UNIT 3 ANIMAL TIMING BEHAVIOUR

Learning Outcomes:

- ☐ describe the regular changes and cycles in the physical environment
- ☐ define key terms such as diurnal, crepuscular, phase shift, zeitgeber
- ☐ explain how endogenous and exogenous biological rhythms differ
- ☐ discuss the mechanism and importance of biological clocks and their role in allowing animals to be prepared for future events
- ☐ describe examples of human and other animal biorhythms and explain their biological significance.

Barnacles in the intertidal area use the limbs to filter food when the tide is ir

EARTH'S RHYTHMS

- The yearly orbit of Earth about the sun together with the tilt of its axis cause the seasons. The contrast between seasons generally increases with increasing latitude. Seasons have characteristic abiotic conditions (e.g. temperature ranges, day length, rainfall).
- The daily rotation of Earth produces alternating light and dark periods, their relative lengths varying according to latitude and season. Other abiotic factors affected by sunlight (e.g. temperature, humidity, wind) also change daily.
- The monthly orbit of the moon provides changes of illumination at night. The combined effect on the oceans of the moon's gravitational pull and the rotation of the Earth causes twice-daily ocean tides. The tides cause a cycle of exposure and coverage of the intertidal area. Tidal levels vary over the 29.53 days of the moon's phases owing to the relative sun-moon positions, with tidal heights at a particular location also affected by its topography.

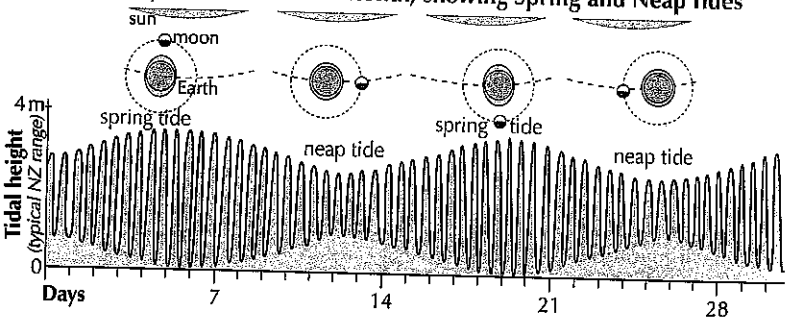
ENVIRONMENTAL RHYTHMS AND ANIMAL BEHAVIOUR

- Most animals have their daily and annual rhythms of activity linked to the cyclical environmental changes caused by Earth's rhythms. They include periods of activity and sleep, feeding and drinking, fluctuations in body temperature, sensitivity to pain and hormone levels.
- The biological advantages to an animal species of synchronising its activities t Earth's rhythms may include a better food supply, relative absence of predator and competitors for food, and more favourable environmental conditions.
- **Annual Rhythms** (yearly and/or seasonal). Mating and rearing of young are timed to exploit annual periods of abundant food and suitable environmental conditions. Other behaviours that assist an animal to survive seasonal harsh conditions are: migration *(e.g. birds)* to a more suitable environment; **hibernation** *(e.g. bats, land snails, amphibia, bears),* which involves being dormant over seasonal cold conditions; and **aestivation** *(e.g. some insects, land snails),* which involves being inactive over seasonal hot or dry conditions.

The membrane sealing the shell of this garden snail is produced for hibernation and for aestivation.

- **Lunar Rhythms** (monthly). Some marine animals synchronise egg laying with a specific part of a lunar rhythm, usually in conjunction with tidal, diurnal and annual rhythms, to ensure successful fertilisation and the best conditions for development. The two periods of **spring tides** (with a neap tide between) per lunar month are a semilunar rhythm.

