The following is suggested material for exam answers, to provide a starting point when planning answers. It is not intended to be exhaustive, and the exam board will reward any other relevant points. Detailed and up-to-date examples are particularly important to achieve the top grades.

Theme 1 Foundation

1.1 Perspectives

Answers to review questions

1 *Answer pending copyright approval*

2 *Answer pending copyright approval*

3 A technocentric perspective is technology-based: it assumes all environmental issues can be resolved through technology and nature is a resource to be harnessed and controlled for unlimited economic growth. Example: libertarian cornucopians.

An anthropocentric perspective is human-centered: it views humankind as being the most important element of existence; it splits into a wide variety of views but lacks consideration for ecological interdependencies. Example: Judeo-Christian theology.

An ecocentric perspective is nature-centered: it sees the natural world as having preeminent importance and intrinsic value; it favours small-scale, low-technology lifestyles with restraint in the use of all natural resources. Example: deep ecologists.

Answers to exam-style questions

1 *Answer pending copyright approval*

2 Factors may include:

- Cultural: Some cultures place a high value on nature and thus have a more ecocentric environmental value system.
- Religious: Some religions deify certain organisms/landscapes and thus have a more ecocentric EVS.
- Economic: Some would argue that more economically wealthy societies tend towards a more technocentric/anthropocentric EVS.
- Sociopolitical: Some would argue that a society with a strong sociopolitical movement would tend towards a more anthropocentric EVS.
- Experience/history: Societies that have experienced anthropogenic disasters may become more prone to adopt ecocentric value systems.

[Award 3 max if only one category of EVS is addressed (question asks for 'contrasting cultures').
Note: Full credit can be given for giving a specific example to outline a link between a factor and EVS. However, if factors are simply named/listed without any explanatory outline broadly linking them to EVS, then just 1 mark can be awarded for every two valid factors identified, up to 2 max.]

1.2 Systems

Answers to review questions

1 Biosphere, hydrosphere, cryosphere, atmosphere, lithosphere.

[1 mark for each correct sphere name.]

2 Answers include:
- Open system: Inputs and outputs of matter and energy.
- Closed system: Inputs of matter and energy, and outputs of energy.
- Isolated system: No inputs or outputs of matter or energy.

[1 mark for each system and a description of the inputs and outputs. Answers without the full information about inputs and outputs do not receive a mark. For each mark, the name and correct inputs and outputs need to be given.]

3 Pros include: simplification of a complex idea, easy to understand, part of the early development of understanding the Earth's systems.

Cons include: too simplified to give realistic information, does not account for real interactions, the model eliminates elements in the atmosphere such as clouds and greenhouse gases that would interfere with the amount of the sun's energy that is absorbed or reflected away from the planet.

[1 mark for describing what the DaisyWorld model is, maximum 2 marks for pros and 2 marks for cons.]

4 Simplified models look at parts of systems in isolation. Emergent properties only occur when these parts of the system interact with one another. The outcomes of such interactions can be unpredictable but have a large impact on the system's regulation. The simplified model is not designed to take these into account, instead it focuses on individual impacts within the system.

[1 mark for describing a simplified system, 1 mark for explaining what emergent properties are, and 1 mark for stating that interactions are not included in simple models.]

5 Feedback in a system is what controls how the system will respond to different inputs. Positive feedback is a number of changes in a system that cause the equilibrium to shift to a different point, and this feedback can be amplified as it continues. Negative feedback is the self-regulation in a system that reacts to changes in the environment to ensure the equilibrium is not disturbed.

[1 mark for describing feedback, 1 mark for describing how a negative feedback system work, 1 mark for describing positive feedback, 1 mark for clearly stating how these two systems are different.]

Answers to exam-style questions

1 Deforestation is the removal of trees from a forest ecosystem. This usually includes removing the whole forest. The trees in the forest are a long-term storage of carbon, and removing them from the system effectively removes the majority of the carbon in the system. This is because the felled trees are removed from the system and are therefore not able to return the carbon back to the environment during decomposition.

[1 mark for describing what deforestation is, 2 marks for ways in which that impacts carbon storage.]

2 [1 mark for an explanation of what models are and 1 mark for how they can be used to make predictions.]
[2 marks for explaining each relevant issue that models can help improve, maximum of two issues.]
[1 mark for a concluding statement relating to models having limited impact if the scope of the issue is greater than what has previously been observed.]

1.3 Sustainability

Answers to review questions

1 Factors for sustainable development – economic sustainability, social sustainability and environmental sustainability.

2 Example answer: The doughnut economics model of sustainability is better as it considers economy and society as part of the environment, taking into consideration the fact that all economic decisions and social actions have some impact on the environment.

3 Environmental justice is the fair treatment of all individuals with respect to resource allocation and access, regardless of their race, religion, culture, education, gender or economic status, e.g. everyone having access to freshwater.

4 Data collection at local levels, monitoring use and misuse of resources, generating community awareness, advocating policies, early warning systems, collective responsibility for resources.

5 Response must include appropriate reasons, including changes in land use (e.g. increased deforestation for agriculture and urbanization), climate change (e.g. increase in carbon dioxide emissions), decrease in biodiversity.

Answers to exam-style questions

1 Clear understanding of the doughnut economic model including social foundation, economic ceiling and the concept of 'safe and just space for humanity'; examples showing how embracing the doughnut economy has contributed to sustainability; examples may include countries, cities, communities, businesses; description of interconnectedness between social, economic and environmental aspects.

2 Describe social justice and equity, role of social justice in equitably distributing benefits of sustainable practices, long-term approach (accessibility for current and future generations), addressing root causes to gain long-term benefits, ethical considerations influence responsible and conscientious environmental management.

Theme 2 Ecology

2.1 Individuals and populations, communities, and ecosystems

Answers to review questions

1 Carrying capacity for human populations refers to the maximum number of individuals of a species, in this case humans, that a given environment can sustainably support over the long-term. It is the point at which the available resources, such as food, water and living space, are no longer sufficient to support further population growth. Carrying capacity takes into account both the natural resources available and the impact of human activities on the environment. When a population exceeds its carrying capacity, it can lead to resource depletion, environmental degradation, and a decline in overall quality of life.

2 The term 'niche' in ecology refers to the specific role and position of a species within its ecosystem. It includes the species' interactions with other organisms and its utilization of environmental resources. A niche encompasses various aspects, such as the type of food a species consumes, its habitat preferences, its reproductive strategies, and its interactions with other species, including competition and predation. The niche of a species is like its ecological 'job description', detailing how it fits into the larger ecosystem and contributes to its functioning.

3 S- and J-population growth curves are models used to represent different patterns of population growth.

- S-population growth curve (logistic growth): The S-curve represents logistic growth, where a population initially grows rapidly, then levels off as it approaches its carrying capacity. As resources become limited, the growth rate decreases, leading to a stable population size around the carrying capacity. This type of growth is characteristic of species that exhibit density-dependent regulation, where factors like competition for resources and disease become more significant as population density increases.
- J-population growth curve (exponential growth): The J-curve represents exponential growth, where a population grows continuously at an accelerating rate without constraints. This type of growth occurs under optimal conditions with abundant resources and minimal limiting factors. Exponential growth is unsustainable over the long-term, as resources eventually become scarce, leading to a population crash or a transition to logistic growth if the environment's carrying capacity is reached.

2.2 Energy and biomass in ecosystems

Answers to review questions

1 Ecological pyramids are graphical representations that illustrate the relationships between different trophic levels within ecosystems. There are three types of ecological pyramid: pyramids of number, pyramids of biomass, and pyramids of energy.

a Pyramids of number: These pyramids show the number of individuals at each trophic level. The base of the pyramid represents the primary producers, and as you move up the number of individuals generally decreases. This type of pyramid is suitable for ecosystems where the organisms at lower trophic levels are small and reproduce rapidly, such as invertebrates and plants.

b Pyramids of biomass: Biomass refers to the total mass of organic matter in a given trophic level. Pyramids of biomass represent the amount of biomass present at each trophic level. Similar to pyramids of number, the biomass decreases as you move up the pyramid. This type of pyramid takes into account the energy stored in the organic matter and provides a better representation of the energy available to higher trophic levels.

c Pyramids of energy: These pyramids illustrate the flow of energy through different trophic levels. The base of the pyramid represents the primary producers, and as you move up the energy available

decreases due to energy losses and inefficiencies in energy transfer. Pyramids of energy are the most accurate representation of the actual energy available to sustain higher trophic levels.

Ecological pyramids provide insights into the structure and functioning of ecosystems by showcasing the relationships between different organisms and trophic levels, highlighting energy flow and the transfer of matter. These pyramids also help us understand the constraints on the number of trophic levels, as energy losses and inefficiencies limit the amount of energy available for higher trophic levels.

2 Autotrophs and heterotrophs play crucial roles in energy and matter transfer within ecosystems:

- Autotrophs are organisms, primarily plants, that produce their own food through processes like photosynthesis. They convert solar energy into chemical energy in the form of glucose. This energy is the foundation of ecosystems, as it is transferred to heterotrophs.
- Heterotrophs are organisms that obtain energy by consuming other organisms. They have diverse strategies, including herbivores (consume plants), carnivores (consume other animals), detritivores (consume dead organic matter), parasites (obtain nutrients from a host), and decomposers (break down organic matter). Heterotrophs obtain carbon compounds from autotrophs or other heterotrophs, forming different trophic levels in a food chain.

Energy flows through different trophic levels in a food chain by primary producers (autotrophs) converting solar energy into chemical energy through photosynthesis. This energy is then passed on to primary consumers (herbivores), secondary consumers (carnivores), and so on. However, energy losses occur at each level due to incomplete consumption, incomplete absorption, and respiration, which releases energy as heat.

3 The number of trophic levels in ecosystems is limited by energy losses and inefficiencies. Generally, only about 10 per cent of the energy is transferred from one trophic level to the next. This energy limitation restricts the length of food chains. Organisms at higher trophic levels do not necessarily need to consume more food to compensate for energy losses; they rely on the energy stored in the organisms they consume.

In summary, autotrophs generate energy from sunlight, which is then transferred through heterotrophs in different trophic levels. Energy losses and inefficiencies in energy transfer limit the number of trophic levels in ecosystems.

Answers to exam-style questions

1 **a** Answers may include:

- Condensation: $O_3 \rightarrow O_2 + O$
- Evaporation: $Cl + O_3 \rightarrow ClO + O_2$
- Freezing: $SO_3 + H_2O \rightarrow H_2SO_4$
- Melting: $NOx + H_2O \rightarrow HNO_3$

[Accept other reasonable response. Accept any valid chemical changes identified by formulae or words (e.g. decomposition of ozone).]

b Any two from:

- Radiation of sunlight/solar energy/heat/light towards Earth
- Radiation of heat/IR away from Earth
- Reflection of light/heat towards space from Earth/clouds
- Scattering of light/heat from particulate matter

- Movement of (sensible) heat pole-wards by wind currents/tricellular winds/Hadley Cell/hurricanes/tropical cyclones
- Movement of latent heat in water vapour by winds

2 Answers may include:
- Find the dry weight of food presented to the population at start.
- Collect and find the dry weight of food remaining after a number of days; subtract the weight of food remaining from that presented / find dry weight of food eaten.
- Collect and find the dry weight of faeces produced over this period.
- Subtract weight of faeces from food eaten to find food absorbed/gross productivity: Food eaten – Faecal loss = Gross productivity.
- Divide final weight/gross productivity by number of days of the study.

[Do not credit reference to weighing organisms (only relevant in net productivity).]

2.3 Biogeochemical cycles

Answers to review questions

1 Stores (reservoirs):
- Atmosphere (N_2 gas)
- Soil (organic and inorganic nitrogen compounds)
- Living organisms (plants, animals).

Major flows and processes:
- Nitrogen fixation (conversion of N_2 gas to ammonia by nitrogen-fixing bacteria)
- Nitrification (ammonia to nitrite, then to nitrate by nitrifying bacteria)
- Assimilation (plants take up nitrates and incorporate them into organic compounds)
- Ammonification (conversion of organic nitrogen into ammonium by decomposers)
- Denitrification (conversion of nitrates and nitrites back into N_2 gas by denitrifying bacteria).

2 The Haber process produces synthetic ammonia from atmospheric nitrogen and hydrogen gas. This ammonia is used to make fertilizers, greatly enhancing crop yields in agriculture. However, the process requires significant energy from fossil fuels and releases greenhouse gases. While it has boosted food production, its environmental impacts include contributing to pollution, eutrophication of water bodies due to runoff of excess fertilizers, and its role in increasing atmospheric nitrogen, which can harm ecosystems.

