# Ecology of the New Zealand Rocky Shore Community

A Resource for NCEA Level 2 Biology

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Ecology of the New Zealand Rocky Shore Community:
A Resource for NCEA Level 2 Biology

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# FOREWORD

The New Zealand Marine Studies Centre launched a nationwide citizen science project in Seaweek 2013. Anyone can take part in this project which aims to monitor biodiversity and changes in the New Zealand seashore over time. There are two ways of taking part in the project

1. Marine Metre Squared is a simple way for individuals, families, schools and community groups to monitor the shore.

2. Seashore Survey is aimed at secondary school students to tie in with NCEA standards.

This resource book is intended to assist teachers of NCEA Level 2 biology to carry out studies of the New Zealand rocky shore.

Darren Smith developed this resource when he was on the Endeavour Teacher Fellowship, New Zealand Science, Mathematics and Technology Teacher Fellowship Scheme 2012. This scheme was funded by the Ministry of Science and Innovation and administered by the Royal Society of New Zealand. Darren Smith was hosted by the New Zealand Marine Studies Centre, Department of Marine Science, University of Otago.

For further resources and information about the Marine Metre Squared project go to mm2.net.nz

We welcome your comments and suggestions.

Please email marine-studies@otago.ac.nz or phone 03 479 5826.

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# PART 1: LIFE ON THE ROCKY SHORE

## 1.1 INTRODUCTION

New Zealand has approximately 14,000 km of coastline consisting of rocky shores, sheltered estuarine mudflats, and beaches of loose, mobile sediments like sand and gravel. Our coasts experience a regular, dramatic change in sea level caused primarily by tides. On the north and west coasts of the south island sea levels may fluctuate by up to 4 m between the high and low tides. On average NZ experiences two high tides and two low tides per day. The **intertidal zone**, sometimes called the littoral zone, is the area of the seashore that is regularly covered by the sea during high tides and exposed to the air during low tides.

The organisms living between the tides are true marine creatures, yet are uniquely adapted for life at the interface between the land and the sea. As marine species they need to be submerged in seawater for at least a part of the tidal cycle to feed, respire, excrete, and reproduce and disperse their offspring. However, like terrestrial species, they also need to be able to survive the harsh conditions that go with regular periods of exposure to the air when they are uncovered by the falling tide; these include wide variations in temperature, salinity, pH and oxygen availability; being battered by wind and breaking waves; the desiccating effects of wind, sunlight and high salinity; and predation by terrestrial animals.

So, when it is such a demanding and hostile environment, why are any species found in the intertidal zone at all? The answer is that the intertidal zone offers unique opportunities – ecological niches – for those species that have adapted to withstand the demands of living in such an extreme, changeable environment.

## 1.2 BIODIVERSITY ON THE ROCKY INTERTIDAL SHORE

Rocky shores have the greatest **biodiversity** of any coastal habitat in New Zealand as they provide many **ecological niches**. These niches are created by the abundance and variety of food types in shallow coastal seas, the stability and complexity of the rocky substrate that creates numerous sheltered microhabitats for organisms to live in or on, and the widely varying abiotic conditions from the low shore to the upper shore that prevent any single species from dominating the entire shore.

Shallow, coastal seas surrounding New Zealand are very productive compared to the open ocean. Nutrients washed from the land and from the decay of seaweeds are plentiful; as light is not limiting at these shallow depths, photosynthetic algae thrive. Rocky shores also provide stable platforms for seaweeds like kelps to grow to a large size. These factors mean that seaweed productivity is high and therefore there is abundant food for grazing animals like marine snails, chitons and urchins, which in turn can support large numbers of predators like whelks and seastars.

As **sessile** animals are permanently attached to surfaces they cannot move to forage or hunt for food so instead depend on their food being transported to them by water movement in the sea. Food such as microscopic **phytoplankton** and **zooplankton** is plentiful in the nutrient-rich coastal seas. This plentiful food supply supports many different species of filter feeding animals in large numbers on the rocky shore which extract the plankton from the water when submerged by the tide *e.g.* mussels, oysters, bryozoans, seasquirts, anemones and barnacles.

Rock surfaces provide a relatively permanent, stable platform for animals and algae to attach to or shelter beneath in a dynamic environment exposed to strong water currents and wave action. The rock provides a stable anchorage for many sessile organisms and allows them to grow to a large size without being dislodged. With a plentiful supply of food, their relatively large size means that they can produce many offspring. Rocky shores generally have a three dimensional structure. This complex habitat provides many different spatial niches. Crevices between and under rocks and boulders create microhabitats that provide shelter from the heating and drying effects of the sun and the wind, protection from breaking waves, and a safe refuge from larger predators.

One of the most significant factors in creating a large number of ecological niches in the intertidal zone is the widely changing abiotic conditions. No single organism is adapted to withstand the full, extreme range of abiotic conditions across the entire intertidal zone *and* cope with the high levels of predation and competition found in the lower shore; rather, different species have adapted to withstand the biotic interactions and tolerate a particular range of abiotic conditions found at a particular shore level: these are the underlying factors that lead to zonation on the rocky shore.

## 1.3 THE INTERTIDAL ZONES

There are several main tidal zones recognised on the seashore. These are shown in Figure 1.

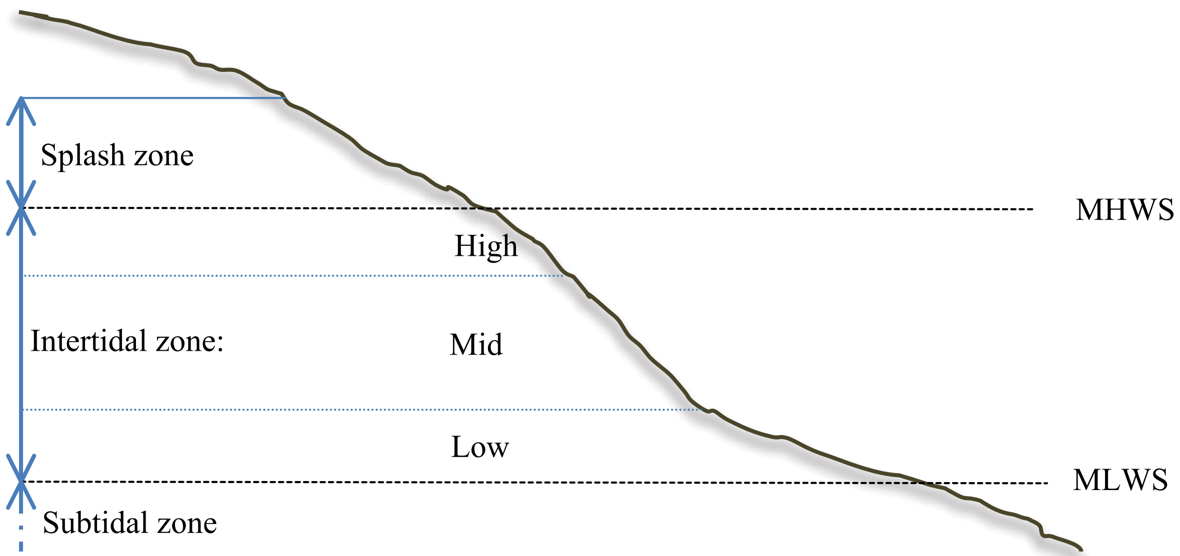


**Figure 1** Classification of seashore zones.

The **splash zone** is not a truly tidal zone as it is above the height of the average spring high tide (mean high water springs, MHWS) and so is not normally submerged except in exceptional conditions such as **perigee**, during low pressure weather systems when the water is not held down as much by atmospheric pressure, or during strong onshore winds when sea water is pushed onto the coast. Although terrestrial, the splash zone is influenced by wave action and wind, with surf and salt spray wetting the rock. On very exposed coasts with large waves and surf, the splash zone can be several metres wide.

The **intertidal** zone is the area of the shore between MHWS and the height of the average low tides during large spring tides (mean low water springs, MLWS). It can be subdivided into the high, mid and low intertidal shore. The high shore is regularly covered by seawater during the highest part of the tides only and generally spends more time exposed to the air than submerged by water (Figure 2). The mid shore is exposed to air and submerged by water for approximately equal periods of about 6 hours per tidal cycle. The low shore is rarely exposed for more than just a few hours at low tide. The rise and fall of the tides is the single most important factor influencing life in the intertidal zone.

The **subtidal** zone is the region of the shore below MHWS. This part is only ever uncovered by exceptionally low spring tides. It is a fully marine zone but, being near to the sea surface, it has a higher light intensity, dissolved oxygen concentration and wave action than the seafloor in deeper water.

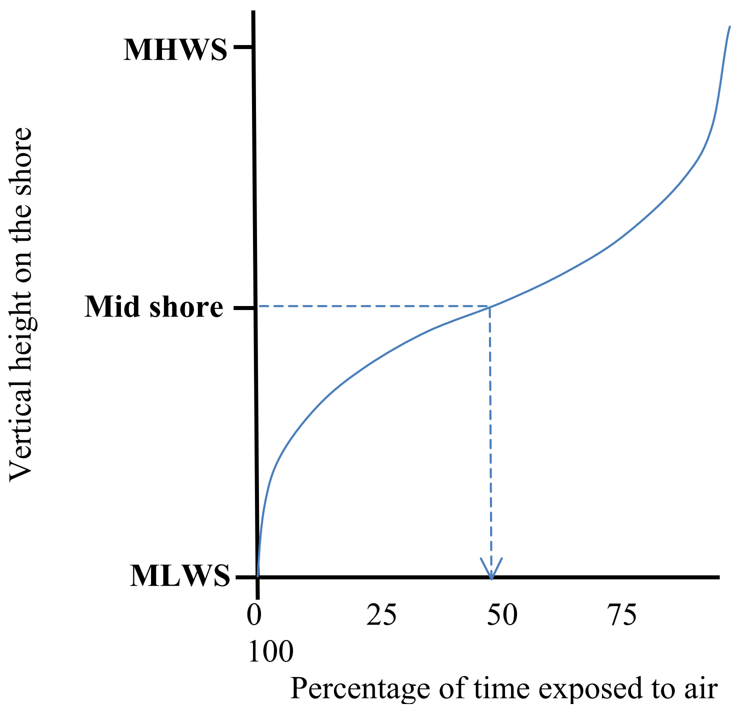


**Figure 2** Aerial exposure time changes with vertical height on a tidal shore.

The main environmental gradient influencing life in the intertidal zone is the time spent exposed to air. Aerial exposure time increases with height on the shore as submergence time decreases. Differences in aerial exposure time cause big changes in environmental conditions over a few vertical metres as shown in Figure 3, and it is gradients in these

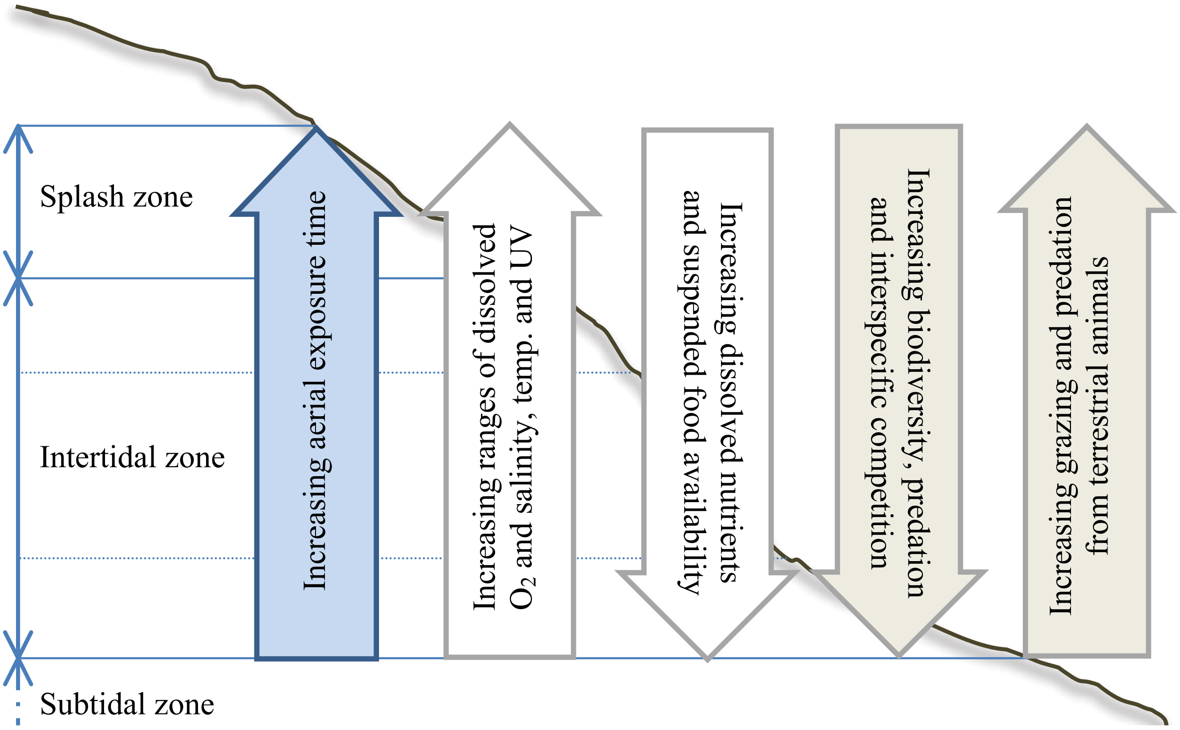


**Figure 3** Trends in environmental factors (gradients) with vertical height on a tidal shore.

environmental factors that mainly determine the vertical distribution of intertidal organisms.

## 1.4 THE ABIOTIC ENVIRONMENT

**Abiotic** or physical factors like temperature, **salinity**, pH and dissolved oxygen are generally quite stable in the sea where the water acts as a large reservoir that buffers short term changes. However, these sea factors tend to vary more widely on land. The intertidal zone alternates between **terrestrial** and marine conditions each day as the tide rises and falls. As most intertidal species are marine, large variations in these abiotic factors are a major source of **physiological stress**; the upper vertical distribution limit for most intertidal species is determined by their **tolerance** to a particular limiting abiotic factor.

### 1.4.1 Temperature

In the far south of mainland New Zealand, the average sea temperature ranges between 11 – 15 °C from winter to summer, whereas the air temperature can vary by 9°C. In sub-tropical northern New Zealand the average seasonal sea temperature range is just 2°C, between 18 – 20 °C, whereas the average air temperatures varies by about 7.5°C.

However, these are average temperatures; it must be remembered that in the temperate parts of New Zealand in winter it is quite possible for intertidal organisms to experience low tides with air temperatures of 17°C during the middle of the day and -4°C just 12 hours later – maybe even more with wind chill. As the sea temperature may be 11°C at the same time, the organisms can experience rapid changes in body temperature as they are covered and uncovered by the tide.

As temperature increases, the risk of **desiccation** also increases. High air temperatures coupled with low humidity and coastal breezes mean that the evaporation rate is high.

### 1.4.2 Salinity

Salinity is a measure of the amount of dissolved minerals or 'salts' in water. The salinity of the open sea remains fairly constant at between 33 and 35 parts per thousand (one part per thousand is equivalent to 1 g salt dissolved in 1 L water). However, in the intertidal zone organisms can experience large, rapid changes in the salinity of their environment due to changes in the weather and climate. On a hot, breezy day, evaporation of freshwater increases salinity in tide pools, crevices and in sediments. In contrast, large amounts of rainfall dilute standing water on the shore, decreasing its salinity.

### 1.4.3 Dissolved oxygen concentration

Oxygen dissolved in the sea results from **photosynthesis** of marine producers like phytoplankton and **macroalgae** and diffusion between the air and the sea at the water surface. The oxygen content of the sea is approximately 50 times less than the air at 25°C. As seawater temperature increases, dissolved oxygen concentration decreases. As standing water in tide pools and crevices warms, the oxygen concentration can decrease below a point that organisms can obtain enough to meet their **respiration** by simple diffusion.

### 1.4.4 Nutrient availability

Important nutrients for algal growth like iron, magnesium, nitrate and phosphate are dissolved in seawater. Therefore, they increase in concentration down the shore as seawater submersion time increases

### 1.4.5 Wave action

The main stress from the coastal marine environment is the amount of wave action. Shores that receive a lot of wind-driven waves are known as 'exposed'. The effect of breaking waves on the shore is to drive salt water higher up the shore than by the tide alone. This increases the width of the intertidal zones by regularly wetting a region area of the shore (Figure 4).

Another effect of wave action is to create a mechanical stress on intertidal organisms. There is a lot of energy in breaking waves and organisms need to be able to withstand repeated battering by the waves. A cubic metre of water has a mass of 1000 kg or one tonne, a large wave will contain several cubic metres of water so will transfer a lot of energy onto the shore as it breaks.

