9693 A2 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 A2 topics 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
- links, where appropriate, to the AS content
- 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.

8 Physiology of marine primary producers

The relationship between habitat and the distribution of primary producers.

Factors affecting the rate of photosynthesis.

> § ***Making links with AS***
>
> ✓ Section 2(c) *Producers in the context of food chains and food webs*
>
> ✓ Section 3(a) *Capture of energy by photosynthesis*
>
> ✓ Section 4(f) *Nutrient cycles and biological uses of nutrients*

(a) *Demonstrate an understanding of the ecological importance of primary producers for carbon fixation and shelter*.

Primary producers in marine ecosystems include phytoplankton, larger algae such as *Sargassum*, and flowering plants such as the sea grasses. Primary producers fix carbon, in the process of photosynthesis, making organic substances which are then available to higher trophic levels. Primary producers are therefore the starting organisms in food chains and food webs.

Beds of sea grass, growing in shallow coastal waters with a sandy or muddy substrate, provide habitats for many other organisms, including many different species of fish, molluscs and crustaceans. Sea grass provides food for primary consumers, a habitat for many other organisms and shelter for juvenile fish. Sea grasses also help to reduce water current speed and increase sedimentation. Their roots and rhizomes stabilise the substrate and, as a result, reduce coastal erosion.

(b) *Explain why different types of primary producers are found in different habitats, including*

- *the open ocean* (*containing phytoplankton* [*confined to diatoms, dinoflagellates and cyanobacteria*] *and floating macroscopic algae* [*confined to* Sargassum])
- *shallow waters* (*containing zooxanthellae in corals, sea grass such as* Thalassea *and kelp forests*)
- *intertidal regions* (*containing green, red and brown algae*)

Surface waters (the photic zone) of the oceans support many different types of phytoplankton, drifting passively with the currents. **Phytoplankton** is responsible for most of the primary production in the marine environment and includes diatoms, dinoflagellates and the cyanobacteria. Diatoms are characterised by their cases (frustules) consisting of silica and their yellow-brown chloroplasts. Dinoflagellates have two flagella; one in a groove along the main axis of the cell, the other in a transverse groove.

Cyanobacteria (blue-green bacteria) are sometimes also referred to as blue-green algae. These are present in phytoplankton, often in the form of chains of minute spherical cells. Cyanobacteria are prokaryotic organisms and therefore have no chloroplasts; the photosynthetic pigments are present in their cytoplasm.

Sargassum is a genus of brown alga, widely distributed in tropical and temperate oceans. *Sargassum* typically grows in shallow water and coral reefs, but there are also free-floating, planktonic species. The Sargasso Sea, a region in the North Atlantic Ocean, contains large masses of floating rafts of *Sargassum*.

Shallow waters provide a habitat for many different species of **algae** and other plants. Corals contain symbiotic **zooxanthellae**, photosynthetic organisms that provide the coral with a range of organic substances including glucose and amino acids. **Sea grasses** include the genera *Thalassea* and *Zostera* and grow in shallow, sheltered areas, rooted in a muddy or sandy substrate. **Kelp forests** occur in cool, clear waters in depths of up to about 40 m. Kelps are brown algae and include species such as *Laminaria hyperborea* and *Macrocystis pyrifera* which require a hard substrate for attachment. The blade, or lamina, of the kelp floats in the water column and can reach impressive lengths of over 50 metres in some species.

Intertidal regions, particularly on rocky coasts, provide a habitat for many different species of sea weeds, notably fucoid brown algae. These algae include species such as *Fucus vesiculosus* (bladder wrack) and *Ascophyllum nodosum* (egg wrack). These species of algae have a means of attachment to rocks (a holdfast), helping them to avoid the scouring effect of waves and the tide.

There is often a marked zonation of algae on a rocky shore, which is partly due to their resistance to desiccation. Those species growing near the top of the shore are exposed to the air for longer periods of time than those growing nearer to the low water mark. Relative rates of growth, resistance to grazing by herbivores and competition between species are also important factors in the location of these algae on shores.

Rocky shores are usually dominated by brown algae, but green algae and red algae also occur. Green algae include *Ulva* (sea lettuce); red algae include *Chondrus*.

Practical work could include an ecological investigation into the distribution of algae on a rocky shore and plankton sampling.

If a plankton net is available, it is possible to make a quantitative estimation of plankton numbers. A net can be towed behind a boat, or lowered into the water to a certain depth and hauled back up. In both cases, it is possible to make an estimate of the volume of water sampled, using the formula $V = \pi r^2 \times d$, where r is the radius of the aperture of the net and *d* is the distance through which the net has travelled. It should be noted, however, that this gives an approximate volume only.

The numbers of phytoplankton in a sample can be found using a microscope and a suitable counting chamber, such as a Sedgewick-Rafter counting chamber (Figure 8.1).

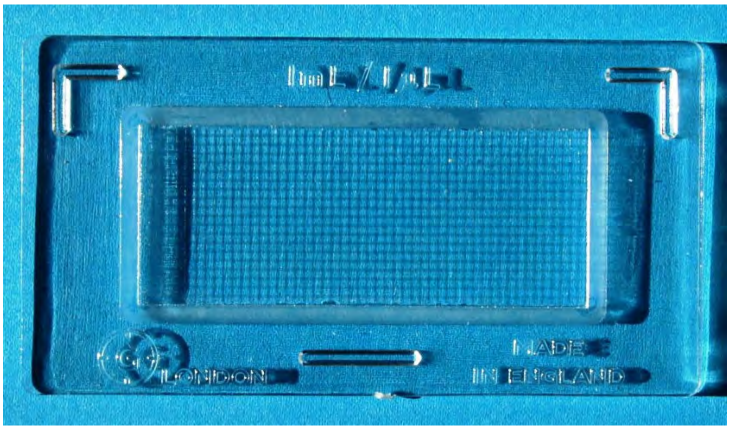

Figure 8.1 A Sedgewick-Rafter counting chamber
[Photo © John Adds]

(c) *Demonstrate an understanding that photosynthesis (carbon dioxide + water → glucose + oxygen) is the process that nearly all primary producers use to fix carbon.*

Primary producers fix inorganic carbon and make organic compounds available to herbivores and other organisms in food chains and food webs. Almost all primary producers fix carbon through the process of **photosynthesis**, using light as a source of energy, as represented by the outline equation:

carbon dioxide + water → glucose + oxygen

It should be noted that primary production can also occur using energy derived from the oxidation of inorganic substances such as hydrogen sulfide and ammonia. This process is referred to **chemosynthesis** and occurs in the deep ocean around hydrothermal vents [see AS Topic 2(b)]. However, the total fixation of carbon by chemosynthesis is very small compared with photosynthesis.

The majority of primary production in the oceans is carried out by phytoplankton, but the productivity varies according to the availability of factors including light and inorganic nutrients.

(d) *Demonstrate an understanding that photosynthesis involves the use of light energy from the Sun, pigments including chlorophyll, and a number of enzymes.*

Photosynthesis is the process by which plants capture light energy from the Sun and use this to form chemical bond energy in organic molecules, such as carbohydrates. Photosynthesis uses the inorganic molecules carbon dioxide and water and produces organic molecules, releasing oxygen as a by-product. Photosynthesis involves two main stages, referred to as the light-dependent reaction and the light-independent reaction.

Phytoplankton and other eukaryotic plant cells contain chloroplasts, the organelles in which photosynthesis occurs. Chloroplasts contain a number of pigments (coloured substances), which absorb light energy and start the process of photosynthesis. It is possible to extract these pigments and separate them using the technique of chromatography. Chloroplasts contain different groups of pigments including:

- chlorophylls
- carotenoids
- phycobilins.

Chlorophylls have a green colour and absorb light in the red and blue-violet part of the spectrum. There are a number of different forms of chlorophyll, including chlorophyll *a* and chlorophyll *b*. Carotenoids are yellow or orange pigments which absorb blue-violet light. The most widespread carotenoid is β-carotene.

Other pigments found in algae include fucoxanthin, a yellow-brown pigment found in brown algae, and the phycobilins which are present in red algae.

The individual reactions in the light-independent stage of photosynthesis are controlled by enzymes. For example, the fixation of carbon dioxide is catalysed by the enzyme ribulose bisphosphate carboxylase (RuBisCO).

(e) *Explain why and how light intensity, light wavelength and temperature affect the rate of photosynthesis and can act as limiting factors.*

Photosynthesis involves a sequence of reactions and the overall rate of the process depends on the rate of the slowest of these reactions. For example, in a low light intensity, the rate at which the products of the light-dependent reactions are formed will affect the rate at which carbon dioxide is fixed in the light-independent reactions. In this situation, light intensity is said to be the limiting factor. An increase in light intensity will increase the rate of photosynthesis until another factor, such as the availability of carbon dioxide, becomes limiting.

Factors affecting the rate of photosynthesis include:
- light intensity
- light wavelength
- concentration of carbon dioxide
- temperature.

Light intensity

In the absence of light, no photosynthesis occurs, but respiration continues. As the light intensity increases, the rate of photosynthesis also increases. The light compensation point occurs at a light intensity where the volume of carbon dioxide produced in respiration is the same as the volume of carbon dioxide used in photosynthesis. As the light intensity increases further, the rate of photosynthesis exceeds the rate of respiration and there is a net uptake of carbon dioxide. Eventually, the rate of photosynthesis levels out and reaches a plateau (Figure 8.2). At this point, another factor has become limiting. At very high light intensities, the rate of photosynthesis may actually decrease, due to adverse effects of the intense light.

