_abnormality_in_farmed_Atlantic_salmon_Salmo_salar

Relevance to salmon husbandry

1) **Swim up fry**

Salmon fill their **swim bladder** with air for the first time as **swim-up** fry, enabling them to control their position in readiness for first feeding.

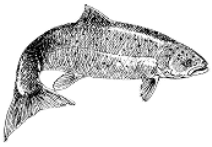
‘Swim up’, is an important stage of development for the salmon hatchery husbandry staff to observe and respond to in a salmon hatchery.

2) Salmon in submersible cages

Given that salmon are physostomous fish possessing a duct through which they can inflate or deflate the bladder, people have asked if it is possible to rear fish in submerged cages to avoid bad weather conditions and reduce sealice burden (sealice live predominantly in the top 5-10m of the water column). Korsøen et al (2009) investigated whether large salmon submerged below 10 m in winter conditions behaved normally and performed as well as control fish held in standard surface cages. The fish were unable to maintain gas in the swim bladder resulting in a faster swimming speed at a higher angle of incidence. The results suggest that continuous submergence below 10 m for longer than 2 weeks reduces the welfare and performance of Atlantic salmon.

Korsøen, Ø. J., Dempster, T., Fjelldal, P. G., Oppedal, F., & Kristiansen, T. S. (2009). Long-term culture of Atlantic salmon (Salmo salar L.) in submerged cages during winter affects behaviour, growth and condition. *Aquaculture, 296(3-4), 373–381.*
sci-hub.tw/10.1016/j.aquaculture.2009.08.036

SAP 13 Salmon anatomy and physiology



Kidney

The salmon kidney is a dual function organ, with the head (anterior) and rear (posterior) portion, sometimes called the trunk kidney, with distinctly different roles. The kidney occupies a dorsal position in the body cavity and is placed just under the vertebral column.

Fused Atlantic salmon kidney

The visible external structure of the kidney varies in different fish species from distinctly bilobed anterior and posterior kidneys, to kidneys that are fused and intimately embedded between the vertebrae, as typified by the salmonids (see... **the scientists say**).

What does the salmon's kidney look like to the naked eye?

The kidney runs the length of the body just beneath the backbone and under the swim bladder, partially concealed by a pale layer of connective tissue. In the salmonids, as the front and rear of the kidney are fused, they form a smooth continuous structure, which in healthy fish has a dark cherry red colour, appearing almost black in some cases.

What does the kidney do?

The head kidney is non-excretory and **endocrine** in function with an inter-renal gland that performs the same role as the **adrenal cortex** of mammals, producing steroid hormones which regulate carbohydrate and fat metabolism and mineralocorticoid hormones which regulate salt and water balance in the body. Along with the spleen, it also replenishes red blood cells. Conversely, the posterior (trunk) kidney is **excretory** in nature.

The posterior kidney is responsible for completing the removal of ammonia, which is discharged as urine, with the internal 'Malpighian capsules' providing the filtration capacity. Most waste ammonia diffuses from the gills, with filtration from the blood by the liver and kidney completing the cleansing operation.

Freshwater fish produce a lot of dilute urine to counteract water ingress whereas in saltwater marine fish minimise urine production to conserving water to counteract dehydration and excrete salts. Consequently, the kidney plays a vital part in **osmoregulation**, helping to maintain a stable concentration of internal body fluids.

These multiple roles differentiate the fish kidney function from other vertebrates.

12.1 Kidney structure

The kidney receives blood supply via the renal artery and renal portal vein for cleansing. The functional unit of the trunk kidney is the microscopic **nephron**, consisting of two parts, the **renal corpuscles** and the **renal tubule** (urinary tubule). The renal corpuscle or 'Bowman's capsule' is a double layer cup-like structure which contains a tuft of capillaries known as a glomerulus. The glomerulus and Bowman's capsule together constitute the renal or 'Malpighian capsule' which is the filtration apparatus of the kidney.

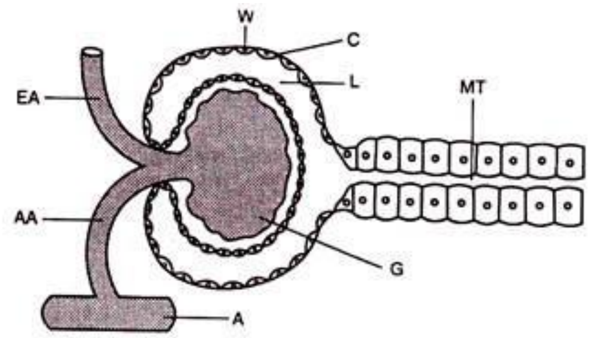


Fig. 11.8 : Diagram of renal corpuscles of fish. A, aorta; AA, afferent arteriole; C, capsule; EA, efferent arteriole; G, glomerulus; L, lumen; MT, mesonephric tubule; W, wall.

The afferent and efferent arterioles are the main arteries that are responsible for the supply of blood into and out of the glomerulus. In both freshwater and marine fish, the first step in urine formation is the production of a 'glomerular filtrate'. The glomeruli of freshwater teleosts are numerous and large, whereas in marine teleosts, glomeruli are reduced in size and number. Some marine fish lack glomeruli and therefore produce no filtrate and urine.

> **Key characteristic** of the kidney is its multifunctional nature....
>
> - filtration, removing nitrogenous and other wastes to be discharged as urine (posterior kidney),
> - osmoregulation, conserving ions to maintain a stable internal salt concentration and excreting excess water (posterior kidney) in freshwater and conserving water and excrete salts in saltwater
> - producing hormones (endocrine function), and
>
> red blood cells (anterior kidney)

After the filtrate removed by the glomerulus passes through the ciliated neck of the tubule, glucose and other useful molecules are retrieved from the filtrate to be utilised, whilst other wastes are pumped in for removal. Larger molecules are retrieved by **pinocytosis** and ions moved by **ATPases.**

Articulate creative: Recreate the renal corpuscle diagram above with drop down named components and descriptions that appear when hovering.

The aorta supplies the blood to be filtered by the kidneys.

An afferent arteriole is a part of the renal artery that carries blood containing nitrogenous wastes. Into the glomerulus of the kidney.

An efferent arteriole is a part of the renal artery that carries filtered pure blood back to the circulatory system.

The glomerulus has a permeable membrane which allows water, salts, glucose, amino acids and small protein molecules to pass through.

The Capsule its Lumen (the inside space) collect and hold the filtrate

The Mesonephric tubule receives the filtrate which proceeds down the tubule and selectively adds and removes solutes and water, to turn a general blood filtrate into urine waste for discharge.

...the scientists say

There are five categories of fish kidney defined by Ogawa (1961). He suggested that the kidneys of freshwater fish can be grouped within first three of the five types described below.

1) No clear demarcation between head and trunk kidneys and the two kidneys are completely fused throughout as typified by the salmonids.

2) A visible (macroscopic) demarcation between the head and trunk kidneys. The middle and posterior portions are fused. From the middle-fused part two tube like structures emerge and the head kidneys are at the tips, typified by the cyprinids (carp family).

3) A clear distinction between the head and trunk kidneys. The kidney is distinguished into head, trunk and tail portions. The tail kidneys are fused, while the trunk and head kidneys are separated and are located at the tip of the anterior most region.

4) The head and trunk kidneys are separate except at the posterior most region where the kidneys are fused

5) The two kidneys are separate from each other and the tail kidneys thin and tube-like while the anterior trunk kidneys are thick. There is no morphological distinction between head and trunk kidneys.

Ref: https://www.yourarticlelibrary.com/fish/anatomy-and-physiology/excretory-system-in-fishes-with-diagram/88303

The above may be too bit specific and only of minor general interest. Could be replaced by some information about urine flow rates and urine composition in SW- and FW-adapted salmon.

Relevance to salmon husbandry

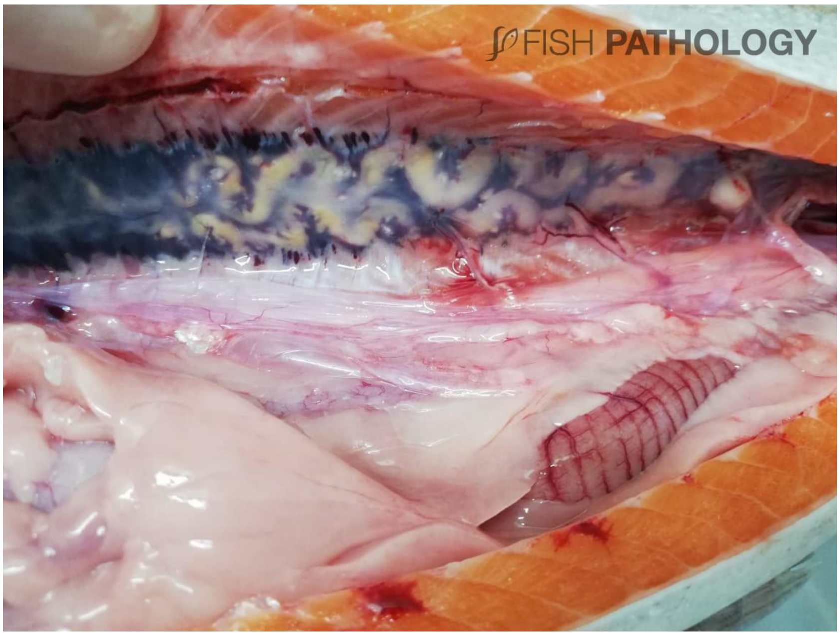
The kidney can become swollen and grey, with an irregular surface and the ureters sinuous, and thickened due to the mineral deposits when there are high levels of carbon dioxide (CO2) in the water (greater than 10-20 mg/L). This condition is known as Nephrocalcinosis. Overcrowding and low water flows can be a contributory cause, alongside infrequent causes, including magnesium deficiency, selenium toxicity and a diet low in minerals.

The risk of high CO2 is greater within RAS, making the monitoring and control of CO2 an important aspect of RAS water quality management. Research has demonstrated the risk of Nephrocalcinosis within RAS salmon production.

Fivelstad et al (2017) reported at PCO2levels (medians in the range 8.0-11.6 mmHg or about 21-30mgL-1), 9 of 26 salmon in a RAS (34%) developed nephrocalcinosis ($p < 0.05$) after 12 weeks in 34‰ sea water at 10 °C.

Fivelstad, S., Hosfeld, C. D., Medhus, R. A., Olsen, A. B., & Kvamme, K. (2018). Growth and nephrocalcinosis for Atlantic salmon (Salmo salar L.) post-smolt exposed to elevated carbon dioxide partial pressures. Aquaculture, 482, 83–89.

sci-hub.tw/10.1016/j.aquaculture.2017.09.012

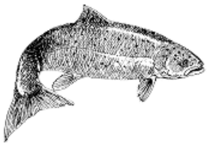


Gross appearance of nephrocalcinosis. The kidney is swollen and grey with an irregular surface and white mineral deposit in the ureters.

Image from Fish Pathology: https://fishhistopathology.com/home/2019/08/22/nephrocalcinosis-in-fish-gross-pathology/

(Note No permission to use)

SAP 14 Salmon anatomy and physiology



Digestive organs and system

The structure and function of the adult salmon's digestive organs typify those of most predatory fish species. When food is ingested, the digestive process begins, breaking down the large molecules into smaller molecules until they are eventually absorbed by the fishes' bloodstream. They can then be transported for use as an energy source, for cell repair and tissue maintenance, or, most importantly to the fish farmer, the growth of new muscle fibres.

Their digestive enzymes dominated by proteases (protein digesting enzymes) and lipases (fat digesting enzymes) can efficiently break down the salmon's diet rich in protein and fish oils. The **manufactured feeds** provided to farmed salmon closely mimic the nutritional profile of oil rich pelagic fish species, such as the clupeidae (herring family) that form a big part of their natural diet.

What are the main components of the salmon's digestive tract?

The newly hatched salmon fry (**alevin**) has a yolk sac attached to its stomach that supplies the essential nutrients stored for its subsistence until the digestive tract is functional and ready to accept **exogenous** food.

Salmon digestive tract

The structural components of a salmon's digestive system include the mouth, teeth, gill rakers, oesophagus, stomach, pylorus, pyloric caeca, pancreatic tissue (**exocrine and endocrine**), **liver**, gall bladder, intestine and anus.

As a carnivorous fish the mouth is large for engulfing prey whole, or in large chunks. Teeth are present on the jaws (maxillary and dentary) and tongue for grasping live prey. Gill rakers and pharyngeal teeth are short, typical of a carnivorous fish and pointed for moving prey down the throat.

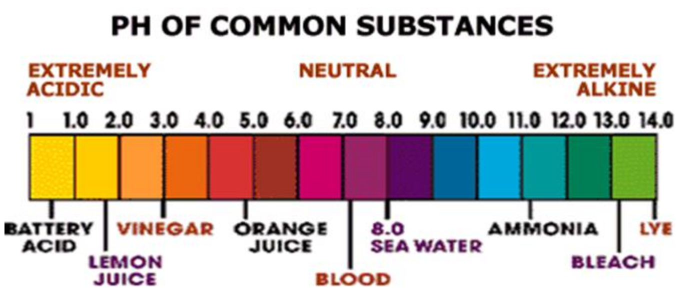
The digestive function and **appetite** are regulated by the combined actions of the **nervous system** and chemical signals that regulate movement of food through the alimentary canal, secretion of digestive enzymes and absorption of nutrients.

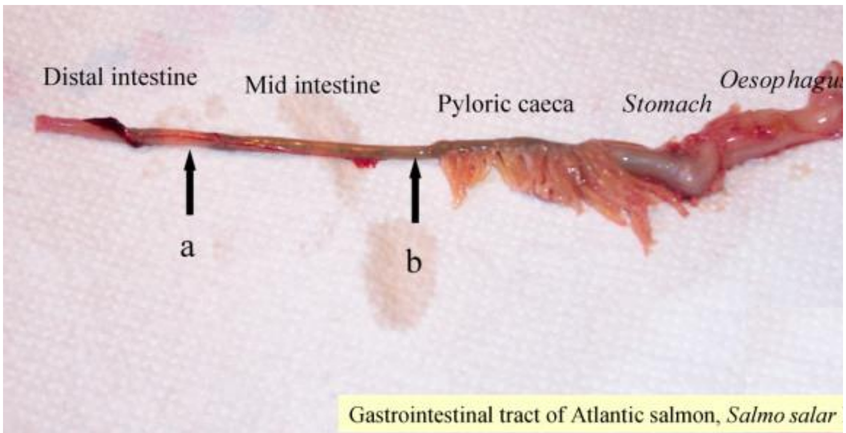
Limited information exists on osmoregulation and the regulation of **immune functions** of the alimentary canal. However, the role of the lower intestine in **osmoregulation** and as a site for **electrolyte** secretion and absorption is widely recognized

Key characteristics of the digestive system are:

- The salmon has a muscular ‘U shaped’ stomach that physically compresses food to aid digestion
- The stomach has an acidic pH of 2-4 to activate protein digestion.
- The intestine has an alkaline pH of pH of 8-9 and secretes enzymes as well as absorbing the products of digestion.
- The pyloric caecae have a role like the intestine and release alkaline digestive enzymes
- The salmon has a short intestine compared to some omnivorous and herbivorous species, as its protein rich diet does not take as long to digest
- The pancreatic tissue produces digestive enzymes (all macro-nutrients) and hormones to regulate blood sugar.

pH scale graphic **Articulate creative: Reproduce this scale**





Salmons digestive tract (Make interactive with better image)

13.1 The digestive process?

Articulate creative: produce drop-down named components of the digestive tract; oesphagus, stomach pyloric caecae, intestine and rectum. Names show when hovering the digital image below. Need to indicate Liver and Gall Bladder inputs somehow...Note: Need to take own ‘improved’ digital image...

Oesophegus: The oesophagus, which is lubricated by mucus, leads to the stomach which is muscular and elastic for holding large prey items.

Stomach: The stomach of predatory fish is a strong and tube-like muscular wall with a glandular lining. It can be a straight, or curved, as typified by the salmon. Once the prey has been ingested the muscular U-shaped’ stomach undergoes contractions, helping to physically break down the food being stored, and accelerating the chemical digestive process. The hydrochloric acidic secreted by **gastric pits** in the stomach lining, reduces the pH to between 2 and 4, similar to the acidity of vinegar. (**See pH graphic of common substances**) This is the optimum for the enzyme ‘pepsinogen’, secreted by the stomach wall and activated at low pH to become pepsin which can break down the large protein molecules.

Pylorus: Once the digestive process has begun, small quantities of partially digested food periodically pass from the stomach to the intestine via this muscular valve. The pylorus is a sphincter that prevents premature movement of the food bolus out of the stomach.

Pyloric caeca: Around the pylorus 40-74 'pouches' extend outward from the pyloric sphincter regions of the stomach and the anterior intestine. They play a role in the digestion and absorption of nutrients from food and resemble the intestine **histologically**.

Pancreatic tissue: Found in the vicinity of the pyloric caeca, but not contained within a discreet body and diffuse. As in all vertebrates, the pancreas has two digestive functions. It is the source of:

a) exocrine secretion of digestive enzymes (proteases, lipases, and carbohydrases) into the intestine and

b) endocrine secretion of the hormones insulin and glucagon that act to regulate blood sugar.

Intestine: The intestine is typically a short, S-shaped tube in carnivorous fish, lined with finger-like projections (villi) that greatly increase the surface area for absorption. The intestinal wall, while not as active as the exocrine pancreas, can secrete digestive enzymes, as well and is the site where most of the absorption of nutrients occurs. The large protein, fat, and any starch molecules in food that have been broken into smaller molecules by gastric acid and digestive enzymes move by diffusion or active transport (**ATPase pumps**) into the network of capillaries surrounding the gut.

It is not as muscular as the stomach and can vary in length, depending on the feeding habits and diet of the fish. In carnivorous species, such as salmon and trout, it is less than the length of the fishes' body. Conversely, in herbivorous fish such as some cyprinids the intestine length can be up to nine times the length of the body. This is because it takes a lot longer for chemical action to breakdown plant-based carbohydrates in the diet, than it does to breakdown protein from animal sources.

Relevance to salmon husbandry

1) Salmon feed formulations

Salmon diets are designed to have a similar nutritional profile to the salmon's natural foods and are high in protein and oil, mostly supplied by industrial fish meal and oil.

As the salmon has a limited ability to digest carbohydrate, this is mainly added to extruded diets to improve the structure of the pellet and allow more oil to be absorbed and provided for energy.

2) Gut evacuation and starvation

Gut evacuation rates (GER) & gut evacuation times (GET) are affected by water temperature, meal size, and feeding regime (timing of meals). Diet composition (at least for extruded feeds) does not have a noticeable effect.

Industry standard pre-harvest or pre-treatment starvation times are typically 3 days at <8°C, 2 days at 8-14°C, and 1 day at >14°C.

See 'the science says'

The digestive enzymes released are alkaline (pH 8-9) and further breakdown the products of digestion, to small enough molecules for absorption into the bloodstream. Unlike cyprinids, the carnivorous salmonids have low concentrations of 'carbohydrases', the enzymes necessary for **carbohydrate** breakdown, as most of their energy requirement is provided by oils (fat).

Liver and Gall bladder: The liver in fish produces bile which is stored in the gall bladder until a bolus passes the stomach, at which time the bile is expelled into the intestine. Bile contains waste products of liver activity which pass out of the fish in the faeces.

Bile has a digestive function in that it emulsifies lipids, greatly increasing their absorption in the intestine. The liver is key in the anabolism and catabolism of amino acids absorbed during digestion and is also the site of storage of food energy in the form of glycogen.

Does the intestine have any other role?

The cells of the gut lining in Saltwater fish use **Na + -K + ATPase** to create an **electrochemical gradient** similar to the **chloride cells of the gill** (but in the opposite direction). This moves NaCl into the tissue surrounding the gut creating a localized area of where the **osmoality** is greater than sea water which causes water to flow into the blood of the fish, thereby partially compensating water loss through osmosis.

