Introduction to ecosystems

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Week 1: What is an ecosystem?

Introduction

Throughout this course you will be considering these overarching questions:

- What is the importance of understanding ecosystems?
- How do they work?
- How crucial is their conservation?

We start by defining the term ‘ecosystem’.

Before we can begin to tackle the larger issues of ecosystems and how they have been compromised by human intervention, we must understand what is meant by ‘ecosystem’. By the end of this first week you will be able to explain how an ecosystem is defined, in terms of energy flow, and be able to define and use terms which are introduced in the videos and text and apply them to new situations and examples where appropriate.

There is more than one way in which an ecosystem can be defined. In the following video Dr Mike Gillman highlights the difference between two schools of thought. One definition is that an ecosystem is an area where groups of organisms experience similar conditions.

Alternatively, an ecosystem is a living system of energy transfer, a whole complex of organisms living together, linked by energy transfer. The key difference is that ‘area’ defines one, whereas ‘energy relationships’ define the other.

As you watch ‘What is an ecosystem?’, consider the following questions, which we will discuss in the next section:

- What is the key difference between the definitions?
- What is the working definition of ‘ecosystem’ that we are going to use in this course?

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Before you start, The Open University would really appreciate a few minutes of your time to tell us about yourself and your expectations of the course. Your input will help to further improve the online learning experience. If you’d like to help, and if you haven't done so already, please fill in this optional survey.

1.1 Define an ecosystem

Figure 1

You should now be able to provide definitions of the key terms you have encountered in the previous video. Begin to construct your personal glossary of them, which you can keep by you as you study.

Building your own glossary is an effective way of consolidating your learning. We have provided a Glossary template which you can use to build your own if you choose. There are already a few entries in the Glossary, to give you a feel for the sort of definitions that you should be including. But whatever method you choose for collecting together terms and definitions, by the end of your study of ecosystems you should have a working document that you can add to if you study other science subjects.

To formulate a working definition of an ecosystem you may have to use some of the terms you have added to your glossary. Is the following definition a suitable one to work with?

An ecosystem is a set of organisms and abiotic components linked by processes of energy transfer and cycling of materials.

1.2 Investigating ecosystems

Let's examine the concept of an ecosystem in more detail using an example that is familiar to many people: a pool on a rocky beach, in Britain (Figure 2). As you work through, consider what defines the limits of a particular ecosystem.

- How does the tide change the nature of a rock pool ecosystem?
- What role does the Sun take in sustaining the ecosystem in the rock pool?

Also think about how can this be extrapolated and applied to other ecosystems with variable physical environments.

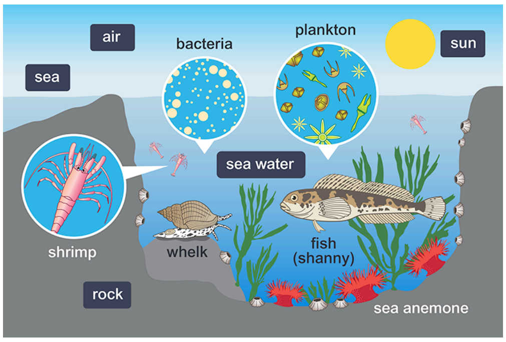

Figure 2 A rock pool

1.2.1 The rockpool

Figure 3

Like all ecosystems, a rock pool is linked to the wider world and to other ecosystems. This link is most apparent in the shape of the tides every day, which change the sea water in the pool and bring in new organisms from the open ocean (as well as allowing others to escape back into the sea). The tides also change the physical characteristics of the pool and its surroundings. When the tide is out, the rock pool is a collection of organisms living together in a fairly clearly defined place. When the tide is in, the pool may become no more than a small depression on the rocky sea bed.

Now let's look at the components of our rock pool ecosystem. Remember, any ecosystem contains living things, a physical environment and a source of energy.

The most obvious living things will tend to be the largest ones: seaweeds, sea anemones, whelks, shrimps, fish and so on. But this shouldn't blind us to the importance of the organisms we can't see. For example, the water itself is full of tiny plants and animals – called 'plankton' – that are food for many of the larger creatures. And the water and rocks contain huge numbers of the simple single-celled organisms called bacteria, and other microscopic forms of life, that play an important part in the working of the ecosystem.

The most obvious components of the physical environment of the pool are the rock that surrounds it, the sea water in it, and the air above it (when the tide is out). But these physical factors are far from fixed. The tides, and the effect of sunlight on the exposed pool, mean that the organisms that live in it must be able to withstand changes and extremes of, for example, temperature or salt content. Some small pools dry up altogether in the summer or ice over in winter when the tide is out.

Almost all of the energy that supports the life in the pool arrives in the form of light from the sun. Some of this energy is captured by seaweeds attached to the rocks and microscopic plants (types of plankton). These plants are eaten by animals, which are eaten by other animals, and so on. But the sun is not the only source of energy involved in the workings of this particular ecosystem: the tides that sweep across the pool are driven up and down the beach by the gravitational pull of the moon.

Activity 1

Using your knowledge of rock pools, pick out a few of the key features of the ecosystem, using these headings:

- rock pool ecosystem – links to other ecosystems and the wider world
- ecosystem
- living things
- physical environment
- energy.

Make some note on the key features, in the box below.

Provide your answer...

Answer

Here is a list of key features for each heading:

- rock pool ecosystem – links to other ecosystems and wider world
- ecosystem – living organisms, physical environment, energy
- living things – plants, animals, plankton, bacteria
- physical environment – rock, sea water, air, tides
- energy – sunlight (also tides caused by pull of the moon).

Did you note many of the same points? Is there anything else you'd include? Is there anything you'd leave out?

Remember that it is the observer – you or I – who defines an ecosystem, and selects which organisms or aspects of the environment to study. In much the same way, you have to decide what is important when you make notes.

However big or small our ecosystem, and whichever aspect of the system we choose to study, it is ecology that provides the framework that allows us to investigate how it works – and to wonder at the beauty and strangeness of it all.

1.3 Study a habitat

It is possible to observe ecosystems physically, mapping out observations to determine the network that exists in a given habitat. These observations provide a valuable baseline for understanding a given ecosystem, making it easier to determine the possible negative factors that might be influencing it.

In this video, we join a group of students who are learning how to classify habitats, in the field. After you watch the video, add a definition of an 'indicator species' to your glossary.

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1.4 The wetlands of Wicken Fen

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Wicken Fen is a conservation area in the east of England, near Cambridge. It is one of Britain's oldest nature reserves and home to around 7,000 species of mammals, birds, plants, insects and other invertebrates.

Wicken Fen has been described as 'biodiversity hotspot', and offers the opportunity to observe multiple habitats, each with its own ecosystem, interacting with each other and forming larger ecosystems. The wide range of habitats, the diversity of species, and the complex food webs present in Wicken Fen are all factors in determining biodiversity.

Take this opportunity to explore the area around Wicken Fen.

1.4.1 Following the food web in Wicken Fen

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The definition of an ecosystem can be framed in terms of energy flow. You need to know what organisms are living in it – the biodiversity of the system. Next, you can work out how the organisms are linked.

The sum of the nutritional links between organisms in an ecosystem is known as the food web.

Activity 2

There are two food webs mentioned in the film and one animal that links them together. What is the significance of this link?

Note your thoughts in the box provided.

Provide your answer...

Answer

The dragonflies link the aquatic with the terrestrial food webs. Energy obtained by the dragonfly larvae feeding below the surface is transferred to the terrestrial food chain. This example emphasises the complexity of links that need to be unravelled if a picture of energy flow is to be drawn accurately.

1.4.2 Managing habitats in Wicken Fen

The diversity of life in Wicken Fen is influenced by the way in which humans use the habitats that make up the ecosystem, as Professor Gowing explains. It is possible to determine the best management programme, by setting up an experiment.

Whilst watching the video, consider the following:

- Why does Wicken Fen have to be managed?
- What were the key features of the experiment that was set up at Wicken Fen in the 1920s?

Go to the Week 1 forum to discuss your thoughts with fellow learners.

!Warning! Tahoma not supportedOpen this in a new tab and come back here when you're done.

!Warning! Tahoma not supportedAs learners can study at their own pace we cannot always guarantee there will be other active learners while you are studying.

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1.5 Week 1 quiz

This quiz is about defining the term ecosystem and applying your knowledge to a simple ecosystem.

Complete the Week 1 quiz now.

Open the quiz in a new window or tab then come back here when you're done.

1.6 Summary of Week 1

In the final video of this week, Dr David Robinson, Senior Lecturer in Biological Science at The Open University, discusses what you have learned so far in this course and then introduces some of the ideas and examples explored in Week 2.

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There are different ways that an ecosystem can be defined and you discussed this with other learners, to reach a working definition of an ecosystem. You examined the core concept of an ecosystem through the example of a rock pool. Guidance as to how to study ecosystems was provided through the case study of Wicken Fen.

The next part of our learning journey starts with carbon and the capture of energy from light by plants. Plants are at the base of the food chain for all the animals in an ecosystem. The familiar woodland is an ideal place to begin to understand ecosystems in more depth.

!Warning! Tahoma not supportedIf you would like a short break or to !Warning! Tahoma not supportedfind out more about !Warning! Tahoma not supportedcoastal habitats and Wicken Fen !Warning! Tahoma not supportedvisit our !Warning! inherit not supportedEcosystems!Warning! Tahoma not supported !Warning! Tahoma not supportedarea on OpenLearn.

You can now go to Week 2.