Tidal Cycles over a Lunar Month, showing Spring and Neap Tides



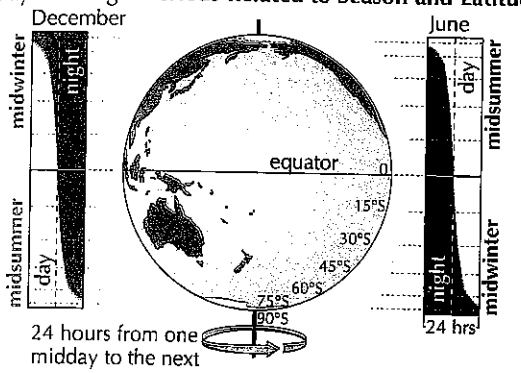
- **Tidal Rhythms** (cycle of one high and one low tide every 12.4 hours). Animals in the intertidal region have rhythms of activity correlated with the tides, gener-

A shore at high tide — The same shore at low tide — Animals exposed at low tide

ally feeding when covered with water and hiding in shells, burrows and crevices when exposed. The tidal cycle is about 50 minutes later each day.

- **Daily Rhythms** (daily night/day cycle of 24 hours). Three types of activity by animals are linked to Earth's daily cycle:
  1. **diurnal** – mostly active during the day *(e.g. humans, honeybees, blackbirds)*
  2. **nocturnal** – mainly active at night *(e.g. bats, wetas, moths, slaters, owls)*
  3. **crepuscular** – active at dusk and dawn *(e.g. rabbits, mosquitoes, fiddler crabs).*

Day and Night Periods Related to Season and Latitude

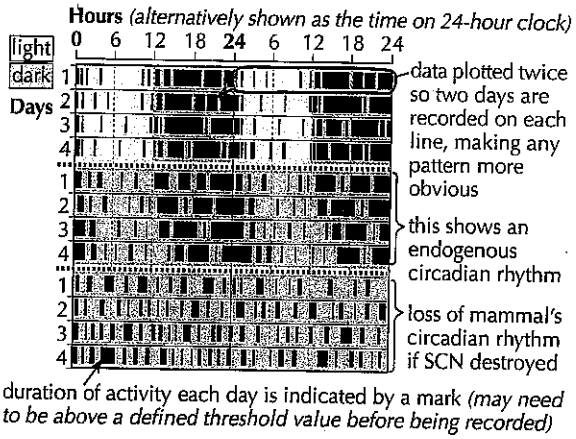


- Animal responses are not always exactly synchronised with Earth's cycles (which are precise) because they may also be controlled by internal timing mechanisms having periods differing from Earth's cycles. Consequently, the corresponding animal rhythms when they are under constant conditions (and therefore controlled only by internal timing mechanisms) are prefixed by '*circa-*' (approximately), e.g. **circannual**, **circalunar**, circasemilunar, **circadian** (approximately daily), and **circatidal**. In nature this does not normally occur as external stimuli synchronise (**entrain**) internal clocks with environmental rhythms, although they are often described as being only approximate.

