Topic 1: Foundations of environmental systems and societies (16 hours)

Big questions: This topic may be particularly appropriate for considering big questions A, C, D and E.

Sub-topic 1.1: Environmental value systems

Significant ideas:

- Historical events, among other influences, affect the development of environmental value systems (EVSs) and environmental movements.
- There is a wide spectrum of EVSs, each with its own premises and implications.

Knowledge and understanding:	Guidance:
• Significant historical influences on the development of the environmental movement have come from literature, the media, major environmental disasters, international agreements and technological developments. • An EVS is a worldview or paradigm that shapes the way an individual, or group of people, perceives and evaluates environmental issues, influenced by cultural, religious, economic and socio-political contexts. • An EVS might be considered as a system in the sense that it may be influenced by education, experience, culture and media (inputs), and involves a set of interrelated premises, values and arguments that can generate consistent decisions and evaluations (outputs). • There is a spectrum of EVSs, from ecocentric through anthropocentric to technocentric value systems. • An ecocentric viewpoint integrates social, spiritual and environmental dimensions into a holistic ideal. It puts ecology and nature as central to humanity and emphasizes a less materialistic approach to life with greater self-sufficiency of societies. An ecocentric viewpoint prioritizes biorights, emphasizes the importance of education and encourages self-restraint in human behaviour. • An anthropocentric viewpoint argues that humans must sustainably manage the global system. This might be through the use of taxes, environmental regulation and legislation. Debate would be encouraged to reach a consensual, pragmatic approach to solving environmental problems. • A technocentric viewpoint argues that technological developments can provide	• A society is an arbitrary group of individuals who share some common characteristics, such as geographical location, cultural background, historical timeframe, religious perspective, value system and so on. • A variety of significant historical influences could be covered, but with a minimum of three in-depth examples. Possible examples could include: James Lovelock's development of the Gaia hypothesis; Minamata disaster; Rachel Carson's book *Silent Spring* (1962);, Davis Guggenheim's documentary *An Inconvenient Truth* (2006); Chernobyl disaster of 1986; Fukushima Daiihi nuclear disaster of 2011; whaling; Bhopal disaster of 1984; Gulf of Mexico oil spill of 2010; Chipko movement; Rio Earth Summit 2012 (Rio+20); Earth Day; Green Revolution; Copenhagen Accord; recent or local events of student interest. • In the range of historical influences selected, it is beneficial to have both local and global examples. • EVSs are individual; there is no "wrong" EVS. • During the ESS course students should be encouraged to develop their own EVS and to be able to justify their decisions on environmental issues based on their EVSs. **International-mindedness:** • Ecosystems may often cross national boundaries and conflict may arise from the clash of different value systems about exploitation of resources (for example, migration of wildlife across borders in southern Africa).

solutions to environmental problems. This is a consequence of a largely optimistic view of the role humans can play in improving the lot of humanity. Scientific research is encouraged in order to form policies and to understand how systems can be controlled, manipulated or changed to solve resource depletion. A pro-growth agenda is deemed necessary for society's improvement. • There are extremes at either end of this spectrum (for example, deep ecologists–ecocentric to cornucopian–technocentric), but in practice, EVSs vary greatly depending on cultures and time periods, and they rarely fit simply or perfectly into any classification. • Different EVSs ascribe different intrinsic value to components of the biosphere. **Applications and skills:** • **Discuss** the view that the environment can have its own intrinsic value. • **Evaluate** the implications of two contrasting EVSs in the context of given environmental issues. • **Justify,** using examples and evidence, how historical influences have shaped the development of the modern environmental movement	• Differences in cultures and societies may influence the development of environmental value systems. **Theory of knowledge:** • EVSs shape the way we perceive the environment—which other value systems shape the way we view the world? **Connections:** • ESS: Conservation of biodiversity (3.4); soil degradation and conservation (5.3); photochemical smog (6.3), acid deposition (6.4); climate change—causes and impacts (7.2); resource use in society (8.2) • Diploma Programme: Social and cultural anthropology, geography (HL)

Sub-topic 1.2: Systems and models	
Significant ideas: • A systems approach can help in the study of complex environmental issues. • The use of systems and models simplifies interactions but may provide a more holistic view without reducing issues to single processes.	
Knowledge and understanding: • A systems approach is a way of visualizing a complex set of interactions which may be ecological or societal. • These interactions produce the emergent properties of the system. • The concept of a system can be applied at a range of scales. • A system is comprised of storages and flows. • The flows provide inputs and outputs of energy and matter. • The flows are processes that may be either transfers (a change in location) or transformations (a change in the chemical nature, a change in state or a change in	**Guidance:** • A systems approach should be taken for all the topics covered in the ESS course. • Biosphere refers to the part of the Earth inhabited by organisms that extends from the upper parts of the atmosphere to deep within the Earth's crust. • Students should interpret given system diagrams and use data to produce their own for a variety of examples, such as carbon cycling, food production and soil systems. • Students are **not** expected to know any particular system diagram

energy).

- In system diagrams, storages are usually represented as rectangular boxes and flows as arrows, with the direction of each arrow indicating the direction of each flow. The size of the boxes and the arrows may be representative of the size/magnitude of the storage or flow.
- An open system exchanges both energy and matter across its boundary while a closed system exchanges only energy across its boundary.
- An isolated system is a hypothetical concept in which neither energy nor matter is exchanged across the boundary.
- Ecosystems are open systems; closed systems only exist experimentally, although the global geochemical cycles approximate to closed systems.
- A model is a simplified version of reality and can be used to understand how a system works and to predict how it will respond to change.
- A model inevitably involves some approximation and therefore loss of accuracy.

Applications and skills:

- **Construct** a system diagram or a model from a given set of information.
- **Evaluate** the use of models as a tool in a given situation, for example, climate change predictions.

symbols such as those of Odum or Sankey.

International-mindedness:

- The use of models facilitates international collaboration in science by removing language barriers that may exist.

Theory of knowledge:

- Models are simplified constructions of reality—in the construction of a model, how can we know which aspects of the world to include and which to ignore?

Connections:

- ESS: Introduction to water systems (4.1); introduction to soil systems (5.1); terrestrial food production systems and food choices (5.2); introduction to the atmosphere (6.1)
- Diploma Programme: Design technology (topic 3), geography (option G), biology (topic 4)

Sub-topic 1.3: Energy and equilibria

Significant ideas:

- The laws of thermodynamics govern the flow of energy in a system and the ability to do work.
- Systems can exist in alternative stable states or as equilibria between which there are tipping points.
- Destabilizing positive feedback mechanisms will drive systems toward these tipping points, whereas stabilizing negative feedback mechanisms will resist such changes.

Knowledge and understanding:

- The first law of thermodynamics is the principle of conservation of energy, which states that energy in an isolated system can be transformed but cannot be created or destroyed.
- The principle of conservation of energy can be modelled by the energy transformations along food chains and energy production systems.
- The second law of thermodynamics states that the entropy of a system increases over time. Entropy is a measure of the amount of disorder in a system. An increase in entropy arising from energy transformations reduces the energy available to do work.
- The second law of thermodynamics explains the inefficiency and decrease in available energy along a food chain and energy generation systems.
- As an open system, an ecosystem will normally exist in a stable equilibrium, either in a steady-state equilibrium or in one developing over time (for example, succession), and maintained by stabilizing negative feedback loops.
- Negative feedback loops (stabilizing) occur when the output of a process inhibits or reverses the operation of the same process in such a way as to reduce change—it counteracts deviation.
- Positive feedback loops (destabilizing) will tend to amplify changes and drive the system toward a tipping point where a new equilibrium is adopted.
- The resilience of a system, ecological or social, refers to its tendency to avoid such tipping points and maintain stability.
- Diversity and the size of storages within systems can contribute to their resilience and affect their speed of response to change (time lags).
- Humans can affect the resilience of systems through reducing these storages and diversity.
- The delays involved in feedback loops make it difficult to predict tipping points and add

Guidance:

- The use of examples in this sub-topic is particularly important so that the abstract concepts have a context in which to be understood.
- Emphasis should be placed on the relationships between resilience, stability, equilibria and diversity.
- A stable equilibrium is the condition of a system in which there is a tendency for it to return to the previous equilibrium following disturbance.
- A steady-state equilibrium is the condition of an open system in which there are no changes over the longer term, but in which there may be oscillations in the very short term.
- A tipping point is the minimum amount of change within a system that will destabilize it, causing it to reach a new equilibrium or stable state.
- Examples of human impacts and possible tipping points should be explored.

International-mindedness:

- The use of energy in one part of the globe may lead to a tipping point or time lag that influences the entire planet's ecological equilibrium.

Theory of knowledge:

- The laws of thermodynamics are examples of scientific laws—in which ways do scientific laws differ from the laws of human science subjects, such as economics?

Connections:

- ESS: Systems and models (1.2); communities and ecosystems (2.2); terrestrial food production systems and food choices (5.2); energy choices and security (7.1)
- DP: Physics (topic 2 and option B); chemistry (topics 5, 7 and 15; option C);

to the complexity of modelling systems. **Applications and skills:** • **Explain** the implications of the laws of thermodynamics to ecological systems. • **Discuss** resilience in a variety of systems. • **Evaluate** the possible consequences of tipping points.	biology (topic 6); design technology (topic 2)

Sub-topic 1.4: Sustainability	
Significant ideas: • All systems can be viewed through the lens of sustainability. • Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs. • Environmental indicators and ecological footprints can be used to assess sustainability. • Environmental impact assessments (EIAs) play an important role in sustainable development.	
Knowledge and understanding: • Sustainability is the use and management of resources that allows full natural replacement of the resources exploited and full recovery of the ecosystems affected by their extraction and use. • Natural capital is a term used for natural resources that can produce a sustainable natural income of goods or services. • Natural income is the yield obtained from natural resources. • Ecosystems may provide life-supporting services such as water replenishment, flood and erosion protection, and goods such as timber, fisheries, and agricultural crops. • Factors such as biodiversity, pollution, population or climate may be used quantitatively as environmental indicators of sustainability. These factors can be applied on a range of scales, from local to global. The Millennium Ecosystem Assessment (MA) gave a scientific appraisal of the condition and trends in the world's ecosystems and the services they provide using environmental indicators, as well as the scientific basis for action to conserve and use them sustainably. • EIAs incorporate baseline studies before a development project is undertaken. They assess the environmental, social and economic impacts of the project, predicting and	**Guidance:** • A sustainability lens should be used throughout the course, where appropriate. • EFs can be used to give students a sense of their own impact at the start of the course and are addressed in more detail in topic 8. • There is no expectation to explore an EIA in depth, but rather to focus on the principles of their use. **International-mindedness:** • International summits and conferences aim to produce international tools (bodies, treaties, agreements) that address environmental issues. • EIAs vary across national borders. **Theory of knowledge:** • EIAs incorporate baseline studies before a development project is undertaken—to what extent should environmental concerns limit our pursuit of knowledge?

evaluating possible impacts and suggesting mitigation strategies for the project. They are usually followed by an audit and continued monitoring. Each country or region has different guidance on the use of EIAs.

- EIAs provide decision-makers with information in order to consider the environmental impact of a project. There is not necessarily a requirement to implement an EIA's proposals, and many socio-economic factors may influence the decisions made.
- Criticisms of EIAs include: the lack of a standard practice or training for practitioners, the lack of a clear definition of system boundaries and the lack of inclusion of indirect impacts.
- An ecological footprint (EF) is the area of land and water required to sustainably provide all resources at the rate at which they are being consumed by a given population. If the EF is greater than the area available to the population, this is an indication of unsustainability.