3 Human activities have a significant influence on the carbon cycle, primarily through the release of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere. These activities contribute to changes in the natural carbon cycle and are a major driver of global climate change. Here are some key ways in which human activities impact the carbon cycle:
- Fossil fuel combustion: The burning of fossil fuels such as coal, oil and natural gas for energy production, transportation and industrial processes is the largest source of human-generated CO_2 emissions. This adds vast amounts of CO_2 to the atmosphere, which would otherwise be stored underground for millions of years.
- Deforestation: Clearing forests for agriculture, urban development and other purposes reduces the Earth's carbon sequestration capacity. Trees and forests act as 'carbon sinks', absorbing CO_2 from the atmosphere and storing it in their biomass. When forests are removed or degraded, this stored carbon is released back into the atmosphere.

- Land use changes: Converting natural landscapes, such as wetlands or grasslands, into urban areas or agricultural land can release carbon stored in the soil into the atmosphere. Changes in land use can also alter the balance of carbon between different reservoirs, affecting the carbon cycle.
- Industrial processes: Certain industrial processes, such as cement production, release CO_2 as a byproduct. These emissions, often referred to as 'process emissions', contribute to the buildup of greenhouse gases in the atmosphere.
- Agriculture: Agricultural practices, such as rice cultivation and livestock farming, release methane (CH_4), which is another potent greenhouse gas. Additionally, the use of synthetic fertilizers can release nitrous oxide (N_2O), which is also a potent greenhouse gas.

4 Biogeochemical cycles are natural processes that enable the recycling and movement of chemical elements, including carbon, nitrogen and phosphorus, between living organisms and their environment. These cycles ensure that essential elements are continuously available to support life on Earth.

5 Ecosystems play a crucial role in the carbon cycle. Carbon flows within ecosystems through processes like photosynthesis (carbon uptake by plants), feeding (transfer of carbon through food chains), respiration (release of carbon dioxide by organisms during metabolism), defecation, death, and decomposition (returning carbon to the environment). These processes maintain the balance of carbon within ecosystems.

6 Fossil fuels, such as coal, oil and natural gas, were formed over millions of years from the remains of ancient plants and organisms. During their formation, these ecosystems acted as carbon sinks, sequestering carbon from the atmosphere. However, when fossil fuels are burned for energy, they release the stored carbon back into the atmosphere as carbon dioxide (CO_2). Recognizing this is crucial because it underscores the link between burning fossil fuels and the increase in atmospheric CO_2 levels, which is a primary driver of global climate change. It emphasizes the need to transition to cleaner energy sources to mitigate the effects of human activities on the carbon cycle and climate.

Answers to exam-style questions

1 Answers may include:

- Understanding concepts and terminology of environmental value systems, ecocentrism, origins of and influences on EVS, alternative energies, renewable/non-renewable, fossil fuel technologies/infrastructure, impacts of global warming/climate change, sustainability, self-restraint, self-sufficiency, energy availability/affordability/reliability, energy security, etc.
- Breadth in addressing and linking energy choices, e.g. fossil fuels, renewables, nuclear, *etc.,* and influences upon these choices through cultural, political, economic, technological, environmental, geographical factors, *etc.* Also factors influencing growth of ecocentrism, e.g. education, cultural backgrounds, globalized media, climate change/energy-related disasters, *etc.*
- Examples of factors promoting fossil fuel energy choices, e.g. availability of coal in Russia, fracking in USA, falling price of coal worldwide, etc., and technological factors, e.g. low technology in LEDCs, existing infrastructure in MEDCs, *etc.,* and economic factors, e.g. China's dependency on industry, LEDCs seeking rapid economic growth, *etc.,* and energy security issues, e.g. Middle East oil, oil in USA, all kinds of fossil fuel in Russia, coal in China, etc. Also, examples of influences promoting ecocentrism, *e.g.* global social media, climate change disasters, NGOs, e.g. Greenpeace, education on sustainability, e.g. IB ESS, international movements, e.g. UN Sustainable Development Goals, etc.
- Balanced analysis distinguishing and weighing against one another potential reasons for the simultaneous growth in both fossil fuel consumption and ecocentrism.
- A conclusion that is consistent with, and supported by, analysis and examples given, e.g. 'while the widespread impacts of fossil fuel use and globalized media have promoted a growing support for ecocentric values in the wider populace, it is the governments that ultimately make decisions and their priorities often lie with the economics and politics that favour the continued use of these fuels.'

2.4 Climate, biomes, and their influences

Answers to review questions

1 The two essential characteristics of Earth's atmosphere that define ecological systems are climate and weather. Climate refers to long-term average atmospheric conditions over decades or centuries, while weather refers to short-term atmospheric conditions over hours, days or weeks.

2 Abiotic factors, such as temperature, rainfall, soil composition and nutrient availability, play a crucial role in determining the distribution and structure of terrestrial biomes. These factors influence the types of species that can thrive in a specific region and contribute to the formation of distinct biome types.

3 The tricellular model of atmospheric circulation divides the Earth's atmospheric circulation into three cells: Hadley, Ferrel and Polar. These cells impact global climate patterns, precipitation distribution and temperature gradients, influencing the structure and relative productivity of various terrestrial biomes worldwide.

4 The tropical rainforest biome is primarily found near the equator, spanning regions such as the Amazon Basin, Congo Basin and Southeast Asia. Savanna grassland biomes are typically situated in tropical and subtropical areas, including parts of Africa, South America, Australia and India.

5 The tropical rainforest and savanna grassland biomes have contrasting features. Rainforests are characterized by high rainfall, dense vegetation and a layered structure. They contain a variety of plant and animal species, and are known for their high biodiversity. In contrast, savannas have a drier climate, with scattered trees and extensive grasslands. They experience seasonal rainfall patterns and are adapted to periodic fires, leading to a different mix of flora and fauna compared to rainforests.

6 When comparing net productivity and biodiversity levels between tropical rainforests and savannas, some similarities and differences arise. Rainforests generally exhibit high net productivity due to their abundant rainfall, which supports rapid plant growth. Savannas have lower net productivity due to the seasonal nature of rainfall. Biodiversity is usually higher in rainforests due to the complex structure and diverse ecological niches they offer. Savannas have lower biodiversity due to their harsher conditions and lower plant density.

Answers to exam-style questions

1 Resilience is the ability to withstand disturbances, or the tendency to maintain stability and avoid tipping points; generally, biomes with higher primary productivity (e.g. rainforests/estuaries/wetlands) are more resilient than those with lower productivity (e.g. tundra/deserts). More productive biomes can support more species/diversity; diversity increases resilience because the loss of one species is more easily replaced by others. More productive biomes support more branching food chains and greater complexity of interrelationships. This allows for more negative feedback mechanisms and shifting feeding habits maintaining stability, so providing more resilience.

More productive biomes produce larger biotic storages; larger storages are less likely to be eliminated or reduced beyond a tipping point, so contribute to greater resilience. Larger storages provide higher maximum sustainable yields so are less prone to overharvesting. Higher productivity entails faster plant growth, thus more effective regeneration after a disturbance. Oceanic biomes have low productivity per unit area but their large size increases their resilience. Coral reefs have high productivity but narrow niche requirements give them low resilience.

[Allow credit for valid counterexamples as in last two MPs, 7 max.]

2 Answers may include:

- Understanding concepts and terminology of equilibria, sustainability, natural capital/income, climatic factors (temperature/precipitation/seasonality), greenhouse gases, climate change, biome shifts, water conservation, irrigation, desertification, vegetarian vs meat-rich diets, mitigation, adaptation,

commercial vs artisanal, intensive vs extensive, food miles, selective breeding/genetic engineering, etc.

- Breadth in addressing and linking influences of climate on food production, e.g. water scarcity, shifting biomes, mean temperatures/precipitation, desertification, wind/rain/erosion, *etc.,* and influences of food production on climate, e.g. methane production, deforestation, use of fossil fuels, global transport, etc., and ways in which production strategies may adapt to, or mitigate, climate change.
- Examples of food production strategies that *adapt* to climate change, e.g. water conservation, drip irrigation, terracing, drought-/temperature-resistant crops, aquaponics, greenhouses, *etc.,* and strategies that *mitigate* climate change, e.g. switching from meat-rich diets, localizing food production, employing artisanal/low-energy farming strategies, etc.
- Balanced analysis of the extent to which production strategies from a range of contexts may contribute to, or mitigate against, an equilibrium between food production and the climate, etc.
- A conclusion that is consistent with, and supported by, analysis and examples given, e.g. 'Although there are many production strategies that mitigate or adapt to climate change, the relationship has already shifted so far away from a sustainable equilibrium, that with growing populations it seems unlikely that their contribution will be sufficient to avoid a tipping point in the future'.

3 Mangroves and tropical rainforests mitigate climate change or reduce CO_2 in the atmosphere by absorbing CO_2. Mangroves sequester/remove a greater amount of CO_2 (per unit area) than the other ecosystems; tropical forests and mangroves are more efficient at storing carbon or are more effective carbon sinks. Tropical forests hold more carbon in their living biomass; mangroves hold more carbon in the soil. Both tropical rainforests and mangroves store the highest amount of CO_2 within their living biomass for their own ecosystem category. Mangroves hold approximately 1,500 metric tonnes of carbon per hectare; tropical forests hold approximately 230 metric tonnes of carbon per hectare. Tropical forests may remove less CO_2 per unit area but occupy a far greater area globally; mangroves remove more CO_2 per unit area but occupy less area globally.

[Accept quantification without units, 2 max.]

2.5 Zonation, succession and change in ecosystems

Answers to review questions

1 Transects are lines or trails used to collect data along an environmental gradient to investigate zonation and changes in biotic and abiotic factors. They help measure variables such as temperature, pH and species abundance at regular intervals. By analysing data collected along transects, scientists can identify trends and relationships between these factors and species distribution, providing insights into how environmental conditions influence community structure.

2 Primary succession occurs in areas with no pre-existing soil or community, such as bare rock surfaces or newly exposed substrates. Pioneer species, adapted to harsh conditions, colonize these areas and initiate soil formation. Secondary succession occurs when a pre-existing community is disrupted, leaving bare soil. Propagules, reproductive structures like seeds, enable new species to colonize and initiate succession. An example of primary succession is volcanic rock colonization, while abandoned agricultural fields represent secondary succession.

3 r-strategists are species with high reproductive rates, producing many offspring quickly. They are adapted to pioneer communities and rapid colonization, often with limited parental care. K-strategists have lower reproductive rates but invest more in each offspring, suited for climax communities with stable conditions. Their strategies align with their respective successional stages: r-strategists initiate colonization and K-strategists contribute to later, more established communities.

Answers to exam-style questions

1 Succession is the process of changes in community/ecosystem over time, whereas zonation is the process of changes over an environmental gradient/space.

2 r-strategists produce greater numbers/many offspring, have fast population growth; they distribute themselves more widely/colonize more quickly; they mature quickly/reproduce earlier/establish themselves faster; they are better adapted to harsh/low-nutrient conditions/less specialized niches.

Theme 3 Biodiversity and conservation

3.1 Biodiversity and evolution

Answers to review questions

1 Habitat diversity, species diversity, and genetic diversity.

2 Natural selection.

3 Answers may include:
- Random genetic mutation creates differences in behaviour or looks.
- Mutation represents a favourable advantage in that time.
- The favourable advantage leads to individuals being selected for mating.
- Mating results in the flow of the genes responsible for the adaptation.
- Over time, the genes pass through generations and the individuals with these traits are no longer able to reproduce with their ancestral species.

4 B – mixed deciduous forest.

5 A mixed deciduous forest will have many different species of tree and the data shows that other vegetation is also varied, possibly due to the variety of niches available due to the variety of trees. By contrast, the coniferous forest has few tree species and therefore the availability of varied niches will be limited, resulting in a lower diversity of 'other' plant species.

Answers to exam-style questions

1 Genetic mutation and sexual reproduction.

2 Whales, bats, humans and other types of mammals all share the same composition of bones within their limbs. This bone structure has evolved to develop into the ideal limb for the needs of those animals. The bones have evolved into the fin of whales, the wings on bats, and human hands.

3 The largest mass-extinction event took place between the Permian and Triassic era, 252 million years ago. This event was triggered by a large volcanic eruption that produced acidic conditions in the planet's water. This caused the extinction of around 96 per cent of life on Earth due to the fact that most life was concentrated in the oceans at this time.