Biological Clocks

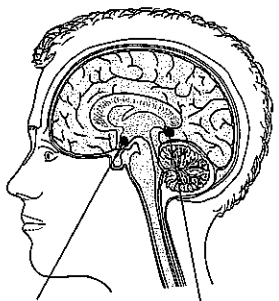
- Regular, repeated patterns of behaviour require timing mechanisms. Rhythms controlled by stimuli external to an animal are called **exogenous rhythms** *(e.g. daily activity controlled by sunlight).*
- Rhythms controlled by internal timing mechanisms are called **endogenous rhythms**. External stimuli may occasionally be misleading or not allow an animal time to adequately prepare itself for a seasonal environmental change. *For example: sheep need to be ready to mate in the autumn so that lambs will be born in the spring when there is plenty of food, so it is important that they are not misled by a brief warm spell.*
- Many rhythms are controlled by a combination of endogenous and exogenous timing mechanisms.
- One technique to identify whether a rhythm is exogenously or endogenously controlled is to place the animals in a constant (unchanging) environment and see whether they continue to show the rhythm. If the rhythm continues, there must be some kind of internal clock mechanism. A continuing rhythm in constant environmental conditions is called free-running. The period (the time between repetitive peaks of activity patterns) of a free-running rhythm may be longer or shorter than the period of the environmental rhythm. *For example, almost all fruit fly larvae hatch in the early morning, even if kept in constant conditions.*
- Most biological clocks do not exactly keep time with the rhythms of the external environment and need to be continually reset by environmental cues, such as light, temperature, or pheromones. These clock-setting environmental cues are called **zeitgebers** (time-givers). The regular resetting of the clock is called **entrainment**. Day length is a reliable cue, and entrainment by light allows animals to better exploit the seasonal changes associated with changes of day length *(see the diagram, left).*
- The internal clock mechanism has been found to be under genetic control in many of the organisms studied. *For example, fruit fly larvae keep track of time using an internal clock controlled by a single gene called the 'per' gene (for period gene). Different mutations of the gene have been found to shorten or lengthen their daily rhythm. The gene seems to produce a protein that probably affects the expression of other genes. As the protein accumulates it eventually turns off the gene that codes for it. This provides a 24-hour timekeeper in the fly's brain. In mice another gene called the 'clock' gene has been discovered.*
- When the start of the period of the rhythm is changed so that it is earlier or later, either under laboratory conditions or if the animals (including humans) are moved to another time zone, it is called a **phase shift.**
- Experimental investigations of activity rhythms in an animal species usually involve keeping it in an environment varying in only one factor. The animal's activity is generally recorded as an actogram. An actogram may be drawn with the data repeated for each day to more clearly show a pattern of behaviour, as illustrated below.

Understanding Actograms



Biological Clock Mechanisms

- Circadian (daily) clock mechanisms have been discovered in every animal group as well as in plants, protists (one-celled organisms) and fungi. Light is the key environmental cue for a circadian rhythm.
- In mammals, including humans, the 'pacemaker' or master circadian clock is found in two tiny groups of cells called the suprachiasmatic nuclei (SCN) in the hypothalamus of the brain.



Hyopthalamus, the location of suprachiasmatic nuclei (SCN)

Pineal gland (produces melatonin)

- Light entrains the clock via messages from the eyes to the SCN, which then send nerve messages to the pineal gland. In diurnal mammals, the pineal gland produces the hormone **melatonin** at night and promotes sleep. Towards the end of the night, production is suppressed and the animal wakes. As the clock is entrained by light it can be upset by changed light/dark cycles, such as when suffering 'jetlag'.
- More melatonin is produced over 24 hours in the short days of winter than in the long days of summer. This may contribute to Seasonal Affective Disorder (SAD) in humans, which occurs in winter and is similar to depression. SAD can be treated with exposure to very bright lights. The varying amounts of melatonin may also help in the timing of the onset of reproductive cycles in many animals.
- If the SCN are destroyed the animal loses its circadian rhythms, but these can be restored by transplanting SCN from another animal.
- Invertebrates do not have any SCN but in some molluscs, cells in the eyes function as the master circadian clock.
- The circadian clock of birds is found in the pineal gland, which is sensitive to light and produces the hormone melatonin. If the skull of a bird is blackened so light cannot get through to the pineal gland, then the bird will not have its rhythm entrained by light.