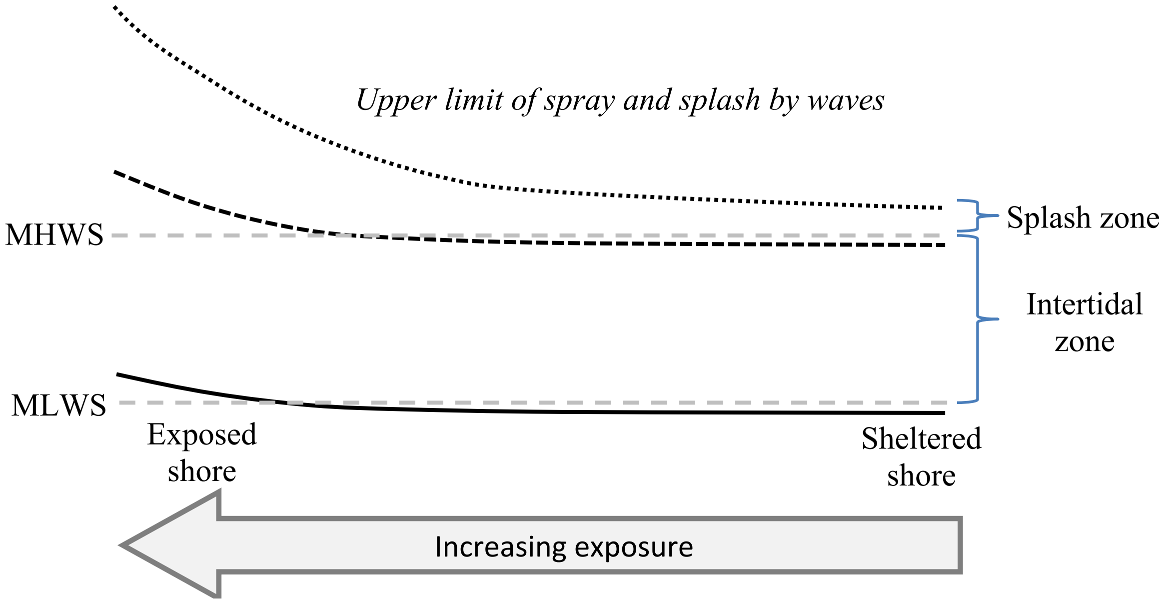


**Figure 4** The effects of exposure on zonation.

## 1.5 THE BIOTIC ENVIRONMENT

The upper shore is a harsh environment and fewer species are adapted to tolerate the extreme abiotic conditions here than lower on the shore, therefore **interspecific competition** for food and space is lower for those species that can cope with these conditions. As a result, biodiversity generally increases down the shore. With more species come more interspecific interactions. **Biotic** factors in an ecosystem are related to the living parts of that system and include competition for resources, predation, herbivory, parasitism and mutualism.

The lower vertical distribution limit for most intertidal species is determined by interspecific competition, food availability and predation pressure.

### 1.5.1 Interspecific competition

Competition between different species increases down the shore with increasing biodiversity. The main resource that sessile organisms compete for on the rocky shore is living space on the rock. Planktonic larvae and algal spores of sessile organisms need room to settle on, attach and grow. Most seaweeds and many marine invertebrates are **benthic**: they live on the seafloor surface. Many of these organisms have planktonic larval stages that settle, metamorphose and grow to adulthood on the rocky shore *e.g.* seaweeds, barnacles, seasquirts, mussels, oysters, and tubeworms. Therefore space on rocky surfaces to attach and grow is fiercely competed for by many different species.

Although filter feeders compete for food, plankton abundance is rarely a limiting factor in coastal seas. Similarly, dissolved nutrients are rarely limiting for algae. Like plants, algae are **photoautotrophic**: they obtain their nutrition by photosynthesis. Marine algae do this in one of two ways: they either drift in the well-lit surface waters as microscopic phytoplankton, or permanently attach to a solid substrate from which they can grow *e.g.*

seaweeds[1]. Seaweeds tend to dominate the shallow subtidal and low intertidal areas of all but the most exposed shores. Here they compete with each other and with sessile animals for attachment space on the rock. As seaweeds can grow they can cover large areas of the rock. This can exclude sessile filter feeding animals as the seaweeds reduce the water flow to the animals living beneath them[2]. However several animals will burrow under or allow themselves to be overgrown by seaweeds as this may offer them some protection from predators. As seaweeds grow they also compete with other algal species for light. A dense algal 'canopy' can overgrow other slower-growing or smaller algal species, reducing the amount of light they receive and therefore their rate of photosynthesis.

### 1.5.2 Predation

Predation pressure from marine animals increases down the shore. Predatory animals like whelks, seastars and fish are mobile and as the tide rises these animals move up the shore to feed. They can potentially move to any region of the intertidal zone, but the amount of time they can spend feeding decreases with height up the shore as the aerial exposure time increases. These predators generally do not feed when they are exposed to the air and, unlike many of their prey species, are not adapted to tolerate long periods of exposure. Therefore, there is relatively low predation pressure from marine animals in the high shore due to the limited time they can spend feeding in the upper shore. The high shore therefore acts as a **habitat prey refuge** from marine predators for sessile species such as mussels and barnacles, where the total mortality due to predation is lower than it would be lower down the shore.

Although the high shore offers a habitat prey refuge from marine predators, shore birds like gulls, tattlers and oyster catchers do prey on species in the upper shore when the tide is out. Many species in the high shore show adaptations to reduce the risk of predation from seabirds. Some animals like periwinkles, chitons and topshells will hide in inaccessible rocky crevices and amongst seaweed; others like shore crabs bury themselves in the sediments that often accumulate underneath rocks. Many high shore sessile species possess structural adaptations to withstand predation from seabirds. Barnacles and mussels have strong shells that are firmly cemented to the rocks to avoid being broken open or dislodged by foraging birds; with their relatively small size this means that they are a poor meal for a relatively large bird and are therefore overlooked by most predators, as larger birds tend to concentrate on larger prey that yield a bigger nutritional benefit for the energy cost of their efforts. The idea of a small (or large) size acting as a deterrent to predators is known as a **size prey refuge**.

### 1.5.3 Food availability

Filter-feeding animals can only feed when they are submerged so it stands to reason that they will be more numerous in the lower shore where they spend longer periods covered

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[1] Not all intertidal algae are large seaweeds or macroalgae. The surface of the substrate is covered by a thin living film of bacteria and microalgae. This microscopic community is an important source of food for grazing primary consumers like limpets and topshells. These 'biofilms' are the pioneer communities in an ecological succession on the rocky substrate.

[2] Although it does provide new niches for many organisms so increases biodiversity. The surface of the seaweed provides microhabitats for some epibionts (epi- = surface; biont = organism) like spiral tube worms, ascidians, bryozoans and hydroids; small crustaceans, echinoderms, molluscs and even fish find shelter between and beneath the fronds; and the seaweed itself is an important food source for many grazers.

by seawater. The number of potential food sources decreases as biodiversity decreases down the shore (this is particularly true for those animals that graze on large seaweeds that are generally restricted to the lower shore). There is also the ever-present risk of desiccation and thermal shock for animals that are active on the exposed shore during low tide. Hence for most intertidal animals, feeding opportunities are limited to the times and regions of the shore that are covered by seawater. All of these factors mean that opportunities to feed decrease with increasing height on the shore.

However, for scavenging **detritivore** animals like isopods (sea slaters) and amphipods (sand hoppers) there are more feeding opportunities higher up the shore as plant and animal remains collect in the drift line, where they are washed up by the high tide and stranded as the tide ebbs.

## 1.6 ZONATION

Biological zonation is the distribution of species into visible bands or **zones** along (perpendicular to) an environmental gradient.

On the rocky shore, the environmental conditions may change from fully terrestrial to fully marine over a few vertical metres. As a result of this strong **environmental gradient**, intertidal species occur in discrete horizontal zones according to their ability to cope with the different physical stresses of the gradient (Figure 5), and their interactions with other species in their habitat (that are also affected by the same abiotic factors).

In the intertidal zone, **tolerance** for a particular, **limiting abiotic factor** usually determines the upper vertical limit of a species' distribution, whereas the lower limit tends to be set by biotic factors such as interspecific competition and predation.

Tolerance is the ability of an organism to withstand a range of values for an abiotic factor in a changing environment *e.g.* temperature, salinity, pH and light intensity. Tolerance has a **physiological** basis: there are biological processes occurring within the organism that enable it to maintain an internal environment that allows the organism to survive despite the changing external environment. If the external environment exceeds the tolerance limits of the organism for too long, then it cannot regulate its internal environment and it will die. Figure 6 shows how a species might respond to a changing abiotic factor. The response could be for an individual organism in terms of its growth, respiration, reproductive rate or for a population.

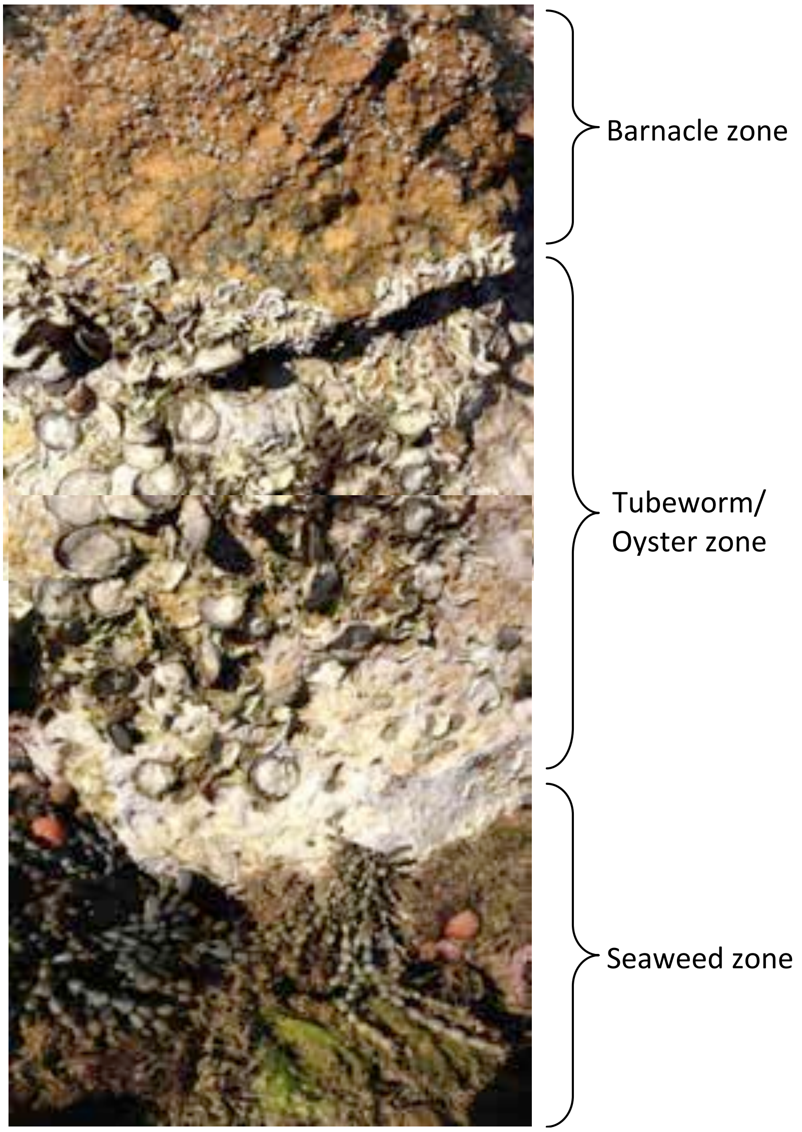


**Figure 5** Biological zonation on a near vertical 1.5 m rock surface at Portobello, Dunedin. Here, aerial exposure time increases with height.

An organism will have an upper and a lower tolerance limit for different abiotic factors and these determine the **tolerance range**. Organisms cannot survive the extreme conditions outside this range. An organism will have an **optimum range** within which it is best adapted, and its response is the greatest. Either side of the optimum range lay the physiological **stress** zones where the organism 'struggles' to survive as it uses energy and nutrients to oppose the negative environmental conditions, leaving less for growth and reproduction. For example, in a cold environ-ment, an organism may have to actively warm itself up by moving to a warmer region or, if it is a 'warm-blooded' animal[3], it may increase its metabolic rate.

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[3] 'Warm-blooded' animals should be referred to as homoeothermic, meaning that they normally maintain a relatively constant internal body temperature that is independent of the environmental temperature. Similarly 'cold-blooded' animals maintain a body temperature that is the same as their environment, warm or cold.

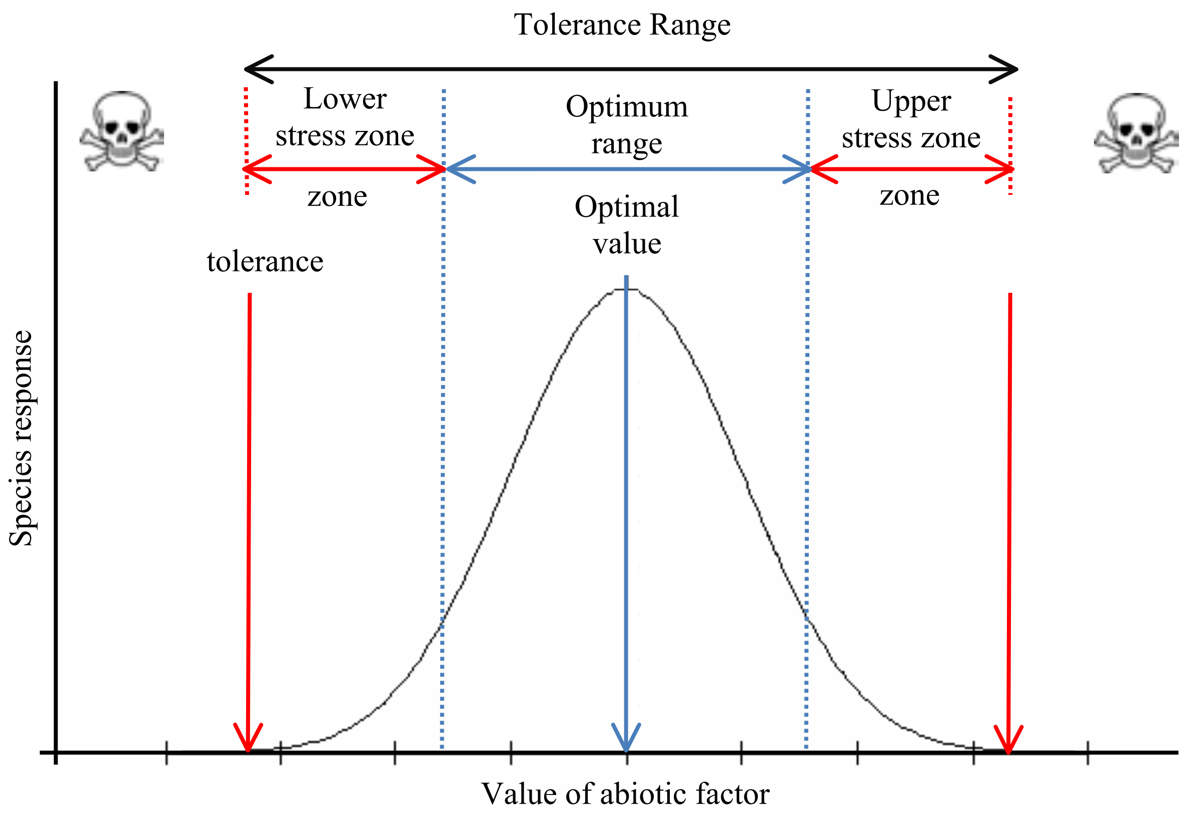


**Figure 6** Typical physiological tolerance curve showing how species respond to changing abiotic factors that they cannot escape from.

No two species can occupy the same ecological niche indefinitely; interspecific competition will ultimately result in the exclusion of the poorer-adapted species from that niche *i.e.* one species' population will decline as the others' grows: this is **Gause's Principal of Competitive Exclusion**.

The potential niche a species could occupy in the absence of better-adapted competitor is known as its **fundamental niche**. As interspecific competition is one of the more important factors determining the lower vertical distribution limit on the shore, this would seem to suggest that species occupying the higher shore could potentially live further down. This has been observed in field experiments where scientists removed a species from the rock and observed the expansion of a competing species' zone as it populates the newly cleared area in the lower shore.

Predation on the rocky shore has a similar effect. The high shore may act as a relatively safe prey refuge, where mobile marine predators like seastars and whelks either cannot tolerate the harsher environmental conditions during exposure, or have very limited feeding opportunities due to the shorter periods of submergence in the high shore when the predators are active.

Evidence from 'cage exclusion' experiments has shown that if predators are kept out of the lower shore using cages over the rock that allow prey species to settle, but are too small to admit predators, then the prey species are able to settle and populate the lower shore.

The effects of interspecific competition and predation therefore act to limit the spatial niche that many rocky shore organisms can occupy; this means that the actual or **realised niche** of the species are often smaller than their potential or fundamental niches[4]. However, one outcome of this is that many species are able to coexist on the shore and no single species tends to dominate. To illustrate these concepts, let us look at an example. Figure 7 represents the distribution of three interacting species that occupy two adjacent zones on the mid shore.

The barnacles and the oysters compete for living space on the rock. At the end of their planktonic larval stages both species cement themselves to a bare patch on the rock and remain there for the rest of their lives. Barnacles and oysters are both filter-feeders. They have different structural adaptations for extracting their planktonic food from the water. The barnacle uses feathery modified legs to comb the water for food particles. Oysters (and other bivalves like mussels) have rows of cilia on their gills that create feeding currents to draw water and plankton into the gills which are mucus lined to trap food. Although both species reduce their metabolic rate during exposure to conserve energy and reduce oxygen demand and waste build-up, the barnacles can open their shell valves to take some air into the shell during exposure which enables them to continue respiring at low tide. Barnacles have a higher tolerance to aerial exposure than oysters and can withstand being uncovered by the tide for longer periods.

The third species is a predatory whelk that feeds on both the barnacles and the oysters when submerged by the tide. Just before exposure by the falling tide, the whelk will seek a damp, shaded crevice in or under the rock. It secretes sticky mucus on to the base of its foot for attachment to the rock surface. A tough, waterproof pad on the foot called an operculum seals the snail into its shell and it remains inactive until it is resubmerged by the rising tide.

In the example in Figure 7, the realised spatial niche of the barnacle species has been determined by the barnacles' tolerance for aerial exposure, the presence of the competing rock oysters, and by predation from the lined whelks. In the absence of the oysters and whelks it is likely that the barnacles' distribution would increase down the shore. However, it is unlikely to increase up the shore as the barnacles is likely to be living at its upper tolerance limit for some limiting abiotic factor associated with the long periods of aerial exposure. Therefore, the barnacles' fundamental spatial niche is wider than the one it is forced to occupy, but only in terms of the lower distribution limit.

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[4] Interspecific competition for resources other than living space can limit a species' distribution and therefore reduce the size of its realised niche *e.g.* food availability and periods of activity.

