5.3 Classification of biodiversity

Understanding

- The binomial system of names for species is universal among biologists and has been agreed and developed at a series of congresses.
- When species are discovered they are given scientific names using the binomial system.
- Taxonomists classify species using a hierarchy of taxa.
- All organisms are classified into three domains.
- The principal taxa for classifying eukaryotes are kingdom, phylum, class, order, family, genus and species.
- In a natural classification the genus and accompanying higher taxa consist of all the species that have evolved from one common ancestral species.
- Taxonomists sometimes reclassify groups of species when new evidence shows that a previous taxon contains species that have evolved from different ancestral species.
- Natural classifications help in identification of species and allow the prediction of characteristics shared by species within a group.

Applications

- Classification of one plant and one animal species from domain to species level.
- External recognition features of bryophytes, filicinophytes, coniferophytes and angiospermophytes.
- Recognition features of porifera, cnidaria, platyhelminthes, annelida, mollusca and arthropoda, chordata.
- Recognition of features of birds, mammals, amphibians, reptiles and fish.

Skills

- Construction of dichotomous keys for use in identifying specimens.

Nature of science

- Cooperation and collaboration between groups of scientists: scientists use the binomial system to identify a species rather than the many different local names.

International cooperation and classification

Cooperation and collaboration between groups of scientists: scientists use the binomial system to identify a species rather than the many different local names.

Recognizable groups of organisms are known to biologists as species. The same species can have many different local names, even within one language. For example, in England the species of plant known to scientists as *Arum maculatum* has been called lords-and-ladies, cuckoo-pint, jack in the pulpit, devils and angels, cows and bulls, willy lily and snake's meat. In French there is also a variety of local names: la chandelle, le pied-de-veau, le manteau de la Sainte-Vierge, la pilette or la vachotte. In Spanish there are even more names for this one species of which these are just a few: comida de culebra, alcatrax, barba de arón, dragontia menor, hojas de fuego, vela del diablo and yerba del quemado. The name primaveras is used for *Arum maculatum* in Spanish but for a different plant in other languages.

Local names may be a valuable part of the culture of an area, but science is an international venture so scientific names are needed that are understood throughout the world. The binomial system that has developed is a good example of cooperation and collaboration between scientists.

The credit for devising our modern system of naming species is given to the Swedish biologist Carl Linnaeus who introduced a system of two-part names in the 18th century. This stroke of genius was the basis for the binomial system that is still in use today. In fact Linnaeus was mirroring a style of nomenclature that had been used in many languages before. The style recognizes that there are groups of similar species, so the name for each species in a group consists of a specific name attached to the group name, as in the Ancient Greek αδιαυτου το λευκον and αδιαυτου το μεαυ (used by Threophrastus), Latin *anagallis mas* and *anagallis femina* (used by Pliny), German weiss Seeblumen and geel Seeblumen (used by Fuchs), English wild mynte and water mynte (used by Turner) and Malayan jambu bol and jambu chilli (applied by Malays to different species of *Eugenia*).

▲ Figure 1 *Arum maculatum*

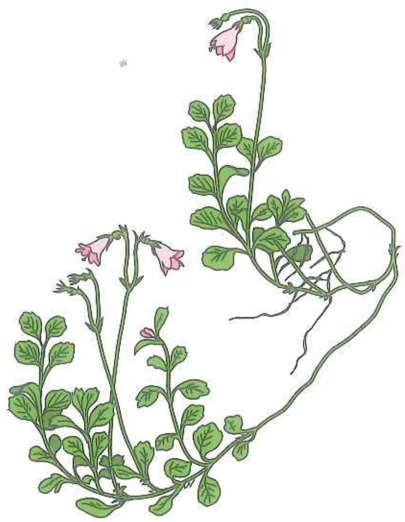
Development of the binomial system

The binomial system of names for species is universal among biologists and has been agreed and developed at a series of congresses.