Week 2: Understanding ecosystems

Introduction

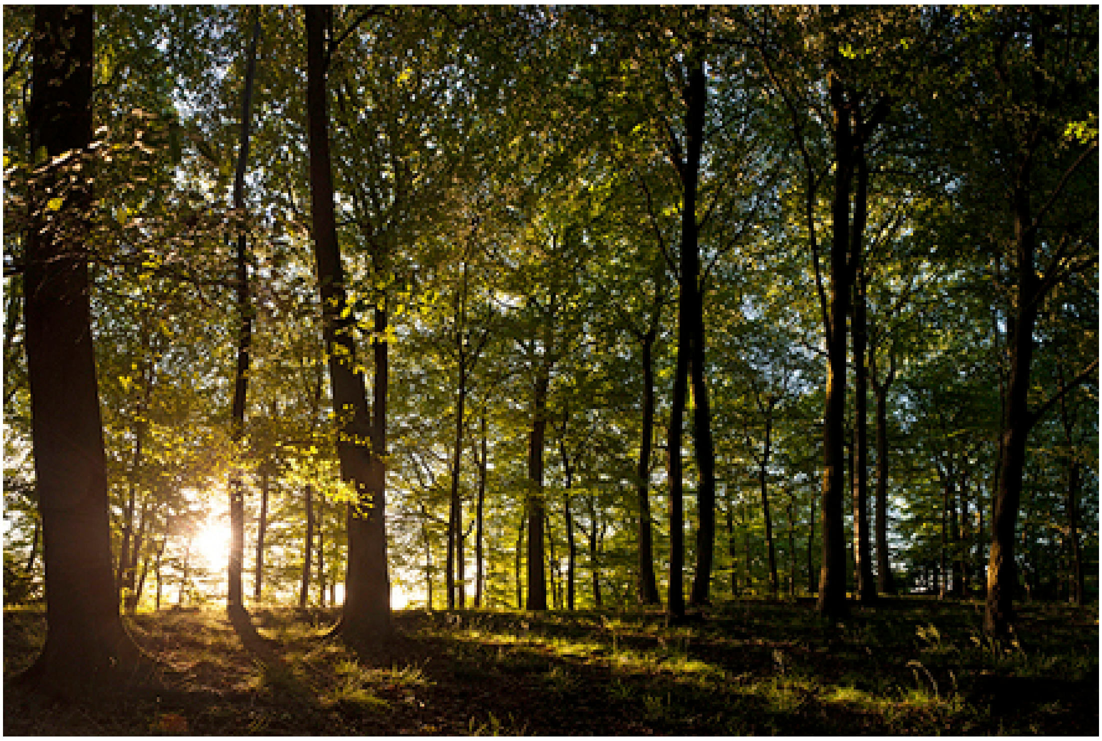

Figure 1

Ecosystems comprise more than relationships between organisms in the habitat. They are affected by factors such as light, water, carbon dioxide and nutrients and, of course, human activity.

It is nearly impossible to understand all the interactions occurring in a given ecosystem at any one time, but it is possible to observe the types of interactions that are present – and there are six, described by Dr Mike Gillman in the following video. Analysing interactions in terms of these types can help to define the boundaries of a system, though this is not an easy task. Dr Vincent Gauci considers the routes of energy loss in ecosystems.

Video content is not available in this format.

2.1 The carbon cycle

Dr Vince Gauci describes how carbon that plants have fixed from the atmosphere moves through an ecosystem and eventually is returned to the atmosphere. Carbon can be stored for long periods in the natural environment.

When you've watched the video think of some examples of places where carbon is stored.

Video content is not available in this format.

Life on earth is carbon based. A key feature of ecosystems is the passage of carbon through the system as part of the carbon cycle. Solar energy is captured in the leaves of plants and drives the incorporation of carbon into organic molecules. Carbon dioxide, in effect, combines with water to produce simple molecules. The process is called photosynthesis and in this video Sir David Attenborough describes it as the very basis of life.

How does the availability of light, water, carbon dioxide and nutrients affect the productivity of an ecosystem?

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2.2 Exploring oak woodland

Figure 2

We now explore oak woodland, and the food chains and webs that exist in it. Woodlands produce a huge variety of habitats, which in turn are occupied by a huge variety of organisms.

In 'Touring an oak woodland', Professor David Streeter introduces you to a complex ecosystem. As you watch the video, recall the concept of indicator species, which you saw in the first week and consider the follwoing questions.

- Why are the inter-relationships in ecosystems like woodlands so complex?
- What can food chains tell us about the ecosystems that exist in a particular woodland area?
- How have woodlands been managed?

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2.2.1 Following a food chain

In 'Following a food chain', Professor David Streeter and Professor Chris Perrins show how you can study one particular food chain in a complex ecosystem.

Each individual food chain tells only part of the story of the oak woodland. What would a diagram of the food chain in the oak wood featuring the winter moth look like?

Video content is not available in this format.

2.3 Fungi and the woodwide web

Figure 3

Fungi are an important component of ecosystems, especially in forests or woodlands, as they are valuable for decomposition. Decomposition breaks down dead organic matter, releasing nutrients, which can then be reabsorbed.

In this audio, Dr David Robinson talks about how fungi also have an intimate relationship with trees, which extends the woodland ecosystem underground.

Reflect on the chain of interactions occurring between trees and fungi, starting with the photosynthesis in the tree canopy and ending with fungus in the tree's roots absorbing nutrients.

Audio content is not available in this format.
Investigating symbiotic relationships

2.3.1 Unearthing the woodwide web

In nature, most trees form fungal connections. The health of the forest depends on fungus – decaying branches and leaf litter are rich with nutrients, and fungi can ferry these back to living plants.

Video content is not available in this format.

Activity 1

Having watched the video note some answers to the following questions.

- What is the significance of the long strands formed underground by fungi?
- How do they form partnerships with trees?
- What do these partnerships look like?

Provide your answer...

Answer

Many fungi form long fungal strands. The individual fungus can colonise quite a large area of the forest floor and this serves as a sort of plumbing system allowing it to conduct carbohydrates, nutrients and water.

They form partnerships with trees through mycorrhizae which infect the tips of the tree roots. The trees are then linked into the fungal underground web.

The tree roots 'team up' with the fungus.

2.3.2 Mutual benefits

There is a close relationship between fungi and trees, as this video makes clear.

As you watch the video note how this close relationship is being used to artificially reinvigorate ecosystems.

Video content is not available in this format.

2.3.3 Competition in forest ecosystems

Figure 4

Discuss with other learners in the Week 2 forum the role of competition between organisms in wood and forest ecosystems.

- Think about the implications for competition of the fungal web.
- How does the shading effect of the canopy influence seedling development?

2.4 Life in trees

Figure 5

In considering food chains in an oak wood you saw animals adapted to a life in trees. Mammals that live in trees show a range of adaptations that make them well suited to the arboreal lifestyle.

Woods and forests present a number of problems for mammals that inhabit them. The habitat stretches vertically for a substantial distance yet for tree-dwellers to travel any horizontal distance they must either go down to the ground each time, or jump from sometimes flimsy branches over large gaps. Sir David Attenborough describes how squirrels have overcome the problem.

Video content is not available in this format.

2.4.1 The colugo

Figure 6 An adult colugo and its offspring

An animal that is not closely related to the flying squirrel but shares common features is the colugo. The colugo is a bit of a mystery and the historical confusion is evident from its common name – the flying lemur. It neither flies (in that it doesn't flap its limbs) nor is it a lemur.

The colugo is not a monkey either, despite the fact that its main predator is the monkey-eating eagle. Having once been placed with insectivores and then with bats, it's now in a mammalian order of its own (the Dermoptera, i.e. 'skinwings'), recognising its ancient and distinct evolutionary beginnings. This ancient origin is why it is such an interesting animal as it early on became adapted to a tree-dwelling life. As you read about the colugo, think about adaptations that have hidden 'costs' to the animal.

One particular evolutionary development associated with tree dwelling is taking to the air. The gliding habit evolved independently in different mammalian and reptilian lineages and yet the anatomical modifications that allow it are similar in, for example, flying squirrels and the colugo. In particular, the 'sail of skin', technically termed a patagium, stretches between the limbs – and a good deal further in the colugo, acting as an effective (and to some degree manoeuvrable) gliding membrane.

Colugos are sizeable mammals (about the size of a domestic cat) and entirely arboreal. Their record-breaking glides (in excess of 70 m) are achieved without great loss of height. But in trees, they move about rather awkwardly. The patagium is then an encumbrance and there's a limited ability to grasp effectively – the colugo lacks the opposable thumb of primates. So the benefits of a gliding lifestyle are achieved at a 'cost'. The resulting vulnerability – especially to the Philippine monkey-eating eagle (a species under threat, as are colugos) – may help explain why the colugo is nocturnal.

2.4.2 Flying squirrels

Flying squirrels are not closely related to the colugos but they have features in common. You have seen squirrels and read about the colugo. As you watch the video, think about how flying squirrels steer during their glides. Note the advantages of the gliding habit.

Video content is not available in this format.

Figure 7 Flying squirrel

Activity 2

Consider these questions and note your answers in the box below.

- Identify one similarity and one difference between flying squirrels and colugos.
- On the evidence of the video sequence, comment on how flying squirrels steer during gliding.
- What are the disadvantages and consequences of the gliding habit in flying squirrels?

Provide your answer...

Answer

Both colugos and flying squirrels have a flap of skin stretched between their limbs on each side of the body – the patagium. However, in contrast to the squirrels, colugos are not as adept at moving through the trees as the patagium is much larger and an encumbrance except in flight.

During gliding squirrels steer partly with their tail and partly be altering the tension of the patagium, which alters its aerodynamic properties.

The ability to glide enables colugos and squirrels to travel long distances between trees at a low energetic cost. However, they are very vulnerable to predators and so generally only come out at night.

2.4.4 Flying foxes

Many species of flying fox (fruit bat) have important roles in ecosystems, dispersing seeds, pollinating flowers or providing food for predators. As they have evolved not only have they acquired adaptations that enable them to exploit aerial and forest habitats, but they have also evolved alongside plants in a process called co-evolution.

What are the likely advantages to flying foxes of their particular form of roosting, taking into account vulnerability to predators, the location of food and temperature regulation?

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Colonies of flying foxes may comprise as many as a few million individuals (five million is David Attenborough's estimate), each with a wingspan of about 1.4 m, with the entire 'camp' perched on often denuded trees and engaged in intense social activity.

It's little wonder that witnessing such a site has been described as a 'memorable auditory and olfactory experience'. Such concentrations of flying foxes are 'visible, audible and smellable for miles' and therefore inevitably attract predators. But congregations of this type may decrease the likelihood of any one individual falling prey to predators, such as eagles. Communication between members of the camp may also increase the efficiency of locating suitable food. But the fact that food sources are depleted so comprehensively when visited en masse raises questions as to the degree of benefit of group living.