Applications and skills:

- **Explain** the relationship between natural capital, natural income and sustainability.
- **Discuss** the value of ecosystem services to a society.
- **Discuss** how environmental indicators such as MA can be used to evaluate the progress of a project to increase sustainability.
- **Evaluate** the use of EIAs.
- **Explain** the relationship between EFs and sustainability.

Connections:

- ESS: Human systems and resource use (topic 8)
- Diploma Programme: Social and cultural anthropology; design technology (topics 2 and 8); geography (topic 3, options C and G); economics

Sub-topic 1.5: Humans and pollution

Significant ideas:

- Pollution is a highly diverse phenomenon of human disturbance in ecosystems.
- Pollution management strategies can be applied at different levels.

Knowledge and understanding:

- Pollution is the addition of a substance or an agent to an environment through human activity, at a rate greater than that at which it can be rendered harmless by the environment, and which has an appreciable effect on the organisms in the environment.

Guidance:

- The terms "pollutant" and "contaminant" in environmental chemistry are considered more or less synonymous.
- Pollution which arises from numerous widely dispersed origins is described as non-point source. Point source pollution arises from a single clearly

• Pollutants may be in the form of organic or inorganic substances, light, sound or thermal energy, biological agents or invasive species, and may derive from a wide range of human activities including the combustion of fossil fuels. • Pollution may be non-point or point source, persistent or biodegradable, acute or chronic. • Pollutants may be primary (active on emission) or secondary (arising from primary pollutants undergoing physical or chemical change). • Dichlorodiphenyltrichloroethane (DDT) exemplifies a conflict between the utility of a "pollutant" and its effect on the environment. **Applications and skills:** • **Construct** systems diagrams to show the impact of pollutants. • **Evaluate** the effectiveness of each of the three different levels of intervention, with reference to figure 3. • **Evaluate** the uses of DDT.	identifiable site. • "Biodegradable" means capable of being broken down by natural biological processes • The principles of this sub-topic, particularly figure 3, should be used throughout the course when addressing issues of pollution. • Students should be aware that for some pollutants there may be a time lag before an appreciable effect on organisms is evident. • With reference to figure 3, students should appreciate the advantages of employing the earlier strategies of pollution management over the later ones, and the importance of collaboration. • Students might demonstrate knowledge of both the anti-malarial and agricultural use of DDT. **International-mindedness:** • Pollution cannot be contained by national boundaries and therefore can act either locally, regionally or globally. **Theory of knowledge:** • Experts sometimes disagree about pollution management strategies—on what basis might we decide between the judgments of the experts if they disagree? **Connections:** • ESS: Stratospheric ozone (6.2); photochemical smog (6.3); water pollution (4.4); terrestrial food production systems and food choices (5.2); human population carrying capacity (8.4); biodiversity and conservation (topic 3) • Diploma Programme: Social and cultural anthropology; chemistry (options A, B, C and D); design technology (topic 2), geography (option G); economics

Process of pollution	Level of pollution management
HUMAN ACTIVITY PRODUCING POLLUTANT ↓	**Altering human activity** The most fundamental level of pollution management is to change the human activity that leads to the production of the pollutant in the first place, by promoting alternative technologies, lifestyles and values through: • campaigns • education • community groups • governmental legislation • economic incentives/disincentives.
RELEASE OF POLLUTANT INTO ENVIRONMENT ↓	**Controlling release of pollutant** Where the activity/production is not completely stopped, strategies can be applied at the level of regulating or preventing the release of pollutants by: • legislating and regulating standards of emission • developing/applying technologies for extracting pollutant from emissions.
IMPACT OF POLLUTANT ON ECOSYSTEMS	**Clean-up and restoration of damaged systems** Where both the above levels of management have failed, strategies may be introduced to recover damaged ecosystems by: • extracting and removing pollutant from ecosystem • replanting/restocking lost or depleted populations and communities.

Figure 3

Pollution management targeted at three different levels

Topic 2: Ecosystems and ecology (25 hours)

Big questions: This topic may be particularly appropriate for considering big questions A and E.

Sub-topic 2.1: Species and populations

Significant ideas:

- A species interacts with its abiotic and biotic environments, and its niche is described by these interactions.
- Populations change and respond to interactions with the environment.
- Any system has a carrying capacity for a given species.

Knowledge and understanding:

- A species is a group of organisms that share common characteristics and that interbreed to produce fertile offspring.
- A habitat is the environment in which a species normally lives.
- A niche describes the particular set of abiotic and biotic conditions and resources to which an organism or population responds.
- The fundamental niche describes the full range of conditions and resources in which a species could survive and reproduce. The realized niche describes the actual conditions and resources in which a species exists due to biotic interactions.
- The non-living, physical factors that influence the organisms and ecosystem—such as temperature, sunlight, pH, salinity, and precipitation—are termed abiotic factors.
- The interactions between the organisms—such as predation, herbivory, parasitism, mutualism, disease, and competition—are termed biotic factors.
- Interactions should be understood in terms of the influences each species has on the population dynamics of others, and upon the carrying capacity of the others' environment.

Guidance:

- Students should address this topic in the context of valid named species, for example, use "Atlantic salmon" rather than "fish", "Kentucky bluegrass" rather than "grass" and "silver birch" rather than "tree".
- It is useful to be aware that for some organisms, habitats can change over time as a result of migration
- This sub-topic provides lots of opportunities for use of simulations and data analysis.

International-mindedness:

- The change in one community can impact on other communities (butterfly effect).

Theory of knowledge:

- Through the use of specialized vocabulary, is the shaping of knowledge more dramatic in some areas of knowledge compared to others?

Connections:

- ESS: Human population carrying capacity (8.4)
- Diploma Programme: Social and cultural anthropology; biology (topic 4)

- A population is a group of organisms of the same species living in the same area at the same time, and which are capable of interbreeding.
- S and J population curves describe a generalized response of populations to a particular set of conditions (abiotic and biotic factors).
- Limiting factors will slow population growth as it approaches the carrying capacity of the system.

Applications and skills:

- **Interpret** graphical representations or models of factors that affect an organism's niche. Examples include predator–prey relationships, competition, and organism abundance over time.
- **Explain** population growth curves in terms of numbers and rates.

Sub-topic 2.2: Communities and ecosystems

Significant ideas:

- The interactions of species with their environment result in energy and nutrient flows.
- Photosynthesis and respiration play a significant role in the flow of energy in communities.
- The feeding relationships of species in a system can be modelled using food chains, food webs and ecological pyramids.

Knowledge and understanding:	Guidance:
• A community is a group of populations living and interacting with each other in a common habitat. • An ecosystem is a community and the physical environment with which it interacts. • Respiration and photosynthesis can be described as processes with inputs, outputs and transformations of energy and matter. • Respiration is the conversion of organic matter into carbon dioxide and water in all living organisms, releasing energy. Aerobic respiration can be represented by the following word equation. glucose+oxygen → carbon dioxide + water	• The distinction between storages of energy illustrated by boxes in energy-flow diagrams (representing the various trophic levels), and the flows of energy or productivity often shown as arrows (sometimes of varying widths) needs to be emphasized. • Details of chloroplasts, light-dependent and light-independent reactions, mitochondria, carrier systems, adenosine triphosphate (ATP) and specific intermediate biochemicals are not expected. • This topic should be actively linked with sub-topic 1.3, as questions will arise requiring students to use their knowledge of thermodynamics with energy flow in ecosystems.

- During respiration, large amounts of energy are dissipated as heat, increasing the entropy in the ecosystem while enabling organisms to maintain relatively low entropy and so high organization.
- Primary producers in most ecosystems convert light energy into chemical energy in the process of photosynthesis.
- The photosynthesis reaction is can be represented by the following word equation.

  carbon dioxide + water → glucose + oxygen
- Photosynthesis produces the raw material for producing biomass.
- The trophic level is the position that an organism occupies in a food chain, or the position of a group of organisms in a community that occupy the same position in food chains.
- Producers (autotrophs) are typically plants or algae that produce their own food using photosynthesis and form the first trophic level in a food chain. Exceptions include chemosynthetic organisms that produce food without sunlight.
- Feeding relationships involve producers, consumers and decomposers. These can be modelled using food chains, food webs and ecological pyramids.
- Ecological pyramids include pyramids of numbers, biomass and productivity and are quantitative models that are usually measured for a given area and time.
- In accordance with the second law of thermodynamics, there is a tendency for numbers and quantities of biomass and energy to decrease along food chains; therefore, the pyramids become narrower towards the apex.
- Bioaccumulation is the build-up of persistent or non-biodegradable pollutants within an organism or trophic level because they cannot be broken down.
- Biomagnification is the increase in concentration of persistent or non-biodegradable pollutants along a food chain.
- Toxins such as DDT and mercury accumulate along food chains due to the decrease of biomass and energy.
- Pyramids of numbers can sometimes display different patterns; for example, when individuals at lower trophic levels are relatively large (inverted pyramids).
- Biomass, measured in units of mass (for example, g m^{-2}), should be distinguished from productivity, measured in units of flow (for example, g m^{-2} yr^{-1} or J m^{-2} yr^{-1}).
- Although there is variation in the literature, for this syllabus "pyramids of biomass" refers to a standing crop (a fixed point in time) and "pyramids of productivity" refer to the rate of flow of biomass or energy.

Pyramid	Units
Biomass (standing crop)	g m^{-2}
Productivity (flow of biomass/energy)	g $m^{-2}yr^{-1}$ J $m^{-2}yr^{-1}$

International-mindedness:

- Ecosystems such as lakes and forests can exist across political boundaries.

Theory of knowledge:

- Feeding relationships can be represented by different models—how can we decide when one model is better than another?

Connections:

- ESS: Energy and equilibria (1.3); sustainability (1.4); climate change—causes and impacts (7.2); water pollutiion (4.4); terrestrial food production systems and food choices (5.2); biodiversity and conservation (topic 3)
- Diploma Programme: Biology (topics 4 and 9; option C)

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- A pyramid of biomass represents the standing stock or storage of each trophic level, measured in units such as grams of biomass per square metre ($g\ m^{-2}$) or Joules per square metre ($J\ m^{-2}$) (units of biomass or energy).
- Pyramids of biomass can show greater quantities at higher trophic levels because they represent the biomass present at a fixed point in time, although seasonal variations may be marked.
- Pyramids of productivity refer to the flow of energy through a trophic level, indicating the rate at which that stock/storage is being generated.
- Pyramids of productivity for entire ecosystems over a year always show a decrease along the food chain.

Applications and skills:

- **Construct** models of feeding relationships—such as food chains, food webs and ecological pyramids—from given data.
- **Explain** the transfer and transformation of energy as it flows through an ecosystem.
- **Analyse** the efficiency of energy transfers through a system.
- **Construct** system diagrams representing photosynthesis and respiration.
- **Explain** the relevance of the laws of thermodynamics to the flow of energy through ecosystems.
- **Explain** the impact of a persistent or non-biodegradable pollutant in an ecosystem.

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Significant ideas:

- Ecosystems are linked together by energy and matter flows.
- The Sun's energy drives these flows, and humans are impacting the flows of energy and matter both locally and globally.

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Knowledge and understanding:

- As solar radiation (insolation) enters the Earth's atmosphere, some energy becomes unavailable for ecosystems as this energy is absorbed by inorganic matter or reflected back into the atmosphere.

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Guidance:

- Students should have the opportunity to measure productivity and biomass experimentally.

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- Pathways of radiation through the atmosphere involve a loss of radiation through reflection and absorption as shown in figure 4.