To ensure that all biologists use the same system of names for living organisms, congresses attended by delegates from around the world are held at regular intervals. There are separate congresses for animals and for plants and fungi.

International Botanical Congresses (IBC) were held every year during the late 19th century. The IBC held in Genoa in 1892 proposed that 1753 be taken as the starting point for both genera and species of plants and fungi as this was the year when Linnaeus published *Species Plantarum*, the book that gave consistent binomials for all species of the plant kingdom then known. The IBC of Vienna in 1905 accepted by 150 votes to 19 the rule that "La nomenclature botanique commence avec Linné, *Species Plantarum* (ann. 1753) pour les groupes de plantes vasculaires." The 19th IBC will be in Shenzhen, China, in 2017.

The first International Zoological Congress was held in Paris in 1889. It was recognized that internationally accepted rules for naming and classifying animal species were needed and these were agreed at this and subsequent congresses. 1758 was chosen as the starting date for valid names of animal species as this was when Linnaeus published *Systema Natura* in which he gave binomials for all species known then. The current International Code for Zoological Nomenclature is the 4th edition and there will no doubt be more editions in the future as scientists refine the methods that they use for naming species.



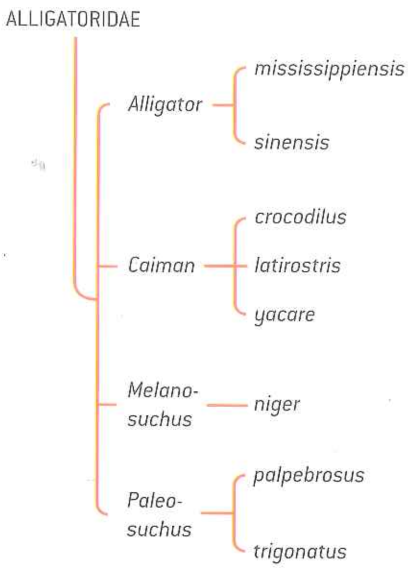
▲ Figure 2 *Linnaea borealis*. Binomials are often chosen to honour a biologist, or to describe a feature of the organism. *Linnaea borealis* is named in honour of Carl Linnaeus, the Swedish biologist who introduced the binomial system of nomenclature and named many plants and animals using it

The binomial system

When species are discovered they are given scientific names using the binomial system.

The system that biologists use is called binomial nomenclature, because the international name of a species consists of two words. An example is *Linnaea borealis* (figure 2). The first name is the genus name. A genus is a group of species that share certain characteristics. The second name is the species or specific name. There are various rules about binomial nomenclature:

- The genus name begins with an upper-case (capital) letter and the species name with a lower-case (small) letter.
- In typed or printed text, a binomial is shown in italics.
- After a binomial has been used once in a piece of text, it can be abbreviated to the initial letter of the genus name with the full species name, for example: *L. borealis*.
- The earliest published name for a species, from 1753 onwards for plants or 1758 for animals, is the correct one.



▲ Figure 3 Classification of the alligator family

The hierarchy of taxa

Taxonomists classify species using a hierarchy of taxa.

The word taxon is Greek and means a group of something. The plural is taxa. In biology, species are arranged or classified into taxa. Every species is classified into a genus. Genera are grouped into families. An example of the genera and species in a family is shown in figure 3. Families are grouped into orders, orders into classes and so on up to the level of kingdom or domain. The taxa form a hierarchy, as each taxon includes taxa from the level below. Going up the hierarchy, the taxa include larger and larger numbers of species, which share fewer and fewer features.

The three domains

All organisms are classified into three domains.

Traditional classification systems have recognized two major categories of organisms based on cell types: eukaryotes and prokaryotes. This classification is now regarded as inappropriate because the prokaryotes have been found to be very diverse. In particular, when the base sequence of ribosomal RNA was determined, it became apparent that there are two distinct groups of prokaryotes. They were given the names Eubacteria and Archaea.