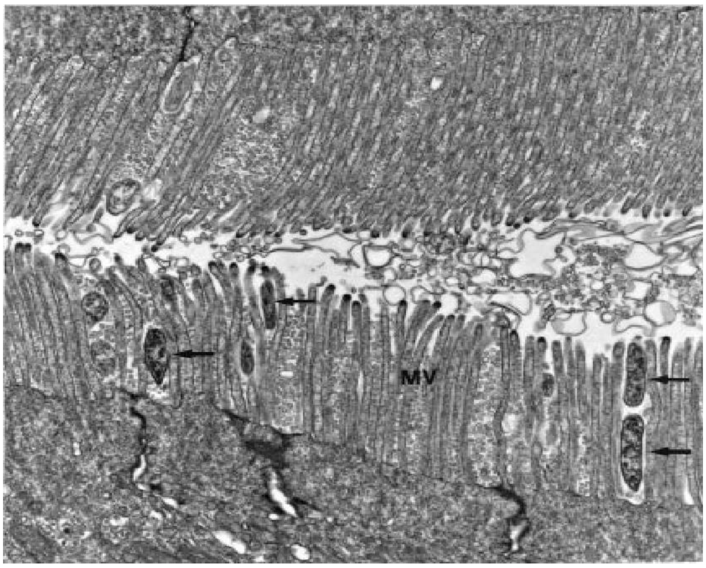
13.2 Health of farmed fish's digestive tract

A healthy digestive system is crucial for optimal farmed salmon performance. The expense of fish meal as a high-quality protein source, and the need for the sustainable management of the oceans industrial fish stocks has been driving radical changes in salmonid feed formulation. As the inclusion rates of **plant proteins** has gone up, damage to the gut **microvilli** in farmed salmonids appears to have increased.

What are the indicators of a healthy digestive system?

The salmon, in common with other fish, mammals and humans, has a unique and necessary gut **microbiota**. The fish **microbiome** can be diverse, including **protoctista**, fungi, yeasts, viruses, and members of the **Archaea** and Bacteria, the latter being the dominant microbiota of the fish intestine. Although the microbial community changes with life stage and habitat, a relatively stable gut microbiota is established within the first 50 days of life for many species. A comparison of the gut microbiota of 12 (adult) bony fish, found bacteria representing 17 phyla, with most species having between 7 and 15 phyla, a far higher average than found in egg and larvae microbiota. A recent meta-analysis investigating the factors affecting the gut microbiota composition of fish reported that **trophic level,** habitat and possibly **host phylogeny** are the most likely influences.

Char mid gut microvilli



The incidence of intestinal disorders due to radical changes in the gut microbiota composition of carnivorous farmed species, including Atlantic salmon, have been increasing. The gut microvilli are vulnerable as they are only protected by a single layer of epithelial cells. Any damage can impact on nutrient uptake and affect growth and performance. As some feed additives can be detrimental to gut microvilli, new yeast-based products with proven gut health benefits have been being developed and deployed. This has been linked to impact of increased levels of plant proteins on the gut microbiota. Concerted efforts are being made to reduce the negative impacts of plant ingredients, often through supplementation and further modification of the compound diets, as the **fish meal replacement** trend is unlikely to diminish.

Can the gut microvilli be protected?

The mucus, composed of mucins and glycoproteins, associated with the microvilli serve as an important barrier protecting the absorptive surface from feedstuffs, colonization by detrimental bacteria, and toxins. **Mannan oligosaccharides** derived from yeasts have been shown to affect gut health by pathogen adsorption and **immune modulation** when ingested, safeguarding farmed fish against enteritis and poor gut morphology. This can lead to inefficient feed conversion and the repair of damaged **enterocytes** which is an energy consuming activity directing valuable resources from growth to tissue repair and maintenance.

...**the scientists say**

1) Intestinal pH optima

The present knowledge of many aspects of digestive functions in fish is limited, particularly for Atlantic salmon. More understanding of the mechanisms underlying 'challenges' to gastrointestinal health and the means to prevent their development are needed. Symptoms indicating digestive malfunction that have been observed in cultivated salmon over the last 10–15 years, are thought to be partially due to new feed ingredients.

Research work undertaken on mechanisms underlying intestinal malfunctions and concluded that:

- The pH optima for enzyme function were mostly outside the prevailing chyme pH range in the stomach and along the intestine

- Intestinal chyme pH showed dependency on water salinity and dietary protein to energy ratio, but not by fish size

https://www.sciencedirect.com/science/article/abs/pii/S0044848615001155

2) Gut Evacuation

The gut evacuation rate (GER) and gut evacuation time (GET) for food to pass through the gut of farmed fish is relevant to designing feeding regimes (specifically the interval between meals as appetite is inversely related to stomach fullness), and also to how long fish should be starved prior to harvest to ensure the gut is empty of digesta.

The graphs show the results from two trials. On the left, salmon at 12°C were fed diets with 35% and 45% protein, and the time taken for food to pass through the different sections of the gut was measured. The stomach is almost empty by 48h (A), and digesta peaks in the pyloric caeca and mid-gut at 12h post feeding. These sections of the gut are also almost empty by 48h. Food in the hind gut peaks at 24h post-feeding and is almost empty by 48h, as in the other gut sections.

Feeding regime will affect gut evacuation rate and time. The graphs below show the results of a trial where fish at 7°C were fed a diet containing x-ray dense particles (the prandium, P) over a period of 3 hours. Knowing the number of particles per gram of food, the quantity eaten and the quantity remaining in the fish could be measured from x-rays of anaesthetised fish, allowing gut evacuation to be measured. The treatments differed in whether the fish were fed (with unlabelled food) or starved for 48h before the labelled meal, and indefinitely afterwards. Treatment A was starve-feed-starve (FSPF), Treatment B was starve-feed-feed (SPF), Treatment C was feed-feed-starve (FPS), and Treatment D was feed-feed-feed (FPF). SFS fish were hungry when the labelled meal was presented so they ate about 4% of body weight. This large meal and the fact that the fish were starved after the prandium meant that the evacuation time was around 60h. The SPF group also took a large meal but because they were fed after the prandium, the GET was around 40h. The FPS group were not very hungry when the labelled food was offered so they ate about 1% of their body weight but because they were starved after the prandium, the GET was about 60 hours. Finally, the FPF group also took a small meal but because they were fed after the prandium, the GET was only 20h. Basically, starvation slows food transit and feeding speeds it up.

276 H. Sveier et al. / Aquaculture 180 (1999) 265–282

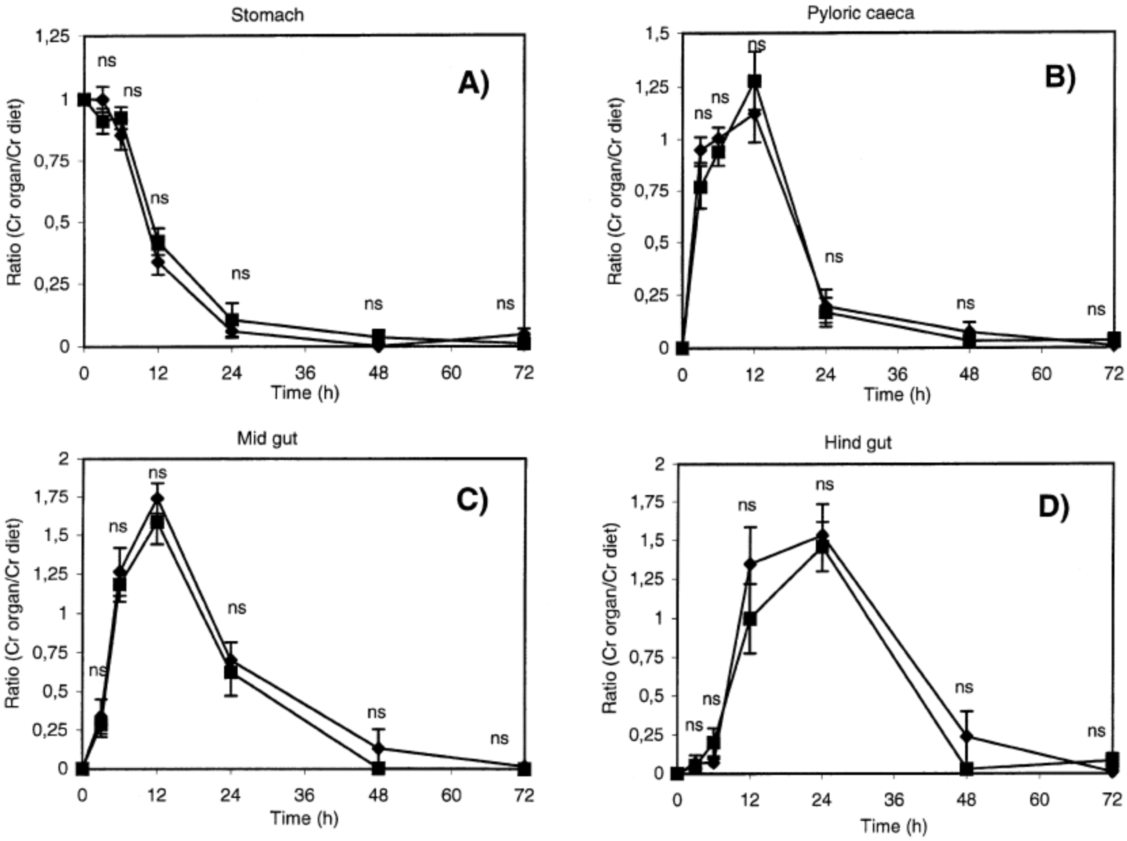


Fig. 3. The effect of protein level on the time-lapse for movement of a single meal through the gastrointestinal system. The bars indicate 1 S.D. and different letters show statistical differences between protein level at a given time. –◆– 30% protein –■– 45% protein.

The science says (cont)

Gut microbiota of marine fish

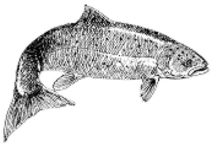
The diversity amongst fish means that baseline data from wild fish and a clear understanding of the role that specific gut microbiota play is still lacking. The factors shaping marine fish gut microbiota are reviewed below and gaps in the research highlighted.

https://www.frontiersin.org/articles/10.3389/fmicb.2018.00873/ful

Gut morphology – Key to efficient nutrition

https://thefishsite.com/articles/gut-morphology-a-key-to-efficient-nutrition

SAP 15 Salmon anatomy and physiology



Homeostasis

Salmon, like all higher vertebrates, possess highly developed and powerful homeostatic mechanisms to regulate their physiology. Homeostasis is the tendency for an organism or cell to maintain a constant internal environment within narrow tolerance limits. The fish's internal equilibrium is maintained by adjusting physiological processes, including:

- Blood oxygen and carbon dioxide concentration
- Blood pH (Averages 7.4)
- Blood nutrient and glucose levels (**appetite** control)
- Salt and Water balance (**osmoregulation**)

Homeostatic mechanisms operate via feedback loops involving either the **nervous** or **endocrine** systems (or both). When specialised receptors detect an internal change to conditions, a response is generated to correct the change. The **afferent pathways** send messages to the control centres and the **efferent pathways** send the output to the effector leading to a response to the change.

When levels return to equilibrium, the effector ceases to generate a response and an internal balance is therefore maintained and internal physiological conditions are kept within the fish's tolerance limits. If homeostasis breaks down and these limits are exceeded for a period, **stress** can result and lead to **disease**.

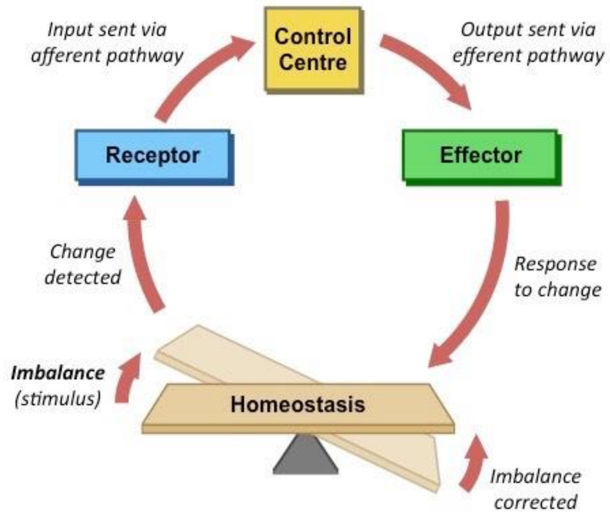
Homeostasis operates at all temperatures. For example, a salmon acclimated at 6°C can regulate its blood chloride level, just as well as a fish acclimated to 16°C. At extreme temperatures beyond the salmon's tolerance limits, this ability breaks down. This is not a characteristic unique to cold blooded animals as the same can happen to warm-blooded mammals including humans!

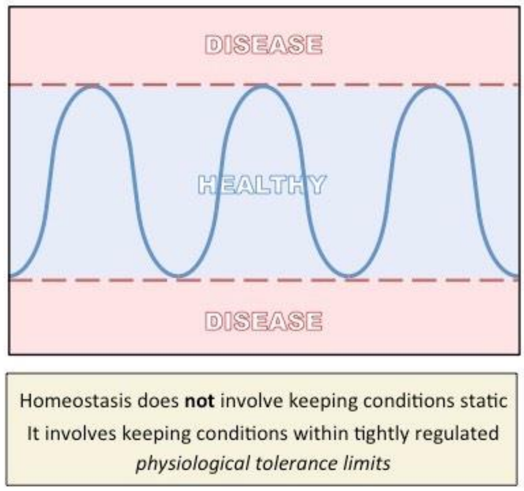
Physiological responses to low dissolved oxygen

The multitude of responses to low oxygen levels is a good example of homeostasis in action. The fish is compensating in order to maintain a sufficient supply of oxygen to the cells and tissues, as required to support respiration and metabolism.

- Increased gill ventilation rate
- Reduced swimming activity Increase blood flow to gills
- Changing location in cage/tank
- **Perfusing** more **secondary lamellae**
- Reducing blood flow to digestive organs
- Releasing **Red Blood Cells** from spleen/erythropoiesis
- Lowering **metabolism**
- Eating and growing less
- **Bohr shift//Root effects** (offloading of O_2 from haemoglobin to tissues in response to lowering of blood pH due to metabolic CO_2 production)

+





Articulate Creative': Recreate the graphic above (Static – non interactive will do I think)

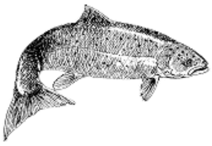
Relevance to salmon husbandry

The first three homeostatic responses to lowered dissolved oxygen levels referred to above are visible to the observant stock husbandry man.

- Increased gill ventilation rate
- Reduce swimming activity Increase blood flow to gills
- Change location in cage/tank

When these fish behaviours are observed, oxygen levels should be measured and action taken to remediate, such as increasing flow rates, and or additional oxygenation of the water. The observation may be caused by a system RAS failure.

SAP 16 Salmon anatomy and physiology



Metabolism and acclimation

The salmon's optimum temperature for growth and activity is close to 15oC.

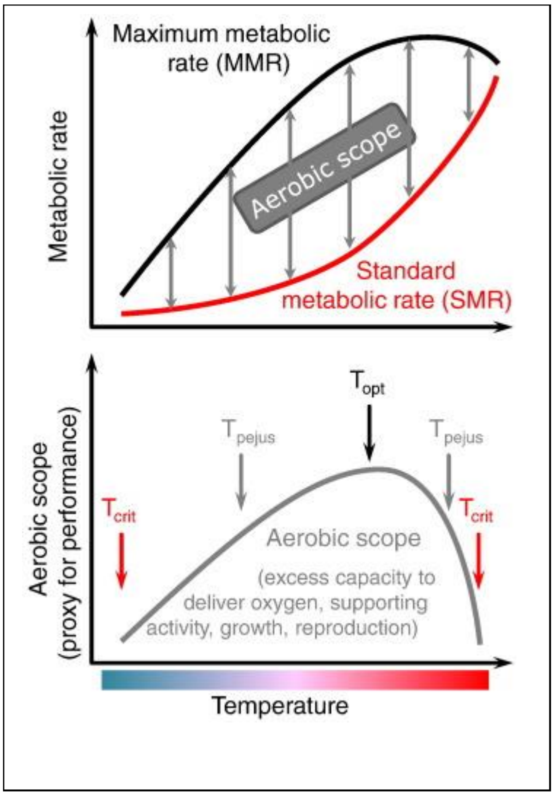
What does it mean to be 'cold blooded'?

Salmon, like all fish, are cold-blooded, meaning that they cannot regulate their body temperature, which always remains the same as the external aquatic environment. Cold-blooded animals are known as 'ectothermic', differentiating them from warm-blooded 'endothermic' mammals. Temperature affects enzyme reaction rates, and the warmer it is, the faster the reactions. This affects the metabolic rate and life processes such as locomotion (swimming), appetite and growth.

How do salmon adjust to sudden changes in water temperature?

An important distinction needs to be made between the effects on metabolism of acute (abrupt) changes in temperature, and the long-term effect once the fish has undergone biochemical adjustments known as 'thermal acclimation'.

Thermal acclimation is a mechanism that ensures that fish do not overheat at high temperatures, or grind to a standstill at low temperatures.



Aerobic scope for additional activity is greatest at the optimum temperature of 15oC for salmon (T opt)

Key characteristics of salmon metabolism

- Water temperature determines the metabolic rate, which influences, appetite, feeding, digestion, growth, swimming activity, reproduction, and behaviour as fish are cold blooded
- The optimum temperature for a salmon's physiological activities, including growth is 15oC.
- In the short term, temperature changes result in acute physiological effects.
- In the long term, fish can acclimatise to a new temperature and restore normal physiological functions.
- Thermal acclimation takes several weeks following an abrupt change in water temperature.

While it is true that growth is faster in fish at higher temperatures compared with colder temperatures (within tolerance limits), the differences in oxygen consumption and metabolic rates are much less than seen immediately after an abrupt temperature change.
This also means that for a given body size, warm water species have much the same oxygen consumption as cold-water species.

15.1 Metabolism - Terms and units of measurement

The salmons metabolic rate (O_2 consumption, mg/kg/hr) can function at 4 levels.

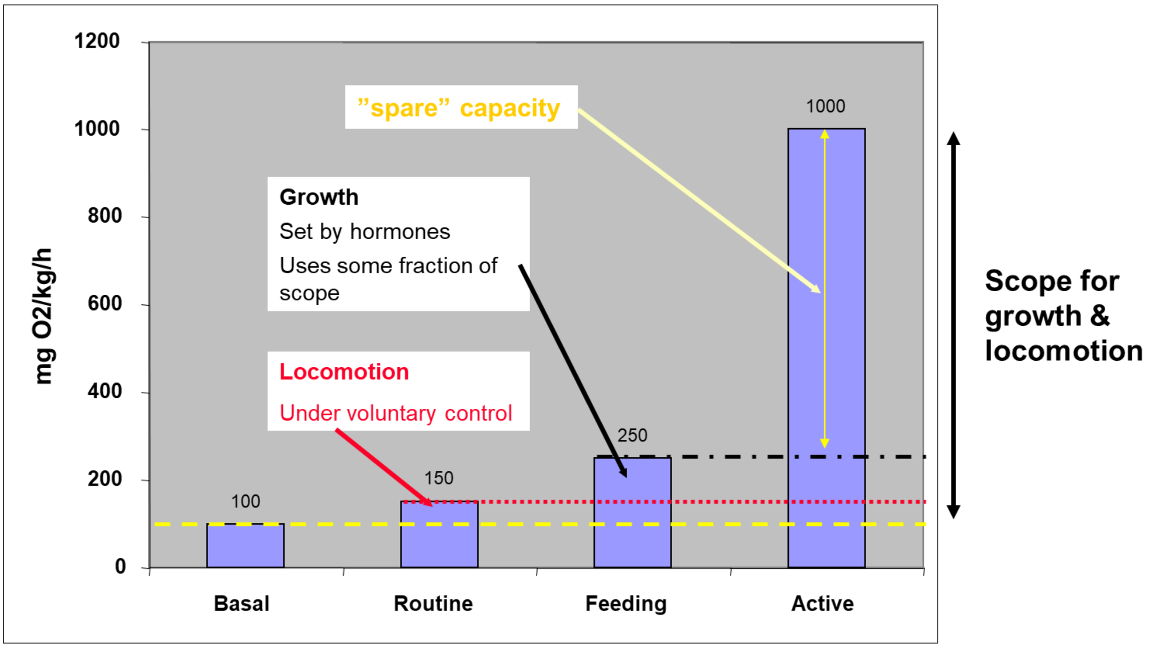
The metabolism of a fish which consumes oxygen at different rates can be likened to a car engine burning fuel. the engine is running, but out of gear and the car standing standing still. It uses fuel, but very little. This is equivalent to the Basal metabolic rate (BMR). When the car is put in to gear and as the divers foot put depresses the accelerator, the fuel consumtion goes up. Initially, this can be likened to the Routine metabolic rate (RMR), but when the the accelerator pressed to the floor the engines workrate is maximised and it can not go any faster or consume fuel at a higher rate. This is equivalent to the Active metaboloc rate (AMR) which is typically 8 to 10 times the the BMR

See Terms used in metabolism

- Basal (BMR). Minimum in resting fish, no food. Also called Standard (SMR).
- Routine (RMR). Normal spontaneous activity, no food.
- Specific Dynamic Action (SDA) or heat increment. Feeding, digestion, biochemical processing. Typically, 2-3 times the BMR or 1.5 times the RMR.
- Active (AMR). Maximum sustained activity. Equivalent to ”aerobic capacity” Typically 8 to 10 times the BMR.