Another possible benefit of roosting is that foliage might be protective, shading these mammals from wind, rain and sun, though trees that become camps lose many of their leaves. Fruit bats, for instance, regulate their body temperature, partly by behavioural means. Huddling together in groups should in theory reduce the rate of heat loss in cooler conditions, and decrease the rate of warming when it's very hot. In both circumstances, the surface area that each individual exposes is lessened by contact.

As you saw in the video, eagles (and owls) take a toll of flying foxes in transit, and the largely nocturnal habit of these species once again probably reflects selection pressure of this type. Flying foxes living on islands (more than 60 per cent of species do so) tend to venture forth in the daylight and in such environments predators are often less evident. Flying foxes can devastate crops, but they can also maintain 'the fertility of the rain forest'. Flying foxes can certainly help disperse trees by transporting their seeds to new locations, either through their messy eating of fruits or by seeds passing intact through the gut. The seeds of the commercially important West African iroko tree depend on the straw-coloured flying fox for their dispersal. Flying foxes also help in the recolonisation of deforested areas and in the establishment of plants on land newly formed or recently devastated by volcanic eruption.

Flying foxes are also important pollinators; many island species occupy the ecological niches taken over elsewhere by insects or humming-birds, for example. The transfer of pollen from one flower to another on a different tree (i.e. cross-pollination) can confer a significant advantage to the species because it promotes genetic diversity of the next generation. So the development of mechanisms that promote cross-pollination are very advantageous to trees. In Australia, pollination of some eucalyptus species depends almost entirely on visits from flying foxes. The flowering process of the Kajeng Jaler tree from Malaysia is intimately geared to the feeding habits of the dawn bat. Its flowers open just two hours or so after dusk and drop before dawn, coincident with the bat’s feeding time. The size and shape of the flower opening ensure that only the dawn bat can enter; as its long tongue reaches down to access the nectar, the position of the pollen-producing parts of the flower (the stamens) is such that pollen is deposited on the animal’s fur.

This is a further demonstration of the way in which the evolution of one species can increase its dependence on another, often reflecting some form of mutual advantage. This phenomenon is known as coevolution.

Figure 8 Flying fox

2.5 Week 2 quiz

This test is about energy sources, the flow of energy through a terrestrial ecosystem and the relationships between organisms within that ecosystem.

Complete the Week 2 quiz now.

2.6 Summary of Week 2

In this look back at the week, Dr David Robinson from The Open University discusses what you have learned so far in this course. The next week focuses on the adaptations of animals to the challenges posed by different types of ecosystems.

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Woodlands are a good example of an intricate and complex ecosystem and you have now seen that there is a fascinating web of relationships beneath the ground that forms the wood-wide web. Above the ground there are animals that are well adapted to glide through the trees and you explored the comparisons between the adaptations of squirrels, colugos and bats.

Next week we'll be looking at ecosystems in different parts of the world, and in particular, how some organisms survive in extreme conditions through physiological adaptations. Understanding physiological adaptations is part of the process of making sense of ecosystems. Examples will be taken from extreme habitats – deserts and the polar regions.

If you would like a short break, or to find out more about studying with The Open University, take alook at our online prospectus.

You can now go to Week 3.

Week 3: Animals and ecosystems at the extremes

Introduction

Figure 1

Studying ecosystems in the most inhospitable places reveals a range of adaptations to survival. Desert or polar ecosystems seem remote, but their links with other ecosystems are very important.

Conditions in deserts and around the poles are harsh and the organisms that live in these habitats have a range of adaptations that enable them to live there, though often on the margins of survival. So, understanding how organisms survive is part of our under-standing of the ecosystems as a whole. Studying how the organisms fit into an ecosystem involves considering a number of features. You will look at the integration of behaviour anatomy, physiology and biochemistry in diverse vertebrates that live in extreme conditions.

Figure 2

3.1 Deserts

Figure 3 The Wahiba Sands Desert, Oman, Middle East

Deserts have a unique climate, with characteristic organisms. In such an extreme environment, organisms will develop their own ‘niches’. A niche encompasses the role of an organism in a particular ecosystem, the habitat, how it eats, what it eats, and its predators.

There may be empty niches in a habitat. An invader may take over a niche by ejecting the species currently occupying it. In general, two species cannot occupy the same niche in the same geographical location.

In desert ecosystems, insectivorous, herbivorous and seed-eating niches are occupied by small animals, including arthropods, lizards, small birds, rodents, squirrels and shrews. Medium and large-sized animals such as hares, gazelle, camels and ostrich occupy grazing and browsing niches. Predators include foxes, e.g. kit fox (*Vulpes macrotis*) and cats, e.g. cougar (*Puma concolor*) in the deserts of the southern USA and Mexico, and Rüppell’s fox (*Vulpes rueppelli*) in the Arabian desert. Desert vertebrates make use of a variety of microenvironments and their associated microclimates, small-scale areas in which the climate is different from that of the habitat as a whole.

For example, in a desert ecosystem, a cavity beneath a rock, a microenvironment, would have a lower ambient temperature (T_a) than the surface and hence a different microclimate. A hyper-arid sandy desert, such as the Arabian desert, has a relatively low variety of microenvironments and associated microclimates available for vertebrates. Nevertheless, the sand at a few centimetres depth is significantly cooler than at the surface, and provides a relatively cool microenvironment for animals. In contrast, American deserts such as the Sonoran have a diverse range of microenvironments, and contain a richer diversity of vertebrate species.

Although our discussion here is restricted to vertebrates, you should be aware that many invertebrates, particularly insects, inhabit desert environments, and they provide an important food supply for many desert birds and mammals.

3.1.1 On size and shape

The ways in which animals interact with the environment is affected by their body size and shape.

One way to classify desert animals is in terms of the range of body sizes and the rate of evaporation.

The logic of this classification can be appreciated by the following exercise. If you represent a small animal by a cube, and then make a larger scale model of it twice natural size, the linear dimensions of the larger animal would all be twice as large (Figure 4).

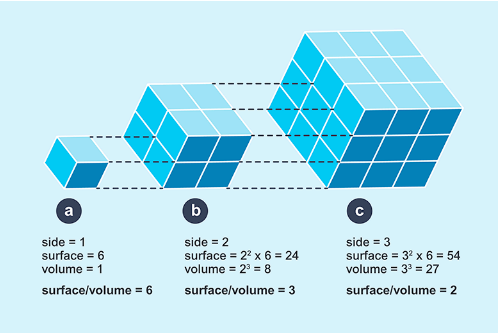

Figure 4 How animals interact with the environment is affected by their body size and shape

However, the surface area of the model would not be increased by a factor of 2, nor would the volume, as can be seen by comparing Figure 4a and 4b. If the linear dimensions double; the surface area increases by a factor of 4 (2^2) and the volume by a factor of 8 (2^3). So the ratio of surface area to volume is lower in a large animal than a smaller one. Since heat is transferred at the surface, a small animal has greater potential for rapidly gaining and losing heat than a larger one because of its relatively large surface area. A smaller animal also has greater relative potential for evaporative water loss through its large area of skin, relative to its volume.

However, animals are not cube-shaped, and certain desert species have features that can increase their surface area relative to their volume.

Activity 1

Consider this question and note your answers in the box below

What desert animals that you know of from your general knowledge have features that increase their surface area relative to their volume?

Provide your answer...

Answer

An obvious adaptation that increases surface are is large ears and so you might have chosen the desert fox, jerboa, the jack rabbit or the elephant. A more unusual adaptation is found in the frilled neck lizard, which has a flap of skin that it can extend both for display and to regulate body temperature.

Figure 5

3.1.2 Behavioural strategies of evaders

Figure 6 The water-holding frog (*Cyclorana platycephala*) (left) and the painted burrowing frog (*Neobatrachus sudelli*) (right)

Small animals, classified as evaders, include desert amphibians and reptiles, and also mammals – rodents and insectivores. The term ‘evaders’ refers to the animals’ behaviour, which helps to prevent overheating of the body on hot sunny days, and avoids the need for cooling by evaporative water loss, which is not feasible for small animals living in an arid habitat. Evaders make use of microenvironments such as shady rock crevices, underground burrows and shade cast by plants, for behavioural thermoregulation. Evaders also prevent excessive cooling of the body by behaviour, retreating to shelter when the ambient temperature (T_a) plummets at night.

The ultimate evaders are desert frogs such as *Cyclorana* spp. and *Neobatrachus* from Australia, which spend most of the year in aestivation, inside a burrow. Aestivation is a special kind of dormancy, which enables animals to survive lack of water and high T_a during a hot dry season. During the short rainy season, desert frogs accumulate water in the bladder, where it remains during aestivation. A famous example, *Cyclorana platycephala*, is known as the water-holding frog; aboriginal people used to dig up the aestivating frogs and squeeze them, in order to collect and drink the water.

During aestivation, the frogs are protected from losing water to the dry soil in the burrow by a cocoon. At the end of the rainy season, the frogs burrow into the soil, and the skin undergoes a type of moulting process in which layers of epidermis are separated from the body but not shed, forming a protective cocoon, covering all parts of the body apart from the nostril openings. The cocoon thickens, becoming heavily keratinised, and prevents loss of water from the frog's body during the 9–10 months of aestivation. At the start of the rainy season, heavy rain with consequent seepage of water into the frogs' burrows, stimulates the frogs to emerge. Breeding and feeding occur during the short wet season.

Reptiles

Reptiles with a scaly keratinised skin are not so prone to evaporative water loss as amphibians, and are the vertebrates that you are most likely to see on a visit to a desert. Reptiles are ectotherms and rely on solar radiation for warming the body, and maintaining high body temperature (T_b) during the day. Desert reptiles have no problem in gaining heat for maintaining T_b at a high level on hot sunny days (Figure 7).

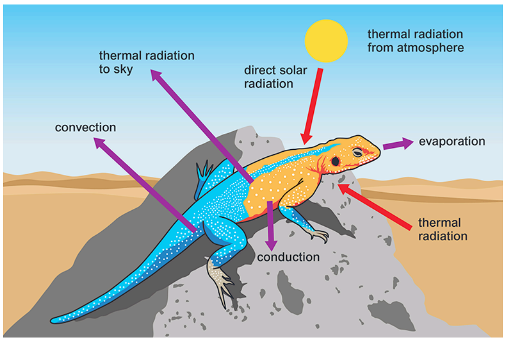

Figure 7 A side-blotched lizard (*Uta stansburiana*) basking in the Sun

What are the sources of energy gain and routes of heat loss for the lizard?