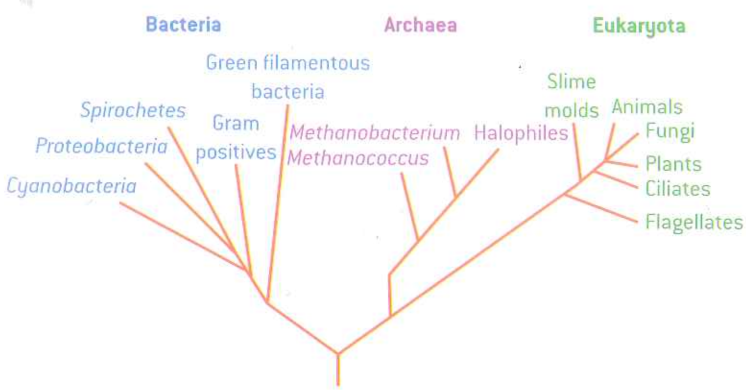
Most classification systems therefore now recognize three major categories of organism, Eubacteria, Archaea and Eukaryota. These categories are called domains, so all organisms are classified into three domains. Table 1 shows some of the features that can be used to distinguish between them. Members of the domains are usually referred to as bacteria, archaeans and eukaryotes. Bacteria and eukaryotes are relatively familiar to most biologists but archaeans are often less well known.

Feature	Domain		
	Bacteria	Archaea	Eukaryota
Histones associated with DNA	Absent	Proteins similar to histones bound to DNA	Present
Presence of introns	Rare or absent	Present in some genes	Frequent
Structure of cell walls	Made of chemical called peptidoglycan	Not made of peptidoglycan	Not made of peptidoglycan; not always present
Cell membrane differences	Glycerol-ester lipids; unbranched side chains; d-form of glycerol	Glycerol-ether lipids; unbranched side chains; l-form of glycerol	Glycerol-ester lipids; unbranched side chains; d-form of glycerol

▲ Table 1

Archaeans are found in a broad range of habitats such as the ocean surface, deep ocean sediments and even oil deposits far below the surface of the Earth. They are also found in some fairly extreme habitats such as water with very high salt concentrations or temperatures close to boiling. The methanogens are obligate anaerobes and give off methane as a waste product of their metabolism. Methanogens live in the intestines of cattle and the guts of termites and are responsible for the production of "marsh gas" in marshes.

Viruses are not classified in any of the three domains. Although they have genes coding for proteins using the same genetic code as living organisms they have too few of the characteristics of life to be regarded as living organisms.



▲ Figure 4 Tree diagram showing relationships between living organisms based on base sequences of ribosomal RNA

Eukaryote classification

The principal taxa for classifying eukaryotes are kingdom, phylum, class, order, family, genus and species.

Eukaryotes are classified into kingdoms. Each kingdom is divided up into phyla, which are divided into classes, then orders, families and genera. The hierarchy of taxa for classifying eukaryotes is thus kingdom, phylum, class, order, family, genus and species.

Most biologists recognize four kingdoms of eukaryote: plants, animals, fungi and protoctista. The last of these is the most controversial as protoctists are very diverse and should be divided up into more kingdoms. At present there is no consensus on how this should be done.

Activity

Identifying a kingdom

This is a definition of the characteristics of organisms in one of the kingdoms. Can you deduce which kingdom it is?

Multicellular; cells typically held together by intercellular junctions; extracellular matrix with fibrous proteins, typically collagens, between two dissimilar epithelia; sexual with production of an egg cell that is fertilized by a smaller, often monociliated, sperm cell; phagotrophic and osmotrophic; without cell wall.

▲ Figure 5 Brown seaweeds have been classified in the kingdom Protoctista

Examples of classification

Classification of one plant and one animal species from domain to species level.

