9693 AS Marine Science

Teacher Support

Contents

Introduction

The GCE Advanced Subsidiary Level and Advanced Level in Marine Science syllabus includes a scientific study of the sea and its ecosystems and how human activities have an impact on the marine environment.

This booklet has been written specifically to assist teachers in the interpretation and application of the syllabus, with references to both the theory and practical content. It is expected that practical work will underpin and illustrate the theory content of the whole syllabus and will include both laboratory-based activities and field trips.

The syllabus, together with sample assessment materials, mark schemes and other resources can be found on the Cambridge International Examinations website http://www.cie.org.uk/ to which reference should be made.

The aims of this booklet are to provide:

- guidance on the teaching of the theory content by including definitions of terms used in the syllabus and a fuller explanation of the learning outcomes.
- suggestions for practical activities and outline methods for the more complex activities.
- references to sources of further information, including web based and reference books.

Each of the subject content sections of the syllabus includes a number of learning outcomes. In this booklet, each learning outcome, (a), (b), (c), etc., is followed by an explanatory note to amplify the learning outcome.

For further information and details of each learning outcome, please refer to the resources listed at the end of each syllabus section.

1 Scientific method

The relationship between hypothesis, experiment and theory in science.

Uncertainty in experimental results.

It is expected that most of the learning outcomes in this syllabus section will be achieved by candidates carrying out practical activities. It should be noted that although there is no separate assessment of practical work, candidates may be asked about practical activities in any of the examination papers.

Candidates should therefore be able to design experiments, with references to the control of variables and collection of quantitative data; interpret experimental data to determine whether or not they support or refute the hypothesis; formulate a hypothesis on the basis of experimental data and explain how inherent variations and limitations in the measurement of experimental data lead to uncertainly in the results.

(a) *Describe how scientific method involves interplay between observations and the formation, testing and evaluation of hypotheses*.

The principle of scientific method is based on the collection of data by observation and experimentation and the formulation of hypotheses. The hypotheses may be subsequently refined on the basis of the observations. Scientific research involves proposing hypotheses to explain observed phenomena, then designing and carrying out experiments to test the hypotheses.

(b) *Design experiments to test a given hypothesis, in which variables are controlled and quantitative results are collected*.

Candidates should be able to apply their knowledge of practical techniques to design experiments. As an example, to design an experiment to test the hypothesis that the rate of photosynthesis of an aquatic plant increases as light intensity increases. In this example, it is important to recognise that light intensity is the key variable and others, including temperature and the wavelength of light are the control variables. The effect of control variables should be eliminated by careful experimental design if valid results are to be obtained.

The nature of the results obtained depends on the actual investigation, but could include measurements of volume, time, length, mass or temperature, with appropriate SI units. If a rate is measured, this should be expressed in relation to time.

(c) *Interpret experimental data to determine whether they support or refute the hypothesis being tested*.

Candidates should be able to recognise trends in data presented in the forms of tables or in graphical form. For example, they should be able to recognise whether or not there is a relationship between two variables and to comment on this in the context of a stated hypothesis. Candidates will not be expected to use a statistical test to support a hypothesis.

(d) *Formulate a hypothesis on the basis of experimental data*.

With reference to experimental data, candidates should be able to state an operational hypothesis. For example, a table of data might suggest that, as the concentration of nitrate ions increases, the growth of algae also increases. From the data, candidates could suggest the hypothesis that 'there is a positive relationship between the concentration of nitrate ions and the growth of algae'.

(e) *Explain how inherent variations and limitations in the measurement of experimental data lead to uncertainty in the results*.

Candidates should recognise the relationship between variability of experimental data and the validity of any conclusions drawn. Candidates should also be able to comment on how variability and accuracy may influence the validity of conclusions drawn from experimental data.

(f) *Demonstrate an understanding that a hypothesis that is consistently supported by experimental testing can become a theory*.

A hypothesis is a proposed explanation for an observed phenomenon, which can then be rigorously tested using scientific method. A hypothesis may be regarded as a prediction; if this is supported by experiments that confirm the hypothesis, the hypothesis may be put forward as a theory.

(g) *Explain the meaning of the term* theory *with reference to examples from the Subject Content*.

A scientific theory is supported by a number of testable statements and is used as a general principle to explain a phenomenon. Scientific theories are intended to be accurate, predictive models of the natural world. Examples in the syllabus include the Darwin-Dana-Daly theory of atoll formation and the theory of plate tectonics.

(h) *Use the knowledge and understanding gained in this section in new situations or to solve related problems*.

Questions on any of the papers may expect candidates to be able to apply their knowledge and understanding of the syllabus content to new and possibly unfamiliar contexts.

Scientific method

References

CaCarey S *A Beginner's Guide To Scientific Method* (4th edition 2011) Wadsworth PuPublishing Co Inc ISBN-10 1111726019

http://en.wikipedia.org/wiki/Scientific_method

(An introduction to scientific method)

http://www.columbia.edu/cu/physics/pdf-files/Lab_1-01.pdf

(Uncertainty in experimental results)

http://www.wpi.edu/Academics/Depts/Chemistry/Courses/General/uncertainty.html

(Uncertainty, precision and error in experimental results)

2 Marine ecosystems and biodiversity

The relationships between organisms within ecosystems.

Predator-prey relationships.

The connection between environment, biodiversity and ecological niches.

(a) *Explain the meaning of the terms* ecosystem, habitat, population, community, species, biodiversity, ecological niche.

The term *ecosystem* refers to living organisms and the physical and chemical factors which influence them. In other words, it includes both biotic and abiotic components. A rocky shore could be considered as an ecosystem, including the organisms living there, linked together by flows of energy forming a food web, and their environment. A *habitat* is the place where organisms live; for example, the area surrounding a hydrothermal vent provides a habitat for species of tube worms and other specialised organisms.

A *population* consists of organisms of the same species, usually defined as living in the same area. For example, a population of ghost crabs (*Ocypode saratan*) living on a sandy shore. A *community* includes all the different species living in a habitat at the same time. We might refer to, for example, the mollusc community on a rocky shore, which would include all the different species of molluscs living in this habitat.

A *species* is defined as a group of similar organisms that can interbreed and produce fertile offspring. Examples of species include the skipjack tuna (*Katsuwonus pelamis*) and red mangrove trees (*Rhizophora mangle*). Notice that in the binomial system of nomenclature, each species is given a name consisting of two parts. The first, known as the generic name, refers to the genus and the second, known as the specific name, refers to the species.

Biodiversity takes into account the numbers of different species present and the range of habitats and ecosystems. Coral reefs, for example, have a high biodiversity with many different species present, whereas a sandy shore has a low biodiversity as there are relatively few different species in this habitat.

Ecological niche is sometimes defined as the role of an organism within an ecosystem, taking into account its relationships with other organisms. In a marine ecosystem, the niche of a great white shark is the top predator. Organisms which occupy similar niches will tend to compete with each other for resources, such as food and space to live in their habitat.

Practical work could include the use of a quadrat to investigate the diversity of organisms in a suitable habitat, for example on a rocky shore or on a sandy shore.

(b) *Describe each of the following types of interrelationship within a marine ecosystem*:
- *symbiosis*
- *parasitism*

The term *symbiosis* refers to a relationship between two different organisms, where both derive some benefit from the relationship. Examples of symbiosis include corals and zooxanthellae, cleaner fish and grouper, and chemosynthetic bacteria and tube worms.

Parasitism is a relationship between two organisms where one, the parasite, obtains benefit at the expense of the other, known as the host, which is usually harmed by the relationship. Parasites obtain their nutrients from their host. Parasites can be divided into two main groups, called ectoparasites and endoparasites. Ecotoparasites, for example fish lice, live on the outside of their host. Endoparasites live inside their host, for example, inside the digestive system, attached to their gills, or within muscle tissue. Nematodes, also known as roundworms, are common endoparasites in fish.

(c) *Explain the meaning of the terms* producer, consumer, predator, prey *and* trophic level *within the context of food chains and food webs.*

Green plants, algae and some types of bacteria are referred to as *producers* as they are able to synthesise organic substances from simple organic compounds, using light energy from the Sun, in the process of photosynthesis. Producers provide food for virtually all other organisms in food chains and food webs. The term *consumer* refers to an organism that obtains its energy requirements by feeding on other organisms. Primary consumers (also known as herbivores) feed on plant material; secondary consumers (or carnivores) feed on herbivores. There may also be tertiary consumers, feeding on the secondary consumers, in a food chain. A food chain shows the sequence of organisms feeding on other organisms; a series of interlinked food chains forms a food web.