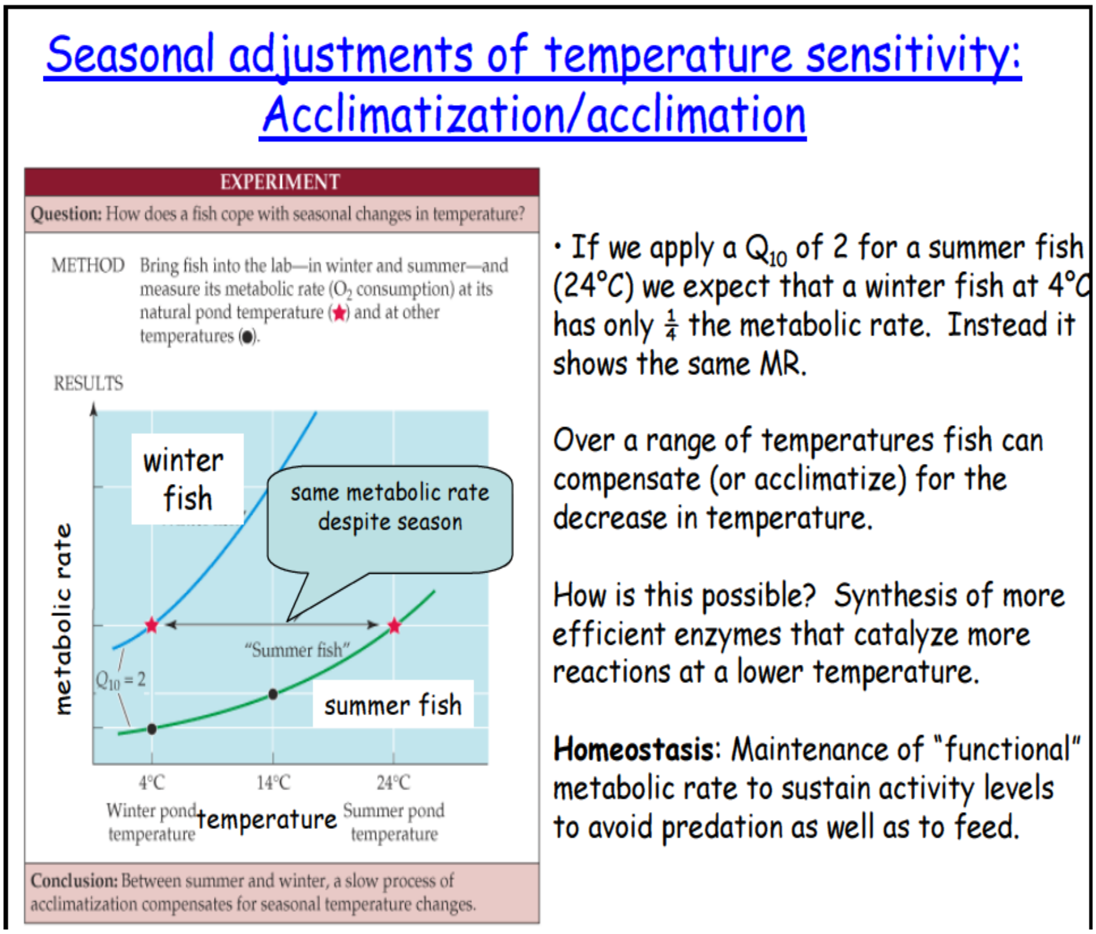
Terms used in metabolism

Articulate creative: Link the terminology to the graphic to get the definitions above as drop downs



...**the scientists say**

Fish can slowly adjust their functional metabolic rate to be relatively constant as seasonal temperature regimes change, as illustrated by the below research results.



Articulate creative:

The two diagrams need to be simplified

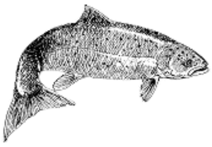
Relevance to salmon husbandry

The salmon farmer is acutely aware of the influence of water temperature changes on metabolism and key fish activities, particularly appetite, feeding and growth. Feed rates are revised accordingly.

See Fish feeding and nutrition

Whenever salmon are moved from one environment to another, water temperatures are checked. If there is a significant difference, the temperatures are either equalised in the two environments, or the fish are carefully acclimatised on transfer, to avoid any temperature shock and subsequent stress.

SAP 17 Salmon anatomy and physiology



Sensing the outside world

The Atlantic salmon is equipped with a remarkable set of tools that have evolved to help them navigate, detect predators, and prey, and defend themselves in the diverse environments they live. In common with other **teleosts,** they have a well-developed nervous system, that allows them to sense and respond to the outside world due to a range of well-developed sensory faculties.

What is the basic macro-structure of the nervous system?

Anatomically, the nervous system can be divided into a central nervous system (CNS) and peripheral nervous system (PNS). There is a great interaction and interchange between nervous system and endocrine systems. Some neurons display the characteristics of both nervous and hormonal systems and are termed as **neurosecretory** or **neuroendocrine**.

The central nervous system consists of brain and spinal cord. All nervous tissues other than brain and spinal cord make up the peripheral nervous system, consisting of nerves (composed of nerve cells known as neurons), ganglia, and receptors and are divisible into **somatic** (controlling movement under conscious control) and **visceral** (directing bodily functions not under conscious control).

Salmon brain exposed

What is the nervous system made up of?

The nervous system is made up of two chief types of cells, the nerve cells and supporting cells. The nerve cells are known as neurons and are functional units.

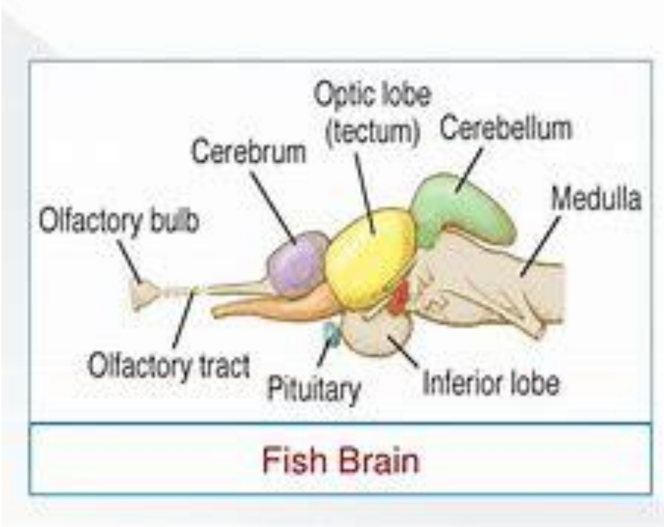
Messages travel through the body of a nerve cell and are adapted for transmission of the impulse to the next functional unit. This may be another nerve cell, a muscle or a gland acting as a system of communication and ‘command control’.

How does the salmon’s nervous system function?

The central nervous system of the salmon as with other bony fish (Osteichthyes) is comprised of a brain and a spinal cord, just like our own central nervous system.

The salmon’s brain is typical of most fish and is small compared to its overall body size, approximately 1/15th the mass of a similarly sized mammal or bird. Some bony fish, such as the freshwater elephant fish (Family Mormyridae), have exceptionally large brains in comparison to overall body size.

Regardless of brain size, **osteichthyes’** brains are structurally and functionally similar and divided into several anatomical and functional parts, all closely interconnected but each serving as the primary centre for integrating responses and activities. Several of these centres or parts are primarily associated with one type of sensory perception, such as sight, hearing, or smell (olfaction).



Salmon brain anatomy

Articulate creative: Make a drop-down information box for each brain component's function, using the text opposite (The component names need to be modified)

The **olfactory lobes** lying at the rostral, or nose end of the fish**,** provide the sense of smell. Some species of bony fish have exceptionally large olfactory lobes, particularly catfish and other predators that hunt by smell. The salmon's is of a moderate size as they are largely visual feeders.

The **telencephalon** lies behind the olfactory lobes and is the equivalent to the cerebrum in most other vertebrates. Our cerebrum is the part of our brain that is allowing us to read this sentence. Together, the olfactory lobes and the telencephalon comprise the forebrain.

The **diencephalon,** a hormone-balancing structure, connects the forebrain to the midbrain and is associated with the **pineal body**, which detects light and dark and coordinates colour changes.

The **mesencephalon** (midbrain) itself is comprised of two optic lobes, which are especially well-developed in **osteichthyes** that hunt by sight, such as the salmon.

The **metencephalon** (hindbrain) lies at the caudal (rear) end of the brain and contains the cerebellum that controls movement and balance in humans. The cerebellum has a similar function in the salmon, coordinating balance and controlling the movements that help the fish to swim and is the largest part of the brain in many fish.

The **myelencephalon** connects the hindbrain to the spinal cord and has a function in osmoregulation (water balance) and respiration.

The **Hypothalamus** is connected by a thin stalk to the **pituitary** hanging beneath it, the master gland that controls the endocrine system.

A fish's spinal cord transmits motor messages to its peripheral nerves and sends sensory messages back to the brain. The **peripheral nervous system** branches throughout the body and ensures that the salmon has high levels of sensory detection that enable it to thrive in diverse aquatic environments.

How does the salmon's peripheral nervous system enable sensory detection?

As in all vertebrates, the nervous system of fishes is the primary mechanism coordinating body activities, as well as integrating these activities in the appropriate manner in response to stimuli from the environment. The central nervous system, consisting of the brain and spinal cord, is the primary integrating mechanism.

The peripheral nervous system, consisting of nerves that connect the brain and spinal cord to various body organs, carries sensory information from special receptor organs such as the eyes, internal ears, nares (sense of smell), taste glands, and others to the integrating centres of the brain and spinal cord. Coded information is carried to the various organs and body systems, such as the skeletal muscular system, for appropriate action in response to the original external or internal stimulus.

Another branch of the nervous system, the **autonomic nervous system**, helps to coordinate the activities of many glands and organs and is itself intricately connected to the integrating centres of the brain.

What is the range of salmon sensory functions?

Pain

A salmon, like other vertebrates, seldom needs to rely on a single type of sensory information to determine the nature of the environment around it. For example, a catfish uses taste and touch when examining a food object with its oral barbels.

Relevance to salmon husbandry

Animal welfare legislation recognises fish as sentient and this has driven the development of legislation to ensure higher welfare standards for farming and slaughter of fish.

The consumer is increasingly aware of welfare issues and will adjust their buying behaviour if dissatisfied. Eliminating pain and reducing stress is a central consideration for salmon farmers today.

Like most other animals, salmon have many touch receptors over their body surface. Pain and temperature receptors can be presumed to produce the same kind of information to a fish as to humans. Fishes react in a negative fashion to stimuli that would be painful to human beings, suggesting that they feel a sensation of pain.

Sound

Sound perception and balance are intimately associated senses in a salmon. Having a greater density, water is a much efficient conductor of sound pressure waves than in air. Therefore, sound travel 4-8 times as faster under water. The organs of hearing are entirely internal, located within the skull, on each side of the brain and behind the eyes. Sound waves, especially low frequencies, travel readily through water and are transmitted to the hearing organs by the bones and fluids of the head and body. Compared with humans, however, the range of sound frequencies heard is greatly restricted. Some fish communicate with each other by producing sounds in their **swim bladders**, in their throats by rasping their teeth, and in other ways.

Articulate creative

Insert salmon image (line drawing or digital image) that includes the following hotspot areas..... On hovering over the area, the name of the organ appears, their sensory function and each paragraph opposite.

Pressure

The **lateral line** is an important sensory system that is absent in other vertebrates (except some amphibians). This consists of a series of heavily innervated small canals located in the skin and bone around the eyes, along the lower jaw, over the head, and down the mid-side of the body, where it is associated with the scales. Intermittently along these canals are located tiny sensory organs (pit organs) that detect changes in pressure. The system allows a fish to sense changes in water currents and pressure, thereby helping the fish to orient itself to the various changes that occur in the physical environment and to sense its prey and predators.

> **...the scientists say**
>
> Research relevant to salmonid sentience and monitoring farmed salmon welfare is required here.

Salmon Olfaction (Smell)

The sense of smell is important in almost all fishes, including salmon, especially as a navigation aid. The **olfactory**, or nasal, organ of fishes is located on the dorsal surface of the snout. The lining of the nasal organ has special sensory cells that perceive chemicals dissolved in the water, such as substances from food material, and send sensory information to the brain by way of the first cranial nerve. Odour can also serve as an alarm system. Many fishes, especially various species of freshwater minnows, react with alarm to a chemical released from the skin of an injured member of their own species.

Taste

Many fishes have a well-developed sense of taste, and tiny pit like taste buds or organs are located not only within their mouth cavities but also over their heads and parts of their body. Catfishes, which often have poor vision, have barbels ("whiskers") that serve as supplementary taste organs, those around the mouth being actively used to search out food on the bottom. Salmon have taste buds in their gill arches to help feed detection, as well as the tongue.

Balance

Besides sound detection, the inner ear functions to 'orientate' or 'balance' the salmon by providing a sense of gravity, even when suspended in lightless, pelagic habitats. The **endo-lymphatic duct**, a short and closed tube connecting the membranous labyrinth of the inner ear with the blind ended **endo-lymphatic sac** is instrumental. In elasmobranchs (sharks, rays, and skates) the endo-lymphatic duct arising from the inner ear extends to the external environment. Sand particles enter through this duct and reach the **gelatinous cupulae** covering the sensory cells and perform the same function as otoliths in teleosts.

Otoliths are biomineralized 'ear stones' that contribute to both hearing and vestibular function (balance) in fish and are found in different shapes and sizes for different fish species. In response to sound or movement, the inertia of the otolith relative to the body tissue of the fish creates a shearing force on the underlying sensory epithelium, resulting in hair cell activation or inhibition which provides a signal that allows the fish to orientate. Biologists can estimate fish age by counting the opaque zones visible in otoliths, called annuli, just as one would count rings on a tree to determine its age.

Image of Vestibular system (Inner ear) Can we find a better one?

Articulate creative: Produce a simplified (better) version of the below graphic

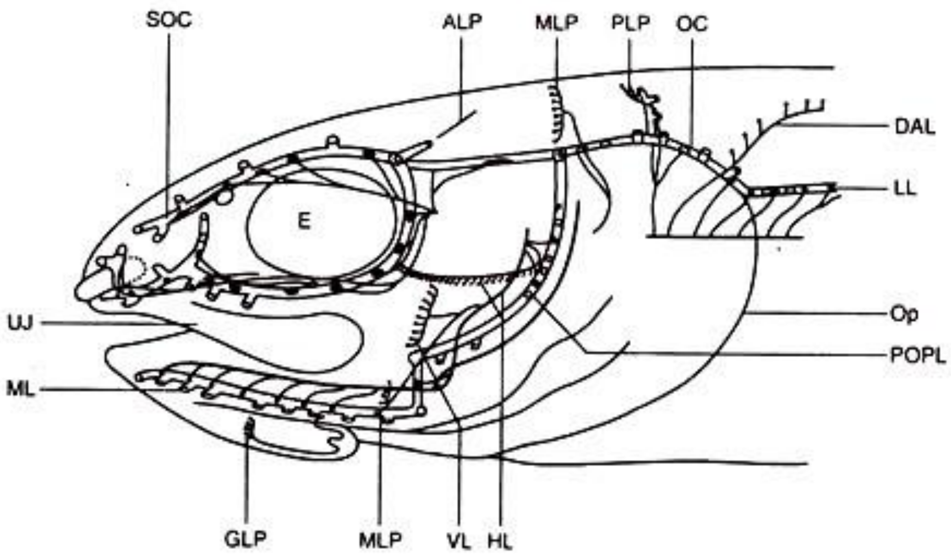
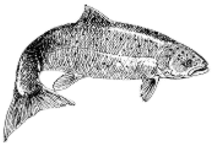


Fig. 15.5 : Sensory lines; organs and innervation of organs in bowfin (*Amia*). ALP, anterior pit line; DAL, dorsal sensory line organ; E, eye; GLP, gular pit line; HL, horizontal pit line; LL, lateral line; ML, mandibular line; MPL, middle pit line; OC, occipital canal; Op, operculum; PLP, posterior pit line; POPL, preopercular line; SOC, supra orbital canal; UJ, upper jaw, VL, vertical pit line.



Endocrine system

Many of the key activities of higher animals, including reproduction, appetite, feeding, and growth are under the direction or influence of hormones released in response to external environmental stimuli that have been detected by the **nervous and sensory system**.

The glands that secrete hormones into the bloodstream and body tissues along with the central nervous system to control and regulate many kinds of body functions are known as endocrine glands. In fishes, various endocrine gland has been found associated with different tasks and functions.

Key characteristics of the endocrine system

- The pituitary (hypophesis) at the underside of the brain is the 'master gland', controlling most endocrine functions.
- The adrenal gland secretes adrenalin which promotes metabolism and prepares the fish for exertion.
- Cortisol, produced by the adrenal gland is monitored as a stress indicator.
- Thyroid gland secretes thyroxine that controls oxygen consumption and influences growth
- The pancreas secretes insulin for carbohydrate metabolism and blood sugar regulation

Endocrine glands of fishes: Different types of endocrine glands are found in fish such as the;

- Pituitary gland or Hypophysis
- Thyroid Gland
- Adrenal gland
- Corpuscles of Stannius
- Ultimobranchial Glands
- Urohypophysis
- Pancreatic islets
- Pineal gland

The **pituitary gland or hypophysis** in adult fish is attached with it by a stalk (called infundibular or neurohypophyal) and occupies a position on the underside of the brain, in the region of diencephalon. Often known as the 'master gland', as it regulates many of the activities of other glands, including the adrenal and thyroid glands. It also has a direct role in growth, reproduction, osmoregulation, and pigmentation.

The other glands have more specific roles:

Gland	Function	Comments
Thyroid	Secreted thyroxine to control oxygen consumption. Influences growth, nitrogen metabolism and scale formation.	Also influences fish migration
Adrenal	Secretes adrenalin and cortisol. Promotes metabolism of proteins (catabolism), carbohydrates, water, and the utilisation of steroid fat. Gets the fish ready for extreme exertion.	Cortisol is often monitored in fish as a stress indicator. (See **Fish health and welfare**)

Corpuscles of Stannius	Secretes hypocalcin to regulate calcium balance	
Ultimobranchial Glands	Secretes calcitonin to regulate the calcium level in blood	
Urohypophysis	Secretes urotensins for metabolic regulation	Known as the neurosecretory organ
Pancreatic islets	Secretes insulin for carbohydrate metabolism	Controls blood sugar levels
Pineal gland	Secretes melatonin	Photosensory and secretory function

What external stimuli influence the endocrine system?

Many salmon life processes are under the influence of **photoperiod**. These may be short-term diurnal (24h) processes such as appetite and feeding or long-term processes such as reproduction and growth.

Light, and its characteristics including intensity, colour, duration, rate of change, and direction of change, enters the fish's brain through the pineal window where it acts on the pineal gland.