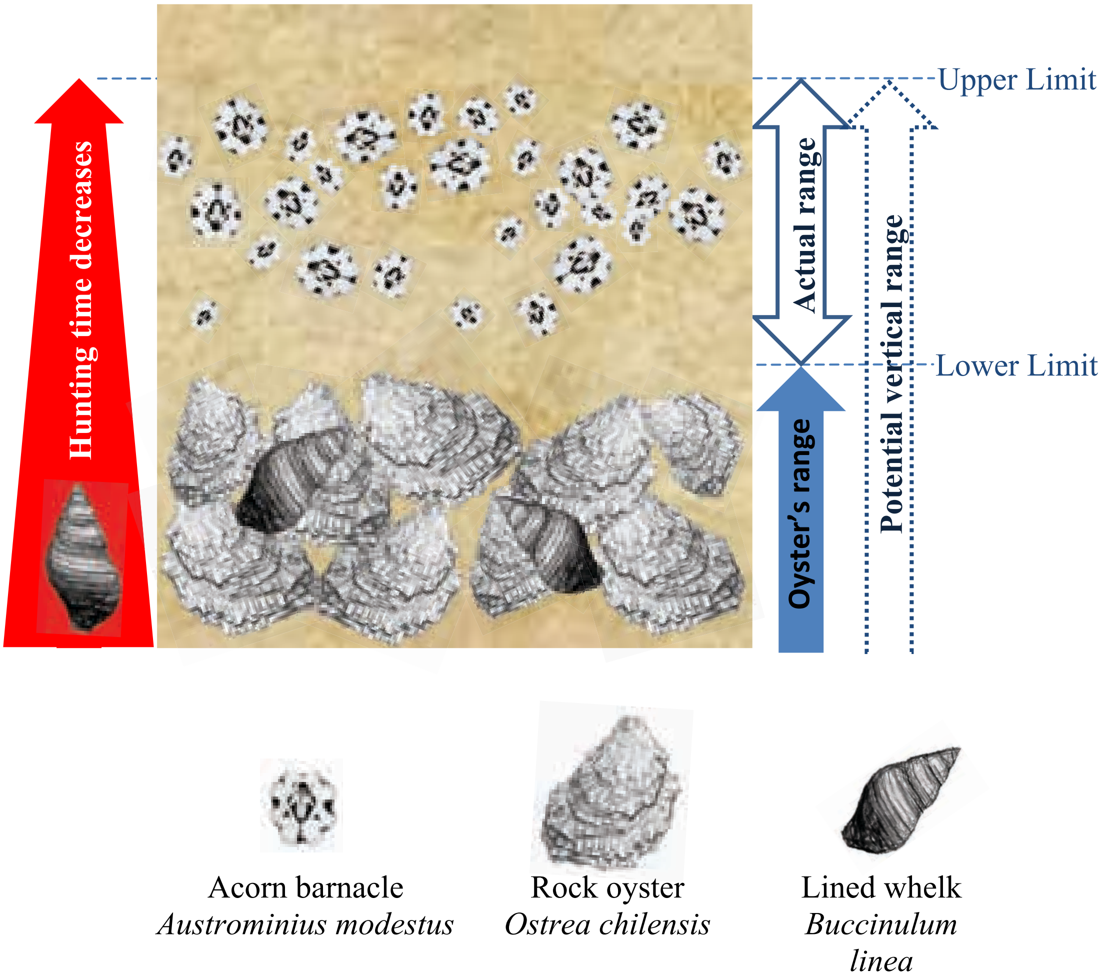


**Figure 7** The effects of tolerance, predation and interspecific competition on the upper and lower vertical distribution limits of acorn barnacles (*Austrominius modestus*).

## 1.7 ADAPTATIONS TO LIFE IN THE INTERTIDAL ZONE: COPING WITH STRESS

The organisms living in the rocky intertidal zone are almost all marine in origin but have **adapted**[5] to cope with the demands of spending part of their day uncovered by the sea. Many of the **adaptations** that have evolved in intertidal organisms to survive to help them cope with, avoid or minimise stresses associated with periods of aerial exposure. Of all of the widely varying abiotic factors, heat and desiccation are probably the most important in setting the upper limits of intertidal species' distribution on the rocky shore.

### 1.7.1 Heat and desiccation

Even in cold, temperate environments like southern New Zealand, the air temperature can reach over 30°C in summer. However, it is not just the maximum temperature that is important, but the temperature variation. Seasonal variations over a year can account for air temperatures between 30°C and -5°C at sea level in Dunedin. Monthly variations may be equally dramatic: in March 2012 the highest recorded air temperature in Invercargill in

[5] This has occurred over many generations as they have evolved by natural selection.

southern New Zealand was 24.3°C while the lowest was 1.5°C (Deep South Weather, 2012). Daily variations in air temperature of 20°C between day and night are not uncommon in New Zealand. However, drastic changes in temperature can occur much more rapidly if the influences of the tide, time of day and sea temperature are considered together. For instance, during a midday low tide, an organism's body temperature can rise from the temperature of the seawater to well above that of the air temperature, a difference of up to 25°C (Helmuth, 1998). The organism's body temperature could then rapidly drop back down to that of the seawater when it is re-immersed by the rising tide (see Figure 8), but on a clear night just a few hours later, it can decrease to several degrees below air temperature during the next low tide.

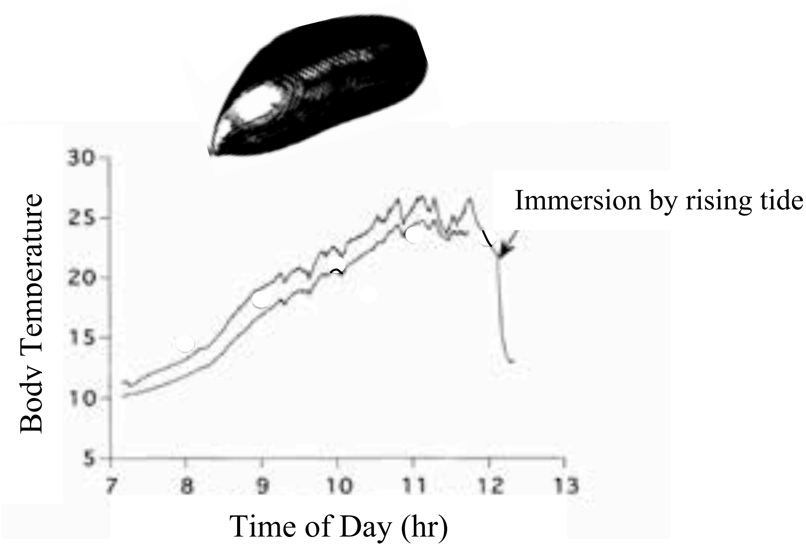


**Figure 8** Changes in body temperature of the intertidal mussel *Mytilus californianus* over part of a tidal cycle during the summer. Modified from Helmuth (1998).

Intertidal organisms are **ectothermic** which means that they lack any physiological mechanisms to generate body heat. As a result, their body temperature is greatly affected by their environment. This is particularly true for small organisms that have a low body mass and therefore a relatively low heat capacity.

Physiology involves the biochemical reactions and processes that occur within an organism to maintain life. For every 10°C increase in body temperature, the rate of a biochemical reaction is approximately doubled, and for every 10°C decrease the rate is halved. Hence an organism that experiences a temperature change of 20°C would experience a fourfold change in metabolic rates *e.g.* their respiration rate would increase by four times and so their rate of glucose use, oxygen demand and carbon dioxide production would increase accordingly; a marine organism exposed to the air cannot feed or carry out gas exchange with seawater, so normal rates of aerobic respiration cannot be sustained.

High temperatures also disrupt the organisation, stability and structure of delicate molecules in cells, such as membrane lipids, enzymes, DNA and RNA. For many important biological molecules, function is dependent on structure, so any change in structure may cause a loss of function.

Intertidal organisms can slowly adjust to long-term seasonal variations, but not to very short-term changes over the course of hours: therefore they need to withstand this short-term variation by tolerating it, avoiding it or reducing its effects.

Most intertidal organisms live at a level of the shore that is very close to their upper thermal tolerance limit *i.e.* close to the point where the high environmental temperatures would be fatal. But how can some species live higher on the shore than others where they experience not only higher temperatures, but a greater range of environmental temperatures?

Many intertidal species are **eurythermal**: they can tolerate much higher environmental temperatures than their non-intertidal relatives. Their physiological processes have adapted to function at higher temperatures. Figure 9 shows how the upper lethal limit of temperature of five different species of porcelain or half-crab varies with their vertical position on the shore at each of four different regions in the western Pacific Ocean. The differences in the upper thermal tolerance limit of the closely related crabs can be related to both their vertical position on the shore and their climate in relation to their latitude (distance from the equator).

Intertidal species also have a much wider temperature tolerance range than subtidal species. In controlled laboratory incubation experiments by Somero (2002), the body temperature of some rocky shore invertebrates has been shown to vary by up to 25°C with no harmful effects. These organisms' body systems are well adapted to changing conditions and they have evolved physiological mechanisms to tolerate a wide range of body temperatures[6].

Individual organisms can adjust their physiologies to short term changes over periods of days or weeks by a process called **acclimatisation**. The properties of their body systems may alter to resist the influence of the environmental change. A good example of acclimatisation is a process called homeoviscous adaptation ('homeo-' = same; 'viscous' = opposite of fluid/runny) in cell membranes. As temperature decreases, membranes become more viscous[7], and as temperatures rise membranes fluidity increases. Fluidity is an important physical property of a cell membrane and can affect critical membrane functions. For instance, mitochondrial cell membranes are the site of the majority of ATP production in aerobic respiration. Any changes to the fluidity of mitochondrial membranes will alter their structure and reduce ATP production. The effect on the organism is a reduction in respiratory rate and therefore metabolism.

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[6] These species are known as thermoconformers as their body temperature 'conforms to' and changes with the environmental temperature.
[7] Try this at home: observe how cooking oil becomes runnier (less viscous) in a frying pan as it gets hotter.

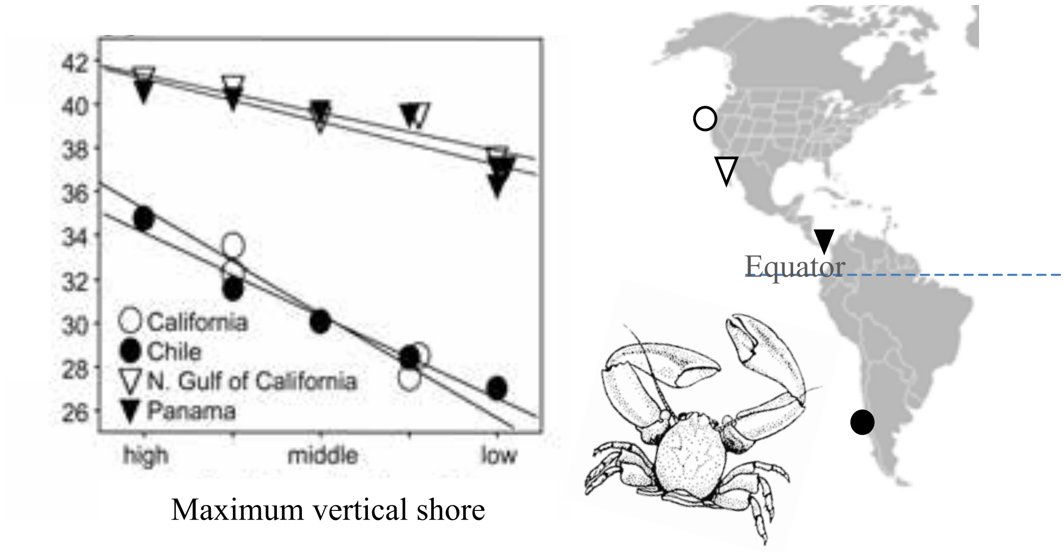


**Figure 9** Upper limits of thermal tolerance for intertidal crabs, *Petrolisthes* spp. Each symbol represents a different species of the genus *Petrolisthes i.e.* each open circle is a species of crab from California. $LT_{50}$ is the temperature at which 50% of the crabs studied died during the incubation experiment *i.e.* the average lethal limit. (Stillman, 2002).

In laboratory experiements, American intertidal species such as Californian blue mussels (*Mytilus californianus*), abalone (*Haliotis* spp.[8]) and rock oysters (*Crassostrea virginica*) can change the lipid content of their cell membranes to counter changes in its fluidity caused by temperature changes (cited by Rais and Stillman, 2010); these intertidal animals can respond by inserting more or less cholesterol and saturated fats into their cell membranes which help the membranes to remain fluid or "runny" despite body temperature changes.

Because intertidal organisms are ectothermic, they cannot regulate their body temperature by physiological means. However, non-physiological adaptations have evolved in intertidal organisms that help them to cope with extreme environmental temperatures by reducing heat gain and promoting heat loss. Additionally, physiological adaptations have evolved that protect or repair the cellular damage caused at extremely high body temperatures.

A physiological adaptation to potentially damaging high environmental temperatures is the production of heat shock proteins during periods of thermal stress. The proteins function is to help maintain metabolic function by stabilising and repairing important enzymes and protecting them from heat damage. These proteins have evolved in many intertidal molluscs such as mussels, limpets, topshells and periwinkles to help them tolerate high temperatures in the exposed upper shore.

[8] New Zealand paua belong to the genus *Haliotis* which are known as abalone in Australia and the USA.

Figure 10 (Tomanek and Somero, 2000) shows the heat stress response of four different species of closely related marine snails of the *Tegula* genus[9].

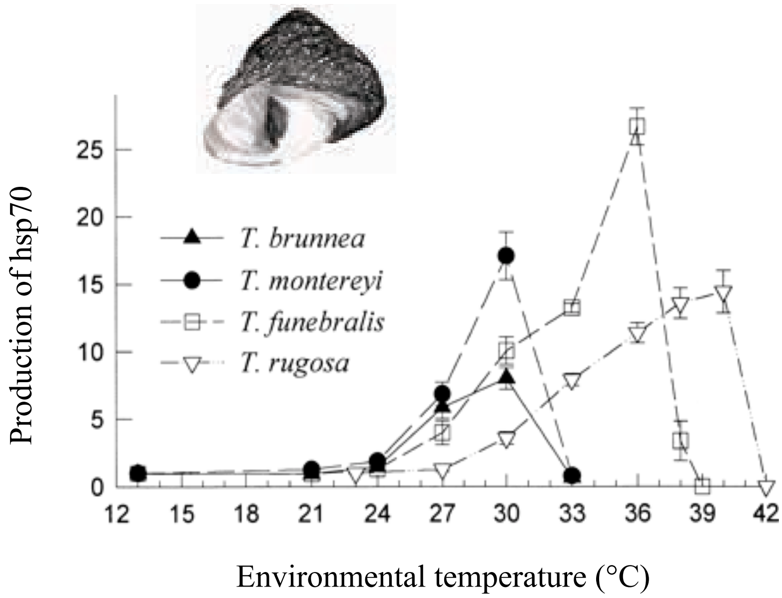


**Figure 10** Production of heat shock protein hsp70 marks the start of the thermal stress zone in American subtidal and intertidal topshells, *Tegula* spp. (Somero, 2000).

The snails were incubated at different temperatures and the amount of heat shock protein (hsp70) in their body tissues was measured. *T. rugosa* is a subtropical species, whereas the others are temperate species. Two species, *T. funebralis* and *T. rugosa* live in the intertidal zone, whereas the other two species are subtidal. The function of hsp70 is to repair and stabilise important metabolic enzymes in the snail's tissues. It is only produced at body temperatures that cause thermal stress. At the point where the production of hsp70 falls to zero, the animal has exceeded its thermal tolerance and has died.

The graph shows that the intertidal species experience thermal stress at higher temperatures than the subtidal species; this implies that their tolerance range for temperature is broader (above 12 °C at least). The graph also shows that the heat shock response occurs over a much wider temperature range in the intertidal species. This suggests that the temperature range of the stress zone of the intertidal species is wider than that of the subtidal species *i.e.* they can manage a wider range of temperatures through the production of the heat shock protein.

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[9] *Tegula* are found in North America are known as topshells. They are ecologically similar to our NZ topshells, *Diloma* spp. and *Nerita* spp.

Heat gain can be minimised by having a relatively large body size compared to species lower in the intertidal. This results in a low surface area to volume ratio and so the surface available for heating is kept relatively small. A relatively large body size also means that there is more body tissue to heat up which therefore takes longer for any significant tempera-ture rise to happen. This phenomenon can be seen in periwinkles (*Austrolittorina* sp.) and snakeskin chitons (*Sypharochiton pelliserpentis*) where larger individuals tend to be distributed higher up the shore as they can tolerate longer exposure to higher temperatures during low tide.

**Figure 11** Ridges on the limpets' shells increase surface area for radiating heat and therefore increase cooling .

Dark colours absorb solar radiation and so lead to heat gain. Barnacles have light coloured shell plates and the blue banded periwinkle *Austrolittorina antipodum* has white stripes that reflect radiation and reduce heating. The rays of limpet shells also help the re-radiation of heat by providing a greater surface area for cooling (Figure 11).

Many terrestrial organisms use evaporative cooling to keep their body temperature below its tolerance limit. For water to evaporate, heat energy must be transferred from a tissue which creates a cooling effect. Unfortunately for marine organisms, cooling by evaporation causes water loss which can lead to desiccation stress and subsequent death. However, some animals can draw on a reservoir of 'extra' water for cooling above that which is required for survival. Barnacles hold extra water within the mantle cavity of their shell plates which can be used for cooling without causing dehydration. Chitons and limpets settle into a 'home scar': a specially created depression or cup in the rock that the animal has created and returns to before being uncovered by the falling the tide. This home scar may contain a reservoir of water that the animal can use for evaporative cooling.

As temperature increases, evaporation rate increases and with it, the threat of desiccation or drying out. Intertidal organisms have become adapted to withstand desiccation either by minimising water loss or by being able to tolerate dehydration for limited periods.