Chemosynthetic bacteria, such as those found associated with hydrothermal vents, are able to produce organic substances by oxidising hydrogen sulphide. In a hydrothermal vent community, these chemosynthetic bacteria are the producers that provide food for other organisms in this community.

A *predator* is an animal that catches, kills and eats another animal. Predators are usually secondary consumers in food chains and include carnivorous fish. The term *trophic level* refers to 'feeding levels' in a food chain, or a food web. Producers occupy the first trophic level, primary consumers occupy the second trophic level and secondary consumers occupy the third trophic level. This is shown in the diagram below.

Producer → Primary consumer → Secondary consumer

First trophic level → Second trophic level → Third trophic level

Note that in food chains and food webs, the arrows represent the direction in which energy and biomass are transferred.

(d) *Explain how populations of predator and prey may be interrelated.*

The availability of food is a major factor which will affect the numbers of predators in an ecosystem. If the availability of food (e.g. the numbers of prey organisms) increases, the numbers of predators may correspondingly increase. The converse is also true, as the numbers of prey organisms decrease, this will be followed by a decrease in the numbers of predators. The numbers of prey organisms and predators show a series of fluctuations, where the numbers of predators lags behind the numbers of prey organisms. This is illustrated in Figure 2.1, showing a typical 'predator-prey relationship' between hares (herbivorous mammals) and lynx (a large predatory cat).

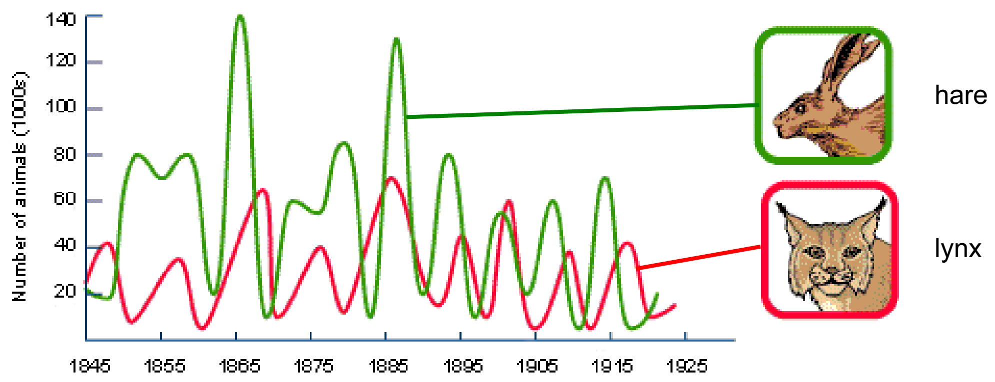

Figure 2.1 A typical predator-prey relationship
(http://www.bbc.co.uk/schools/gcsebitesize/science/images/bilynxandhare.gif)

Similar relationships exist in marine ecosystems, for example, between mussels and predatory starfish.

(e) *Describe shoaling and explain why shoaling may be a successful strategy for feeding, reproduction and predator avoidance, with reference to tuna and sardines*.

A shoal of fish consists of large numbers of fish of the same species and approximately the same size. When a shoal of fish is swimming in a coordinated way, it is sometime referred to as a 'school'. The formation of a shoal has a number of advantages to the fish, including:

- increased hydrodynamic efficiency – fish may save energy by swimming together in a coordinated way
- avoidance of predation – large shoals of fish may confuse a predator; also, with so many eyes, it is more likely that a predator will be seen
- increased foraging efficiency – the time taken to find food is decreased
- reproductive advantage – there is an increased chance of finding a mate within a shoal than there is for an individual fish

Both tuna and sardines form shoals. When threatened by predators, sardines can form massive 'bait balls' consisting of many hundreds of thousand individuals. The skipjack tuna, *Katsuwonus pelamis,* also forms large shoals of up to 50 000 individuals.

(f) *Explain the meaning of the term* succession *and describe examples, including the tube worms* Tevnia *and* Riftia.

The term *succession* refers to the gradual process of change that occurs in community structure over a period of time. This can be illustrated by the change which occurs in abandoned grassland. After a period of time, shrubby perennial plants become established and these are eventually replaced by tree seedlings, giving rise to woodland. As the plant communities change, there are corresponding changes in the animal communities associated with them.

Succession also occurs around hydrothermal vents in the deep oceans. The first organisms to grow around a vent are bacteria, which are followed by small crustaceans, molluscs, crabs and fish. Eventually, a complex community consisting of many different species is established. One of the first animal species to inhabit the area around a hydrothermal vent is the tube worm *Tevnia*. This species is replaced by the larger and faster growing tube worm *Riftia*. Tube worms form symbiotic relationships with chemosynthetic bacteria, which provide organic substances directly to the tissues of the tube worms.

(g) *Understand why extreme and unstable environments tend to have relatively low biodiversity, giving examples including coral reefs* (*stable and not extreme*), *sand on a reef slope* (*unstable*) *and hydrothermal vents (extreme).*

In general, environments that are unstable or extreme tend to have a low biodiversity. Sand, for example, easily dries out and is easily eroded by wind and water currents. Some organisms are able to survive by burrowing into sand. The water surrounding hydrothermal vents is under very high pressure and at a high temperature; relatively few organisms are adapted to survive in these conditions. Coral reefs provide a stable and favourable environment for many different organisms and have a correspondingly high biodiversity.

(h) *Give examples of organisms that occupy specialised and generalised niches, including coral-eating butterfly fish and tuna*.

Niche can be defined as the role of an organism in an ecosystem. Organisms with a specialised niche have a narrow range of food requirements or live in a specific habitat, whereas those with a generalised niche can exploit a wider range of food sources and live in a wider range of habitats. Most species of butterfly fish feed on corals and sea anemones. Many species are also territorial and live closely associated with a specific area of coral. Tuna feed on a range of different species of fish, as well as squid and crustacean. Tuna are also highly migratory fish, Bluefin Tuna, for example, are widely distributed in the Atlantic Ocean.

(i) *Explain why habitats with high biodiversity tend to contain narrow ecological niches*.

High biodiversity means that many different species live within one ecosystem. Each species of organism has its own niche within the ecosystem; if niches overlap, one species will die out as a result of interspecific competition. Narrow niches tend to reduce the extent of overlap and therefore reduce interspecific competition. Coral reefs have a high biodiversity and include many species with narrow niches, including fish exploiting a variety of different food sources such as corals, seaweeds, and small animals living in the coral.

(j) *Use the knowledge and understanding gained in this section in new situations or to solve related problems*.

Questions on any of the papers may expect candidates to be able to apply their knowledge and understanding of the syllabus content to new and possibly unfamiliar contexts.

Marine ecosystems and biodiversity

References

Barnes RSK and RN Hughes *An Introduction to Marine Ecology* (3rd edition 1999) Blackwell ISBN 978 0 86542 834 8

Chapman JL and MJ Reiss *Ecology Principles and Applications* (2nd edition 1999) Cambridge University Press ISBN 0 521 58802 2

Chenn P *Ecology* (1999) John Murray ISBN 0 7195 7510 9

Tait RV and FA Dipper Elements of Marine Ecology (4th edition 1998) Butterworth Heinemann ISBN 0 750 62088 9

http://www.botos.com/marine/vents01.html
(Hydrothermal Vent Communities)

3 Energetics of marine ecosystems

Photosynthesis and chemosynthesis as means of energy capture.

Productivity and energy flow along food chains.

(a) *Explain that photosynthesis captures the energy of sunlight and makes the energy available to the food chain*.

Green plants, including phytoplankton in aquatic food chains, capture light energy and use this to synthesise organic substances, including carbohydrates, in the process of *photosynthesis*. In this way, energy is made available to higher trophic levels in food chains and food webs. Energy, in the form of organic substances, passes to the primary consumers, such as herbivorous zooplankton.

Practical work could include the measurement of light penetration using a Secchi disc (Figure 3.1). *Commercially produced Secchi discs are available, but they can easily be constructed from a round tin-lid, for example, painted with alternate black and white sectors. The disc is attached to a length of string, with knots every 50 cm. The disc is lowered into the water until it is no longer visible and the depth recorded. The disc is then slowly raised until it reappears and this depth recorded. The mean of these two depths gives a measure of the transparency of the water. Candidates could measure water transparency at different times of the year and account for any differences.*

Figure 3.1 A Secchi disc
(http://dipin.kent.edu/images/Secchi%20Disk.jpg)

(b) *Explain that chemosynthesis captures the chemical energy of dissolved minerals, and that chemosynthetic bacteria at hydrothermal vents make energy available to the food chain*.