Human Rhythms

- **Circadian rhythms** affect many areas of our daily lives.
- Recent research, measuring the daily rhythms of temperature and hormone production of 24 volunteers of all ages and both sexes over a month, found that the daily cycle of their clocks had a free-running period of 24 hours 11 minutes ± 16 minutes.
- The SCN also play a role in the circadian rhythms of many **hormones** produced by the pituitary. The pituitary hormones influence the workings of many body systems, e.g. endocrine, urinary, cardiovascular and immune systems.
- The effectiveness of the human immune system, as measured by the number of lymphocytes (white blood cel follows a circadian rhythm, peaking in the late evenir Melatonin seems to enhance the immune system.
- Tiredness, shortened attention span, etc. associated w 'jetlag' are caused by disrupted circadian rhythms frc rapidly changing to a new time zone. Various circadi rhythms adjust to the new time zone at different rates there is a period when they are out of synchronisation. R setting the internal clock is hastened by exposure to brig light, especially in the morning of the new time zone.
- Shift work also has similar effects to 'jetlag' but they a more long-term. Research has shown that shift worke show higher than average sleep disruptions and fatigu and may have personal relationship difficulties as well gastrointestinal disorders and cardiovascular disease. The also have an increased probability of making errors.
- Other facets of human experience that have a circadia rhythm are: responses to drug treatments such as chem therapy or asthma treatments, pain sensitivity, urir production, alcohol metabolism, the chances of makir serious errors during work or driving, birth and death time and the ability to learn. Average learning ability rises du ing the first half of the morning to a high for the day, decreases to a low about lunch time, rising again in the afternoon but sinking to a low level by early evening.

Key Points Summary

- There are regular cycles in the physical environment such as day and night, seasons and the tides. These are caused by Earth's spin and tilt, and by the moon orbiting Earth.
- Most animals show rhythms of activity linked to annual, lunar, daily and tidal environmental cycles.
- For an animal to show a rhythmical activity there must be a timing mechanism, which may be exogenous (external) or endogenous (internal).
- An animal often needs to be prepared in advance for environmental changes such as the arrival of winter. This requires an endogenous timing mechanism or biological clock.
- A biological clock has been found in every group of organisms. In mammals, the circadian clock is found in the suprachiasmatic nuclei situated in the brain. It is entrained or reset by light. In the absence of cues the rhythms will show a free-running period.
- Humans have circadian rhythms that affect many aspects of their lives, such as waking/sleeping, driving and the effectiveness of learning.

Assessment Activities

1 Matching Terms with Descriptions

a) occurring every year	**aestivation**
b) a suspension in activity during the summer	**circadian**
c) occurring every 12.4 hours	**circalunar**
d) occurring daily	**annual**
e) active during the day	**tidal**
f) active during the night	**crepuscular**
g) active during dusk and dawn	**diurnal**
h) period of deep sleep over winter with a very low metabolic rate	**endogenous rhythm**
i) occurring every lunar cycle	**entrainment**
j) rhythmical activity controlled by external factors	**suprachiasmatic nuclei (SCN)**
k) rhythmical activity controlled by internal factors	**free-running**
l) when a rhythm continues in the absence of external cues	**hibernation**
m) environmental cue that adjusts a biological clock	**'jetlag'**
n) regular resetting of a biological rhythm by an environmental cue	**melatonin**
o) changing the start time of a biological rhythm so that it is earlier or later	**nocturnal**
p) master circadian clock in mammals	**phase shift**
q) hormone produced by the pineal gland in response to messages from the suprachiasmatic nuclei	**exogenous rhythm**
r) caused by upsetting circadian rhythms	**zeitgeber**

2 Applying Scientific Concepts

Describe, using a named example, one advantage for a species to be:

a) diurnal b) nocturnal c) crepuscular.

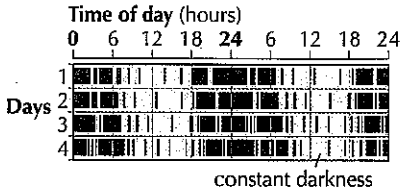
3 Understanding Biological Clocks

a) Where is a mammal's biological clock located?

b) Explain how it is able to regulate biological rhythms and state which hormone is involved.

4 Interpreting Scientific Data

Results of experiments on the activity of animals kept in constant conditions often show this typical pattern:



a) What is the name of this type of rhythm? (Give reasons for your choice.)

b) What is the name given to this pattern of behaviour?

c) What is the approximate average daily phase shift over the period of time shown?

