A LEARNING RESOURCE

Biology of the New Zealand Greenshell Mussel

(Kutai, Kuku)

NZ Seafood Industry Training Organisation

QUALITY - GROWTH - EXCELLENCE

Contents

1. Describe the Greenshell™ Mussel

Classification

All living creatures, both plant and animal, are classified by a hierarchical, scientific system that classifies them according to their similarities.

Mussels belong to a scientific grouping of animals (Phylum) known as the Mollusca or **Molluscs.** One of the distinguishing features of this grouping of animals is the presence of a **shell** (produced by a mantle)**.** It is from this feature that the grouping gets its common name of "**Shellfish**".

All molluscs are then further subdivided into groupings based on their shared characteristics. This phylum includes seaslugs, bivalves (two shells), univalves (one shell), chitons, & cephalopods (squid, octopus).

Mussels belong to the Class of **Bivalves** – so called because they have two distinct shells or valves. The bivalves are the second most numerous group of molluscs. Some 10,000 species may be found worldwide and nearly 400 of these can be found in New Zealand waters.

Naming

In order to correctly identify a mussel it is necessary to use the **scientific name**. The scientific name is consistent throughout the world so that you can be sure exactly what animal is being talked about. Every different animal has its own unique, scientific name.

The scientific name contains two parts : i.e. *Genus species*

If two animals have the same *Genus* it indicates that they are very closely related. This part of the name may be shared by close relatives, like a surname. However the two-part name is always unique.

The scientific name often uses Latin words, which generally have some meaning relevant to the species being named. For example words may be used which represent the country where the species is found or describe a distinguishing feature. Sometimes the species may be named after the person who discovered it.

Common names however are simply the names by which the animal is "commonly" known and can vary from country to country and even between people. Each animal may be known by several different common names.

For example:

Table 1. Some cultured mussel species from different parts of the world

Scientific name	Common Names	Found	Cultured
Mytilus edulis	Blue Mussel Black Mussel European Mussel	World wide distribution	Canada, USA, Europe, Africa
Mytilus galloprovincialis	Mediterranean Mussel Blue Mussel Black Mussel	Mediterranean New Zealand	Eastern Europe, South Africa
Perna canaliculus	Green Lipped Mussel Greenshell™ Mussel Kutai Kuku Green Mussel New Zealand Mussel	New Zealand	New Zealand
Perna perna		South America, Africa, SE Asia, India	Brazil, Chile
Perna viridis	Green Mussel	Indo-pacific region	Pacific islands, India, Asia

There are 16 species of mussel in New Zealand, but the two most well known are the two edible types the blue mussel (*Mytilus galloprovincialis*) and the **Greenshell mussel** (***Perna canaliculus***).

Some of the more common mussel species in NZ are listed over the page including both their scientific and common names.

Pictures of each species, distinguishing features and habitats are also given to enable the Greenshell™ mussel to be compared and readily identified.

Table 2. Distinguishing features and habitat of common New Zealand mussel species

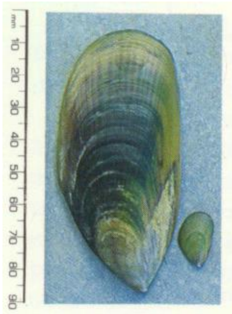
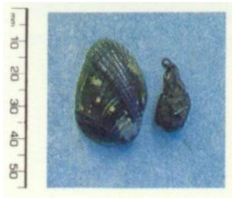
Scientific Name	***Perna canaliculus***	***Mytilus galloprovincialis***	***Modiolarca impacta***	***Aulacomya maorianus***	***Xenostrobus pulex***
Common Names	Green-lipped Mussel Greenshell™ Mussel Kutai Kuku Green Mussel	Blue Mussel Black Mussel Mediterranean Mussel	Nesting Mussel Small Brown Mussel	Ribbed Mussel	Little Black Mussel
Picture	 a.  b.	 a.  b.	 a.  b.	 a.  b.	 b.

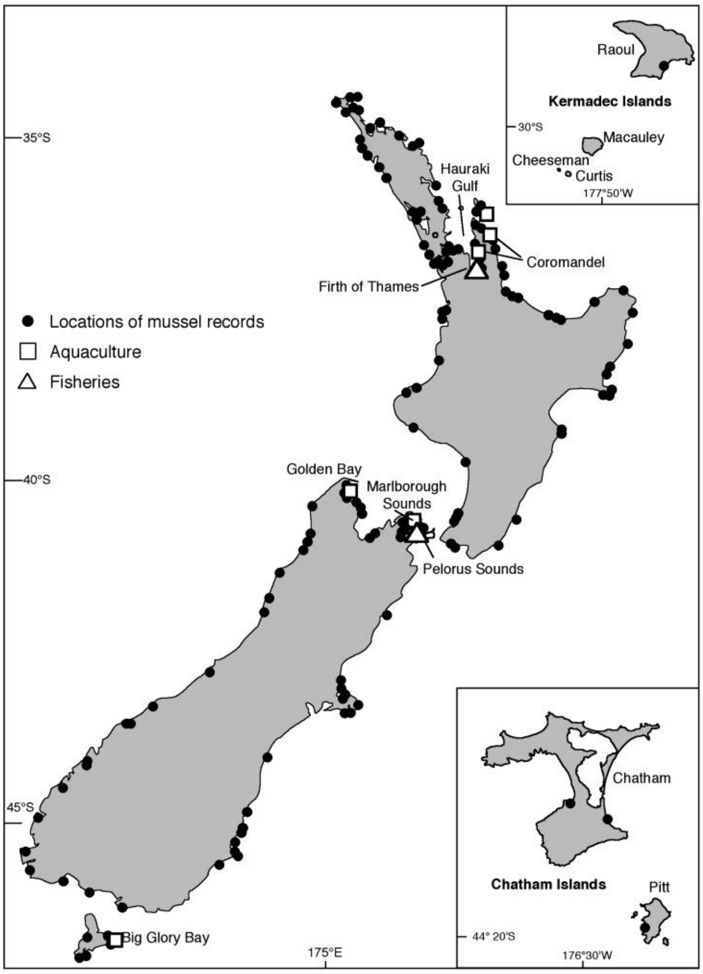
Table 2 - continued. Distinguishing features and habitat of common New Zealand mussel species