The lizard gains heat energy via thermal radiation from the Sun, the atmosphere and the ground. Heat energy is lost via conduction from the body to the ground, by evaporative water loss, convection and thermal radiation to the sky. On a hot sunny day, more heat is gained than lost, and it is important for a desert reptile to avoid overheating. It is equally important to reduce loss of body heat when T_a plummets at night or during the winter.

During the day, reptiles may move between warm and cool areas in order to maintain T_b. This movement between warm and cool areas for maintaining body temperature is called shuttling. Those species that maintain high stable T_b when environmental conditions allow by adopting heliothermic (sunbasking) strategies, are called thermal specialists. In contrast, there are some species, known as thermal generalists, which allow their T_b to fluctuate and decline, even when they could shuttle between sun and shade to maintain high stable T_b during the day, or use their burrow at night to prevent cooling of T_b to the outside T_a. Bedriagai's skink (*Chalcides bedriagai*) is a thermal generalist, preferring to spend a lot of time hiding under rocks rather than basking in the Sun.

The side-blotched lizard (*Uta stansburiana*), found in the Sonoran desert, is a typical thermal specialist. It is a small species, only 4–6 cm long when full grown.

In the morning, *Uta* warms by basking, initially orientating itself at right angles to the Sun's rays and flattening the body against the substratum for maximum exposure to solar radiation. When warmed *Uta* turns the body so that it faces the Sun while resting. *Uta* maintains T_b around 36–38°C. Active foraging for insects, scorpions and spiders may overheat the body, and for cooling off, especially around noon, *Uta* moves to the shade of rocks and scrubby bushes. Shuttling in this way enables this species to stay active during the day for most of the year except in areas where winter temperatures dip to freezing.

Nocturnal desert animals

Figure 8 The Moorish gecko (*Tarentola mauretanica*)

A few desert reptiles are nocturnal; the Moorish gecko (*Tarentola mauretanica*), is found in arid regions in North Africa (also in Spain, France and Greece, so it is not restricted to deserts).

Tarentola is most active for a few hours after sunset. During the night, itsT_b is as low as 18°C, and can fluctuate by up to 11°C. Those lizards that tolerate wide fluctuations in T_b, even when they could use features of the environment to maintain a steady T_b, are known as thermal generalists. The Moorish gecko is a thermal generalist at night, when it is active rather than resting in its burrow. During the early morning the Moorish gecko basks in the sunlight and its skin darkens until almost black. At night the gecko is very pale.

What functions and advantages do the changes in skin colour give?

Dark colours absorb and radiate heat better than light colours. At night a light colour should reduce heat loss by radiation, and there is not much heat available to absorb. During the day, dark skin promotes absorption of solar heat. Although radiation to the atmosphere by the dark skin is also promoted, the energy so lost is of little significance compared to the large amount of solar heat absorbed.

The advantage to the gecko of warming up in the morning is uncertain, but it is possible that a physiological process such as digestion of the food eaten during the night requires a higher T_b than the gecko can maintain at night.

The ability of the gecko to vary skin colour shows that behavioural thermoregulation in reptiles is supplemented by physiological mechanisms.

Sheltering in the available shade in the desert, or being active at night, are simple strategies for keeping T_b below lethal levels. In sandy desert areas, the sand itself plays an important role in behavioural thermoregulatory strategies. The Mojave fringe-toed lizard (*Uma scoparia*) is restricted to fine, wind-blown sand, e.g. in dunes, dry lake beds and desert scrub in the Mojave desert. Burrows in sand collapse immediately or soon after the animal has moved on, so animals buried in sand rely on air trapped between sand particles for breathing. *Uma* is a 'sand-swimmer' and its dorsoventrally flattened body and shovel-shaped head facilitate movement through the sand, which is especially important when escaping from predators such as snakes and badgers.

Figure 9 The Mojave fringe-toed lizard (*Uma scoparia*)

The eyelids are protected from sand by large eyelid fringe scales. The digits have large lamellar fringes, elongated scales, especially long on the hind feet, which enable the lizards to run at speed on the sand surface. *Uma* grows up to about 110 mm in length, and its activity pattern is diurnal, varying according to ambient temperature. In March and April *Uma* is active for short periods because of the low spring temperatures in the Mojave. In summer, from May to September, the lizards are active during mornings and late afternoons, feeding on insects and plants. Sand-swimming lizards are also found in the Namib desert and include the wedge-snouted sand lizard (*Meroles cuneirostris*).

Desert burrows

Look at the way in which the surface temperature of sand can change through a day (Figures 10 and 11).

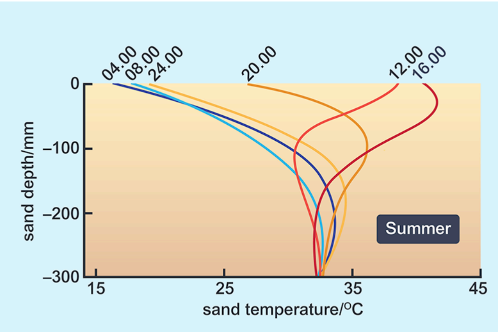

Figure 10 Temperatures below the sand surface on a dune in the Namib desert on a summer day

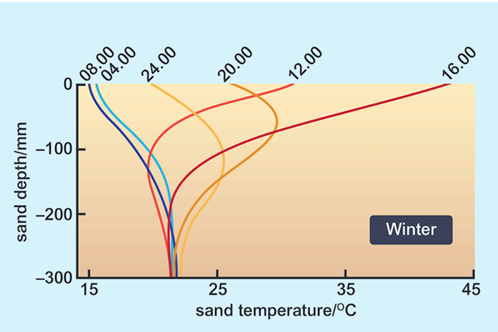

Figure 11 Temperatures below the sand surface on a dune in the Namib desert on a winter day

Although the temperatures of sand at various depths in the Mojave desert would not be precisely the same as those in the Namib, the physical characteristics and thermal environment provided by dry sand are broadly the same in all deserts at similar T_a.

A benign temperature is available below the surface at all times of the day in both seasons, in spite of extremes on the surface. These surface temperature extremes are not very different in summer and winter. The high afternoon surface temperature in winter is due to hot, dry winds (Berg winds) that reach the desert in the winter months.

Burrowers

Burrows provide important microenvironments for many desert evaders, and their structure and use vary between species. The desert tortoise (*Xerobates agassizii*) lives in deserts in the USA and Mexico, and feeds on annual herbs, cacti and shrubs, obtaining most of its water from the plants.

Figure 12 The desert tortoise (*Xerobates agassizii*)

In the Mojave desert, the tortoises live in sandy areas as well as rocky hillsides, including scrub-type vegetation, Joshua tree/yucca and creosote bush/ocatillo habitats. For the tortoises, burrows are important refuges for thermoregulation, summer aestivation and winter hibernation. Tortoise burrows in the Mojave desert are extensive and can be up to 12 m long; the same burrows are used for many generations, and are shared with other species such as burrowing owls and ground squirrels. Each desert tortoise may use up to 12 burrows in its home range and each burrow is used by different tortoises at different times. For short rest periods during the day tortoises dig shallow depressions, known as pallets, which barely cover the carapace.

Bear in mind that when occupied by a tortoise, a burrow's relative humidity may rise to 40 per cent because of the tortoise's water loss by evaporation from the lungs, exposed skin and eyes. Stable T_a and humidity in the burrow protect the tortoise from extremes of high T_a and from winter frosts. It was noticed that tortoises are fussy about the burrow selected for resting. At the end of foraging, tortoises were observed to enter and leave several burrows before settling. Mojave desert tortoises are active between March and June, a time when the winter rains have stimulated the growth of annual plants, providing abundant food for the tortoises. The tortoises begin foraging during the morning but usually by noon they have moved into pallets and burrows to shelter from high T_a. At night, burrows provide shelter from low T_a and also protection from nocturnal predators such as kit foxes and badgers. By the end of June, when surface temperature may reach 60°C, and annual plants have dried up, the tortoises retreat to their deep burrows and aestivate, a behaviour that helps to conserve body water. During aestivation, up to a quarter of the tortoises' body mass may be water stored in the bladder. Occasionally an aestivating tortoise emerges to drink during summer thunderstorms. In the eastern Mojave desert tortoises are active for most of the summer because there, summer rainstorms provide sufficient new plant growth. For their winter hibernation, tortoises aggregate in the burrows; up to 25 individuals have been found in one burrow. Hibernation lasts from October to the end of February, and during this time T_b of the tortoises is the same temperature as the burrow, around 5–16°C in winter. Note therefore that hibernation in the desert tortoise is not the same physiological process as it is in hibernating mammals . Reptiles do not regulate T_b physiologically during hibernation; T_b is the same as burrow T_a. You will find that in some references, reptile 'hibernation' is termed 'brumation'.

Mammalian desert burrowers

You may be surprised to learn that like desert ectotherms, small desert rodents also depend on burrows for thermoregulation. Merriam's kangaroo rat (*Dipodomys merriami*) is a typical evader, living in the Sonoran desert, Arizona, and in Death Valley, California, two of the hottest and driest areas in the Western Hemisphere.

Figure 13 Merriam's kangaroo rat (*Dipodomys merriami*)

Individuals live in a maze of burrows, which they defend. They remain in their burrows during the day, and often plug the entrance with soil. At night kangaroo rats emerge from their burrows for just two hours to collect seeds, in particular seeds of the creosote bush, which they push into their cheek pouches, returning at intervals to empty the food into their burrow. In this way, food caches are built up; kangaroo rats always eat inside the burrow, drawing on their food cache. Inside the burrow, the air is cooler and more humid than above the ground, as moisture from respiratory water loss accumulates. Measurements made on similar burrows in the Negev desert, Israel, showed T_a of around 26°C at 1 metre depth for 24 hours per day when ambient temperature above ground ranged from 16–44°C. However, not all small desert animals can burrow.