Light intensity decreases as the depth of water increases; the upper regions of oceans therefore have the highest photosynthetic productivity.

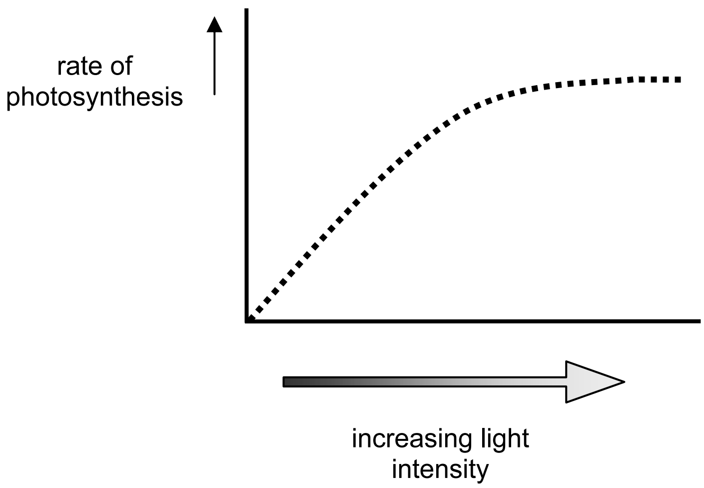

Figure 8.2 The effect of light intensity on the rate of photosynthesis

Light wavelength

The chloroplast pigments absorb certain wavelengths of light most strongly. Chlorophyll *a*, for example, absorbs blue-violet light (wavelength 420 nm) and red light (wavelength 660 nm). There is little absorbance of light between about 500 nm and 600 nm and light of these wavelengths is reflected.

A graph showing the relationship between absorbance and wavelength, for a pigment, is referred to as an absorption spectrum. An action spectrum is a graph showing the relationship between the rate of photosynthesis and the wavelength of light. The wide range of pigments present in different species of phytoplankton enables them to utilise a wide range of wavelengths of light for photosynthesis.

Concentration of carbon dioxide

Carbon dioxide exists mainly in the form of hydrogencarbonate ions (HCO_3^-) in sea water, derived from dissolved carbon dioxide from the atmosphere. The availability of carbon dioxide can act as a limiting factor on the rate of photosynthesis, although in marine ecosystems plant growth is probably not limited by carbon dioxide.

Temperature

Temperature affects the rate of enzyme-controlled reactions and therefore has an effect on the light-dependent stage of photosynthesis. In general, as temperature increases, the rate of photosynthesis increases up to an optimum. Above this temperature, the rate of photosynthesis declines as the temperature increases. Different species of phytoplankton are adapted to different temperature ranges; species of plankton in cold water carry out photosynthesis at a similar rate to those adapted to equatorial, warmer water. Seasonal variations in phytoplankton productivity are associated with changes in temperature, light intensity and the availability of nutrients.

In addition to carbon dioxide, phytoplankton also requires a supply of mineral ions for growth [see AS Topic 4(f)]. In some situations, the availability of nitrogen, phosphorus and trace elements, such as iron, may limit growth. In areas where there is a high concentration of nutrients, phytoplankton may grow rapidly giving rise to a ‘bloom’ (Figure 8.3). Some algal blooms give rise to a reddish-brown colouration of the water, referred to as a ‘red tide’. These may contain toxic species of dinoflagellates.

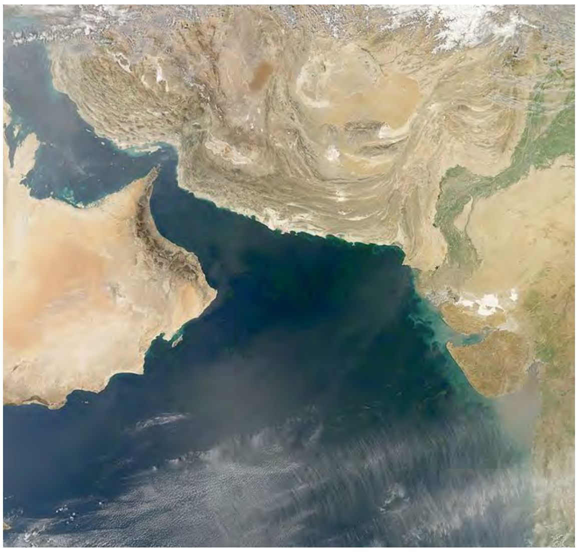

Figure 8.3 A phytoplankton bloom in the Arabian Sea
[Source: http://en.wikipedia.org/wiki/File:Phytoplankton_Bloom_in_the_Arabian_Sea.jpg

Practical work could include investigation of factors affecting the rate of photosynthesis. This can be carried out using a suitable aquatic plant and varying one factor, such as light intensity. As an alternative to an aquatic plant, there are interesting possibilities using immobilised algae.

(f) *Describe how light of different wavelengths penetrates to different depths in water, and relate this to the presence of accessory pigments, including xanthophylls and phycobilins, in marine primary producers*.

The surface layer of the oceans in which there is sufficient light for photosynthesis is referred to as the photic zone and extends to between about 30 metres and 150 metres from the surface. The longer wavelengths of light, in the red, orange and yellow part of the spectrum, penetrate clear water to about 15 to 50 metres. Shorter wavelengths of light, in the blue and green parts of the spectrum, can penetrate to greater depths than the longer wavelengths, reaching 100 metres or lower.

Species of phytoplankton in the deeper parts of the photic zone contain accessory pigments including xanthophylls (e.g. lutein) and phycobilins. These pigments enable phytoplankton to capture a wider range of wavelengths of light. Phycobilins, for example, absorb light in the middle part of the visible spectrum. Phytoplankton growing in shallow water may contain phycobilins that absorb yellow or red light, whereas those species in the lower parts of the photic zone contain phycobilins that absorb green light strongly. The light energy captured by these accessory pigments is passed to chlorophyll *a* and used for photosynthesis.

Practical work could include the extraction and separation of pigments from algae, using chromatography.

(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.

Physiology of marine primary producers

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://er.jsc.nasa.gov/seh/Ocean_Planet/activities/ts3ssac3.pdf
(Identification of plankton)

http://www.ucmp.berkeley.edu/glossary/gloss3/pigments.html
(Pigments in photosynthesis)

http://oceanservice.noaa.gov/facts/light_travel.html
(Penetration of light in the ocean)

http://www-saps.plantsci.cam.ac.uk/prac_activ.htm
(Suggestions and methods for practical work, including photosynthesis and chromatography)

9 Aspects of marine animal physiology

Respiration.

Gaseous exchange and transport systems.

Osmoregulation.

> § ***Making links with AS***
>
> ✓ Section 7(a) *Chemical composition of sea water*
>
> ✓ Section 7(d) *Reasons for the variability of the concentration of dissolved oxygen*

(a) *Demonstrate an understanding that respiration (glucose + oxygen → carbon dioxide + water) is the process that organisms use to release the energy they require*.

Aerobic respiration is the process by which almost all living organisms obtain the energy they need, by the oxidation of organic molecules such as glucose.

This process can be represented by the equation:

glucose + oxygen → carbon dioxide + water

It should be noted, however, that this equation is a simplification of the process and does not show all the intermediate reactions involved. What is important is that respiration converts the chemical energy of glucose into a form of energy which can be used by the organism for processes such as muscle contraction and growth. All heterotrophic organisms obtain the organic molecules either directly or indirectly from autotrophic organisms (the primary producers) in food chains and food webs.

(b) *Demonstrate an understanding that the raw materials and waste products of respiration must be moved to and from the surface of organisms*.

In order to live, organisms need to exchange materials with their environment. Materials exchanged include respiratory gases (oxygen and carbon dioxide), nutrients, and excretory products (waste substances produced as a result of metabolism). In relatively small and simple organisms, such as protozoa, exchange takes place across their entire body surface. As organisms increase in size and complexity, there are specialised exchange surfaces such as lungs or gills, which are adapted for the exchange of materials.

(c) *Discuss how surface area to volume ratio is dependent on the size and shape of an organism, and relate this to the need for specialised gaseous exchange surfaces in larger animals*.

As a general rule, as the size of an organism increases, its surface area decreases in relation to its volume. Very small organisms, therefore, have a relatively large surface area in relation to their volume. This principle can be illustrated by reference to two cubes; one, for example, with a side 1 cm long and another with side of 10 cm (Figure 9.1).

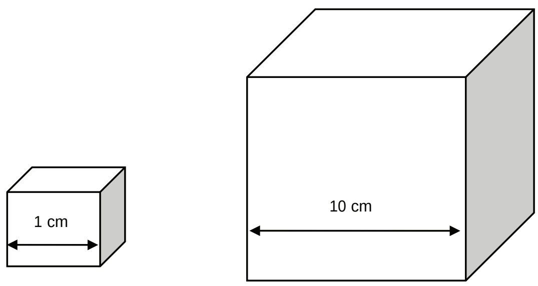

Figure 9.1 Surface area : volume relationship in two cubes.
In the smaller cube, the surface area is 6 cm^2 and the volume is 1 cm^3.
In the larger cube, the surface area is 600 cm^2 and the volume is 1000 cm^3.