Species	Greenshell Mussel *Perna canaliculus*	Blue Mussel *Mytilus galloprovincialis*	Nesting Mussel *Modiolarca impacta*	Ribbed Mussel *Aulacomya maorianus*	Little Black Mussel *Xenostrobus pulex*
Colour	Green to black dependent on water depth / uv exposure and age. Juveniles are bright green. Has distinctive green lip (hence its name) along the inside shell margin.	Blue to Black. Usually with a chalky white appearance around the anterior or hinge area. When cultured shell appears glossy blue/black and is quite fragile	Juveniles (1mm) may be confused with perna because of their green colouration. Adult's olive brown – to black with a low gloss.	Sienna to purplish-black	Blue-Black
Shape	Glossy smooth shell. Shell is slightly more rectangular shaped with more prominent angles than *Mytilus*.	Glossy smooth shell with growth lines only. Dorsal and Ventral surfaces are more rounded than *Perna.*	Oval shaped valves with opposing lines of ridges and growth lines. Valves are strongly ribbed front and rear with a smooth zone in between.	Shell narrow & elongated. Deep longitudinal (radial) ridges fan out from the anterior point. These are crossed by concentric growth lines	Small, ovate, smooth shell. Often mistakenly considered to be young blue mussels (*Mytilus*).
Size	Up to 240 mm in height	Up to 100 mm in height	Up to 50 mm	Up to 85 mm in height	Up to 30 mm
Other Distinguishing Features	Has no anterior adductor muscle.	Has an anterior adductor muscle. Posterior adductor muscle is smaller than in *Perna.*	Normally wrapped in loosely woven blanket of byssal threads (hence name) in small groups along with others of its kind		

Table 2 - continued. Distinguishing features and habitat of common New Zealand mussel species

Species	Greenshell Mussel *Perna canaliculus*	Blue Mussel *Mytilus galloprovincialis*	Nesting Mussel *Modiolarca impacta*	Ribbed Mussel *Aulacomya maorianus*	Little Black Mussel *Xenostrobus pulex*
Habitat	Prefers the warmer northern waters but tolerant of a wide range of temperatures and salinities. Found in the low intertidal area and subtidal to over 50m. Prefers sub tidal Larvae prefer to settle on fine filamentous substrates such as algae, or in culture special fibrous collection ropes. May form dense beds up to $100m^2$ Attaches to wharf piles, rock faces, culture ropes etc Also found amongst algae beds and in deeper water over mud or sand bottoms.	Found naturally in the high intertidal range. Attaches to hard surfaces such as wharf piles, rock faces, culture ropes etc. Not as tolerant of very strong wave action.	Fairly common on kelp holdfasts and the under surfaces of rocks on the lower shore. Shallow water.	Common. Usually found in the company of blue mussels. On low tidal rocks	Very common (especially open coast) High intertidal – on rocks and wharves. Appears in densely packed colonies often appearing as a belt along the shore at around mean tide height. Prefers heavy wave action and tolerates temporary burial.
Geographical Distribution	Unique to NZ Widely found throughout the whole of NZ (including the Chatham & Kermedec Islands) but most common in central and northern NZ	More common in the south of NZ. Abundant in Cook Straight. Occasional isolated populations in northern districts.	Throughout NZ (including Chathams)	Found Cook Strait and South NZ (including Chatham, Bounty, Auckland and Campbell islands).	Throughout NZ + W,E,S Australia (including Snares & Auckland Islands)
Aquaculture Notes	Principal Species farmed in NZ The Main areas where mussels are farmed are Marlborough/Golden Bay, Coromandel/Thames, Stewart Island. Though farms have recently been established outside of these areas.	One of the principal species farmed overseas. *(The main species of blue mussel farmed overseas is Mytilus edulis)*			

Pictures taken from a. Jenkins 1985, b. Gunson1993,



Known locations of the Greenshell™ mussel in NZ (taken from Jeffs et al 1999)

2. Anatomical Features of Greenshell™ Mussels

2.1 External Features of Mussels – location, identification and function

Bivalves are flattened from side to side (laterally compressed) so that the valves are positioned to the left and right of the body. In other molluscs such as oysters or scallops, where the shells are different, the left valve is usually the cupped valve, which contains the body.

The mussel shell is typically pointed at the umbo, which is found at the front or **anterior** of the animal.

The valves are hinged by a flexible ligament (**hinge**), around which develops a series of small ridges or teeth to ensure a snug fit when closed, and to prevent any sideways displacement of the valves. The **hinge** is located on the **dorsal** (back) surface of the animal. The ligament, which is constructed of horny conchiolin, is internal and tends to spring the valves apart. Hence in a dead or relaxed state mussel shells are naturally open.

The shell is rounded at the rear or **posterior** end. The shape and nature of the shell are quite variable depending on the environment in which the mussel has been grown. Rings of growth may be evident in the shell similar to rings on trees which are caused by changes or **checks in growth**. In aquaculture these checks are often caused by management practices such as transporting spat or reseeding. Factors which can affect the growth of mussels are covered in section 4 of this resource.

The long axis of the mussel (often referred to as length) is actually the animals height. The shape of the shell enables mussels to attach to surfaces in crowded groups while still gaining access to the water to take in food and get rid of wastes.

Often the **byssus** (beard) or strong attachment threads are obvious hanging outside the shell on the anterior ventral surface opposite the hinge. The mussel uses these threads to attach itself to the surface and can release its hold on these strands, and secrete new ones at any time enabling it to move, or alter position. The amount of byssus produced varies dependent upon the environment the mussel is living in (eg the strength of current it has to resist).