4 As conditions in the environment shift, these are detected by the living organisms and their populations react to these changes. At times conditions have shifted so significantly that large volumes of organisms die as a result. This can be detected by a rapid shift from certain types of organisms, to completely different organisms. These are identified and official markers for these periods are called 'golden spikes'.

5 When thermonuclear bombs were first developed and tested, there was little known regarding the length of time the radioactive nature of the fallout would last. Radioactive substances and areas impacted by fallout from radioactive explosions will stay radioactive for thousands of years, if not more. Therefore land, plants and animals that were impacted by coming in contact with nuclear dust following explosions are still radioactive and detectable in records taken from sediment and ice cores.

3.2 Human impact on biodiversity

Answers to review questions

1 Direct: Collection for the pet trade; poaching for valuable body parts.

Indirect: Habitat destruction; climate change.

2 Large geographical distribution.

3 Species knowledge is only as good as the number of researchers collecting the information, therefore some species that are endangered may not be included. Or, there are many unknown species and some of those may inadvertently become more threatened by actions designed to save another species.

4 Some of our natural resources are not owned by anyone and are therefore considered resources to be used for the common good. Despite this, the natural progression of competition drives individuals to use that resource unsustainably. This further drives others to need to do the same to be able to continue to compete for the resource. This carries on until the use of that resource is so unsustainable that the system collapses. This has been happening is many parts of the oceans. Cod fishing in Newfoundland is a particular case study highlighting the impact of overfishing on the ocean system.

5 Involvement from the local community, strict regulation on the collection of a species, international protection against trade, rehabilitating damaged habitats before attempting reintroductions.

Answers to exam-style questions

1 Indigenous people have developed over generations around the environment that they live in. They have mostly worked in harmony with their environment over many generations, proving that their practices are sustainable. Conservation practices need to 'fit' the habitat, climate and conditions that are threatening that area. Using indigenous knowledge will not only harness the best practice that has been proven over generations, but the conservation scheme is more likely to be successful if they are involved in the development and running of these programmes. Therefore, harnessing indigenous knowledge and support results in sustainable management of these areas.

2 KBAs are areas that are designated as having specific importance for different organisms, during their lifetime. This covers areas such as breeding sites, overwintering areas and locations on migratory pathways. These areas bring awareness to the habitat and its importance that helps to preserve these vital areas. Many of these sites are within biodiversity hotspots or Ramsar sites, but many are not. This is an issue as KBA designation does not offer any specific protections for the habitat or the species that use it. Those KBAs in areas holding other official designations will be legally protected by those designations, but those that fall outside these areas have no legal protection and they are not required to develop management plans to address the need to preserve that habitat. Therefore, it is good to have brought these sites together under one designation, but without official protection from the designation it does not really offer protection. This makes these areas less effective than they could be.

3 [1 mark each for defining biodiversity hotspots and KBAs. At least two named examples of areas, the type of conflict and its impacts on conservation (two detailed or three less detailed).]
[1 mark for a conclusion summarizing the main issues.]

4 Environmental justice gives indigenous communities a voice and the rights to be part of the decision making that takes place in regard to their ancestral land.

5 [1 mark for introducing the habitat or species being discussed.]
[2 marks for each lens, explaining an aspect of that lens and an example to support that aspect.]
[2 marks for discussing the links and complexities of the aspects of conservation.]
[1 mark for concluding how effective the conservation has been.]

3.3 Conservation and regeneration

Answers to review questions

1 *Ex situ* conservation.

2 Mixed conservation includes in situ conservation that deals with the issues present within the habitat, and ex situ conservation that looks at supporting species through captive breeding programmes and research to enhance and support populations of animals in the natural habitat. This allows all aspects related to the pressure on a species to be addressed together.

3 A flagship species is one that is used as a symbol for a specific habitat or conservation type. This makes that species automatically linked to the conservation practices in people's minds. These are often cute and charismatic animals designed to attract people to the cause.

4 New Zealand has been an isolated island for many thousands of years and as such has developed a large amount of endemic flora and fauna.

5 Rewilding is when an area is returned to its original natural wild state. Conservation through non-active management is when a habitat is left alone without human management.

6 Rewilding is a process of minimal management to restore an area to its native habitats. This increases the diversity of organisms present at each stage of the trophic level, which increases the resilience of the food web as the loss of a species will not result in the collapse of the system.

7 When protecting a habitat, support is essential to address legal issues, funding and recognition. Governmental organizations can provide legal support, but this process takes many years to formalize and the lack of in situ support makes implementation of international laws difficult in some places. Non-governmental organizations can create social media campaigns that will raise global and local awareness in the wider population. These organizations can influence legal decisions through raising the profile of the issue, but they have no official influence over the creation of legal support.

8 NGOs are not constrained by political restrictions and can take rapid action on environmental issues. They are able to rapidly mobilize people to back a campaign and can be effective at raising awareness that results in the issue being brought to the attention of local governments.

9 If an apex predator is reintroduced after a long period of time, the other organisms will have developed no resistance or behaviour to avoid predation from them. Populations of smaller predators and herbivores will be reduced, impacting the population they prey on.

10 Ecotourism uses the environment and the activities associated with the natural environment to attract tourism. This allows local communities to generate income and share their traditions with people from around the world. However, this can bring pollution and destruction of the natural environment if the volume and activities of tourists are not sustainably managed.

Answers to exam-style questions

1 For example:
- Solitary lifestyle – makes it hard to find a mate, reducing rate of increase in population.
- Long lifespan – this usually means that it takes longer for juveniles to mature and be able to breed.
- Extended brood care – this reduces the frequency of birth events per individual.
- Specialized diet – this means the species is reliant on the abundance of one type of food. If that food becomes reduced, the species will not survive.

[To get marks both the factor and the explanation for this being a factor need to be present. If only the factors are named then no marks are awarded.]

2 [1 mark for identifying a strength of each type of organization in aiding in conservation.]
[1 mark for addressing the benefits of comprehensive protection, and 1 mark for identifying that success is reliant on the involvement of the local community.]

3 For example:
- Galápagos Islands, conflict with tourism that is impacting the natural ecosystems and reducing biodiversity.
- Nature reserve in Congo rainforest needed to impose regulations on the use of land in the protected area, resulting in the Baka tribe being banned from accessing the ancestral grounds.

[2 marks for explaining the impact of a conflict with conservation in a named protected area. Maximum of three examples. 1 mark for suggesting a solution.]

4 For example:
- Biodiversity – many endemic species of plants and animals.
- Geographical – first continent to break away from the main continent millions of years ago so lots of time in isolation. Australia is distant from other continents and has different climatic conditions.
- Evolutionary – long-term isolation results in speciation and rise of endemic species. Climate conditions provide unique conditions that have driven speciation around the continent.

[1 mark for describing the biodiversity in Australia, 2 marks for explaining two geographical reasons for high biodiversity in Australia, and 2 marks for explaining two evolutionary reasons for the high biodiversity.]

5 For example:
- Eco sanctuaries – fenced protected habitats, for protection of native flora and fauna.
- Positive – species reintroductions, and protection from invasive alien species.
- Negative – isolation is leading to speciation, pest eradication needed to allow fenced area to be developed.
- Conclusion – some success, but better management needed.

[1 mark for explaining what eco sanctuaries in New Zealand are.]
[2 marks for explaining two positive outcomes of eco sanctuaries, and 2 marks for explaining negative outcomes of eco sanctuaries.]
[1 mark for a concluding comment.]

Theme 4 Water

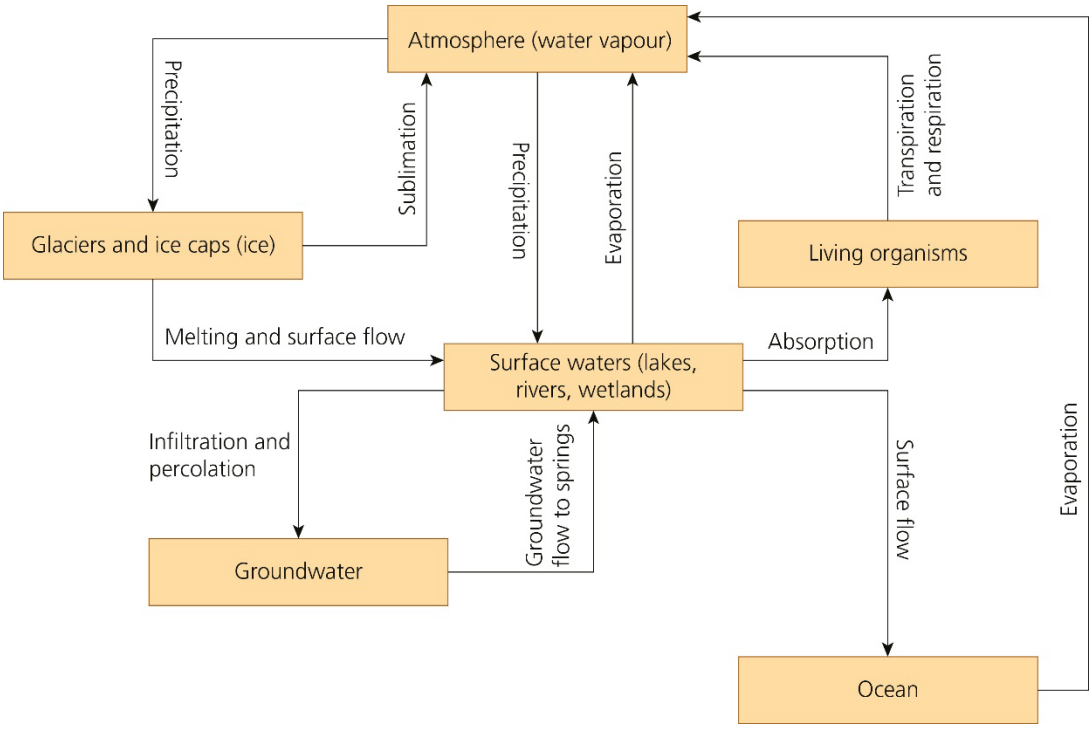
4.1 Water systems

Answers to review questions

1 Open.

2 The volume of water in the lake will increase. This might lead to flooding of the land around the lake. It might occur because of a season of heavy rainfall, or warm weather causing melting of glaciers. Outflows might exceed inflows if there is a particularly dry season, with lower rainfall and higher rates of evaporation than normal.

3



4 Water molecules are polar, having a slight negative charge on one end (the oxygen end), and a slight positive charge on the other (the hydrogen end). This makes water molecules tend to cohere, stick together, and resist being pulled apart. This gives water a high specific heat capacity, which means that its temperature is stable and doesn't change easily. This makes it provide a stable environment for living things. Water's polarity gives it a high specific latent heat of vaporization, meaning that it does not evaporate easily. This allows it to remain liquid in hot and dry environments and to keep organisms from overheating by evaporative cooling. Water becomes less dense when it turns to ice, so that ice floats on liquid water, allowing organisms to live below. Water's polarity makes it a universal solvent, as it gives it good solvent properties.

5 Deep ocean water is darker, having almost no light, whereas surface waters are well illuminated. Deep ocean water is usually colder and denser than surface waters. The deepest water is usually at 4°C, which may be warmer than the surface during winter. Deep water usually has low dissolved oxygen concentration compared to surface water. Deep water usually has a high concentration of nutrients compared to surface water.

6 There is no photosynthesis in deep ocean water, because it is dark and since light is needed for photosynthesis. Deep water is dark because light from the sun is absorbed by the upper layers. With no

photosynthesis, there is no production of oxygen in the deep water, unlike at the surface. Since deep water is so far from the surface, oxygen from the air is unlikely to diffuse to the deep water. Since there is no photosynthesis, decomposition and respiration result in a reduction in oxygen. Decomposition releases nutrients into the water. Conditions in surface and deep waters are maintained due to thermal stratification, where warmer water remains floating above colder water, and substances in deep water cannot normally return to the surface.

4.2 Water access, use and scarcity

Answers to review questions

1 Domestic [two from]: Metering encourages people to use less water as they become more aware of their water consumption, and may have to pay more to consume more water. Water-saving devices such as low-flush/dual-flush toilets or taps that automatically switch off reduce water usage. Grey-water recycling reduces total water use by reusing slightly dirty water for purposes like flushing toilets and watering plants.

Agriculture [two from]: Drip irrigation uses perforated pipes or hoses to deliver small amounts of water directly to individual plans, reducing wastage, waterlogging, and evaporative losses. Aquaponics uses water more efficiently by growing both crops and fish in the same water, reducing the total need for water. Drought-resistant crops require less water, so reduce the amount of water used in irrigation. Producing crops instead of livestock saves water since crops use much less water than livestock do.