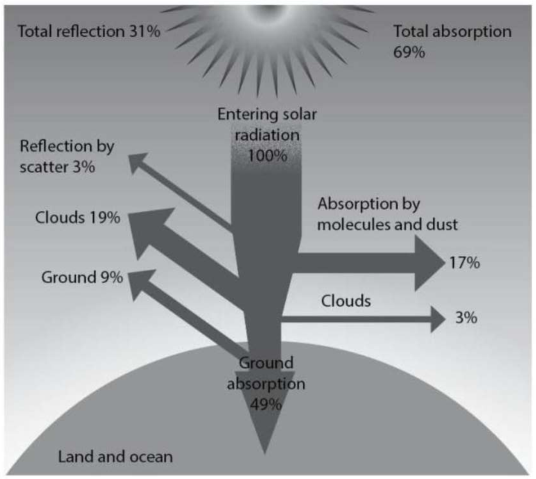

Figure 4

- Pathways of energy through an ecosystem include:
  - conversion of light energy to chemical energy
  - transfer of chemical energy from one trophic level to another with varying efficiencies
  - overall conversion of ultraviolet and visible light to heat energy by an ecosystem
  - re-radiation of heat energy to the atmosphere.
- The conversion of energy into biomass for a given period of time is measured as productivity.
- Net primary productivity (NPP) is calculated by subtracting respiratory losses (R) from gross primary productivity (GPP).

- Students could design experiments to compare productivity in different systems.
- The distinction between storages of energy illustrated by boxes in energy-flow diagrams (representing the various trophic levels), and the flows of energy or productivity often shown as arrows (sometimes of varying widths) needs to be emphasized. The former are measured as the amount of energy or biomass per unit area and the latter are given as rates, for example, J m^{-2} yr^{-1}.
- Students should understand the link between sustainable yields and productivity.
- Values for GPP and NPP should be compared from various biomes.
- The term "assimilation" is sometimes used instead of "secondary productivity".
- The roles of calcification, sedimentation, lithification, weathering and volcanoes in the carbon cycle are **not** required.
- Detailed knowledge of the role of bacteria in nitrogen fixation, nitrification and ammonificaction is **not** required.
- $\text{Efficiency} = \frac{(\text{original}-\text{new})}{\text{original}} \times 100$

International-mindedness:

- Human impacts on the flows of energy and matter occur on a global scale.

Theory of knowledge:

- The Sun's energy drives energy flows, and throughout history there have been "myths" about the importance of the Sun—what role can mythology and anecdotes play in the passing on of scientific knowledge?

Connections:

- ESS: Introduction to the atmosphere (6.1); introduction to water systems (4.1); introduction to soil systems (5.1); human population carrying capacity (8.4)
- Diploma Programme: Biology (topics 4 and 9; option C); chemistry (option C); geography (topic 3); physics (sub-topic 2.8)

$$NPP = GPP - R$$

- Gross secondary productivity (GSP) is the total energy or biomass assimilated by consumers and is calculated by subtracting the mass of fecal loss from the mass of food consumed.

$$GSP = \text{food eaten} - \text{fecal loss}$$

- Net secondary productivity (NSP) is calculated by subtracting respiratory losses (R) from GSP.

$$NSP = GSP - R$$

- Maximum sustainable yields are equivalent to the net primary or net secondary productivity of a system.
- Matter also flows through ecosystems linking them together. This flow of matter involves transfers and transformations.
- The carbon and nitrogen cycles are used to illustrate this flow of matter using flow diagrams. These cycles contain storages (sometimes referred to as sinks) and flows, which move matter between storages.
- Storages in the carbon cycle include organisms and forests (both organic), or the atmosphere, soil, fossil fuels and oceans (all inorganic).
- Flows in the carbon cycle include consumption (feeding), death and decomposition, photosynthesis, respiration, dissolving and fossilization.
- Storages in the nitrogen cycle include organisms (organic), soil, fossil fuels, atmosphere and water bodies (all inorganic).
- Flows in the nitrogen cycle include nitrogen fixation by bacteria and lightning, absorption, assimilation, consumption (feeding), excretion, death and decomposition, and denitrification by bacteria in water-logged soils.
- Human activities such as burning fossil fuels, deforestation, urbanization and agriculture impact energy flows as well as the carbon and nitrogen cycles.

Applications and skills:

- **Analyse** quantitative models of flows of energy and matter.
- **Construct** a quantitative model of the flows of energy or matter for given data.

- **Analyse** the efficiency of energy transfers through a system.
- **Calculate** the values of both GPP and NPP from given data.
- **Calculate** the values of both GSP and NSP from given data.
- **Discuss** human impacts on energy flows, and on the carbon and nitrogen cycles.

Sub-topic 2.4: Biomes, zonation and succession

Significant ideas:

- Climate determines the type of biome in a given area, although individual ecosystems may vary due to many local abiotic and biotic factors.
- Succession leads to climax communities that may vary due to random events and interactions over time. This leads to a pattern of alternative stable states for a given ecosystem.
- Ecosystem stability, succession and biodiversity are intrinsically linked.

Knowledge and understanding:

- Biomes are collections of ecosystems sharing similar climatic conditions that can be grouped into five major classes: aquatic, forest, grassland, desert and tundra. Each of these classes has characteristic limiting factors, productivity and biodiversity.
- Insolation, precipitation and temperature are the main factors governing the distribution of biomes.
- The tricellular model of atmospheric circulation explains the distribution of precipitation and temperature and how they influence structure and relative productivity of different terrestrial biomes.
- Climate change is altering the distribution of biomes and causing biome shifts.
- Zonation refers to changes in community along an environmental gradient due to factors such as changes in altitude, latitude, tidal level or distance from shore (coverage by water).
- Succession is the process of change over time in an ecosystem involving pioneer, intermediate and climax communities.
- During succession, the patterns of energy flow, gross and net productivity, diversity, and mineral cycling change over time.

Guidance:

- Students should be encouraged to study at least four contrasting pairs of biomes of interest to them, such as temperate forests and tropical seasonal forests; or tundras and deserts; or tropical coral reefs and hydrothermal vents; or temperate bogs and tropical mangrove forests.
- Examples of zonation may be studied as part of sub-topic 2.5.
- It is important to distinguish zonation (a spatial phenomenon) from succession (a temporal phenomenon).
- Named examples of organisms from the pioneer, intermediate and climax communities should be provided.
- Ecosystems demonstrating zonation or undergoing succession are appropriate for ecological fieldwork.
- *r*-strategist species are those that produce large numbers of offspring so they can colonize new habitats quickly and make use of short-lived resources, whereas *K*-strategist species tend to produce a small number of offspring, which increases their survival rate and enables them to survive in long-term climax communities.

- Greater habitat diversity leads to greater species and genetic diversity.
- *r*- and *K*-strategist species have reproductive strategies that are better adapted to pioneer and climax communities, respectively.
- In early stages of succession, gross productivity is low due to the unfavourable initial conditions and low density of producers. The proportion of energy lost through community respiration is relatively low too, so net productivity is high—that is, the system is growing and biomass is accumulating.
- In later stages of succession, with an increased consumer community, gross productivity may be high in a climax community. However, this is balanced by respiration, so net productivity approaches 0 and the productivity–respiration (P:R) ratio approaches 1.
- In a complex ecosystem, the variety of nutrient and energy pathways contributes to its stability.
- There is no one climax community, but rather a set of alternative stable states for a given ecosystem. These depend on the climatic factors, the properties of the local soil and a range of random events that can occur over time.
- Human activity is one factor that can divert the progression of succession to an alternative stable state by modifying the ecosystem; for example, the use of fire in an ecosystem, the use of agriculture, grazing pressure, or resource use (such as deforestation). This diversion may be more or less permanent depending upon the resilience of the ecosystem.
- An ecosystem's capacity to survive change may depend on its diversity and resilience.

Applications and skills:

- **Explain** the distributions, structure, biodiversity and relative productivity of contrasting biomes.
- **Analyse** data for a range of biomes.
- **Discuss** the impact of climate change on biomes.
- **Describe** the process of succession in a given example.
- **Explain** the general patterns of change in communities undergoing succession.
- **Discuss** the factors which could lead to alternative stable states in an ecosystem.
- **Discuss** the link between ecosystem stability, succession, diversity and human

International-mindedness:

- Zonation occurs on different scales that can be both local and global.

Theory of knowledge:

- Ecosystems are studied by measuring biotic and abiotic factors—how can you know in advance which of these factors are significant to the study?

Connections:

- ESS: Energy and equilibria (1.3): investigating ecosystems (2.5); climate change—causes and impacts (7.2); terrestrial food production systems and food choices (5.2); soil degradation and conservation (5.3)
- Diploma Programme: Geography (topic 3); biology (topic 4)

activity. • **Distinguish** the roles of *r* and *K* selected species in succession. • **Interpret** models or graphs related to succession and zonation.	

Sub-topic 2.5: Investigating ecosystems

Significant ideas:

- The description and investigation of ecosystems allows for comparisons to be made between different ecosystems and for them to be monitored, modelled and evaluated over time, measuring both natural change and human impacts.
- Ecosystems can be better understood through the investigation and quantification of their components.

Knowledge and understanding:	Guidance:
• The study of an ecosystem requires that it be named and located; for example, Deinikerwald in Baar, Switzerland—a mixed deciduous–coniferous managed woodland. • Organisms in an ecosystem can be identified using a variety of tools including keys, comparison to herbarium or specimen collections, technologies and scientific expertise. • Sampling strategies may be used to measure biotic and abiotic factors and their change in space, along an environmental gradient, over time, through succession, or before and after a human impact (for example, as part of an EIA). • Measurements should be repeated to increase reliability of data. The number of repetitions required depends on the factor being measured. • Methods for estimating the biomass and energy of trophic levels in a community include measurement of dry mass, controlled combustion and extrapolation from samples. Data from these methods can be used to construct ecological pyramids. • Methods for estimating the abundance of non-motile organisms include the use of quadrats for making actual counts, measuring population density, percentage cover and percentage frequency.	• When constructing identification keys, students should be reminded that generic terms such as “big” or “small” are not useful. Comparative, quantitative descriptors and simple identification of the presence or absence of external features are most useful in keys. • The design of sampling strategies needs to be appropriate for its purpose and provide a valid representation of the system being investigated. Suitable sampling techniques include random or systematic in a uniform environment, or transects over an environmental gradient. • Students should be familiar with the measurement of at least three abiotic factors. These could come from different ecosystems, such as: – marine—salinity, pH, temperature, dissolved oxygen, wave action – freshwater—turbidity, flow velocity, pH, temperature, dissolved oxygen – terrestrial—temperature, light intensity, wind speed, particle size, slope, soil moisture, drainage, mineral content. • Suitable human impacts might include toxins from mining activity, landfills, eutrophication, effluent, oil spills, overexploitation and change of land use (for example, deforestation, development or use for tourism activities). • Interesting studies can be made using historic maps or geographic information system (GIS) data to track land use change.

- Direct and indirect methods for estimating the abundance of motile organisms can be described and evaluated. Direct methods include actual counts and sampling. Indirect methods include the use of capture–mark–recapture with the application of the Lincoln index.

$$\text{Lincoln index} = \frac{n_1 \times n_2}{n_m}$$

  – n_1 is the number caught in the first sample
  – n_2 is the number caught in the second sample
  – n_m is the number caught in the second sample that were marked
- Species richness is the number of species in a community and is a useful comparative measure.
- Species diversity is a function of the number of species and their relative abundance and can be compared using an index. There are many versions of diversity indices, but students are only expected to be able to apply and evaluate the result of the Simpson diversity index as shown below. Using this formula, the higher the result (D), the greater the species diversity. This indication of diversity is only useful when comparing two similar habitats, or the same habitat over time.

$$D = \frac{N(N-1)}{\sum n(n-1)}$$

  – D is the Simpson diversity index
  – N is the total number of organisms of all species found
  – n is the number of individuals of a particular species

Applications and skills:

- **Design** and carry out ecological investigations.
- **Construct** simple identification keys for up to eight species.
- **Evaluate** sampling strategies.