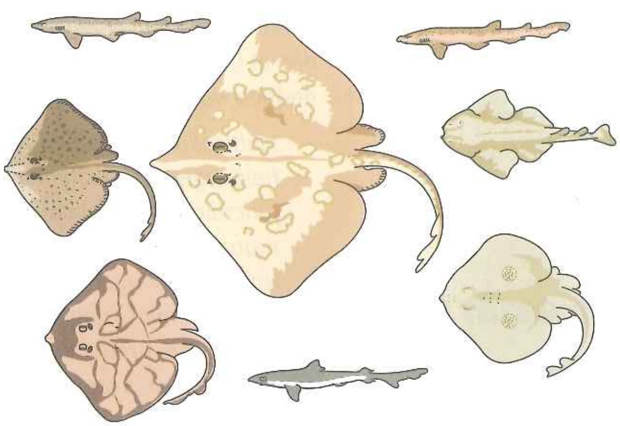
Animals and plants are kingdoms of the domain Eukaryota. Table 2 shows the classification of one plant and one animal species from kingdom down to species.

Taxon	Grey wolf	Date palm
Kingdom	Animalia	Plantae
Phylum	Chordata	Angiospermophyta
Class	Mammalia	Monocotyledoneae
Order	Carnivora	Palmales
Family	Canidae	Arecaceae
Genus	*Canis*	*Phoenix*
Species	*lupus*	*dactylifera*

▲ Table 2

Data-based questions: Classifying cartilaginous fish

All the fish shown in figure 6 are in the class Chondrichthyes. They are the most frequently found fish in this class in north-west Europe.



▲ Figure 6 Cartilaginous fish in seas in north-west Europe

1 State the kingdom to which all of the species in figure 6 belong. [1]

2 a) Four of the fish in figure 6 are classified in the same genus. Deduce which these fish are. [1]

b) Deduce with a reason whether these four fish are in:

(i) the same or different species [2]

(ii) the same or different families. [2]

c) State two characteristics of these four fish that are not possessed by the other four fish. [2]

3 The other four fish are classified into two orders. Deduce, with a reason, how the four fish are split into two orders. [2]

Natural classification

In a natural classification, the genus and accompanying higher taxa consist of all the species that have evolved from one common ancestral species.

Scientific consensus is to classify species in a way that most closely follows the way in which species evolved. Following this convention, all members of a genus or higher taxon should have a common ancestor. This is called a natural classification. Because of the common ancestry we can expect the members of a natural group to share many characteristics.

An example of an unnatural or artificial classification would be one in which birds, bats and insects are grouped together, because they all fly. Flight evolved separately in these groups and as they do not share a common ancestor they differ in many ways. It would not be appropriate to classify them together other than to place them all in the animal kingdom and both birds and bats in the phylum Chordata. Plants and fungi were at one time classified together, presumably because they have cell walls and do not move, but this is an artificial classification as their cell walls evolved separately and molecular research shows that they are no more similar to each other than to animals.

It is not always clear which groups of species do share a common ancestor, so natural classification can be problematic. Convergent evolution can make distantly related organisms appear superficially similar and adaptive radiation can make closely related organisms appear different. In the past, natural classification was attempted by looking at as many visible characteristics as possible, but new molecular methods have been introduced and these have caused significant changes to the classification of some groups. More details of this are given later, in sub-topic 5.4.

TOK

What factors influence the development of a scientific consensus?

Carl Linnaeus's 1753 book *Species Plantarum* introduced consistent two-part names (binomials) for all species of the vegetable kingdom then known. Thus the binomial *Physalis angulata* replaced the obsolete phrase-name, *Physalis annua ramosissima, ramis angulosis glabris, foliis dentato-serratis*. Linnaeus brought the scientific nomenclature of plants back to the simplicity and brevity of the vernacular nomenclature out of which it had grown. Folk-names for species rarely exceed three words. In groups of species alike enough to have a vernacular group-name, the species are often distinguished by a single name attached to the group-name, as in the Ancient Greek αδιαυτου το λευκον and αδιαυτου το μεαυ (used by Threophrastus), Latin anagallis mas and anagallis femina (used by Pliny), German weiss Seeblumen and geel Seeblumen (used by Fuchs), English wild mynte and water mynte (used by Turner) and Malayan jambu bol and jambu chilli (applied by Malays to different species of *Eugenia*).