There is no light for photosynthesis in the deep ocean. Some species of bacteria are able to derive energy from the oxidation of inorganic substances, such as hydrogen sulphide, and use this energy to synthesise organic compounds. This process is called *chemosynthesis*. Fluid emerging from hydrothermal vents is rich in hydrogen sulphide and other gases. Chemosynthetic bacteria oxidise hydrogen sulphide and are able to fix carbon dioxide to form organic substances. These organic substances provide a food source for all other animals in the hydrothermal vent ecosystem. It is interesting to note that these chemosynthetic bacteria form symbiotic relationships with tube worms and giant clams.

(c) *Explain the meaning of the term* productivity *and how productivity may influence the food chain*.

In ecology, the term *productivity* means the rate of production of biomass. In almost all ecosystems, green plants are the primary producers and we usually refer to primary production in relation to plants. Productivity is often measured in terms of energy capture per unit area (or per unit volume in the case of aquatic ecosystems) per year. Since consumers depend directly or indirectly on the energy captured by primary producers, the productivity of an ecosystem affects all trophic levels. When conditions are favourable for photosynthesis, the productivity of the ecosystem tends to be relatively high, such as in tropical rain forests, algal beds and reefs.

(d) *Calculate and explain the energy losses along food chains due to respiration and wastage*.

Of the total energy reaching the Earth from the Sun, only a very small percentage is captured and used for the synthesis of organic substances by primary producers. Light energy is reflected by surfaces, or may pass straight through a producer without being absorbed. Energy loss also occurs thorough inefficiencies of photosynthesis. Candidates may be asked, for example, to calculate the percentage of incident light energy which appears as energy of newly synthesised organic substances. The total energy captured by primary producers is referred to as the gross primary production (GPP). Some of the organic substances will be used by the producers as substrates for respiration. This represents a loss of energy. The remaining organic substances, referred to as the net primary production (NPP), represent an energy source which can be transferred to higher trophic levels. We can represent this in the form of an equation:

$$NPP = GPP - R$$

where NPP is the net primary production; GPP is the gross primary production and R represents energy losses through respiration.

Approximately 10% of the energy available at one trophic level is transferred to the next trophic level. Reasons for wastage include that facts that not all of one organism may be eaten by another; there are also losses in excretion and egestion. Substrates are used for respiration to provide energy for movement and consequently energy is lost in the form of heat. This is illustrated in Figure 3.2.

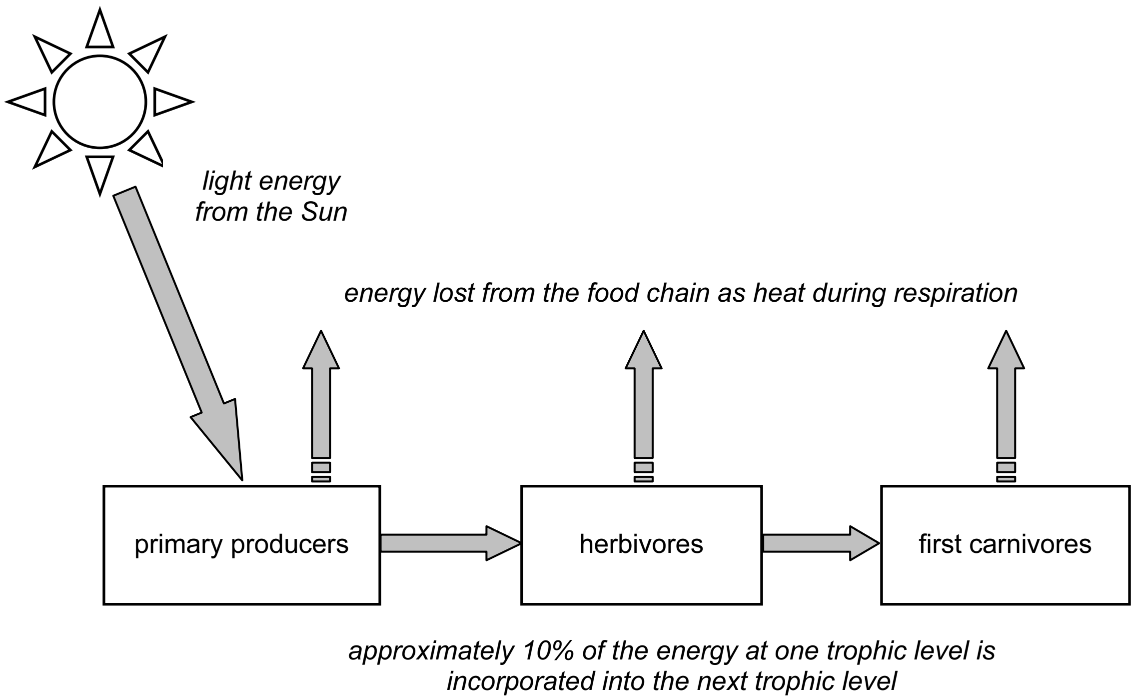

Figure 3.2 Flow of energy in a food chain

(e) *Calculate and account for the efficiency of energy transfer between trophic levels*.

Suppose that the net productivity of plants in a food chain is 36 000 kJ per m^2 per year and that the net production of herbivores is 1 700 kJ per m^2 per year. The efficiency of transfer of energy from the producers to the herbivores is therefore (1 700 ÷ 36 000) × 100 = 4.72%.

Energy losses from the energy consumed by the herbivore include heat from respiration, losses in urine and undigested plant material in faeces. The energy of production of herbivores represents the total energy available to carnivores, the next trophic level.

(f) *Represent food chains as pyramids of energy, numbers and biomass*.

Ecological pyramids are a way of representing food chains graphically. An ecological pyramid has the producers at the base, then a series of horizontal bars representing the successive trophic levels. In each case, the width of the bar is proportional to the numbers, biomass, or energy.

It is possible to have inverted pyramids of numbers and biomass, but pyramids of energy are always the 'right way up' because it is impossible to have more energy in a higher trophic level than in a lower trophic level. Figure 3.3 shows a typical pyramid of energy.

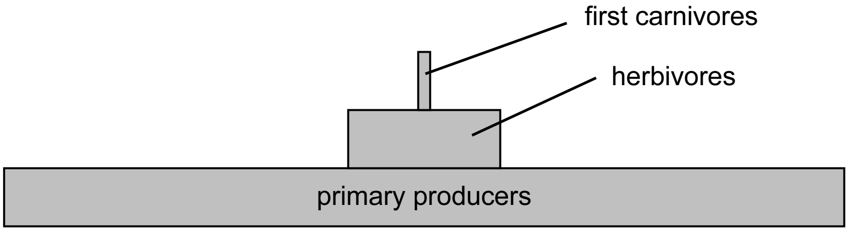

Figure 3.3 A pyramid of energy shows the energy content at each trophic level

(g) *Use the knowledge and understanding gained in this section in new situations or to solve related problems*.

Questions on any of the papers may expect candidates to be able to apply their knowledge and understanding of the syllabus content to new and possibly unfamiliar contexts.

Energetics of marine ecosystems

References

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Tait RV and FA Dipper Elements of Marine Ecology (4th edition 1998) Butterworth Heinemann ISBN 0 750 62088 9

Chapman JL and MJ Reiss *Ecology Principles and Applications* (2nd edition 1999) Cambridge University Press ISBN 0 521 58802 2

(useful as a general reference source for principles of ecology, including energy flow in ecosystems)

http://www.noc.soton.ac.uk/o4s/exp/001_secchi.php

(How to make and use a Secchi disc)

4 Nutrient cycles in marine ecosystems

Inputs and outputs to the reservoir of dissolved nutrients.

The biological uses of nutrients.

Nutrient availability and productivity.

(a) *Demonstrate an understanding that there is a reservoir of nutrients dissolved in the surface layer of the ocean*.

Algae require light for photosynthesis. Light intensity decreases as the depth of the ocean increases and therefore photosynthesis is restricted to a surface layer in which there is sufficient light. This layer (referred to as the 'photic zone') varies in depth from about 30 m to 150 m, although it is considerably less is turbid water. The surface layer of the ocean contains many different ions, some of which are shown in Table 4.1.

Ion	Mean concentration in seawater (parts per thousand)
Chloride	19.345
Sodium	10.752
Sulphate	2.701
Magnesium	1.295
Calcium	0.416
Hydrogencarbonate	0.145

Table 4.1 Concentrations of major ions in typical sea water

These ions, together with nitrate and phosphate ions, form a reservoir of nutrients for the growth of algae and other primary producers. Nitrate and phosphate ions occur at low concentrations in sea water; the mean concentration of nitrate is 0.5 parts per million (ppm) and the mean concentration of phosphate in seawater is 0.07 ppm.