2 Rainwater harvesting is done to increase the availability of water in both agricultural and domestic settings. In both settings, catchment systems with pipes and storages, such as tanks or cisterns, may be used. The use of rainwater in agriculture is mainly for irrigation, while in domestic settings it is mainly for cleaning or flushing toilets. In agriculture, rainwater is more likely to be stored in ponds, while in domestic setting it is more likely to be stored in tanks. The volume of rainwater harvested is likely to be much larger in agricultural than domestic settings.

3 New Zealand: Ecocentric, as it prioritizes the natural environment over human interests.

UK: Technocentric, as it aims to use technological approaches to solve an environmental problem.

4 Water security is the ability to meet all people's needs for safe drinking water. Countries with abundant freshwater supplies, and the economic means to supply their population with water, such as Canada, Sweden, or New Zealand, may have high water security.

Water scarcity is a lack of available freshwater. It may be due to either physical or economic scarcity. Physical scarcity means a country that has a dry environment (e.g. Jordan), while economic scarcity means a country that has abundant water but lacks the economic means to distribute it (e.g. Haiti).

Water stress is difficulty meeting the water needs of people or ecosystems. It may be due to water scarcity, but is also affected by water quality, and political/economic decisions about water use and distribution. Water stress is broader than water scarcity and can be quantified as having less than 1,700 m^3 per person per day, while water scarcity means having less than 1,000 m^3 per person per day. Niger is an example of a country with high water stress.

5 Four from:

- Dam: River is blocked to collect water in a reservoir. A dam requires appropriate terrain and significant surface water. [Give a named example.]
- Estuary barrage: Mouth of the river is barricaded to store water before it flows into sea. An estuary barrage requires a large river that is not used for other purposes, and the economic means for construction. [Give a named example.]

- Inter-basin transfer: Large pipes, aqueducts or canals are used to transfer water from one river basin to another where there is higher demand. Inter-basin transfer needs suitable large river basins, and the economic and technological ability for project. [Give a named example.]
- Water-treatment plant: Water from the environment and/or sewage is treated using various methods [describe the methods]. A water-treatment plant should establish appropriate methods for its specific needs. [Give a named example.]
- Aquifer recharge: Excess water is injected into an empty aquifer, to be used later when needed. Aquifer recharge needs appropriate geology, with an available aquifer, and variable water availability. [Give a named example.]
- Desalination/solar distillation: Salty and/or contaminated water is cleaned by distillation or reverse osmosis. Desalination/solar distillation requires abundant energy in a suitable form, and access to appropriate water. [Give a named example.]

4.3 Aquatic food production systems

Answers to review questions

1 Harvesting a resource (e.g. fish) at the highest possible rate that allows consistent harvest over many years, without depleting the resource. Requires that enough of the resource is left unharvested to maximize the rate of replenishment.

2 As fishing effort increases, yield increases, until a maximum is reached at a certain value. Above that certain value of effort, yield declines with increasing effort, until yield is zero. Marks may be credited for a sketched and annotated graph.

3 A quota is a limit to the amount of a resource (e.g. fish) that may be harvested/caught. It can be used to limit fishing effort to a level that achieves MSY. It must be established based on population size, growth rate, and carrying capacity, and it should be set low if there is uncertainty. It must be well enforced.

4.4 Water pollution

Answers to exam-style questions

1 Deforestation increases surface runoff, as there are no trees to serve as a barrier to water flow. It decreases infiltration as water flows more rapidly over the surface. It reduces transpiration as there are no trees to absorb water and transfer it to the atmosphere. It reduces local humidity and cloud formation, as less water enters the atmosphere. It reduces local precipitation as there is less water vapour in atmosphere.

2 Water security is the ability of a country to meet the needs of all its people for safe drinking water. Desalination can be used to provide freshwater from saltwater or contaminated water. Desalination can be done by distillation, where water is boiled and vapour collected and condensed. This requires a heat source, usually provided by burning fossil fuels but it could alternatively be provided by solar energy. It can also be done by reverse osmosis, where water is pumped through a membrane that is impermeable to salt. This requires electrical energy to provide pressure.

Evaluate a named country in terms of its need for water, water stress or scarcity. Evaluate a named country in terms of its availability of saltwater or contaminated water. Evaluate a named country in terms of the availability of an appropriate energy source. Address sustainability as it relates to the capacity to continuously provide enough water for the population's needs. Address sustainability as it relates to energy use.

3 Three from:
- Drip irrigation, where water is slowly released from perforated pipes or hoses, directly on to the crops, at a rate to match plants' needs.
- Rainwater harvesting, where rainwater is collected and stored for later use in irrigation.
- Planting drought-resistant crops, which require less irrigation water.
- Aquaponics, where fish and crops are grown together in the same water, reducing total need.
- Converting from livestock to crops, to reduce total water consumption.

4 Economic development is often associated with increased industry, which typically consumes large volumes of water. Increased intensity of agriculture may mean more use of water for irrigation. More people will receive pipe-borne supply, increasing personal use at home. Increased income or wealth in individuals may lead to higher personal consumption levels in homes. Also use of water for leisure activities (e.g. swimming pools, golf courses).

5 Quotas are limits set on harvest rate. They may be set for individuals or for an entire fishery (total allowable catch). The objective is to lower fishing effort/catch, so as to maintain fish population at a sustainable level so as to maximize population growth and reproduction rate. Quotas are difficult to set, as they depend on complete knowledge of population structure and dynamics. Quotas are difficult to enforce as fishing usually happens at sea, where policing of fisheries is difficult or impossible. Quotas can be unpopular as they restrict fishers' incomes. If quotas are set too high, e.g. due to political interference or limited or incorrect information, overexploitation can occur. If stock is already overexploited, quotas should be set very low to allow recovery. Population growth will be slow in overexploited stock or small populations. For severely overexploited fisheries, a complete moratorium or prohibition on fishing might be necessary.

6 Aquaculture has increased global fish production, while production of wild-caught fish has stabilized or slowed. This allows increased demand for fish to be met despite overfishing and depletion of many wild fisheries. With demand continuing to rise due to increasing human population, and due to the popularity of fish, aquaculture will need to continue to grow. However, aquaculture depends on large volumes of clean water, and causes water pollution. Fish feeding in intensive aquaculture is often unsustainable as it either depends on wild-caught fish or on farm-produced protein. Most fish that humans eat are predators from high trophic levels, so they use energy inefficiently and require large amounts of primary production to support them.

The environmental impacts of aquaculture include habitat destruction or depletion of water resources, the escape of alien invasive species, and the spread of diseases to wild fish. Intensive aquaculture often uses high stocking densities, making disease a problem, so fish farmers use antibiotics or pesticides, which cause pollution. Extensive aquaculture is less harmful to the environment, but produces less food per unit area. For aquaculture to be sustainable, it must reduce its environmental impact. For it to meet human demands for fish, it must increase its productivity/intensity. High productivity and low environmental impact are difficult to achieve, so sustainably meeting demand may not be possible.

7 Humans release nutrients (e.g. fertilizers) into water. Excess nutrients causes rapid algal growth/algal bloom and eutrophication. Algae eventually die and decompose, reducing oxygen further. Humans also release organic matter (e.g. sewage, food waste, farm waste) into water. This organic matter undergoes decomposition by bacteria. If bacteria are aerobic they use up oxygen, reducing the concentration of dissolved oxygen. The decomposition of organic matter also releases nutrients into the water, promoting algal bloom and creating a positive feedback loop.

8 Establish testing sites at various points along the river, upstream and downstream of the source. Take samples at regular time intervals. Carry out tests such as biochemical oxygen demand, dissolved oxygen, faecal coliform count, nitrate, phosphate [credit description of up to two tests]. Carry out biotic index test, such as BMWP or Trent biotic index [credit outline of one test].

9 Reducing use of pollutants:
- Reducing amount of fertilizer used/matching use to crops' needs.
- Using slow release/organic fertilizers.
- Using alternative methods for promoting soil fertility (e.g. crop rotation/use of legumes).

Reducing release of pollutants:
- Improving drainage from farms, so that nutrient runoff is trapped.
- Treating farm runoff.
- Using wetlands to treat farm runoff.
- Appropriate strategies to reduce soil erosion.
- Domestic wastewater treatment.

Removing pollutants/repairing damage:
- Dredging organic-rich sediments.
- Bioremediation/using plants to absorb nutrients.
- Aerating the water.
- Adding coagulants/alum or equivalent.

[Maximum 2 marks from each category.]

HL only

10 As atmospheric carbon dioxide concentration rises, some of it dissolves in the ocean. Some of the dissolved carbon dioxide reacts with water, forming carbonic acid and causing ocean acidification. Shelled animals and algae take carbon dioxide out of the water to create their shells/skeletons (calcium carbonate). When those animals die, their shells/skeletons sink and become buried in the sediments at the bottom of the ocean. Over millions of years, these may be converted into rocks/limestone/carbonate rock.

11 Low-intensity hunting or harvesting by indigenous peoples may be ethically acceptable if judged on the ethics of sustainability, as it can allow for conservation of the resource for others/future generations to use. This argument recognizes the rights of other people, and considers the consequences of people's actions.

If the intrinsic rights of marine mammals are considered, it could be argued that the rights of the indigenous people to hunt should not supersede the rights of the animals to live. However, indigenous peoples often recognize the intrinsic rights of animals, but can still ethically justify their hunting as part of their way of life. Where indigenous people's practices recognize the intrinsic value of animals, their practices may be a valuable tool for conservation or a source of understanding of sustainability.

For some indigenous peoples, such as people living in the Arctic, hunting marine mammals is the only/best/easiest way to meet the needs of the people, as agriculture is not an option in their environment.

Indigenous hunts may be considered unethical if the right of animals to be free from pain and cruelty is recognized, depending on the methods used to kill the animals.

The rights of indigenous peoples to practise their traditional culture/religion are widely recognized, especially in light of historical efforts to suppress many indigenous cultures.

The ethics of indigenous hunting are complex, and different worldviews/perspectives/EVSs may influence a person's interpretation of the ethical questions. An unresolved ethical question relates to whether ethical views of one culture should be applied to another.

12 Both biotic and water-quality indices take into account multiple factors to draw a single conclusion about water quality. Biotic indices are an indirect measure of pollution, related to different species' tolerance

for pollution, while water-quality indices are based on direct measures of pollution. Water-quality indices tend to measure water quality at a single point in time, whereas biotic indices give an indication of water quality over an extended period of time. Water-quality indices may require significant mathematical manipulation of data, whereas biotic indices can often be determined with relatively simple mathematics. Biotic indices typically require a single test (though it should be repeated for reliability), whereas water-quality indices typically require multiple tests, using complex equipment.

Theme 5 Land

5.1 Soil

Answers to review questions

1 Organic: Substances derived from living organisms; may include leaf litter/faeces/shed parts of animals/exudate from roots. When partially decomposed it is called detritus, when fully decomposed it is called humus.

Inorganic: Mineral particles produced by weathering of parent rock. Depending on size, mineral particles may be sand, silt or clay. Air and water.

2 Weigh a sample of soil. Heat it at about 105°C to remove moisture/water, then cool and reweigh. Heat it in a furnace at 550°C for 30 minutes or on a Bunsen burner for 1–2 hours. Cool to a safe temperature then reweigh. Calculate percentage organic matter as mass lost divided by mass of dried soil, multiplied by 100. Practise care when handling hot equipment and working with furnace or Bunsen burner.

3 Sandy: Well aerated because of large spaces between mineral particles. This promotes plant growth as roots can respire aerobically. Drain rapidly, removing most minerals and reducing fertility. Low water retention means plant growth depends on regular rainfall/irrigation. Low productivity overall.

Clay: Small spaces between soil particles cause poor drainage, so soil tends to become waterlogged. This makes clay soils poorly aerated, hindering respiration in roots. Easily compacted, hindering root growth. Many minerals are present, but they are tightly bound to soil particles, so are unavailable to plants. Low productivity overall.

4 Organic matter is added to the soil by living organisms (e.g. leaf litter, faeces). Bacteria and fungi break down the organic matter, acting as decomposers. This leaves a sticky, dark brown/black substance that coats the mineral particles.