The desert wood rat (*Neotoma lepida*) lives in deserts in the southern USA, including Death Valley, California. Wood rats do not burrow but build elaborate houses around the base of cacti or shrubs, amongst a patch of agaves, or beneath a rock outcrop. Wood rat houses can reach huge sizes and their interior is significantly cooler, by about 5°C, than the outside during the heat of the day. Desert wood rats shelter in their houses during the day, and emerge to forage at night, eating creosote bush, cholla, prickly pear cactus and agave.

3.1.3 Behavioural strategies of evaporators

Evaporators are animals that depend on sufficient water intake to enable them to cool T_b by evaporation. Few of these species can survive in deserts, and those that do either live on the edges of deserts where they can access water, or have behavioural and physiological adaptations that reduce reliance on evaporative cooling. So for evaporators, evasion may be an important part of their thermoregulatory strategy. Evaporators include medium-sized mammals such as jack rabbits, dogs, foxes, and also desert birds such as larks.

The jack rabbit (*Lepus californicus*) is a hare, living in the Sonoran and Mojave deserts. Jack rabbits do not burrow, although they are quite small, weighing about 2 kg.

A jack rabbit would need to lose at least four per cent of its body mass per hour to thermoregulate by evaporation. There is little or no free water around; water is obtained from the diet, green plants, including cacti in the summer. The classic work of Knut Schmidt-Nielsen (1965) showed that behaviour is important for the jack rabbit's survival. During the hottest part of the day the animal chooses a shaded depression in the ground, often in the lee of a bush, in which it crouches (Figure 6).

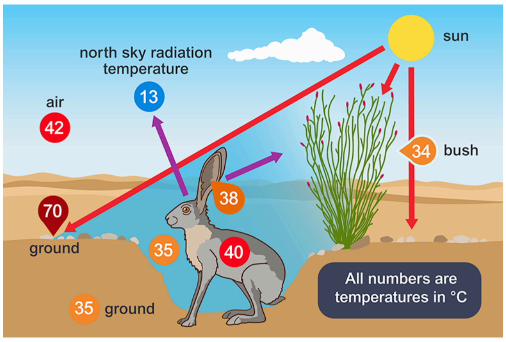

Figure 14 The desert jack rabbit in a shaded depression showing a behavioural adaptation to cope with the severe environment

The bottom of such a depression has a much lower temperature than that of the rest of the surface, the hot desert wind and much of the radiation passing over the animal's head. From its sheltered position, the jack rabbit's large radiator-like ears can be exposed, not directly to the Sun, but to a clear blue sky. The radiation temperature of the north sky at midday is only 13°C so if the ears, which are richly vascularised, have a temperature of 38 °C, and have a surface area of 400 cm^2, are directed towards the sky, they can radiate about 13 kJ h^{-1}, which is about half of the animal's metabolic heat production. The jack rabbit forages during the night.

The kit fox (*Vulpes macrotis*) lives in the Sonoran, Mojave and Great Basin deserts in southwestern USA. Kit foxes have very large ears, which are thought to provide an increased surface area for cooling the body.

They are carnivores, and hunt at night, preying on kangaroo rats, tortoises and jack rabbits, and occasionally catching ground-nesting birds, reptiles and insects. They reduce evaporative water loss by spending the day in underground dens, emerging at sunset to begin hunting. The physiological importance of dens for desert foxes should not be underestimated. By remaining in the den during the day, a desert fox reduces drastically the need for panting, a mechanism used by foxes and dogs for cooling the body by evaporative water loss.

A few species of small birds live in the most extreme deserts. Dune larks (*Mirafra erythroclamys*) are the only birds that live year round in the Namib sand sea, one of the driest regions of the world. Dune larks feed on insects and spiders, which they collect during the day, while walking over the sand surface; they also peck insects from just below the sand surface. In winter the birds feed on seeds blown in from adjacent grass land. The scarcity of water in the Namib sand sea means that dune larks drink rarely and the birds rely on water in their food and on metabolic water. Birds do not sweat, but they use both cutaneous and respiratory evaporative water loss for cooling the body. During the hottest part of the day, from around 12.00 to 15.00, dune larks seek shade and stand still. Presumably this behaviour helps the birds to cool T_b and reduces evaporative water loss.

Taxidermic mounts have been used to determine operative environmental temperature, T_e, for the birds. T_e is the temperature that an animal would reach in the environment if it was biologically inactive, i.e. only the physical characteristics of the animal are taken into account. It is defined, in physical terms, as the temperature of a black body of uniform temperature, in an identical situation to that which the animal occupies, with the same values for conduction, convection and radiation. As the definition is purely physical, it is possible to make models of animals and to use them to measure T_e experimentally.

The results of these experiments suggest that in winter, the strategy of finding a shady spot during the hottest part of the day lowers T_b sufficiently, so there is no need for physiological cooling, in particular evaporative water loss, for maintaining T_b

While desert animals classed as 'evaporators' could use evaporative cooling for maintaining T_b at high T_a, the need for this is avoided by simple behavioural strategies. Nocturnal foraging and daytime use of dens, burrows and shade for cooling reduce the need for physiological cooling by evaporative water loss, thereby conserving water.

3.1.4 Behavioural strategies of endurers

Figure 15 Dorcas gazelle (*Gazella dorcas*)

Endurers are defined as large desert mammals such as oryx and camel, and large desert birds, including ostrich and emu. The term 'endurers' suggests that these animals are forced to endure the extreme conditions of the desert climate because they cannot shelter from high T_a and intense solar radiation during the day or low T_a at night, as they are too large to hide in burrows or dens. Nevertheless, in spite of their size, endurers do take advantage of aspects of the environment for cooling by means of behavioural strategies.

Large mammals tend to be inactive during the hottest part of the day, thereby reducing metabolic heat production. The Arabian oryx (*Oryx leucoryx*) lives in the Arabian desert, including areas where free-standing water is rarely if ever available. On hot days oryx dig into the sand with their hooves, exposing the cool sand below the surface, and sit in the depressions. Body heat is lost to the cooler sand by conduction. Where possible, the oryx also spends time sitting in the shade of evergreen trees (*Maerua crassifolia*) during the hottest part of the day. Oryx forage at night during the summer, avoiding exposure to high T_a and intense solar radiation. They feed on grasses and rely on the water content of the plants for their intake of water.

Dorcas gazelle (*Gazella dorcas*) live at the borders of the Sahara desert and are the smallest species of gazelle, weighing just 15–20 kg. They have very long limbs in proportion to their body size, and large ears: both features maximise any convective cooling caused by breezes. Dorcas are described as the most desert-adapted of all gazelles, as like the oryx, they are reputed to be able to survive without drinking any water at all. Their feet are splayed, an adaptation for walking and running on sand. Dorcas gazelle graze and browse at night and at dawn and dusk, feeding on leaves, flowers and pods of acacia trees, and using their hooves to dig for bulbs.

Long limbs, tails or necks provide large surface areas from which heat can be dissipated, and behaviour patterns may maximise loss of heat from these areas. The ostrich (*Struthio camelus*) is the largest living bird, weighing up to 150 kg. Ostriches forage during the day. The birds select plants with high water content when grazing, especially during times of water shortage. The naked neck of the ostrich and its long naked legs provide a large surface area for convective and radiative cooling, especially in breezy conditions. The ostrich uses behaviour to enhance the cooling effects of feather erection at a high ambient temperature and incident solar radiation. Sparsely distributed long feathers on the dorsal surface of the bird erect in response to warming of the skin, thereby increasing the thickness of the insulation between solar radiation and skin. The gaps between the feathers allow through air movements, which cool the skin by convection. The birds supplement the physiological response during the hottest part of the day by orientating themselves towards the Sun and bowing out their wings away from the thorax, forming an 'umbrella' which shades the exposed thorax. The naked skin of the thorax acts as a surface for heat loss by both radiation and convection. At night when ambient temperatures plummet, ostriches conserve heat by folding the wings close to the thorax and tucking the naked legs under the body while they sit on the ground. The dorsal feathers respond to low T_a by flattening and interlocking, which traps an insulating layer of air next to the skin, and keeps most of the skin at 34.5° C.

Evaporative water loss is the most effective means of reducing body temperature during heat stress. However, in deserts, very little, if any, free-standing water is available. For all groups of desert vertebrates, behavioural strategies for maintaining T_b play a crucial role in preventing overheating of the body, which reduces the need for evaporative cooling and thereby conserves water. In the following section, we will see how in desert vertebrates, behavioural strategies for controlling body temperature are integrated closely with biochemical and physiological mechanisms.

Desert animals are classified in terms of their body size and physiology into three groups: evaders, evaporators and endurers. The logic for this classification is that the smaller the animal, the larger its surface area to volume ratio. Small animals therefore gain and lose heat faster than large animals, warming rapidly when exposed to intense solar radiation, and cooling rapidly at night.

Small endothermic evaders, e.g. kangaroo rats, rest in cool microenvironments, e.g. shade or burrows, during the day. Lizards, ectothermic evaders, regulate T_b during the day by shuttling between sun and shelter. They avoid night-time hypothermia by resting in burrows. Nocturnal evaporators, e.g. kit foxes, remain in cool dens during the day. Some endurers, large species such as the oryx, graze nocturnally in summer, sitting in shade during the day. Behavioural strategies for avoiding intense solar radiation link intimately to physiology. Such behaviour prevents large fluctuations in T_b and conserves water by removing the need for evaporative cooling, which is of crucial importance in deserts where water is scarce.

3.1.5 Camels and humans as desert dwellers

Both humans and camels live in desert conditions and both rely on evaporative cooling to regulate their body temperatures. However, as this classic Open University video makes clear, the camel handles its water balance better than humans do, as well as having other adaptations that help it survive in a desert ecosystem.

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3.2 Cold environments

Figure 16 *Saxifraga oppositifolia*

The Arctic regions are the exact opposite of deserts as far as severe climate is concerned. Organisms in the Arctic regions have adapted to habitats influenced by extreme cold, resulting in short growing seasons for plants, land that produces little food, and lack of shelter. Some animals migrate and thus avoid the extreme cold for large parts of the year.