- Formulae do not need to be memorized but should be applied to given data.
- Percentage cover is an estimate of the area in a given frame size (quadrat) covered by the plant in question. Percentage frequency is the number of occurrences divided by the number of possible occurrences; for example, if a plant occurs in 5 out of 100 squares in a grid quadrat, then the percentage frequency is 5%.
- Similar habitats can be compared using D; a lower value in one habitat may indicate human impact. Low values of D in the Arctic tundra, however, may represent stable and ancient sites.
- All ecosystem investigations should follow the guidelines in the *IB animal experimentation policy*.

International-mindedness:

- The use of internationally standardized methods of ecological study are necessary when making comparisons across international boundaries.

Theory of knowledge:

- When is quantitative data superior to qualitative data in giving us knowledge about the world?
- Controlled laboratory experiments are often seen as the hallmark of the scientific method, but are not possible in fieldwork—to what extent is the knowledge obtained by observational natural experiment less scientific than the manipulated laboratory experiment?

Connections:

- ESS: Sustainability (1.4); biodiversity and conservation (topic 3)
- Diploma Programme: Biology (topic 4): chemistry (topic 11)

• **Evaluate** methods to measure at least three abiotic factors in an ecosystem. • **Evaluate** methods to investigate the change along an environmental gradient and the effect of a human impact in an ecosystem. • **Evaluate** methods for estimating biomass at different trophic levels in an ecosystem. • **Evaluate** methods for measuring or estimating populations of motile and non-motile organisms. • **Calculate** and interpret data for species richness and diversity. • **Draw** graphs to illustrate species diversity in a community over time, or between communities.	

Topic 3: Biodiversity and conservation (13 hours)

Big questions: This topic may be particularly appropriate for considering big questions B, C, D, E and F.

<table>
<tr><th colspan="2">Sub-topic 3.1: An introduction to biodiversity</th></tr>
<tr><td colspan="2">Significant ideas:
• Biodiversity can be identified in a variety of forms, including species diversity, habitat diversity and genetic diversity.
• The ability to both understand and quantify biodiversity is important to conservation efforts.</td></tr>
<tr><td>Knowledge and understanding:
• Biodiversity is a broad concept encompassing the total diversity of living systems, which includes the diversity of species, habitat diversity and genetic diversity.
• Species diversity in communities is a product of two variables: the number of species (richness) and their relative proportions (evenness).
• Communities can be described and compared through the use of diversity indices. When comparing communities that are similar, low diversity could be indicative of pollution, eutrophication or recent colonization of a site. The number of species present in an area is often indicative of general patterns of biodiversity.
• Habitat diversity refers to the range of different habitats in an ecosystem or biome.
• Genetic diversity refers to the range of genetic material present in a population of a species.
• Quantification of biodiversity is important to conservation efforts so that areas of high biodiversity may be identified, explored, and appropriate conservation put in place where possible.
• The ability to assess changes to biodiversity in a given community over time is important in assessing the impact of human activity in the community.</td>
<td>Guidance:
• Interpreting diversity is complex; low diversity can be present in natural, ancient and unpolluted sites (for example, in Arctic ecosystems).
• Species diversity within a community is a component of the broader description of the biodiversity of an entire ecosystem.
International-mindedness:
• International scientific collaboration is important in the conservation of biodiverse regions.
Theory of knowledge:
• The term “biodiversity” has replaced the term “nature” in much literature on conservation issues—does this represent a paradigm shift?
• Diversity index is not a measure in the true sense of a word, but merely a number (index), as it involves a subjective judgment on the combination of two measures: proportion and richness. Are there examples in other areas of knowledge of the subjective use of numbers?
Connections:
• ESS: Foundations of ESS (topic 1); investigating ecosystems (2.5); water pollution (4.4); acid deposition (6.4); climate change—causes and impacts (7.2)
• Diploma Programme: Biology (topics 5 and 10)</td></tr>
</table>

Applications and skills:	
• **Distinguish** between biodiversity, diversity of species, habitat diversity and genetic diversity. • **Comment** on the relative values of biodiversity data. • **Discuss** the usefulness of providing numerical values of species diversity to understanding the nature of biological communities and the conservation of biodiversity.	

Sub-topic 3.2: Origins of biodiversity

Significant ideas:

- Evolution is a gradual change in the genetic character of populations over many generations, achieved largely through the mechanism of natural selection.
- Environmental change gives new challenges to species, which drives the evolution of diversity.
- There have been major mass extinction events in the geological past.

Knowledge and understanding:	Guidance:
• Biodiversity arises from evolutionary processes. • Biological variation arises randomly and can either be beneficial to, damaging to, or have no impact on, the survival of the individual. • Natural selection occurs through the following mechanism. 1. Within a population of one species, there is genetic diversity, which is called variation. 2. Due to natural variation, some individuals will be fitter than others. 3. Fitter individuals have an advantage and will reproduce more successfully than individuals who are less fit. 4. The offspring of fitter individuals may inherit the genes that give that advantage. • This natural selection will contribute to the evolution of biodiversity over time.	• Natural selection is an evolutionary driving force, sometimes called "survival of the fittest". In this context, the meaning of "fittest" is understood to be "best-suited to the niche". **International-mindedness:** • Within the human population, distinct characteristics have evolved within different populations through natural selection and exposure to the environmental conditions that were unique to the regions of those populations. How has globalization altered some of the environmental factors that were formerly unique to different human populations? • Human impact has increased the rate at which some mass extinctions have occurred on a global scale. **Theory of knowledge:** • The theory of evolution by natural selection tells us that change in populations is achieved through the process of natural selection—is there a difference between a convincing theory and a correct one?

• Environmental change gives new challenges to species: those that are suited will survive, and those that are not suited will not survive. • Speciation is the formation of new species when populations of a species become isolated and evolve differently from other populations. • Isolation of populations can be caused by environmental changes forming barriers such as mountain formation, changes in rivers, sea level change, climatic change or plate movements. The surface of the Earth is divided into crustal, tectonic plates that have moved throughout geological time. This has led to the creation of both land bridges and physical barriers with evolutionary consequences. • The distribution of continents has also caused climatic variations and variation in food supply, both contributing to evolution. • Mass extinctions of the past have been caused by various factors, such as tectonic plate movements, super-volcanic eruption, climatic changes (including drought and ice ages), and meteorite impact—all of which resulted in new directions in evolution and therefore increased biodiversity. **Applications and skills:** • **Explain** how plate activity has influenced evolution and biodiversity. • **Discuss** the causes of mass extinctions.	**Connections:** • ESS: Biomes, zonation and succession (2.4); climate change—causes and impacts (7.2) • Diploma Programme: Biology (topic 5)

Sub-topic 3.3: Threats to biodiversity	
Significant idea: • While global biodiversity is difficult to quantify, it is decreasing rapidly due to human activity. Classification of species conservation status can provide a useful tool in the conservation of biodiversity.	
Knowledge and understanding: • Estimates of the total number of species on Earth vary considerably. They are based on mathematical models, which are influenced by classification issues and a lack of finance for scientific research, resulting in many habitats and groups being significantly under-recorded. • The current rates of species loss are far greater now than in the recent	**Guidance:** • The total number of classified species is a small fraction of the estimated total of species, and it continues to rise. Estimates of extinction rates as a consequence are also varied, but current extinction rates are thought to be between 100 and 10,000 times greater than background rates. • Case studies of three species should be carried out. In each case, the ecological,

past, due to increased human influence. The human activities that cause species extinctions include habitat destruction, introduction of invasive species, pollution, overharvesting and hunting.

- The International Union of Conservation of Nature (IUCN) publishes data in the “Red List of Threatened Species” in several categories. Factors used to determine the conservation status of a species include: population size, degree of specialization, distribution, reproductive potential and behaviour, geographic range and degree of fragmentation, quality of habitat, trophic level, and the probability of extinction.
- Tropical biomes contain some of the most globally biodiverse areas and their unsustainable exploitation results in massive losses in biodiversity and their ability to perform globally important ecological services.
- Most tropical biomes occur in less economically developed countries (LEDCs) and therefore there is conflict between exploitation, sustainable development and conservation.

Applications and skills:

- **Discuss** the case histories of three different species: one that has become extinct due to human activity, another that is critically endangered, and a third species whose conservation status has been improved by intervention.
- **Describe** the threats to biodiversity from human activity in a given natural area of biological significance or conservation area.
- **Evaluate** the impact of human activity on the biodiversity of tropical biomes.
- **Discuss** the conflict between exploitation, sustainable development and conservation in tropical biomes.

socio-political or economic pressures that are impacting on the species should be explored. The species’ ecological roles and the possible consequences of their disappearance should be considered.

International-mindedness:

- Conservation needs to work at the local grass roots level to create meaningful change in the communities that live alongside conservation areas. International organizations are important for enforcing the Convention on International Trade in Endangered Species (CITES) agreement, assessing global status of species’ numbers and influencing governments.
- The science of taxonomy is important to understand species extinction. Major surveys are carried out using international teams of specialists.

Theory of knowledge:

- There may be long-term consequences when biodiversity is lost—should people be held morally responsible for the long-term consequences of their actions?

Connections:

- ESS: Sustainability (1.4); communities and ecosystems (2.2); water pollution (4.4); soil degradation and conservation (5.3); resource use in society (8.2)
- Diploma Programme: Geography (topic 3); biology (topic 5 and option C)

Sub-topic 3.4: Conservation of biodiversity

Significant ideas:

- The impact of losing biodiversity drives conservation efforts.
- The variety of arguments given for the conservation of biodiversity will depend on EVSs.
- There are various approaches to the conservation of biodiversity, each with associated strengths and limitations.

Knowledge and understanding:

- Arguments about species and habitat preservation can be based on aesthetic, ecological, economic, ethical and social justifications.
- International, governmental and non-governmental organizations (NGOs) are involved in conserving and restoring ecosystems and biodiversity, with varying levels of effectiveness due to their use of media, speed of response, diplomatic constraints, financial resources and political influence.
- Recent international conventions on biodiversity work to create collaboration between nations for biodiversity conservation.
- Conservation approaches include habitat conservation, species-based conservation and a mixed approach.
- Criteria for consideration when designing protected areas include size, shape, edge effects, corridors, and proximity to potential human influence.
- Alternative approaches to the development of protected areas are species-based conservation strategies including:
  - CITES
  - captive breeding and reintroduction programmes, and zoos
  - selection of "charismatic" species to help protect others in an area (flagship species)
  - selection of keystone species to protect the integrity of the food web.
- Community support, adequate funding and proper research influence the success of conservation efforts.
- The location of a conservation area in a country is a significant factor in the success of the conservation effort. Surrounding land use for the conservation

Guidance:

- Economic arguments for preservation often involve valuation of ecotourism, of the genetic resource, and commercial considerations of the natural capital. Ecological reasons may be related to the ecosystem. Ethical arguments are very broad, and can include the intrinsic value of the species or the utilitarian value.
- International conventions on conservation and biodiversity have been adopted over the past decades.
- A specific example of a protected area and the success it has achieved should be studied.