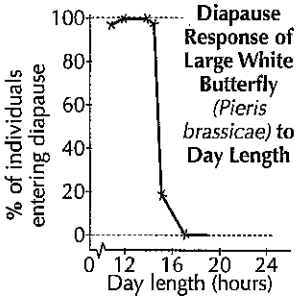
d) Explain why the experiment indicates that the pattern may be caused by an endogenous rhythm.

e) What environmental cue would be most likely to entrain the biological clock of this animal?

f) If the experiment producing the data was terminated at the end of four days (as indicated by the diagram) how would this affect the validity of any conclusion drawn?

5 Interpreting Scientific Data

Many species of insects experience a 'diapause' to help them survive a period of adverse conditions. In species in which it is a normal part of the life cycle it is triggered by the photoperiod, and may occur quite suddenly at a critical day-length. The graph shows the response to changes in day length of one species of butterfly that lives in a temperate climate.



a) What is 'diapause'?

b) What is the critical day length for this species?

c) Describe one probable advantage of using day length as an environmental cue rather than waiting for the adverse conditions (e.g. winter) to arrive.

Answers

Unit 1: Environmental Factors

1 a) habitat b) ecological niche c) behaviour d) abiotic factor e) biotic factor f) intraspecific g) interspecific h) commensalism i) adaptation j) mutualism k) learned behaviour l) innate behaviour m) environment n) environmental cue

Unit 2: Animal Orientation Behaviour

1 a) animal behaviour b) stimulus c) sense organ d) photoreceptor e) compound eye f) photopigment g) lateral line h) statocyst i) central nervous system (CNS) j) effector organ k) orientation response l) taxis m) kinesis n) positive thermotaxis o) migration p) homing

2 a) *one of these answers:* in their winter habitat (Solomon Islands) there would be warmer temperatures so they would need to use less energy keeping warm/ the days would be longer than in NZ so they would have more daylight hours to feed/ there is likely to be more food available; in their summer habitat (NZ) there would be longer daylight hours for feeding than in the Solomon Islands b) *one of these answers:* flying 4000 km would use up much energy that would have to be replaced by acquiring extra food/ risk injury or exhaustion that might result in death c) *any 3 of these:* sun's position, star positions, Earth's magnetic field, visual cues, polarised light, chemical cues

3 a) many separate units called ommatidia, each made up of a lens that focuses light on photoreceptor cells that transmit nerve messages to the brain b) as each ommatidium 'sees' a point of light, a compound eye enables an insect to perceive an image made of many dots of light of varying intensity c) a*dvantage:* good at detecting movement; d*isadvantage:* not good for forming a detailed image

4 a) positive chemotaxis b) effective way for males to find females when they are sexually receptive because the message can be transmitted long distances and is generally directional/ smells can be detected at night when most moths are active/ pheromones last for a reasonable time period

5 a) photokinesis or photo-orthokinesis b) the slaters move faster in unsuitable conditions, so they are more likely to encounter conditions that are more suitable (darkness in this case); once in more suitable conditions they slow or stop and are more likely to stay there; slaters require a moist environment for effective gas exchange

6 a) less accessible to predators/ cooler/ less vulnerable to drying out b) touch, shade, temperature c) *depends on stimulus chosen and nature of investigation selected* d) homing e) investigation would involve either observing homing behaviour of marked limpets with 'landmarks' (e.g. rocks) in different positions, or comparing homing behaviour when their slime (i.e. chemical) trails are present and when removed

Unit 3: Animal Timing Behaviour

1 a) annual b) aestivation c) tidal d) circadian e) diurnal f) nocturnal g) crepuscular h) hibernation i) circalunar j) exogenous rhythm k) endogenous rhythm l) free-running m) zeitgeber n) entrainment o) phase shift p) suprachiasmatic nuclei (SCN) q) melatonin r) 'jetlag'