The pineal gland mediates a range of hormones – melatonin being the most important – and **neurotransmitters**, which instigate and regulate many physiological processes.

Relevance to salmon husbandry

Light regimes are often imposed on salmon during the hatchery freshwater phase, and during grow out, for a variety of reasons

1. Photoperiod manipulations are commonly carried out in fish farming, especially to control sexual maturation. This allows hatcheries to produce eggs all year round, as opposed to being restricted by the seasons.
2. Light regimes are imposed in hatcheries and at times during grow out to increase the fish intake and growth rate.

See Hatchery 2 and Grow out

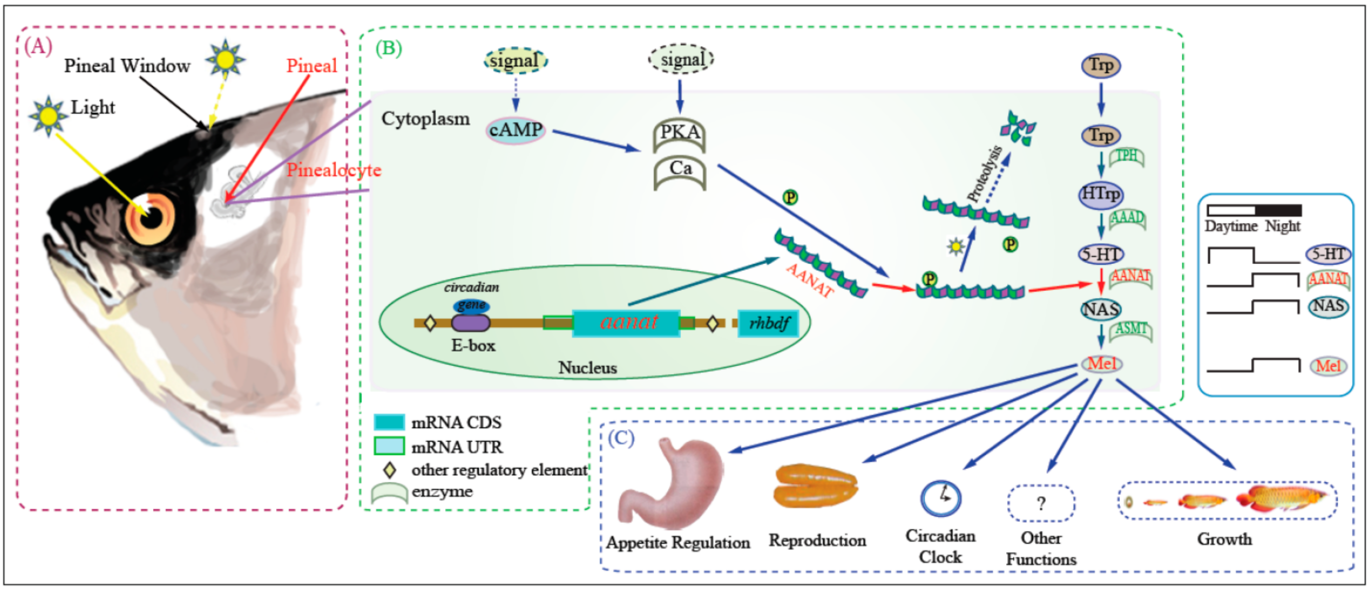
3. The timing of smoltification can be controlled by appropriate photoperiod regimes in the hatchery

See Hatchery 2

4. Light regimes can be imposed to control and reduce the early sexual maturation (grilsing), which can lead to poor product quality and reductions in growth efficiency

See Grow-out

Any more PS?

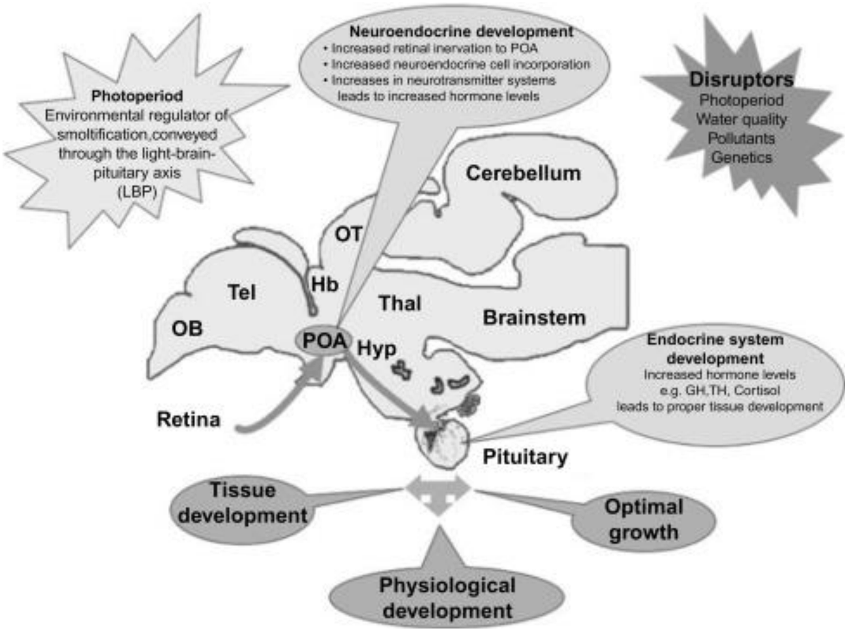


Articulate creative: Recreate a version of this image on the right can be designed as a salmon head with simple interactions to reveal Pineal and the effect of light.

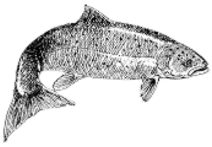
Notation and symbols on this potentially useful graphic need to be simplified and clarified

Alternative smoltification graphic:
https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/smoltification

Articulate: Recreate this image



SAP 19 **Salmon anatomy and physiology**



Appetite control

Like most animals, salmon continue to feed until they have satiated their appetite, and then stop feeding, regardless of how much food is available, until hunger and the desire to feed returns.

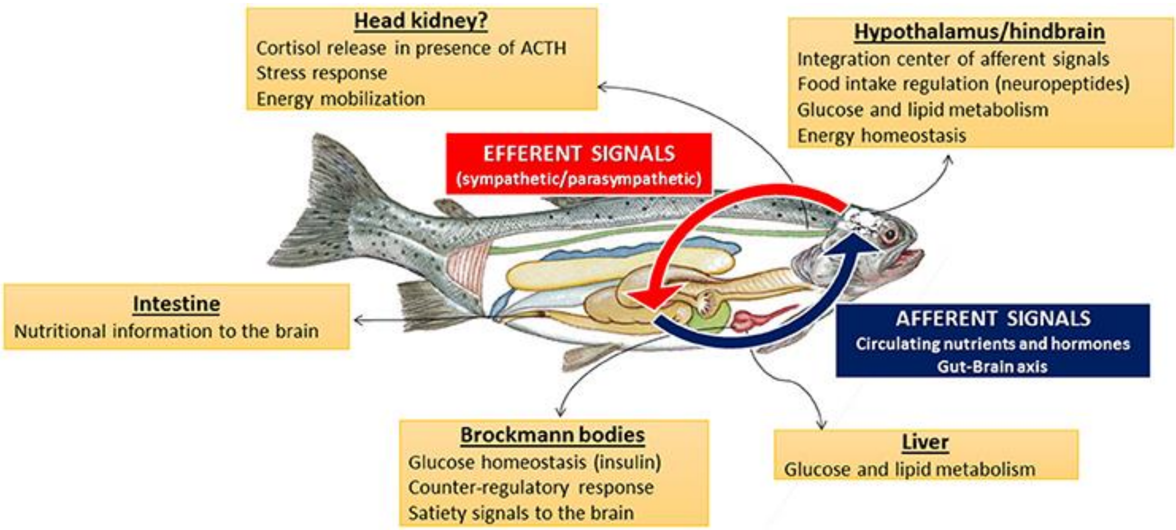
Periods of low feed intake, due to restricted food availability or environmental constraints are usually followed by an increase in appetite and higher than usual feed intake. As a carnivore, with a muscular but elastic stomach, salmon can ingest large prey items and meals to capitalise on periods of high food availability. This enables the fish to make up for the previous lost potential growth and is known as **compensatory growth.**

Key characteristics of appetite

- A salmon will consume as much food as it needs to satiate its appetite.
- Satiation is dependent on sensing a high concentration of blood nutrients, (especially amino acids)
- Feeding activity is regulated by neuropeptides and hormones in the blood stream

How is the salmon's appetite normally controlled?

A complex feedback mechanism to signal hunger and satiation is dependent on sensors for blood nutrients (specifically **amino acids**), metabolic signals, and energy status, and a range of **neuropeptides** and **hormones**. Together they regulate feeding activity. Fish, like all animals, "know" how hungry they are, and a satiated fish will not eat more food if it is offered.



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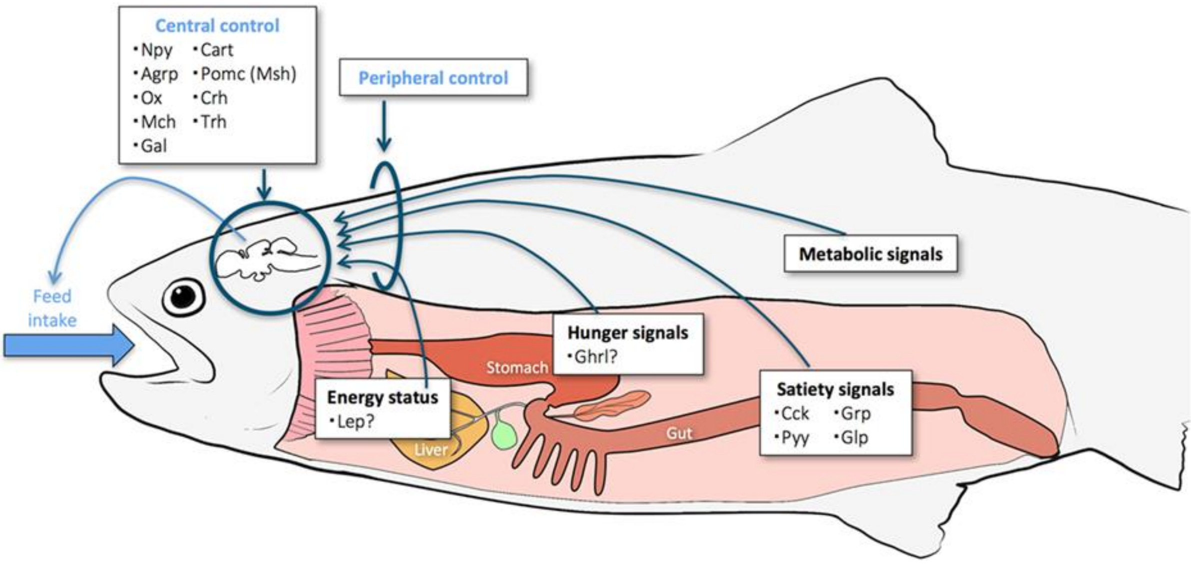
Relevance to salmon husbandry

Feeding salmon on a farm is carried out daily by farm technicians who must carefully monitor fish appetite and behaviour taking any necessary actions to ensure all fish are fed adequately and that optimal feed conversion and minimal wastage is achieved.

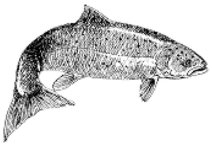
(See **Fish feeding and nutrition**)

You cannot "push" fish to grow faster, unless the fish are chronically underfed.



Articulate creative: To convert a chosen image (or amalgamation of the two images to create an informative interactive version with drop down information

SAP 20 **Salmon anatomy and physiology**



Respiratory system and oxygen consumption

The respiratory system

The salmon's oxygen supply is dependent on heathy functioning **gill lamellae**, designed to support efficient diffusion of dissolved oxygen from their aquatic environment. Oxygen is then transported round the body via the haemoglobin in the **red blood cells** to tissues in the body where it is required to support respiration. Respiration is one of the main ways a cell releases chemical energy to fuel cellular activity. Cellular respiration converts chemical energy from oxygen molecules and nutrients into adenosine triphosphate (ATP), and then release waste products. Although technically a **combustion** reaction, when it occurs in a living cell because of the slow, controlled release of energy from the series of reactions, it does not resemble one.

What is ATP?

Adenosine triphosphate (ATP) is a high energy molecule that cells use to power their various functions such as muscle cell contraction. It is present in the cytoplasm and nucleoplasm of every cell and is provided by being converted to ADP (adenosine diphosphate). Since the basic reaction involves a water molecule, ATP + H2O → ADP + Pi this reaction is commonly referred to as the **hydrolysis** of ATP.

Control of respiration

Scientists have investigated the respiratory rhythm and have identified the part of the body responsible for maintaining it.

...the scientists say....

The reactions involved in respiration are catabolic reactions, which break large molecules into smaller ones, releasing energy because weak high-energy bonds, particularly in molecular oxygen, are replaced by stronger bonds in the products. The overall reaction occurs in a series of biochemical steps, some of which are **redox reactions**.

Neurons located in the brainstem of fish are responsible for the genesis of the 'respiratory rhythm'. The position of these neurons is slightly different from the centres of respiratory genesis in mammals, but they are in the same brain compartment, which has caused debates about the development of respiratory centres by aquatic and terrestrial species and evolutionary links. In both aquatic and terrestrial respiration, the exact mechanisms by which neurons can generate this involuntary rhythm are still not completely understood.

An important feature of the **respiratory rhythm** is that it is modulated to adapt to the oxygen consumption of the body. As observed in mammals, fish "breathe" faster and heavier when they are

Relevance to fish farming

When salmon need more oxygen to fuel respiration, this can often be observed by the fish farmer, as the fish's gill covers (operculum) beat to a faster rhythm than normal. This increases the flow of water over the gill lamellae, bringing them into contact with more dissolved oxygen. When the dissolved oxygen concentration is low in the holding unit and/or the fish stressed, the operculum rhythm increases, providing the farmer a strong visual signal to improve conditions to safeguard **fish health and welfare.**

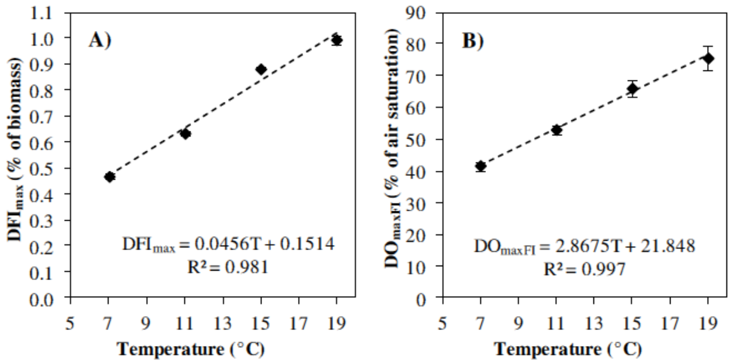
The consumption and digestion of food requires energy released from respiration which can double the oxygen demand due to Specific Dynamic Action (SDA). Therefore, the rearing environment should be maintained at 100% saturation of dissolved oxygen, to ensure fish are not stressed when fed because of SDA and have optimal conditions for digestion and metabolism.

...the science says

This data from: Remen et al 2016 (Aquaculture 464; 582-592), shows the effect of O2 availability on daily feed intake.

The oxygen threshold for maximum feed intake of Atlantic salmon post-smolts is highly temperature dependent.

This is particularly important for senior managers If they think DFI varies linearly with O2, then they will underfeed and lose growth. More interpretation of graphs needed with the emphasis perhaps on the science and a link to the Feeding and Nutrition Unit for the application...



... the scientists have differences of opinion....

Articulate creative: Insert cartoon of two scientists arguing

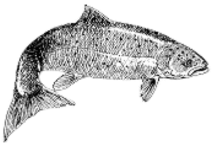
1. Respiratory changes are pre-programmed in the brain, which would imply that neurons from locomotion centres of the brain connect to respiratory centres in anticipation of movements.

2. Respiratory changes result from the detection of muscle contraction, and that respiration is adapted according to muscular contraction and oxygen consumption. This would imply that the brain possesses a detection mechanism triggering a respiratory response when muscular contraction occurs.

Many now agree that both mechanisms are probably present and complementary, or working alongside a mechanism that can detect changes in oxygen and/or carbon dioxide blood saturation.

physically exercised. The mechanisms by which these changes occur have been strongly debated over more than 100 years between scientists

SAP 21 **Salmon anatomy and physiology**



Immune system

Salmon, like all higher vertebrates, have a well-developed immune system although not as advanced as those found in mammals. The system breaks down into two main parts:

- protection from physical invasion and
- combatting internal pathogens.

Physical protection comes in the form of **scales** and the layers of **dermis** and **epidermis**. These provide defence against physical injury and disease organisms in the environment, assisted by a mucus covering containing bactericides and fungicides. This mucus membrane is constantly renewed, sloughing off debris and discouraging parasites.

Pathogens can still enter the fish's body, either through physical injury or the digestive tract. Despite active enzymes in the digestive system and a pathogen-unfriendly pH level, pathogens can sometimes survive.

As soon as a pathogen is detected, the fish's body coordinates its resistance: firstly, the entry point is sealed off to correct any **osmoregulatory** problems and hamper the foreign body's progression.

The innate defence response is activated, which provides an immediate protection to a wide range of invading microbes but does not provide any **lasting immunity.**

... **the scientists say**

The salmon has both innate (non-specific) and adaptive (antigen-specific) capabilities.

Innate immune defences are non-specific, providing a common 'generic' response to pathogens and are the dominant system of host defence in most organisms but do not confer long-lasting immunity against a pathogen.

The innate response is usually triggered when microbes are identified by receptors recognizing the common components of broad groups of pathogenic microorganisms. It should be noted that, damaged, injured, or stressed cells can often send out 'alarm signals' that are recognized by the same receptors that recognize pathogens.

Humoral immunity is the other defence mechanism and conducted by large molecules found in extracellular fluids such as secreted antibodies, complement proteins, and certain antimicrobial peptides. Humoral immunity is so named because it involves substances found in the humors (otherwise known as body fluids)

The **adaptive immune system** evolved in early vertebrates and allows for a stronger immune response as well as 'immunological memory', whereby each pathogen is "remembered" by a signature antigen. The adaptive immune response is antigen-specific and requires the recognition of specific "non-self" antigens during a process called antigen presentation. Antigen specificity allows for the generation of responses that are tailored to specific pathogens or pathogen-infected cells. The ability to mount these tailored responses is maintained in the body by "memory cells". Should a pathogen infect the body more than once, these specific memory cells are used to quickly eliminate it.

Histamines and other products are produced by damaged cells at the entry point to cause inflammation and manufacture the **blood cells**. Fibrinogen (a blood protein) and clotting factors create a barrier of fibrin to build a physical barrier at the same time. Lymphocytes (**White blood cells)** are attracted to the same area and pick up the foreign bodies, taking them away to the **spleen** and **kidney** for handling.

Key characteristics of the immune system are...

- The skin, scales and mucus provide the first line of defence against the physical invasion of pathogens.
- The innate and adaptive immune systems fight pathogens internally, that have broken through the first line of defence.

Components of the internal immune system	
Innate immune system	**Adaptive immune system**
Response is non-specific	Pathogen and antigen specific response
Exposure to a pathogen leads to immediate maximal response	Lag time between pathogen exposure and maximal response
Cell mediated and humoral components	Cell mediated and humoral components
No immunological memory	Exposure leads to immunological memory
Found in nearly all forms of life	Found only in jawed vertebrates

Unfortunately, many bacteria have ways to beat these defences, either by producing a dissolving agent that destroys the **fibrin** and opens the way to infection or by releasing toxins that attack and kill white blood cells.

The salmon also has an 'adaptive' immune response.

The kidney and spleen make antibodies specifically built to fight each antigen (invading pathogen). This process can take up to two weeks. The antibodies attach themselves to their antigen and fight it in one of three ways.