Shell

The shells main purpose is to protect the soft body and it is composed of three layers

Table 3. Layers of the Mussel Shell

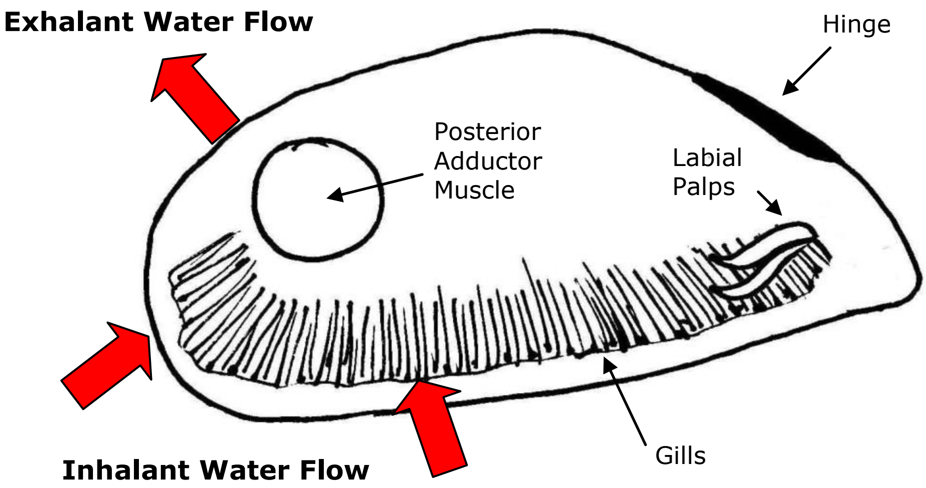
Periostracium	Outer layer	Composed mostly of protein (organic) Protective external layer relatively thin. This layer gives the green colour to *perna*, but can become almost black when exposed to sunlight, in the top layers of the water.
Prismatic Layers	Middle layer	The thickest layer Is often chalky in nature Made mostly of inorganic calcium carbonate (90%) in a crystalline structure (Calcite or aragonite) mixed with small amount of protein substance called conchiolin
Nacreous Layer	Inner layer	Thin, often shiny or lustrous - the pearl forming layer. Very hard Also made of calcium carbonate but here the crystals are in sheets which reflect and bend light giving a shimmery appearance.

2.2 Internal Features of Mussels – location, identification & function

Internal Feature	Function
mantle	• Covering the soft body on each side and looking like a thin fringe which runs to the edge of each shell is the **mantle.** The mantle is usually dark in colour (black to brown) and is comprised of three layers and is thicker on the edge. The main purpose of the outer mantle is to secrete the shell, though it also enables the mussel to **sense the environment** and assists in controlling the in flow of water to the body.  *A feeding Greenshell™ mussel showing the frilly mantle* • The two small lobes of the mantle are fused in two places in order to help separate the inflowing and outflowing currents. • The inner mantle lobe is important for energy storage and reproduction, and forms the bulk of the tissue obvious when you open a mussel.
sensory papillae	• The key sensory role of the mantle uses special structures called "sensory papillae". These are located predominantly on the inner mantle fold and are numerous around the inhalant chamber, particularly posteriorly. They give the mantle of the inhalant chamber its frilly edged appearance.  *Close up view of sensory papillae*
gonad	• In mussels the **gonad** or reproductive tissues in the mussel form predominantly in the inner mantle tissue but also in the main body / mesosoma. In females the gonads produce eggs and in males they produce sperm. • The gonad tissue forms the majority of the "meat" which you eat in a fat mussel. In immature mussels this tissue is undeveloped and appears creamy coloured in both male and female mussels.

Internal Feature	Function
	• As the mussel matures both the size and shape of the gonads change. In mature females the gonads are reddish-orange in colour and in mature males they are creamy white.
adductor muscle	• The adductor muscles function is to hold the shell closed and control the amount the shell opens. • The greenshell mussel has a single large **posterior adductor muscle.** It is this muscle that we cut in order to open the shell. • The blue mussel has two adductor muscles a **posterior adductor muscle** which is slightly smaller than that in the greenshell muscle, and a very small **anterior adductor muscle** found right by the point of the shell. This is one of the key anatomical differences between these two species of mussel.
retractor muscles	• The retractor muscles function is to enable the foot to move in all directions. There are three retractor muscles attached to each shell giving 6 muscles in total. Each runs from the base of the foot to the shell. • The **anterior retractor muscles** attach to the shell by the hinge close to the point of the shell. The **middle retractor muscles** are attached close to the digestive gland, whereas the **posterior retractor muscles** are located next to the posterior adductor muscle**.**
heart	• The heart is found just to the front (anterior) of the adductor muscle and can sometimes be seen beating (around 25 times per minute) through a thin membrane.
foot	• The foot is muscular with a groove running down one surface and has two important roles. It allows the mussel to move over and evaluate surfaces and has an important **sensory function**. When the right surface is found the mussel uses the foot to attach itself. At the base of the foot is the **Byssal Gland** which produces the **byssal threads**. In order to attach itself a mussel will reach out with its foot to find a good attachment point. It then ejects a fluid from the byssal gland down the groove in the foot. Upon contact with the seawater this fluid goes hard and forms a byssal thread. In this way each thread is created separately.
mesosoma	• This organ lies between the gills and behind the foot. The mesosome is important for energy storage and reproduction.
gills	• Scientifically known as ctenidia, the **gills** are a light tan colour and folded to form a W shape. There are two paired gills, they are finely fringed and lie along the length of the muscle. The gills have important functions in both respiration (breathing) and in obtaining food. • Covering the gills is a layer of small hairs or **cilia** which move water and food particles by beating together rhythmically in waves. Water is moved across the gills and out the exhalant chamber behind the adductor muscle. Food is also moved by cilia along special pathways towards the mouth.