Animals that show behavioural adaptations usually have an internal body clock that is synchronised with the tidal cycle; in this way, they are able to effectively predict the falling tide and ensure that they act in sufficient time to reduce water loss before they are uncovered. Mobile animals do this by changing their position on the shore and seeking shelter, whereas sessile animals time their activity periods to coincide with submergence and effectively 'clam up' during exposure.

Many shelled animals can tightly close their shell valves to create a high humidity environment within their shells which helps to reduce water loss, for example many marine snails, barnacles and mussels seal small amounts of seawater inside their shells when uncovered by the falling tide. Soft bodied anemones retract their delicate tentacles and withdraw inside their mucus-covered body, reducing their exposed surface area.

Behavioural adaptations in mobile intertidal animals to reduce water loss by evaporation include by avoidance behaviour or seeking areas of high humidity. Many animals like shore crabs and chitons bury themselves beneath loose sediments or cling to the moist underside of rocks. Chitons respond to both light and gravity and tend to move downward towards dark crevices when exposed to the air, behaviours known as **phototaxis** and **geotaxis**.

Limpets scrape small body sized depressions in the rock (often on the shaded side) called home scars which they can retreat to as the tide falls; they line the scars with mucus which helps to seal them in and reduce water loss.

Topshells and periwinkles (Figure 12) cluster together in large numbers in crevices or on the shaded side of rocks or boulders to increase local humidity and reduce the humidity gradient, thereby reducing the rate of evaporation.

**Figure 12** Blue-banded periwinkles (*Austrolittorina antipodum*) sheltering in crevices in the rock on the upper shore during aerial exposure. The crevices create shaded microhabitats with higher humidity than the surrounding rock surface which, together with the clumping behaviour, and mucus pad secreted by the snail, reduces desiccation.

Intertidal organisms have also evolved structural adaptations to reduce water loss that complement their behaviours. Purple shore crabs (*Hemigrapsus sexdentatus*) have a very high tolerance to aerial exposure thanks to a waxy, waterproof covering on their carapace called a chitinous cuticle. These crabs have a permeable section of their legs through which they carry out gas exchange. This region is not covered by the waterproof cuticle (which would prevent gas exchange) and so represents a potential source of water loss. However, the crabs can tightly fold this portion of their legs up into their carapace and maintain a high local humidity and reduce desiccation.

Most marine snails secrete watery mucus around their shell openings which forms a protective layer of gelatinous slime, a physiological response to aerial exposure. Periwinkles use this same mucus pad to attach to rocks when the tide is out[10]; they also have very small gills that reduce the evaporative surface. Topshells, catseyes periwinkles and whelks also have a thick, horny pad on their foot called an operculum that seals the shell opening behind the snail.

Some organisms have evolved very high tolerances to desiccation stress. Periwinkles that live in the highest levels of the shore can survive the loss of up to 70% of their water content and are capable of rapidly re-hydrating when re-submerged by the rising tide. Many types of seaweed are also capable of withstanding severe dehydration for short periods and very rapid rehydration. The highest zoned seaweeds on the shore are very tolerant of extreme dehydration, with species like sealettuce (*Ulva* sp.) and Neptune's Necklace (*Hormosira banksii*) capable of losing over 90% of their water content between tidal cycles.

The rate of photosynthesis in seaweeds decreases as desiccation increases and, like animals, many intertidal types of seaweed possess adaptations to reduce water loss. Many seaweeds such as kelps secrete a slimy covering called mucilage[11] which helps them reduce water loss. The shape of the seaweeds fronds ('leaves') and the growth form of the algae is also important. Like terrestrial cacti, the fleshy sacs of Neptune's Necklace, gummy weed (*Splachnidium rugosum*) and other sac-like algae store water so that photosynthesis can continue; their rounded shape also provides a low surface area to volume ratio so that evaporation rate is low. Coralline algae often grow in a thick turf which helps to retain water and so keep the local humidity high.

### 1.7.2 Osmotic or salinity stress

Intertidal organisms experience stress due to changes in the salinity of their environment. This stress is known as salinity or osmotic stress and can cause changes in the water or salt content of their body tissues. If the salinity of the environment is greater than the salinity of the body tissues of the organism, then the organism will tend to lose water by osmosis and may gain salts by diffusion. If the salinity of the environment is lower than the salinity of the body tissues, the organism would gain water and lose salts. Only when the salinity of the body tissues became equal to the salinity of the environment would there be no net change in water content. Changes in a cell's water content create physical stresses due to changes in cell volume and pressure which can lead to cell rupture or collapse. Chemical stresses can also occur due to changes in the availability of water and the concentration of reactants in the cell leading to reduced reaction rate or toxicity. If the

[10] It also acts as an insulating pad to reduce heat transfer to and from the rock.
[11] The mucilage of some brown seaweeds like kelp contains a sugar called agarose which binds water and is extracted to make a agar gel.

organism does not counter these changes and regulate its water content (**osmoregulation**) within tolerable levels it will die.

As the tide ebbs, surface films of seawater on the exposed shore become more saline as freshwater evaporates. Likewise, freshwater evaporating from rock pools raises their salinity; this is particularly significant in those smaller pools in the upper shore that are exposed to the air for relatively long periods and lose large amounts of their freshwater by evaporation. Conversely, large amounts of rainfall on the shore at low tide means that organisms experience very low salinity conditions and freshwater can accumulate in rock pools. Organisms in large rock pools will experience a slower decrease in salinity than organisms on or under rocks that are washed with fresh rainwater.

Unlike most estuarine organisms, few intertidal organisms are well adapted to tolerate changes in the salinity of their body tissues. Most intertidal species cannot control the salt content of their body; these types of organisms are called **osmoconformers**.

The salinity of their tissues is generally similar to that of normal seawater (36 ppt.); after all this is the environment that they evolved in and are adapted to. However, as for heat stress, they can limit the effects of changing environmental salinities in their surroundings by either tolerating, reducing or avoiding the effects. Mobile animals reduce the effects of changing salinity by avoiding the stress and moving into a more suitable microhabitat.

Structural adaptations that reduce evaporation can provide protection against water loss due to osmosis; for example the thick waterproof cuticles of crabs and barnacles are effective barriers to water and salt movement. However, gas exchange structures like gills are very vulnerable to osmotic stress. Gills need to have a large surface area and be **permeable** to oxygen and carbon dioxide for efficient respiration. These structures are kept moist and in almost continual contact with water. Whether water is trapped inside a shell as in mussels and barnacles, is present as surface water coating the gills of crabs, or is bathing the gills of fish in a rockpool, the salinity will change with increasing aerial exposure. This can change the water and salt content of the organism's tissues past its tolerance limits.

Physiological adaptations to regulate the body fluid's salt and water content help to counter such changes and maintain a relatively steady salt and fluid balance through a process called osmoregulation. Many invertebrates actively excrete salts like sodium and chloride ions through their nephridia, gills, gut or antennal glands (Taylor and Andrew, 1988). Other organisms can reduce water movement by osmosis by matching the total salinity of their internal fluids to the environment through exchanging 'good' ions and dissolved substances for sodium and chloride ions *e.g.* seaweeds use glycerol, sucrose and mannitol (Biebl, 1962); some invertebrates use amino acids. In this way, the organisms can osmoregulate and so maintain a stable water content in their tissues.

Some organisms like periwinkles have simply evolved physiologies that are capable of putting up with extreme salinity fluctuations and have a very wide passive tolerance range. This is also true of many intertidal algae that have a greater physiological tolerance range than their subtidal relatives.

### 1.7.3 Respiratory stress

With the exception of the high-shore pulmonate limpets[12], most intertidal animals rely directly on water for dissolved oxygen for aerobic respiration. Gas exchange structures like gills need to be moist to function, therefore during aerial exposure, intertidal animals need to maintain wet gill surfaces and avoid desiccation. Additionally, the concentration of dissolved oxygen in water decreases with increasing temperature, so small rockpools that experience the midday sun on the high shore are likely to contain far less oxygen than larger, more shaded pools in the lower shore, especially if the low shore pools are near the splash zone and aerated by breaking waves.

Periwinkles live at the very upper limit of the intertidal zone. Their gills are adapted to efficiently extract oxygen from the air during exposure at low tide. Not only have their gills decreased in size to reduce evaporative water loss, but the lining of their gill cavities has a very rich blood supply that can exchange gases with the moist air surrounding the mucus-lined shell opening, like a simple lung.

In terms of behavioural adaptations, avoidance of stressful conditions is common in mobile animals like crabs and chitons that can move wit the tide and stay submerged. Sessile barnacles and limpets are able to store air bubbles inside their gill cavities during aerial exposure at low tide. The air acts as an oxygen reservoir and keeps the water surrounding the gills enriched with oxygen. Topshells and whelks also trap water in the jelly-like mucus around the edge of their gill-bearing mantle cavities. Oxygen from the air dissolves into this moist layer and can then be extracted by the gills. However, even allowing for the limited ability of some intertidal organisms to extract some oxygen from the air during exposure, most of these marine animals cannot maintain a high respiratory demand when the tide is out. Their gas exchange organs are mainly adapted for extracting oxygen from seawater; prolonged activity during exposure will rapidly deplete oxygen in their tissues and carbon dioxide will accumulate, lowering cellular pH. The most common physiological adaptation is to reduce the oxygen demand and rate of carbon dioxide production by lowering the metabolic (and therefore respiration) rate, and fuelling essential life processes by anaerobic respiration; the lactic acid build up is then reversed during re-submergence as the tide rises.

[12] This group of high-shore molluscs are not thought to be closely related to the common shore limpets, but have evolved from a relatively recent terrestrial ancestor like the land snails. They possess a pseudo-lung rather than gills that enables them to carry out gas exchange in the air and have adapted to the salty conditions on the upper shore. Their resemblance to the true marine limpets is a neat example of convergent evolution: where distantly related species have been ‘shaped’ by natural selection in the same way, by the same environmental pressures in their similar niches.

# PART 2: SURVEYING THE ROCKY SHORE

## 2.1 INTRODUCTION: WHY STUDY THE ROCKY INTERTIDAL SHORE?

New Zealand is a coastal nation. It has one of the largest coastlines relative to our land area in the world. Our coast is under pressure from many different users. The intertidal border between the sea (marine) and land (terrestrial) environments are susceptible to impacts from both the land and the sea including pollution; overfishing; mineral extraction and dredging; invasive pest species like *Undaria* seaweed; nutrient enrichment and increased sediment in rivers from run-off; habitat loss and alteration; and the global effects of climate change that include rising sea level, increased air and sea temperatures, disrupted weather systems and ocean acidification.

The intertidal border between the land and the sea is a productive and diverse habitat. It has a high biodiversity and is home to many slow-moving or sessile species that are relatively easily quantified for monitoring changes. Collecting data on species distribution, abundance, community structure and biodiversity will provide a useful **baseline** for detecting any future changes.

## 2.2 HOW TO CARRY OUT THE SHORE SURVEY

The aim for the class will be to construct a table that shows the mean **density** and distribution of intertidal organisms from the upper limit of the tide's influence to the low water mark.

A class will set up 3-5 randomly placed **transects** that will run from the upper limit of the high tide's influence (the splash zone) down the shore to the water's edge at low tide. Each group of 3-4 people will be responsible for surveying one transect.

Along each transect there will be 11 sampling points. At these points a **quadrat** will be placed to measure the abundance of all[13] of the animals and plants found there. The sampling points will be evenly spaced along the transect at regular intervals of 1/10 the total transect length. Each sampling point will correspond to a different tidal level *i.e.* quadrat 1 (Q1) will always be at the upper limit of the high shore; Q5 will be the mid shore sample, and Q11 the lowest of the low shore samples (Figure 13).

As each group will use the same method, their data can be **pooled**. At the end of the survey the pooled data can be used to calculate the mean density at each shore level for all species found in the survey.

Using a standardised method means that results from different times and places can be compared.

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[13] You should not assume that you know what the dominant or important species in an intertidal community are before you survey it and choose to count only those species; a valid method for a community survey would collect data on <u>all</u> species that can then be analysed for patterns that might suggest significant interactions between different species.

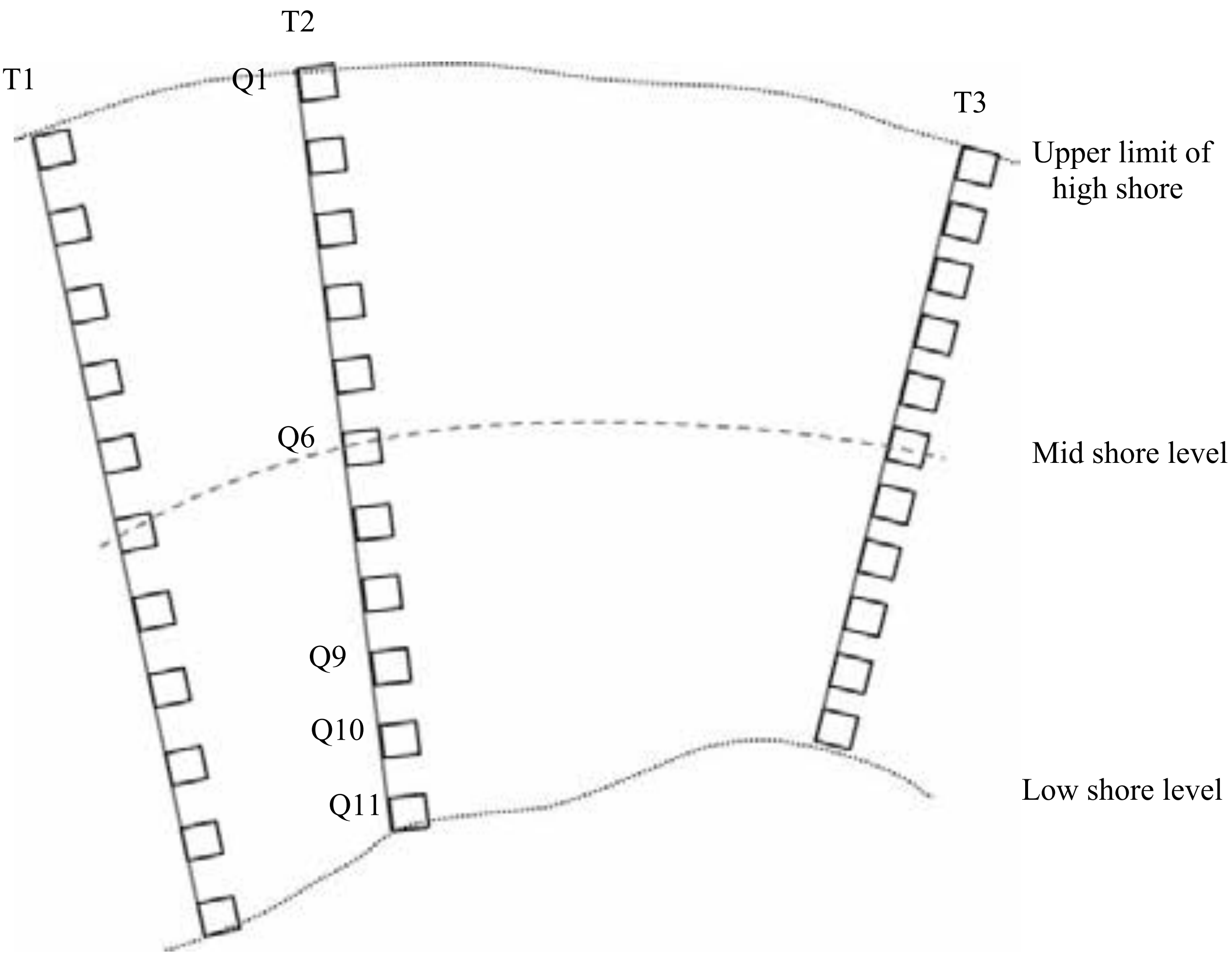



**Figure 13** An example of a survey area (planform view) showing three transects, T1 – 3, each with 11 quadrats (Q1 – 11) at regular intervals of 1/10 of each transect's total length.

### 2.2.1 Why is the quadrat sampling interval always one tenth of each transect's total length?

Most shorelines are irregular shapes and it is unlikely that any two transects will be the same length. Some transects may lay on more steeply sloping parts of the shore than others. To calculate an average density for a species at a particular tidal level, data from different transects need to be pooled together - but how do you know which quadrats are at approximately the same tidal level? The quadrats at the very top and bottom of the transect will be equivalent as the high and low tide levels are easy to fix. You could also assume that the quadrats in the middle of each transect are at the same tidal level – at the mid tide. But how can you make sure that quadrat 3 on transect 1 is at an equivalent tidal height as quadrat 3 on the other transects? The solution is to place quadrats at the same *relative* distances along their transects; these distances are found by dividing each transect into the same number of lengths and placing a quadrat at each of these points. This will enable you to pool quadrats at approximately equivalent tidal heights. A shore profile diagram should always be drawn so that any exceptionally high or low quadrats can be ideitified and analysed later. A convenient number to divide the transect by is 10. This will give 11 quadrats in total, which will provide sufficient data to show the presence of any pattern in species distribution along the transect.