In the smaller cube, the surface area : volume ratio is 6 : 1, but in the larger cube, the ratio is 0.6 : 1. This means that diffusion over the surface of a large organism may be insufficient to meet its needs, as diffusion of respiratory gases into and out of cells away from the surface would be too slow. Some larger organisms are flattened, which is an adaptation to increase their surface area : volume ratio, but many complex organisms have specialised exchange surfaces, including lungs and gills. These present a large surface area over which gas exchange occurs.

(d) *Explain the need for transport systems in large, active animals*.

There is an exchange of materials between organisms and their environment; there is also the need for transport of materials within the organism. For example, oxygen and nutrients are transported to respiring tissues; carbon dioxide and other waste substances are removed. In many small organisms, transport of materials occurs by diffusion or active transport. In larger organisms, the distances involved are too great and diffusion alone is too slow.

Larger animals have internal **transport systems** to ensure that substances are delivered efficiently to cells and tissues, and waste products are transported away. These transport systems usually consist of blood, pumped around the body by one or more muscular hearts. Fish, for example, have a single circulatory system in which blood is pumped from the heart to the gills; blood then flows around the rest of the body before it is returned to the heart.

(e) *Demonstrate an understanding that marine animals are adapted to live in water which, in comparison with air, contains low and variable concentrations of oxygen*.

Atmospheric air contains 21% of oxygen, but the concentration of oxygen dissolved in water is relatively low. The solubility of oxygen in sea water is rather lower than it is in fresh water, due the presence of dissolved salts in sea water. The solubility of oxygen in water also decreases as the temperature increases (Table 9.1).

Table 9.1 The effect of temperature on the concentration of dissolved oxygen in sea water

Temperature / °C	Concentration of dissolved oxygen in sea water at equilibrium with atmospheric air / cm^3 oxygen per dm^3
0	7.97
10	6.35
15	5.79
20	5.31
30	4.46

Many small marine animals (such as cnidarians) obtain the oxygen they require by diffusion across their body surface. Larger, more complex animals have a specialised gas exchange surface, often associated with a transport system for respiratory gases and other substances.

In the majority of aquatic animals with a specialised surface for gas exchange, it is in the form of gills, which have a large surface area for the diffusion of respiratory gases. It is interesting to note that highly active fish have a relatively large gill surface area, compared with slower moving fish. Aquatic vertebrates, and many invertebrates, also have respiratory pigments such as haemoglobin and haemocyanin. These pigments have a high affinity for oxygen and assist in the uptake of oxygen from the environment.

(f) *Describe gaseous exchange by simple diffusion, pumped ventilation and ram ventilation, in examples including coral polyps, grouper and tuna*.

Coral polyps (phylum Cnidaria) have no specialised gas exchange organs, but they have a relatively large surface area and sufficient oxygen is obtained by **diffusion** across their body wall. Gas exchange also occurs across the surface of their gastrovascular cavity.

Many bony fish, including groupers, maintain an almost constant flow of water through their gills. This is achieved by a pumping action of the mouth and operculum. Water is drawn into the mouth as the volume of the oral cavity increases. Water is then drawn through the gills by the action of the opercular covers, which increase the volume of the opercular cavity, resulting in a lower pressure than in the oral cavity. This mechanism is referred to as **pumped ventilation**.

Tuna swim continuously with their mouth open. This mechanism, known as **ram ventilation**, maintains a continuous flow of water over their gills. Some species of fish, for example mackerel, change from pumped ventilation to ram ventilation as their swimming speed increases to between 0.5 and 0.8 metres per second. This reduces the energy cost of maintaining opercular pumping at higher swimming speeds. It is also interesting to note that fish alter the degree of mouth opening during ram ventilation to keep drag to the minimum whilst maintaining their oxygen requirement.

(g) *Explain why marine organisms may need to regulate their water content and ion content, with reference to the composition of sea water and body fluids*.

Many marine animals maintain a different concentration of ions in their body fluids from the surrounding sea water. Table 9.2 shows the concentrations of certain ions in sea water and in the blood plasma, or body fluids, of some marine animals.

Table 9.2 Concentrations of some ions in sea water and in the plasma or body fluids of some marine animals

Sample	**Concentration of solute / millimoles per dm^3**	
	Na^+	**K^+**
Sea water	approx 450	10
Mussel (body fluid)	474	12
Jellyfish (body fluid)	474	10.7
Toadfish (plasma)	160	5
Eel (plasma)	177	3
Salmon (plasma)	212	3

From Table 9.2, it can be seen that the concentrations of sodium and potassium ions in the body fluid of the two invertebrates are very similar to those of sea water. However, the concentrations of these ions in the blood plasma of the toadfish, eel and salmon are much less than the concentrations in sea water. Most marine invertebrates are osmoconformers; the concentration of solutes in their body fluids is the same as the surrounding sea water. This means that water enters and leaves equally, so there is no overall change in the water content of the organisms.

Marine vertebrates with an osmotic concentration of solutes lower than that of sea water lose water by osmosis to the surrounding sea water. Marine organisms therefore require mechanisms to maintain their body solute and water content.

(h) *Outline the process of osmoregulation in a marine bony fish* (*limited to drinking and absorbing salty water, and then actively excreting salt, using energy from respiration*).

Osmoregulation is the process by which living organisms maintain the solute and water content in their blood and body fluids. Marine bony fish (teleosts) have an internal solute concentration approximately one-third that of sea water and therefore tend to lose water, by osmosis, to their environment. This occurs mainly across the permeable surface of their gills.

To compensate for the loss, marine bony fish drink sea water. The excess salts present in the sea water are absorbed in the intestine. Sodium and chloride ions are actively secreted by chloride secretory cells present in the gills. This process requires energy, which is provided by respiration. The overall process of osmoregulation in a marine bony fish is summarised in Figure 9.2.

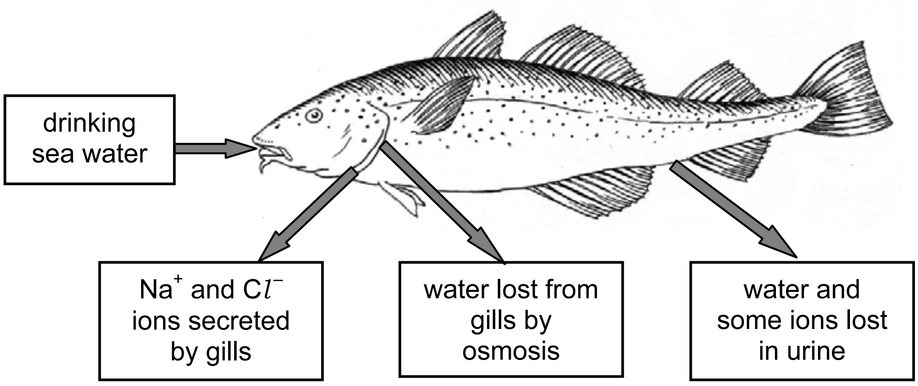

Figure 9.2 Osmoregulation in a marine bony fish

(i) *Explain the meaning of the term* osmoconformer, *with reference to mussels*.

Most marine invertebrates, including mussels, are **osmoconformers**. This means that their internal osmotic concentration is the same as that of their surrounding medium. Their internal concentrations of individual solutes, however, are not necessarily the same as in sea water, which indicates that the invertebrates have mechanisms to regulate their internal solute concentrations. Table 9.3 shows the concentrations of ions in the body fluid of a mussel and in sea water.

Table 9.3 Concentrations of ions in the body fluid of a mussel and of sea water

Sample	**Concentration of ions / millimoles per kg of water**				
	Na^+	**Mg^{2+}**	**Ca^{2+}**	**K^+**	**Cl^-**
Mussel	474	52.6	11.9	12.0	553
Sea water	478.3	54.5	10.5	10.1	558.4

(j) *Explain the meaning of the term* euryhaline, *with reference to salmon*.

Euryhaline organisms are able to tolerate a range of salinities, for example marine animals that are adapted to live in estuarine conditions. The shore crab (*Carcinus maenas*) which is common in estuaries in western Europe, north Africa and north America, can tolerate salinities down to 6 parts per thousand. Species of fish, including salmon and eels, which migrate from the sea into fresh water, are also euryhaline. These migratory fish use different mechanisms to control the concentration of ions in their cells when they are in different environments. For example, when a salmon migrates from sea water into freshwater, the active ion transport in the gills changes direction.

Organisms with only a limited tolerance to changes in the salinity of their external environment are described as being stenohaline.

(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.

Aspects of marine animal physiology

References

Adds J, E Larkcom and R Miller *Exchange and Transport, Energy and Ecosystems* (revised edition 2000) Nelson Thornes ISBN 0 7487 7487 4

Schmidt-Nielsen K *Animal Physiology: Adaptation and Environment* (5th edition 1997) Cambridge University Press ISBN 0 5215 7098 0

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

http://www.biologyreference.com/Fo-Gr/Gas-Exchange.html
(Gills and gas exchange)

10 Marine animal reproductive behaviour

Life cycles of marine animals.

§ ***Making links with AS***
✓ Section 2(e) *Shoaling and reproduction in tuna*

(a) *Compare and contrast the stages in the life cycle of salmon, tuna, oyster, shrimp, giant clam and grouper*.

Life cycle of salmon

Adult salmon migrate from the sea into fast-flowing freshwater streams to lay their eggs in a gravel nest. The eggs hatch into fry known as alevins, which grow and develop through a sequence of stages, known as parr and then smolts. Salmon smolts remain in fresh water for several years before migrating to the sea. After 1 to 4 years, salmon return to the river in which they hatched, to complete their life cycle by spawning. After this, most adult salmon die.