Water Flow Over Gills



Internal Feature	Function
labial or feeding in Palps	• At the anterior end of the gills, near the mouth opening, are two pairs of leaf/feather shaped appendages called **labial palps**. These palps have an important **sensory function** as they sort the particles trapped in the mucus into food of the right size, and waste. Food particles are then placed in the **mouth** whereas particles which are rejected are bound in mucus and ejected as pseudofaeces (note pseudo is Latin for false, ie false faeces) by reversing the water flow over the gills. These pseudofaeces are light and fluffy in texture.
gut	• The other major portion of the mussel we eat is gut. The **gut** encompasses the whole of the digestive system which breaks-down (digests) and absorbs the food particles the mussel eats. • There is a short tube (oesophagus), which leads from the mouth to the **stomach** or **digestive Gland**. The stomach is important for the mixing, sorting, and digestion (breakdown) of the food particles. • There is also a blind sac close to the entrance of the intestine. Within this sac is a gelatinous rod structure called the Crystalline Style. It is golden brown, long and tapers to a point at one end. This Style rotates in the stomach at 1-12 rpsec, pulling food into the stomach and mixing food. The end of the style is ground against a hard pad called the gastric shield. This wears away the end of the style, releasing the digestive enzymes which it contains, into the food to break it down. • The liquefied food is then absorbed through the walls of the gut into the body. • Opposite the oesophagus is the entrance to the **intestine**. This narrow tube winds around the stomach, runs along the dorsal surface of the mussel and finishes at the **anus**, which is located close to the posterior adductor muscle. Any material that is unable to be absorbed by the body is delivered to the intestines, where it is compacted and then exits the anus as faeces. These true faeces are expelled into the exhalent current.

3. Life Cycle, Feeding and Reproductive Cycle

3.1 Life Cycle

Mussels are **broadcast spawners**. This means that they simply release their eggs and sperm into the water. The eggs of perna are about 0.05 mm in size and are fertilized in the open water by sperm which have been released by male mussels.

The larvae of mussels are free swimming and have a planktonic stage which lasts around 4 to 6 weeks before they are ready to settle. The planktonic stage enables the larvae to disperse to new areas, and mussel larvae may be moved several hundred km by the currents. During this stage the larvae go through **2 changes** before metamorphosing into a miniature adult mussel which is called the **spat**.

Within 24-48 hours the fertilized egg has developed into a **D shaped larva** so called because of its straight-hinged shape. These larvae have some ability to move vertically in the water column using an organ called the **Velum** which is covered in small **cilia.** However they are mostly at the mercy of ocean currents. The velum is also used for feeding.

The larva continues to grow and changes shape developing an umbro (point to shell). The **veliger** larva then develops two pigmented eyespots and a functional foot (at which stage it is called a pediveliger and is getting ready to settle).

The **pediveliger** uses its foot to search for settlement surfaces, and its velum to move between potential settlement sites. The larvae look for a suitable filamentous substrate such as seaweed or culture rope. They then attach themselves to the surface by secreting byssal threads.

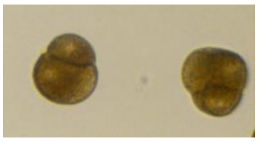
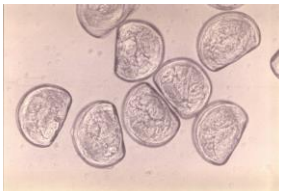
Immediately after settlement the larvae metamorphose into the adult form, loosing the velum and becoming bottom dwellers. At this stage they are known as **spat.**

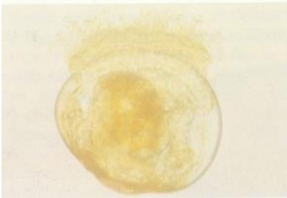
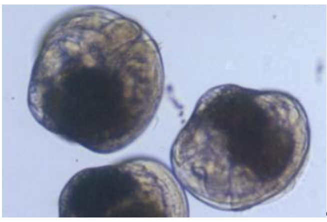
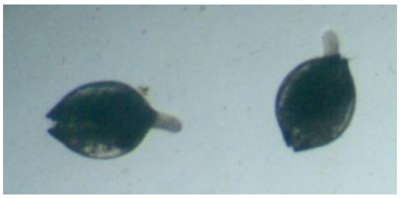
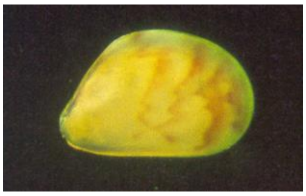
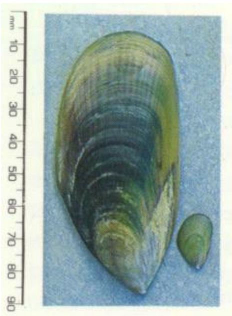
Early on the spat can still move if the site they have chosen doesn't suit, by releasing the byssal threads and using mucus threads which act like parachutes enabling them to drift in the water currents. This enables them to recruit into adult beds. They loose this ability to drift when they are around 6mm in height.

Larvae of the blue mussel *Mytilus* tend to settle close to the water surface due to their preference for intertidal sites, whilst those of the green mussel tend to be more densely distributed, deeper in the water column.

Juvenile mussels continue to grow, and if conditions are right will usually become sexually mature (adults) in the first year of growth.

The Stages in a Mussel Life Cycle

	Sperm	**Egg**	
 *a.*	**Zygote** ↓		*Fertilized Egg*
	Trocophore		
 *a.*	↓ **D Shaped Larva** ↓		*4 days post fertilization* *75 - 135 µm*

 b.	**Veliger**	*136 – 250 µm*
 a.	**Pediveliger**	*220 – 350 µm*
 a.	**Settlement**	*3 days after metamorphosis = 300 um*
 b.	**Spat**	*> 0.3 mm*
 b.	**Juvenile**	
	Adult (mature)	*Approx > 1 year age*

a. Pictures courtesy of Cawthron Institute   *b. Pictures taken from Jenkins (1985)*

3.2 Feeding Method

Mussels are filter feeders, which means that they take in (inhale) seawater from the environment and "filter" out particles present in the water, which are then bound, sorted, and moved to the mouth for consumption. The food particles mussels eat are phytoplankton (algae).