- Detoxify it – so that lymphocytes (white blood cells) can ingest and destroy it
- Attract a "compliment" – another blood component that helps destroy the antigen
- Deactivate reproduction – to stop the antigen proliferating

Lymphoid organs in fish

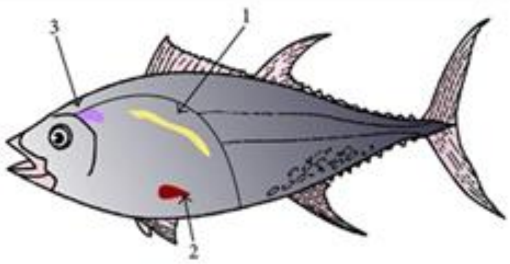
Primary lymphatic organs are where the lymphocytes are formed and mature. There are two types of lymphoid organs seen in fish. Primary lymphoid organs include the **thymus** and **head kidney** which both provide an environment for **stem cells** to divide and mature into **B- and T- cells**.

Secondary lymphoid organs and tissues include lymph nodes, spleen, and mucosal-associated lymphoid tissues. These are all immune devices that are positioned at anatomically strategic sites throughout the body for the efficient induction of adaptive immune responses. The secondary lymphoid organs include kidney, spleen, and mucosa lymphoid tissue. Besides the skin, liver, intestine and heart, they are also important defence organs.

What happens to the Atlantic salmon's immune system when farmed?

There is a risk of stress to any farmed animal, and generally, the more intensive the farming operation, the greater that risk. If salmon are held in poor water quality at high stock densities and are not fed a suitable diet, they will become stressed and their immune system compromised, making it easier for pathogens to invade and proliferate, thereby increasing the likelihood of disease outbreaks. By constantly maintaining optimum conditions in the rearing environment, stress is reduced and disease less likely.

	Innate	Adaptative
Humoral	Antimicrobial peptides	Antibodies:
	Lectins	IgM
	Lysozyme	IgD
	Complement	IgT/IgZ
Cellular	Macrophages	B-lymphocytes
	Neutrophils	T-lymphocytes
	Eosinophils	



Articulate idea: produce fish diagram (salmon version of the tuna) Get learner to explore fish with point and hover to determine where all the lymphoid organs are and what they are called.

Main humoral, cellular, and anatomical components of the immune system in most fishes. Fish lymphoid organs: pronephros (1), spleen (2), and thymus (3).

The **endothelial cells** and **macrophages** present in these organs engulf foreign substances. The development of lymphoid organs does not necessarily signify that immune functions' have matured. Even though the organs develop simultaneously in trout and salmon, the surface **IgM positive cells** appear 8 days pre-hatching in trout and 45 days post-hatch in salmon.

Articulate creative idea: Insert image of pathogen being engulfed by a macrophage and/or endothelial cell

Relevance to the fish farmer

The fish farmer must be aware of all the **infectious disease** challenges their salmon's immune system are going to have to combat. This will vary farm to farm, and all farms should have a Veterinary Health Plan (VHP) that takes full account of all known pathogens and has been devised with the assistance of a Fish Veterinary specialist.

In addition, all measures should be taken to reduce physical stress due to movement and handling at all stages of the farm operation and environmental stress by providing optimal water quality, so as the fish's immune system is not compromised.

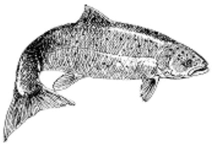
Farmers often use what are termed 'functional diets' with additional components, including 'imuno-stimulants' which are additives devised to strengthen the natural immune system

Fish feeding and nutrition

The 'adaptive immune system' is of great importance to fighting specific pathogens that are known to challenge the fish. Therefore, vaccination regimes are often an essential part of fish health management.

Fish Health and Welfare

SAP 22 Salmon anatomy and physiology



Osmoregulatory system

As a **euryhaline** species, the salmon has a wide tolerance of external salinity. Most fish are **stenohaline**, which means they are restricted to either salt or fresh water and cannot survive in water with a different salt concentration to the water they are adapted to, due to the impact of osmosis.

What is Osmosis?

Put simply, osmosis is "*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*".

In any aquatic environment, freshwater or marine, there are very few fish that have a body fluid concentration (which is mostly composed of salts) equal to the aquatic environment in which they live. Freshwater fish have body fluids of a lower concentration than the external environment and for marine fish the situation is the reverse. Consequently, as the salmon is **anadromous,** it must cope with a different osmotic challenge as it migrates from freshwater to the sea and back again.

What problems can osmosis cause a salmon?

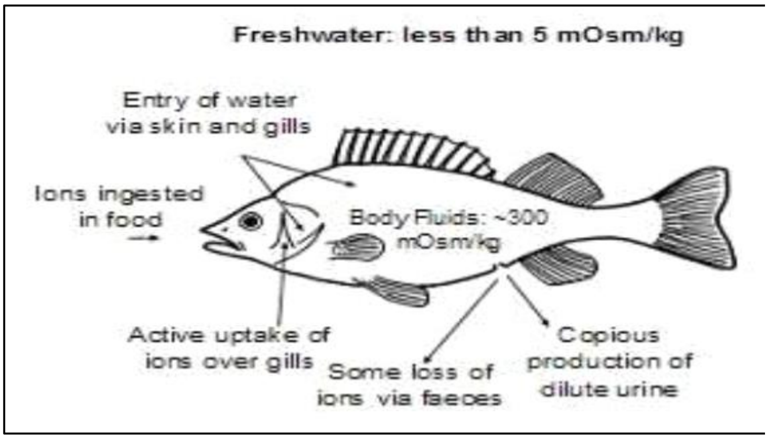
In freshwater, osmosis leads to water ingress through the semi-permeable skin, gills, and gut lining, lowering the concentration of their bodily fluids. Without intervention, this would continue until the internal concentration of the salmon matched the concentration of the surrounding freshwater environment. With no means of regulation, the fish would simply fill up with water, which would be fatal.

During the marine phase, the environment is of a higher salt concentration that the salmon's internal body fluids. Consequently, water leaves its body via the same semi-permeable membranes and without intervention the salmon would dehydrate.

How do salmon cope with the threat of osmosis?

All fish, including salmon, must maintain stable bodily fluid concentration for their normal physiological functions to continue. They do this through what is known as 'osmo-regulation' which works differently in fresh and saltwater.

Freshwater phase



Articulate creative: Need to convert this into an intereactive salmon graphic to show movement of water and ions including mention of ‘sodium pumps

The kidney produces a lot of dilute urine, which is a process requiring metabolic energy.

In freshwater, body salts are lost by diffusion and via faeces.

These are replaced from the environment by the ‘sodium pumps’ located in special **mitochondria**-rich cells in the gills, known as chloride cells. This is also a process requiring energy.

Some salt is also obtained via the food.

Marine phase

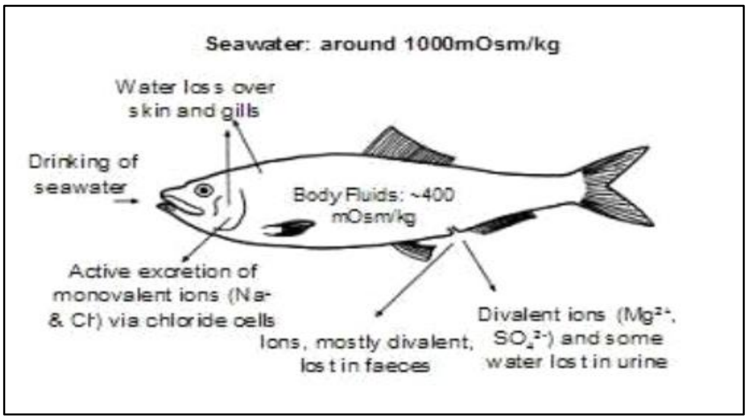
Due to the Atlantic salmon’s anadromous lifecycle the freshwater parr need to prepare physiologically for their downstream migration to more saline waters and ‘smoltify’, effectively putting their freshwater osmoregulatory mechanisms into reverse gear!

They become streamlined and silver, often with a black edge to the caudal fin (tail). But more importantly, it is the unseen internal changes that secure their survival.

Their physiological transformation enables the salmon to cope with increasingly saline waters as it moves down stream into the ‘brackish estuary’. After a few days to fully acclimatise, the smolt makes its way to the north Atlantic feeding grounds and can cope with full-strength sea water (35 ppt salinity)

How does osmoregulation work at sea?

When living in seawater, the salmon has an internal osmotic concentration lower than that of the surrounding seawater, so it tends to lose water by osmosis and gain salt by **diffusion**. It actively **excretes** salt out from the gills which is an energy requiring process.



Articulate creative: Need to convert this into an intereactive salmon graphic to show movement of water and ions

The process of osmoregulation is the reverse of that adopted in freshwater.

The salmon also 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:

- 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 to expel more salts from the system.

Can you identify the kidney?

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 to the freshwater osmo-regulatory mode!

Articulate creative: Ask learner to find the kidney with the cursor… then drop the text below down from a box when pointing at the kidney.

During the marine feeding phase, the kidney produces low volumes of concentrated urine to expel salts and conserve water.

Key characteristics of osmoregulation are ....

Freshwater phase

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

- The kidney produces lots of dilute urine to expel excess water, which, without further intervention would lead to the dilution of body fluids (salts).

- Chloride cells in the gill help to retain salts, counteracting salt dilution.

Marine phase

To counteract dehydration due to osmosis the adult salmon has two physiological devices:

- Drinking sea water to replace water lost through dehydration

- Expulsion of excess salts by chloride secreting cells in the gill lamellae

These mechanisms allow the salmon to osmo-regulate and maintain stable and normal body salt concentrations.

Can osmosis be quantified?

Scientists can quantify what is happening to freshwater and marine fish due to osmosis. There are both 'active' processes (those requiring metabolic energy) and passive processes (those requiring no metabolic energy) at play.

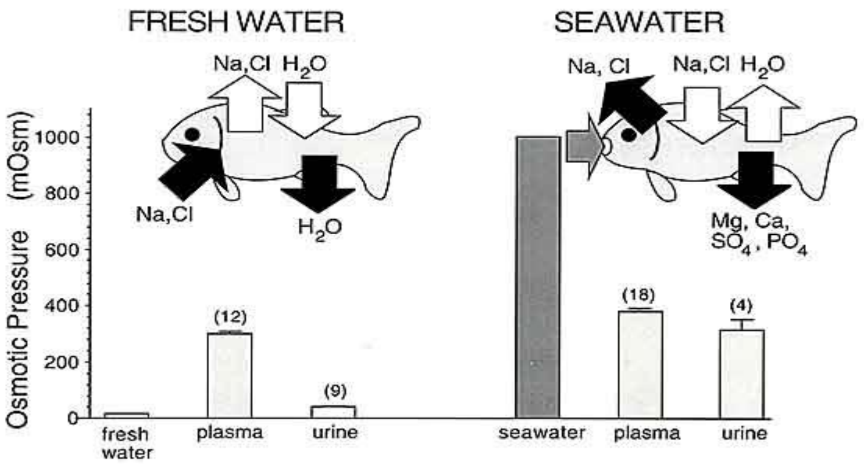
As 'osmo-regulators', salmon tightly regulate the concentration of their body fluids at around 300 mOsm/kg water (about one third the strength of seawater) regardless of the salt concentrations in the environment.

...the scientists say...

Osmosis occurs when two solutions, containing different concentrations of solute, are separated by a selectively permeable membrane. Solvent molecules pass preferentially through the membrane from the low-concentration solution to the solution with higher solute concentration. The transfer of solvent molecules will continue until equilibrium is attained

Osmotic concentration (osmolarity) is the measure of solute concentration, defined as the number of osmoles (Osm) of solute per litre (L) of solution (osmol/L or Osm/L). Whereas **molarity** measures the number of moles of solute per unit volume of solution, osmolarity measures the number of osmoles of solute particles per unit volume of solution.

This value allows the measurement of the **osmotic pressure** of a solution and the determination of how the solvent will diffuse across a semipermeable membrane (osmosis) separating two solutions of different osmotic concentration.



Active transport (uses metabolic energy and is under physiological control)

Passive movement (uses no metabolic energy). Little or no regulation.

Articulate creative: An interactive graphic needed here that shows water movement and the movement of salts in both FW and SW scenarios

Relevance to salmon husbandry:

Typically, within conventional salmon farming systems which have a distinct freshwater and marine phase, the salmon farmer must ensure that the smolts leaving the freshwater hatchery have fully smolted, otherwise the fish will be severely stressed on transfer to the sea cages, and high mortalities could follow.

This is done through a saltwater-challenge test to determine if smolts can regulate their blood Na +. Fish are placed into a known concentration of salt (NaCl) water and blood samples are taken from fish 24 h later for Na + analysis.

During grow-out in sea cages, natural changes in salinity can occur, depending on cage location. Increased freshwater inputs following heavy rainfall are sometimes slow to mix with the marine environment and can form a layer of low salinity water within the cage, temporarily inhibiting the salmon's feeding response, but also helping to deter the build-up of marine sea lice, as they cannot tolerate fresh water.

The situation described above is entirely different in a Recirculation Aquaculture System as salinity is under the control of the Production Managers. The smolts leaving the hatchery phase can enter a Grow out system managed at a low salinity of 5 ppt.

Ask for learning resources

Salmon Hatchery Operations

These learning resources support ‘short episodes’ of focussed learning’ on specific topics within the Salmon Hatchery Unit (EQF Level 4). They are customisable to any salmon hatchery, as specific Standard Operating Procedures (SOPs) and hatchery data can be incorporated within learning activities. Each episode has a title and number that relates to multiple-choice question banks designed to support the Recognition of Prior Learning (RPL) or formative assessment.

The learner will be prepared for following Learning Outcomes with the Salmon Hatchery Operations Unit

1. Describe the Atlantic salmon hatchery production cycle and facilities needed for each stage.
2. Describe how Atlantic salmon egg producers can improve the genetic strains of salmon to suit the needs of the fish farmer and consumer.
3. Explain how all female and triploid Atlantic salmon ova are produced.
4. Describe the husbandry of eggs and alevins from egg reception to first feeding
5. Conduct routine Atlantic Salmon hatchery operations.

The focus is on the Atlantic salmon hatchery operations from egg incubation to first feeding fry. The aim is to provide learners with an underpinning knowledge of the tasks commonly undertaken in a commercial salmon hatchery.

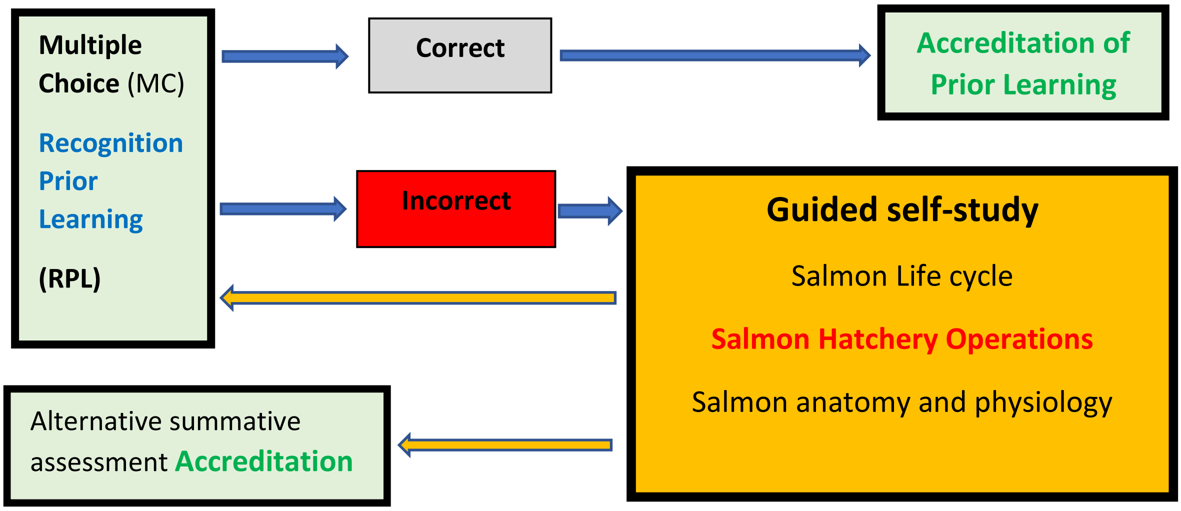
The resources can be used to support the following RPL led process for the development of underpinning knowledge:

Step 1- Undertake multiple choice questions for the section

Step 2 Automated RPL analysis determines which questions have not been answered correctly in full. This can be linked to an accreditation process through consultation with the national VET Awarding body

Step 3 Self-study, guided by the RPL results and feedback (See next page for details)

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



Self-study (navigating Ask for learning materials and external resources)

The learning experience is designed to be interactive and gives the learner control of their learning, starting with the 'Recognition of Prior Learning' (RPL)

Icons within the learning system can be used to flag components and activities to the learner...

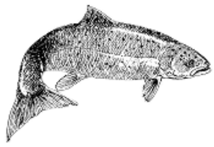
Blue font signifies **mandatory**

Activity	Purpose	Icon
What do you know already? RPL/APL	Mandatory assessment of the learner's current knowledge. Can lead to accreditation for some Units (APL)	Finger raised to a thinking face
Main content	Text and image, providing context and more topic details	No icon needed

Key characteristics	Summary points expanded on in the main content (Mandatory knowledge to be assessed)	A key
Standard Operating Procedures	Link to a specific farm SOP	SOP
Watch this**....**	Selected Youtube or home-produced instructional video	Film reel graphic
....now have a go	Learning activity- may be a calculation or other activity, or formative assessment following a learning episode.	Graphic of tutor pointing to learners
...**the scientists say**	Interesting insights and debates from the scientific community	Mad professor talking head

Navigation to information within the PSA and the web

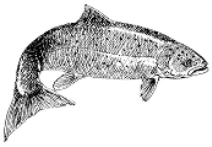
Colour code	Hyperlink
Green font	Links to a section of material in another episode in the same Unit or another Unit within the PSA, making related information more readily available. Navigation back must be easy to keep learners 'on-task'
Blue font	Links to an interim summary definition box and then for a full expansion and data set but ensuring easy navigation back to the main study material.



SHO 1 **Salmon Hatchery Operations**

Resource needs

Sub sections (summarised)	Resources
Introduction	Images (X3): Incubation, first feeding, fry rearing – Articulate creative – carousel
1.1 Key environmental parameters	Summary table of water temp regime
	Hatchery Inventory
	Table of holding Units for facilities
	Hatchery Plan
	Hatchery Thermal Regime
	Water Quality Regime
	Hatchery HRT minimum data
1.2 Stages of hatchery cycle	Video 1: Facility overview with audio showing all the main components



Salmon Hatchery Operations

SHO 1 Salmon Hatchery Operations Overview

In the wild, Atlantic salmon eggs and alevins go through several life-cycle stages before becoming free-swimming fry. The fertilised eggs are burried in **spawning reds** composed of gravel of a suitable size. Water can pass through this gravel matrix, which physically protects the eggs, to supply dissolved oxygen throughout the inclubation period. As they develop, they become **eyed eggs,** later hatching into **alevins** that passively absorbing their yolk sacs before emerging to feed.

The environmental requirements (light levels, water flow, temperature and quality) for each stage of development outlined must be replicated and controlled within the salmon hatchery environment.

Digital still Images of the Hatchery facility

- Incubation
- First feeding
- Fry rearing

Articulate creative: Images presented as a carousel with overlay information of quantitative hatchery stats/capacity data as each image comes up

There are two main phases, ova incubation to nursery transfer and post transfer salmon parr to smolt.

Eggs of known genetics are produced or purchased from a relaible disease free source and brought in to the system. The highest standards of **biosecurity** are applyied throughout each production cycle.

Farm 1 scenario

To supply sufficient smolts for a salmon farm producing 10,000 Tonnes per year, 913,600 2 gramme fry must be grown on to the smolt stage.

If a hatchery puts just over 3 batches of 360,000 eggs through the hatchery incubation system per year each batch produces 284,000 fry to reach the annual target of 913,600 2 gramme fry

Link to Hatchery Plan

Most modern salmon hatcheries are based on Recirculation Aquaculture System (RAS), with control of the water temperature according to a set regime. They deploy water quality monitoring and control systems to optimise the key environmental parameters.