International-mindedness:

- International organizations such as the World Wildlife Fund (WWF), Greenpeace, Friends of the Earth International (FoEI) and Earth First! undertake global programmes in terms of conservation of biodiversity.

Theory of knowledge:

- There are various approaches to the conservation of biodiversity—how can we determine when we should be disposed to act on what we know?

Connections:

- ESS: Environmental value systems (1.1); communities and ecosystems (2.2); resource use in society (8.2)
- Diploma Programme: Geography (topic 3); biology (option C)

area and distance from urban centres are important factors for consideration in conservation area design. **Applications and skills:** • **Explain** the criteria used to design and manage protected areas. • **Evaluate** the success of a given protected area. • **Evaluate** different approaches to protecting biodiversity.	

Topic 4: Water and aquatic food production systems and societies (15 hours)

Big questions: This topic may be particularly appropriate for considering big questions A, B, E and F.

Sub-topic 4.1: Introduction to water systems

Significant ideas:

- The hydrological cycle is a system of water flows and storages that may be disrupted by human activity.
- The ocean circulatory system (ocean conveyor belt) influences the climate and global distribution of water (matter and energy).

Knowledge and understanding:

- Solar radiation drives the hydrological cycle.
- Fresh water makes up only a small fraction (approximately 2.6% by volume) of the Earth's water storages.
- Storages in the hydrological cycle include organisms, soil and various water bodies, including oceans, groundwater (aquifers), lakes, rivers, atmosphere, glaciers and ice caps.
- Flows in the hydrological cycle include evapotranspiration, sublimation, evaporation, condensation, advection (wind-blown movement), precipitation, melting, freezing, flooding, surface runoff, infiltration, percolation, and stream-flow or currents.
- Human activities such as agriculture, deforestation and urbanization have a significant impact on surface runoff and infiltration.
- Ocean circulation systems are driven by differences in temperature and salinity. The resulting difference in water density drives the ocean conveyor belt, which distributes heat around the world, and thus affects climate.

Applications and skills:

- **Discuss** human impact on the hydrological cycle.
- **Construct** and **analyse** a hydrological cycle diagram.

Guidance:

- The effect of urbanization on water flows and potential of flash floods should be covered.

International-mindedness:

- Many hydrological cycles are shared by various nations. This can lead to international disputes.

Theory of knowledge:

- The hydrological cycle is represented as a systems model—to what extent can systems diagrams effectively model reality, given that they are only based on limited observable features?

Connections:

- ESS: Climate change—causes and impacts (7.2); terrestrial food production systems and food choices (5.2); aquatic food production systems (4.3); resource use in society (8.2); sustainability (1.4)
- Diploma Programme: Social and cultural anthropology; geography (options A and D)

Sub-topic 4.2: Access to fresh water

Significant ideas:

- The supplies of freshwater resources are inequitably available and unevenly distributed, which can lead to conflict and concerns over water security.
- Freshwater resources can be sustainably managed using a variety of different approaches.

Knowledge and understanding:

- Access to an adequate freshwater supply varies widely.
- Climate change may disrupt rainfall patterns and further affect this access.
- As populations, irrigation and industrialization increase, the demand for fresh water increases.
- Freshwater supplies may become limited through contamination and unsustainable abstraction.
- Water supplies can be enhanced through reservoirs, redistribution, desalination, artificial recharge of aquifers and rainwater harvesting schemes. Water conservation (including grey-water recycling) can help to reduce demand but often requires a change in attitude by the water consumers.
- The scarcity of water resources can lead to conflict between human populations, particularly where sources are shared.

Applications and skills:

- **Evaluate** the strategies that can be used to meet an increasing demand for fresh water.
- **Discuss, with reference to a case study, how shared freshwater resources have given rise to international conflict.**

Guidance:

- Consider examples of unequal distribution and inequitable supply.

International-mindedness:

- Unequal access to fresh water can cause conflict between countries that have an abundance of fresh water and those that do not.

Theory of knowledge:

- Aid agencies often use emotive advertisements around the water security issue—to what extent can emotion be used to manipulate knowledge and actions?

Connections:

- ESS: Climate change—causes and impacts (7.2); terrestrial food production systems and food choices (5.2) and aquatic food production systems (4.3); resource use in society (8.2) and sustainability (1.4).
- Diploma Programme: Social and cultural anthropology; geography (topic 3; options A, B and F); economics

Sub-topic 4.3: Aquatic food production systems

Significant ideas:

- Aquatic systems provide a source of food production.
- Unsustainable use of aquatic ecosystems can lead to environmental degradation and collapse of wild fisheries.
- Aquaculture provides potential for increased food production.

Knowledge and understanding:

- Demand for aquatic food resources continues to increase as human population grows and diet changes.
- Photosynthesis by phytoplankton supports a highly diverse range of food webs.
- Aquatic (freshwater and marine) flora and fauna are harvested by humans.
- The highest rates of productivity are found near coastlines or in shallow seas, where upwellings and nutrient enrichment of surface waters occurs.
- Harvesting some species, such as seals and whales, can be controversial. Ethical issues arise over biorights, rights of indigenous cultures and international conservation legislation.
- Developments in fishing equipment and changes to fishing methods have lead to dwindling fish stocks and damage to habitats.
- Unsustainable exploitation of aquatic systems can be mitigated at a variety of levels (international, national, local and individual) through policy, legislation and changes in consumer behaviour.
- Aquaculture has grown to provide additional food resources and support economic development and is expected to continue to rise.
- Issues around aquaculture include: loss of habitats, pollution (with feed, antifouling agents, antibiotics and other medicines added to fish pens), spread of diseases and escaped species (some involving genetically modified organisms).

Applications and skills:

- **Discuss**, with reference to a case study, the controversial harvesting of a named species.
- **Evaluate** strategies that can be used to avoid unsustainable fishing.

Guidance:

- Wild fisheries are also known as “capture fisheries”.
- Aquaculture is the farming of aquatic organisms in both coastal and inland areas that involves intervention in the rearing process to enhance production.
- Examine different points of view regarding harvesting of a controversial species; for example, the historical Inuit tradition of whaling versus modern international conventions.
- When looking at the increase in demand for food resources, consideration should be given to changes in attitude towards “health foods” and food fashions.
- Consider how two contrasting fisheries have been managed and relate to the concept of sustainability; for example, cod fisheries in Newfoundland and Iceland. Issues that should be covered include: improvements to boats, fishing gear (trawler bags), and detection of fisheries and boats via satellites. Management aspects should include; use of quotas, designation of marine protected areas (exclusion zones), and restriction on types and size of fishing gear (including mesh size of nets).
- Students should understand maximum sustainable yield (MSY) as applied to fish stocks.

International-mindedness:

- Successful management of marine and some freshwater fisheries requires partnership between different nations.

Theory of knowledge:

- The Inuit people have an historical tradition of whaling—to what extent does our culture determine or shape our ethical judgments?

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- **Explain** the potential value of aquaculture for providing food for future generations.
- **Discuss** a case study that demonstrates the impact of aquaculture.

</td><td>

Connections:

- ESS: Biodiversity and conservation (topic 3); terrestrial food production systems and food choices (5.2); human population carrying capacity (8.4); resource use in society (8.2); sustainability (1.4)
- Diploma Programme: Geography (option B); economics

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<table>
<tr><td colspan="2">Sub-topic 4.4: Water pollution</td></tr>
<tr><td colspan="2">

Significant idea:

- Water pollution, both to groundwater and surface water, is a major global problem, the effects of which influence human and other biological systems.

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Knowledge and understanding:

- There are a variety of freshwater and marine pollution sources.
- Types of aquatic pollutants include floating debris, organic material, inorganic plant nutrients (nitrates and phosphates), toxic metals, synthetic compounds, suspended solids, hot water, oil, radioactive pollution, pathogens, light, noise and biological pollutants (invasive species).
- A wide range of parameters can be used to directly test the quality of aquatic systems, including pH, temperature, suspended solids (turbidity), metals, nitrates and phosphates.
- Biodegradation of organic material utilizes oxygen, which can lead to anoxic conditions and subsequent anaerobic decomposition, which in turn leads to formation of methane, hydrogen sulfide and ammonia (toxic gases).
- Biochemical oxygen demand (BOD) is a measure of the amount of dissolved oxygen required to break down the organic material in a given volume of water through aerobic biological activity. BOD is used to indirectly measure the amount of organic matter within a sample.
- Some species can be indicative of polluted waters and can be used as indicator species.
- A biotic index indirectly measures pollution by assaying the impact on species within the community according to their tolerance, diversity and relative abundance.

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Guidance:

- Sources of freshwater pollution should include runoff, sewage, industrial discharge and solid domestic waste.
- Sources of marine pollution should include rivers, pipelines, atmosphere and activities at sea (operational and accidental discharges).
- The role of positive and negative feedback in the process of eutrophication should be covered. Coastal eutrophication can lead to red tide blooms.
- With respect to measuring aquatic pollution, a polluted and an unpolluted site (for example, upstream and downstream of a point source) should be compared.

International-mindedness:

- Countries with limited access to clean water often have higher incidences of water-borne illnesses.

Theory of knowledge:

- A wide range of parameters are used to test the quality of water and judgments are made about causes and effects of water quality—how can we effectively identify cause–effect relationships, given that we can only ever observe correlation?

Connections:

- ESS: Terrestrial food production systems and food choices (5.2); climate change—causes and impacts (7.2); sustainability (1.4); resource use in society (8.2); biodiversity and conservation (topic 3); solid domestic waste (8.3)

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• Eutrophication can occur when lakes, estuaries and coastal waters receive inputs of nutrients (nitrates and phosphates), which results in an excess growth of plants and phytoplankton. • Dead zones in both oceans and fresh water can occur when there is not enough oxygen to support marine life. • Application of figure 3 to water pollution management strategies includes: 1. reducing human activities that produce pollutants (for example, alternatives to current fertilizers and detergents) 2. reducing release of pollution into the environment (for example, treatment of waste water to remove nitrates and phosphates) 3. removing pollutants from the environment and restoring ecosystems (for example, removal of mud from eutrophic lakes and reintroduction of plant and fish species). **Applications and skills:** • **Analyse** water pollution data. • **Explain** the process and impacts of eutrophication. • **Evaluate** the uses of indicator species and biotic indices in measuring aquatic pollution. • **Evaluate** pollution management strategies with respect to water pollution.	• Diploma Programme: Social and cultural anthropology; chemistry (topic 9; options B and D)

Topic 5: Soil systems and terrestrial food production systems and societies (12 hours)

Big questions: This topic may be particularly appropriate for considering big questions A, B, E and F.

Sub-topic 5.1: Introduction to soil systems

Significant ideas:

- The soil system is a dynamic ecosystem that has inputs, outputs, storages and flows.
- The quality of soil influences the primary productivity of an area.

Knowledge and understanding:

- The soil system may be illustrated by a soil profile that has a layered structure (horizons).
- Soil system storages include organic matter, organisms, nutrients, minerals, air and water.
- Transfers of material within the soil, including biological mixing and leaching (minerals dissolved in water moving through soil), contribute to the organization of the soil.
- There are inputs of organic material including leaf litter and inorganic matter from parent material, precipitation and energy. Outputs include uptake by plants and soil erosion.
- Transformations include decomposition, weathering and nutrient cycling.
- The structure and properties of sand, clay and loam soils differ in many ways, including mineral and nutrient content, drainage, water-holding capacity, air spaces, biota and potential to hold organic matter. Each of these variables is linked to the ability of the soil to promote primary productivity.
- A soil texture triangle illustrates the differences in composition of soils.