## 2.3 EQUIPMENT LIST

The following is essential equipment:

- Quadrat: 0.5 x 0.5 m square frame with a total area of 0.25 m2
- Transect: Measuring tape: 30 – 50 m plastic, reeled
- HB pencil
- A4 hardcover notebook or A4 clipboard in a clear plastic bag
- NZ Rocky Shore Guide (Figure 14)[14].
- Sunscreen, hat, water and sensible footwear

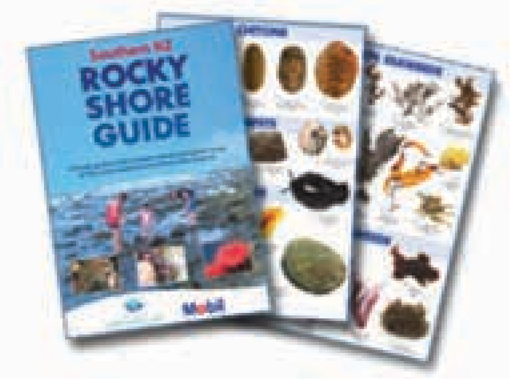



**Figure 14** The NZ Rocky Shore Guide

You may also find the following equipment useful:

- Thermometer: stainless steel probe, -10˚C – 50˚C range
- Digital camera and 30 cm white plastic ruler for scale
- Data recording sheet (see 'Survey Data Sheet', Appendix 1)
- Tent pegs for securing each end of your transect
- Hand lens for identifying small organisms
- Small plastic 'sandwich' bags for collecting small samples of seaweed for preserving or identification after the survey

## 2.4 SURVEY METHOD

1. Aim to begin surveying at low tide. Arrive at the shore at least 30 minutes before low tide so that you have time to mark out your survey area.

2. Measure the width of your survey area along the high shore, either by paces or using a tape. The transects should run down the shore from the upper limit of the sea's influence where the splash zone ends. Finding this region can be difficult, but there are some indicator species that can be used *e.g.* littorinid or periwinkle snails (*Austrolittorina antipoda*) and encrusting marine lichens. Find the height where these organisms are no longer consistently found and let this represent the absolute upper limit of the tide's influence and the start point for your transect.

3. Generate up to 5 random numbers[15] between 0 and the width of your survey area. Each of these numbers is a starting point for your transect in the high shore and the location of your highest shore quadrat, Q1.

[14] Free download for Northern and Southern regions available from the "Resources" section of the New Zealand Marine Studies Centre website http://www.marine.ac.nz/

[15] Random numbers can be generated using a standard scientific calculator, iGenerate Random Numbers iPhone/iPod 'App' or online at http://www.random.org

4. Hold the measuring tape at the highest sampling point (Q1) for the transect at the high shore region and run out the measuring tape down the shore to the water's edge to form a line that is approximately perpendicular to the shoreline; this is your transect line. Walk with the tape on your left hand side – this will help you to walk to the right of the transect and avoid trampling your survey area.

5. Measure the total length of the transect. Divide this number by 10 to find the sampling distance between quadrats along the transect.

6. The first quadrat to sample is in the low shore at the water's edge. This is numbered "Q11" on the survey sheet. Place the quadrat onto the substrate with the top left corner of the quadrat's outer edge on the sampling point on the transect (when facing **up** the shore towards the high tide zone).[16] This quadrat is sampled first.

   **Always face the sea while counting so you can watch for large waves!**

7. Starting in the top left corner, **systematically** search the entire habitat within the quadrat and record the **abundance** of all **macroscopic** organisms. Here are some guidelines to help you record abundance:

   - Record abundances for overlying canopy species first. The canopy species can then be lifted or moved aside to record abundances of the understorey species living beneath them. Remember to look inside crevices and under rocks and weed.
   - Animals should be recorded using a **tally** to produce a total count or **frequency**.
   - Seaweeds should be recorded as **percentage cover**.
   - For small, encrusting animals that form colonies (such as ascidians, bryozoans and sponges) and/or cover a large area (such as barnacles and little black mussels) you can either count the individual colonies, or treat them like seaweeds and record their percentage cover.
   - Where an animal's abundance is much greater than 100 (*e.g.* species like horn snails, blue banded periwinkles and barnacles), you can do a rough count in one part of the quadrat and multiply this up (extrapolate) to represent the whole quadrat.
   - If a relatively large organism is directly beneath or touching the quadrat frame, then you need to count it differently. Only count the organism if more than half of the organism is inside the quadrat.

     **When you have finished searching the quadrat remember to replace any rocks to their original orientation and position.**

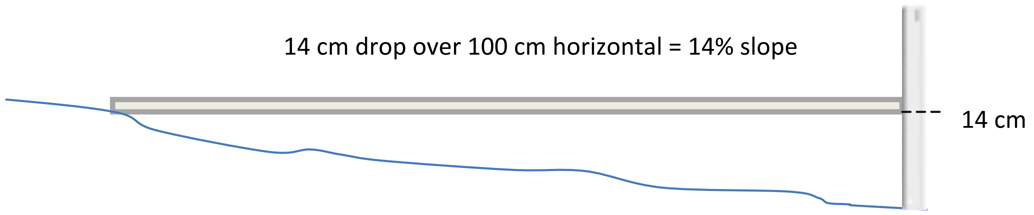
[16] Sampling starts at the low shore and works up the shore with the incoming tide following behind.

8. Record the substrate type in the quadrat. The underlying or base substrate is recorded as either rock, cobble, mixed (loose assorted stones) or pool of water.

9. If you have time, photograph the quadrat from above for visual reference. Include the quadrat, transect and site number, and a 30 cm white plastic ruler for scale in each photograph.

10. Record environmental information about the site. This could include:

- GPS coordinates or map grid reference
- Air and sea temperature.
- **Aspect**. This is the compass direction the shore faces *e.g.* north facing.
- **Exposure** level. This is a measure of how exposed the shore is to wind and wave action *e.g.* sheltered, very exposed, etc.
- Shore gradient or slope. This can be *estimated* by measuring the drop down the shore in 1 horizontal metre. For a more accurate measurement, this can be done several times along the entire length of the transect and averaged for a steadily sloping shore, or used to help create a shore profile diagram where the shore slope changes.




- Significant features: these are any features that you think might influence the survey area *e.g.* large boulders, storm water drain outfall, stream or creek outlet, grazing animals, rock fall, wreckage or rubbish, pipeline, etc.
- Photographs, video or sketched profile diagrams of the survey area so that you or someone else can locate your sampling area again later.

# PART 3: A BRIEF GUIDE TO SEASHORE SURVEYS

## 3.1 INTRODUCTION

An effective, valid biological survey should have six key features; it should be:

- Randomised — Samples should be taken from areas that have been selected at random to avoid any bias in the survey results
- Representative — Gives results that describe the full range of important features of the whole statistical population[17] being surveyed
- Repeatable — Can be carried out again in such a way that the results would be very similar if the population being surveyed had not changed
- Reliable — Results should be accurate (close to the real value in the bigger population) with little variability due to survey errors, allowing you – and others – to have confidence in any conclusions you draw from them
- Realistic — Doesn't measure everything in the population – surveyor makes the best use of the limited time and resources available by measuring enough
- Responsible — Doing the survey does not significantly damage or alter the environment or statistical population being surveyed

## 3.2 TRANSECTS

A transect is a line along which the distribution and abundance of different organisms are surveyed and environmental variables are measured.

A transect is usually placed running along an environmental gradient to show if and how organisms' distributions and environmental variables change along that gradient.

The word "transect" literally means "to cut across" (trans – across; sect – cut). In zonation studies, the transect is usually placed perpendicular (at a right angle) to the direction of the zones so that it "cuts across" the different communities allowing changes in abundance to be measured and related to the change in the environmental gradient.

[17] A note on the word 'population'. This word has different meanings depending on whether you are a biologist or a statistician. In biology, a population is a group of individuals of the same species living in a specific area that are capable of interbreeding and share the same gene pool. In statistics, a population is any group from which a sample is taken. Unfortunately, as a marine ecologist, you are both a biologist and a statistician! So how should we use the word here? We will use the term **population** in the biological sense *i.e.* "the population of half-crabs", and only use the term **statistical population** if we need to talk about the survey statistics.

In an intertidal rocky shore survey, transects are usually run from the top of the high tide zone to the water's edge at low tide (Figure 15). This gives a complete picture of changes in the community from high to low tide.

Several transects are used across the width of the shore so that a **representative** picture of the whole survey area is obtained. The start position of the transects within the sampling area should be **randomly** selected. **Sampling** then occurs along the length of the transect between the top of the high tide zone and the low water mark at regular intervals using **quadrats**.


**Figure 15** Main direction of the environmental gradients on the rocky intertidal shore .

## 3.3 QUADRATS

A quadrat is simply a counting aid that is used to measure the **abundance** of **sessile** (stationery or fixed in place) and slow or poorly **motile** organisms in a **sample** from a bigger **community**. It has a fixed shape, a known area and is usually four-sided.

Figure 16 Open frame quadrat.

The quadrat most commonly used in rocky shore **intertidal** studies is a 0.25 $m^2$ square frame quadrat. This has sides that are 0.5 m in length. However, on a very short, steep shore a rectangular 'letterbox' shaped quadrat can be used (Figure 17(c)).

The frame of the quadrat is usually made of aluminium, wood or rigid plastic tubing. It may be of the string frame type (Figure 17(a)) or a simple square open type (Figure 17(b)). Ideally, one of the 4 corners is marked to a length of 0.1 m to create a 0.01 $m^2$ area (marked ***x***) for **subsampling**.

On a cobble or boulder shore an open frame quadrat is preferable as it allows the surveyor to lift up and examine rocks inside the quadrat (Figure 16).

Marking the quadrat from the corners with alternating 10 cm long black edges with black paint/marker is useful for scaling object sizes and analysing photographs.

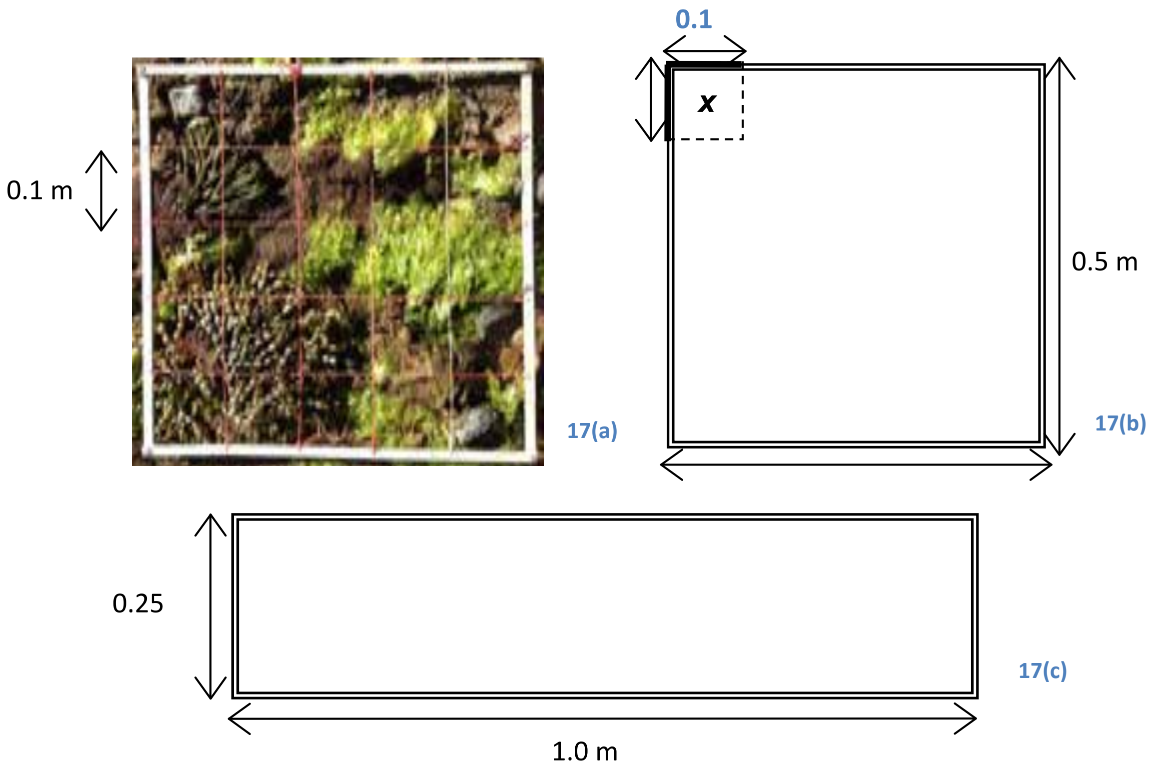



Figure 17 Types of 0.25 $m^2$ quadrat: (a) square string frame (b) basic (c) letterbox for sampling over short vertical distances on steep shores

**Ecologists** use quadrat samples to estimate the **distribution** and **density** of organisms in a particular **habitat**.

Although quadrats can be any shape, they are usually square. This is useful because they can be easily divided into smaller, regular sized areas to count very small, abundant organisms that occur in very high numbers in the quadrat (measuring abundance using a smaller area within the quadrat sample is called subsampling).

For example, in the quadrat below (Figure 18) there are thousands of blue periwinkles (*Austrolittorina antipodum*) inside the 0.25 $m^2$. However, the number of periwinkles inside one of the smaller 0.1 m x 0.1 m squares can be counted more easily. This represents a subsample of the full quadrat.

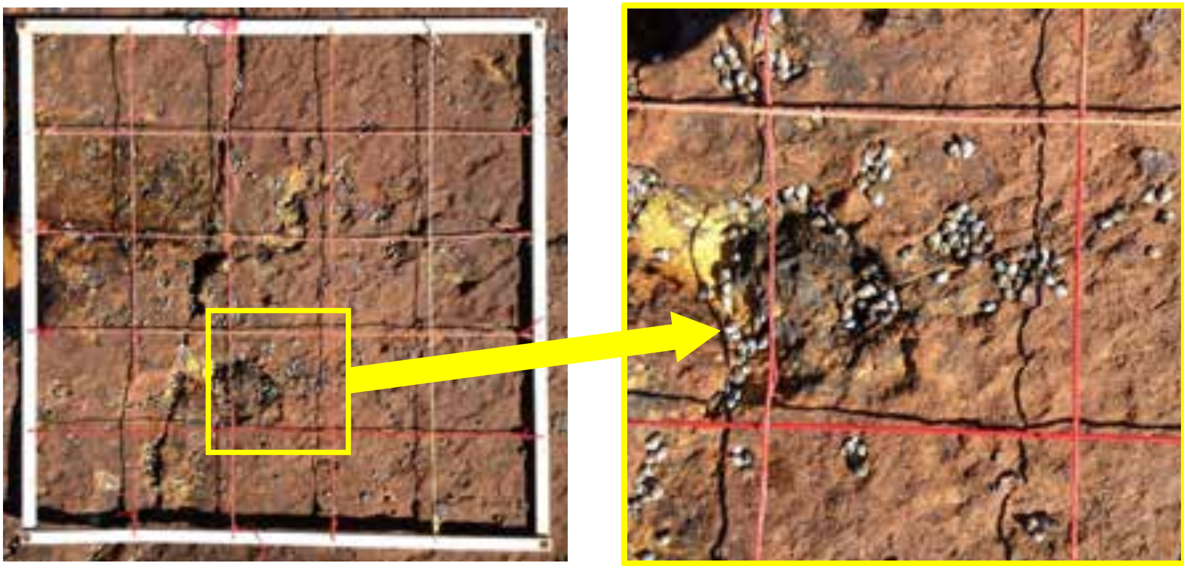


**Figure 18** Showing how to measure abundance of small organisms using subsampling

(There are 59 in the 0.01 $m^2$ subsample. This would give an calculated population density of 59 x 100 per 1 $m^2$ = 5900 individuals/$m^2$.)

If larger organisms are present in low numbers, square quadrats can be easily “flipped” along their edges and placed next to each other to create a larger sized sample *i.e.* four quadrats of 0.25 $m^2$ can be placed together around a single point to make one larger square quadrat with an area of 1 $m^2$.

A number of important factors need to be considered when using quadrats including the number, placement and size of the quadrats.

### 3.3.1 Number

The more quadrats you have, the bigger your sample is and the more **reliable** your sample calculation of the true population **parameter** (*e.g.* density or vertical distribution on the shore) will be. It follows that the best number of quadrats would be enough quadrats to completely cover your seashore! This is called a ‘census’ and is not practical as there is not enough time to count everything. Fortunately, there is no need – a **survey** is a method of estimating a **statistical population** parameter using measurements of smaller samples taken from within that statistical population. Some simple **statistics**, can be calculated that allow ecologists to predict the accuracy of their sampling *i.e.* how close your surveyed value is to the actual population value. What you tend to find is that the larger the sample you take, the closer your survey sample gets to the actual statistical population value; in theory, your value is the same as the actual value when you have sampled the entire habitat[18].

It is better to use several quadrats rather than just one large one. Even though the total area sampled might be the same, using several quadrats in different places helps to create a more representative picture of the whole survey site. The animals and plants on the rock shore tend to be distributed quite unevenly in 'patches'; if you try and build a picture of the survey site from just one quadrat you will either under or overestimate an organism's abundance depending on whether your quadrat is placed on or between one of the patches.

In the following example, the effect of using one 1 $m^2$ quadrat is compared to using four randomly placed 0.25 $m^2$ quadrats to sample a limpet population from a small region of the shore (note that the limpets are not to scale!).

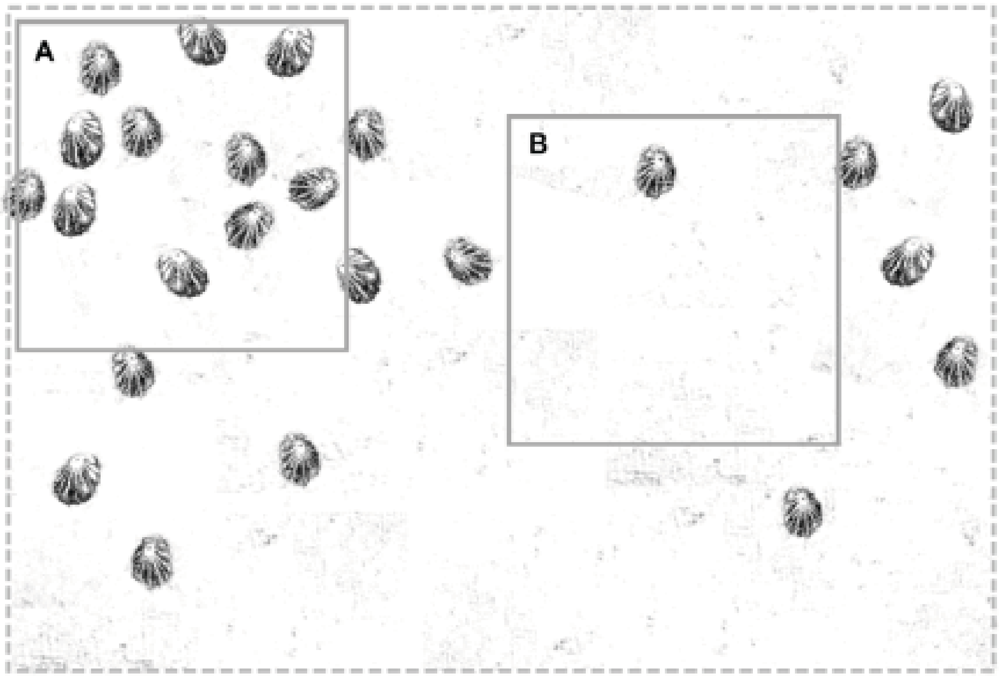



**Figure 19** Sampling a limpet population using one quadrat. The result would be very different if the quadrat were placed in position A or B.