Life cycle of tuna

Tuna live in large shoals in the open ocean. Mature females release up to 2 million eggs per spawning event which, when fertilised, hatch quickly into larvae. The eggs and larvae float and form part of the zooplankton. Tuna larvae feed on zooplankton and grow rapidly. After about 2 to 3 weeks the juvenile tuna feed on small fish, crustaceans and molluscs, reaching maturity at about 1 year.

Life cycle of the oyster

Adult male and female oysters release sperm and eggs into the water and fertilisation occurs. The fertilised eggs develop to form a series of free-swimming planktonic larvae, including veligers. After about 3 weeks development, each larva develops a foot, sinks and attaches to a suitable substrate. Newly attached oyster larvae are referred to as 'spat' and grow to maturity in about 1 to 3 years.

Life cycle of the shrimp

In many species of crustaceans, the females hold their fertilised eggs, but some species of shrimps (including commercially important species) release them immediately. The eggs hatch into larvae which undergo a succession of stages, including the zoea and the mysis stages. The larval stages are present in zooplankton.

Juvenile shrimps move into estuarine waters where they settle at the bottom, feed and grow, before returning to the open sea.

Life cycle of the giant clam

Mature, adult giant clams are hermaphrodites and release both eggs and sperm. Fertilisation occurs externally and the fertilised eggs float with water currents. The eggs hatch to form trocophore larvae which develop a foot and, after about one week, settle on the substrate and metamorphose into juvenile giant clams.

Life cycle of the grouper

In general, as groupers age they move into deeper water. Groupers are usually solitary, but aggregate on the reef edge to spawn. External fertilisation occurs and the fertilised eggs are planktonic. The larval groupers develop in habitats including sea grass beds and mangroves. After a period of time, the juvenile groupers move offshore to join the adult population.

Practical work could include preparation of illustrated posters showing the life cycles of salmon, tuna, oyster, shrimp, giant clam and grouper.

(b) *State the principal habitats for each stage in these life cycles, and discuss why these habitats are advantageous.*

The principal habitats for the stages in these life cycles are summarised in Table 10.1.

Table 10.1 Principal habitats for stages in the life cycles of salmon, tuna, oyster, shrimp, giant clam and grouper

Species	**Principal habitats**	
	Larval stages	**Adults**
Salmon	Freshwater streams	Oceans, pelagic
Tuna	Planktonic	Oceans, pelagic
Oyster	Planktonic	Attached to a hard substrate in tidal or subtidal marine and estuarine areas
Shrimp	Planktonic, then move into estuaries	Benthic, living on the sea floor
Giant clam	Planktonic	Tropical waters on reef flats and shallow lagoons to a depth of up to 20 metres
Grouper	Planktonic, then sea grass beds or mangroves	Coral reefs

From Table 10.1, it can be seen that these species occupy a range of different habitats, and the majority of species have planktonic larvae. The advantages of these habitats include availability of different food at different stages of their life cycle, dispersal by drifting in ocean currents, and shelter from predators.

(c) *Compare the advantages and disadvantages of internal and external fertilisation, and subsequent investment in the care of offspring, with reference to tuna, shark and whale.*

Many marine organisms reproduce by means of **external fertilisation**. Enormous numbers of male and female gametes are released into the water, and this is often synchronised to increases the chances of fertilisation. As an example, a single female oyster may release about 100 million eggs each year. Of these, however, very few will survive to maturity.

Internal fertilisation requires an intromittent organ and the male transfers sperm directly into the reproductive tract of a female. Internal fertilisation necessitates pairing of a male and a female of the same species, but it increases the likelihood of survival of the fertilised egg.

External fertilisation occurs in tuna; male and female gametes are released directly into the water and there is no parental care of the developing young.

Internal fertilisation occurs in sharks and rays and in many species of sharks the embryos develop inside the mother's body. This greatly increases their chances of survival as they are able to avoid predators after birth.

Internal fertilisation also occurs in whales. After a gestation period of about one year (11 to 12 months in the case of humpback whales), the whale calf is born. Whale calves feed on rich milk from their mother, as is the case in all mammals, and the calf stays with its mother for about a year.

These three species illustrate a range of reproductive strategies, from the tuna, which releases many thousands of eggs each time it spawns, to the whale which usually produces one offspring at time, but invests considerable maternal care to greatly increase the chances of survival of the calf.

(d) *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 animal reproductive behaviour

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11 Fisheries management

The need for sustainable fisheries.

Monitoring of fish stocks.

Methods of stock management and the enforcement of restrictions.

Methods of rehabilitating depleted stocks.

§ *Making links with AS*

✓ Section 6(f) *Ecological communities in mangroves*

✓ Section 5(e) *Artificial reefs*

(a) *Explain the need for sustainable fish stocks, with reference to North Sea fisheries.*

The North Sea (Figure 11.1) has traditionally been a productive source of a number of different species of commercially important fish, including cod, herring, haddock and plaice.

Figure 11.1 Location of the North Sea
[Image from: http://www.worldatlas.com/aatlas/infopage/northsea.gif]

Most stocks are over-exploited and the stocks of some species are at their lowest levels. The spawning stock biomass of cod, for example, fell from 157 000 tonnes in 1963 to 38 000 tonnes in 2001, which represents a decrease of nearly 76%. Since then, the spawning stock biomass has increased slightly. It is clear that over-exploitation of stocks can lead to depletion to levels where the population may be unable to recover.

(b) *Discuss the impact of modern fishing technology, including sonar, purse seine fishing, benthic trawling and factory ships, on fish stocks and habitats.*

Modern developments in fishing methods, including increased net size and mechanisation, have the potential for greatly increased catches, but at levels which may be unsustainable, leading to depletion of fish stocks as described in (a) above. **Sonar** means 'sound and ranging' and is a technique which can be used to measure sea depths and locate underwater objects including wrecks and shoals of fish. **Purse seine** nets are used to catch schools of fish near the surface. Schools of fish are detected and the net lowered to encircle the fish. The net closes round the fish, trapping the entire school. Fish caught using this method include tuna, mackerel, sardines and herring. Non-target species, including dolphins, may be caught using this method.

Benthic trawling is a technique used to catch species living on or near the sea bed, operating at depths of about 20 metres to 1000 metres or more. Species caught using trawl nets include cod and flat fish, such as plaice and halibut. Trawling can cause considerable damage to the sea floor ecosystem, but the extent of this damage varies according to fishing frequency and the stability of the substrate. Damage to the habitat may lead to changes in fish stocks through food chains and food webs.

Factory ships are large, ocean-going fishing boats with on-board processing and freezing facilities. They are able to stay at sea for many weeks at a time. Fishing methods employed by factory ships include purse seine netting and trawling. These large scale fishing methods can lead to serious depletion of fish stocks and harmful effects on non-target species.

(c) *Compare and contrast the long-term and short-term sociological impacts of restrictions on fishing, and of unrestricted fishing*.

Human communities that are dependent on fishing may experience changes in income as a result of unrestricted fishing and depletion of stocks. This has impacts on the fishing industry itself and associated industries including processing, marketing, distribution and transport. In the longer term, depletion of stocks may result in socioeconomic changes including displacement of the fishing industry. As an example, by the mid 1960s, catches of herring in the North Sea were greatly decreased and, as a result, the Lowestoft drifter fleet disappeared. However, many of the trawlers were adapted to work as service vessels for the increasing numbers of oil rigs in the North Sea.

(d) *Describe the principal information needed to decide how best to exploit fish on a sustainable basis, including recruitment, growth, natural mortality, fishing mortality, age of reproductive maturity, fecundity and dependency on particular habitats*.

Fisheries data may be gathered in a variety of ways to provide information on the growth of fish stocks and the impacts of fishing. The term **recruitment** refers to the rate of addition of new fish to the population, which depends on the rate of reproduction. In turn, as these fish grow, they become available to fishing gear. This may occur as a result of growth to a size worth catching, or as a result of migration of young fish into an area where they are accessible to fishing. Data on **growth** may be obtained by tagging coupled with methods for determining the age of a fish, such as counting the annual growth rings on scales or otoliths (ear bones).

Mortality of fish stocks has two components, **fishing mortality**, and that due to all natural causes such as predation and disease which is referred to as **natural mortality**. Fishing mortality is proportional to the fishing effort and can be estimated using tagging experiments, or by calculation of mortality rates from data obtained from the history of a fishery.

The **age of reproductive maturity** is variable in fish and may depend upon population density. In sardines, for example, the age at which spawning occurs decreases as the population density decreases. In general, larger and older fish produce more eggs than younger fish. The eggs produced by older fish also tend to be larger, which increases the chances of survival of the larvae. This has important implications for the exploitation of fish stocks; catching fish below their age of maturity will inevitably result in a population decrease.

The term **fecundity** refers to the number of eggs produced by a fish, or other organism. In a given species of fish, fecundity is proportional to the length of the fish. Fecundity and subsequent survival to recruitment age are important factors in determining the size of fish stocks.

Understanding the **habitat** of fish stocks is also important. Broadly, commercial fisheries consist of two groups, demersel and pelagic. Demersel fisheries target species such as cod, haddock and flat-fish which live on, or near the sea bed. Pelagic fisheries exploit those species which form shoals near the surface, such as herring, mackerel and tuna. As outlined in (b), damage to the habitat can result in a decrease in the availability of a target species.