(b) *Explain the processes by which the reservoir of dissolved nutrients is replenished, including upwelling, runoff from the land and dissolving of atmospheric gases*.

Upwelling is the movement of water from deep in the ocean to the surface layer, where the nutrients become available to primary producers. Upwelling is brought about by several processes including the deflection of deep water currents upwards and the movement of water away from a coast by the action of wind. Run-off from the land is part of the hydrological cycle and the water may leach nutrients, including nitrates and phosphates, from the soil. Carbon dioxide in the atmosphere dissolves in seawater forming hydrogencarbonate ions (HCO_3^-), making carbon dioxide available for fixation in the process of photosynthesis, by primary producers.

Atmospheric nitrogen gas is fixed by blue-green algae in Intertidal zones, resulting in the formation of nitrogen-containing organic compounds. In this way, nitrogen can enter marine ecosystems.

Some nutrients, including nitrates and phosphates are also recycled in the surface layer of the ocean as a result of excretion from zooplankton.

(c) *Demonstrate an understanding that the reservoir of dissolved nutrients is depleted by uptake into organisms in food chains*.

One of the ways in which nutrients are removed from the surface waters of an ocean is by their uptake by primary producers, such as phytoplankton, and their use for the synthesis of organic substances. As an example, nitrate ions are used in the synthesis of amino acids and proteins. If the phytoplankton is eaten by zooplankton, the proteins will pass to the next trophic level.

Zooplankton may subsequently be eaten by small fish and, in this way, nutrients are passed along a food chain.

(d) *Explain how productivity may be limited by the availability of dissolved nutrients*.

Inorganic nutrients, such as nitrate ions and phosphate ions are essential for the growth of primary producers. Since consumers depend on these primary producers for food, either directly on indirectly in food chains, the productivity of the primary producers will influence the productivity of higher trophic levels. In water where the nutrient levels are high, for example as a result of upwelling, the productivity is correspondingly high. One of the most productive ecosystems is the Benguela upwelling system, off the west coast of southern Africa.

(e) *Demonstrate an understanding that the nutrients taken up by organisms in food chains may sink to the sea floor in faeces or after death, may be incorporated into coral reefs, or may be removed by harvesting*.

Detritus (decaying organic materials), faeces and dead organisms may gradually sink to the sea floor. This represents a loss of nutrients from the surface water. In deep water, these nutrients will tend to remain on the ocean floor, unless returned to surface waters by upwelling. The growth of corals involves the deposition of calcium carbonate; this represents another way in which nutrients may be removed from water. Finally, harvesting fish and other marine organisms, also results in the loss of nutrients from marine ecosystems.

(f) *Show that each of the nutrient cycles listed below can be summarised as shown in Figure 4.1, and state the biological use of each nutrient*.

- nitrogen, which is used to make proteins;
- carbon, which is used to make all organic materials;
- magnesium, which is used to make chlorophyll;
- calcium, which is used to make bones, corals and shells;
- phosphorus, which is used to make DNA and bones.

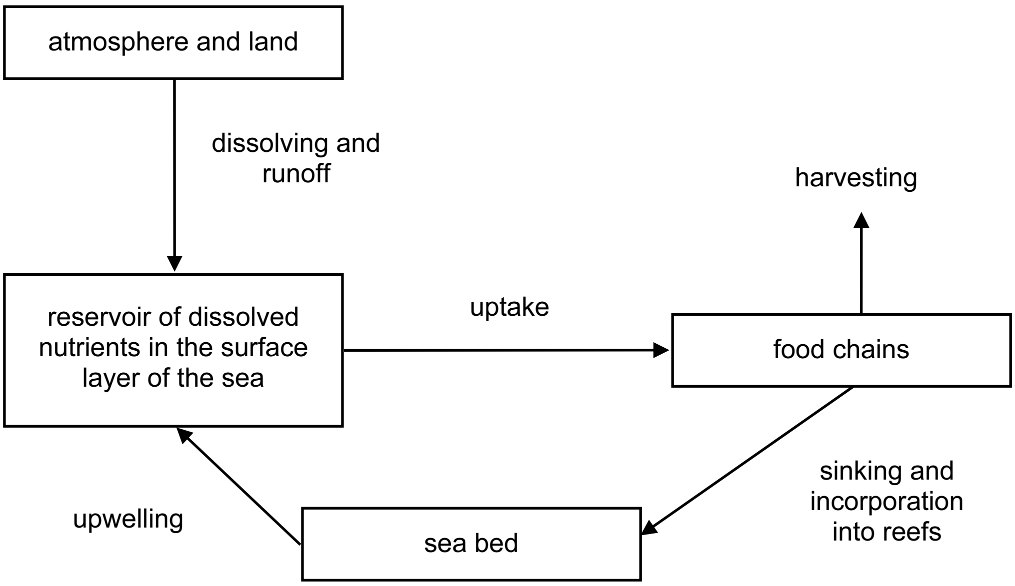

Figure 4.1

Figure 4.1 summarises the ways in nutrients are cycled in marine ecosystems. Nutrients may be derived from both land and the atmosphere, forming a reservoir in the surface layer of the sea. From here, nutrients are taken up by living organisms and incorporated into food chains. Nutrients may be removed by harvesting, sinking to the sea bed, or incorporation into coral reefs. Nutrients from the sea bed may be returned to the surface layer of the sea by the process of upwelling.

Some of biological uses of nutrients are summarised in Table 4.2.

Nutrients	Biological uses
Nitrogen	Synthesis of amino acids and proteins
Carbon	Synthesis of all organic compounds, such as carbohydrates and proteins
Magnesium	Plants require magnesium for the synthesis of chlorophyll
Calcium	Required for the production of bone, coral and shells
Phosphorus	Required for the production of bone and the synthesis of DNA

Table 4.2 Biological uses of nutrients in sea water

(g) *Use the knowledge and understanding gained in this section in new situations or to solve related problems.*

Questions on any of the papers may expect candidates to be able to apply their knowledge and understanding of the syllabus content to new and possibly unfamiliar contexts.

Nutrient cycles in marine ecosystems

References

Barnes RSK and RN Hughes *An Introduction to Marine Ecology* (3rd edition 1999) Blackwell ISBN 978 0 86542 834 8

Tait RV and FA Dipper Elements of Marine Ecology (4th edition 1998) Butterworth Heinemann ISBN 0 750 62088 9

Chapman JL and MJ Reiss *Ecology Principles and Applications* (2nd edition 1999) Cambridge University Press ISBN 0 521 58802 2

http://www.seafriends.org.nz/oceano/seawater.htm#composition

(Details of the composition of seawater)

http://www.marinebio.net/marinescience/02ocean/swcomposition.htm

(Details of the composition of seawater)

5 Coral reefs and lagoons

The Darwin-Dana-Daly theory of atoll formation.

The protective role of reefs and the causes and effects of reef erosion.

Reconstructing the history of reefs.

(a) *Demonstrate an understanding of the Darwin-Dana-Daly theory of atoll formation, and the evidence supporting the theory.*

The theory of formation of coral atolls was first proposed by Charles Darwin following his observations during the voyage of HMS Beagle between November 1835 and April 1836. Darwin's theory was subsequently supported and modified by two geologists, James Daly and Reginald Dana.

The **Darwin-Dana-Daly theory of coral atoll** formation can be summarised as follows:

1 An oceanic volcano, which emerges from the sea surface and forms an island, becomes colonised by reef building corals.

2 This growth of corals begins to form a fringing reef around the island. The island begins to sink slowly. Coral growth continues.

3 The island continues to sink and a barrier reef is formed with a lagoon between the reef and the island.

4 Eventually, the island disappears below the sea surface, leaving an atoll consisting of a ring of small islands with a relatively shallow lagoon in the centre.

Evidence supporting this theory includes data from deep drilling on coral atolls, for example Bikini Atoll in the Pacific Ocean. The data showed that as the depth of the corals increased, the age of the corals also increased and fossil corals from the base of the drilling were dated to approximately 50 million years old. The corals were found to have grown on underlying volcanic rock. Fossil corals were found at depths of about 1200 meters. Since these corals grow only in shallow water, this provides evidence for the gradual sinking of the volcanic island.

(b) *Relate the Darwin-Dana-Daly theory to the physiology of coral*.

In 1842, Charles Darwin produced the first map showing the distribution of corals throughout the world. Darwin also distinguished the three main types of coral reefs: fringing barrier reefs, barrier reefs and atolls.

The distribution of corals can be explained in terms of the conditions required for the growth of corals, including a suitable temperature range, water clarity, salinity, and a suitable rock substrate. The continuous vertical growth of corals, over many thousands of years, occurs if the sea bed subsides, or there is a rise in sea levels.