Larval Feeding

In mussel larvae the velum acts as the sieving apparatus. The velum has a band of long hairs (**cilia**) which collect suspended food particles from the water. These particles are then moved towards the mouth by the beating of shorter cilia contained in a special "food groove" which leads to the mouth.

The velum is also able to absorb dissolved nutrients directly from the water.

These cilia are able to sort and select food of the correct particle size (In newly hatched larvae particles of 2-6 μm are preferred).

Once the particles enter the stomach further sorting occurs and inert particles (not food) can be passed directly to the intestine for removal. Food particles are torn open and digested by the rotation of a crystalline style as in adult mussels.

As the larvae grow the sizes of phytoplankton they can accept increase. Pediveligers are capable of feeding on phytoplankton of 15-20μm in size.

Once the larva settles and undergo metamorphosis, it looses the velum and assumes the adult form (grows gills etc).

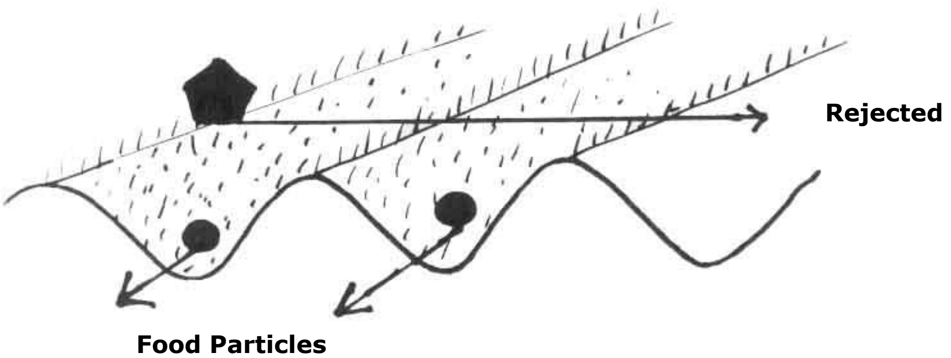
Post Settlement Feeding

In post settlement mussels the gills act as the sieves to remove the particles from the water. Adult mussels are fairly non-selective feeders eating phytoplankton of various sizes. The gills are also able to absorb dissolved nutrients directly from the water.

Covering the gills is a layer of small hairs or **cilia** which move water and food particles by beating together rhythmically in waves. Water is moved across the gills and out the exhalant chamber behind the adductor muscle. (Details the water flow across the gills are shown in the diagram 3.)

From this water the gills strain or filter potential food particles of the correct size from the water and capture these in a layer of mucus which is then moved to special food transport pathways and conveyed to the labial palps by other gill **cilia**.

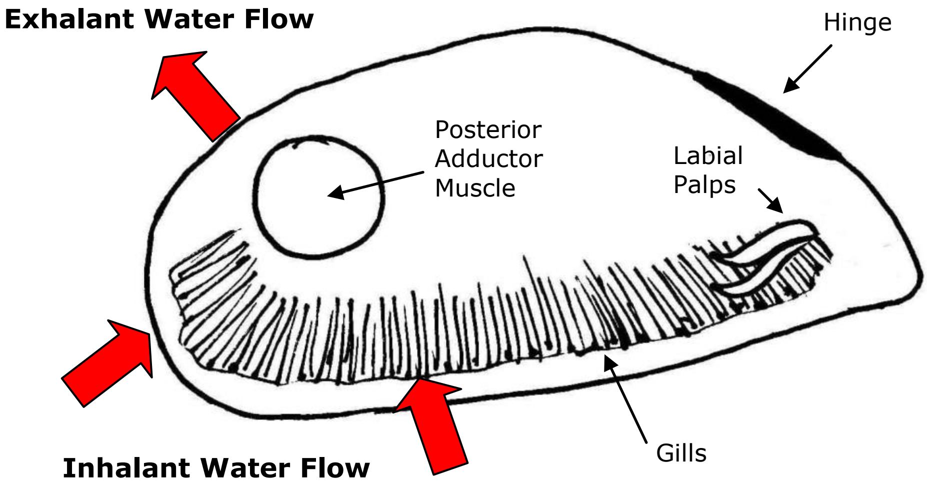
Food particle sorting by gill cilia.



The labial palps further sort the particles trapped in the mucus into food of the right size, and waste. Food particles are then placed in the mouth (waste particles are rejected as psuedofaeces)**.**

As with larval mussels, once food enters the stomach it can be sorted further and non-food items bypass the digestion process and are directed straight into the intestine.

Food pathways for filtered particles.



Mussels are capable of pumping large volumes of water and can increase or decrease this rate dependent upon the concentration of the food in the water around them. An adult mussel typically filters 6-9 litres of water per hour whilst a 12 month old mussel is capable of moving 2-3 litres of water per hour. Rates for individual mussels as high as 350 litres per day have been recorded.

The gills are extremely efficient at filtering this water and can sort down to 1µm in particle size! This means that mussels also efficiently strain out and concentrate any bacteria or contaminants that are present in the water. Hence shellfish can be sources of bacterial infection to organisms which eat them (eg humans) and programs such as the **Sanitation program** are in place to prevent health risks to consumers.

3.3 Reproductive Cycle

Sexual maturity in mussels is often reached by the first year of age, though this very dependent upon growth rates achieved. In Marlborough culture, 14-24 months to maturity is usual. Mussels tend to mature and spawn in cycles which are controlled largely by environmental factors, predominantly **water temperature** and **food availability**. The development of reproductive tissue only begins at temperatures greater than 11°C.

Greenshell mussels tend to spawn mainly between spring and autumn. However, within a population of mussels there may be adults at a variety of different stages of gonad development year round, and spawning condition may be maintained for several months. Not all mussels spawn at the same time. Spawning peaks occur in Aug/Sep & Mar/Apr.