At high latitudes, the Sun's rays always strike the Earth at a large angle from the vertical so they travel through a thicker layer of atmosphere and are attenuated by the time they reach the ground. Because the Earth's axis of rotation is inclined to its path around the Sun, there are large seasonal changes in day length and the Sun is continuously below the horizon for a period in winter and continuously above the horizon for an equivalent period in summer. The range of annual temperature change is much greater at higher latitudes, and in mid-winter (January and February), the range about the mean is more than 12 °C. In polar climates, the temperature can change abruptly and often unpredictably. In coastal areas, the sea keeps the climate much more equable. Further inland, fluctuations in temperature are even greater. Polar organisms are thus adapted both to the extreme cold and to abrupt fluctuations in temperature.

The Arctic Circle (66° 30′N), and the equivalent latitude in the Southern Hemisphere, are defined as the latitude above which the Sun is continuously below the horizon for at least one day each year. Warm, moist air from the temperate zone rarely reaches high latitudes, so in most polar areas precipitation is low. Much of the water is locked away as ice, which has a low vapour pressure, and the air is very dry (often as dry as a tropical desert) and ground water is inaccessible to plants as well as to animals.

Terrestrial environments in the Arctic are, by geological standards, relatively new, most of the land having been completely covered with a thick layer of ice as recently as 10 000 years ago. Consequently, the soil is thin and fragile, and poor in organic nutrients. The optimum temperatures for plant growth do not coincide exactly with peak sunshine. At Longyearbyen, continuous daylight begins in late April, but the mean temperature does not rise above 0 °C (and so the snow and ice do not melt) for another two months.

These circumstances, combined with the severe climate, mean that the growing season for plants is short but intensive, and total productivity on land is low, producing little food and still less shelter for animals.

3.2.1 Life on land at high latitudes

Relatively few species of terrestrial organisms live permanently at high latitudes. For example, although the land area of Svalbard is about 62 000 km^2, almost half that of England, there are only a few hundred species of insects and other invertebrates, two resident terrestrial mammals, the arctic fox (Figure 17a) and reindeer (Figure 17b), one bird (an endemic species of ptarmigan) and no reptiles, amphibians or completely freshwater fish.

Figure 17 (a) The arctic fox (*Alopex lagopus*); (b) The subspecies of reindeer *Rangifer tarandus platyrhynchus*

However, many other species spend part of the year on or near the land, often while breeding or moulting: seasonal visitors include more than 30 species of migratory birds (various kinds of geese, auks, puffins, skuas, terns, gulls, and eider ducks and snow buntings), and mammals that feed in the sea, such as polar bears, walruses and several species of seal. The simple ecosystem on land and the severe, erratic climate tend to produce ‘cycles’ of population abundance followed by mass mortality or migration (e.g. lemmings in Scandinavia and Russia). Interesting physiological and behavioural adaptations to these fluctuations in food supply have evolved in some of the larger animals. The vast continent of Antarctica has no indigenous terrestrial vertebrates, although many birds, including penguins, skuas, terns and gulls, and six species of seal spend time on or near land.

Only two species of terrestrial mammal occur naturally throughout the year on Svalbard (although a few others have been introduced by humans during the past century). Figure 17a shows the arctic fox (*Alopex lagopus*), which also occurs throughout the Arctic, and in mountains at lower latitudes. The picture in Figure 17a, taken in late autumn, shows an adult in its long, dense winter coat. The summer coat is usually greyish brown, often with white markings. *Alopex* is bred in captivity for its fur, which can vary in colour from grey to bluish in winter, and chocolate brown to fawn in summer, hence the common names, silver fox or blue fox. Figure 17b shows a subspecies of reindeer (*Rangifer tarandus platyrhynchus*) that is endemic to Svalbard. This picture was taken in July, when the vegetation is at its highest, and this young male is growing antlers for the mating season in September.

The situation in the polar seas is very different, which you will discover as you conclude your study of extreme ecosystems by learning about life in the polar seas.

3.2.2 Life in the polar seas

Life in the polar sea ice forms part of a web of interactions, which Dr Mark Brandon discusses with Brett Westwood as he considers the tiny life trapped in the sea ice that is the foundation for the entire food chain at the poles.

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Seawater freezes at −1.9° C, but because of the anomalous relationship between the density and temperature of water, ice floats, insulating the water underneath from the cold air above. Except in very shallow areas, the sea-ice does not extend to the sea-bed, even at the North Pole. Storms and currents sometimes break up the ice, creating many temporary, and some permanent, areas of open water even at high latitudes in mid-winter. Such turbulence also oxygenates the water and admits more light, making the environment much more hospitable to larger organisms.

The movements of ocean currents are complex and may change erratically from year to year. This often results in an upwelling of deep water rich in nutrients and promotes high primary productivity in the sea. In most arctic regions, the sea is both warmer and more productive than the land. So at high latitudes there are many more organisms in the sea than on land, at least during the brief summer, and, as in the case of the baleen and sperm whales, some are very large.

Krill

You heard previously how Dr Mark Brandon and colleagues studied krill under the sea ice. In this video scientists from the British Antarctic Survey (BAS) are trawling for krill and sorting them for later analysis – some task!

As you watch listen out for answers to the following questions:

- What is the role of krill in the Antarctic food chains?
- How do the food chains in the polar seas compare with those introduced earlier by Professor David Streeter in the oak wood?

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3.3 Apply your knowledge of ecosystems

Figure 18

A number of interesting points came out of the previous section. Consider some other, wider questions about possible changes in the ecosystems and how they might affect life in the polar regions. For this activity you may need to draw on your general knowledge at that of others, in addition to your understanding of the course so far.

Go to the Week 3 forum and discuss the following questions.

- What kinds of physiological adaptations to fluctuating food supply have organisms in the Arctic regions made?
- What kinds of behavioural adaptations do organisms in the Arctic regions have that specifically suit the ecosystems they are a part of?
- How do emperor penguins' breeding patterns fit the harsh ecosystem they are a part of?
- How would leopard seals be affected if the penguin population experienced a boom or a decline? What would this mean for the rest of the ecosystem they are a part of?

3.4 Week 3 quiz

This test is about the physical characteristics of extreme ecosystems and the adaptations that some animals have to the harsh conditions.

Complete the Week 3 quiz now.

3.5 Review of Weeks 1 to 3

Figure 19

These three weeks have introduced you to the concept of an ecosystem and the debate about how to set the boundaries of such systems. Energy is the key link within ecosystems and the pathways by which energy flows can be explored within an ecosystem by examining the food chains that are present.

In some types of ecosystem the food chains are long, complex and many-branched. In the polar seas you have found that they can be very short, such as the 3-step chain from plankton, through krill to the largest animal on the planet, the blue whale.

Some of the examples of animals in ecosystems have introduced you to the concept of adaptation. You saw squirrels flying through the air and may in your discussion have linked their adaptations to those of other animals, such as the flying lizard and the flying snake. These adaptations to gliding enable faster travel through the complex, forest environment. Gliding shows how similar solutions can arise during evolution in unrelated groups of organisms.

In the second half of this course you will be looking at the impacts humans have on ecosystems, but major events occurring on the planet may also have impacts. Volcanic eruptions and tsunamis are obvious examples. This video shows a large scale event in an ice sheet in Antarctica. The effect on the area itself is substantial, but could it have wider implications? This is a larger question which you should ponder on and come back to when considering human impacts on ecosystems.

Video content is not available in this format.

A continuing theme has been that of conservation. How do you study ecosystems and then conserve them? Conservation raises a whole series of questions. For example, should conservation efforts be concentrated at the individual species level or should they all be directed to conserving habitats?

Take this question away with you as you finish the next three weeks of the course. You will appreciate that there is no simple answer, but if you know what you have in an ecosystem then at least you can start to decide what action to take to conserve it. Identifying animals, plants and fungi is, therefore, an essential part of the study of ecosystems. Next week, you will take part in an activity about identifying organisms in an ecosystem, using the iSpot website to post observations.

If you would like a short break or tofind out more about animals living at the extremes visit our !Warning! inherit not supportedEcosystems area on OpenLearn.

You can now got to Week 4.

Week 4: The unseen world

Introduction

Figure 1

This week you will learn about the smaller organisms at the base of food chains in simple and complex ecosystems. Then look for organisms in your own area and identify them using the iSpot community.

Three-quarters of the Earth's surface is covered with water, and that water is full of particles and a vast array of different kinds of creatures make their living by filtering those particles out of the water. There are many very small organisms that inhabit the water world. Understanding their lifestyle and inter-relationships requires us to understand their biology, but also something about the physical nature of the environment in which they find themselves. We are dealing with a different world at the level of the very small.

In the following audio Dr Aaron Bernstein talks to Brett Westwood about some of the wonders of the microbial world and how it redefines our understanding of life. Listen out for answers to the following questions:

- Dr Bernstein compares the living world with a tapestry. Why does he regard this as a useful analogy?
- Why is it a problem to define species in the microbial world?

Audio content is not available in this format.

4.1 Seas, ecosystems and small organisms

Figure 2 Daphnia, a genus of small, planktonic crustaceans

Many very small organisms live in water. Understanding their lifestyle means understanding the physical nature of the environment, because it is a different world for the very small.

4.1.1 Investigating small organisms

In the next video you will be able to watch a marine scientist collecting plankton samples in a hi-tech way, but first listen to some background to the work as David Robinson talks to Penny Boreham about small organisms. Some of the planktonic organisms are single cells whereas others, such as the young stages of larger animals like crabs, are multicellular.

In the interview, you will also hear about an organism called 'Tony'. Tony is found in a very unusual ecosystem – one that you may not have thought about before – and you will learn more about this in the video entitled 'Investigating flagellates'.

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Dr Gabrielle Kennaway is trying to find out more about planktonic organisms within their ecosystems and she is using very sophisticated equipment to sample the plankton. She refers to the equipment as a CDT, an instrument for measuring conductivity, temperature and depth that is equipped with sampling bottle. She is particularly searching for phytoplankton, microscopic plant life. She will show you how phytoplankton can be detected in the water and she reveals a very interesting event.

Dr Paul Tett is interested in the behaviour of phytoplankton. He discusses the sources of energy in this aquatic ecosystem. Being small has advantages for phytoplankton and you should try and note the advantages that Dr Tett describes.