The conditions required for the growth of the majority of corals can be summarised as follows.

A temperature range between about 16 and 35 °C, with optimum temperatures between 23 and 25 °C.

Clear water without silt. Silt reduces light penetration which will inhibit the photosynthesis of the symbiotic algae (zooxanthellae) in coral tissues.

A suitable depth. Rapid growth of corals usually occurs within 20 m from the sea surface. In deep water, there is insufficient light for photosynthesis of symbiotic algae.

A suitable substrate for attachment, including the basaltic rocks of undersea mountains.

(c) *Discuss the role of reefs in dissipating the energy of waves, and in providing protection for shores and anchorages*.

Coral reefs absorb the energy of waves and so protect the shoreline from erosion. This provides a number of benefits including protection of coastal properties, protection of ecosystems and reducing the cost of providing breakwaters. Reduced wave action also provides safer anchorage for boats. Overall, these benefits have a significant economic advantage.

(d) *Discuss the factors than can lead to a transition from reef growth to reef erosion*.

Healthy coral reefs accumulate calcium carbonate at rates between about 3 to 15 m per 1000 years. However, there are several factors which result in reef erosion. These factors include predation, storm damage and exposure to the air. One example of a coral predator is the crown-of-thorns starfish (*Acanthaster planci*) on certain Indo-Pacific reefs. Exceptionally low tides can result in corals being exposed to the air, and corals being dried or overheated. Storm damage, from hurricanes or tropical storms, can have a significant adverse effect on coral reefs. The damage is due to physical breakage of corals, and the scouring effect of abrasive sediments. Hurricane Hattie (1961), for example, destroyed a stretch of 43 km of the barrier reef of British Honduras. It has been estimated that complete recovery will take between 25 to 100 years.

(e) *Discuss the impact of reef erosion, and the use of artificial reefs, on the protection of shores and anchorages*.

Reef erosion leads to shores and coastal properties being more exposed to the damaging effects of waves. Many different materials are used to construct **artificial reefs**, including concrete or stone blocks, large sacks filled with sand and even sunken ships (notably the USS Oriskany, sunk in 2006).

Artificial reefs become colonised by a wide range of organisms, including algae, corals and numerous species of fish.

Artificial reefs function as a submerged breakwater, they dissipate wave energy, reducing coastal erosion and protecting anchored boats.

(f) *Describe the methods used for reconstructing the history of reefs, including drilling, geomorphologic analysis and carbon dating*.

The term **geomorphology** refers to the study of landforms and the processes involved in shaping them. When applied to coral reefs, this refers to the three main categories of reef, fringing reefs, barrier reefs and atolls. The growth and geological history of a reef can be investigated by techniques including drilling and carbon dating. Deep drilling of coral reefs provides cores of material which can be used to identify corals and to estimate the rate of growth of the reef. As corals grow, they produce 'bands' which are similar to the annual growth rings of a tree. Interpretation of the bands provides evidence for changes in the growth rate of corals, in response to changes in environmental conditions, such as temperature or nutrient availability.

Carbon dating (also referred to as radiocarbon dating) can be used to find the age of a sample of coral. As corals grow, carbon, originating from carbon dioxide, is deposited in their skeleton in the form of calcium carbonate. Some of the carbon taken up by corals, in the form of ^{14}C, slowly decays to ^{12}C. The proportion of ^{14}C to ^{12}C in a sample of material is used to estimate the age of the corals. Carbon dating is used on organic remains up to about 50 000 years old.

(g) *Explain how these methods may be used to investigate the effect of sea level changes on coral reefs*.

The growth of corals depends upon a number of factors, including the availability of light. For this reason, growth is usually restricted to the top 20 m of water. Fossil corals, found at depths of 1200 m for example, are evidence of subsidence. Over geological time (hundreds of thousands or millions of years) new corals slowly grow on top of the old as the reef gradually sinks.

Fossil corals are also found above sea level. This provides evidence for changes in sea level; an increase in sea level allowing the growth of corals, followed by a decrease in sea level, leaving the corals high and dry. Studies on corals recently exposed by excavation in Mexico have been correlated the growth of corals with changes in sea level between ice ages.

(h) *Use the knowledge and understanding gained in this section in new situations or to solve related problems.*

Questions on any of the papers may expect candidates to be able to apply their knowledge and understanding of the syllabus content to new and possibly unfamiliar contexts.

Coral reefs and lagoons

References

Barnes RSK and RN Hughes *An Introduction to Marine Ecology* (3rd edition 1999) Blackwell ISBN 978 0 86542 834 8

Tait RV and FA Dipper Elements of Marine Ecology (4th edition 1998) Butterworth Heinemann ISBN 0 750 62088 9

http://researcharchive.calacademy.org/research/izg/CORAL_REEFS4.html

(Coral reef ecology and formation)

http://oceanservice.noaa.gov/education/kits/corals/media/supp_coral04a.html

(Includes an animation of formation of an atoll)

http://earthobservatory.nasa.gov/Features/Paleoclimatology_CloseUp/paleoclimatology_closeup_2.php

(Coral growth and climate change)

6 The ocean floor and the coast

Tectonic processes and the ocean basin.

The littoral zone.

(a) *Describe the theory of plate tectonics and the evidence supporting the theory*.

In1912, the geologist Alfred Wegener proposed the theory of continental drift. He suggested that many millions of years ago, there was just one land mass, referred to as Pangaea, which slowly separated to form today's land masses. In the 1960s, this theory was extensively revised and is now known as the **theory of plate tectonics**. This theory suggests that the outer crust of the Earth, known as the lithosphere, consists of a number of separate plates which 'float' on the underlying layer (the asthenosphere). These plates move slowly relative to each other. Where plates move in relation to another, there are three different types of boundaries between them known as convergent, divergent and transform boundaries. Earthquakes, mountain building, volcanic activity and the formation of ocean trenches all occur along these plate boundaries.

Evidence supporting the theory of plate tectonics includes fit between coastlines (for example the east coast of South America and the west coast of Africa); palaeontology showing the distribution of fossil species; magnetic stripes in the ocean floor. The pattern of magnetic stripes provides clear evidence of ocean floor spreading.

(b) *Relate tectonic processes to the production of ocean trenches, mid-ocean ridges, hydrothermal vents, abyssal plains, volcanoes, earthquakes and tsunamis*.

Ocean trenches are formed along tectonic plate boundaries where one plate is forced under another plate (subduction). Ocean trenches are long and narrow and are the deepest part of the ocean floor, for example, the Challenger Deep in the western Pacific Ocean is approximately 10 000 m below sea level.

Mid-ocean ridges are underwater mountain ranges, formed by upward movement and spreading of the underlying magma, which cools and solidifies as it emerges. This process occurs at a divergent tectonic plate boundary and is responsible for seafloor spreading.

Hydrothermal vents occur in the deep ocean, typically along mid-ocean ridges where two tectonic plates are diverging. Sea water which seeps into cracks in the ocean floor (and water from the upwelling magma) is released from the hot magma. Hydrothermal vents occur at depths of about 2100 m below sea level.

Abyssal plains are relatively flat areas of the ocean floor, situated between ocean trenches and continental rises. An abyssal plain is formed by the upwards movement of molten material from the oceanic crust, which solidifies and forms new ocean crust. This process is referred to as mantle convection. The abyssal plain arises as the uneven rock surface becomes covered with fine-grained sediments. Abyssal plains have a depth of between about 3000 and 6000 m below sea level.

A **volcano** is formed where there is an opening in the Earth's crust, allowing hot gases and molten rock to escape from beneath the surface. Volcanoes can form where there is thinning of the crust at tectonic plate boundaries, for example at divergent plate boundaries. Volcanoes can also be formed where tectonic plates are moving towards each other, or converging. Most divergent tectonic plate boundaries are under the sea and therefore most volcanic activity is submarine. This results in the formation of new seafloor. Divergent tectonic plate boundaries also give rise to mid-ocean ridges; where these rise above sea-level, volcanic islands may be formed, such as Iceland.

An **earthquake** occurs when there is a sudden release of energy in the Earth's crust, creating seismic waves. Earthquakes can arise from convergent tectonic plate boundaries. If the two plates are unable to slip past each other, they may lock. Continued plate movement results in strain building up until the plates suddenly move again, releasing stored energy and creating an earthquake.

Sudden tectonic plate movement can also give rise to **tsunamis**. A tsunami is a long wavelength wave produced by the sudden movement of a very large volume of water. This may occur at a convergent tectonic plate boundary, where the abrupt slippage of one plate against another results in both an undersea earthquake and a tsunami. In deep, oceanic water, a tsunami wave travels quickly. As the wave approaches shallow, coastal water, it slows down but forms large, destructive waves.