There are five stages which identify the stages of mussel gonad development:

		Marlborough	***Coromandel***
1	Immature or Resting	Sep-Jan	Aug-Sep
2	Developing	Jan-Mar	Oct
3	Mature		
4	Spawning	Aug-Sep & Mar-Apr	Aug & Summer
5	Spent		

In mussels the **gonad** or reproductive tissues form both in the inner mantle tissue and in the mesosoma. In **immature** or **resting** mussels this tissue is undeveloped, of consistent texture and appears creamy coloured. Hence, male and female mussels cannot be identified when immature or resting. Both the size and shape of the gonads change as the animal matures.

As the gonads begin to develop spaces form called **follicles.** The cells which line these follicles produce the gametes (eggs and sperm). In females the eggs progressively grow in size until in **mature** females they are packed in so tightly they form polygon shapes. In males the sperm form laminae (layers) around the follicles which are dense and compact in mature males.

During **spawning** the gonads empty, until in the **spent** animal only residual gametes and collapsing follicles are found.

Females tend to spawn out completely relatively quickly whereas males tend to spawn gamete more slowly over an extended period and then reabsorb what remains.

In summer the spawning is prolonged and does not appear to be followed by a major resting phase, most mussels enter straight into redevelopment.

Hence the time marketable mussels are most likely to be limited is after the winter spawning event (less often in summer). This is particularly the case in Coromandel where mussels recondition rapidly in summer.

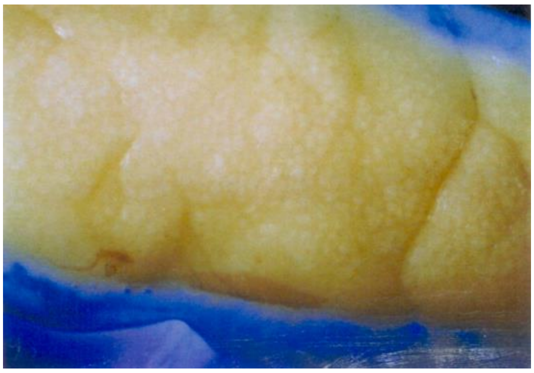
The density of the follicles and their size is a good indicator of condition.

The female gonad or **ovary** produces **eggs** (ova) and as these form, the ovary develops an orange/pink colour. A female mussel may produce up to 100 million eggs in a season.

The male gonad or **testes** produces **sperm** and the testes are creamy white in colour.

When mussels are close to peak condition the mesosoma becomes large and swollen, and discharge tubules may appear like veins across the surface of the gonads. At this time when ready to spawn, they may release sperm or eggs when touched.

Close-up of ripe female gonad. (Buchanan 1999)



Close-up of ripe male gonad. (Buchanan 1999)

Once spawned the gonad becomes almost transparent in some cases, though there may be some remnants of eggs and sperm remaining. Mussels in this stage are referred to as **Spent** and are not suitable for harvesting.

The sexes are separate in green mussels though in blue mussels there may be some hermaphrodites which have both patches of white and orange and produce both female eggs and male sperm.

Table 4. Reproductive Cycle in Greenshell Mussels

Reproductive Stage	**Immature or Resting**	**Developing**	**Mature**	**Spawning**	**Spent**
Timing Marlborough	Sept-Jan Summer spawn not followed by major resting phase	Jan-Mar May-July		Aug-Sep Mar-Apr	Aug-Nov males (partial spawning only with reabsorbtion)
Timing Coromandel	Aug-Sep Summer spawn not followed by major resting phase	October on Pick up much quicker than Marlborough		July-Sep Summer (less defined/obvious as quickly recondition)	Aug-Sep
Texture	Clear smooth even	Follicles sparse small – then cover up to 75% of gonad.	Follicles cover >75% of the gonad. Large & densely packed. Gonad granular / textured appearance.		
Colour	Creamy white	Patchy colour development at start. Males develop white patches – sperm, on cream background. Females light orange speckles initially developing to darker orange even colour.	Female acquires bright orange/pink colouration. Male mottled creamy white colouration	Becomes patchy	Almost translucent tissue with practically no gonad remaining. Some patches may be evident.
Ducts		Becoming visible in second half of development	Clear and Easy to see	Clear and easy to see	
Gonad size			Distended		
Other			May release gametes when touched		
Histology	Dense even cell texture	Follicles become visible then gametes	Ova compacted into polygon shaped configurations. Sperm arranged in compact laminae	Decreased density, ova more rounded, male laminae appearance lost. Gonad increasingly becomes empty	Follicles collapsing – only residual gametes present. Some cytolysis

4. Growth of the Greenshell™ Mussel

4.1 Growth

The growth rate of the larval stages of mussels is mostly dependent on food availability, temperature and also salinity. Normally the larval phase lasts between 4 and 6 weeks.

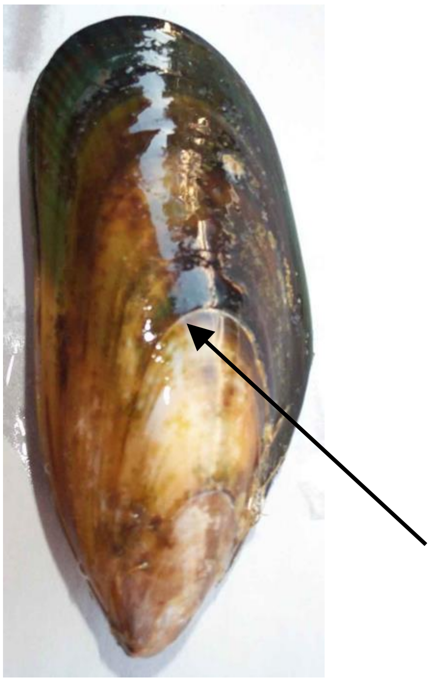
Following settlement growth rates vary widely, and again are dependent on food availability and water temperature at the settlement site. These factors can vary widely from site to site, between seasons and between subsequent years.