Applications and skills:

- **Outline** the transfers, transformations, inputs, outputs, flows and storages within soil systems.
- **Explain** how soil can be viewed as an ecosystem.

Guidance:

- Studies of specific soil profiles, such as podsol, are **not** required.
- Familiarity with the soil texture triangle diagram used for soil type classification based on the percentage of sand, silt, and clay in the soil is required.

International-mindedness:

- Significant differences exist in arable (potential to promote primary productivity) soil availability around the world. These differences have socio-political, economic and ecological influences.

Theory of knowledge:

- The soil system may be represented by a soil profile—since a model is, strictly speaking, not real, how can it lead to knowledge?

Connections:

- ESS: Communities and ecosystems (2.2); flows of energy and matter (2.3); investigating ecosystems (2.5); biomes, zonation and succession (2.4); introduction to water systems (4.1); terrestrial food production systems and food choices (5.2); soil degradation and conservation (5.3); acid deposition (6.4); climate change (7.1 and 7.2); resource use in society (8.2); solid domestic waste (8.3)
- Diploma Programme: Geography (topic 3)

• **Compare and contrast** the structure and properties of sand, clay and loam soils, with reference to a soil texture diagram, including their effect on primary productivity.	

Sub-topic 5.2: Terrestrial food production systems and food choices

Significant ideas:

- The sustainability of terrestrial food production systems is influenced by socio-political, economic and ecological factors.
- Consumers have a role to play through their support of different terrestrial food production systems.
- The supply of food is inequitably available and land suitable for food production is unevenly distributed among societies, and this can lead to conflict and concerns.

Knowledge and understanding:	Guidance:
• The sustainability of terrestrial food production systems is influenced by factors such as scale; industrialization; mechanization; fossil fuel use; seed, crop and livestock choices; water use; fertilizers; pest control; pollinators; antibiotics; legislation; and levels of commercial versus subsistence food production. • Inequalities exist in food production and distribution around the world. • Food waste is prevalent in both LEDCs and more economically developed countries (MEDCs), but for different reasons. • Socio-economic, cultural, ecological, political and economic factors can be seen to influence societies in their choices of food production systems. • As the human population grows, along with urbanization and degradation of soil resources, the availability of land for food production per capita decreases. • The yield of food per unit area from lower trophic levels is greater in quantity, lower in cost and may require fewer resources. • Cultural choices may influence societies to harvest food from higher trophic levels. • Terrestrial food production systems can be compared and contrasted according to inputs, outputs, system characteristics, environmental impact and socio-economic factors. • Increased sustainability may be achieved through:	• Possible examples for contrasting terrestrial food production systems include North American cereal farming and subsistence farming in Southeast Asia, or intensive beef production in South America and the Maasai tribal use of livestock. These examples are not meant to be prescriptive and appropriate local examples are also encouraged. • Factors to be used in comparing and contrasting food production systems include: – inputs, such as fertilizers (artificial or organic); water (irrigation or rainfall); pest control (pesticides or natural predators); labour (mechanized and fossil-fuel dependent or physical labour); seed (genetically modified organisms—GMOs—or conventional); breeding stock (domestic or wild); livestock growth promoters (antibiotics or hormones versus organic or none) – outputs, such as food quality, food quantity, pollutants (air, soil, water), consumer health, soil quality (erosion, degradation, fertility); common pollutants released from food production systems include fertilizers, pesticides, fungicides, antibiotics, hormones and gases from the use of fossil fuels; transportation, processing and packaging of food may also lead to further pollution from fossil fuels – system characteristics, such as diversity (monoculture versus polyculture); sustainability; indigenous versus introduced crop species – environmental impacts, such as pollution (air, soil, water); habitat loss; biodiversity loss; soil erosion or degradation; desertification; disease

- altering human activity to reduce meat consumption and increase consumption of organically grown and locally produced terrestrial food products
- improving the accuracy of food labels to assist consumers in making informed food choices
- monitoring and control of the standards and practices of multinational and national food corporations by governmental and intergovernmental bodies
- planting of buffer zones around land suitable for food production to absorb nutrient runoff.

Applications and skills:

- **Analyse** tables and graphs that illustrate the differences in inputs and outputs associated with food production systems.
- **Compare and contrast** the inputs, outputs and system characteristics for two given food production systems.
- **Evaluate** the relative environmental impacts of two given food production systems.
- **Discuss** the links that exist between socio-cultural systems and food production systems.
- **Evaluate** strategies to increase sustainability in terrestrial food production systems.

epidemics from high-density livestock farming

- socio-economic factors, such as farming for profit or subsistence, for export or local consumption, for quantity or quality; traditional or commercial farming.

- Food waste is an issue arising in MEDCs, where regulatory standards may be set according to commercial preferences so that consumable food is discarded. It can also be an issue in LEDCs, where the necessary refrigeration and transport infrastructure is insufficient to avoid food spoilage.

International-mindedness:

- Food choices can be influenced by culture, religion or regional food production differences.

Theory of knowledge:

- Consumer behaviour plays an important role in food production systems—are there general laws that can describe human behaviour?

Connections:

- ESS: Environmental value systems (1.1); flows of energy and matter (2.3); communities and ecosystems (2.2); investigating ecosystems (2.5); threats to biodiversity (3.3); water pollution (4.4); introduction to soil systems (5.1); soil degradation and conservation (5.3); resource use in society (8.2); solid domestic waste (8.3); human population carrying capacity (8.4)
- Diploma Programme: Biology (options B and C); chemistry (options B and C); geography (option F); economics

Sub-topic 5.3 Soil degradation and conservation

Significant Ideas:

- Fertile soils require significant time to develop through the process of succession.
- Human activities may reduce soil fertility and increase soil erosion.
- Soil conservation strategies exist and may be used to preserve soil fertility and reduce soil erosion.

Knowledge and understanding:

- Soil ecosystems change through succession. Fertile soil contains a community of organisms that work to maintain functioning nutrient cycles and that are resistant to soil erosion.
- Human activities that can reduce soil fertility include deforestation, intensive grazing, urbanization and certain agricultural practices (such as irrigation and monoculture).
- Commercial, industrialized food production systems generally tend to reduce soil fertility more than small-scale subsistence farming methods.
- Reduced soil fertility may result in soil erosion, toxification, salination and desertification.
- Soil conservation measures include soil conditioners (such as organic materials and lime), wind reduction techniques (wind breaks, shelter belts), cultivation techniques (terracing, contour ploughing, strip cultivation) and avoiding the use of marginal lands.

Applications and skills:

- **Explain** the relationship between soil ecosystem succession and soil fertility.
- **Discuss** the influences of human activities on soil fertility and soil erosion.
- **Evaluate** the soil management strategies of a given commercial farming system and of a given subsistence farming system.

Guidance:

- Applying knowledge of specific food production systems to their associated soil degradation and consequent soil conservation management strategies is recommended.

International-mindedness:

- Variant use of soil systems can lead to different degradation and conservation.

Theory of knowledge:

- Our understanding of soil conservation has progressed in recent years—what constitutes progress in different areas of knowledge?
- Fertile soil can be considered as a non-renewable resource because once depleted, it can take significant time to restore the fertility—how does our perception of time influence our understanding of change?

Connections:

- ESS: Communities and ecosystems (2.2); investigating ecosystems (2.5); introduction to soil systems (5.1); terrestrial food production systems and food choices (5.2); biomes, zonation and succession (2.4); climate change—causes and impacts (7.2); resource use in society (8.2)
- Diploma Programme: Chemistry (options A and C); geography (topic 3)

Topic 6: Atmospheric systems and societies (10 hours)

Big questions: This topic may be particularly appropriate for considering big questions B, E and F.

<table>
<tr><th colspan="2">Sub-topic 6.1: Introduction to the atmosphere</th></tr>
<tr><td colspan="2">Significant ideas:
• The atmosphere is a dynamic system that is essential to life on Earth.
• The behaviour, structure and composition of the atmosphere influence variations in all ecosystems.</td></tr>
<tr><td>Knowledge and understanding:
• The atmosphere is a dynamic system (with inputs, outputs, flows and storages) that has undergone changes throughout geological time.
• The atmosphere is a predominantly a mixture of nitrogen and oxygen, with smaller amounts of carbon dioxide, argon, water vapour and other trace gases.
• Human activities impact atmospheric composition through altering inputs and outputs of the system. Changes in the concentrations of atmospheric gases—such as ozone, carbon dioxide, and water vapour—have significant effects on ecosystems.
• Most reactions connected to living systems occur in the inner layers of the atmosphere, which are the troposphere (0–10 km above sea level) and the stratosphere (10–50 km above sea level).
• Most clouds form in the troposphere and play an important role in the albedo effect of the planet.
• The greenhouse effect of the atmosphere is a natural and necessary phenomenon maintaining suitable temperatures for living systems.
Applications and skills:
• Discuss the role of the albedo effect from clouds in regulating global average temperature.
• Outline the role of the greenhouse effect in regulating temperature on Earth.</td>
<td>Guidance:
• Students should recognize the atmosphere as a dynamic system. The composition of the atmosphere has changed throughout geological history. Living organisms (biotic components) have transformed the atmospheric composition of the Earth and vice versa throughout history.
• The use of chemical symbols or chemical formulae for atmospheric gases is not required.
International-mindedness:
• Impact to the atmosphere from pollutants can be localized, as evidenced by the destruction of the ozone layer over the poles of the Earth.
• Pollutants released to the atmosphere are carried by currents in the atmosphere and may create damage in a location other than where they are produced.
Theory of knowledge:
• The atmosphere is a dynamic system—how should we react when we have evidence that does not fit with an existing theory?
Connections:
• ESS: Climate change—causes and impacts (7.2); systems and models (1.2); introduction to water systems (4.1); introduction to soil systems (5.1); biomes, zonation and succession (2.4); acid deposition (6.4) climate change—causes and impacts (7.2)</td></tr>
</table>

	• Diploma Programme: Geography (topic 3); physics (sub-topic 8.2)

Sub-topic 6.2: Stratospheric ozone

Significant ideas:

- Stratospheric ozone is a key component of the atmospheric system because it protects living systems from the negative effects of ultraviolet radiation from the Sun.
- Human activities have disturbed the dynamic equilibrium of stratospheric ozone formation.
- Pollution management strategies are being employed to conserve stratospheric ozone.

Knowledge and understanding:

- Some ultraviolet radiation from the Sun is absorbed by stratospheric ozone causing the ozone molecule to break apart. Under normal conditions the ozone molecule will reform. This ozone destruction and reformation is an example of a dynamic equilibrium.
- Ozone depleting substances (including halogenated organic gases such as chlorofluorocarbons—CFCs) are used in aerosols, gas-blown plastics, pesticides, flame retardants and refrigerants. Halogen atoms (such as chlorine) from these pollutants increase destruction of ozone in a repetitive cycle, allowing more ultraviolet radiation to reach the Earth.
- Ultraviolet radiation reaching the surface of the Earth damages human living tissues, increasing the incidence of cataracts, mutation during cell division, skin cancer and other subsequent effects on health.
- The effects of increased ultraviolet radiation on biological productivity include damage to photosynthetic organisms, especially phytoplankton, which form the basis of aquatic food webs.
- Pollution management may be achieved by reducing the manufacture and release of ozone-depleting substances. Methods for this reduction include:
  - recycling refrigerants
  - developing alternatives to gas-blown plastics, halogenated pesticides, propellants and aerosols
  - developing non-propellant alternatives.

Guidance:

- The use of chemical symbols, formulae or equations for the destruction of ozone is **not** required.
- Relate to figure 3.