Disease free conditions must be maintained throughout to produce high quality smolts for grow out.

1.1 Key environmental parameters

The environmental requirements of the eggs and juveniles gradually change as they develop, whilst maintaining high standards of hygiene remains paramount throughout. Water temperature, flow rates, water quality and lighting are important parameters to monitor and control at each stage, whilst feed quality and feeding practices become important from first feeding onwards.

Water temperature

The water temperature is controlled within RAS systems and temperatures can be held within the optimum range (8-12oC). This development time in days can be calculated using '**Degree days'** and a knowledge of the temperature regime. Water temperature is routinely monitored as unexpected temperature changes can occur (although unusual) as a result of;

- chiller malfunction,
- poor chiller capacity or
- long-term power outage and emergency power generators not working properly, although this is the least common cause.

Water flow

Water flow rates should be sufficient to remove metabolic wastes and maintain oxygen level above 90% saturation in the outlet. **Link to Water Quality table.**

A water flow pattern should be established in holding unit that eliminates dead areas. Flow rates should be measured with a flowmeter at the inflow to each holding unit and the HRT (Hydraulic Retention Time) can be calculated.

- This is calculated in minutes by Volume Tank(m3)/Flow (m3/hr)*60 min.

The HRT minimum values established should be applied to guarantee an appropriate flow pattern in every unit. **Link to HRT data**

Oxygen

Dissolved oxygen is measured daily at selected sampling sites, where deviations could result in stress to the eggs or fish. This is the outlet or the opposite side of water inlet in the fish holding units. In the egg incubators it should be measured in each tray. At each stage, the holding units are monitored for several days at full water flow before stocking.

Flow rates are measured with a flowmeter and hydraulic tests can be conducted to measure **HRT** and assess the flow pattern.

A minimum level of 90% oxygen saturation in outlet water is the target. This requirement changes as the fish grow.

Key points

- Salmon RAS hatcheries provide a controlled environment that replicates the conditions for incubation and fry rearing found in the Atlantic salmon's nursery streams.
- The length of the production cycle from receipt of eggs to nursery transfer at 2 grammes can be predicted, once the thermal regime is known.
- Key environmental parameters (dissolved oxygen, pH, carbon dioxide, dissolved gasses, and ammonia) are monitored at well-chosen locations within the hatchery system and optimised.

Farm 1 Water Quality Table

Carbon Dioxide

Carbon dioxide is a waste product of respiration, and levels are indicative of the total **metabolic activity** in the system. Excess carbon dioxide can cause pH reduction and levels should be maintained at < 6mg/l for eggs and alevins and <15 mg/L for fry (measured at the outlet).

Total Gas Pressure (TGP)

TGP should be measured at least weekly, and whenever changes are made that have the potential to affect the total gas content, such as water temperature or flow adjustment. Nitrogen is the gas most often leading to **supersaturation** problems. This can be caused by leaks in pumps or couplings, negative pressure in pipes or heating of water without adequate ventilation. Although this is an unlikely event within a well-maintained RAS operation, it cannot be ruled out and vigilance is required.

Reduced water depths during first feeding can cause the fish problems as they are unable to control their depth to adjust the water pressure they are exposed to. If total gas increases above 100% there is a danger of **gas bubble disease** (bubbles forming in tissues) with detrimental effects to eggs or fish. However, if the holding units are maintained at a reasonable depth of 0.7 Metres, this problem is not expected from first feeding onwards.

Water pH

The **pH** is an important water parameter that must always be carefully monitored. The acceptable pH range for eggs and alevins in most salmon hatcheries is 6.8-8.0. At a pH below 6.0, there is a risk of metal ions in the water becoming toxic to eggs and juveniles, but the application of sand filters can eliminate this risk.

The pH can be controlled by adjusting flow rates and the addition of hydrated lime or bicarbonate within some hatchery systems.

Ammonia

Ammonia is a metabolic waste from the break-down of organic substances or protein **catabolism** by animal life forms. It is toxic to fish at low concentrations and removed by bacteria in the RAS 'biofilters', initially converting it into nitrite followed by relatively harmless nitrate.

Care needs to be taken at hatching as the ammonia level can spike due to the breakdown of dispersed eggshells. The control of the pH levels within RAS is essential to limiting **Ammonia toxicity**.

What facilities are needed for ova incubation and fry rearing?

Hachery 1 is designed to serve an ongrowing unit producing **X Tonnes of harvest salmon** annually (Link to table of holding units) which determines the number and capacity of the incubators, first feeding and fry rearing units.

The incubation facility is composed of a vertical silo inclubator that occupies a XM2 square footprint and contains X incubation trays, each with a capacity of Y eggs.

Link to hatchery inventory (which shows each item of hatchery equipment, describes its design/construction and application)

1.2 The hatchery process from egg receipt to nursery transfer

Hatchery 1 - Video 1

PS Hatchery guided tour to provide a facility overview with audio showing all the main components and highlight key features within the facility.

Could also highlight key challenges and 'mission-critical' stages of the hatchery process, priming, but not replicating 'discrete' instructional videos to come later.

Designed to complement the Interactive hatchery visual aid

Go on the 'hatchery guided tour' for an introduction to the facility, equipment and technologies

The main stages of the ova to nursery transfer are as follows.

Articulate creative

1. **Interactive graphic Stages of the salmon hatchery production cycle**

Diagramatic facility layout of a chosen farm to demonstrate each stage of the process from receipt of eggs through to nursery and smolt.

This could be produced as an interactive diagram with hotspots so as information drops down on a 'point and click' basis.The drop down box could provide an image of the ova, alevin, first feed fry and parr, according to the specific production stage.

Learning activity 1

Arranging given stages of the hatchery process into the correct sequence, using LMS 'drag and drop'.

This activity could follow the video hatchery tour to consolidate learning, based on the learners recollection.

A link to the facility/equipment for that stage is offered.

Text and or an audio overlay could be included.

2. **Hatchery workflow chart** - Devised to illustrate each stage of the hatchery process (receipt of eggs to nursery) and linked farm Standard Operating Procedures (SOPs) applying to each stage.

Functionality:

- The farm SOP (or flow chart SOP summary) can be called up for reference 'on a point and click' basis
- The process column will act as a dashboard taking learner to the corresonding learning episode when clicked (Ova procurement, egg receipt, etc)

Hatchery workflow chart (To become interactive – see outline specification above)

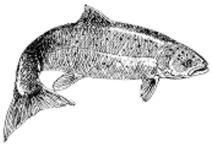
Hatchery 1 cycle	Last updated - 02.09.2020	SOP		DAY									
Process	Operation		Prior to Day 1	1	2	3	4	5	6	7	8	9	10
Ova procurement	Quantify Ova requirements												
	Develop annual ova procurement plan												
	Procure suitable disease free ova												
Egg receipt	Collect ova												
	Disinfect Ova												
Manage biosecurity	Biosecure hatchery												
Maintain Ova	Quantify Ova												
	Set up incubators												
	Incubate ova												
	Monitor ova, remove morts, monitor water												
Maintain alevins	Maintain incubators during hartch												
	Monitor and maintain alevins												
	Sample alevins for yolk sac absorbtion												
First feed fry	Prepare first feed system												
	Transfer alevins to first feed units												
	First feed fry												
	Remove and record mortalities												
Feed growing fry	Feed fry 1 week post first feeding												
	Feed growing fry												
	Sample weigh fry												

SHO 2 **Salmon Hatchery Operations**

Resources needed

Sub sections	Resources
Introduction	Image needed: Certified disease-free salmon eggs of known genetics
2.1 Selective breeding	Image needed: Image to illustrate selective breeding of Atlantic salmon for the farmer and consumer.
	Image needed: XX male testes
	Image needed: Pressure shocking salmon eggs
2.2 Hatchery production planning	Images needed (X4): hatchery stacked incubators, hatchery incubators being stocked, transferring first feeding fry, plane in flight

Salmon Hatchery Operations



SHO 3 Egg procurement

Many large salmon farming companies are self-sufficient, engaging in the entire salmon production cycle from egg production to harvest to reduce their risk exposure and increase control. This enables them to develop genetic strains of Atlantic salmon to suit their farms and a final product that satisfies the consumer. However, this also means they have a more complex production process and organisation to manage and coordinate.

Certified disease-free salmon eggs of known genetics from Aquagen - provided by Vikan

For others, the production cycle starts with the receipt of eyed eggs that are flown in by a suitable supplier and collected.

This strategy allows them to focus on hatching bought in eggs and growing fish, whilst relying on their egg suppliers for egg production and genetic improvement. Often, egg procurement is managed by the senior management within the company as positive business relationships need to be established.

Ideally, stock performance data for each stage of production should be shared with egg suppliers within 'high trust' partnerships. This enables the suppliers to constantly improve the genetic strain of salmon to better suit the farming regime.

2.1 Selective breeding

Specialist commercial salmon egg producers run multiple salmon breed improvement programmes to establish family groups of salmon with specified traits in demand from their clients and are better suited to farm conditions than the wild salmon that they originate from.

Aquagen - breed improvement case study:

AquaGen brood stock was originally derived from a collection of Atlantic salmon from 40 Norwegian rivers in the 1970s, providing a diverse gene pool from the outset. Thereafter, their breeding programmes have selected for 'desired traits' to create a wide product range for their salmon farming clients.

Some desired traits are general and are in demand from all salmon farmers, such as fast growth, efficient food conversion, flesh quality and disease resistance, whilst others are more specific.

Presently, Aquagen have more than 20 traits recorded from 600 families (groups of approximately 40-50 salmon). Comprehensive performance monitoring and recording within the management of the breeding program ensures progress in trait development whilst minimising the risk of any detrimental side effects.

Atlantic salmon are selectively bred to suit the farmer and consumer.

Aquagen and other specialist breeders have been using '**marker assisted selection'** technology, for over ten years, which allows individual parent fish to be directly selected, based on them having a **genetic marker** associated with a desired trait. The initial family-based breeding programmes created 'superior' groups of fish regarding the desired traits. However, within each family group individuals show great variability, and genetically superior individuals can remain hidden.

In the last 4-5 years the Atlantic salmon breed improvement process has been given a further boost by '**genomic selection'** a powerful tool allowing several thousand genetic markers to be referenced for selecting individual brood stock with specific traits. Using this technology, a series of traits can by selected for concurrently, as they are not in competition with one another. Genomics allows the best performing individuals from families to be identified, selected, and described genetically most comprehensively. The so-called **SNP chip** (which can vary in size and quality) can analyse up to 930,000 genetic markers per fish which are then correlated with desirable and undesirable traits. Genomic selection is more precise compared with family selection as selection takes place at the individual level and breed improvement can be accelerated.

What genetic traits do most farms need?

Salmon farmers require stock that can perform well within their farm system, whether based on open ocean cages or RAS production and help them to overcome commonly encountered challenges, such as disease susceptibility and the early maturation of males, which can impact on the quality of harvested fish.

Benchmark Genetics - RAS case study:

Benchmark genetics have launched a new product range specializing in full-cycle land-based RAS systems — SalmoRAS4+ and SalmoRAS4+IPN.

These two strains are specially selected for fast growth and highly resistant against Infectious Pancreas Necrosis (QTL-IPN). To reduce or eliminate the risk of early maturation of males, They can be offered as **All-Female** and **Triploid** where the fish are sterile and not able to mature.

... **the science says**

An insight to genomics from the manager of Mowi breed development (20 mins lecture) Genomics is explained 9 minutes in.

https://www.bing.com/videos/search?q=Youtube+selective+breeding+of+Atlantic+salmon&docid=608040474602442147&mid=5D77C878957D728F16F15D77C878957D728F16F1&view=detail&FORM=VIRE

Triploidy : "As with survival, growth appears to be strongly affected by family, and through correct selection, triploids were found to outperform their diploid siblings with minimal deformity rates"

https://thefishsite.com/articles/sterile-salmon-a-sustainable-future

How are all female and sterile triploid salmon produced?

There are two main ways that the salmon's gender can be changed:

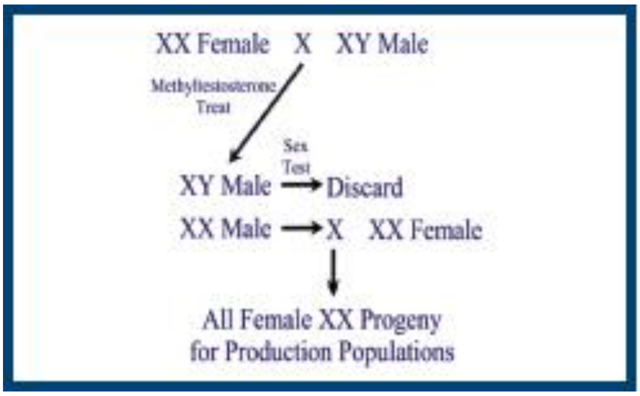
- **Masculinisation** of fish that are genetically female
- **Triploidisation** of eggs that are genetically all female

Masculinisation

At the cellular level, the male has the X and Y **chromosomes (XY)**, whereas the female has two X **chromosomes (XX)**. Both are termed **diploid** as they contain two complete sets of chromosomes, one from each parent.

The male sex hormones (testosterone) can be fed to juvenile growing salmon which will over time 'masculinise' the female fish, so as they develop testes and sperm despite being genetically female, or alternatively described as XX males.

Articulate creative: The production of XX Males



Dietary treatment with methyltestosterone at doses of 1 or 3 mg/ kg of food for 800 °C days from first feeding, results in 100% masculinisation of female Atlantic salmon.

When sexually mature, it is possible to tell masculinised females (XX male) from normal males (XY), due to the absence of the sperm duct between the testes and vent. Those fish with a sperm duct are normal males (XY) and discarded.

Image of XX male testes

When the sperm from a masculinised female (XX males) is used to fertilise salmon eggs, all progeny are female as the male Y chromosome has been eliminated.

What is the advantage of an all-female salmon population?

The main advantage of an all-female population is that setbacks arising from the early maturation of males can be eliminated. This can offer an ideal solution for land-based RAS-plants where temperatures above 15°C are applied to the entire production process from ova to harvest.

Triploidisation

By using high pressure in combination with specific temperature levels, the fertilized ova get three pairs of chromosomes instead of the natural two, producing salmon that are unable to reproduce.

Image - Pressure shocking salmon eggs

As the fish are sexually sterile and never mature, sexual products are not produced. A larger proportion of the metabolizable energy from their diet is used for growth.

The production of triploid sterile salmon has also been recognised as a solution to the environmental challenge of escapees, as they cannot breed with wild salmon populations.

Articulate creative: Detail specification for better presentation of all female and triploidy to be discussed with Articulate developers and defined.

2.2 Hatchery production planning

The **annual output of fry** from the hatchery for transfer to the nursery is determined by the number of batches that can be produced each year and the size of each batch.

The constraints that apply during both the incubation and fry rearing phases need to be considered.

Interactive graphic - Hatchery 2

Diagrammatic facility layout to demonstrate stock rates and mortality/losses expected for each stage of the process from receipt of eggs through to nursery and smolt.

Produced as an interactive diagram with hotspots dropping down mortality information on a point and click basis.

Note: The learning object could be integral to Hatchery 1) graphic, allowing learners to select information on mortality, the ova/fish or equipment.

Hatchery holding capacity: The hatchery incubators holding capacity determines the size of each batch (number of eggs) that can be incubated at one time.

The holding capacity is determined by the total surface area of the incubators and **egg incubation stock density limits.**

Batches per year: The **Degree days** exposure is predictable and can be manipulated.

Once the hatchery's **thermal regime** has been established, the length of the cycle (egg receipt to first feeding) can be determined, leading to an assessment of the number of batches that can be taken through the hatchery annually.

Key points

- Selective breeding can produce salmon with desired traits (fast growth, disease resistance and flesh quality) to suit the farmer and consumer.
- Genomic selection including the application of the SNP chip and multiple genetic markers, allows superior individual fish to be identified and selected
- The production of all female and triploid stock can be used to overcome sexual maturation problems
- The number of ova required annually depends on the annual production target for fry transfer and expected survival rate. This is calculated by- target no fry for transfer X (100/survival rate)
- The length of the production cycle (egg -nursery) is temperature and time dependant and determines the number of batches possible each year.
- Procured eggs are certified disease free, have desired genetic traits, and can be delivered to suit the hatchery plan

Eggs per batch

There are key information requirements when planning stock inputs (eggs) needed to achieve a specified output (first feeding fry).

The stockman's calculations are simply based on the:

- expected survival-rate and
- output target number

The calculation of egg requirement is straightforward:

Egg requirement=target fry numbers for transfer X (100/survival rate)

So, if the survival rate was 70% and 100,000 fist feeding fry for transfer the target,

the egg requirement is 10,000 X (100/70) = approximately 143,000

Egg procurement: Once the quantity and frequency of ova required has been calculated, a suitable egg supplier must be found. An egg procurement plan is required for a 12-month period, specifying the frequency, timing and the quantity of ova needed in each batch.

Atlantic salmon hatcheries can be designed so that each batch of eggs received is discrete and the stock held in separate rooms through to the parr stage.

How is a suitable salmon ova supplier sourced?

The eggs must be sourced from a certified disease-free supplier. A health certificate is attached to the shipment which is checked by receiving staff. The considerations are the:

- reputation of alternative suppliers of high quality certified disease-free eggs.
- suitability of the **genetic strains** available within farm's production system.
- cost of eggs and their transportation and
- requirements of the farm's hatchery production cycle in relation to egg availability.

Articulate creative: Under the **annual output of fry** panel that contains four sections, each illustrated by an image- hatchery holding capacity, (Image of hatchery stacked incubators) batches per year (Image of transferring first feeding fry), eggs per batch (image of hatchery incubators being stocked) egg procurement. (image of plane flying in ova) Each of the four topic sections text should drop down from the panel image.

Learning Activity 2

Stockman's calculations 1:

a) Assess egg requirements to meet output (first feeding target) allowing for mortality.

With and without the assistance of a PC and spreadsheets

b) Assess the requirement for hatch trays based on stock rates and eggs per litre.

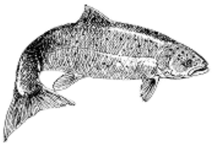
Hatchery planning 1:

Produce an egg purchase plan for a given hatchery output target, including quantities and timing, taking account of ova development times (degree-days)

This could be undertaken using a given Excel spreadsheet, or a spreadsheet could be devised by the learner, and the exercise integrated with ICT core skills development.

SHO 4 **Salmon Hatchery Operations**

Sub sections	Resources	Comments
Introduction	Image needed: Image of salmon ova in polystyrene packaging	
	Image needed: packaged eggs showing ice trays	
3.1 Hatchery arrival	Image needed: Eggs damaged in transit	
	Instructional video: Ova collection and egg receipt	



Salmon Hatchery Operations

SHO 4 Egg transit and receipt

When eggs are produced overseas, this necessitates international transportation by the supplier to meet orders. Typically, the eggs have been subjected to 360 **Degree-days** and are at the robust **eyed stage** at the time of packaging. They can be safely transported as air freight.

Salmon ova in polystyrene boxes -provided by Vikan Settefisk

The eggs are measured by volume into egg trays and boxes and their size (which can vary between batches) determines the precise number of eggs in each compartment.

Salmonid egg boxes vary in volume and are typically composed of 4 trays each with 6 chambers of 0.5 litres capacity. On average there are 6,000 eggs held per litre, depending on the size of the eggs, giving each box a 72,000-egg capacity.

The egg boxes are,

- constructed with minimal polystyrene packaging to be environmentally friendly but are well insulated,
- conform to the size of a European Union pallet to meet air transport requirements,
- stable when stacked to reduce the need for handling in transit,
- fitted with two trays of ice overlying the egg trays to maintain the eggs at an optimal environment, which is cool (4-6 Degrees C) and moist, as some ice slowly melts.

Image of packaged eggs showing ice trays - provided by Vikan Settefisk

The eggs should be immediately collected by the hatchery manager responsible for clearing customs, who then transports them by road to the hatchery for transfer and layout in the incubators, following disinfection.

3.1 Hatchery arrival

Hatchery preparations should be coordinated with egg collection to ensure the system is ready. The hatchery staff should check hatchery containment barriers, particularly floor drain screens and hatchery containment vaults, to ensure they are in good condition and securely in place.