For example in culture, mussels of target harvest size (80-115 mm) are typically achieved in 14-24 months, following reseeding in Marlborough, and 7-14 months in warmer Coromandel waters.

Method of Shell Production

Mussels grow by adding new shell along the edges of the existing shells. This new shell is produced by the outer mantle. The outer lining of the mantle lobe thickens the shell whereas the marginal mantle folds add new shell.

As the growth rate changes, rings (like growth rings in a tree) are formed. Periods of slow growth result in strong or concentrated lines which are evident as ridges (or'rings') on the shell. These "checks" in growth are often most obvious following reseeding.



Cultured mussel showing 'check' line. (Photo: V. Seager)

4.2 Factors which Affect Growth

The main factors affecting mussel growth in culture are stocking density, food supply (quantity, quality, & replenishment) and temperature of the water.

Stocking Density

The stocking density is a measure of the quantity of mussels occupying a known volume of water (both the size and number of mussels are important). Correct stocking densities are critical to produce quality product. Stocking densities must be matched to individual site characteristics and particularly the food supply or productivity of the farm. Too high stocking density will result in a variable sized crop with poor mussel condition particularly from the centre of the farm. Too low and full potential of the area is not realized causing an increase in the cost of production.

Critical factors in controlling stocking density are the number of mussels per m of dropper, the spacing between droppers and the balance between these two factors. The stocking density must also be relevant to the size of the mussels being seeded (eg spat seeding vrs final seeding).

The effects of stocking density may be compounded by other effects such as the decrease in the current flow which may occur through the farm when droppers are placed closer together. High densities of mussels per meter may result in increased competition between mussels for available food and hence a greater size variation. Farmers may also vary the total farm stocking by altering the layout of the farm area such as the distance between the long lines (number of longlines) or the length of the long lines.

The suitability of a chosen stocking density or farm layout regime may also vary dependent on both seasonal and annual variations affecting food supply throughout the farm, water replacement rates and productivity of the area.

Optimal stocking densities vary dependent on the individual farm but examples of variations in the two main factors include;

number of mussels per m of dropper
(may range from 130-180 per m in Marlborough 200-250 per m common in Coromandel)

number of droppers per m of longline
(600 - 1000 mm spacings common in Marlborough & Coromandel)

Food Availability / Phytoplankton Levels

Optimal growth is achieved when food availability is not limiting but is matched to total farm stocking rate / temperature so that there is sufficient food for all mussels to grow.

The production of phytoplankton in the water varies seasonally and annually dependent upon:

Light levels (ie day length)
Nutrients (eg freshwater runoff, upwellings, storms, nutrient cycling)
Temperature

These three things are required for phytoplankton to grow and multiply and result in constant changes in phytoplankton abundance.

As mussels are filter feeders, higher concentrations of phytoplankton in the water will require lower filtration rates to intake the maximum volume of food and enhance growth. Mussels can alter their filtration rates based on the concentration of plankton in the water.

Seasonal variations in plankton may also be considered when deciding on stocking strategies for different farms (eg rotational cropping, suitable seeding size).

Higher levels of phytoplankton in the water will generate faster growth rates.

Food Quality (Type of Phytoplankton)

Mussels are selective filter feeders and therefore the level of suspended matter in the water (such as measured by a sechii disk) or the levels of total phytoplankton in the water (e.g. chlorophyll level) are not necessarily good indicators of mussel growth.
Some of the suspended matter in the water column may not be food (such as suspended sediments after heavy storms or rainfall) and some of the phytoplankton species may be of relatively poor nutrition (of the wrong size or poorly digestible). Algal blooms may not be favourable to good growth if the species, which is most abundant, is nutritionally deficient or poorly digested by mussels.

Best conditions for growth occur when there is a low proportion of non-food particles in the water and a good mixture of algal types giving a nutritionally varied and adequate diet.

Water Flow or Replacement Rates

Mussels are constantly removing phytoplankton from the water. In a farm situation this results in decreasing concentrations of plankton in the water, which is moving past the mussels. It is important that this water is mixed and or replaced with "ungrazed" water in order to ensure that the concentration of food in the water the mussels are feeding on is always sufficient for growth.

Even in areas with low tidal currents high wind exposure can result in good water mixing and cycling of nutrients, allowing good phytoplankton growth and replacement of phytoplankton concentrations around the mussels.

Farm layout regimes and management techniques can have important impacts on water flows through the farm and hence food exchange. In culture problems such as "dropper twisting" result in reduced food supply & water flow around portions of the crop affecting growth rates in some mussels and reducing crop consistency. The effects of twisting may be reduced by appropriate management techniques (eg untwisting by divers, staggered hanging techniques, spacer bars, reduced dropper depth).

For optimum growth therefore it is essential that there are good levels of water exchange or currents throughout the whole farm. This ensures that depleted water is constantly replaced (eg increased algae concentrations, consistent dissolved oxygen).

Water Quality

- **Temperature**
  Mussels tolerate a wide temperature range (from 5 - 27°C) though they tend to be more abundant in warmer northern waters. They will only mature and spawn in temperatures above 11°C.

  Water temperature has an impact on growth rates, both directly through its effect on the metabolism of the mussel and indirectly through its affect on phytoplankton growth (ie food supply). As water temperatures increase so do filtering rates of mussels and their metabolic rate (and hence the potential for a higher growth rate).

  Other factors however, such as food availability interact with temperature to determine the actual growth rates achieved.

- **Dissolved Oxygen**
  Mussels, like other animals require oxygen to survive. But due to the fact that they are stationary, they have relatively low oxygen requirements. This oxygen is absorbed from the water by the gills.

  In most cases oxygen levels in marine areas are well above the levels required by mussels for growth. Occasionally however it is possible there may be incidences where limited areas suffer from a high biological oxygen demand (such as in a pollution event or die off from an algal bloom) and deaths may occur as a result.