The area of the shore (inside the dashed border) is 6 $m^2$. There are 24 limpets in total. Therefore the actual population density of limpets in this area is 24/6 = 4 limpets/$m^2$.

First we can see an effect of sampling with a single large quadrat of 1 $m^2$ area (Figure 19). If the quadrat is placed at **A** then the density would be 11/$m^2$ which is too high. If the quadrat were placed at **B**, then the density would be only 1 limpet/$m^2$ which is too low. So even though the total area sampled is the same, the results are very different and neither is very accurate.

[18] This rarely happens as even the best surveyors overlook some organisms in their sample or miscount them. These are normal sampling errors and can be reduced and quantified, but never eliminated – see the section on accuracy, validity and reliability.

Here is an alternative using four randomly placed 0.25 $m^2$ quadrats (Figure 20). The total area sampled is the same as the 1 $m^2$ quadrat (4 x 0.25 $m^2$ = 1 $m^2$). The population density is the sum of the number of limpets in the four quadrats: 3 + 1 + 0 + 0 = 4 limpets/ $m^2$ which is much closer to the actual density of the limpets. Note that the quadrats that are empty are important in gaining an accurate value of the density estimate as they help to show the patchy distribution of the limpets in their habitat.

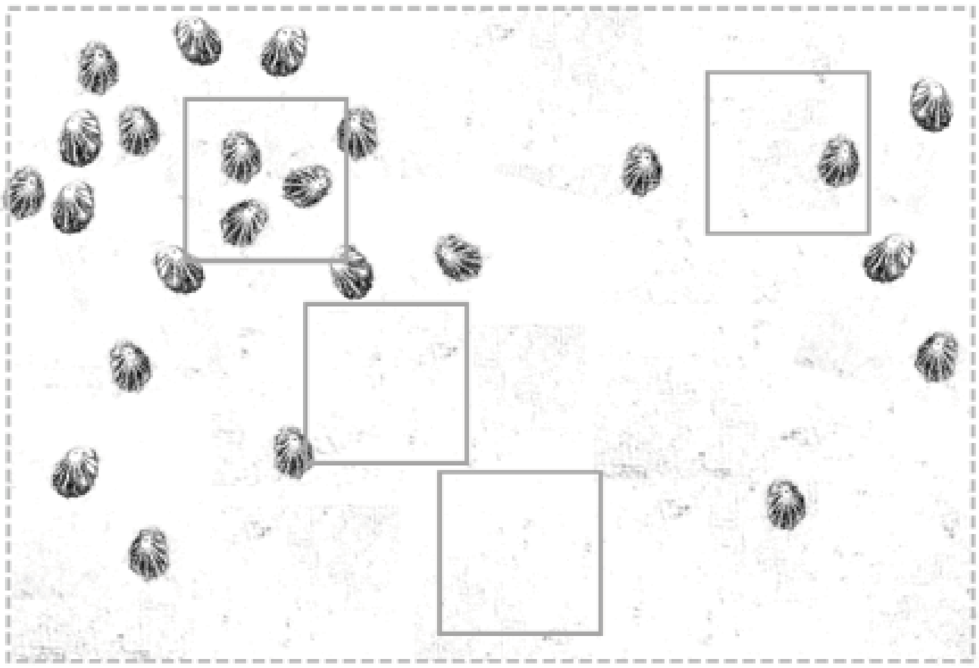


**Figure 20** Sampling a limpet population using four randomly-placed

### 3.3.2 Placement

An important assumption of any survey is that it is **representative** of the larger population being studied. This means that no feature of the population is under or over-represented in the results. It is important to **randomise** the location of the samples in the habitat to avoid your survey being **biased**. Bias is when there is a tendency to choose or select something that can influence results. In surveying, this may be selecting the position of a quadrat on the shore to include an "interesting" feature, or clump of organisms – or even to *avoid* having to count a large clump of tiny organisms! This could lead to an estimate that is inaccurate and may not reflect the true nature of the site being surveyed. If organisms occur in clumps, the space between them is just as important as the clumps themselves and needs to be included in the survey; if the real environment is patchy, a valid survey should show this.

Let us look at our limpet example again. If the position of the quadrats was chosen, then we might be tempted to place the quadrats in areas where the limpets are, and avoid the areas where they are not (Figure 21). We can see that this would lead to a large overestimate of their actual abundance in this habitat: 5 + 4 + 2 + 3 = 14 limpets/$m^2$ compared to an actual density of 4 limpets /$m^2$.

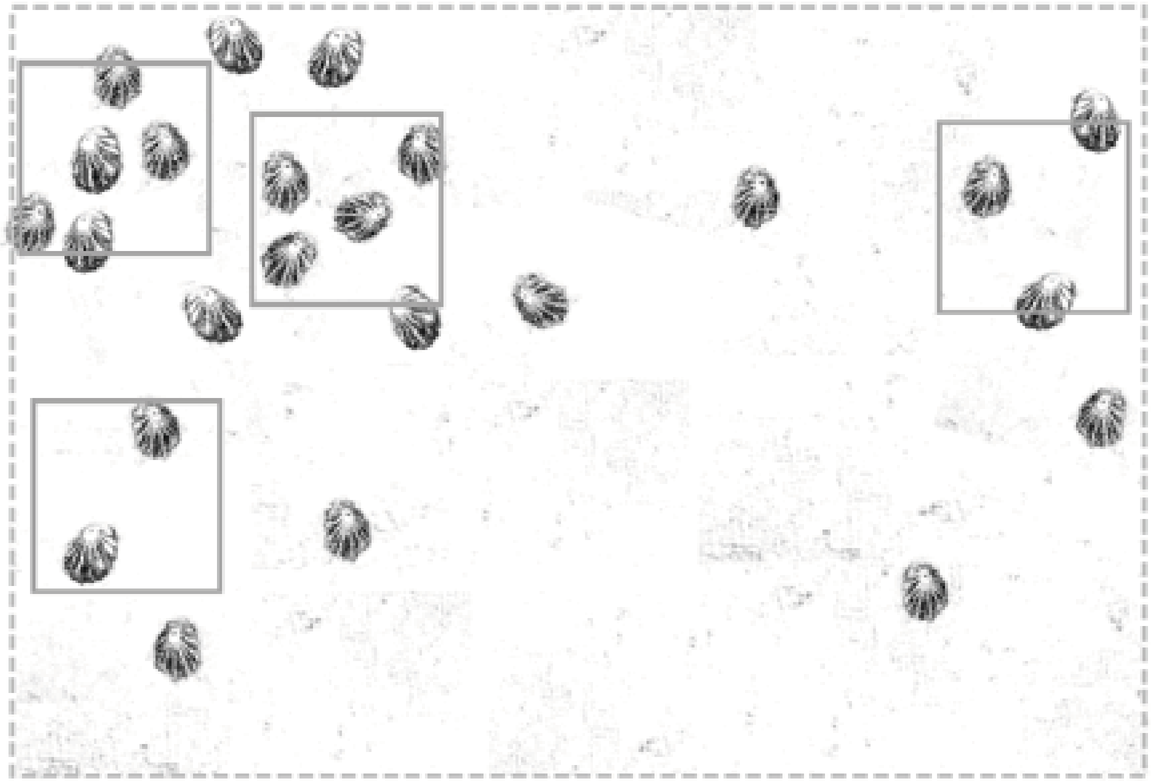


**Figure 21** Showing the importance of selecting random sites to position the quadrats.

But in this habitat, just like on the rocky shore, the limpets are not distributed evenly; they are randomly dispersed in patches throughout the survey area. So for our samples to accurately describe the real habitat we need to represent the areas in the habitat *without* any limpets – the space between the limpets is just as important as the clumps; and the best way to represent the entire habitat is by not choosing where the quadrats are placed but positioning them randomly.

### 3.3.3 Size

The size of a quadrat is very important. A lot of study has been done on the 'best' size of quadrat to use. A valid quadrat size depends on what is being counted. For intertidal rocky shore organisms, a quadrat with an area of 0.25 $m^2$ is often used and suitable for estimating abundance for most organisms. If larger motile animals like seastars, urchins or kelp plants are present then a larger sample is required. This can be as large as you time and resources allow.

How do you know that the quadrat area is big enough? You can plot a species accumulation curve (Figure 22). This is done by first recording the number of species in a small quadrat, then counting the number of new species found as the size of the quadrat is increased. The number of new species found as added to the number found in the smaller quadrat and a cumulative or 'running' total is calculated. As the cumulative number of species begins to level off, you can predict what the optimum quadrat size will be. In the diagram below, the optimum quadrat size would be around point **X** where the majority of the predicted number of species will be found for a reasonable counting effort.

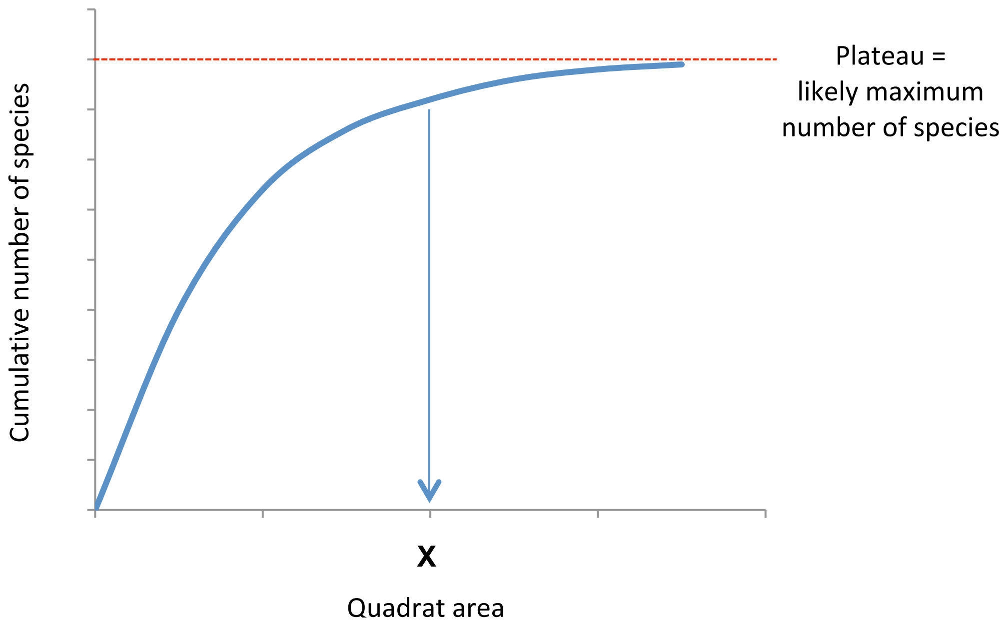



**Figure 22** Species-accumulation curve showing the effect of increasing sample size on the number of species recorded.

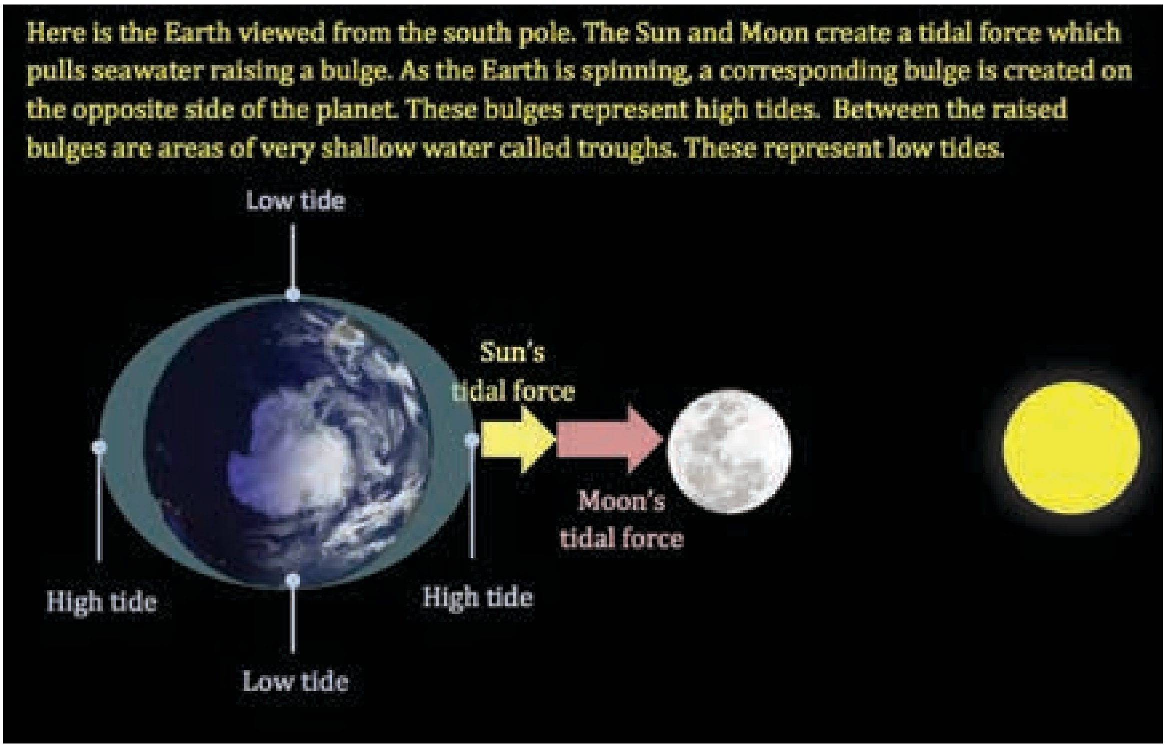
Increasing the size of the quadrat beyond this point is only likely to produce a small increase in the number of species yet would require a lot more counting effort so is probably not worth it.

# PART 4: THE TIDES

The effect of the tides is that the height of tidal seas changes in a regular, predictable cycle.

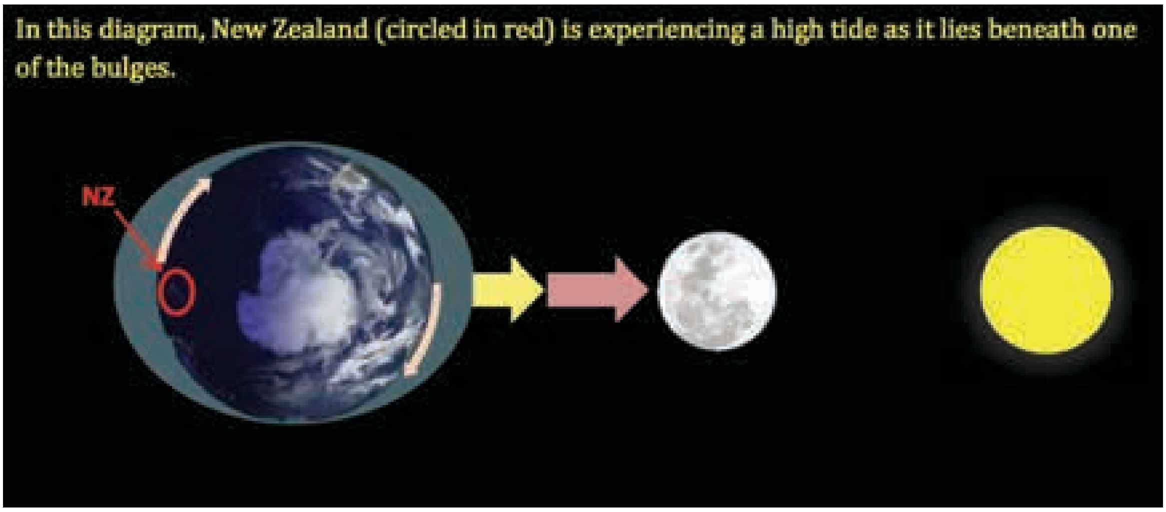
The moon and the sun create a gravitational pull on the water of the world's seas and oceans and create a tidal force. Although the sun has more mass than the moon, the sun is much further away from the Earth and its tidal force is only about half that of the moon.