(c) *Explain why the water coming from hydrothermal vents is under pressure, hot and rich in minerals*.

Hydrothermal vents (Figure 6.1) were discovered in 1977. They are formed along divergent plate tectonic boundaries in the deep ocean. Cold sea water seeps into cracks and fissures along these boundaries and is heated by the hot underlying magma under the ocean floor. The hot water is forced back up to the ocean floor, carrying dissolved minerals. A hydrothermal vent forms where the hot water passes up through the ocean floor and, as it cools, the dissolved minerals start to precipitate out. Minerals in a hydrothermal vent include sulphides of iron, copper and zinc.

Hydrothermal vents are found at depths of over 2000 m, where the pressure is very high (in excess of 200 atmospheres or 20 megapascals). Due to this high pressure, the water in a hydrothermal vent may be superheated and reach temperatures higher than 100 °C.

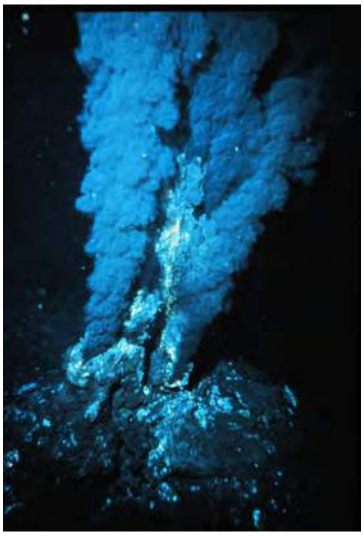

Figure 6.1 A hydrothermal vent
(http://www.astro.yale.edu/chunter/presentations/cty/Hydrothermal_vent.jpg)

(d) *Explain how isostasy may produce shallow seas within or at the edge of continents*.

The term **isostasy** literally means 'weighing the same'. When applied to geology, it refers to the buoyant properties of layers of rocks which float on other layers, according to their density and thickness. This explains why the Earth's crust floats on the denser, underlying layer, just as an ice cube floats in a glass of water.

The continental shelf is a gently sloping region surrounding the continents, over which the sea is relatively shallow. The continental shelf is covered with sediments, derived from erosion of the continents. The continental shelf is part of the continent itself and was above sea level during the ice age, when the sea level was lower than at present. The depth of water over the continental shelf depends upon two main factors, isostatic changes in land height and changes in sea level.

The principle of isostasy shows that the Earth's crust is generally higher where it is thicker and less dense; lower where it is thinner and denser. The density of the continental crust is less than that of the oceanic crust. Table 6.1 shows the approximate densities of different layers of the Earth.

Layer	Density / g per cm^3
Continental crust	2.7 to 3.0
Sediments on continental shelf	2.4
Oceanic crust	3.0 to 3.3
Mantle	3.3 to 5.7

Table 6.1 Densities of some layers of the Earth

These figures support the fact that the continental crust and the oceanic crust float on the mantle, which has the highest density.

(e) *Demonstrate an understanding of the processes of erosion and sedimentation that give rise to the morphology of the littoral zone, including rocky shores, sandy shores, muddy shores, estuaries and deltas*.

The littoral zone can be defined as the area of a coast between the high water mark and the lowest part of the shore which is permanently submerged. The littoral zone is, therefore, part of the sea shore, the area where the land meets the sea. Sea shores vary from steep, rocky areas to large expanses of mud flats. The nature of the shore depends on two main factors: the geology of the adjacent land and the exposure to erosion by the sea.

Rocky shores are characterised by outcrops of rock which are exposed to erosion by the sea, producing a variety of different sized boulders, stones and pebbles. Some types of rock, such as granite, are resistant to weathering and break down less easily than softer rocks, such as sandstone. On many rocky shores, the repeated pounding effect of the sea grades the rocks according to size with the largest boulders being left at the top of the shore. The slope of rock shores varies widely, from those which are very steep where cliffs drop into the sea, to those which are almost horizontal, where flat rocks form a wave-cut platform. Rocky shores are the most exposed type of shore and the most resistant to erosion.

Sandy shores can be formed by erosion of sandstone rocks and deposition of sand by the sea itself. Sandy shores consist of small, hard rock particles of silica and other minerals. Sandy shores usually slope gradually towards the sea.

Muddy shores are the least exposed to erosion and fine particles of silt can settle. The silt particles include very fine mineral sediments and organic remains. Muddy shores usually have little slope and, in some areas, form expansive ‘mud flats’.

An **estuary** may be defined as a semi-enclosed coastal body of water, which has a connection with the sea and within which sea water is diluted with fresh water derived from land drainage. Many estuaries have a muddy substrate as the relatively slow flow of water allows fine suspended particles to settle.

Deltas are formed when a river carrying suspended sediments reaches a large body of water, such as a lake or an ocean. As the river increases in width, the flow rate of water decreases and, as a result, the suspended sediments settle. Over a long period of time, the sediments accumulate to form a wide, fan-shaped structure. Within the delta, the river may divide up to form a number of distributary channels. Deltas are so-called because of the similarity of their shape to the Greek letter delta (Δ). Notable deltas include the Nile River Delta and the Mississippi River Delta.

Practical work could include a simple study of the relative size and abundance of particles from a shore*. This can be carried out by placing a sample of the substrate in a measuring cylinder, mixing thoroughly with water and allowing it to settle. Particles will settle out according to their size and density and their relative proportions can be measured.*

For reference purposes, the sizes of some particles are shown in Table 6.2.

Particle type	**Diameter / mm**
Silt	0.002 to 0.02
Fine sand	0.02 to 0.2
Coarse sand	0.2 to 2.0
Gravel (small stones)	> 2.0

Table 6.2 Diameters of some mineral particles

(f) *Demonstrate an understanding of how environmental factors influence the formation of ecological communities in the littoral zone, including mangrove, sandy shore and rocky shore*.

Mangroves are trees and shrubs that grow in tropical and subtropical saline coastal habitats, usually between latitudes 25° N and 25° S. These form woodland or a shrubland habitat, in coastal or estuarine conditions where sedimentation of silts occurs. The habitat itself is referred to as a mangrove swamp, mangrove forest, or simply mangrove.

Mangroves are specifically adapted to a wide range of salinity and low oxygen concentrations in the sediments. They have, for example, specially adapted root-like structures (called pneumatophores) which obtain oxygen directly from the air. The extensive root systems of mangroves help to trap particles suspended in the water and reduce water flow which increases the deposition of sediments. The root systems and accumulated sediments provide habitats for a wide variety of other organisms, including algae, oysters, crabs, barnacles and other crustaceans, sponges and fish.

The root system of mangroves also dissipates wave energy and thus helps to protect coastal areas from erosion.

Sandy shores are relatively unstable as the fine mineral particles are easily moved by winds and tides. Sand does not provide a suitable substrate for the attachment of sea weeds, for example, and does not provide shelter for organisms living on the surface. However, a number of burrowing organisms are associated with sandy shores and include ghost crabs, bivalve molluscs and annelid worms such as ragworms and lugworms. On coasts where sand is mixed with muddy deposits, the substrate is more stable and supports a wider range of organisms.

Rocky shores support a wide range of organisms, as the relatively stable substrate of large rocks and stones provides a firm surface for the attachment of many species of algae and animals such as molluscs and cnidarians (including sea anemones). Rock pools retain water when the tide retreats and may support a wide range of different species.

Rocky shores often show clear zonation of different species, which many appear in distinct bands along the shore. This is associated with their resistance to desiccation. Those living near the top of the shore are exposed to the air for longer periods of time when the tide goes out, than those lower down on the shore. Those organisms living near the top of the shore are adapted to withstand longer periods of exposure to the air. Environmental factors that influence communities on a rocky shore include desiccation, temperature, wave action, light intensity, aspect, slope and the nature of the substrate.

Practical work could include a visit to a coastal habitat*. Candidates should record the organisms present and their distribution, for example, by using a quadrat at regular intervals from the high water mark to the low water mark. Measurements of abiotic factors, including temperature and the nature of the substrate, should also be recorded.*

(g) *Use the knowledge and understanding gained in this section in new situations or to solve related problems*.

Questions on any of the papers may expect candidates to be able to apply their knowledge and understanding of the syllabus content to new and possibly unfamiliar contexts.