The International Botanical Congress held in Genoa in 1892 proposed that 1753 be taken as the starting point for both genera and species. This was incorporated in the American "Rochester Code" of 1883 and in the code used at the Berlin Botaniches Museum and supported by British Museum of Natural History, Harvard University botanists and a group of Swiss and Belgian botanists. The International Botanical Congress of Vienna in 1905 accepted by 150 votes to 19 the rule that "La nomenclature botanique commence avec Linné, Species Plantarum (ann. 1753) pour les groupes de plantes vasculaires."

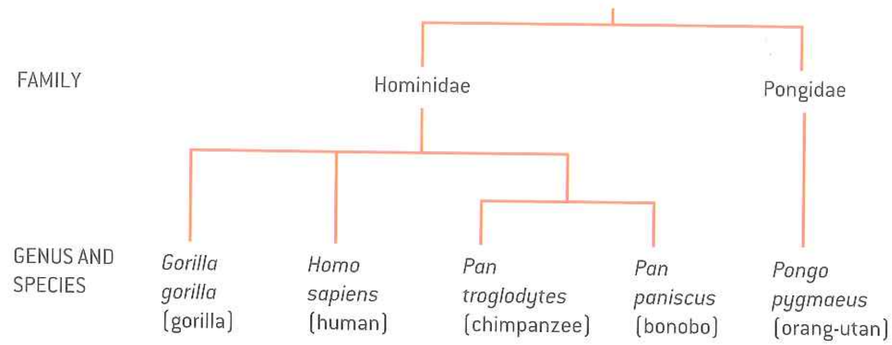
1 Why was Linnaeus's system for naming plants adopted as the international system, rather than any other system?
2 Why do the international rules of nomenclature state that genus and species names must be in Ancient Greek or Latin?
3 Making decisions by voting is rather unusual in science. Why is it done at International Botanical Congresses? What knowledge issues are associated with this method of decision making?

Reviewing classification

Taxonomists sometimes reclassify groups of species when new evidence shows that a previous taxon contains species that have evolved from different ancestral species.

Sometimes new evidence shows that members of a group do not share a common ancestor, so the group should be split up into two or more taxa. Conversely species classified in different taxa are sometimes found to be closely related, so two or more taxa are united, or species are moved from one genus to another or between higher taxa.

The classification of humans has caused more controversy than any other species. Using standard taxonomic procedures, humans are assigned to the order Primates and the family Hominidae. There has been much debate about which, if any, of the great apes to include in this family. Originally all the great apes were placed in another family, the Pongidae, but research has shown that chimpanzees and gorillas are closer to humans than to orang-utans and so should be in the same family. This would just leave orang-utans in the Pongidae. Most evidence suggests that chimpanzees are closer than gorillas to humans, so if humans and chimpanzees are placed in different genera, gorillas should also be in a separate genus. A summary of this scheme for human classification is shown in figure 7.



▲ Figure 7 Classification of humans

Advantages of natural classification

Natural classifications help in identification of species and allow the prediction of characteristics shared by species within a group.

There is great interest at the moment in the biodiversity of the world. Groups of biologists are surveying areas where little research has been done before, to find out what species are present. Even in well-known parts of the world new species are sometimes discovered. Natural classification of species is very helpful in research into biodiversity. It has two specific advantages.

1 Identification of species is easier. If a specimen of an organism is found and it is not obvious what species it is, the specimen can be identified by assigning it first to its kingdom, then the phylum within the kingdom, class within the phylum and so on down to species level. Dichotomous keys can be used to help with this process. This process would not work so well with an artificial classification. For example, if flowering plants were classified according to flower colour and a white-flowered bluebell *Hyacinthoides non-scripta* was discovered, it would not be identified correctly as the species normally has blue flowers.