Egg receipt:

- Egg boxes should be unloaded sequentially, disinfected externally before being opened, and egg trays removed.

- Each box should be inspected for damage and their condition recorded in an 'Eggs Receipt Record'.

Learning Activity 3

Egg receipt documentation

A simple learning exercise that lays out 'dummy' documentation, providing the key information, explains its significance, demonstrating what must be checked, completed, and signed for on collection.

Articulate Interactivity

Dummy document

The document could be simply annotated so as the learner can explore the document and receive drop down explanations for the key components, highlighting any actions that they must take and the reason for them.

- Photos of the damage should be taken, and the supplier informed. A report should be conducted by the hatchery manager.

- The eggs should be inspected paying attention to their general appearance and looking for signs of physical damage.

- Once any damaged boxes or eggs have been identified, the incubator trays receiving those eggs should be labelled to track their progress.

Insurance policies should be in place to safeguard against significant losses due to the damage of eggs in transit.

Acclimatisation: Developing salmon ova are sensitive to thermal shock and any sudden and marked temperature changes should be avoided. If there is a 1 Degree centigrade or more difference between the egg boxes and the hatchery incubation facility, careful acclimatisation is required on arrival at the hatchery following collection.

Water from the incubator is trickled over the eggs at no more than 5-minute intervals and the temperature checked, until the eggs are within 1 oC of the incubation temperature.

Dissinfection: The practice of disinfecting salmonid eggs at hatcheries is essential to **biosecurity** and ensuring that infectious diseases are not transferred to the hatchery from other aquaculture facilities.

Once transferred to the hatchery, salmon eggs are disinfected in line with Buffodine protocols and rinsed to eliminate the transfer of any pathogenic agents. The pH is monitored during disinfection and **buffered** by adding a sodium carbonate solution to keep it between pH 6-8.

Although generally effective for disinfection of the egg surface and reproductive fluids, the use of disinfectants will not prevent **vertical disease transmission** emphasising the importance of the careful selection of egg suppliers.

All packing material should be disinfected and disposed of outside of the hatchery facility.

Articulate creative: Create a panel of images as hot buttons that drop down the SOP flowcharts below when hovering and the paragraph of text above: egg receipt, acclimatisation, and disinfection.

- **Insert farm egg receipt SOP**
- **Insert farm egg acclimation SOP**

- **Egg farm disinfection SOP**

Instructional video Ova collection and egg receipt

a) the process of collecting and checking ova, the completion of documentation, and remediation in the event of problems, could be added.

Role play to illustrate possible problems/scenarios

b) The egg receipt process from hatchery arrival, to demonstrate the **Egg receipt and disinfection SOP**

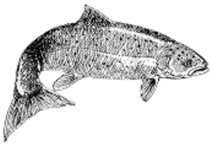
Could include MC questions overlay on the choice and use of disinfectant, to consolidate key learning points in relation to the SOP

Key points

- The salmon eggs are packaged within insulated polystyrene egg boxes by the ova producer and flown to the local airport for collection
- The airport collection includes checking for packaging damage and recording on arrival and clearing customs controls
- On arrival at the hatchery the external surfaces of the egg box packaging are disinfected, and the temperature of the eggs checked
- If there is a 1 Degree C or more temperature difference to the incubation facility, the eggs are acclimatised before disinfection
- The eggs are disinfected with an iodinated solution and kept within a pH range of 6-8.
- Following disinfection, the eggs a rinsed in clean water in preparation for laying out in the incubators

SHO 5 **Salmon Hatchery Operations**

Sub sections	Resources	Comments
Introduction	Image needed: eggs in incubation trays	
4.2 Incubator set up	Image needed: of horizontal incubator	
	Image needed: of vertical incubator	
	Video: Egg counting	To be story boarded
4.3 Incubate ova	PS Hatchery temperature profile table	
	Video: Egg incubation	To be storyboarded



SHO 5 Egg incubation

In the wild, Atlantic salmon eggs are incubated within **gravel redds** constructed in the substrate of their nursery stream by the mature female during spawning. Clean, cool, well oxygenated water passes through the redd, as they develop undisturbed and in darkness until ready to hatch.

Eyed eggs - provided by Vikan Settefisk

These natural conditions are replicated in Atlantic salmon hatcheries through well-designed incubation equipment carefully prepared and stocked with disinfected bought in eggs of a known **genetic strain**.

Whether in a natural gravel redd or a managed hatchery, the rate of salmon egg development is temperature dependant. In a hatchery situation, water temperature can be controlled to manipulate egg development and hatching to meet the requirements of the **hatchery production plan.** Typically, the target incubation temperature is 6 to 8 oC with a maximum daily temp variation within 0.5 oC to avoid stressing the eggs.

On arrival at the hatchery, typically, the ova have already been subjected to 350-360 **Degree Days** and if the hatchery is maintained at 8 Degrees Centigrade, they would be 41 days from hatching.

5.1 Quantifying eggs

The **disinfected ova** can be sampled to assess their size per unit of volume. This measure can then be used to check the ova delivery (quality and quantity) if the manager deems this necessary. The sample count can also be applied to the volumetric measurement of eggs to lay out a known quantity in each incubator tray. Under normal circumstances hatcheries rely on their supplier's egg count.

How are egg numbers assessed?

Although different batches of eggs can vary in size, year to year, due to the variable conditions the brood stock may experience, the ova from within each batch show minimal size variation.

Articulate creative: infographic learning object

Annotated infographic to visually demonstrate the egg counting calculation process

See:https://akffa.files.wordpress.com/2013/02/counting-salmon-eggs-volumetrically.pdf

- Diagram of a container of a fixed volume being filled up with orange spheres that represent the eggs.
- Eggs are poured (numbers are shown going up on a live counter as they are poured) and a final number given at the end
- Calculation is conducted to show eggs per unit of volume.
- a graphic shows a vessel of know volume being filled with orange spheres.
- Then full a calculation based on the previous count is completed visually

Therefore, by removing a known volume of eggs as a sample and counting them, it is possible to accurately calculate the number of eggs per litre for that batch. Thereafter, the volume of eggs to achieve a target stock density in the incubator trays can be accurately derived.

A sample volume is taken from the disinfected batch of ova and counted to establish the number of ova per litre.

> **Instructional video**
>
> **Egg counting**
>
> Story boarded video of egg sampling and volumetric counting

- Insert Egg counting SOP

> **Learning activity 4**
>
> Stockman's calculations
>
> **Egg assessment calculation**
>
> Volumetric assessment of ova numbers (ova per litre) and associated calculations to establish the volume of eggs to lay out in each incubator tray.

5.2 Incubator set up

All salmon incubators are designed to ensure a uniform flow of water through the incubator trays so as all eggs receive a constant supply of oxygen to survive and develop.

There are two commercially available, systems horizontal, and vertical incubators.

Horizontal incubators

The horizontal incubation troughs have the advantage of allowing full access and visibility of the incubation process and can hold up to 4 or 7 baskets of approximately 40 x 40 cm (holding 1-2 litre eggs each). They are made from smooth reinforced glass-fibre polyester and are approximately 215 or 360 cm long. Therefore, they take up a lot of hatchery space, which is a disadvantage.

The base screens of the egg incubation baskets (with 1-2 mm perforations) fit precisely. The baskets are designed with a downstream lip which lies in contact with the trough base and forcing the water to 'up well' (0.6 litres/min) through each base screen and batch of eggs, leaving the basket through the back face screen, ensuring all baskets in the trough are supplied with a sufficient flow of water.

> Image - Horizontal incubator

The trough is dual function and has the advantage that it can also be used for first feeding the fry after the alevins' yolk sac has been absorbed.

Vertical incubators

vertical incubators guarantee safe conditions for hatching of salmonid eggs and can be combined and arranged in different ways, to utilise the available space as effectively as possible. They also offer water flow control in each tray and a better working position for the technicians.

Eggs being monitored in the vertical incubator- provided by Vikan Settefisk

The water (7 litres/min) from the inlet, flows through the trays on which the eggs sit, and leaves the water tray over the front via side channels to the next tray, were it flows again through the egg tray and so on, so that all trays will be supplied with a sufficient flow of water.

Without disturbance to the other trays, each tray can be drawn out to check the ova and perform husbandry operations and can provides optimal conditions from the fertilized egg to the swim-up fry stage.

Vertical incubators can house 4, 8, 12 or 16 trays, for 50.000, 100.000, 150.000 or 200.000 eggs, respectively, with up to 1 litre of eggs per tray) made from strong non-toxic plastic material. Typically, they include aluminium or stainless-steel frames (approx. 64 cm deep), 58-60 cm wide and 44, 82, 139 or 175 cm high) and egg trays with polyester screens (approx. 1-2 mm).

Optional isolation panels (clear or black) for the front or back are available. Most commercial hatcheries deploy vertical incubator systems as they are more space efficient and easier to maintain.

The water flow in the incubators should be adjusted to the manufacturer's recommendations.

There should be enough water flow to provide well oxygenated conditions for the ova, and without agitation or movement of the ova on the base of the incubator. The technicians must ensure there is no air entrapment within the incoming water flow as this can block areas of screens reducing DO levels and or unnecessarily agitate the eggs when released.

5.3 Incubate Ova

The ova are kept in the dark and incubated at 6 to 8 oC.

How can the development of salmon ova and hatching times be predicted?

Development and Degree days (d°C)

The development and growth of fish embryos is temperature dependent. Degree days allow ova development to be monitored when temperature varies due to seasonal changes or the imposition of water temperature regimes.

Degree Days = temperature (°C) x days. For example: 9°C x 15 days = 135 d°C. The use of Degree hours has also been developed to calculating the hatching times for salmon ova, but this is not widely applied in the industry.

Articulate creative: Recreate Degree days graph

(See Benchmark url) - biological degree days

However, observations in hatcheries have shown that the biological development in Atlantic salmon eggs at temperatures lower than 5°C is quicker than the degree days would suggest. The biological degree days at temperatures below 5°C relates to the actual temperature as shown in the **Degree days graph**.

Learning activity 5

Stockman's Calculations 3

Predicting ova development and hatch dates using 'degree days' and a knowledge of ova development requirements.

Several exercises to be developed

What is the water temperature regime for PS hatcheries?

A stable, controlled temperature is a critical requirement during incubation and the target temperature is 8 oC. However, 'voluntary' changes in the incubation temperature can occur due to RAS chiller malfunction. As any unplanned change in water temperature can affect the Degree-days exposure, the manager responsible must assess the impact on the planned hatch date. The embryonic development of eggs impacted should be carefully monitored and any subsequent problems in the absorption of the yolk sac, or its elongation due to stress, noted and reported. A water temperature target 'modification may be required to ensure the target hatch date is still met.

Hatchery staff must all be aware of the current target incubation temperature and notify the manager whenever the incubation temperature is +/- 0.5 °C from the target.

What is the water flow requirement?

SOP – Water Quality and supply

The target flow rate per tray is typically 7 L/min or according to supplier recommendations. The critical low flow rate is 5 L/min. Flow rates +/- 0.5 L/min from the target (7 L/min), should be addressed by increasing or decreasing the flow accordingly.

Each tray can be fitted with a flow meter so as water flows can be constantly monitored. (L/min) and recorded. The water level of the trays should not fall beneath their standpipes. This would indicate that the tray's water inlet screen has been blocked by algae or suspended solids and needs to be cleaned.

How much light can the incubating ova be exposed to?

The Atlantic salmon ova in the spawning redd are buried within a matrix of gravel and are not exposed to light throughout the incubation of ova and alevins. These conditions are replicated in a salmon hatchery by keeping the eggs in darkness or only exposing them to red light for **ova husbandry** purposes.

Instructional video - Ova incubation

Story boarded video of egg incubation, including, sampling/egg counting, incubation set up and incubation monitoring process to demonstrate the SOP

Articulate creative

Digital images:

Images of all facilities and equipment used for egg incubation

Annotated diagram:

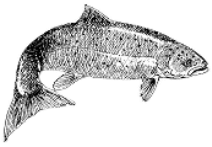
Diagram of the incubator, showing the water flow by adding arrows to show the inlet and outlet

Key points

- Atlantic salmon egg development is temperature dependent and can be predicted by using Degree days and manipulated to suit the hatchery production plan.
- At temperatures under 5°C egg development is more rapid than the degree days predictions would suggest.
- Eggs can be counted by sampling to assess the eggs per unit volume and applying this to derive egg numbers from volumetric measures.
- Salmon eggs can be incubated in trays held either in horizontal incubators, which can also be used to feed fry, or vertical incubators which are more space efficient.
- Salmon eggs must be incubated in the dark and red lights only used during inspection.
- Routine and regular water temperature monitoring allows water temperatures and predicted hatch dates to be modified in response to any ‘unplanned’ water temperature changes detected.
- Water flows should be maintained at 7L/minute and deviations of 0.5 litres (above or below) should be corrected

SHO 6 **Salmon Hatchery Operations**

Sub sections	Resources	Comments
Intro	Image needed: Healthy eyed eggs	
6.2 Incubator hygiene	Image needed: dead and moribund eggs in trays	
	Video: Incubator maintenance	Story boarded
	Images needed (X3) • Removing dead eggs • Removing moribund eggs • Removing eggshells from screens	Showing removal process
	Egg ID chart	



SHO 6 Egg husbandry

During incubation, the hatchery water quality and temperature must be checked regularly, and high standards of hygiene maintained in the incubation trays. Husbandry staff should pay attention to the **target temperature** of the incubation system which is updated by the hatchery manager according to water temperature records.

Healthy ova incubating - provided by Vikan Settefisk

Routine (SOPs) for water quality monitoring, checking flow rates and the removal of dead and moribund eggs should be followed by all staff.

6.1 Water quality monitoring

In addition to monitoring and optimising the incubation temperature according to the hatchery thermal regime, water quality is routinely monitored in two ways:

Hand-held probe

Sampling the RAS system at the sump system and each tray using the **hand-held probe** for the following parameters

- Dissolved oxygen
- pH
- Conductivity

Laboratory sampling

Laboratory staff analyse samples taken at the RAS sump and water supply inlet by the hatchery staff as part of routine daily duties. **Heavy metal** concentrations and other parameters are assessed using **laboratory water quality analysis** techniques.

Key points

- Water quality parameters are monitored daily by hand-held probe (DO, pH, salinity, and conductivity)
- Eggs are checked daily under red light and dead and moribund eggs removed.
- At 420-430 degree-days the embryo releases an enzyme that softens the chorion and the eggs hatch
- The eggshells accumulate as debris which is removed from screens
- Any remaining eggshell debris degrades releasing ammonia

6.2 Egg incubation maintenance

The ova should be checked under red light daily for mortalities and associated fungal growth. Dead eggs will show up as white eggs or eggs with white patches. Moribund eggs are discoloured or pale. This can lead to **fungal growth** in the incubator tray (Saprolegnia sp)

Mortalities and areas of fungal growth should be carefully removed using pipette or forceps. This activity must be carried out according to biosecurity protocols and utensils disinfected before use in egg trays.

At all times care should be taken not to disturb or damage eggs adjacent to those being removed.

The numbers of dead eggs should be low, as unviable eggs are removed by the supplier prior to packaging for transit.

An identification chart to identify egg quality issues (white patches, etc) can be used. The egg mortality trends for each batch of eggs should be analysed statistically and records kept.

What happens when the eggs hatch?

The salmon eggs will hatch at 420-430 degree-days, initiated by the release of **enzymes** by the embryo that softens the **chorion.**

Youtube video Hatching salmon ova, showing alevins breaking free of their eggshells

This allows the alevin to break free and the discarded eggshells accumulate as debris. During the hatch period and before the eggshells are removed or naturally dissolve, screens must be kept clear to ensure adequate water flows are maintained throughout the incubators.

The eggs should all hatch over a 4-day window, during which time the water quality, particularly ammonia levels, must be closely monitored as the breakdown of proteins in the eggshells can lead to a 'spike' in ammonia.

Once the hatch is complete, the eggshell debris and remaining eggshells should be removed from the surface of the water to limit the release of ammonia.

Instructional video – Incubator maintenance story boarded Include footage of healthy and unhealthy ova and the procedure for dead ova removal, hatchery water monitoring (quality, flows and temperature)

All incubation hygiene and water quality monitoring tasks should be conducted according to the **egg husbandry SOP** and hatchery records continually updated.

- **Insert egg husbandry SOP**

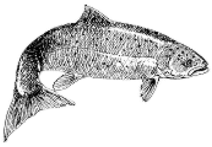
Incubator hygiene images Articulate creative- Presented in carousel? • Removing dead eggs • Removing moribund eggs • Removing eggshells from screens

SHO 7 **Salmon Hatchery Operations**

Resources needed

Sub sections	Resources	Comments
Introduction	Image needed: Healthy alevins	
	Image needed: Alevin substrate	
	Image needed: Close up of alevin sitting in substrate	
6.1 Alevin husbandry routines	Video: Settled and unsettled alevins	
	Short video: Settled and unsettled alevins	
	Instructional video: Installation of substrate, removal, and classification process for dead and moribund, including anaesthesia.	Story boarded
6.2 Alevin Health monitoring	Image: Physical trauma	
	Image- Yolk sac elongation	
	Image -Yolk sac adema	
	Image- Coagulation of yolk sac	
	Image – Kyphosis	
	Images - Spiral shaped spinal deformity and jaw deformity	
	Instructional video- Process for checking health of alevins.	
	Images - Alevins showing full yolk sac absorption	
	Instructional video: Yolk sac absorption sampling	

Salmon Hatchery Operations



SHO 7 Alevin husbandry

In the wild after the eggs have hatched the alevins remain in the **spawning redd** undisturbed, passively absorbing their yolk sac until ready to start feeding. Salmon hatchery operators need to replicate these conditions by providing a dark, undisturbed environment and access to a suitable substrate. This allows alevins to conserve energy and develop in to healthy ‘swim up’ fry at the critical first feeding stage.

Healthy alevins image

How sensitive are the alevins when they first hatch?

Immediately after hatching the alevins are very delicate and susceptible to handling damage. Contact with their surroundings protects and calms them, reducing their level of physical activity. They drop through the hatching grid within 2-4 hours of hatching at 8 oC and descend to the ‘alevin substrate’ provided. This takes considerably longer at lower temperatures, as the alevins are less active. Offering a large surface area and multiple points of contact, the substrate performs the same role as the spawning redd gravel. It physically supports the alevins, keeping them upright and therefore helping them to conserve energy.

Alevin substrate image

What conditions do alevins need whilst absorbing their egg sac?

It is important the alevins are incubated with a substrate in complete darkness. Good husbandry routines are essential to keeping the alevin’s rearing environment clean and undisturbed. There should be minimal active swimming movement as the alevin’s energy reserve in its yolk sac are finite and must be used for growth and development.

Image of alevin close-up sitting in substrate

What happens if the alevins become too active?

Alevin movement burns energy, reduces the size of fry at first feed and risks damage to the yolk sack through pinching off the entrained oil globule. This in turn significantly impacts on the size of the first feeder and reduces its chances of survival.

7.1 Alevin husbandry routines

Video clip - Short 2 parts

Part 1 Alevins unsettled and too active burning energy with no substrate

Part 2 Alevins settled in the substrate with limited movement

The hatchery hygiene routines are vitally important. The alevins yolk sac development should be checked under red light and without white light in the room at least three times a week. The frequency is increased under the hatchery manager's instruction when mortalities are high.

Any dead alevins should be gently removed with tweezers or pipets and disposed of according to the hatchery mortality handling SOPs.

Moribund alevins should also be removed in the same way and **euthanised using an anaesthetic overdose** - MS222 bath for a minimum of 15 minutes.

Classification of mortalities: Before disposal, all mortalities should be classified by 'suspected cause' using a standardised classification system.

The primary potential causes of mortality are:

- the environment (water quality)
- fish development & maturation (pinheads)
- morphological abnormalities (deformities)
- mechanical damage and handling
- other miscellaneous causes such as sampling.

The meticulous removal and disposal of dead or moribund fish minimises the potential for infection from opportunistic and pathogenic organisms and is therefore essential to effective hatchery husbandry.