Video content is not available in this format.

4.1.2 Investigating flagellates

Dr Gianfranco Novarino is working on flagellates that occupy a very unusual ecosystem deep in the ground at Cape Cod, an organically contaminated aquifer – an underground water-bearing rock. It is, as he describes, a very basic ecosystem and probably one that you would not have thought of. Can you think why studying such ecosystems is important?

Video content is not available in this format.

Figure 3

Activity 1

You now know something of the role of microscopic organisms in marine and aquatic ecosystems. What roles can you suggest that they might have in terrestrial ecosystems?

Provide your answer...

Answer

Microscopic organisms have a variety of essential roles in terrestrial ecosystems. Examples you might have thought of include decomposing organic material, fixing nitrogen from the atmosphere and providing food for other organisms. Bacteria and other microorganisms are part of food chains in the soil. For example, important predators of soil microorganisms are nematode worms which are very tiny, about 1.0 mm in length.

4.1.3 Filtering food from the ocean

As you learned earlier, the oceans are rich in nutrients in the form of very small and microscopic organisms. A whole range of animals make a living by filtering the small organisms from the surrounding water. Professor Mimi Köehl describes the problems that filter feeders have and helps you to visualise them.

Video content is not available in this format.

Activity 2

In Week 3 you learnt about size and shape in relation to animals and temperature. Now, think about the size and shape of organisms that live in a fluid medium. !Warning! Calibri not supportedGive some examples of the particular problems that they encounter as a consequence of the physical properties of the fluid.

Provide your answer...

Answer

Water is more viscous than air. It is also denser. For small organisms the water is very sticky, so because of their size it is like living in honey rather than water. Single cell organisms that swim using a whip-like strand called a flagellum can't move by beating it backwards and forwards, but need to use a corkscrew motion, as described by Dr Tett in the video 'Investigating phytoplankton' (Section 4.1.1). You might also have thought of problems of buoyancy. Fins that provide lift, such as those of sharks, counteract the tendency for the body to sink as it is denser than water.

4.2 Analysing ecosystems – a summary

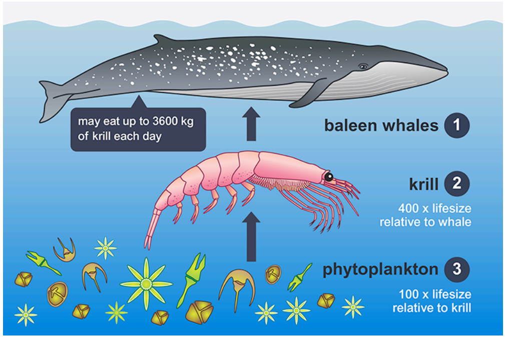

Figure 4

You have now looked at a range of ecosystems and the organisms that comprise them and it should be clear that you can study a system at a number of levels. At the top level is the flow of energy through the system. Sunlight drives photosynthesis and primary production, but also provides a source of heat energy that animals can utilise in raising body temperature or need to avoid in extreme habitats such as deserts.

The links between organisms in an ecosystem are most obvious in food chains, so in addition to describing a system in terms of energy flow, you can describe it in terms of links between plant, animals, fungi or bacteria.

The diversity of life in a particular system provides another level of analysis, where the physical properties of the habitats that make up the ecosystem have an influence on the adaptations that organisms have to survive there and the number of niches available. Some ecosystems encompass diversity hotspots, a term applied to Wicken Fen.

In the next two weeks you will be considering the impact of humans on different ecosystems and you will appreciate that in order to understand and conserve you need to know what life forms are part of the system you are dealing with. In the next activity you will be exploring the identification of animals, plants and fungi and the ecological links between species.

4.3 Identifying organisms

Identifying organisms inhabiting a particular ecosystem can be difficult. You are encouraged to do just that, using the iSpot website to help identification. Chris Packham introduces you to iSpot.

Video content is not available in this format.

Discovering the species of organism that inhabits a particular ecosystem is obviously a crucial stage in working out the interactions that form the food chains and routes of energy flow in ecosystems. Identification can be difficult but there are online resources available to help. In this practical activity you are encouraged to go and look at animals, plants or fungi in a habitat that is easily accessible to you, photograph them if you can, and use the iSpot website to get help in identification. You will need to register with the iSpot website, but registration is free.

Try and find four different organisms living in a habitat near you and suggest the place that they might occupy in an ecosystem. Ideally, for each you should take a photograph and upload it to iSpot. You will find instructions on how to do this in the iSpot guidance document.

If you live in a region of the world where the climate is seasonal, you could look for organisms that are characteristic of the season of the year.

The Great British Year poster covers the British seasons and suggests organisms to look out for each month.

For any observation that you upload you can see if an interaction with another species has been recorded. You can also record an interaction that you have observed. For example, a photo of a butterfly might be linked to a particular food plant. Using the interaction feature on iSpot enables you to begin to construct links within an ecosystem.

Be sure to tag your contribution as #oueco, so that you can connect with observations made by others on this course. Finally, contribute your observations to the discussion in the next step.

Figure 5

4.3.1 Ecosystems and diversity

Figure 6

This is an opportunity for you to share the links to and discuss your four iSpot observations and your deductions about their links with other organisms.

Go to the Week 4 forum and discuss the following questions:

- Are the four that you have observed linked to each other?
- Can you make any links to other people's observations?

4.4 Week 4 quiz

This quiz is about the smaller organisms at the base of food chains in simple and complex ecosystems.

Complete the Week 4 quiz now.

4.5 Summary of Week 4

Dr David Robinson, Senior Lecturer in Biological Science at The Open University, discusses what you have learned so far and what's coming next.

Video content is not available in this format.

In Weeks 3 and 4 we have considered ecosystems in three very different areas of the globe – deserts, the polar regions and the seas. Each area raised questions for you about how organisms function in different ecosystems and how they are adapted to the physical properties of their environment. You also learned about the need to identify organisms so that the nature of relationships within ecosystems can be evaluated.

In the next two weeks you will examine the impact that humans have on ecosystems, using examples from around the world.

If you would like a short break, or to find out more about studying with The Open University, take alook at our online prospectus.

You can now go to Week 5.

Week 5: Human impact

Introduction

Figure 1

How do humans affect ecosystems? Early humans were components of the ecosystem in which they evolved. Modern humans spread across a range of systems that differ from those in which the species originated.

Ecosystems satisfy our needs for food, water and shelter, but unfortunately, human activities inevitably have an impact and may disrupt many ecosystems, some of them permanently. Human impacts may alter the interactions that take place within an ecosystem, or affect the productivity of the system – or both.

Dr Mike Gillman and Dr Vince Gauci consider the consequences of human interference in well-balanced ecosystems.

Video content is not available in this format.

5.1 Managing or meddling

Video content is not available in this format.

Having a better understanding of how ecosystems function, and the energy flows through them, means that future damage and disruption can be limited.

Here are some questions raised by this video and the previous one. Make brief notes on possible answers in preparation for the discussion at the end of this week.

- Can you think of examples where ecosystems have been negatively affected by human activity, and where they have been managed and operated to benefit humans without damage to the system?
- How does damage to one ecosystem have an impact on another? Why are small changes so significant?
- Do you agree with the following assessment: ‘Some elements [of ecosystems] are crucial but there are some additional extras the system could survive without.’

5.2 Managing an ecosystem – the art of coppicing

Professor David Streeter mentioned management of woodland by coppicing in an earlier video.

Careful management of woodland can make a significant contribution to a local economy. Woodland that has been coppiced is a good example of a harvested, but sustainable, ecosystem. Watch this video in which Dr Janet Sumner shows how coppicing is done in managed woodland.

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5.3 The survival of Wicken Fen

We will now revisit Wicken Fen, Britain's oldest nature reserve. The reserve is being managed artificially, in order to support multiple habitats, and by extension multiple species and multiple food chains. Those working on the reserve believe that without management the fen would be overtaken by bushes and trees, which would reduce the number of habitats, and support fewer species.

Video content is not available in this format.

Is this a case where human intervention is a positive factor acting on the ecosystems present? Would you consider the fen to be an artificial ecosystem – one that would not exist but for human intervention? Here are some questions raised by this video. Make brief notes on possible answers in preparation for the discussion later.

- What are the factors contributing to high level of species diversity?
- What is the significance of Wicken Fen?
- What kind of ecosystems and habitats would result if Wicken Fen wasn't managed by humans?
- Does the need for biodiversity outweigh the need for natural succession?
- What kind of management tools are used to managed Wicken Fen?
- What would be the result if Wicken Fen was destroyed or lost?

Contributors to this video include David Gowing (OU), Joanna Freeland (OU), Adrian Calston (Property Manager, Wicken Fen), Carol Laidlaw (Warden, Wicken Fen), Martin Lester (Head Warden, Wicken Fen).

5.4 Conserving a rare species

The fen-raft spider (*Dolomedes plantarius*) was only discovered in the UK in 1956. It is very rare and its distribution prior to 1956 is not known. This throws up some interesting questions about a re-introduction programme, since the habitats into which spiders are released may – or may not – have originally had the spider in.

Think about the implications, before watching the next video and learning more about the re-introduction programme.

Habitat restoration and managed re-introduction are two techniques that are key to conserving individual species. The fen-raft spider is an endangered species, as Dr Helen Smith and Chris Sperring explain in the video.

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Activity 1

What is the significance of joined-up habitats in a conservation programme?

Provide your answer...

Answer

Connecting back together a lot of habitats can create huge areas for wildlife. So introducing species at one site, and other nearby sites, is like laying stepping stones to start to create a much bigger joined-up population and to utilise a larger network. In highly developed countries land becomes fragmented so corridors that link conservation areas are crucial to maintaining diversity. If the climate changes, such corridors can provide migration routes to, for example, cooler habitats.

You can find out more about the fen raft spider online.

Figure 2 The fen raft spider (*Dolomedes plantarius*)

5.5 Week 5 quiz

This quiz is about the human impact on ecosystems and the effects of ecosystem management.

Complete the Week 5 quiz now.

5.6 Human influences on ecosystems

Figure 3

Here are some of the questions that you have been considering this week.