Candidates should appreciate how each of the following factors determines what might be a sustainable harvest from a fish population:

- recruitment
- growth
- mortality
- age of reproductive maturity
- fecundity
- dependency on a particular habitat.

(e) *Outline the principal tools used to ensure that fish stocks are exploited on a sustainable basis, including*:

- *restriction by season*
- *restriction of location, including refuge zones*
- *restriction of method, including minimum mesh sizes and the compulsory use of rod and line*
- *restrictions on the size of fish that can be retained*
- *restriction of fishing intensity, including restrictions on the number of boats, boat and engine size, and the amount of fishing gear*
- *market-oriented tools, including the labelling of tuna as dolphin-friendly* (Figure 11.2).

Candidates should recognise the methods listed above as approaches to help ensure that fish stocks are exploited on a sustainable basis, that is, maintaining a consistent catch rate without damaging the environment and depleting fish stocks.

The main methods used to help prevent over-exploitation of fish stocks can be considered in two groups:

✓ **technical**, which aim to reduce the number of young fish caught before they mature, for example, by minimum mesh size.

and

✓ **direct** methods, which aim to limit the quantity of catch, for example, by limiting the fishing effort.

Candidates could prepare a table summarising technical and direct methods for protecting fish stocks and outlining the methods and their aims.

Figure 11.2 A can of 'dolphin friendly' tuna
[Photo © John Adds]

(f) *Discuss the principal methods of monitoring* (*including air and sea patrolling, inspection of catch, catch per unit effort, satellite monitoring*) *and enforcement* (*including imposition of fines, confiscation of boats and gear, imprisonment*).

Candidates should be aware that the above methods are used to monitor catching and to enforce legal restrictions, and to ensure that catches do not exceed legal quotas. The term **catch per unit effort** (CPUE), also known as the catch rate, is a means of determining stock sizes for management purposes. CPUE can be found by dividing the catch by the effort used, for example, the time spent fishing, or the amount of fuel used. Fishermen are required to keep records of these factors, to provide data relating to fish stock abundance.

Fines imposed for exceeding legal quotas can be considerable, for example £500 000 (nearly 800 000 US dollars). Fishermen may be given a limited time to pay the fine or face a prison sentence.

(g) *Discuss the advantages and disadvantages of the tools and methods in (e) and (f), including their effectiveness and their impact on non-target species*.

Candidates could summarise the effectiveness of the methods for regulating the exploitation of fish stocks and the methods for monitoring catch rates in the form of tables, such as those shown in Tables 11.1 and 11.2.

Table 11.1 Methods for regulating the exploitation of fish stocks

Method	**Effectiveness**	**Effect on non-target species**
Restriction by season		
Restriction of location		
Restriction of method		
Restrictions on the size of fish retained		
Restriction of fishing intensity		
Market-oriented tools		

Table 11.2 Methods for monitoring fish catches

Method	**Effectiveness**	**Effect on non-target species**
Patrolling		
Inspection of catch		
Catch per Unit Effort		
Satellite monitoring		
Enforcement (fines, etc.)		

(h) *Discuss the opportunities for, and advantages and disadvantages of the rehabilitation of depleted stocks, including replanting mangroves, building artificial reefs and introducing cultivated stock to the wild*.

Mangroves have important ecological roles, including providing nursery grounds for many species of fish and crustaceans. In parts of south-east Asia, for example, significant areas of mangroves have been lost, partly due to shrimp farming. However, efforts are being made to replant mangroves which have the benefits of both providing habitats for commercially important species of fish and crustaceans, and providing protection of coastal areas from storm damage.

Artificial reefs can be constructed from a wide range of materials, including old rubber tyres and concrete blocks filled with ash. The aim of constructing artificial reefs is to provide habitats for fish, increasing their abundance. It is clear that many such artificial reefs rapidly become colonised by fish, including groupers. It has also been suggested that redundant oil-drilling rigs could be sunk in deep water to act as artificial reefs. This, however, remains controversial as there is concern about their possible adverse impact on deep sea ecosystems.

There have been a number of attempts to **introduce cultivated stock** to the wild, for example, plaice, prawns and pink salmon. These are cultivated in hatcheries, before being released into the wild. The success of this technique is very variable and needs to be carried out on a sufficiently large scale to have any significant impact on the numbers of fish subsequently available to be caught. Although these methods do have the potential for increasing wild stock, much of the recent increase in production is a result of aquaculture.

(i) *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.

Fisheries management

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12 Aquaculture

Processes for intensive and extensive aquaculture.

The requirements and impacts of aquaculture.

(a) *Explain the meaning of the terms* intensive *and* extensive *aquaculture* techniques.

Aquaculture involves the farming of aquatic species under controlled conditions, as opposed to catching wild species. Aquatic organisms farmed using aquaculture include different species of fish, molluscs, crustaceans and aquatic plants.

Essentially, this means that the organisms are reared in enclosed bodies of water, such as ponds or tanks, or kept in cages submerged in the sea. **Intensive aquaculture** means that organisms are kept in enclosures where it is possible to monitor and control environmental factors such as the concentration of dissolved oxygen. Intensive aquaculture operations usually make it possible to have a relatively high density of organisms, which requires a high input of food and possibly antibiotics. The productivity of intensive systems is relatively high.

Extensive aquaculture involves rearing organisms in a natural situation, such as in a pond or in an estuary, with little attempt to control the environment. Extensive aquaculture systems usually have a lower stocking density than intensive systems, with a correspondingly lower input of food and a lower productivity than intensive systems.

(b) *Outline the process for the aquaculture of grouper, tuna, shrimp and giant clam*.

Groupers are farmed widely in south-east Asia. Larvae are kept in tanks and fed on a diet which includes zooplankton. Growing fish are kept in underwater net cages, anchored to the sea floor, and fed on a carefully controlled diet including pelleted food. The food supplied and growing conditions are carefully monitored to ensure that there are minimal adverse effects on the environment.

Increasing quantities of **tuna** are being produced through aquaculture, in net pens and fed on bait fish. In Australia, southern bluefin tuna are reared in this way, and in the Mediterranean farming of the northern blue fin tuna is beginning.

Aquaculture of **shrimps** started in the early 1970s and now over 50 countries produce shrimps in this way. Shrimps are generally reared in ponds and tanks, and are fed on algae, zooplankton and specially formulated feeds. In intensive shrimp farming systems, the yields can be considerable, for example, up to 20 000 kg per hectare per year. Shrimp aquaculture ponds are shown in Figure 12.1.

Figure 12.1 Shrimp aquaculture ponds in Mexico
[Source: http://www.fao.org/docrep/005/y1818e/y1818e00.jpg]

Aquaculture of **giant clams** began in the early 1970s in response to a decline in their availability. Giant clams are farmed by a number of Pacific countries. They are reared in wire mesh cages, which are raised off the sea floor. This helps to prevent attack by predators and to protect the growing clams from sand and silt that may be disturbed by wave action. Giant clams contain symbiotic zooxanthellae from which the clams obtain most of their nutrients, including carbohydrates, amino acids and fatty acids. Giant clams require clear sea water with a good water exchange rate to ensure that they receive sufficient light and nutrients.

(c) *Explain the requirements for sustainable aquaculture* (*availability of stock, availability of clean water, efficiency and use of feed, availability of labour, disease management, availability of location, market demand, access to market, return on investment*).

Candidates should understand the importance of the following factors in relation to sustainable aquaculture:

- availability of stock, for example, as larvae for rearing to adults
- availability of clean water
- efficiency and use of feed
- availability of labour
- disease management
- availability of location
- market demand
- access to market
- return on investment.

All of the above factors should be considered in relation to both intensive and extensive aquaculture systems. The capital outlay on some intensive systems, for example, may be very considerable (multimillion dollars) and this, coupled with running costs, is an important consideration.

(d) *Identify the principal impacts of aquaculture* (*habitat destruction, overexploitation of feedstocks, pollution, introduction of exotics, spread of disease, competition for resources, social impacts, economic impacts*).

Whilst aquaculture has a number of benefits, particularly in terms of food production, there are also a number of potential negative impacts. Candidates should recognise the possible impacts of aquaculture on the environment, for example, **destruction of mangroves** for prawn farms and the possibility of **eutrophication** arising from fish farming activities, and also the possible **socio-economic** impacts. These include competition between local, traditional fishing activities and employment in the aquaculture industry.

There have been instances where alien farmed species have escaped (for example, as a result of storm damage to submerged cages) with resulting ecological damage to natural populations as a result of competition.

It is clear that both socio-economic factors and the possible negative ecological factors are important when considering the future sustainability of aquaculture.

(e) *Use this knowledge and understanding to assess the suitability of proposed aquaculture projects, in terms of requirements and impacts*.

This topic offers candidates an opportunity to prepare a 'case study' based on a real, or hypothetical, local aquaculture project. To take an example, consider a proposal to start a new aquaculture venture, to produce shrimps in Malaysia. What are the factors that need to be considered? What are the possible ecological and socio-economic impacts of the project?

(f) *Suggest how the negative impacts of aquaculture might be minimised*.

Candidates should consider ways in which the negative impacts of aquaculture listed in (d) above could be reduced. To illustrate one example, one of the major problems associated with intensive systems is the potential for eutrophication. One way in which this can be reduced is to recycle water in growing tanks, filter and remove wastes, rather than allowing waste water to be discharged directly into the sea. Another example is the use of vaccination of fish, rather than using antibiotics to control the spread of disease in farmed fish.

(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.

Aquaculture

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13 Human impact on marine ecosystems

Ecological impacts of industrial activities.