5 Humus causes mineral particles to stick together, improving soil crumb structure. This allows free drainage of water, avoiding waterlogging while allowing some water retention, thus preventing complete drying out. Leaching of minerals is reduced as drainage is relatively slow. Humus undergoes gradual decomposition/mineralization, releasing minerals slowly and making them available to plants. Plants therefore have access to water, minerals and air, and productivity can be high.

5.2 Agriculture and food

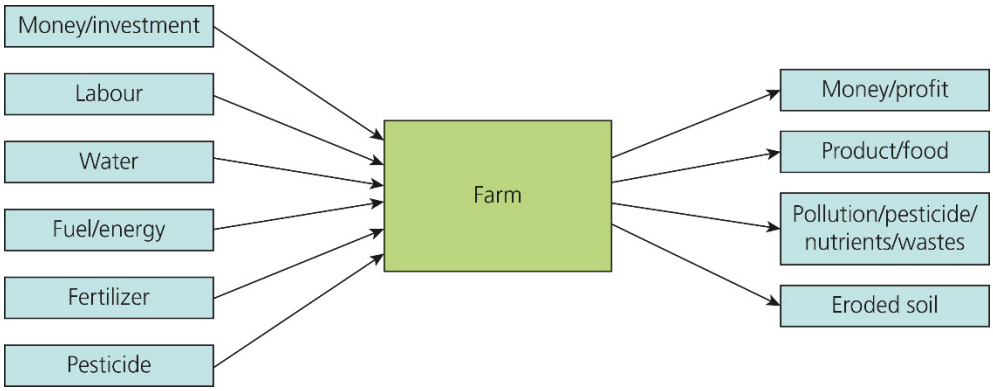
Answers to review questions

1 Total global food production is currently more than enough to provide sufficient calories to all people. However, it is difficult to determine whether it would provide enough food for a healthy/balanced diet. Many people lack sufficient food, or experience hunger or undernourishment (at least sometimes). Many people experience nutrient deficiencies because they lack access to all required nutrients. Food distribution is uneven/inequitable, and there are places where people do not receive enough food. Some people who are experiencing poverty may not be able to afford the food they need. Some food that is produced does not reach people because food loss occurs along the food supply chain. Food waste occurs in homes, restaurants, and food shops.

2 Food is left unharvested in the field where it is produced. Food is lost or damaged during packaging or transportation. Food is discarded because it does not meet (quality) standards required by the market, buyers, or sellers. Food is spoilt in storage or shipping, or on display in shops.

3 To reduce food waste by 50% (half), and to reduce food loss along the supply chain.

4



5 Extensive farming produces relatively low yield per unit area of land, while intensive farming produces relatively high yield. Extensive farming involves fewer inputs, while intensive farming involves more inputs.

6 Commercial farms typically use soil intensively; they grow a large number of crops on a (relatively) small area of land, often in a monoculture. This leads to continuous depletion of soil nutrients, which are replaced by adding fertilizer.

7 Selective breeding, where crops with desirable characteristics were bred over many generations to improve the yield.

Increased irrigation, using high-tech methods, to provide crops with enough water to grow.

Application of synthetic fertilizers to crops, to promote growth and increase productivity of soils/allow for intensive use of soils.

Application of pesticides to reduce losses due to pests.

8 Fertilizers change the number and types of soil bacteria. This affects the natural nutrient cycling that occurs in soils. (Natural) soil fertility is reduced, making the crops more dependent on fertilizers.

9 Any three from:

- Using organic fertilizer, such as manure or compost.
- Growing mixed herbal leys/nitrogen-fixing plants (e.g. legumes) to add nutrients to the soil.
- Adding mycorrhizal fungi to the soil to promote nutrient uptake by plants.
- Agroforestry, where trees are used to improve soil fertility as they draw nutrients from deeper soil layers.

10 Crop rotation involves growing different crops (in sequence) in the same soil. Crops are chosen to complement each other's nutrient needs and provide nutrients for each other. Each crop uses different nutrients; some add nutrients to the soil. Legumes are often included to add nitrogen to the soil. A fallow period may be included to allow natural processes to replenish soil nutrients.

11 Conservation tillage involves reducing or avoiding ploughing the land. This reduces the likelihood of soil erosion (by wind or water). Crop residues remain in the soil, providing organic matter, habitat and food for soil organisms. Crop residues shelter the soil, reducing soil temperature and evaporation. Soil compaction is reduced since less heavy machinery is required.

12 Trees draw nutrients from deep layers of the soil, and add them to the surface when leaves/branches/fruits/flowers fall. Trees shelter the farm, reducing erosion and storm damage due to wind. Trees can provide useful and valuable products, such as fruit, or fodder for livestock. Trees can provide shelter for crops/livestock from direct sunlight.

13 Livestock are at a higher trophic level and so require food, making their production more energetically inefficient than crops. The impact of providing crops/food production for livestock must be added to the

impacts of livestock themselves. Livestock require more water than crops. Livestock/ruminants may produce pollutants such as methane, which is a greenhouse gas.

14 Any four from:

- Machinery used in agriculture runs on fossil fuels, and releases carbon dioxide.
- Production of agrochemicals involves industrial processes using fossil fuels, which release carbon dioxide.
- Ruminants emit methane.
- Farming waterlogged fields/rice paddies releases methane.
- Use of nitrogenous fertilizer on farms leads to production of nitrous oxide by soil bacteria.

15 One example from:

- Maize/cotton/banana/papaya/other named example can be modified to be resistant to pests, which increases yield and reduces need for pesticides.
- Potato/tomato/other named example can be modified to delay spoilage/lengthen shelf life/prevent browning, which reduces food loss/waste.
- Pigs/other named example can be modified to reduce nutrient content of their faeces, which reduces pollution from farm waste.

16 Two examples from:

- Using a small-scale, solar-powered plant on the farm to produce fertilizer for crops: Increases crop productivity/growth with fewer negative impacts of fertilizer use.
- Genetically modifying crops/livestock: Improves yield/reduces environmental impact by transferring genes from another species into the crop/livestock species.
- Reducing greenhouse gas emissions: Reduces the use of nitrogenous fertilizers by reducing/modifying the farming of cattle/ruminants/rice.
- Reducing food loss/waste to improve the efficiency of food production: Extends the shelf life of products by changing the way/conditions in which food is handled, transported and stored.

17 Rewilding vs permaculture: Both seek to increase biodiversity on the farm. Both ultimately aim to leave land with minimal management and achieve naturally stable/resilient ecosystem. Permaculture involves deliberate/careful design of the farm ecosystem, while rewilding allows the ecosystem to develop naturally. Permaculture aims to produce food/agricultural products, while rewilding aims to increase biodiversity on land without necessarily producing anything.

Rewilding vs non-commercial crops: Both involve growing crops/plants that have no commercial value or are not intended for sale. Both result in increased biodiversity on the farm. Rewilding involves allowing the ecosystem to develop naturally, while non-commercial cropping involves intentionally planting particular species. Rewilding is specifically aimed at restoring natural ecosystems/increasing biodiversity, while non-commercial cropping is usually intended to provide some specific benefit to the farm.

No-till vs permaculture: Both aim to leave the soil undisturbed and to result in reduced soil erosion/degradation. Both usually involve less heavy machinery than conventional agriculture. No-till is usually practised on commercial farms and often in monocultures, while permaculture tends to be less commercial and polycultural. No-till may increase pest problems or involve increased use of pesticides/herbicides, while permaculture usually aims to manage pests/weeds biologically and reduce use of pesticides.

18 Any four from:

- Reduces soil erosion/compaction.
- Increases organic matter content of soil/soil crumb structure.
- Can reduce need for fertilizers and pollution from nutrient runoff/leaching.

- Reduces use of machinery, and therefore emissions of carbon dioxide/use of fossil fuels.
- Potentially increases need for/pollution from pesticides.

19 [Two marks from each:]

- Sustainable: Harvesting wild species can be sustainable where harvest rates are lower than growth/replenishment rates, e.g. Brazil nuts are harvested after they have fallen from the trees, and the harvest does no harm to the trees. With a profitable harvest coming from the forest, communities and governments are motivated to protect/conserve the forest, so such a harvest is not only sustainable in itself, but also promotes sustainable use of the forest resources.
- Unsustainable: The harvest may be unsustainable where the harvested resource is rare or vulnerable, e.g. pangolins/other named animal may be hunted to extinction if there is demand for them, and no/ineffective regulation of the harvest. With high demand for these animals, the price is high, and there is strong motivation for hunters to overexploit the resource.

Answers to exam-style questions

1 Conservation tillage is intended to conserve soil by reducing the amount of ploughing which soil is subjected to. This practice reduces soil erosion, by leaving the surface/topsoil relatively undisturbed, so that wind or water is less likely to remove it. As a result, the nutrients and organic matter which are concentrated in the topsoil are retained on the farmland, reducing the need for the addition of fertilisers. Crop residues are typically left in the soil, which may suppress weeds, contribute organic matter as they decompose, and provide food and habitat for useful soil organisms. Since less ploughing is done, the use of machinery such as tractors is reduced, so the farm uses less fossil fuel, and emits less carbon dioxide, and the cost of operation may be reduced.

However, crop residues left on the land may encourage the growth of weeds and other pests. This may reduce yield, as crop production may be reduced, so farmers using conservation tillage often increase the use of herbicides and other pesticides.

Overall, conservation tillage uses soil more sustainably, and can be more sustainable than conventional farming if pests can be controlled without use of synthetic pesticides.

2 Ploughing breaks up soil/topsoil making it susceptible to (wind/water) erosion, so farmed land often lacks O/organic and A/topsoil horizons. Repeated monoculture depletes soil nutrients as minerals are repeatedly taken up by plants and not replaced. Fertilizers add minerals to soil, but change the soil biota/bacterial communities in the soil, e.g. nitrogen-fixing bacteria are reduced and denitrifying/nitrifying bacteria are increased. Pesticides may contaminate soil, killing many soil organisms.

3 The Green Revolution increased the use of modern technology, such as selective breeding, machinery and agrochemicals, in food production, beginning in the 1950s–60s. It significantly increased food production, especially for cereal crops, in certain countries. It has resulted in global food production meeting/exceeding the per capita energy needs of the global population.

Without the Green Revolution it is likely that many (more) people would be unable to obtain sufficient food. Food security is the physical and economic ability of people to meet their dietary needs for a healthy life. To achieve global food security, sufficient food of appropriate variety should be made available everywhere, at affordable prices. Since the Green Revolution focused on food production, it did not have (direct) effects on distribution and affordability of food. Many people in various parts of the world do not have access to sufficient food, but suffer from various forms of hunger/malnutrition despite the scale of global food production.

The Green Revolution's focus on a small number of crops (arguably) reduced/compromised the production of other foods, which may have been important for food security in particular places. It has had negative environmental impacts on soil, water, and air quality. Widespread soil degradation due to Green Revolution agriculture makes food production unsustainable, since healthy soil is an essential and

finite resource for farming, compromising long-term food security. Its dependence on fossil fuels for the production of agrochemicals and operation of machinery makes it unsustainable.

In conclusion, Green Revolution agriculture was essential for achieving the level of food security that we currently experience, but it has not met all people's needs for food, and its negative environmental impacts, and dependence on fossil fuels and soil-degrading methods, makes it unsustainable, so that long-term food security has not been achieved.

4 The addition of organic matter such as compost or manure adds nutrients to soil. Organic matter releases nutrients slowly, providing a steady supply for an extended period. Certain plants can add nutrients to the soil (e.g. legumes add nitrogen). Cover crops (grown as green manure) can be ploughed into the soil, adding nutrients (and organic matter). Crop rotation can be designed to add nutrients to the soil (e.g. from legumes) and/or allow recovery of nutrients during fallow period. Trees can be planted, to draw nutrients from deep in the soil and add them to the surface. Mixed herbal leys can be grown to add nutrients (and organic matter).

5 Planting trees as windbreaks/agroforestry can reduce soil erosion while drawing nutrients from deep soil layers up to the surface. Cover crops grown on soil not being cultivated can reduce soil erosion while adding nutrients/can be ploughed into the soil (as green manure). Using organic matter as mulch reduces soil erosion while slowly releasing nutrients into the soil as the organic matter decays.

6 Any two transfers from:

- Water infiltrating into/percolating through the soil.
- Nutrients leaching downwards in the soil.
- Erosion of soil particles (by wind/water) from one location to another.
- Biological mixing of soil particles, where burrowing animals move particles in various directions.

Any two transformations from:

- Decomposition of organic matter into humus.
- Mineralization of humus into inorganic minerals.
- Nutrient cycling, where minerals are converted from one substance to another (e.g. nitrates converted to nitrogen gas, or ammonia converted to nitrites then to nitrates).