2 Because all of the members of a group in a natural classification have evolved from a common ancestral species, they inherit similar characteristics. This allows prediction of the characteristics of species within a group. For example, if a chemical that is useful as a drug is found in one plant in a genus, this or related chemicals are likely to be found in other species in the genus. If a new species of bat was discovered, we could make many predictions about it with reasonable certainty that they are correct: the bat will have hair, mammary glands, a placenta, a four-chambered heart and many other mammalian features. None of these predictions could be made if bats were classified artificially with all other flying organisms.

▲ Figure 8 Members of the Hominidae and Pongidae

Activity

Controlling potato blight

Phytophthora infestans, the organism that causes the disease potato blight, has hyphae and was classified as a fungus, but molecular biology has shown that it is not a true fungus and should be classified in a different kingdom, possibly the Protoctista. Potato blight has proved to be a difficult disease to control using fungicides. Discuss reasons for this.

Dichotomous keys

Construction of dichotomous keys for use in identifying specimens

Dichotomous keys are often constructed to use for identifying species within a group. A dichotomy is a division into two; a dichotomous key consists of a numbered series of pairs of descriptions. One of these should clearly match the species and the other should clearly be wrong. The features that the designer of the key chooses to use in the descriptions should therefore be reliable and easily visible. Each of the pair of descriptions leads either to another of the numbered pairs of descriptions in the key, or to an identification.

An example of a key is shown in table 3. We can use it to identify the species in figure 9. In the first stage of the key, we must decide if hind limbs are visible. They are not, so we are directed to stage 6 of the key. We must now decide if the species has a blowhole. It does not, so it is a dugong or a manatee. A fuller key would have another stage to separate dugongs and manatees.

1	Fore and hind limbs visible, can emerge on land	2
	Only fore limbs visible, cannot live on land	6
2	Fore and hind limbs have paws	3
	Fore and hind limbs have flippers	4
3	Fur is dark	sea otters
	Fur is white	polar bears
4	External ear flap visible	sea lions and fur seals
	No external ear flap	5
5	Two long tusks	walruses
	No tusks	true seals
6	Mouth breathing, no blowhole	dugongs and manatees
	Breathing through blowholes	7
7	Two blowholes, no teeth	baleen whales
	One blowhole, teeth	dolphins, porpoises and whales

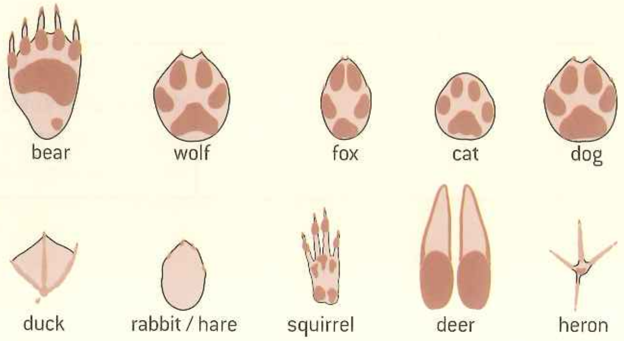
▲ Table 3 Key to groups of marine mammals

Activity

Constructing dichotomous keys

Keys are usually designed for use in a particular area. All the groups or species that are found in that area can be identified using the key. There may be a group of organisms in your area for which a key has never been designed.

- You could design a key to the trees in the local forest or on your school campus, using leaf descriptions or bark descriptions.
- You could design a key to birds that visit bird-feeding stations in your area.
- You could design a key to the invertebrates that are associated with one particular plant species.
- You could design a key to the footprints of mammals and birds (figure 10). They are all right front footprints and are not shown to scale.



▲ Figure 10 Footprints of mammals and birds

▲ Figure 9 Manatee

Plants

External recognition features of bryophytes, filicinophytes, coniferophytes and angiospermophytes.