The accumulation of toxins in food chains.

Global warming and its impact.

The ecological effects of shipwrecks.

> § ***Making links with AS***
>
> ✓ Section 2(a) *Habitat and biodiversity*
>
> ✓ Section 2(c) *Food chains and food webs*
>
> ✓ Section 7 *Factors affecting the chemical composition of sea water*

(a) *Explore the ecological impacts of*
- *the oil industry*
- *desalination plants*
- *agriculture*
- *sewage and refuse disposal*
- *dredging*

on marine water quality, habitats, biodiversity and food webs.

Oil pollution of the marine environment arises from a number of sources, including urban run-off, oil tanker washing and accidents involving oil tankers. Some examples of oil tanker accidents and their environmental effects are shown in Table 12.1.

Table 13.1 Major sources of oil pollution involving tanker accidents

Name of tanker	Year	Notes
Torrey Canyon	1967	Wrecked off the coast off Cornwall, England, carrying 120 000 tonnes of crude oil. It is estimated that 15 000 sea birds were killed. Much environmental damage was also caused by the detergents used in an attempt to disperse the oil.
Amoco Cadiz	1978	Ran aground and broke up off the coast of Brittany, France, releasing 1.6 million barrels of oil. Stormy weather hampered the clean up operation; rough seas caused the formation of an emulsion of oil and water. It has been estimated that this accident caused the deaths of nearly 20 000 sea birds and 9 000 tonnes of oysters. Many other molluscs, crustaceans and echinoderms (sea urchins) were also killed.
Exxon Valdez	1989	Ran aground in Prince William Sound, off the south coast of Alaska, spilling up to 750 000 barrels of crude oil. Immediate environmental effects were the deaths of hundreds of thousands of sea birds, at least 2 800 sea otters, and many other mammals. Shore organisms were also destroyed by the use of high pressure hot water in an effort to clean oil from rocky shores.
Braer	1993	Ran aground off Shetland, Scotland, carrying 84 700 tonnes of crude oil. Severe weather at the time caused much of the oil to disperse, although sea birds and the salmon farming industry were affected. Oil spray was also blown on-shore, contaminating up to 50 km^2 of farmland and destroying crops.
Shen Neng 1	2010	Ran aground off the north-east coast of Australia, carrying 950 tonnes of oil and 65 000 tonnes of coal. Fuel oil leaked from punctured tanks, close to the Great Barrier Reef.

Recently, a major oil spill occurred in the Gulf of Mexico, as a result of an explosion and subsequent destruction of the oil drilling rig Deepwater Horizon, in April 2010. Estimates indicate that up to 698 million litres of oil leaked into the Gulf, before the well was capped. The oil spillage has the potential to cause massive environmental damage directly to marine organisms, food chains, sea food industries and to life along hundreds of miles of coastline.

Desalination is the process of removing salts from sea water to obtain drinking water, or water for crop irrigation. This is an energy-dependent process and is often carried out by vacuum distillation. There are two major environmental impacts of desalination; firstly the effects on marine organisms as a result of extracting water directly from the sea and secondly, the effects of returning concentrated brine to the marine environment. The concentrated brine is denser than natural sea water and so it tends to sink, causing harm to bottom-dwelling organisms.

Agriculture may impact the marine environment in two principal ways. Fertilisers, containing nitrates and phosphates, may leach into water courses and flow into estuaries causing eutrophication (nutrient enrichment that may cause the rapid growth of algae). Pesticide residues may also enter the marine environment in a similar way. Some pesticides are chemically stable and can pass along food chains, increasing in concentration at each trophic level.

Sewage is often treated before the final effluent reaches the sea, but raw sewage may be piped directly into sea water. Sewage contains a mixture of components, including suspended organic matter, phosphates and nitrates, detergents, and microorganisms. The major components of sewage and their effects in the marine environment are summarised in Table 12.2.

Table 13.2 Major components of sewage and their effects on the marine environment

Components of sewage	**Effects on the marine environment**
Suspended organic matter	Particles reduce light penetration and create a high demand for oxygen during the breakdown of organic matter by microorganisms.
Phosphates and nitrates	Excess nitrates and phosphates lead to eutrophication and consequent algal blooms.
Detergents	May contain phosphates which lead to eutrophication; foam on the surface reduces aeration of the water.
Microorganisms	Viruses and bacteria present in sewage pose a direct health risk to humans; microorganisms may also accumulate in shellfish.

Dumping at sea is a method used to dispose of a wide range of **refuse**, including sewage sludge, industrial wastes and rubbish. Rubbish includes glass and plastic bottles, tin cans and plastic bags. Many plastic degrade very slowly and plastic bags pose a particular danger to many forms of wildlife, particularly turtles, which may eat them, mistaking them for jellyfish. Animals may be poisoned or starved as a result of ingesting plastics, or may be trapped in discarded plastic items.

Dredging is used to keep shipping lanes clear and to extract gravel and metal nodules from the sea bed. This has several harmful effects on the marine environment, including reducing habitat diversity and biodiversity, and producing a plume of sediment, which adversely affects filter-feeding organisms. Dumping of dredged material is harmful to the sea bed and may contain toxic metals.

(b) *Explain the reasons for the links between human activities in (a) and their ecological impacts, making reference to the physical properties and chemical composition of sea water where necessary*.

The activities listed in (a) cause pollution of the marine environment in a variety of ways. These include introducing substances which are directly toxic to marine organisms, and altering the chemical and physical properties of sea water by, for example, changing the salinity or adversely affecting light penetration. Candidates could summarise the information in (a) in the form of a table as suggested below.

Table 13.3 Ecological impacts on the marine environment of human activities

Human activity	**Impacts on the marine environment**
The oil industry	
Desalination plants	
Agriculture	
Sewage and refuse disposal	
Dredging	

(c) *Explain the accumulation of toxins in food chains, making reference to antifouling paint and mercury pollution, and explore its impact on human food sources*.

Antifouling paint is used on ships' hulls to reduce the growth of attached organisms such as barnacles. Antifouling paint contains a substance known as tributyl tin (TBT) which has been shown to have adverse effects on populations of molluscs, including oysters. TBT and some other pollutants can cause a condition referred to as *imposex* in molluscs, in which females grow male reproductive organs. This leads to sterility and death of the female molluscs.

There is an International Convention on the Control of Harmful Anti-Fouling Systems on Ships (AFS Convention), which is accepted by at least 25 countries. This convention came into force in September 2008.

On the 1st January 2008, an EU ban on the presence of TBT-based antifouling paint on the hulls of ships in EU ports came into effect.

Mercury, and other heavy metals, may accidentally enter the marine environment in effluent from industrial processes. Mercury compounds, such as methyl mercury, are particularly toxic and, although they may occur in very low concentrations in plankton, the compounds accumulate and increase in concentration at each trophic level. As a result, they may be present in fish such as tuna at concentrations which are harmful to humans. This process, where a compound increases in concentration as it passes along a food chain, is referred to as **bioaccumulation** and is illustrated in Figure 12.1.

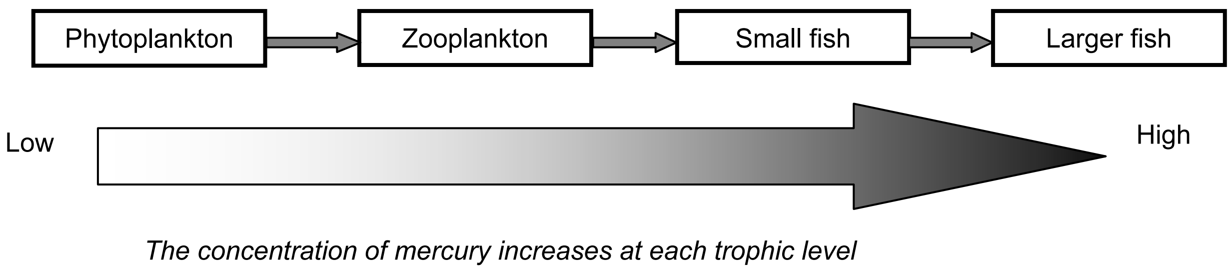

Figure 13.1 Bioaccumulation of mercury in a food chain

Minamata disease, discovered in Japan in 1956, was caused by the release of methyl mercury into sea water. This caused the death or damage to the nervous system of many people who had eaten locally-caught fish or shellfish.

(d) *Demonstrate an understanding of the evidence for global warming.*

The greenhouse effect is a natural phenomenon which is essential for maintaining global temperatures. Gases in the atmosphere trap heat and keep the temperature of the surface of the Earth higher than it would be without these gases.

Several gases in the atmosphere absorb heat. These gases are known as greenhouse gases and include carbon dioxide, methane and chlorofluorocarbons (CFCs). The levels of these gases in the atmosphere have increased over the last 150 years, which has led to an enhanced greenhouse effect, resulting in a rise in temperature on the surface of the Earth. Analysis of data relating to global temperatures shows an increase of 0.5 °C over the last 150 years. Further evidence for changes in global temperatures is provided by analysis of ice cores, changes in sea level, and surveys of melting glaciers.

(e) *Discuss and evaluate the evidence for and against the hypothesis that global warming is caused by human activities*.