7 Source:

- Organic matter undergoes decomposition/respiration by decomposers, releasing carbon compounds into the air.
- Carbon dioxide is released in aerobic conditions, and methane in anaerobic conditions.

Sink:

- As plants grow in soil they draw carbon out of the atmosphere during photosynthesis.
- Some of the biomass they produce is passed to the soil, as growth of roots.
- Some carbon is released from the roots into the soil (exudate), where it forms organic matter.

8 Organic matter affects the crumb structure of soil by causing mineral particles to stick together in clumps of various sizes. In clay soils this improves drainage and aeration by creating larger spaces between particles. In sandy soils this reduces drainage and increases water retention. Organic matter promotes the growth of soil microorganisms, which contribute to nutrient cycling. Organic matter slowly decomposes releasing minerals/nutrients that become available for plants, making the soil more fertile. Decomposition results in the formation of humus, a dark, sticky substance that gives soil a dark brown or black colour. Decomposing organic matter is also food for detritivores, so it increases the abundance and diversity of animals in the soil.

HL only

9 Hydroponics involves growing crops in nutrient-enriched water, with no soil. It eliminates impacts on soil (e.g. erosion, salinization, contamination). It may consume large volumes of water, but this can be

avoided by using a closed-loop system where water is recycled. It eliminates leaching of nutrients/eutrophication by retaining nutrients within the system.

Genetic engineering can be used to increase food production by improving farm yield, producing fast-growing crops or livestock, and reducing pest losses. Some genetically modified crops and livestock require less fertilizer/pesticide, so reduce dependency on industrial processes/fossil fuel consumption, and negative impacts of agrochemical use. Some GM crops and livestock produce less waste (e.g. less crop residue/less nutrient-rich manure), so make more efficient use of resources. Some GM crops/livestock may require less water, so reduce water depletion/pollution. However, some GM crops/livestock are more dependent on agrochemicals (e.g. herbicide-tolerant crops) so they may have a larger environmental impact. Concerns remain about possible ecological effects of GM crops and livestock on wild varieties.

Controlled-environment agriculture uses enclosed spaces such as greenhouses to grow crops. This may allow higher productivity since environmental conditions can be adjusted for maximum crop growth. It may reduce the release of pollutants into the environment, as pollutants may be retained inside the building. However, it may require significant amounts of energy to operate (e.g. for grow lights and machinery).

10 Meat production causes significant environmental impacts, such as methane emissions/water pollution. It uses more resources/water/land than crop production. It is less efficient than crop production because of losses of energy along the food chain/second law of thermodynamics. Crops must be produced or pasture must be provided to feed livestock, potentially taking away resources from production of crops that could feed people. It has been estimated that eliminating meat production would significantly reduce the environmental impact of food production and allow for greater production of crops for human consumption. Different meats and animal products have different environmental impacts and levels of inefficiency (e.g. beef's impact is highest and its efficiency of resource use is lowest).

However, livestock can play an important part in sustainable agriculture as part of sustainable/integrated/mixed farming systems. Livestock can provide organic fertilizer, which promotes crop growth/food production with lower environmental impact compared to synthetic fertilizer. Meat and animal products (e.g. dairy) provide important dietary nutrients, which may be difficult to replace with substitutes, so elimination of meat production may have negative effects on food security/public health. Meat and animal products are an important part of many people's cultural practices, so eliminating them may be socially/culturally harmful. Livestock can often be grown on marginal land that is unsuitable for arable farming, so elimination of livestock may not provide for an equivalent increase in crop production.

In conclusion, reduction of meat production would have many environmental benefits such as reduced greenhouse gas emissions and water consumption, but elimination entirely may be harmful to sustainable agriculture, public health and sociocultural practices.

11 Indigenous/traditional ecological knowledge is seen as valuable because it has been successful. Indigenous people often see farming systems holistically and reject commercial models of farming, and modern permaculture/organic farming takes a similar view. Companion planting is practised by many North American peoples (e.g. the Three Sisters) and has been widely adopted in modern 'sustainable' agriculture (e.g. organic farming, permaculture) as intercropping/polyculture.

Other practices are unlikely to be sustainable in the modern world, because of larger populations, lower availability of space, or already degraded ecosystems. Slash and burn was (possibly) sustainable in the past (e.g. Milpa in Central America), but it is unlikely to be sustainable today, except in specific circumstances where there is low pressure on ecosystems. Indigenous hunter–gatherer practices have (possibly) inspired modern movements towards harvesting wild species/secondary forest products, e.g. Brazil nut harvesting in the Amazon uses a practice found among indigenous people to provide nuts for the global trade.

12 Livestock add manure to soil, increasing its organic matter content and adding nutrients. Organic matter promotes the growth of soil microorganisms (and animals), thereby improving/restoring soil quality. Grazing by livestock can promote storage of organic matter/carbon in the soil by the grazed plants. Livestock can be used to clear vegetation and break up the soil surface in preparation for planting, without using heavy machinery. Intensity of grazing must be carefully managed to avoid overgrazing. Specific patterns of grazing, such as mob grazing or ultra-high stock density grazing, may be particularly effective at promoting carbon storage in soil.

Theme 6 Atmosphere and climate change

6.1 Introduction to the atmosphere

Answers to review questions

1 The tricellular model of atmospheric circulation has three main cells: the Hadley cell, the Ferrel cell, and the Polar cell. Provide a clear and accurate description of the processes involved in each cell:

- Hadley cell: Warm air rises at the equator, moves towards the poles in the upper atmosphere, and descends at around 30° latitude.
- Ferrel cell: Mid-latitude air circulation, involving rising air at around 60° latitude and descending air at around 30° latitude.
- Polar cell: Cold air descends at high latitudes, moves towards lower latitudes at the surface, and rises again at around 60° latitude.

Warm air rises at the equator (Hadley cell), moves poleward, and releases heat. Mid-latitude rising air (Ferrel cell) and high-latitude descending air (Polar cell) also contribute to heat redistribution.

2 Name the greenhouse gases (e.g. water vapour, carbon dioxide, methane, nitrous oxides) and aerosols. Give a clear and accurate explanation of the role of GHGs:

- They trap and re-emit infrared radiation from the Earth‘s surface, contributing to the greenhouse effect and keeping the Earth warmer than it would be without them.
- Aerosols can scatter and absorb solar radiation, influencing cloud formation and albedo, and can also directly absorb and emit infrared radiation.
- Greenhouse gases warm the atmosphere, while aerosols may have no warming or cooling effects (depending on the composition and altitude).

3 Global warming refers to the long-term increase in Earth’s average surface temperature primarily due to human activities, such as the burning of fossil fuels and deforestation. The enhanced greenhouse effect is caused by increased concentrations of gases such as carbon dioxide, methane, and nitrous oxides. These gases trap more heat, leading to a rise in Earth’s temperature. Global warming contributes to changes in weather patterns, such as more frequent and intense heatwaves, altered precipitation patterns, and increased frequency of extreme weather events. The consequences of this include rising sea levels, shifts in ecosystems, and potential impacts on biodiversity.

6.2 Climate change – causes and impacts

Answers to review questions

1 Weather is short-term conditions; climate is long-term patterns.

Weather is variable; climate is average patterns.

Weather is local/regional; climate is global.

Weather is dynamic; climate is static.

2 Identification of local impacts, and recognition of specific ecosystem changes.

Identification of global impacts, and understanding the far-reaching effects on ecosystems.

Specific examples illustrating local and global ecosystem impacts.

Demonstration of biodiversity’s role, and recognizing biodiversity’s impact on resilience.

3 Identification of factors, and recognizing various influences on perspectives.

Individual perspectives, and understanding factors affecting individual views on climate change.

Societal perspectives, and understanding factors affecting collective views on climate change.

Diversity of factors, and recognizing the multifaceted nature of influences.

Awareness of societal and economic conditions, and acknowledging the broader context influencing perspectives.

Environmental ethics, and incorporating ethical considerations in climate change perspectives.

HL only

4 Understanding of climate models, and recognition of the purpose and function of climate models.

Purpose of predictions, and identification of the intended use of climate models in predicting climate change impacts.

Consideration of feedback loops, and recognition of the role of feedback mechanisms in climate models.

Inclusion of positive and negative feedback, and demonstration of understanding of both positive and negative feedback loops.

Global energy balance, and acknowledgement of the influence of climate models on the global energy balance.

Incorporation of specific elements, and discussion of solar radiation, terrestrial albedo changes, and methane gas release.

Critical evaluation, and assessment of the reliability and limitations of climate models in predicting impacts.

5 Identification of tipping points, and recognition of specific instances of tipping points in the named examples.

Explanation of interaction, and description of how tipping points interact to form cascades.

For example:

- Coral bleaching example, and reference to instances where coral bleaching initiates tipping cascades in marine ecosystems.
- Atlantic thermohaline circulation example, and citation of cases where changes in ocean currents trigger cascading effects.
- Amazon rainforest–Cerrado transition (CAT) example, and provision of instances of how changes in the Amazon Rainforest impact the Cerrado and vice versa.

Understanding of cascading effects, and demonstration of awareness of how changes in one element trigger changes in others.

6.3 Climate change – mitigation and adaptation

Answers to review questions

1 Answers may include:

- Burning of fossil fuels such as coal, oil and natural gas for energy production, transportation, and industrial processes.
- Deforestation for agriculture, urbanization and other land use reduces CO_2 sequestration.
- Cutting down trees also releases the stored carbon into the atmosphere.

- Agricultural practices such as rice cultivation, livestock farming, and fertilizer use emit greenhouse gases such as methane and nitrous oxide.
- Improper waste-management practices, including landfilling and open burning of waste, produce methane and CO_2 emissions.
- Energy-intensive activities such as mining, manufacturing, and heavy machinery operations.

2 Mitigation: Mitigation refers to actions taken to reduce or prevent the emission of greenhouse gases into the atmosphere, addressing the root causes of climate change. Mitigation aims to reduce the drivers of climate change by slowly transitioning from fossil fuels to renewable energy sources (solar, wind, hydroelectricity), improving energy efficiency in buildings and transportation, afforestation and reforestation projects to sequester carbon dioxide, and/or promoting sustainable land use practices. These actions typically have long-term effects and contribute to addressing climate change over decades to centuries. For example, Germany has invested heavily in solar energy, leading to decreased reliance on fossil fuels for energy production.

Adaptation: Adaptation focuses on managing the unavoidable impacts of climate change by adjusting systems, behaviours, and infrastructure to become more resilient to its effects. Examples include building seawalls, storm surge gates and flood barriers to protect coastal communities from rising sea levels, implementing drought-resistant agricultural techniques, crop diversification to cope with changing precipitation patterns, developing early warning systems for extreme weather events, and/or relocating populations away from vulnerable areas. Responses are often more immediate and address the current and near-future impacts of climate change, aiming to minimize risks, and protect communities and ecosystems. For example, the Netherlands has the largest flood-protection project in the world. The surge barriers are almost 9 km long.

HL only

3 Governmental stakeholders:

- Policy development and implementation: Developing adaptation and mitigation policies, setting emission-reduction targets, establishing carbon-pricing mechanisms, promoting renewable energy adoption.
- International cooperation: International negotiations and agreements to fight climate change, e.g. Paris Agreement and UNFCCC.
- Enforcing law and managing compliance: Monitoring emissions, imposing fines and tax.
- Provide investment for climate projects, such as climate-resistant infrastructure, subsidies and incentives.

Non-governmental stakeholders:

- NGOs raise awareness: Collect resources and finances to support local communities, advocate policy changes.
- Research institutes conduct climate-specific research for better understanding of climate issues, and help in finding long-lasting solutions for existing climate issues.
- Local communities help in community-led-initiatives focused on urban projects such as greening, and empower communities to take action at the local level.

4 Answers may include:

- Lack of political willingness; short-term economic goals may be more popular; climate management and implementation strategies require a shift from conventional fossil fuel-based production systems to cleaner and sustainable renewable energy sources. This may not benefit the GDP and thus may not be a popular choice for politicians whose main focus is economic growth.
- Resource availability, financial constraint, and technological barriers in developing countries may hinder climate policy implementation.

- Climate systems are complex and difficult to predict. They have to be addressed by transboundary policies, which may not be possible unless countries willingly participate in the agreements.
- Behaviours of individuals and societies and their perspectives towards climate change affect the management strategies. The unequal distribution of climate impacts makes some communities more vulnerable to climate change than others.