The ocean floor and the coast

References

Barnes RSK and RN Hughes *An Introduction to Marine Ecology* (3rd edition 1999) Blackwell ISBN 978 0 86542 834 8

(Includes various relevant material including ocean habitats, plate tectonics, hydrothermal vents and mangroves)

Tait RV and FA Dipper Elements of Marine Ecology (4th edition 1998) Butterworth Heinemann ISBN 0 750 62088 9

http://www.geologyrocks.co.uk/tutorials/plate_tectonics_evidence

(Evidence for plate tectonics)

http://www.ceoe.udel.edu/extreme2004/geology/hydrothermalvents/index.html#

(Formation of hydrothermal vents)

http://www.botos.com/marine/vents01.html

(Includes information about the formation and properties of hydrothermal vents)

http://www.theseashore.org.uk/theseashore/Factors%20Affecting.html

(Field Studies Council information on the ecology of different types of coastal habitats)

7 Physical and chemical oceanography

Factors affecting the chemical composition of seawater.

Layering and mixing in the oceans.

The tides.

Ocean currents.

El Niño, monsoon winds and tropical cyclones.

(a) *Demonstrate an understanding of the effects of volcanic activity, runoff and atmospheric dissolution on the chemical composition of sea water*.

Sea water is the water in the sea or an ocean and on average it has a salinity of about 35 parts per thousand (35 ‰). The salinity varies and may be significantly lower than this, for example where sea water is diluted by freshwater from a river, or as a result of melting glaciers.

The chemical composition of sea water remains fairly constant and the salinity is mainly due to the presence of sodium ions and chloride ions. Other ions, including sulphate, magnesium, hydrogencarbonate and potassium, are also present. Table 4.1 shows the concentrations of major ions present in typical sea water.

Although the composition of sea water remains fairly constant, and probably has done for many millions of years, local changes can occur as a result of volcanic activity, runoff and atmospheric dissolution. Gases emitted from volcanoes include carbon dioxide, sulphur dioxide, hydrogen sulphide and hydrogen chloride. These gases dissolve in atmospheric water and enter sea water in precipitation, as part of the hydrological cycle. Submerged volcanoes at tectonic plate boundaries emit gases, including chlorine, and gases from volcanoes are the major source of the chloride ions present in sea water.

Runoff refers to the flow of water from land, arising from rain or from melting snow and ice. As part of the hydrological cycle, much of this water may eventually drain into oceans, either directly, or from rivers. Water passing through soil, or water from urban runoff flowing into drains, may pick up a variety of pollutants, including pesticides, fertilizers and oil-derived substances. Some pollutants have initially have a very low concentration, but if taken up by living organisms, the pollutants can pass through food chains and food webs, increasing in concentration at each trophic level. An example of this is the release of mercury compounds in industrial wastewater entering Minamata Bay from 1932 until 1968. These mercury compounds accumulated in shellfish and other marine organisms. When shellfish were eaten by humans, the mercury compounds caused neurological disorders, paralysis and death.

Gases dissolved in sea water are in equilibrium with the atmosphere. However, the actual concentration of gases in sea water depends on their relative solubility, and the temperature and salinity of the water. The gases dissolved in sea water consist mainly of nitrogen, oxygen and carbon dioxide. Nitrogen may be fixed by nitrogen-fixing microorganisms into products which are usable by other organisms. Oxygen is essential for respiration and carbon dioxide is used in the process of photosynthesis.

(b) *Outline the effects of evaporation and precipitation on salinity*.

Salinity is a measure of the saltiness, or salt concentration, of water and is usually expressed as parts per thousand (‰). The mean salinity of sea water is 35 parts per thousand. Evaporation of water increases the concentration of salt, leading to the water becoming hypersaline. This may happen in a lagoon, for example, where high temperatures increase evaporation. The effect is increased where there is less mixing with sea water. The Dead Sea is an extreme example of evaporation of water leading to the accumulation of solutes. In this case, the salinity is approximately 10 times greater than that of sea water.

Precipitation, which includes rain and snow, leads to dilution of sea water and consequently a decrease in the salinity. A decrease in salinity also occurs in estuaries as a result of mixing with fresh water from rivers, or near melting glaciers.

Practical work could include measurement of the density of sea water using a hydrometer and investigation of the effect of evaporation on the density of sea water.

(c) *Describe how temperature and salinity gradients form in water columns to produce ocean layers* (*including the surface layer, thermocline and deep ocean*), *and how subsequent mixing of these layers may occur*.

The density of water depends on temperature and salinity. As the temperature increases, the density of water decreases. There is a tendency, therefore, for warm water to form a layer on top of colder, denser water. The result of this is the formation of a temperature gradient and the temperature generally decreases as the depth increases. There is a relatively shallow layer of warn water floating on a deep layer of colder water. The interface between the two layers, where the temperature decreases abruptly as the depth increases is referred to as the **thermocline**. The surface layer of water in an ocean may reach a temperature of 25 °C or higher, the temperature decreases to about 1 °C at depths of over 2000 metres.

There is a similar gradient of salinity in the oceans. As the salinity of water increases, the density of water also increases. There is a tendency therefore, for water with as lower salinity, and therefore lower density, to float on top of water with a higher salinity. This effect results in a general increase in salinity as the depth increases, with a region referred to as the **halocline** where there is a significant change in salinity as the depth increases.

Wind blowing across the surface of the sea can set up turbulence and currents, resulting in mixing of the surface layers, down to a depth of about 200 metres. Mixing can also occur as a result of temperature changes; if the surface layer cools, for example, the density will increase and the water will tend to sink.

(d) *Demonstrate an understanding of the physical and biological reasons for the variability of the concentration of dissolved oxygen*.

The concentration of dissolved oxygen in water is very variable and depends upon a number of factors. As a general rule, as the temperature of water increases, the solubility of oxygen in water decreases. Table 7.1 shows the concentration of dissolved oxygen in freshwater, saturated with oxygen, at a range of temperatures. Oxygen is slightly less soluble in saline water than it is in fresh water.

Temperature of water / °C	**Concentration of dissolved oxygen / mg per dm^3**
0	14.6
5	12.8
10	11.3
15	10.2
20	9.2
25	8.4

Table 7.1 Relationship between temperature and the concentration of oxygen dissolved in water

In the surface layers of the ocean, the concentration of dissolved oxygen is usually high; indeed the water may become supersaturated with oxygen. This is due to two main processes, turbulence and mixing by waves helping atmospheric oxygen to dissolve, and photosynthesis of algae, which produce oxygen as a by-product. Dissolved oxygen is removed from water by respiration of marine organisms.

The concentration of dissolved oxygen changes as the depth of water changes. It is generally high in the surface layers, but decreases to a minimum as the depth increases, before increasing again as the depth continues to increase. The depth at which the concentration of dissolved oxygen is lowest is referred to as the **oxygen minimum layer**. This is usually between depths of 100 m and 1000 m.

(e) *Describe how tides are produced, and how the alignment of the Moon and Sun, coastal geomorphology, wind, air pressure and size of water body affect the tidal range*.

The regular rise and fall of sea level is referred to as the tide and is due to the gravitational effects of the Sun, Moon, Earth and the rotation of the Earth. Tides have a cycle of approximately 12.5 hours; so most coastal areas experience two high tides and two low tides every day.

The tidal amplitude varies. When the Earth, Moon and Sun are aligned, the amplitude is greatest, resulting in what are known as **spring tides** (see Figure 7.1. At other phases of the Moon, such as first quarter, the tidal range is smaller; these are referred to as **neap tides**.

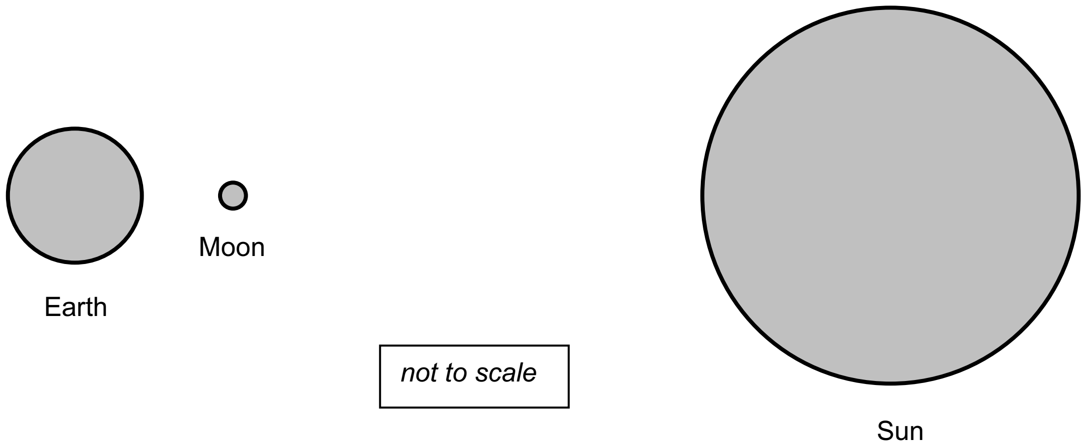

Figure 7.1 Spring tides occur when the Earth, Moon and Sun are aligned during a new moon (as illustrated here) or during a full moon.