All plants are classified together in one kingdom. In the life cycle of every plant, male and female gametes are formed and fuse together. The zygote formed develops into an embryo. The way in which this embryo develops depends on the type of plant it is. The different types of plants are put into phyla.

Most plants are in one of four phyla, but there are other smaller phyla. The *Ginkgo biloba* tree for example is in one of the smaller phyla. The four main plant phyla are:

- Bryophyta – mosses, liverworts and hornworts
- Filicinophyta – ferns
- Coniferophyta – conifers
- Angiospermophyta – flowering plants.

The external recognition features of these phyla are shown in table 4.

	Bryophyta	Filicinophyta	Coniferophyta	Angiospermophyta
Vegetative organs – parts of the plant concerned with growth rather than reproduction	Rhizoids but no true roots. Some with simple stems and leaves; others have only a thallus	Roots, stems and leaves are usually present		
Vascular tissue – tissues with tubular structures used for transport within the plant	No xylem or phloem	Xylem and phloem are both present		
Cambium – cells between xylem and phloem that can produce more of these tissues	No cambium; no true trees and shrubs		Present in conifers and most angiosperms, allowing secondary thickening of stems and roots and development of plants into trees and shrubs	
Pollen – small structures containing male gametes that are dispersed	Pollen is not produced		Pollen is produced in male cones	Pollen is produced by anthers in flowers
Ovules – contains a female gamete and develops into a seed after fertilization	No ovaries or ovules		Ovules are produced in female cones	Ovules are enclosed inside ovaries in flowers
Seeds – dispersible unit consisting of an embryo plant and food reserves, inside a seed coat	No seeds		Seeds are produced and dispersed	
Fruits – seeds together with a fruit wall developed from the ovary wall	No fruits			Fruits produced for dispersal of seeds by mechanical, wind or animal methods

▲ Table 4

Animal phyla

Recognition features of porifera, cnidaria, platyhelminthes, annelida, mollusca and arthropoda, chordata.

Animals are divided up into over 30 phyla, based on their characteristics. Six phyla are featured in table 5. Two examples of each are shown in figure 11.

Phylum	Mouth/anus	Symmetry	Skeleton	Other external recognition features
Porifera – fan sponges, cup sponges, tube sponges, glass sponges	No mouth or anus	None	Internal spicules (sketetal needles)	Many pores over the surface through which water is drawn in for filter feeding. Very varied shapes
Cnidaria – hydras, jellyfish, corals, sea anemones	Mouth only	Radial	Soft, but hard corals secrete $CaCO_3$	Tentacles arranged in rings around the mouth, with stinging cells. Polyps or medusae (jellyfish)
Platyhelminthes – flatworms, flukes, tapeworms	Mouth only	Bilateral	Soft, with no skeleton	Flat and thin bodies in the shape of a ribbon. No blood system or system for gas exchange
Mollusca – bivalves, gastropods, snails, chitons, squid, octopus	Mouth and anus	Bilateral	Most have shell made of $CaCO_3$	A fold in the body wall called the mantle secretes the shell. A hard rasping radula is used for feeding
Annelida – marine bristleworms, oligochaetes, leeches	Mouth and anus	Bilateral	Internal cavity with fluid under pressure	Bodies made up of many ring-shaped segments, often with bristles. Blood vessels often visible
Arthropoda – insects, arachnids, crustaceans, myriapods	Mouth and anus	Bilateral	External skeleton made of plates of chitin	Segmented bodies and legs or other appendages with joints between the sections

▲ Table 5 Characteristics of six animal phyla

1 Study the organisms shown in figure 11 and assign each one to its phylum. [7]

2 List the organisms that are:

a) bilaterally symmetric

b) radially symmetric

c) not symmetrical in their structure. [3]