- Can you think of examples where ecosystems have been negatively affected by human activity, and where they have been managed and operated to benefit humans without damage to the system?
- How does damage to one ecosystem have an impact on another? Why are small changes so significant?
- Do you agree with the following assessment: 'Some elements [of ecosystems] are crucial but there are some additional extras the system could survive without.'
- What are the factors contributing to high level of species diversity and does the need for biodiversity outweigh the need for natural succession?
- What is the significance of Wicken Fen? What kind of ecosystems and habitats would result if it wasn't managed by humans? What would be the result if Wicken Fen was destroyed or lost?

As you consider the questions, you might like to explore the topics covered this week in the Ecosystems area on OpenLearn.

Use your answers to these questions to discuss the advantages and disadvantages of management of ecosystems in the Week 5 forum.

You will continue to explore the impact of humans on the environment in Week 6.

Week 6: Fragile ecosystems

Introduction

Figure 1

We bring the last five weeks together, looking at issues of large scale management and conservation, concluding with a study of the Galápagos archipelago World Heritage Site.

6.1 Gorillas and tourism

Bwindi Impenetrable National Park in Uganda was formed in an attempt to protect the jungle in the area, one of Africa's richest ecosystems, from human activities. Initially it was preserved in a hostile way, with local residents forcibly evicted and barred from future entry into the park. This sparked angry protest from local communities, and there were violent clashes as a result.

An integrated conservation development programme was conceived to protect the area without alienating local communities, who had been dependent on the resources available in the forests and jungle for their livelihood.

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Contributors to this video include G. Kalema-Zikusoka, T. Yese, C. Bwiza, J. Byamukama, M. Mapesa.

The crucial point of the development programme was to involve communities in the increased tourist interest in the park and its gorilla population.

As you watch the next film, reflect on why the Bwindi Park was established, and how this affected the local population. What difference has the establishment of the park made to the ecosystems there? Consider whether the economic activities around the park make enough of a difference to the local communities around the park

Video content is not available in this format.

Join the Week 6 forum and discuss the problems faced by the Bwindi Inpenetrable National Park in conserving their population of gorillas. Are there any general conclusions that can be drawn from the gorillas that can be applied to the conservation of other species?

Figure 2

6.2 China’s Loess Plateau

China’s Loess Plateau is a region that stretches for 640,000 square kilometres across north central China. It is an example of an ecosystem that has been ravaged by human activities, such as agriculture.

Video content is not available in this format.

Contributors to this video include John D Liu.

The hills and valleys of China’s Loess Plateau eroded because grazing domestic animals denuded them of vegetation. Valuable soil was washed away into the nearby Yellow River, leaving the plateau unfertile.

The rehabilitation of the plateau has been a slow and arduous task. As you watch the next video think about the following questions:

- What were the activities that resulted in the destruction of the Loess Plateau?
- What actions were taken to restore the plateau?

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Activity 1

How can the destruction and rehabilitation of the Loess Plateau be understood in terms of an ecosystem?

Write some notes in the box below.

Provide your answer...

Answer

The Loess Plateau can be considered as a discrete ecosystem. As it became over-exploited the flow of energy through the food chains within the ecosystem changed and reduced. Unless the primary flow of energy from sunlight into plant material for consumers is maintained, the ecosystem will change in character and, as in the case of the Loess Plateau, parts can become almost barren. Several thousand years of human agriculture denuded the hills and valleys of vegetation. Domestic animals fed on vegetation and there was no chance for young trees and shrubs to grow. Rain no longer seeped into the ground but washed down the sides of the hills carrying away soil. Thus the primary route for energy to enter the ecosystem disappeared.

6.3 Galápagos

Figure 3

The Galápagos archipelago is a unique ecosystem with a diverse collection of island habitats. It is a World Heritage Site and many of the plant and animal species are found nowhere else. The islands also have historical significance in the development of biological science, following the visit by Charles Darwin in 1835. The islands had a profound influence on his ideas about species formation, which culminated in his book *On the origin of species by means of natural selection* (1857).

The islands have been the focus of scientific research for many years, but the conservation problems are substantial. This week the course will feature a series of video portraits about the archipelago. This series of portraits of the islands highlights the biodiversity found there, the problems of invasive species, the value of the islands for research and the problems of maintaining a flourishing ecosystem. As you watch the videos, think about these questions and take notes that will help you to answer them.

- Bearing in mind the definition of an ecosystem that you encountered at the start of this journey, is it reasonable to regard the whole archipelago as an ecosystem?
- What tensions arise between keeping the islands pristine, allowing visitors and allowing colonisation from the mainland?
- What major threats to the integrity of the habitats on Galápagos can you identify? Are they peculiar to the islands or applicable to ecosystems in general?

6.3.1 Darwin's arrival on the Galápagos Islands

Although it is possible to follow in Darwin's footsteps, as Dr David Robinson demonstrates in this video, the habitat has changed substantially as a consequence of the introduction of alien animals in the past. There are very few of the larger islands where you can see ecosystems unaffected by alien introductions and thus see them as Darwin saw them.

Video content is not available in this format.

The finches that Darwin brought back from the Galápagos hold a special place in the history of the development of the theory of evolution by means of natural selection. There are 13 species and they occupy different niches in the habitats on the islands.

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6.3.2 Darwin's thoughts on the iguanas

The marine iguanas of the Galápagos are the only marine lizards and occur nowhere else. They occupy a fragile ecosystem that is very vulnerable to changes in sea temperature. There is also a species of land iguana on the islands.

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Activity 2

Why, do you think, is the marine iguana so vulnerable to sea temperature changes? What impacts of environmental change might make the land iguana vulnerable?

Provide your answer...

Answer

The marine iguana feeds exclusively on a small number of species of seaweed. The seaweed needs relatively cool water and in some years, when the ocean currents reverse, the seas around the islands get too warm for the seaweed and it dies back. The marine iguanas then have no food and die in large numbers. Any prolonged warming of the seas would make the species highly vulnerable to extinction. Land iguanas get most of their water from prickly pear cacti and the rest from rain fall. Any prolonged period without rain due to changes in climate put land iguanas at risk.

6.3.2 Invasive alien species

The tortoises that gave the Galápagos islands their name are now threatened by alien introductions. Goats have been a particular problem, but slowly the populations have been brought under control. The habitat, the wariness of goats and remoteness of the islands make eradicating goats a very expensive proposition.

Video content is not available in this format.

Like the animals on the Galápagos, much of the flora of the islands is also vulnerable to the impacts of introduced alien species. In recent years around 500 species have been introduced. Amongst the most devastating has been the red quinine tree.

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6.3.3 Galápagos research and human effects

Most of the animals and birds on the islands have no fear of humans, which is one of a number of reasons why the islands are such an attractive place to carry out research.

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This video highlights the pressures of increasing tourism and increasing population. Since the video was made, an area of land close to Puerto Ayora, the main town on Santa Cruz, has been set aside for 1200 new houses, which will double the size of the town.

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6.3.4 A fragile ecosystem

Figure 4

Before you started watching this week's videos about the Galápagos you were asked to consider three questions. You should now be able to answers them and set them in the context of your overall study of ecosystems.

Activity 3

Answer the questions in the box below.

- Bearing in mind the definition of an ecosystem that you encountered at the start of this journey, is it reasonable to regard the whole archipelago as an ecosystem?
- What tensions arise between keeping the islands pristine, allowing visitors and allowing colonisation from the mainland?
- What major threats to the integrity of the habitats on Galápagos can you identify? Are they peculiar to the islands or applicable to ecosystems in general?

Provide your answer...

Answer

The islands are probably best regarded as individual ecosystems but the marine environment around the islands might be considered as a single, separate, ecosystem. As you learnt earlier, the physical boundaries of an ecosystem are influenced by the definition that you adopt and it would be possible to argue that for a definition in terms of energy flow, the whole archipelago is a single ecosystem.

Keeping the remaining pristine islands in pristine condition can be done by not allowing access, but it is difficult to prevent humans landing on islands and patrols to keep intruders at bay would themselves compromise the pristine nature of the islands. Another factor to consider is the money that visitors bring. Would they be so keen to contribute money if they couldn't visit?

The threats to the integrity of the habitats fall into three broad categories. Human activity and population growth is an obvious one that effects the islands and it is a global factor. Alien introductions of plants and animals have wrought havoc in the past and can do so in the future. They are a risk to all ecosystems but the Galápagos are particularly vulnerable. Finally, global climate changes or volcanic activity could change the habitats on the islands.

6.4 End of course quiz

This is a longer quiz so you can check your understanding of the whole course.

Take the end of course quiz now.

6.5 Conclusion

Dr David Robinson, Lead Educator and Senior Lecturer in Biological Science at The Open University, discusses and summarises the contents of this course, and the skills and knowledge you will have gained from it.

Your journey has taken you to a variety of places, from Wicken Fen in Britain to the Bwindi Impenetrable National Park in Africa; from the Loess Plateau in China to the Pacific Islands of the Galápagos. These places have shown you a variety of different ecosystems, but there are two common themes: conservation and restoration. Neither of these activities can be undertaken without a very clear understanding of the ecosystems themselves.

At the start of this course three over-arching questions were posed. You should now be able to answer those questions.

'What is the importance of understanding ecosystems, how do they work and how crucial is their conservation?'

Video content is not available in this format.

6.6 Beyond ecosystems

Figure 5

Well done for completing *Introduction to ecosystems*. If you have studied the full course and completed all the quizzes you will receive a Statement of Participation certificate as a record of your achievement. You can access and print it from your MyOpenLearn profile.

!Warning! inherit not supportedIf you would like to learn more about natural history in general, here are some possibilities:

Explore OpenLearn further:

- Ecosystems: Taking it further
- Woodlands – in our Neighbourhood Nature unit
- Polar regions – using our Frozen Planet interactive
- The Galápagos World Heritage Site – by listening to our podcasts

Continue your membership of the iSpot community and contribute your observations at www.ispotnature.org/.

Contribute to the UK national map of trees at !Warning! inherit not supportedtreezilla.

Good luck with your learning.

Now you've completed the course we would again appreciate a few minutes of your time to tell us a bit about your experience of studying it and what you plan to do next. We will use this information to provide better online experiences for all our learners and to share our findings with others. If you'd like to help, please fill in this optional survey

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