The tidal range (tidal amplitude) is the difference in height between low water and high water and varies considerably in different parts of the World, from over 12 m to practically nothing. The nature of the coast, including slope, size of the body of water, and weather conditions can all affect the tidal range.

The shape of the coastline can influence the tidal range. For example, where the tide enters a tapering river mouth, the height of the tide is increased by the opposite sides of the channel. A similar effect occurs in a bay. Changes in wind and air pressure can have a significant effect on the tidal range. For example, a strong on-shore wind and low atmospheric pressure can produce a ‘tidal surge’ resulting in an exceptionally high tide.

In the oceans, the tidal amplitude is about 0.6 m; this is increased as the oceanic tide enters the shallow continental margins. The lowest tidal amplitudes are found in relatively small bodies of water, including the Mediterranean Sea, Red Sea and the Baltic Sea. Small tidal ranges occur in large lakes, but this effect is often masked by the effect of wind.

***Practical work could include measurements of tidal range**. Where it is safe and practicable to do so, simple measurements using a metre rule or a ranging pole will generate interesting data on changes in daily tidal amplitudes and longer-term changes.*

(f) *Explain how wind, temperature, density, the Coriolis effect and the shape of the sea bed produce ocean currents and upwelling*.

Ocean currents are the continuous movement of ocean water, driven by forces acting on the water, including waves, wind, the Coriolis effect, temperature, salinity and tides. The contours of the sea bed influence the strength and direction of the current.

Surface ocean currents are generally driven by the wind and characteristically have a clockwise spiral in the northern hemisphere and a counter-clockwise spiral in the southern hemisphere. Deep ocean currents are driven by temperature and density gradients. Upwelling areas are regions where significant vertical movement of water occurs. A mid-ocean ridge can deflect deep water currents upwards and this is one way in which upwelling is caused.

The Coriolis effect is due to the rotation of the Earth and causes water to move to the right in the northern hemisphere and to the left in the southern hemisphere. This means that the direction of surface ocean currents is not determined entirely by wind direction, by is deflected by the Coriolis effect.

Practical work could include measurement of current speed and direction*. This can be carried out using a simple float, e.g. a plastic bottle weighted so that it is just floating and attached to a measured length of string. Current speed = distance moved by the float ÷ time. Direction of the current can be determined using a compass. Candidates could investigate whether the current speed and direction changes at different times of the day.*

(g) *Discuss the causes and effects of El Niño events in the Pacific Ocean*.

El Niño (also referred to as the El Niño southern oscillation) is a sequence of events that occurs in the southern Pacific Ocean. In normal conditions, cold water, rich in nutrients, flows in a northerly direction along the west cost of South America. This is accompanied by an upwelling of nutrients, caused by winds blowing form the south. This results in the water having a high productivity, with very large numbers of anchovies and sardines feeding in the plankton-rich water. This high productivity supports a substantial fisheries industry and many species of sea birds and other organisms.

Approximately every 7 to 10 years, the prevailing winds stop blowing in their normal pattern from the east or south-east. Warm equatorial water is blown by abnormal winds from the west. As a result, pressure gradients in the west and east Pacific Ocean are reversed, causing a reversal of wind direction and equatorial currents. This creates a large area of warm water; upwelling stops and so the supply of nutrients to the surface water is reduced. The increase in temperature results in the death of many cold-water species and, coupled with the lack of nutrients, this causes the primary production to decrease dramatically. This affects higher trophic levels in food chains and food webs with the consequent collapse of commercial fish stocks.

A major El Niño event occurred in 1982 to 1983. Surface temperatures increased by 5 °C, accompanied by heavy rain in the normally dry eastern Pacific. The exact cause of El Niño is not known, but it has been suggested that it could be a consequence of global warming.

(h) *Explain the seasonal differences in temperature between the Asian continent and the Indian Ocean, and explain how these differences give rise to the patterns of monsoon winds*.

Asia is considered to be the largest content and there is wide range of climatic conditions, varying from hot and wet to cold and dry. A monsoon is a seasonal wind of the Indian Ocean. Land masses absorb heat faster than the sea and therefore heat up more quickly. In the winter months, the sea is warmer than the land mass and air over the sea rises as it warms and becomes less dense. This draws in cooler air from the land, from a north-easterly direction. In India, this occurs in the post-monsoon season, during the months of October to December.

In the summer months, from May until August, the land heats up quickly and there is relatively large temperature difference between Central Asia and the Indian Ocean. Air over the land warms, becomes less dense and rises. This draws in air saturated with water vapour from the Indian Ocean, from a south-westerly direction. The summer monsoons bring thunderstorms and exceptionally heavy rain. It has been estimated that these summer monsoons bring over 80% of India's annual rainfall. As the Indian land mass cools during September, this monsoon weakens and is replaced with the dry, north-east post-monsoon.

(i) *Discuss the factors required for a region of low pressure to develop into a tropical cyclone, and explain the role of evaporation, condensation and latent heat in tropical cyclones*.

A tropical cyclone (Figure 7.2) is a storm system, with a large, low-pressure centre and many thunderstorms with strong winds and heavy rain. Tropical cyclones develop over warm sea water, with a temperature of at least 26.5 °C, in a low pressure area, where evaporation of water occurs. As the water vapour rises, it condenses and releases large amounts of heat energy (latent heat of condensation). This heat energy further increases evaporation, driving the development of the cyclone.

As a result of the rotation of the Earth and the Coriolis effect, the whole cyclone system starts to spin. In the northern hemisphere cyclones rotate counterclockwise; in the southern hemisphere they rotate clockwise. The tropical cyclone moves across the surface of the sea in a direction largely determined by the direction of prevailing winds. The pathway of the cyclone is referred to as the *track*.

Figure 7.2 A tropical cyclone seen from a satellite
(http://0.tqn.com/d/weather/1/0/3/3/-/-/sidr_tmo_2007318.jpg)

(j) *Recall that tropical cyclones are also referred to as hurricanes and typhoons and discuss their impact on coastal communities*.

The terms tropical cyclones, hurricanes and typhoons all refer to the same type of tropical storm, but are used in different parts of the world:

- hurricane in the North Atlantic Ocean
- typhoon in the north-west Pacific Ocean
- tropical cyclone on other regions, including the Indian Ocean and South Pacific Ocean.

Tropical cycles are destructive to coastal communities because of the high winds and heavy rainfall. They can also cause storm surges (an increase in sea level) resulting in flooding of low-lying coastal areas, with associated risks of drowning. Wind speeds associated with cyclones can exceed 90 km per hour, with gusts exceeding 280 km per hour. These wind speeds cause extensive damage to coastal properties. The heavy rainfall can result in widespread flooding, which may extend inland as the cyclone moves into central parts of the continent. The high winds also cause exceptional waves, resulting in serious erosion of the shore and damage to moored boats. The heavy rainfall associated with cyclones may, however, benefit arid areas. The storm surges can also replenish nutrients in coastal water and, consequently, increase productivity.

(k) *Use the knowledge and understanding gained in this section in new situations or to solve related problems*.

Questions on any of the papers may expect candidates to be able to apply their knowledge and understanding of the syllabus content to new and possibly unfamiliar contexts.

Physical and chemical oceanography

References

Barnes RSK and RN Hughes *An Introduction to Marine Ecology* (3rd edition 1999) Blackwell ISBN 978 0 86542 834 8

Tait RV and FA Dipper Elements of Marine Ecology (4th edition 1998) Butterworth Heinemann ISBN 0 750 62088 9

http://www.marinebio.net/marinescience/02ocean/swcomposition.htm

(Composition of sea water and its effects on marine organisms)

http://www.physicalgeography.net/fundamentals/8p.html

(Physical and chemical properties of sea water)

http://ga.water.usgs.gov/edu/dissolvedoxygen.html

(Dissolved oxygen in water)

http://www.bbc.co.uk/weather/coast/tides/

(Information about tides; tide tables and graphs)

http://geography.about.com/od/physicalgeography/a/monsoon.htm

(Information about India's monsoons)

http://www.aoml.noaa.gov/hrd/tcfaq/A15.html

(Explains how tropical cyclones form)

http://www.bom.gov.au/cyclone/about/about-tropical-cyclones.shtml

(Information about tropical cyclones, with particular reference to Australia)