6.4 Stratospheric ozone

Answers to review questions

1 Effects on humans: Skin damage, skin cancer, premature ageing; cataracts, eye cancer, macular degeneration.

Effects on ecosystems: Reduced photosynthesis; reduced productivity; reduced flow of energy in the ecosystem; altered biogeochemical cycles.

2 The greenhouse effect refers to the warming of the Earth due to the envelope of gases such as carbon dioxide, methane and water vapour that trap the outgoing radiations. The Earth's surface absorbs the incoming solar radiation and gets warmed. It then slowly releases this heat in the form of IR radiations, which travel back towards space. These radiations are trapped by the greenhouse gases present in the atmosphere, increasing the temperature of the Earth.

3 Human activities that may enhance the greenhouse effect include: burning of fossil fuels; cattle farming; industrialization; increased vehicular pollution; improper waste disposal; land use changes.

HL only

4 Ozone-depleting substances are chlorine, bromine or other halogen-containing compounds that cause the breakdown of ozone molecules, thus thinning the stratospheric ozone layer. ODSs are mainly human-made compounds, which include CFCs, HCFCs, halons, methyl bromide and carbon tetrachloride, among others. The ODSs enter the Earth's stratosphere and release their halogen atoms. These halogen atoms bind to the ozone (O_3) molecules and break them into O_2 and O.

5 The Kigali Amendment aims to phase down the use of HFCs, the potent greenhouse gases used in refrigeration and air conditioning.

Developed countries were required to start reducing HFC production and consumption by 2019, with a freeze in 2024, and subsequent reductions. Developing countries have more flexible timelines.

The amendment promotes the transition to environmentally friendly alternatives to HFCs.

Ratification by participating countries is crucial for its implementation.

6 Answers may include:
- Air conditioning units release CFCs and HCFCs.
- These ODSs rise to the stratosphere.
- UV radiation breaks them down, releasing chlorine and bromine atoms.
- These are carried into the polar region by the mid-latitude jet streams.
- Chlorine and bromine atoms destroy ozone molecules.
- Ozone depletion is more pronounced over the poles due to polar vortices.
- Cold temperatures and specific atmospheric conditions enhance ozone destruction.

Answers to exam-style questions

1 a An ozone hole is the thinning of the stratospheric ozone layer over a specific region.

b The ozone layer absorbs harmful UV radiation and protects lifeforms from its negative effects.

c In 2018, the ozone hole was very large with a concentration of 111.8 DU, due to the colder than normal winters in the Antarctic region that year. This seems to be reduced in 2019 as the ozone hole is smaller with 167 DU of ozone concentration. Thereafter in 2020 and 2021, we can again see a decline in the ozone concentration.

d The Antarctic polar vortex acts as a barrier, trapping cold air.

- Formation of polar stratospheric clouds (PSCs) within the vortex.
- PSCs provide surface for chemical reactions involving ODSs.
- Ozone-depleting reactions occur on PSCs.
- Sunlight returns in spring, initiating ozone destruction.
- Resultant 'ozone hole' over Antarctic region.
- Ozone depletion worsened by human-made ODSs.

2 [Five marks from:]

- Eccentricity: Changes in the shape of the Earth's orbit over 100,000-year cycles.
- Axial tilt (obliquity): Variation in the tilt of the Earth's axis from 22.1° to 24.5° over a 41,000-year cycle.
- Precession: Wobble in the Earth's axis orientation over a 26,000-year cycle.
- Combined effects: Influence on the distribution and intensity of solar radiation received by the Earth's surface.
- Impact on climate: Modulation of seasons, temperature, and ice ages over geological timescales.

3 Local/regional scale:

- Coral bleaching: Great Barrier Reef, Australia
- Melting permafrost: Arctic regions.

Ecosystem scale:

- Disruption of ecological succession and habitat loss: Amazon rainforest
- Seasonal changes: Migration patterns of Arctic terns.

Global scale:

- Ocean acidification: Impact on marine food chains
- Melting polar ice caps: Threat to polar bear populations.

4 **a** Nigeria, Mali, Sudan.

b Floods: Chile, Peru, India, Thailand.

Storms: The USA, including California, Oregon and Washington; Mexico, Philippines.

c Adaptation strategies:

- Coastal protection measures such as building seawalls and dykes, and restoring natural coastal ecosystems like mangroves to mitigate the impacts of sea-level rise and storm surges.
- Crop diversification and resilient farming practices such as drought-resistant crops, implementing irrigation systems, and adopting agroforestry techniques to adapt to changing climate conditions and ensure food security.

Mitigation strategies:

- Investing in wind, solar, hydroelectric, and other renewable energy sources to reduce reliance on fossil fuels and lower greenhouse gas emissions.
- Planting trees and restoring degraded forests to absorb carbon dioxide from the atmosphere, enhancing carbon sinks, and mitigating climate change impacts.

d In areas with high population density:

- Focus may be on reducing emissions from transportation and industries.
- Implementation of mass transit systems to reduce reliance on individual vehicles.

- Promoting energy-efficient buildings and urban planning.
- Adoption of renewable energy sources for densely populated areas.

In areas with low population density:

- Emphasis on sustainable land use practices to minimize deforestation and land degradation.
- Promotion of renewable energy options suitable for rural settings, such as solar or wind power.
- Implementation of agricultural practices that sequester carbon and reduce methane emissions.
- Community-based initiatives to enhance resilience to climate change impacts such as drought or flooding.

e *Answer pending copyright approval*

Theme 7 Natural resources

7.1 Natural resources, uses and management

Answers to review questions

1 Natural capital is a collection of all natural resources that can provide a sustainable income of goods and services. It includes forests, wetlands, mineral deposits, fossil fuels, etc.

Natural income is the annual yield of goods and services produced by the natural capital. For example, timber from forests, water from glaciers, fish from rivers/oceans, etc.

2 Advantages of using renewable resources:
- They do not cause pollution of particulate matter (soot).
- They do not release greenhouse gas.
- They reduce dependence on fossil fuels, which are finite.
- They create more jobs.
- They have stable energy prices that are not affected by geopolitics.
- They are reliable.

Disadvantages of using renewable resources:
- They depend on geographical location, e.g. wind and solar energy.
- They require high initial cost for set up.
- The energy produced may be intermittent.
- The storage of energy is a challenge.

[Discuss each in detail with a named example.]

3 Any four from:
- EIAs help in identifying potential environmental effects of proposed projects.
- They help in making informed decisions.
- They may be required as a part of the regulatory approval process.
- They allow local communities and stakeholders to present their viewpoints on big projects.
- They help in risk assessment and mitigation planning.

Answers to exam-style questions

1 Define resource security as the ability of societies to ensure the long-term availability of sufficient natural resources to meet demand.

Outline the factors – reduction in demand; less consumption; less wastage.
- Increase in supply: Better access to reserves; peaceful geopolitical conditions; strong supply chain; increasing self-sufficiency.
- Use of technology: For better extraction methods of resources; alternate energy sources; for desalination.

2 Definition of ecosystem goods: Economic benefits coming from ecosystems.

Ecosystem services: Actions performed by the biotic parts of the ecosystem that are beneficial to humans and other living organisms.

Identification of an ecosystem: For example rainforest, coral reef, grassland or any other ecosystem.

Identification and explanation of ecosystem services: For example, a tropical rainforest may offer carbon sequestration through its dense vegetation and provide climate regulation by influencing local weather patterns.

Identification and explanation of ecosystem goods: For example, for a tropical rainforest, goods like timber, and non-timber forest products such as fruits and medicinal plants.

Conclusion.

3 Identify a natural resource: Oil, coal, timber, gold, radioactive element, etc.

Explanation of historical changes: A brief historical overview of how the value of the named natural resource has changed over time, due to demand, market dynamics, technological developments, or geopolitical shifts.

Analysis of economic, social, or environmental impacts.

7.2 Energy sources, use and management

Answers to review questions

1 Renewable resources can be regenerated back at the same pace they are used or removed from the system, while non-renewable resources take millions of years to be regenerated.

2 Advantages:
- Steady supply of electricity.
- A large amount of energy can be produced with a small quantity of energy resources.
- The energy produced is clean, and does not emit harmful greenhouse gases.

Disadvantages:
- It produces hazardous waste that needs to be carefully disposed of away from lifeforms.
- It is non renewable as the energy source is finite.

3 The use of cobalt enhances battery performance, providing stability and extending overall lifespan. However, concerns arise due to ethical issues related to cobalt mining, including child labour and environmental impact.

HL only

4 Energy security is the access to affordable and reliable energy choices for the people in a given country. It reduces reliance on energy imports.

5 Identify the potential geopolitical conflicts related to the global demand for batteries.

Discuss the resource competition and supply chain disruptions associated with the demand for batteries.

Explore the technology transfer and intellectual property rights issues related to advanced battery technologies.

Mention the challenges of battery recycling and waste management.

Discuss the geopolitical implications of electric vehicle adoption.

Conclude with a clear and well-supported argument.

Answers to exam-style questions

1 Challenges associated with the use of nuclear energy for electricity generation are [max 2 marks]:
- Potential risks associated with nuclear accidents, such as Chernobyl or Fukushima – emphasize environmental and health consequences.

- Challenge of managing and disposing of radioactive waste generated during nuclear power plant operation.
- Significant upfront costs involved in constructing nuclear power plants and ensuring safety measures.

Benefits associated with the use of nuclear energy for electricity generation are [max 2 marks]:

- Low greenhouse gas emissions compared to fossil fuels.
- High energy output – nuclear power produces large amounts of electricity from a relatively small amount of fuel.
- Nuclear power provides a stable and consistent source of electricity.

2 Clearly state the specific region under consideration.

Analysis of government policies [2 max]:

- Policies that incentivize the adoption of renewable energy, such as feed-in tariffs, subsidies, or tax credits.
- Clear analysis of the regulatory environment, including laws and regulations that support or hinder the transition to renewables.

Impact on transition [2 max]:

- Assessing the progress of policies using statistics.
- Identify challenges of the chosen region.
- Summary and future.

3 Give names of countries that will be discussed in the response. For example – China, India, UK, USA. Give a brief context or background regarding the country's energy landscape.

Environmental implications [3 max]:

- Air pollution: Greenhouse gas emissions, particulate matter (PM2.5, PM10)
- Contribution to climate change through its reliance on non-renewables
- Country's stance on international climate agreements
- Impact on biodiversity, considering habitat destruction and species loss.

Economic implications [3 max]:

- Resource availability and rate of depletion
- Challenges posed by relying on non-renewables in terms of energy security
- Factors like price volatility, geopolitical tensions, or dependence on external suppliers
- Transition costs to renewable energy sources: Investments, job transitions, and economic restructuring.

Conclusion statement.

4 Outline the relevance of technological advancement, and the importance of energy efficiency in the context of production and consumption.

Technological advancements in energy production [3 max]:

- Solar, wind, hydropower
- Smart grids technology: Efficient energy distribution and consumption
- Energy storage systems: Lithium ion batteries.

Technological advancements on energy consumption [2 max]:

- Energy efficient appliances: Energy-saving light bulbs; heating and cooling appliances; washing machines and dishwashers; induction hobs; refrigerators
- Smart buildings: Efficient energy use; lighting control; eco-friendly material for décor; sensors.

Interconnectedness of energy production and consumption [2 max]:

- Interconnectivity of devices for better energy management: Building automation and management; connectivity to smart grid
- Remotely controlling home devices to avoid wastage
- Lights where intensity can be changed according to requirement.

Summary statement.

7.3 Solid waste

Answers to review questions

1 Solid domestic waste is of the following types:

- Organic waste: Kitchen waste, other organic material including leaves, flowers, fruits.
- Recyclable waste:
  - Paper and cardboard waste: Old books, magazines, notebooks, cartons, packaging material consisting of paper shards.
  - Glass: Glass bottles and containers, broken glass, other mixed glass waste.
  - Plastic: Plastic bottles and containers, toys, some plastic construction material.
  - Metal: Aluminium cans, metal scraps.
- Toxic waste: Paints, chemicals, batteries, pesticides, spray cans, medical waste.

2 Advantages of landfills:

- Is initially inexpensive, but expenses rise swiftly as sites reach capacity.
- Methane produced during decomposition can be harnessed for energy and electricity generation that can be used to heat houses, such as in Sweden.
- Repurposing old landfill sites for construction projects after landscaping is a possibility. This may create jobs for the local community.
- If properly managed, landfills can help in keeping cities and towns clean.