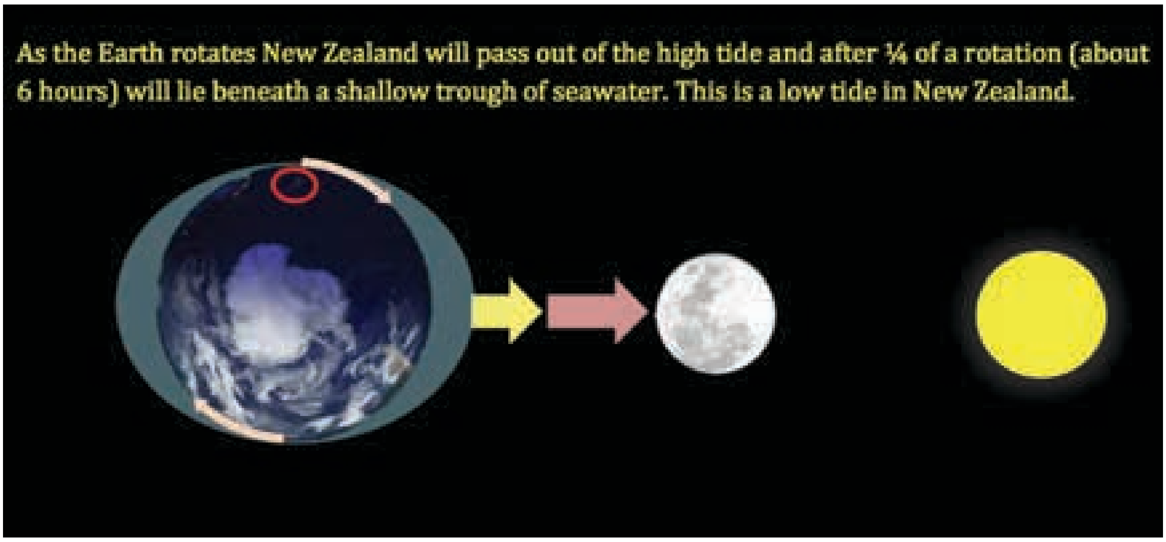
These gravitational forces create a 'bulge' of water on the Earth's surface in the direction of the pull. Because the Earth is spinning, another corresponding bulge is created on the opposite side of the Earth where the gravitation attraction by the moon is less and by so-called 'centrifugal force'. These two bulges correspond to increased sea levels that we call high tides.

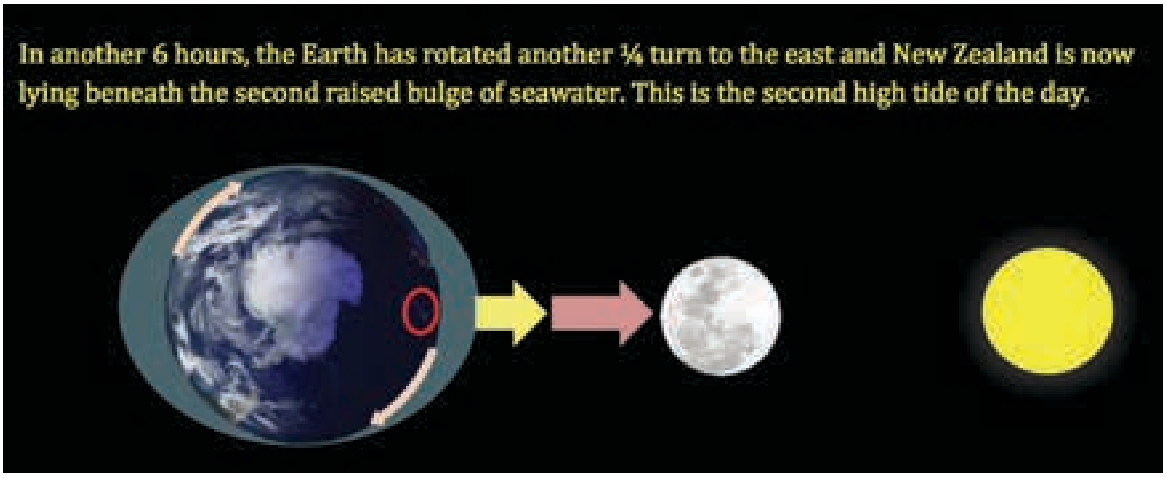



On a sloping land mass, the increase in height of seawater over a point corresponds to the flood tide we say the tide is "coming in". As we pass through the bulging tidal sea, the water level drops and we experience an ebb tide as the water 'goes out'.

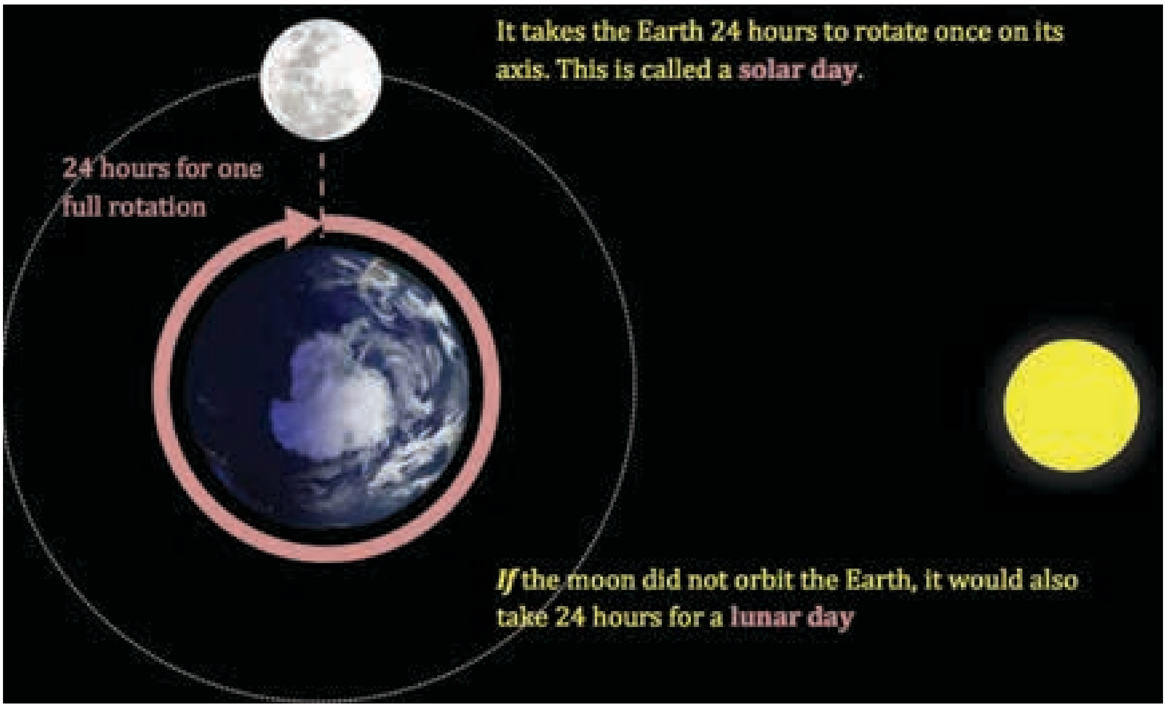
As the Earth rotates toward the East, the two bulges of water *seem* to travel around the Earth across the surface towards the West – but as the Earth rotates *it* moves beneath the bulges.



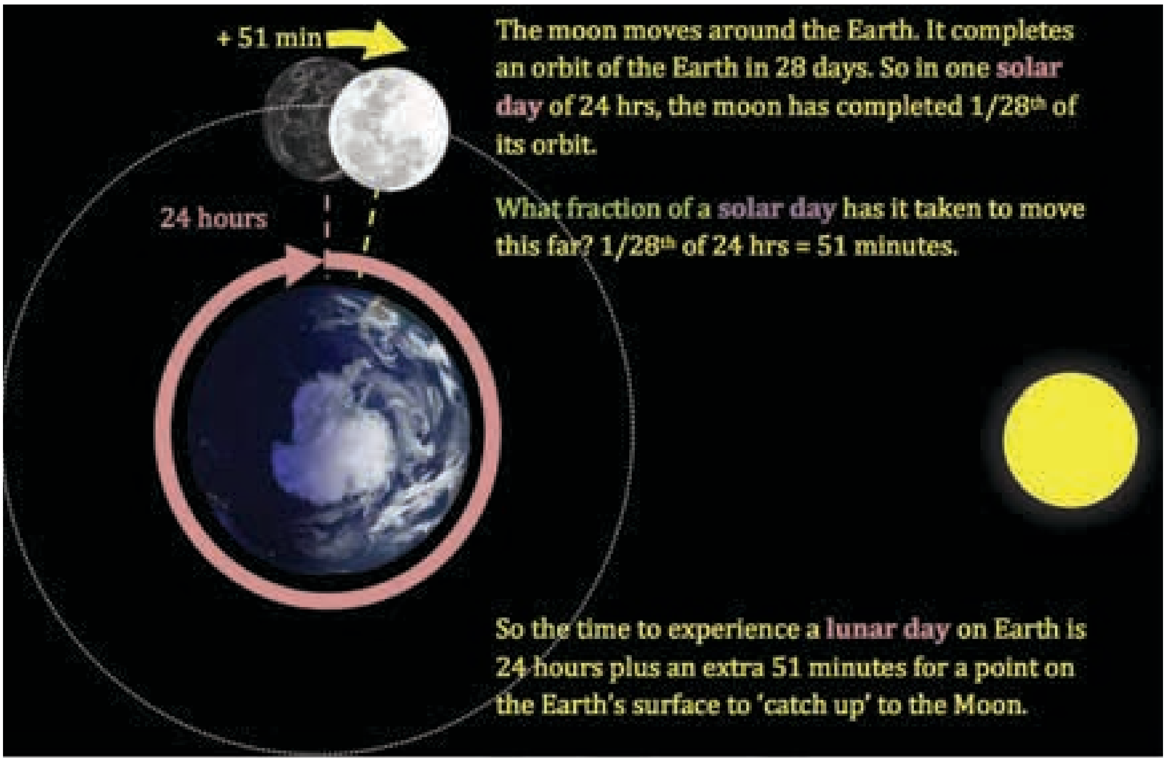



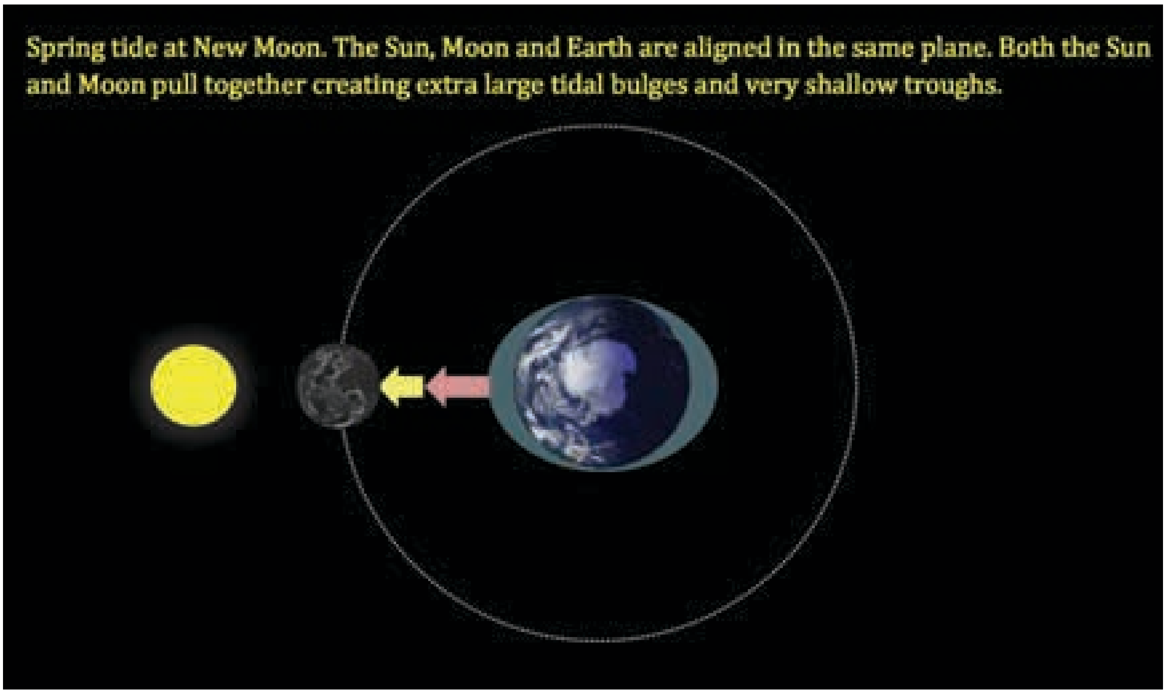

It takes one solar day (24 hours) for a complete rotation of the Earth on its axis. Therefore a point on the Earth's surface would be expected to pass beneath a bulge of seawater twice a day, giving two high tides per day that were 12 hours apart.

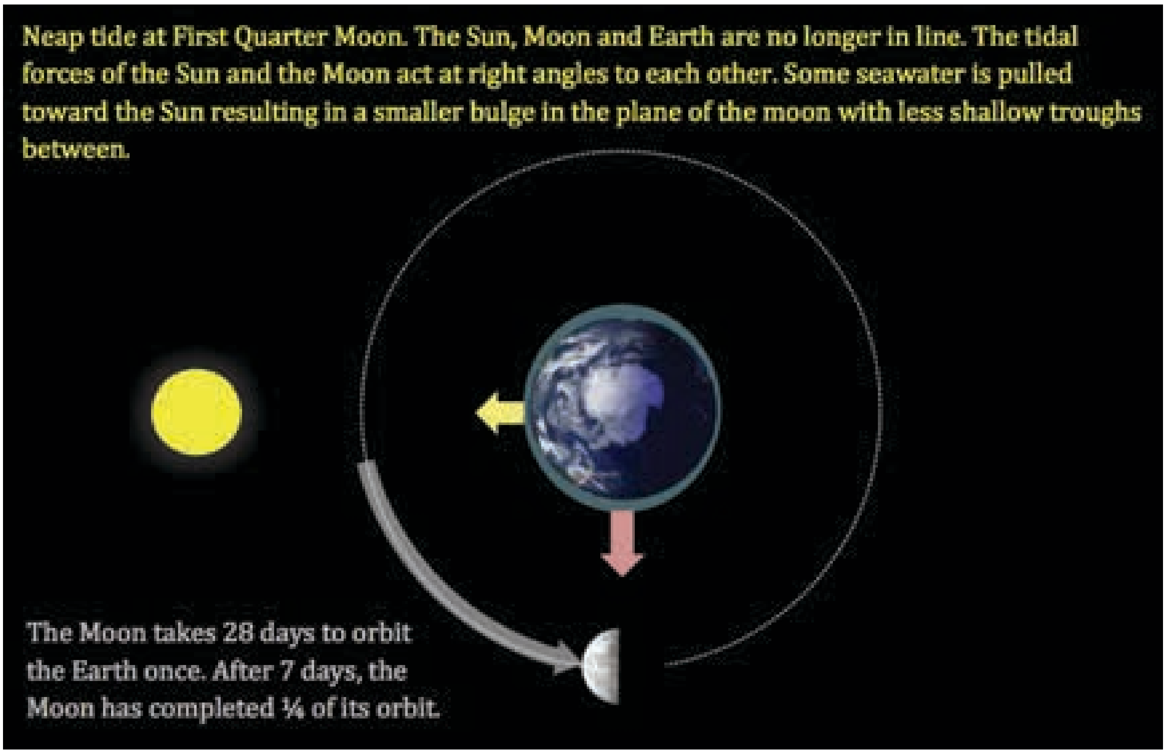


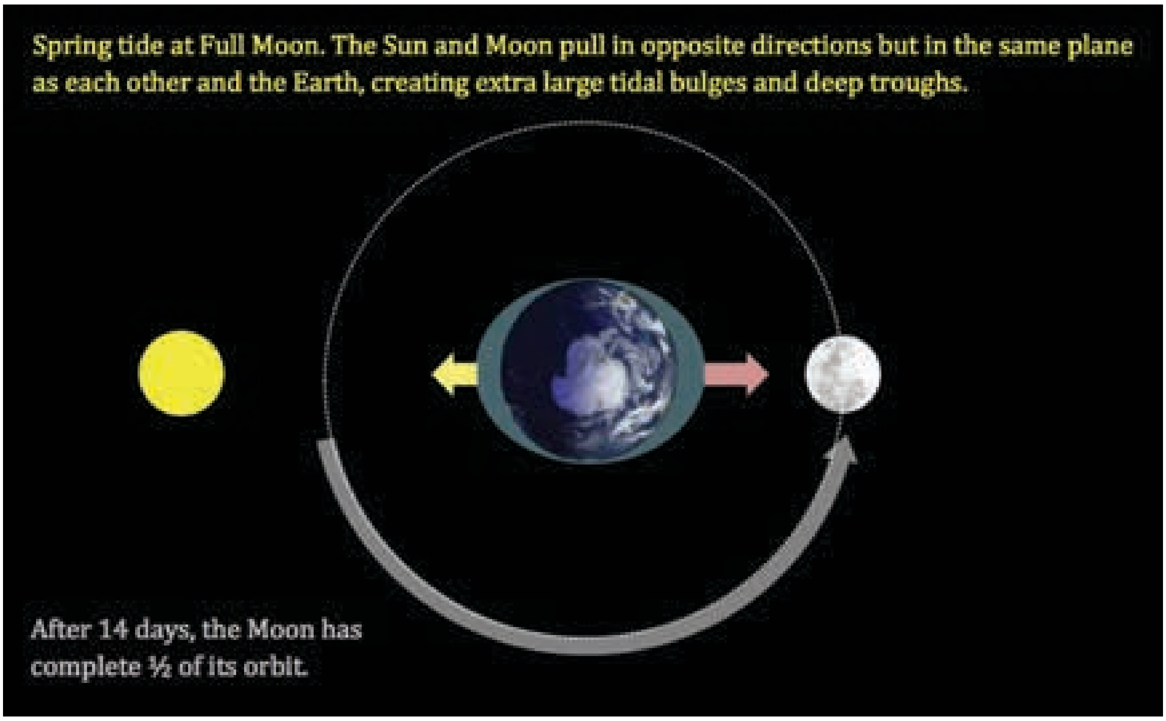

But the moon is moving too. It takes 28 days to complete one orbit around the Earth. As the moon moves, it delays the tidal cycle each day by 1/28$^{th}$ of 24 hours or 51 minutes. This means that the time between two high tides is not 12 hours, but 12 hours 51 minutes *e.g.* if the first high tide on day 1 was at 09:00, the first high tide on day 2 would be approximately 09:51.