International-mindedness:

- The depletion of ozone has global implications to ocean productivity and oxygen production.
- National economic approaches may have an impact on international environmental discussions.

Theory of knowledge:

- The Montreal Protocol was an international agreement created by the UN—can one group or organization decide what is best for the rest of the world?

Connections:

- ESS: Energy and equilibria (1.3); humans and pollution (1.5); resource use in society (8.2); communities and ecosystems (2.2); investigating ecosystems (2.5)
- Diploma Programme: Chemistry (topics 5 and 14); geography (option G); economics.

UNEP has had a key role in providing information, and creating and evaluating international agreements, for the protection of stratospheric ozone. • An illegal market for ozone-depleting substances persists and requires consistent monitoring. • The *Montreal Protocol on Substances that Deplete the Ozone Layer* (1987) and subsequent updates is an international agreement for the reduction of use of ozone-depleting substances signed under the direction of UNEP. National governments complying with the agreement made national laws and regulations to decrease the consumption and production of halogenated organic gases such as chlorofluorocarbons (CFCs). **Applications and skills:** • **Evaluate** the role of national and international organizations in reducing the emissions of ozone-depleting substances.	

Sub-topic 6.3: Photochemical smog

Significant ideas:

- The combustion of fossil fuels produces primary pollutants that may generate secondary pollutants and lead to photochemical smog, the levels of which can vary by topography, population density and climate.
- Photochemical smog has significant impacts on societies and living systems.
- Photochemical smog can be reduced by decreasing human reliance on fossil fuels.

Knowledge and understanding:	Guidance:
• Primary pollutants from the combustion of fossil fuels include carbon monoxide, carbon dioxide, black carbon or soot, unburned hydrocarbons, oxides of nitrogen, and oxides of sulfur. • In the presence of sunlight, secondary pollutants are formed when primary pollutants undergo a variety of reactions with other chemicals already present in the atmosphere. • Tropospheric ozone is an example of a secondary pollutant, formed when oxygen molecules react with oxygen atoms that are released from nitrogen dioxide in the presence of sunlight. • Tropospheric ozone is highly reactive and damages plants (crops and	• The use of chemical symbols, formulae or equations is **not** required. • Relate to figure 3. **International-mindedness:** • The global rise of urbanization and industrialization has led to an increase in urban air pollution. **Theory of knowledge:** • Environmental problems are often emotive—under what circumstances should we maintain a detached relationship with the subject matter under investigation?

forests), irritates eyes, creates respiratory illnesses and damages fabrics and rubber materials. Smog is a complex mixture of primary and secondary pollutants, of which tropospheric ozone is the main pollutant.

- The frequency and severity of smog in an area depends on local topography, climate, population density, and fossil fuel use.
- Thermal inversions occur due to a lack of air movement when a layer of dense, cool air is trapped beneath a layer of less dense, warm air. This causes concentrations of air pollutants to build up near the ground instead of being dissipated by “normal” air movements.
- Deforestation and burning, may also contribute to smog.
- Economic losses caused by urban air pollution can be significant.
- Pollution management strategies include:
  - altering human activity to consume less fossil fuels—example activities include the purchase of energy-efficient technologies, the use of public or shared transit, and walking or cycling
  - regulating and reducing pollutants at the point of emission through government regulation or taxation
  - using catalytic converters to clean the exhaust of primary pollutants from car exhaust
  - regulating fuel quality by governments
  - adopting clean-up measures such as reforestation, regreening, and conservation of areas to sequester carbon dioxide.

Applications and skills:

- **Evaluate** pollution management strategies for reducing photochemical smog.

Connections:

- ESS: Climate change—causes and impacts (7.2); acid deposition (6.4); stratospheric ozone (6.2); humans and pollution (1.5); investigating ecosystems (2.5)
- Diploma Programme: Chemistry (topic 5); geography (option G), economics

Sub-topic 6.4: Acid deposition

Significant ideas:

- Acid deposition can impact living systems and the built environment.
- The pollution management of acid deposition often involves cross-border issues.

Knowledge and understanding:

- The combustion of fossil fuels produces sulfur dioxide and oxides of nitrogen as primary pollutants. These gases may be converted into secondary pollutants of dry deposition (such as ash and dry particles) or wet deposition (such as rain and snow).
- The possible effects of acid deposition on soil, water and living organisms include:
  - direct effect—for example, acid on aquatic organisms and coniferous forests
  - indirect toxic effect—for example, increased solubility of metal (such as aluminium ions) on fish
  - indirect nutrient effect—for example, leaching of plant nutrients.
- The impacts of acid deposition may be limited to areas downwind of major industrial regions but these areas may not be in the same country as the source of emissions.
- Pollution management strategies for acid deposition could include:
  - altering human activity—for example, through reducing use, or using alternatives to, fossil fuels; international agreements and national governments may work to reduce pollutant production through lobbying
  - regulating and monitoring the release of pollutants—for example, through the use of scrubbers or catalytic converters that may remove sulfur dioxide and oxides of nitrogen from coal-burning powerplants and cars.
- Clean-up and restoration measures may include spreading ground limestone in acidified lakes or recolonization of damaged systems—but the scope of these measures is limited.

Guidance:

- The use of chemical symbols or chemical formulae is **not** required.
- Possible case studies of intergovernmental situations involving acid deposition to consider include the USA Midwest and Eastern Canada interaction, as well as the impact of industrial Britain, Germany and Poland on Sweden.

International-mindedness:

- The polluting country and the polluted country are often not the same: acid deposition affects regions far from its source. Therefore, solving this issue requires international cooperation.

Theory of knowledge:

- To what extent does the recognition of the ethical responsibility of knowledge influence the further production or acquisition of knowledge?

Connections:

- ESS: Photochemical smog (6.3); humans and pollution (1.5); investigating ecosystems (2.5)
- Diploma Programme: Chemistry (topic 8); economics

Applications and skills: • **Evaluate** pollution management strategies for acid deposition.	

Topic 7: Climate change and energy production (13 hours)

Big questions: This topic may be particularly appropriate for considering big questions A, B, C, D, E and F.

Sub-topic 7.1: Energy choices and security

Significant ideas:

- There is a range of different energy sources available to societies that vary in their sustainability, availability, cost and socio-political implications.
- The choice of energy sources is controversial and complex. Energy security is an important factor in making energy choices.

Knowledge and understanding:	Guidance:
• Fossil fuels contribute to the majority of humankind’s energy supply, and they vary widely in the impacts of their production and their emissions; their use is expected to increase to meet global energy demand. • Sources of energy with lower carbon dioxide emissions than fossil fuels include renewable energy (solar, biomass, hydropower, wind, wave, tidal and geothermal) and their use is expected to increase. Nuclear power is a low-carbon low-emission non-renewable resource but is controversial due to the radioactive waste it produces and the potential scale of any accident. • Energy security depends on adequate, reliable and affordable supply of energy that provides a degree of independence. An inequitable availability and uneven distributions of energy sources may lead to conflict. • The energy choices adopted by a society may be influenced by availability; sustainability; scientific and technological developments; cultural attitudes; and political, economic and environmental factors. These in turn affect energy security and independence. • Improvements in energy efficiencies and energy conservation can limit growth in energy demand and contribute to energy security. **Applications and skills:** • **Evaluate** the advantages and disadvantages of different energy sources. • **Discuss** the factors that affect the choice of energy sources adopted by different societies.	• Strengths and weaknesses of the use of a fossil fuel, of a renewable source of energy, and of nuclear power should be considered. • Use case studies to highlight the energy choices of different countries. **International-mindedness:** • Choice of energy sources can have impacts at both local and global level as emissions of greenhouse gases can contribute to global climatic change. • Political and economic situations around the world can affect energy security and choice of options. **Theory of knowledge:** • The choice of energy sources is controversial and complex—how can we distinguish between a scientific claim and a pseudoscience claim when making choices? **Connections:** • ESS: Energy and equilibria (1.3); sustainability (1.4); resource use in society (8.2); human population carrying capacity (8.4). • Diploma Programme: Social and cultural anthropology; chemistry (option C); design technology (topic 2); physics (topics 8 and 11); geography (topics 3 and 4); economics

• **Discuss** the factors which affect energy security. • **Evaluate** the energy strategy of a given society.	

Sub-topic 7.2: Climate change—causes and impacts

Significant ideas:

- Climate change has been a normal feature of the Earth's history, but human activity has contributed to recent changes.
- There has been significant debate about the causes of climate change.
- Climate change causes widespread and significant impacts on a global scale.

Knowledge and understanding:	Guidance:
• Climate describes how the atmosphere behaves over relatively long periods of time, whereas weather describes the conditions in the atmosphere over a short period of time. • Weather and climate are affected by oceanic and atmospheric circulatory systems. • Human activities are increasing levels of greenhouse gases (GHGs, such as carbon dioxide, methane and water vapour) in the atmosphere, which leads to: – an increase in the mean global temperature – increased frequency and intensity of extreme weather events – the potential for long-term changes in climate and weather patterns – rise in sea level. • The potential impacts of climate change may vary from one location to another and may be perceived as either adverse or beneficial. These impacts may include changes in water availability, distribution of biomes and crop growing areas, loss of biodiversity and ecosystem services, coastal inundation, ocean acidification, and damage to human health. • Both negative and positive feedback mechanisms are associated with climate change and may involve very long time lags.	• GHGs are those atmospheric gases that absorb infrared radiation, causing global temperatures to be higher than they would otherwise be. • Students should be able to distinguish between the natural and the enhanced greenhouse effect and to identify a variety of human activities that contribute to GHG emissions. Students must understand the concept of tipping points and how it might be applied to climate change. • A minimum of two different viewpoints should be considered. **International-mindedness:** • The impacts of the climate change are global and require coordinated international action. **Theory of knowledge:** • There has been considerable debate about the causes of climate change—does our interpretation of knowledge from the past allow us to reliably predict the future? **Connections:** • ESS: Systems and models (1.2); energy and equilibria (1.3); threats to biodiversity (3.3); access to fresh water (4.2); aquatic food production systems (4.3); terrestrial food production systems and food choices (5.2); introduction to the atmosphere (6.1); stratospheric ozone (6.2); human population carrying capacity (8.4) • Diploma Programme: Social and cultural anthropology; chemistry (option C); physics (topic 8); geography (topics 3 and 4); economics; biology (topic 4)

- There has been significant debate due to conflicting EVSs surrounding the issue of climate change.
- Global climate models are complex and there is a degree of uncertainty regarding the accuracy of their predictions.

Applications and skills:

- **Discuss** the feedback mechanisms that would be associated with a change in mean global temperature.
- **Evaluate** contrasting viewpoints on the issue of climate change.

Sub-topic 7.3: Climate change—mitigation and adaptation

Significant ideas:

- Mitigation attempts to reduce the causes of climate change.
- Adaptation attempts to manage the impacts of climate change.

Knowledge and understanding:	Guidance:
• Mitigation involves reduction and/or stabilization of GHG emissions and their removal from the atmosphere. • Mitigation strategies to reduce GHGs in general may include: – reduction of energy consumption – reduction of emissions of oxides of nitrogen and methane from agriculture – use of alternatives to fossil fuels – geo-engineering. • Mitigation strategies for carbon dioxide removal (CDR techniques) include: – protecting and enhancing carbon sinks through land management; for example, through the UN collaborative programme on reducting emissions from deforestation and forest degradation in developing countries (UN-REDD)	• CCS is carried out by carbon dioxide being compressed, transported and stored permanently underground (geological sites used as repositories) or chemically fixed to form a carbonate. • Mitigation is the use of technology and substitution to reduce resource inputs and emissions per unit of output. • Adaptation is the adjustment of natural or human systems in response to actual or expected climatic stimuli or their effects, which either moderates harm or exploits beneficial opportunities. • Two mitigation and two adaptation strategies should be considered. **International-mindedness:** • The impacts of climate change are global and require global mitigation. **Theory of knowledge:** • There is a degree of uncertainty in the extent and effect of climate change—how can we be confident of the ethical responsibilities that may arise from knowledge when that knowledge is often provisional or incomplete?