3 Disadvantages of incineration:

- May release toxic fumes, which can cause severe decline in air quality of surrounding areas.
- Burning of plastic can release microplastics, dioxins, bisphenols and phthalates, which can cause detrimental effects on neurodevelopment and the endocrine and reproductive systems.
- Incinerators have high operating costs and require skilled labour.
- Usually the waste-to-energy plants are located in low economically developed areas, exposing a particular section of the society to most of the harmful effects.

4

Landfills	**Composting**
Cheap and easy way to dispose of waste	May be cheap but takes a very long time
Do not require segregation of waste	Requires segregation of waste
Any material can be sent into the landfill	Only organic matter can be used for composting

Answers to exam-style questions

1 The recycling rate increased from 40.5 per cent in 2010 to 44 per cent in 2021. The highest recycling rate was 46 per cent in 2019. The recycling rate may have continued to increase after 2019, however a decline is observed in 2020 that may be due the COVID-19 pandemic.

The UK government has introduced many policies that discourage landfill, such as the landfill tax, which aims to reduce the amount of waste being sent to landfills. This strategy forced citizens to adopt recycling methods. Several other strategies were put in place to make opting for recycling easier for citizens:

- Providing convenient recycling bins or collection centres (especially for e-waste).
- Educating people about the benefits of recycling.
- Educating people about valuing resources.
- Providing platform to recyclers to promote their business.
- Offering financial incentives for recycling.
- Encouraging businesses to build in waste reduction in their business model design.
- Improving the quality of recycled materials.
- Creating a stronger market for recycled goods.
- Making businesses responsible for what they produce – promoting the use of raw materials that can be recycled over materials that cannot be recycled.
- Reducing or rethinking packaging material.
- Making special provisions for returning batteries from all types of appliances back to the producers. Businesses to set up collection points for this.
- Issuing fines for non-compliance with recycling rules and regulations.

2 Definition of landfilling: Involves burying waste in designated areas, often lined with protective barriers to prevent contamination of soil and water.

Advantages:

- It is cost-effective.
- Space utilization: It allows for the disposal of a large volume of waste in a confined space.
- Methane, a byproduct of waste decomposition, can be captured and used as a source of energy.

Disadvantages:

- Can result in environmental pollution if not properly managed, leading to soil and water contamination.
- Available land is finite: Finding suitable sites can be challenging.
- Poses long-term risks: The release of harmful gases and leachates over time.

Definition of incineration: Burning waste at high temperatures to reduce its volume and generate energy.

Advantages:

- Significantly reduces the volume of waste, minimizing the need for extensive landfill space.
- Heat generated during incineration can be harnessed to produce electricity or heat buildings.
- Can help decrease methane emissions.

Disadvantages:

- Releases pollutants into the air: Potentially harmful gases and particulate matter.
- Establishing incineration facilities can be expensive and require advanced technologies to control emissions.
- Ash residues from incineration may contain potentially hazardous materials such as dioxins, which can cause cancer, reproductive and developmental problems, and compromise the immune system.
- Hazardous ash requires proper disposal after burning.

3 Plastics are used in many sectors. They can sometimes be recycled but mostly they are one-time use and go straight to the landfills. Plastics take several hundred years to decompose in landfills.

- Reducing is considered the most preferred option as it ensures that a huge amount of waste is not generated in the first place. Before buying, people must think whether or not they really need that product/container/packaging. Considering our choices of buying one-time use plastics in daily life, such as toothbrushes, ball pens, and straws, can make a big difference in the amount of non-recyclable plastic that ends up in landfills. Making conscious decisions such as choosing to use refillable ink pens rather than ball pens is an example of preventing waste creation. Similarly, using shampoo bars instead of liquid shampoo in bottles can reduce a huge amount of plastic waste.
- Reusing comes next as it can help to reduce the demand for new products in the market and shift the economy towards being more sustainable. Food-storage containers can be reused many times before they are discarded. We must pay attention to the grade of plastic while buying food in containers. All water bottles can be reused by refilling them. People can carry their own water bottles and refill them instead of buying packaged water. However, this may not be possible everywhere.
- Recycling is the third best way of ensuring that much of the product (waste) comes back for further use. It delays the time that waste reaches landfills. Plastic bottles, caps and containers can be recycled into reusable plastic bags, containers and casings.
- Recovery is placed fourth in the hierarchy of waste management as it is the best option for waste that cannot be recycled. It may be possible to recovery energy from this type of waste, for example by composting.
- Disposal is considered as the last and least sustainable option when a product can neither be recycled nor can anything be recovered from it. Most of this type of waste goes to landfill or incineration.

4 Advantages of recycling:

- Reduces waste sent to landfills and incineration.
- Saves energy.
- Saves natural resources.
- Reduces the production of greenhouse gases.
- Prevents pollution.
- Creates job opportunities.

Disadvantages of recycling:

- High initial costs of setting up a recycling plant.
- Recycled products may not be durable; as a result they may quickly end up in landfills.
- Requires energy.
- Requires technical knowhow.
- Processing costs are high.

5 Waste from battery-manufacturing industries:

- Resource recovery: Valuable components are recovered and reused. Separation techniques remove unused lithium and nickel from spent batteries before discarding the waste. This reduces the need for additional raw materials to make batteries, and minimizes the environmental impacts of disposing of huge quantities of e-waste.
- Recycle any scrap metal that can be obtained from spent or unused batteries, and reduce the use of hazardous chemicals/elements in batteries.
- Better industrial EPR programme: Reduce illegal dumping; producer takes responsibility for the product until the end of its lifetime.

Theme 8 Human populations and urban systems

8.1 Human populations

Answers to review questions

1 Japan – it has a death rate much higher than its birth rate, resulting in a negative value of the natural increase rate.

2 Nigeria, Gabon and Cambodia. They all have a high birth rate and much lower death rate, showing that their population is rapidly increasing. Life expectancy is lower than in other countries so the doubling time of their population is very short, e.g. 3.52 years for Gabon's population to double.

3 Norway, Denmark (Scandinavian countries) and Iceland (Nordic country) have low birth rates and death rates that are similar to birth rates, except for Iceland where death rates are somewhat lower. They all have low natural increase rates and have relatively stable populations.

4 China with a doubling time of just over 384 years.

5 The life expectancy is one of the highest in the table, but the death rate is not high. Therefore more people are staying alive for longer, resulting in an increased elderly population. Medical advances and standards of living in these countries mean that the population continues to grow.

Answers to exam-style questions

1 High infant mortality rates mean there are many deaths; populations are increasing too rapidly, resulting in a lack of resources, etc., for all.

2 There are many strategies that could be used to directly change people's behaviour and to influence people indirectly to change their behaviour. Direct ways could be fines for having more children than 'allowed', or taxation on more than one child. Indirect ways include enhancing the medical care, facilities and availability of contraception to reduce the number of unwanted births and to ensure that those children who are born are more likely to survive. In reality, both strategies are really needed to successfully implement anti-natalist policies.

3 The Demographic Transition Model tracks the development of a country in relation to the changes in its birth and death rates. Typically, countries in Stage 1 had very high birth rates and very high death rates, often due to the lack of financial aid, sanitation and medical care available to developing countries. Yet, globalization has resulted in information being readily available around the world regarding issues that would require aid and support, and therefore these issues do not become so bad that the death rates return to rates the same as Stage 1. Therefore, all countries are in at least Stage 2 of the DTM.

8.2 Urban systems and urban planning

Answers to review questions

1 Africa has the most countries with the lowest levels of urbanization.

2 Both North and South America have high levels of urbanization. However, South America has a number of countries with levels dropping below 50 per cent.

3 Large parts of the rural environment require workers to grow crops as mass mechanization has not yet been adopted throughout India.

4 Large parts of central Australia are uninhabitable as they are desert. The majority of the population live in the urban areas around the coast.

5 Push factors: Lack of employment opportunities; lack of higher education; limited public transport; any other suitable reason for people wanting to leave rural areas.

Pull factors: Availability of job opportunities; increased education opportunities; proximity to work; convenience.

6 Increasing semi-permeable surfaces to allow absorption of rainwater into the underlying soil and reduce the risk of flooding. Tiered billing system that charges heavy users more for their water, encouraging water conservation in homes and businesses and reducing the volume of water used. Any other relevant strategy and impact.

7 Green roofs, vertical gardens, water-saving devices, use of renewable energy sources. Any other reasonable way to make a building more sustainable.

8 Biotic: humans, flora and fauna, or disease. Abiotic: climate, topography, infrastructure, job availability.

9 People migrate from rural to urban communities for many reasons. Rural communities often have much lower numbers of job opportunities and facilities than urban areas. This can push people to move to the urban areas where everything is much more convenient.

10 Urban sprawl increases the amount of land that is converted into concrete covering. This dramatically changes the natural flow of water and reduces the amount that reaches the soil beneath the city. Larger populations of people require more food, which can result in more areas being converted to agriculture, therefore losing the biodiversity.

11 Green architecture in cities is essential to make sure the latest technology is being developed and used, such as buildings that harness the natural environment, 3D-printed housing, houses made from waste plastic bottles. This allows people to use waste products to create useful spaces for people to live or work in at no cost to the environment.

8.3 Urban air pollution

Answers to review questions

1 CO, CO_2, PM10 and PM2.5, NOx, SO_2, VOCs and hydrocarbons.

2 Natural: volcanoes and wildfires. Anthropogenic: vehicles and power stations.

3 Pedestrianization creates areas of the city that are safe for walking and only allow essential vehicles to enter. This reduces the level of traffic within the city and therefore these areas are less directly impacted by exhaust fumes.

4 A catalytic converter is placed in the exhaust and cleans the exhaust fumes before emission into the atmosphere. It converts NOx, hydrocarbons and CO into O_2, CO_2, N_2, and H_2O, and is up to 99 per cent effective at this removal.

5 Photochemical smog builds up when there is little air movement. If a city is situated in a valley or bowl then the photochemical smog events can be much greater than in cities in flat areas. This is due to the fact that wind movement does not remove the pollution from the bowl very quickly, resulting in daily build-ups.

6 The burning of fossil fuels in vehicles, factories and homes creates NOx and SO_2 that interact with water in the atmosphere to create nitric and sulfuric acids.

7 Acid rain can remove essential nutrients from the soil, resulting in reduced plant growth and a reduced crop yield.

8 Midday to early afternoon.

Answers to exam-style questions

1 Changing behaviour includes switching to energy and vehicles that do not rely on the burning of fossil fuels. This will result in a reduction in the primary pollutant production, which are a key component of the formation of acid rain.

[1 mark for stating what kind of change of behaviour might be appropriate, 1 mark for how this impacts pollution formation, and 1 mark for linking it to acid rain.]

2 Areas that are impacted by tropospheric ozone are generally urban areas that have a lot of residents and people who work there on a daily basis. Continual exposure to air pollution can significantly impact respiratory function, particularly for those who already have a respiratory disease such as asthma. To protect against this, individuals can wear face masks that filter out the polluted air, limit outdoor exercise, seal houses and run air purifiers in homes. This increases electricity usage, potentially resulting in greater use of fossil fuels. Tourism in these areas is significantly reduced during pollution events due to low visibility, noticeable smell of burning, and not being able to engage in outdoor activities. This places a high financial burden on those who either live or have businesses within these urban areas.

[1 mark for stating why tropospheric ozone is bad for human health, 4 marks max for ways people can protect themselves from air pollution, and 1 mark for a final statement regarding the overall impact.]

3 Acid rain forms from SO_2 and NOx emissions. $NO_2 + H_2O \rightarrow HNO_3$ (nitric acid) and $SO_2 + H_2O + O_2 \rightarrow H_2SO_4$ (sulfuric acid). Both primary pollutants interact with water; sulfur dioxide also interacts with oxygen to create the acids that impact the pH of atmospheric water.

[1 mark for the primary pollutants, 1 mark for including interactions with atmospheric oxygen, 1 mark for a full, correct equation for the formation of either nitric or sulfuric acid.]

4 There are many similarities and differences in how newly built and retrofitted cities can become more sustainable. New cities can harness new technologies and build a city around knowledge regarding cooling, heating, water movement, electricity generation, etc. However, in old cities it can be hard to retrofit some areas that are maybe protected as World Heritage Sites, etc. Some old buildings may not be suitable for the addition of a green roof and therefore there can be more constraints in retrofitting an existing city. In conclusion, whether a city is old or new there are many ways to improve sustainable practices and reduce air pollution within urban areas.

[2 marks for strategies to improve existing cities, and 2 marks for elements to be included in the creation of new cities, and 1 mark for a concluding statement.]