The concentration of carbon dioxide in the atmosphere has risen significantly over the last 150 years, from an estimated 270 parts per million (ppm) in the 1850s, to over 380 ppm in 2005. This rise is largely due to an increase in the combustion of fossil fuels, such as oil, coal and natural gas, and the process of deforestation. Both of these processes produce carbon dioxide faster than it can be removed from the atmosphere. This does not necessarily mean that global warming is caused by human activity, but there are clearly links between the two. Opponents to the hypothesis that global warming is caused by human activity cite natural variations in global temperature, changes in ocean currents and changes in solar radiation as possible causes of global warming.

(f) *Describe the possible impacts of global warming, including sea level rise and coral bleaching*.

Some computer models have predicted that, if atmospheric carbon dioxide levels continue to rise at their present rate, mean global temperatures could increase by at least 1.5 °C by the year 2030. This increase is sufficient to have a number of effects, including **rising sea levels**, as a result of expansion of sea water and the melting of glaciers and polar ice, and **coral bleaching**. Coral bleaching is a process which involves the loss of symbiotic zooxanthellae from coral when it is under stress, as a result of a small increase in temperature, for example. Prolonged or severe coral bleaching results in death of the coral.

(g) *Compare and contrast the ecological impacts of the wreck of an oil-filled tanker and a vessel deliberately sunk as a wreck dive*.

Loss of both crude oil and fuel oil from a wrecked oil tanker can have devastating ecological consequences, as described in (a) above. After the initial losses, oil may continue to leak from a sunken tanker for many years.

Before a vessel is sunk as a wreck for divers, the ship is thoroughly cleaned of all oils, hydraulic fluids and any dangerous chemicals, such as PCBs which may be present in electrical components. Any structures that may corrode quickly are also removed. Holes are cut in the ship's hull to facilitate sinking and to allow access to divers. One notable example of a ship deliberately sunk to act as an artificial reef and as a dive wreck is the *USS Oriskany*, sunk off the coast of Florida in 2006.

(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.

Human impact on marine ecosystems

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14 Marine conservation and ecotourism

Conservation.

Ecotourism.

> § ***Making links with AS***
>
> ✓ Section 2(a) *Ecosystem and biodiversity*

(a) *Explain the meaning of the term* conservation.

Conservation has been defined as 'the protection and preservation of natural resources and of the environment.' The main aims of conservation are to:

- conserve a range of different habitats so they are not lost as a result of pressures from human populations
- encourage biodiversity in a range of habitats.

The term conservation often applies to a single species which is considered to be endangered, e.g. conservation of leatherback turtles, or conservation of whale sharks.

(b) *Explain the arguments for and against the desirability of conserving marine species and ecosystems.*

The conservation of marine species and their habitats aims to maintain species diversity. This may be achieved by fisheries management, which maintains the population of target species and minimises the effects on non-target populations. Damage to the habitat, for example by dredging or trawling, can cause adverse effects which may result in the loss of a particular species associated with that habitat.

Conservation measures may, however, have negative socio-economic effects on local human populations who previously depended on the marine resources within that area.

(c) *Discuss, in the context of human activity on marine species and ecosystems, the need for conservation.*

The negative impacts of human activities on marine species and ecosystems are the result of two main factors, over-fishing leading to depletion of stocks, and pollution.

Over-fishing of cod in the North Sea illustrates the need for conservation. Stocks in the North Sea have fallen to about one-tenth of the level 30 years ago. It is possible that numbers will fall to a level from which it is difficult to recover. One of the consequences of this is that a decline in the large predatory fish allows other species to flourish. Depletion of one species, as a result of over-fishing for example, can therefore affect populations of other species.

(d) *Demonstrate an understanding of why, to be successful, conservation must sustain ecological linkages and processes.*

If it is to be successful, conservation must be based on a detailed understanding of the ecological processes and interrelationships between organisms and their environment. We need to understand why some species and habitats are more vulnerable than others, and how degraded ecosystems can be improved. Without such understanding, attempts at conservation may not be successful.

(e) *Demonstrate an understanding that there are competing requirements between the activities of coastal communities, including agriculture, industry, shipping, sewage and refuse disposal, aquaculture, fisheries, tourism and conservation.*

Candidates should recognise that there are possibly conflicting interests between a number of different activities of coastal communities, as listed in (e) above. All of these activities make specific demands on the marine environment and have the potential to cause negative effects. It is clearly important to consider all the possible demands and interests in order to maintain, or possibly enhance, biodiversity.

(f) *In given examples of conservation issues, identify stakeholders, conflicts of interest causes and possible solutions*.

One example of a conservation issue is the establishment of Marine Protected Areas (MPAs). These are designated areas that include part of the oceans, in which certain activities, such as fishing, are controlled to protect species. In some MPAs, there may be a complete ban on taking any marine organisms. When setting up MPAs, biologists may put forward the case for conservation of certain endangered species. This is adjusted by stakeholders until an agreement is reached. There is, however, a possible conflict of interest between stakeholders such as those dependent on tourism, who can see the benefit of managed and improved habitats and fishermen who need a daily income. One possible solution to the problem is a dialogue so that fishermen may understand the potential benefits of maintaining their fishing grounds to ensure sustainable catches.

(g) *Define* ecotourism *as tourism based on the appreciation of the natural environment, and identify and assess types of ecotourism that support or undermine conservation*.

Ecotourism (also referred to ecological tourism) has a number of aims including:

- travel to natural destinations, including fragile and protected areas
- having a low impact on the area
- educating the traveller
- providing funds for local conservation
- benefiting the local economic development
- encouraging respect for different cultures.

This is clearly not the same as placing hotels in a beautiful landscape and exploiting the local area. The concept of ecotourism is often misunderstood and there is a wide spectrum of tourism activities from those with true ecotourism criteria, to those which although claiming to be environmentally friendly are, in reality, nothing of the sort. At worse, these tourist activities are environmentally destructive and culturally insensitive.

Practical work could include a visit to an 'ecotourism resort' and an assessment of how far the aims of ecotourism are being met.

(h) *Argue the benefits to conservation of responsible practice in tourism, including energy conservation, recycling, use of sustainable sources of building materials and sponsorship of conservation*.

Candidates should recognise that energy conservation, recycling and the use of sustainable sources of building materials are practices which reduce the impact of tourism on the environment and help to ensure sustainability of ecotourism. The revenue generated by ecotourism should also help to sponsor conservation projects. However, there may be a conflict of interest here as many ecotourism resorts are owned by foreign investors and there is a risk, therefore, that profits will not be re-invested in the local economy or in conservation projects.

(i) *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 conservation and ecotourism

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15 Marine biotechnology

Biotechnology.

Genes, promoters and phenotypes.

Advantages and dangers of genetic engineering.

(a) *Define* biotechnology *as the industrial application of biological processes*.

Biotechnology is the application of scientific and engineering techniques to biological processes. These processes often involve the use of microorganisms, such as bacteria and fungi to make a commercially important product. Biotechnology is not new, as these processes have traditionally been used in the production of bread, wine, cheese and other fermented products, which exploit the metabolic activities of specific microorganisms.

With the possibilities of genetic modification of microorganisms, the scope of biotechnology has recently increased significantly, with the industrial production of, for example, drugs, enzymes and vaccines.

Some species of jelly fish, illustrated in Figure 15.1, contain a gene for the production of green fluorescent protein. This gene has been isolated and has a wide range of applications in genetic engineering, including its use as a 'marker gene' to show gene expression.

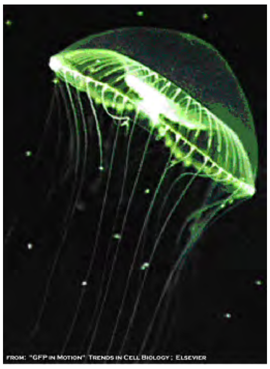

Figure 15.1 Jelly fish containing green fluorescent protein
[Source: http://www.rpc.msoe.edu/cbm2/images/gfp/gfp1-3.jpg]

(b) *State that some microorganisms digest oil, and that these microorganisms are used to digest oil pollution*.

Some naturally occurring species of bacteria (including *Pseudomonas*) are able to break down the hydrocarbons present in oil into carbon dioxide and water. The activity of the bacteria may be increased by the application of inorganic fertilisers, which increases the rate of breakdown of oil. This is an example of the process of **bioremediation**, which uses microorganisms, or other organisms, to break down pollutants into harmless products. Bioremediation offers a method for the removal of oil with a lower environmental impact than some other methods.

(c) *Define the term* gene *and outline the effect of genotype on phenotype*.

A **gene** may be defined as a length of DNA (deoxyribonucleic acid) that codes for a specific polypeptide product. Genes may be regarded as the units of heredity, as they carry genetic information. Genes exist in alternative forms, known as alleles. Alleles may be dominant or recessive. The term **genotype** is used to describe the genetic constitution of an organism, for the character under consideration. The **phenotype** is the physical appearance or particular character of an organism. The phenotype depends upon interaction between the genotype and the environment. In some instances, the environment has little or no influence, for example, in the inheritance of ABO blood groups in humans. In others, the environment has a strong influence on phenotype. For example, the growth of an organism may be influenced by its genotype, but the availability of nutrients (an environmental factor) will also affect the growth. Two organisms with very similar genotypes may grow at different rates, depending of their levels of nutrition.

(d) *Outline the role of promoters in the control of genes*.

In addition to the coding part of a gene, all genes have a **promoter**, which acts as a means of regulating the expression of the gene. The promoter indicates the place at which the process of transcription (the synthesis of messenger RNA, mRNA) should start. This is the start of the process of protein synthesis and is shown diagrammatically in Figure 15.2.