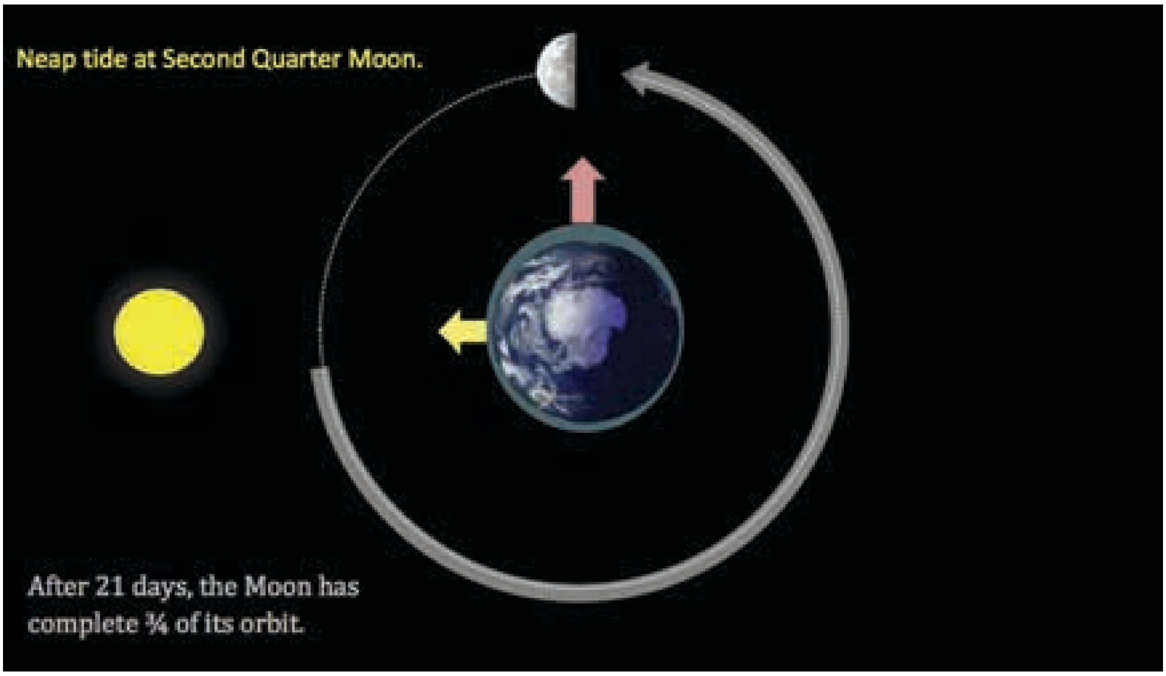


When the moon and the sun are aligned in the same plane as the Earth, their gravitational forces are added together to create an extra-large tidal bulge on the Earth's surface. As more water is pulled into these bulges, the troughs in between contain less water and so correspond to extra low tides. These large tides are called Spring Tides and occur twice a month during new moon and full moon.






When the sun and moon are at right angles during the quarter moon phases, the smaller bulge of the sun is added to the low tide created by the moon. This results in a lower high tide and a higher low tide. These tides are called neap tides and occur every two weeks between the Spring tides.

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# APPENDIX 1: SURVEY DATA SHEET

## SITE DESCRIPTION

*Write a **brief description of the site** and describe any potential influences that are not directly related to tidal movement (e.g. rocky headland with surf beach 3 km to south; freshwater creek 50 m to the north; upper shore modified with harbour wall; popular site for paua collectors, etc.)*

*Draw a **shore profile** to show the approximate heights and lengths of the shore and positions of your quadrats on your transect. Note any significant habitat features on the profile that might affect organisms' distributions in particular quadrats (e.g. rockpools, large boulders, patches of sand, etc.).*

High shore →

Site location name: ____________________ GPS/grid reference: ____________________

Transect number: ____________________ Transect length (m): ____________________

Date: ____________________ Sampling interval (m): ____________________

Surveyor(s): ____________________ Exposure: ____________________

Time of low tide: ____________________ Aspect: ____________________

Depth of low tide: ________________ m Weather conditions: ____________________

Air temperature: ________________ ˚C Sea temperature: ˚C ________________

High shore →

| **DISTANCE ALONG TRANSECT (m)** | 0 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|

| **SEAWEEDS** | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 |
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High shore →

| **ANIMALS** | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 |
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High shore →

| **MAIN SUBSTRATE (>50% of quadrat)** | | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Rock** | Stable hard surface | | | | | | | | | | | |
| **Cobble** | Fist to head sized | | | | | | | | | | | |
| **Mixed** | Loose assorted stones | | | | | | | | | | | |
| **Pool of water** | Rockpool | | | | | | | | | | | |

# APPENDIX 2: INTERNAL ASSESSMENT RESOURCE

Internal assessment resource Biology 2.6A for Achievement Standard 91158
PAGE FOR TEACHER USE

## Internal Assessment Resource

**Achievement Standard Biology 91158:** Investigate a pattern in an ecological community, with supervision

**Resource reference:** Biology 2.6

**Resource title:** Between the Tides

**Credits:** 4

## Teacher guidelines

The following guidelines are supplied to enable teachers to carry out valid and consistent assessment using this internal assessment resource.

Teachers need to be very familiar with the outcome being assessed by Achievement Standard Biology 91158. The Achievement Criteria and the Explanatory Notes (EN) contain information, definitions, and requirements that are crucial when interpreting the standard and assessing students against it.

### Context/setting

The emphasis in this standard is for the student to investigate a pattern (or its absence) in an ecological community with reference to an environmental factor and the biology of interrelated organisms of different species. Refer to EN 2.

Students will use their own field data and observations collected during their practical investigation work at a local rocky intertidal shore, as well as relevant resources and information they collect during their research. You can also provide resource materials (including tables, graphs, resource sheets, photographs, websites, videos and/or reference texts) as appropriate. Refer to EN 3 and 7.

Teachers can adapt the task (and assessment schedule) to suit an investigation of their local rocky shore. Students will use **a range of data, collected by themselves and others, or provided by the teacher**, in order to investigate the presence (or absence) of a zonation pattern in the rocky shore community. Information about at least two interrelated species should be included in their final report.

Internal assessment resource Biology 2.6A for Achievement Standard 91158
PAGE FOR TEACHER USE

## Conditions

2–3 weeks of in and out-of-class time may be required. This does not include time for prior teaching of ecological concepts (see below). The written assessment is to be completed individually over 2 – 3 periods in class.

The following ecological concepts should be taught prior to beginning the task:

- Environmental factors: abiotic, biotic and gradients
- The ecological niche
- Adaptations to exploit a niche: structural (morphological), physiological and behavioural
- Tolerance, limiting factors and Liebig's Law of the Minimum
- Interspecific relationships: competition, predation, mutualism, parasitism, herbivory, commensalism
- Gause's Principle of Competitive Exclusion
- Features of populations: distribution, density, growth and intraspecific competition
- Ecological zonation patterns in communities

## Resource requirements

Students will need access to the Internet, to allow them to investigate the relevant ecological concepts and to collect their own resources and information to use in their final report.

## Additional information

The setting used for this assessment resource is a local intertidal rocky shore.

The investigation is carried out with supervision (EN 8). This means that the teacher provides guidelines for the investigation such as the context for the investigation, instructions that specify the requirements and provides appropriate resources for students to comprehensively investigate a pattern in an ecological community.

Below are some references that could be useful:

Portobello Marine Life Database:
http://www.otago.ac.nz/marinestudies/database/newdatabase/index.html

New Zealand Rocky Shore Guide:
http://www.marine.ac.nz/resources

New Zealand Marine Studies Centre's Marine Metre Squared Seashore Survey biodiversity monitoring project
https://www.mm2.net.nz/

Conditions of Assessment related to this achievement standard can be found at
http://ncea.tki.org.nz/Resources-for-aligned-standards/Science/Biology/Level-2-Biology/Related-resources

Internal assessment resource for Achievement Standard 91158
PAGE FOR STUDENT USE

# Internal Assessment Resource

**Achievement Standard Biology 91158 version 1:**

Investigate a pattern in an ecological community, with supervision

Biology 2.6

**"Between the Tides"**

4 credits

| Achievement | Achievement with Merit | Achievement with Excellence |
|---|---|---|
| Investigate a pattern in an ecological community, with supervision. | Investigate in-depth a pattern in an ecological community, with supervision | Comprehensively investigate a pattern in an ecological community, with supervision. |

# Student instructions

## Introduction

This assessment activity requires you to produce a report about a pattern (or absence of a pattern) in an ecological community. You will investigate **zonation** in the intertidal rocky shore community at [*insert name of local shore here*]

This investigation involves **analysing** and **interpreting** information about this **community**, **an environmental factor** relating to a pattern and how this might affect **at least two species in the ecosystem**.

You will use **the field data and observations collected during your field work** and the **resource information** provided by your teacher.

**Part 1: Research.** You will have [*insert time here*] between [*insert date range here*] to carry out research into the intertidal community found at [*insert name of local shore here*], any relevant environmental factors that affect the community and to research rocky shore survey methods. During this time you can discuss ideas with other students.

**Part 2: Survey.** You will have [*insert time here*] on [*insert date here*] to carry out a survey of the intertidal rocky shore community at [*insert name of local shore here*] and collect your field data.

You may compare the field data you collected during your field work with the data from another group, and/or with historical data or data from different locations found on the The NZ Seashore Survey website (www.mm2.net.nz).

Internal assessment resource for Achievement Standard 91158
PAGE FOR STUDENT USE

## Task

## Part 1: Collecting and processing information

This task is not assessed, but it helps you prepare for writing your report. You can complete this work individually or as part of a group, and discuss your ideas and questions with other people, including your teacher.

You will use the method provided for you to collect information relevant to your investigation by carrying out research and gathering the field data you will need.

Look at the data about the distribution of different species on the shore at [*insert location here*] and use this information to choose at least two named organisms that are related to each other, and to the pattern you are investigating.

Make sure you have collected enough information to allow you to discuss:

- the biology of your two chosen species in terms of their
  - ecological niche
  - adaptations (you could consider: structural, behavioural and physiological adaptations) to occupy their niche in the intertidal zone
  - interrelationships and interactions with other organisms in the intertidal zone that might affect their distribution
- the environmental factors that could affect your organisms (biotic and abiotic)

You may also carry out research using any resources provided by your teacher or obtained from elsewhere. Record details of the information sources you use and include this in a bibliography at the end of your report.

You may organise and store your information (including field work data) in an online document such as a spread sheet or table, for easy access.

## Part 2: Written Report

You will complete your written report **individually** in class, over [*insert number here*] periods.

You will have access to your class notes, research information, field data and observations and any other resources you have collected to help you write your report.

Your report will be assessed on your discussion of the zonation pattern in your rocky shore community, by relating it to environmental factors (biotic and abiotic) and the biology (adaptations and interspecific relationships) of organisms of different species.

[*insert conditions for assessment here to ensure authenticity of the students' reports*]

Internal assessment resource for Achievement Standard 91158
PAGE FOR STUDENT USE

Your report should include:

1. **Introduction** – a brief description of your investigation's focus, including details of your chosen area(s) and the scientific names of the organisms investigated.
2. **Biology of the Ecological Community** – information about the organisms in the community you investigated. Describe the ecological niche and adaptations of at least two species, and relevant interrelationships between these organisms.
3. **Abiotic Environment** – description of the abiotic factors found in the area you investigated. You could include observations or measurements collected in fieldwork.
4. **The data you used to identify a distribution pattern** – this can either be compiled by you *e.g*. a graph or table, or it could be processed data from other sources. It needs to be included in the report and referenced if it is from another source, either as an appendix or in the body of the report.
5. **Description of Pattern** – describe the findings (and/or observations) from the fieldwork/collected data and use these to identify the distribution pattern (or absence of a pattern) in the ecological community. You could include tables or graphs in this section, to clearly show the distribution pattern.
6. **Discussion** – relate the pattern in the community to the biology of the organisms and to the environmental factors in the ecosystem. Include:
    a. explanations for how or why the biology (*i.e.* species' adaptations; interspecific relationships) of at least two species relates to the pattern (or absence of a pattern)
    b. a discussion of how environmental factors (abiotic and/or biotic) might affect the organisms in the community, and how this relates to the observed distribution pattern, or absence of a pattern. This could involve elaborating, applying, justifying, relating, evaluating, comparing and contrasting, and/or analysing.
7. **Bibliography** – a list of the information sources you used to help you write your report, written in a format that allows other people to find the information sources. This will not be assessed, but it is expected good practice to acknowledge information sources you used in your work.

# APPENDIX 3: GLOSSARY

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| **Abiotic** | Related to the non-living or physical part of an organism's environment. |
| **Abundance** | A measurement of the number of organisms or population size. |
| **Accuracy** | A measurement being close to the true or actual value. |
| **Benthic** | Living on the seafloor surface. |
| **Biased** | Non-random, intentionally chosen or selected samples that are not representative of the entire population. |
| **Biotic** | Directly related to the living part of an organism's environment. |
| **Chart datum** | Reference depth of the seafloor on a chart of the lowest tide *e.g.* $3_4$ = 3.4 m depth is usually the shallowest reached. $\underline{0}_4$ = 0.4 m height above. |
| **Community** | All the populations of different species living and interacting together in a particular area or habitat. |
| **Density** | The number of organisms in a given area *e.g.* the number of limpets per one square metre of shore, (limpets/$m^2$). |
| **Desiccation** | Loss of water; drying out; dehydration. |
| **Detritivore** | An organism that feeds on dead plant or animal matter (detritus). |
| **Distribution** | Where and how a population is placed in its habitat. |
| **Ecological niche** | The position that an organism is adapted to exploit in its environment, as described by the its feeding, habitat and activity patterns. |
| **Ecology** | A branch of biology which studies the interactions between organisms and their environment. |
| **Epiphytes** | Plants attached to and growing on the surface of other organisms. |
| **Frequency** | A type of data based on the count or number within a data class *e.g.* the number of limpets in a quadrat sample. |

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| **Fundamental niche** | The ecological niche can potentially occupy in the absence of interspecific competition. |
| **Gause's Principle** | No two species can occupy the same ecological niche indefinitely; the better adapted species will eventually outcompete and exclude the other. |
| **Geotaxis** | Moving towards (positive) or away from (negative) the pull of Earth's gravity. |
| **Gradient** | A steadily changing environmental factor between two points. |
| **Habitat** | The specific place where a population lives. |
| **Interspecific competition** | Competition for resources between different species whose niches overlap. |
| **Intertidal** | A region of the shore between the high (MHWS) and low tide (MLWS) that experiences regular periods of submergence and aerial exposure. |
| **Intraspecific competition** | Competition for resources and mates between members of a population (of the same species). |
| **Limiting factor** | An environmental factor that limits the distribution of an organism. |
| **Macroalgae** | Large seaweeds. |
| **Motile** | Organisms that can move themselves (rather than just be moved: mobile). |
| **Neap tide** | Tide with a low range that occurs every 14 days with the crescent moons. |
| **Osmoregulation** | The physiological process of maintaining a steady body water content. |
| **Parameter** | A measurable feature of something. |
| **Percentage cover** | The proportion of a 2D area covered by something, expressed as % area. |
| **Permeable** | A surface that allows a substance to pass through. |
| **Perpendicular** | Intersecting at right-angles (90˚) to. |

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| **Perigee** | Period when the moon is at its closest point to the Earth and therefore has its greatest tidal effect. |
| **Photoautotrophic** | Ability of an organism to make its own food from light and nutrients. |
| **Photosynthesis** | The process of making food from light and nutrients. |
| **Phototaxis** | Moving towards (positive) or away from (negative) a light source. |
| **Physiology** | Body functions or processes in living organisms. |
| **Phytoplankton** | 'Plant' plankton that drifts in the well-lit surface waters of aquatic environments (*phyto*- = plant; *plankton* = drifting organism) |
| **Planform** | The view from directly above. |
| **Population** | A group of organisms of one species living and breeding in the same specific area. |
| **Precision** | A measurement being close to other measurements. |
| **Prey refuge** | An adaptation that reduces the risk of predation *e.g.* due to activity period (time) habitat (space) or physical size. |
| **Quadrat** | A four sided counting frame to sample species abundance |
| **Randomise** | Remove bias by making sure there is no observable pattern or trend. |
| **Realised niche** | The actual ecological niche an organism occupies due to the constraining effects of interspecific competition |
| **Reliable** | Accurate and precise results; trustworthy; highly confident of. |
| **Representative** | Shows the full range of features of a population. |
| **Respiration** | Biochemical cellular process that transfers energy from nutrients to ATP. |
| **Sample** | A measurement of a parameter from within a larger statistical population. |

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| **Sessile** | Stationary; still; non-mobile; permanently attached to a surface. |
| **Species** | A group of similar organisms able to reproduce successfully in nature. |
| **Splash zone** | A region of the shore above the intertidal zone that is frequently wetted by waves but not rarely submerged during a tidal cycle. |
| **Spring tide** | Tide with a large range that occurs every 14 days at full and new moon. |
| **Statistical population** | Any group of individuals from which a statistical sample is taken. |
| **Statistics** | Calculated quantitative descriptions of different population parameters *e.g.* mean, median, mode, range, standard deviation, confidence limits. |
| **Subsample** | A smaller sample taken from inside a larger one. |
| **Substrate** | The surface to which organisms can attach. |
| **Subtidal** | Region of the shore below the intertidal zone that is rarely exposed to air during low tides. |
| **Survey** | Investigating a statistical populations' features by looking at representative samples (*cf.* **census**: measurement of all individuals). |
| **Systematically** | Methodically; step by step. |
| **Tolerance** | The ability to withstand and survive an environmental factor within some **tolerance range** for that factor |
| **Transect** | A straight line, imaginary or real, cutting across an environment. |
| **Valid** | Correct or appropriate for the context being studied. |
| **Variable** | Any parameter whose value can change. |
| **Zonation** | The occurrence of different species or communities in discrete bands (zones), perpendicular to an environmental gradient. |
| **Zooplankton** | Animals that drift with the currents in aquatic environments (*Zoo*- = animal). |

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