  Normal coastal oxygen levels, in areas with no bloom or pollution problems, provide optimal conditions for growth.

- **Salinity**
  Normal coastal marine salinities are between 30-35 ppt and are best for optimum growth.

  Greenshell™ mussels have been shown to be tolerant to a wide range of water salinities and in laboratory experiments have survived in salinities as low as 25 ppt.
  Short periods of time where salinities drop lower than this can also be tolerated but are likely to cause reduced growth while the low salinity water is present. Salinities may drop as a result of high levels of freshwater inflow (such as occurs in the inner Pelorus Sound) though most often these lower salinity waters are confined to the top few meters of the water column.

  There have been occasional instances of mortalities amongst Greenshell™ mussels growing in beach areas following extended periods of high fresh water inflow.

- **Suspended Solids / Weather Patterns**
  Because shellfish initially sieve food from the water by size rather than identity of the particle, they are very efficient at removing all particles from the water, and can waste a lot of energy in dirty waters removing and transporting sediments and other non-food items. This wasted effort can slow down the growth of the mussel.

Stormy weather can affect water quality by mixing phytoplankton, suspending sediments, or adding sediments of land origin to the water column. The higher the amount of non food items in the water the more energy needs to be expended filtering out and ejecting (psuedofaeces or faeces) non-food particles.

Low proportions of non-food particles in the water are therefore optimal and likely to increase the potential growth of the mussel.

- **Toxic Algae**
  Mussels eat algae and hence blooms can often be beneficial to growth. However some types of algae are toxic to shellfish and can reduce growth or cause mortalities. Non-toxic algae can also affect growth if they reach very high levels in the water and / or die off (creating an oxygen shortage in the water).

Other Factors

- **Handling (Stripping/Reseeding)**
  In aquaculture some stripping and reseeding is necessary to ensure good crop density and hence maximize growth. However, reseeded mussels must expend energy both repositioning and producing new byssal (beard) growth for attachment. This results in a reduced growth for a period of time which is often evident as a check line on the shell.

  Minimal handling is best to get best results for growth.

- **Exposure**
  Greenshell™ mussel spat are physiologically unable to survive exposure to air unlike some of the other mussel species and as such the Greenshell™ mussel is uncommon above the mid shore, and is most common subtidally.

  Optimum growth occurs subtidally as mussels, which are exposed during tidal cycles, have both reduced access to feed in the water and a reduced ability to uptake oxygen.

- **Water Depth**
  Greenshell™ mussels prefer Subtidal habitats and can exist to depths over 50m. However the food supply of mussels requires light to grow and hence where currents are not sufficient to ensure good mixing of the water column food availability may be limited at greater depths.

  The optimum farming depths avoid the surface water layers (which attract blue mussel settlement), avoid droppers laying on the bottom (poor water circulation, food supply) and where the water is deep avoid depths where food supplies may be limiting (or where dropper depth may encourage dropper twisting).

- **Predator & Fouling Control**
  Particularly important for the spat stages of growth are

Competitors	(e.g. blue mussels) which remove food particles from the water.
Foulers	(e.g. seasquirts) which can smother, lower water movement and again reduce the ability of mussels to obtain food from the water.
Predators	(e.g. spotties, snapper)

  Optimal conditions for growth utilize farm management methods to minimize these factors. (eg clean spat catch, careful selection of spat holding areas, suitable farm sites & dropper depths, rotation of spat sites).

5. Disease

Viruses, bacteria, fungi, protozoa, and parasites can cause infectious diseases.

Viruses, bacteria and protozoa are microorganisms, so called because individuals are single cells, which are too tiny to be seen with the naked eye. Viruses are less than 0.3 micrometers in size and actually live inside the living cells of the host who is infected. Infectious diseases can be passed directly from one organism to another (eg mussels to mussel, oyster to mussel).

Non-infectious diseases cannot be passed from one organism to another, but are caused by external factors such as nutrition (eg poor plankton availability or type), environment (eg toxic algae blooms, smothering by competitors) or physical trauma (eg predator damage, reseeding shell damage).

Diseases Present In New Zealand

To date, New Zealand appears relatively free of diseases affecting Greenshell™ mussels.

Although there are several natural parasites of the Greenshell™ mussel, most of these have low infection rates and do not cause either significant mortalities or concern to the aquaculture industry. Some parasites found in mussels include pea crabs, copepods, mudworms and flatworms.

Digestive epithelial virosis, a viral disease has however caused high mortalities in post settlement mussels, and resulted in some problems for the aquaculture industry.

Mussels may also be affected by Algal blooms, although is most cases, the main concern in mussel culture is that algal toxins may be concentrated in the flesh making them a human health risk and thus unmarketable for periods of time. Algal blooms do however also have the potential to affect mussel growth or cause mortalities.

The **shellfish toxin testing program** which is in place to protect humans from consuming toxic shellfish, also warns farmers of bloom conditions by checking water samples for both algae numbers and types.

Below is a list of some diseases present in New Zealand that have the potential to affect Greenshell™ mussels.

- Algal Blooms
- APX (Apicomplexan Parasite X)
- Digestive epithelial virosis
- Flatworm infestation
- Mudworm infestation

Information of each of these diseases, their gross signs, the causative agents, and any treatments or preventions are contained in the following handbook:

Diggles, B,K; Hine, P,M; Handley, S; Boustead, N.C. (2002). A handbook of diseases of importance to aquaculture in New Zealand. NIWA Science and Technology Series No. 49. 200pp.

For convenience, extracts from this handbook on the following four diseases are provided in Appendix A of this resource, courtesy of NIWA.

- **Algal blooms**
- **Digestive epithelial virosis**
- **Flatworm infestation**
- **Mudworm infestation**

See Diggles et al, 2002 (and Appendix A) for more background on other diseases, including gross signs, causative agents, treatment and prevention.

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