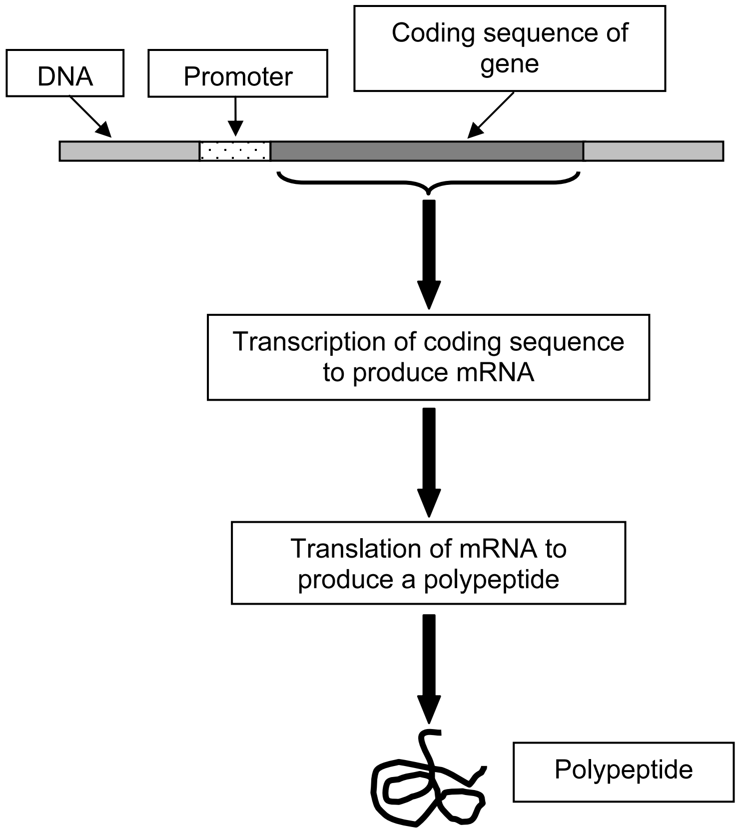

Figure 15.2 A promoter shows where a gene is to be transcribed to produce mRNA

(e) *Define* genetic engineering *as the transfer of a gene or genes from one species to another*.

The term **genetic engineering** (also referred to as gene technology) means the technique of transferring a gene from one organism to another of a different species, using recombinant DNA technology. This results in the production of a genetically modified organism (GMO). For example, it is possible to transfer a gene from a species of bacterium into crop plants so that the crop plants become resistant to insects.

The first organisms to be genetically modified using recombinant DNA technology were bacteria. Insulin, a hormone used in the treatment of diabetes, is produced using genetically modified bacteria and yeast cells.

(f) *Distinguish genetic engineering from other types of biotechnology, and from selective breeding*.

Genetic engineering is a process which involves the transfer of one or more genes from one species of organisms to another, using methods of recombinant DNA technology. This results in the production of a genetically modified organism (GMO) in ways which would not occur naturally. It is a relatively recent technique; the first organisms to be genetically engineered were bacteria, in the early 1970s. Biotechnology is a general term, for applications of scientific and engineering principles to industrial processes, such as brewing beer. Biotechnology may involve the use of genetically modified microorganisms, such as those grown on a large scale to synthesise commercially important products, such as enzymes and drugs.

Selective breeding has been practised for thousands of years and involves traditional methods of plant and animal breeding. In selective breeding, parents with advantageous characteristics are chosen, to produce offspring with advantageous features. This is the method that has been used to produce many different varieties of farm animals, domesticated animals and crop plants.

(g) *Show an understanding that genes cannot be accurately placed in the genome when transferred, and that a promoter may need to be attached to a gene before transfer*.

In genetic engineering, there are various different ways of introducing a new gene into the host cell. One commonly used method is to use a virus as a vector for gene transfer. Once inside the host cell, the new gene may attach to the host cell genome (DNA), but will do so more or less in a random place. It is possible that the new gene will attach to the host cell DNA in a relatively 'quiet' region and, as a result, the rate of gene expression will be slow. In other parts of the host cell DNA gene expression will be high.

Before the transfer of certain genes, a promoter may be attached [see part (d) above]. In effect, the promoter 'switches on' the gene so that it will be expressed continuously.

(h) *State that salmon has been genetically engineered with a growth-promoting gene from another fish, and a promoter to turn this gene on all year round*.

Genetically engineered Atlantic salmon (known as 'AquAdvantage' salmon, shown in Figure 15.4) have been produced by a US biotechnology company. These salmon contain a gene for the production of a growth hormone, taken from a Chinook salmon. This gene is attached to a promoter from another species of fish, the ocean pout. The promoter ensures that the gene for the production of growth hormone remains active, even at low temperatures, so that the genetically engineered salmon continue to grow all year round. These genetically engineered salmon should reach market weight of approximately
3 kg in about 18 months, as opposed to three years for non-genetically engineered farmed salmon.

An outline of the process for the production of genetically engineered salmon is shown in Figure 15.3.

The US Food and Drug Administration has recently concluded that the genetically engineered salmon are safe to be farmed and eaten, although there is likely to be considerable consumer resistance.

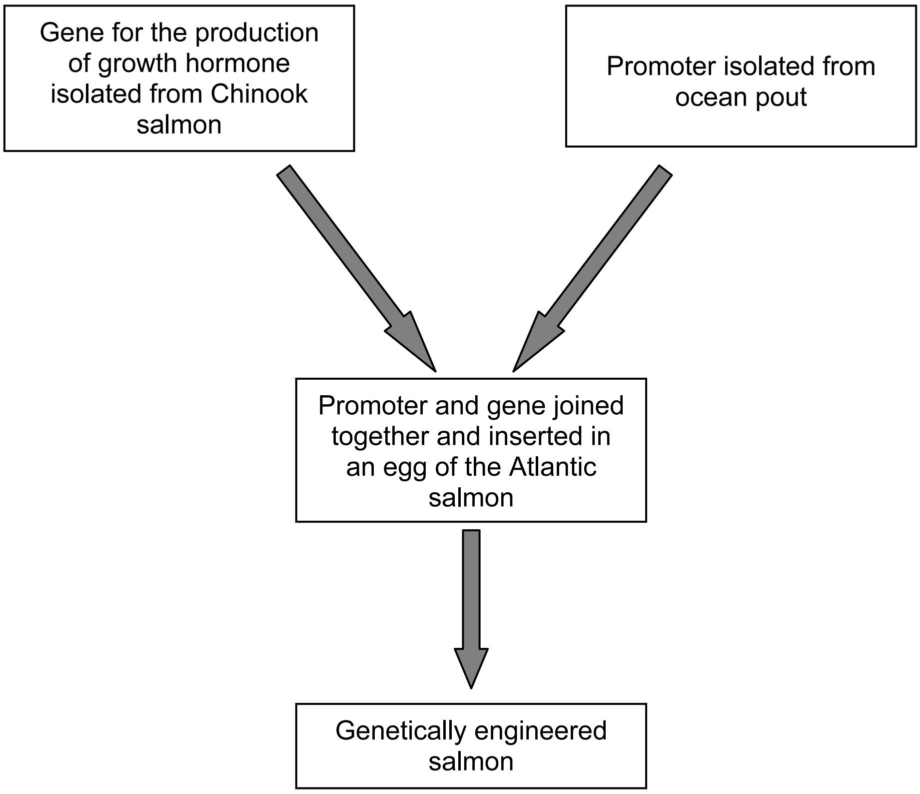

Figure 15.3 Outline of the process for the production of genetically engineered salmon

Figure 15.4 A genetically engineered salmon, with a non-genetically engineered Atlantic salmon of the same age in the foreground
[Picture from: http://www.telegraph.co.uk/foodanddrink/foodanddrinknews/7983700/Fast-growing-GM-salmon-safe-to-be-farmed-and-eaten.html]

(i) *Discuss the advantages of genetic engineering for aquaculture, and the possible impact of the escape of genetically engineered species into the wild*.

Genetically engineered fish offer a number of potential benefits for aquaculture, in particular their rapid growth rate. This raises the possibility of quick food production and reducing the chance of depleting wild populations. It may also be possible to apply the same technology to other species of fish, such as *Tilapia*, which are farmed in many countries around the world.

If genetically engineered salmon are farmed, they will be kept in tanks or enclosures to minimise the risk of escape. Nevertheless, there is considerable concern that if genetically engineered salmon were to escape, they would quickly out-compete wild populations. There are also concerns that escaped genetically engineered salmon could breed with wild populations, so that the modified gene spreads to wild salmon. However, to reduce the chances of this happening, the eggs of genetically engineered salmon are treated so that the fish that grow are all sterile females.

(j) *Demonstrate an understanding of the term* precautionary principle.

There are many different definitions of the **precautionary principle**, but in general, this principle states that if an action or policy has a possible risk of causing harm to people or to the environment, then the burden of proof that it is not harmful falls on those taking the action. The Wingspread Statement on the precautionary principle was formulated in the late 1990s by a meeting in the US and includes the following definition:

"*When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically. In this context the proponent of an activity, rather than the public, should bear the burden of proof*".

[Quoted from: http://www.pprinciple.net/publications/PrecautionaryPrincipleissuespaper.pdf]

This principle applies to many different situations, from road building to the farming of genetically modified organisms. Before any of these can proceed, detailed risk assessments are carried out to ensure that the environmental impact, or risk to people, will be minimal.

(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.

Marine biotechnology

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