Equally meticulous record keeping in the 'Hatchery Mortalities Record' provides a reliable body of information and statistics that should be analysed once a week. The company's fish veterinary services are given access to all records when conducting routine fish health audits.

Post-mortem: If dead or moribund fish are removed and found to have signs of a pathological infection (bacteria, fungi, virus, or parasite), it is assigned a 'Secondary Classification'. Any infection other than Saprolegnia fungal infection should be reported to the Unit Manager, Technical Manager and Facility Manager and disclosed to the facility veterinarian. A full Post-Mortem will normally follow. A clinical diagnosis can only be made by the facility veterinarian, specialized facility personnel, and/or a nominated laboratory.

Instructional video- Alevin husbandry (story boarded)

Installation of substrate, passive alevins, removal, and classification process for dead and moribund including anaesthesia.

Process of identifying the degree of yolk sac absorption and readiness for transfer to nursery

Alevin behaviour that the stockman should be aware of:

- Alevins resting in the substrate (positive observation)
- 'Clumping' post transfer (negative observation)

Key points

- Alevins must be kept undisturbed in the dark with a suitable substrate to minimise their movement and conserve energy for growth and development
- Dead and moribund alevins must be removed with tweezers or pipettes and the cause of mortality determined using a standardised classification system and recorded.
- Alevin's yolk sac development must be checked 3 times a week for abnormalities under red light, including, yolk sac elongation, adema and coagulation and spine and jaw deformities.
- Non-infectious alevin health problems can be caused by water quality, incorrect flow rates, genetic and nutritional diseases
- Any infectious disease other than saprolegnia should be reported and a post-mortem analysis conducted by a qualified veterinarian.
- As the alevins approach full yolk sac absorption, samples should be checked twice daily in a beaker. When 90% of alevins have absorbed 90% of their yolk-sac they are ready for first feeding and transfer to the nursery

- **Insert SOPs for alevin husbandry**

7.2 Alevin health monitoring

Alevins are vulnerable to a range of **infectious diseases** that can be prevented by good hatchery husbandry and hygiene practices, to prevent the onset and escalation of disease problems.

There are other conditions commonly observed in salmon hatcheries indicative on non-infectious health issues.

The causes of these conditions include;

- water quality (including low hardness),
- high gas pressures,

- high water flow rates causing high activity and stress,
- genetics and nutrition, and
- physical trauma

Image- Yolk sac elongation

Yolk sac elongation Clinical Signs: Yolk sac elongation, yolk sac contraction, Posterior displacement of lipid drop.

Most likely cause: High activity of fish due to high water flow or stress.

The image shows:

A: **Hypervascularization** of the yolk sac.

B: Yolk sac elongation with lipid drop strangulation

Image – Yolk sac adema

Yolk sac adema Clinical sign: Fluid presence between yolk sac and yolk sac membrane.

Most likely cause: **Increase gas pressure**. (See Ova and Alevin Husbandry SOP)

Coagulation of yolk sac

Clinical Sign: White spots on yolk sac area. This condition occurs in eggs and yolk sac fry, and the consequences are observed in later stages.

Most likely cause: Poor water quality, low hardness water (<50 mgl $CaCO_3$), high gas pressure and Physical trauma.

Image- Coagulation of yolk sac

- A: Incomplete closure of midline at heart level.
- B: Vascularization of yolk sac.
- C: Coagulation of yolk sac.

Learning activity – Alevin health monitoring

Articulate creative: Interactive visual multiple-choice exercise...that allows learners to health monitor alevins, categorise, and record them, with automatic feedback on their accuracy.

- those that appear to have completed yolk sac absorption ready for first feeding
- yolk sac elongation
- yolk sac adema
- coagulation of yolk sac
- spinal and/jaw deformity

Kyphosis

Clinical sign: Spine deformities.

Most Likely causes: Genetic and nutritional aspects

A: Sipe deformities (Kyphosis)

B: Yolk sac vascularization.

C: Yolk Sac elongation

D: Edema

Image - Kyphosis

Other deformities

Articulate creative

Title Common problems observed in with alevins

Create a panel of causes and drop down each above condition and the labelled image to show the problem, followed by a solution or action to be taken

Images - Spiral shaped spinal deformity and jaw deformity

How regularly does the alevins' health need to be checked?

The alevins are visually checked every day in a well-lit glass beaker, paying careful attention to the yolk sac.

- **Insert SOPs for checking alevin health.**

7.3 Yolk sac absorption sampling

Instructional video- Process for checking health of alevins.

Video to include the procedure and stills above to show the problems that can occur, followed by remediation

Samples should be taken and checked twice daily in a glass beaker, a week prior to when the alevins are predicted to have absorbed their yolk sac (800 Degree days from fertilisation).

The alevins become more robust as their yolk-sac is absorbed and when the process is almost complete, they are ready for first feeding. As a direct visual guide, once 90% of the sample has consumed 90% of their yolk sac, the fish are ready to move to the first feeding units. This assumes that the sample is representative of the population.

Images - Alevins showing full yolk sac absorption

First feeding should not be delayed past the allocated time as the **digestive system** can develop to a stage where the fish cannot digest feed and waste away. There is a risk that a proportion of the fish will die during first feeding If this occurs. Fish suffering this fate are called pinheads, as they have little body mass and a relatively large head.

What happens if first feeding must be delayed for any reason?

If first feeding (and transfer) must be delayed for any reason, water temperatures should be reduced by 0.5 oC as soon as the need to delay is noted. This will help the fish to conserve energy as their metabolic rate will reduce with the lowering of the water temperature.

<table>
<tr>
<td>

Instructional video: Yolk sac absorption sampling

Alevins showing signs of absorption and audio mentions 90% absorption. Show series of stills with audio and text overlay of alevin at different stages of yolk sac absorption (X 6 stages) on time lapse to first feeder.

Show process for checking for 90% absorption with examples less and more than 90% for comparison.

</td>
<td>

...**the science says**

The Freshwater Fisheries Society British Columbia have experimented with salmonid ova to determine the effect of providing substrate during the alevin stage.

Their research concluded that the fish from the group provided substrate reached a half gram 10 days earlier than the control group. All fish had the same temperature, same stock density, same feed rate.https://www.hatcheryinternational.com/testing-out-substrate-for-trout-3398/

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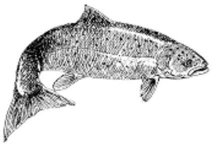
SHO 8 **Salmon Hatchery Operations**

Sub sections	Resources	Comments
Intro	• Images needed (X2): • First feeders at the surface • Holding Units	
7.1 Preparation of first feeding system	Image needed: Alevin substrate positioning	
7.2 Transfer alevins to the first feed units	Images needed (X3): • Egg trays being moved • Tray placed in bin for transport • Trolley for moving trays	
7.3 First feed Fry	Image needed: Automatic feeder being filled	
	Video: Set up and operation of first feeding	Story boarded



SHO 8 First feeding

The future growth and health of a farmed salmon is heavily influenced by the success of the first feeding phase. The key is to develop the feeding response and appetite of the fish which makes feed management easier subsequently. The most reliable commercial fish feed suppliers can be trusted to provide stable pellets of the right particle size and nutritional profile for first feeding fish. The hatchery staff must ensure that their feeding practices are based on careful stock observation during this critical stage.

Images – First feeding

Articulate creative: Carousel with text over lay

- First feeders at the surface
- Holding Units
- Automatic feeders

8.1 Prepare the first feed system

The first feeding system must be prepared and tested in advance of the transfer of first feeders. This is to ensure that stock rates are within the maximum density limits and the aquatic environment is suitable regarding all key parameters (water flow, temperature, and quality).

A typical first feeding systems would consist of a series of circular tanks of 5.0 internal diameter and a metre deep, adjustable to a water depth of 0.7 and 0.9 metres with an inlet and central screen.

Images - Positioning alevin substrate in the first feed unit

A minority of the alevins (5-10%) will not have fully absorbed their yolk sac when the batch is transferred to the first feeding unit. Therefore, it is beneficial to install five or six small areas of alevin substrate away from the central screen. These holding areas have resting places and barriers against the flow for those alevins not quite ready to first feed. They can exhibit natural sheltering behaviour during the transition to active schooling and feeding. This reduces stress and prevents the fry clumping around the screen outlet.

The fish transfer from incubation rack to first feeding holding units must be planned so as it can be completed within a few minutes to minimise fish stress.

Learning activity 7

Stockman's Calculations 4

Calculating the number of incubator trays to transfer the required number of first feeders

The quantity of fish available in the trays must be calculated in advance, ensuring that a maximum stocking density of 9,000/M2 will not exceeded when they are evenly distributed within the first feeding units.

The holding unit should be set up to run at a flow rate equivalent to 0.3 body length/sec as an approximate guide) and an initial water depth of approximately 50 (± 10) cm.

Does the water temperature and quality need to be checked before transfer?

If the temperature difference between the hatchery incubation facility and the nursery unit is more than 1 degrees Celsius, the transport of alevins should be postponed. Once the difference is less than 1 Degree Celsius the transfer can continue and '**temperature shock'** avoided.

The key water quality parameters must be stable and within acceptable limits for the transfer of first feeders. A water quality sample must be taken prior to transfer to measure; Dissolved Oxygen (DO), Hardness, Alkalinity, pH, Total Ammoniacal Nitrogen (TAN) and Nitrite (NO2).

- **Insert Water Quality Testing SOP**

Key points

- Substrate mats are placed away from the central screen in first feeding units to provide shelter for the 5-10% of alevins that have not absorbed their yolk sac.
- There must be <1 Degrees Centigrade difference between incubation and first feeding facilities and the water quality must fall within the limits set for all key parameters.
- Transfer fish from trays within 5 minutes to establish a 9,000/M2 density at a flow rate of 0.3 body lengths per second (approximately 30-40 cm /minute)
- Alevins must be health checked by a veterinarian before transfer
- Alevins should be gently moved in a tray for transit and acclimatised by slowly adding the water from first feeding facility
- First feeders are provided a small particle size of feed pellet that floats before sinking slowly to ensure that food is constantly available to the fish
- Fish are fed by hand initially to get them feeding in groups, before transition to automatic feeders after 2 days
- The substrate is gently lifted twice a day initially to assist cleaning and waste gently brushed to the tank centre when flushed.
- The substrate should be removed as soon as the fish are shoaling and no longer need it for shelter, normally after the first week.
- Mortalities should be removed and classified according to a standardised classification system and recorded.

Recommended water quality parameters in first feed unit

Insert water quality parameters specific to hatchery

Dissolved oxygen must be maintained at no less than 100% saturation and 7 mg/L.

8.2 Transfer alevins to first feed units

Before moving the alevins, a **health check** must be completed by a qualified fish vet to confirm and certify the health of stocks prior to transfer.

Learning Activity

Calculating the number of incubator trays to transfer the required number of first feeders

The alevins should be gently moved in the trays which are designed to be removed.

The numbers transferred to the first feed tank should be pre planned and match a specific number of incubator trays.

Image- Trays being moved

How are the first feeders moved from the incubation trays to the first feeding Unit?

The alevins are removed from their incubation trays and placed in a deep bin held on a transport trolley and wheeled to the first feeding Unit. This keeps the alevins immersed during transit.

The correct quantity of alevins must be introduced and spread evenly between the prepared first feeding holding units, not exceeding the upper limit of 9,000 alevins per M2.

How can you ensure that the fish are evenly distributed between holding units?

This requires some planning and simple logistics. For example, if 2 holding units are available in the nursery for first feeding and the incubator has 14 fry trays then 7 fry trays of fry should be released into each tank, assuming each tray has a similar stock density. This is straightforward.

Tray placed inside bin for transport

Trolley for moving trays

However, it gets a bit trickier if 14 fry trays must be divided into 3 First Feeding tanks. Then you must transfer 4 trays into each of the 3 tanks and distribute the remaining 2 trays evenly amongst the three tanks to achieve the same stock density in each.

8.3 First feed fry

In the wild, first feeding fry are small and delicate and although free-swimming, cannot move far to capture prey. They are reliant on small food items coming to them in the drift. Therefore, when in a hatchery, the fish need a constant flow of small feed particles passing them that can be easily ingested within minimum effort, movement, and energy expenditure.

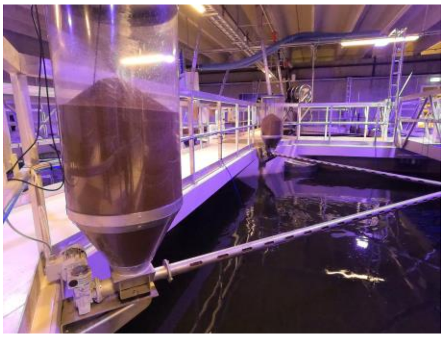
For the first week as the fish develop their appetite and become established on the feed, the flow rate should be kept low, and the feed rate set to ensure good feed availability without excessive waste.

First feeding pellets should float before sinking gently, making them very visible on the surface and as they slowly descend, to stimulate the young salmon’s natural feeding response. The feed should be water stable and not disintegrate.

Hand feeding is essential to allow groups of fish to be observed during the crucial early stages of appetite development. Each group should be seen to be feeding before moving the fish on to automatic feeders, typically after about 2 days.

First feeding requires careful observation of fish behaviour and detailed husbandry management to get feed inputs and flow rates in balance.

Insert Fry Feeding SOP



Automatic feeder

How is tank hygiene maintained with low flow rates?

Flow rates are low for first feeding fry which limits the self-cleansing capacity of the holding unit and waste can settle where the water movement is impeded. Therefore, it is important in the first week to gently lift and replace the substrate twice a day to allow any accumulated waste feed to be removed. The tank systems are designed to assist cleansing and any waste feed can be gently brushed towards the centre screen at the same time as the tank is flushed.

The hatching substrate can be removed as soon as the fish do not require it for shelter, normally at the end of the first week, to allow optimum water quality.

Instructional video- First feeding

Part 1 Set up

Preparing the first feed system, adding substrate,

Set up water flow and check temperature and test water quality.

Part 2 Operation

Transferring first feeders

Feed first feeders

Maintain Hygiene- cleaning substrate, flushing tank, and removing substrate and waste feed.

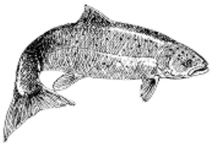
Removal, record and classify mortalities according to SOP.

Mortalities should be removed during first feeding, according to company **Mortality Removal SOPS,** and classified using a **Standardised Mortality Classification System**, and recorded at the point of removal.

SHO 9 **Salmon Hatchery Operations**

Resources to be created

Sub sections	Resources	Comments
8.1 Feeding fry one-week post first feeding	Images needed (4): well distributed healthy fry in holding unit, Feeder being filled, Feeder positioned over water, Feed pellets in hand,	
	Infographic: deigned to illustrate the relationship between feed rate, water flow rate and eliciting a feeding response	Provisional- Design and costing needs discussion
	Fry Feed Table	
8.2 Feeding growing fry	Images (1-3): Damage due to territorial aggression (eyes, fins operculum)	
8.3 Sample weighing	Instructional video: Sample weighing fry procedure	Story board
8.1-8.3	Instructional Video: Feeding growing fry, all aspects	See Story board



SHO 9 Feeding growing fry

Once fry have developed an appetite and have been feeding and growing for a week, one of the most precarious stages of the hatchery operation has been accomplished! The general aim thereafter is to maximise growth whilst minimising feed wastage and maintaining a hygienic rearing environment.

9.1 Feeding fry one-week post first feeding

Salmon are visual feeders and lighting is provided constantly with regular feeding 24 hrs a day to help maximise feed intake and growth.

After the first week the feed rates should be adjusted daily so that there is constant feed availability to the young fish. This needs to be undertaken alongside water flow adjustments to ensure feed particles are passing the young fish continually and can be effortlessly ingested.

Images

- Well distributed feeding fry
- Feeder being filled
- Feeder positioned over water
- Feed pellets in hand

Feed presentation can be improved by careful positioning of the feeders, adjusting the drop height by bringing them closer to the water surface. This helps to trap feed particles in the surface meniscus for longer before they eventually slowly sink. The size and shape of the holding unit, the water level, and the number and type of feeders can all have an influence.

Every two days, as the fish become stronger and actively swim against the current, the flow rate should be very slowly increased.

A good ‘rule of thumb’ (guide) is that the flow rate around the outside of the tank should be fast enough to keep the strongest fish five centimetres from the side of the tank, when judging fish distribution from the water inlet point to a position two thirds around the tank perimeter. As a guide the flow rate should remain equivalent to 0.3 body length/sec.

How is the holding unit kept clean?

The base of the holding Unit needs to be carefully swept clean and flushed twice a day, which is easier at this stage in the absence of substrate. It is important to ensure that the younger fish are not drawn against the screen during flushing and damaged in the process.

Key points

- A 24 hour a day light regime maximises feed intake and growth
- Feed rates are adjusted daily to maintain constant food supply and minimise aggression
- Automatic feeders are carefully positioned to improve feed presentation
- Holding unit flow rates are increased every two days as the fish grow
- The base of the holding unit should be swept and flushed twice daily
- Fry are sample weighed weekly to assess their average weight and growth
- Feed pellet sizes are increased as fish grow according to feed charts
- Feed should be well spread in the holding unit and the speed and direction of water flow controlled to limit dead areas.

Infographic - feeding fry

Articulate creative: Infographic simulation deigned to illustrate the relationship between feed rate, water flow rate and eliciting a feeding response and the impact on feed wastage and hygiene.

This could be interactive, learner controlling and increasing or decreasing the feed rate and or flow rate, until fish can access and ingest food particles near enough to them.... As the learner carries on feeding beyond the optimum, feed waste builds up (due to over feeding).

Learner then cuts back feed rate to **a** level where it is available, and all consumed with minimal waste. If flow rate goes too high, the fish starts moving backwards (can't maintain its position)

An overlay of typical food consumption rates and flow rate figures could quantify the relationship. A timeline could be included in days with fish increasing in size as they grow, according to feed input and biomass

Aim: To illustrate visually the dynamic relationship between the parameters and the balance that must be struck

9.2 Feeding growing fry

As the fish grow stronger, the tank becomes self-cleansing to a large extent. It may however still be necessary to brush the base of the tank two or three times a day to remove waste feed.

It is important to increase the feed sizes according to the approved table as the fish grow. When going up a size, pellets should be mixed for 3 days to allow for a smooth transition.

Feed should be well spread in the holding unit, assisted by a controlled speed and direction of water flow to limit dead areas. Careful observation during the first 3 weeks of feeding is most important as the fish's appetite is changing rapidly. The recommended feed rate provided by the feed manufacturer should be referred to as a guide only, but not followed blindly.

Underfeeding can lead to territorial behaviour and aggression, resulting in damaged eyes, operculum shortening and/or fin damage, all of which can be avoided if the fish have constant access to a suitable food supply, as opposed to strict rationing.

Images

Damage to parr eyes, fins and operculum due to territorial aggression

9.3 Sample weigh fry

Sample weighing should occur on a weekly basis following the designated protocol.

This allows growth, stock biomass and densities to be monitored and feed pellet sizes increased at the appropriate time.

Procedures for sample weighing Fry

To weight the fry biomass, proceed as follows:

1. Set up an electronic scale, with a suitable range and accuracy for the size of fish (0 – 500 g x 0.01 g)
2. Make sure the scale battery is fully charged.
3. Prepare a plastic or glass vessel.
4. Put the empty vessel on the scale and zero the scale.
5. Make sure that total weight of the vessel plus water and fish does not exceed the total weight that the scale can register.
6. Capture the fry and count the sample in to the vessel
7. Read and record the total weight
8. Gently return the fry to the first feeding tanks.

Instructional video - Fry feeding

- Set up feeders and feeding fry
- Removing waste feed and mortalities and classify.

Capture video and add audio to illustrate relationship between feed rate, flow rate, feeding response and feed wastage.... "How to strike the right balance"

Instructional video - Fry sample weighing

- Show balance being set up and battery checked.
- Zero balance
- Catching sample
- Counting sample into the vessel
- Show the weight reading (closeup) and recording
- Operative returning fish to the unit