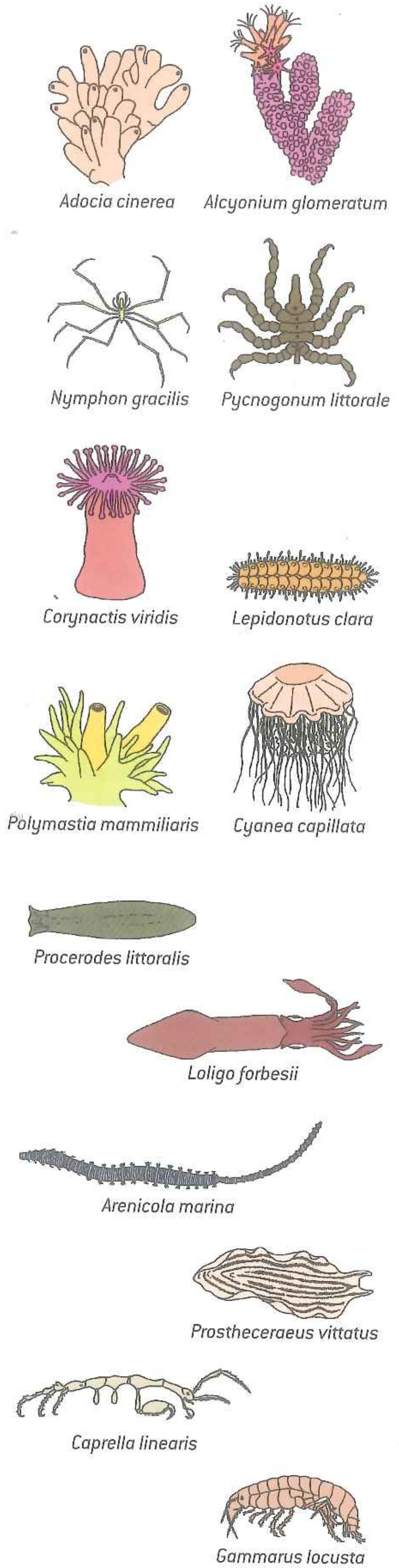
3 List the organisms that have:

a) jointed appendages

b) stinging tentacles

c) bristles. [3]

4 List the organisms that filter feed by pumping water through tubes inside their bodies. [2]



▲ Figure 11 Invertebrate diversity

Vertebrates

Recognition of features of birds, mammals, amphibians, reptiles and fish.

Most species of chordate belong to one of five major classes, each of which contains more than a thousand species. Although the numbers are not certain and new species are still sometimes discovered, there are about 10,000 bird species, 9,000 reptiles, 6,000 amphibians and 5,700 mammals. All of these classes are outnumbered by the ray-finned bony fish, with more than 30,000 species. The recognition features of the five largest classes of chordate are shown in table 6. All of the organisms are vertebrates, because they have a backbone composed of vertebrae.

Bony ray-finned fish	Amphibians	Reptiles	Birds	Mammals
Scales which are bony plates in the skin	Soft moist skin permeable to water and gases	Impermeable skin covered in scales of keratin	Skin with feathers made of keratin	Skin has follicles with hair made of keratin
Gills covered by an operculum, with one gill slit	Simple lungs with small folds and moist skin for gas exchange	Lungs with extensive folding to increase the surface area	Lungs with para-bronchial tubes, ventilated using air sacs	Lungs with alveoli, ventilated using ribs and a diaphragm
No limbs	Tetrapods with pentadactyl limbs			
Fins supported by rays	Four legs when adult	Four legs (in most species)	Two legs and two wings	Four legs in most (or two legs and two wings/arms)
Eggs and sperm released for external fertilization		Sperm passed into the female for internal fertilization		
Remain in water throughout their life cycle	Larval stage that lives in water and adult that usually lives on land	Female lays eggs with soft shells	Female lays eggs with hard shells	Most give birth to live young and all feed young with milk from mammary glands
Swim bladder containing gas for buoyancy	Eggs coated in protective jelly	Teeth all of one type, with no living parts	Beak but no teeth	Teeth of different types with a living core
Do not maintain constant body temperature			Maintain constant body temperature	

▲ Table 6