    - using biomass as a fuel source
    - using carbon capture and storage (CCS)
    - enhancing carbon dioxide absorption by the oceans through either fertilizing oceans with compounds of nitrogen, phosphorus and iron to encourage the biological pump, or increasing upwellings to release nutrients to the surface.

- Even if mitigation strategies drastically reduce future emissions of GHGs, past emissions will continue to have an effect for decades to come.
- Adaptation strategies can be used to reduce adverse affects and maximize any positive effects. Examples of adaptations include flood defences, vaccination programmes, desalinization plants and planting of crops in previously unsuitable climates.
- Adaptive capacity varies from place to place and can be dependent on financial and technological resources. MEDCs can provide economic and technological support to LEDCs.
- There are international efforts and conferences to address mitigation and adaptation strategies for climate change; for example, the Intergovernmental Panel on Climate Change (IPCC), National Adaptation Programmes of Action (NAPAs) and the United Nations Framework Convention on Climate Change (UNFCCC).

Applications and skills:

- **Discuss** mitigation and adaptation strategies to deal with impacts of climate change.
- **Evaluate** the effectiveness of international climate change talks.

Connections:

- ESS: Humans and pollution (1.5); access to fresh water (4.2); photochemical smog (6.3)
- Diploma Programme: Physics (topic 8); economics

Topic 8: Human systems and resource use (16 hours)

Big questions: This topic may be particularly appropriate for considering big questions A, B, C, D, E and F.

Sub-topic 8.1: Human population dynamics

Significant ideas:

- A variety of models and indicators are employed to quantify human population dynamics.
- Human population growth rates are impacted by a complex range of changing factors.

Knowledge and understanding:

- Demographic tools for quantifying human population include crude birth rate (CBR), crude death rate (CDR), total fertility rate (TFR), doubling time (DT) and natural increase rate (NIR).
- Global human population has followed a rapid growth curve, but there is uncertainty as to how this may be changing.
- As the human population grows, increased stress is placed on all of the Earth's systems.
- Age–gender pyramids and demographic transition models (DTM) can be useful in the prediction of human population growth. The DTM is a model that shows how a population transitions from a pre-industrial stage with high CBRs and CDRs to an economically advanced stage with low or declining CBRs and low CDRs.
- Influences on human population dynamics include cultural, historical, religious, social, political and economic factors.
- National and international development policies may also have an impact on human population dynamics.

Applications and skills:

- **Calculate** values of CBR, CDR, TFR, DT and NIR.
- **Explain** the relative values of CBR, CDR, TFR, DT and NIR.
- **Analyse** age–gender pyramids and diagrams showing demographic transition models.

Guidance:

- A variety of predictive models could be included, such as computer simulations, statistical and/or demographic tables for LEDCs and MEDCs, age–gender pyramids, and graphical extrapolation of population curves.
- Development policies may increase or decrease population growth.
  - CBRs and growth rates are reduced through educating of women for greater independence (economic and reproductive), stimulation of economic growth to improve economic welfare and give greater economic independence, mechanization of the agricultural sector and subsequent urbanization.
  - Growth rates may increase if CDRs fall as a result of improved public health, sanitation, and service infrastructure.

International-mindedness:

- A country's development depends on its economy and its demographics. It also depends on the policies of other countries and international organizations such as the World Bank, the International Monetary Fund (IMF) and the World Trade Organization (WTO).

Theory of knowledge:

- A variety of models and indicators are employed to quantify human population dynamics—to what extent are the methods of the human sciences "scientific"?

- **Discuss** the use of models in predicting the growth of human populations.
- **Explain** the nature and implications of growth in human populations.
- **Analyse** the impact that national and international development policies can have on human population dynamics and growth.
- **Discuss** the cultural, historical, religious, social, political and economic factors that influence human population dynamics.

Connections:

- ESS: Sustainability (1.4); humans and pollution (1.5); species and populations (2.1); water pollution (4.4); soil degradation and conservation (5.3); climate change—causes and impacts (7.2); human population carrying capacity (8.4)
- Diploma Programme: Biology (option C); social and cultural anthropology; sports, exercise and health science (option C); geography (topic 1); economics

Sub-topic 8.2: Resource use in society

Significant ideas:

- The renewability of natural capital has implications for its sustainable use.
- The status and economic value of natural capital is dynamic.

Knowledge and understanding:

- Renewable natural capital can be generated and/or replaced as fast as it is being used. It includes living species and ecosystems that use solar energy and photosynthesis, as well as non-living items, such as groundwater and the ozone layer.
- Non-renewable natural capital is either irreplaceable or can only be replaced over geological timescales; for example, fossil fuels, soil and minerals.
- Renewable natural capital can be utilized sustainably or unsustainably. If renewable natural capital is used beyond its natural income this use becomes unsustainable.
- The impacts of extraction, transport and processing of a renewable natural capital may cause damage, making this natural capital unsustainable.
- Natural capital provides goods (such as tangible products) and services (such as climate regulation) that have value. This value may be aesthetic, cultural, economic, environmental, ethical, intrinsic, social, spiritual or technological.
- The concept of a natural capital is dynamic. Whether or not something has the status of natural capital, and the marketable value of that capital varies regionally and over time and is influenced by cultural, social, economic, environmental,

Guidance:

- The valuation of natural capital can be divided into the following two main categories.
  - Use of valuation: resources that have a price—marketable goods, ecological functions, recreational function
  - Non-use of valuation: resources that have intrinsic value (the right to exist), future uses (medicines, potential gene pool), existence value (Amazon rainforest), present for future generations
- Consider at least two examples of how the status of natural capital can vary.
- "Natural capital" is often used interchangeably with the term "resource", and the rate of its replacement is referred to as "natural income".

International-mindedness:

- There are marked cultural differences in attitudes to the management of natural capital.

Theory of knowledge:

- As resources become scarce, we have to make decisions about how to use

technological and political factors. Examples include cork, uranium and lithium. **Applications and skills:** • **Outline** an example of how renewable and non-renewable natural capital has been mismanaged. • **Explain** the dynamic nature of the concept of natural capital.	them—to what extent should potential damage to the environment limit our pursuit of knowledge? **Connections:** • ESS: Environmental values systems (1.1); sustainability (1.4) • Diploma Programme: Social and cultural anthropology; design technology (topics 2 and 8); physics (topic 8); geography (topic 4); economics

Sub-topic 8.3: Solid domestic waste

Significant ideas:

- Solid domestic waste (SDW) is increasing as a result of growing human populations and consumption.
- Both the production and management of SDW can have significant influence on sustainability.

Knowledge and understanding:	Guidance:
• There are different types of SDW, the volume and composition of which changes over time. • The abundance and prevalence of non-biodegradable pollution (such as plastic, batteries or e-waste) in particular has become a major environmental issue. • Waste disposal options include landfills, incineration, recycling and composting. • There are a variety of strategies that can be used to manage SDW (refer to figure 3) influenced by cultural, economic, technological and political barriers. These strategies include: – altering human activity—for example, through a reduction of consumption and composting of food waste. – controlling the release of pollutant—governments create legislation to encourage recycling and reuse initiatives and impose taxes for SDW collection and on disposable items – reclaiming landfills, using SDW for waste-to-energy programmes, implementing initiatives to remove plastics from the Great Pacific	• SDW includes household waste such as paper, glass, metal, plastics, organic (kitchen or garden), packaging, construction debris, and clothing. • Students should consider the amount and source of non-biodegradable pollution generated within a chosen locality and how it is managed. • The adoption of the circular economy provides an alternative approach to waste and sustainability. **International-mindedness:** • Pollution can be transborder; the pollution from one country may affect another. • Differences in development level of countries can influence the amount and type of SDW they generate. **Theory of knowledge:** • The circular economy can be seen as a paradigm shift—does knowledge develop through paradigm shifts in all areas of knowledge? **Connections:** • ESS: Sustainability (1.4); humans and pollution (1.5); flows of energy and matter (2.3); water pollution (4.4); soil degradation and conservation (5.3); acid deposition (6.4)

garbage patch (clean-up and restoration). **Applications and skills:** • **Evaluate** SDW disposal options. • **Compare** and **contrast** pollution management strategies for SDW. • **Evaluate**, with reference to figure 3, pollution management strategies for SDW by considering recycling, incineration, composting and landfills.	• Diploma Programme: Chemistry (option A); geography (topic 4 and option B)

Sub-topic 8.4: Human population carrying capacity	
Significant ideas: • Human carrying capacity is difficult to quantify. • The EF is a model that makes it possible to determine whether human populations are living within carrying capacity.	
Knowledge and understanding: • Carrying capacity is the maximum number of a species, or "load", that can be sustainably supported by a given area. • It is possible to estimate the carrying capacity of an environment for a given species; however, this is problematic in the case of human populations for a number of reasons. • An EF is the area of land and water required to support a defined human population at a given standard of living. The measure of an EF takes into account the area required to provide all the resources needed by the population, and the assimilation of all wastes. • EF is a model used to estimate the demands that human populations place on the environment. • EFs may vary significantly by country and by individual and include aspects such as lifestyle choices (EVS), productivity of food production systems, land use and industry. If the EF of a human population is greater than the land area available to it, this indicates that the population is unsustainable and exceeds the carrying capacity of that area. • Degradation of the environment, together with the consumption of finite resources, is expected to limit human population growth.	**Guidance:** • Discussion of the application of the carrying capacity that allows human populations to grow beyond the boundaries set by their local resources should include: – the range of resources used – human ingenuity, meaning that humans are able to substitute one material for another – variations in lifestyles – importation of resources – technological developments that give rise to continual changes in the resources required and that are available for consumption. • Because carrying capacity for human populations is difficult to calculate, it is also difficult to estimate the extent to which they are approaching or exceeding carrying capacity, although environmental indicators (see sub-topic 1.4) may help in this respect. • The EF is a model that provides a way round this dilemma. Instead of focusing on

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- If human populations do not live sustainably, they will exceed carrying capacity and risk collapse.

Applications and skills:

- **Evaluate** the application of carrying capacity to local and global human populations.
- **Compare and contrast** the differences in the EF of two countries.
- **Evaluate** how EVSs impact the EFs of individuals or populations.

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a given environment and trying to calculate the carrying capacity it provides, it focuses on a given population (with its current rate of resource consumption) and estimates the area of environment necessary to sustainably support that particular population. The size of this area is compared with the area available to the population, then gives an indication of whether the population is living sustainably and within the carrying capacity provided.

International-mindedness:

- Sustainability is the responsible use and management of global resources that allows natural regeneration and minimizes environmental damage.

Theory of knowledge:

- Human carrying capacity is difficult to quantify and contains elements of subjective judgment. It has been claimed that historians cannot be unbiased—could the same be said of environmental scientists when making knowledge claims?

Connections:

- ESS: Sustainability (1.4); humans and pollution (1.5); access to fresh water (4.2); aquatic food production systems (4.3); terrestrial food production systems and food choices (5.2); energy choices and security (7.1); resource use in society (8.2)
- Diploma Programme: Geography (topic 4 and option G)

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