2 a) advantages for diurnal animals include: food that is available in the daytime only (e.g. bees obtaining nectar/ pollen from day-opening flowers); greater warmth in the daytime increases metabolic rate giving faster reactions; vision can be used to locate suitable food sources b) an advantage for nocturnal animals (e.g. moths) is being able to exploit food available at night without experiencing direct competition from diurnal animals feeding on the same food source c) an advantage for crepuscular animals (e.g. rabbits) feeding at dawn and dusk is the avoidance of predators that are diurnal (e.g. dogs) or nocturnal (e.g. cats and owls)

3 a) in the suprachiasmatic nuclei (SCN) b) messages from the eyes regarding the amount of light, sent to the SCN via the optic nerves, continually reset or entrain the natural, endogenous rhythm of the clock; the SCN send messages to the pineal gland, which (in diurnal animals) produces more melatonin during the night; this induces sleep, but at the end of the night the production of melatonin is reduced and the animal wakes

4 a) a circadian rhythm - its period is about 24 hours with one major activity period during the 24 hours) b) nocturnal c) 2 hours phase shift over 4 days = ~30 minutes daily phase shift d) the rhythm persists in the absence of external cues e) light, as animals are being kept in darkness f) time period would be too short to be sure that a free-running endogenous rhythm exists

5 a) a delay at some stage in the development of an insect b) day lengths of less than 15 hours sustain diapause/ a daylength of 15 hours or more breaks the diapause c) it allows the animals to anticipate the arrival of adverse conditions and take appropriate action

Unit 4: Cooperative Animal Relationships

1 a) the sun will have moved several degrees in the time it takes for a bee to fly back to the hive and to dance; an internal clock will enable the workers setting out to find the food to compensate for the sun's movement

2 a) place food sources upwind and downwind of the hive to investigate if there is a difference in the time taken between the departure of the scout and the arrival of several foraging bees at each site; if only the odour

plume was used then the food downwind from the hive would be more difficult or impossible for the bees to locate

3

Reproductive Strategy	1	2
number of young	high	low
mortality of young	high	low
parental investment	low	high
parental risk	low	high

4 a) so that their states and needs would be similar at the start of the experiment b) the woodlice that were able to clump would have lost a smaller percentage of water than the ones who were kept separate

5 a) innate or instinctive behaviour b) learned behaviour c) clumping d) breeding colony e) communal breeding f) worker bee g) queen bee h) drone i) lek j) polygynous k) kin selection l) hierarchy m) pair-bonding n) promiscuous o) territory p) monogamous q) polygamous r) altruism s) polyandrous t) polygynandrous u) parental investment

6 a) altruism b) 90° left of the line from the hive to the sun

7 a) a territory is a defended area b) *advantages*: more likely to successfully raise offspring as more offspring and with a variety of genetic characteristics as they have various mothers, which may allow at least some of them to survive adverse conditions; *disadvantages:* the male has to put in more time and energy into defending his territory, females and offspring as well as collecting food for more offspring – may mean that none of the offspring has as good a chance of survival as if there were only one nest in the territory c) females ensure that their offspring inherit a variety of characteristics and so it is more likely that one will survive

8 a) the queen lays the eggs but workers decide which eggs become queens and look after the queen who spends all her time in the hive laying eggs as she cannot fly out to collect her own food; although the queen controls the workers by producing pheromones, the workers also control the queen who produces more workers so that the hive is a viable unit; as the queen and all the workers share half their genes, either explanation is equally viable for passing genes on to the next generation b) more food can be collected and young raised

Unit 5: Non-cooperative Relationships

1 a) Batesian mimicry; because its involves resembling an unrelated species in the same area that has defences b) whether they shared the same range and predators during their evolutionary history c) observations of the behaviour of honeybee and drone-fly predators

2 a) a lek is a mating display area; a territory is a defended area; a home range is a foraging area b) crepuscular animals are active at dawn and dusk; diurnal animals are active during the day; nocturnal animals are active during the night c) they would be able to feed when their predators are largely absent d) aggressive behaviour occurs during competition between animals for resources; agonistic behaviour occurs between members of a species; predatory behaviour does not fall into either of these categories

3 a) territory b) Müllerian mimicry c) hierarchy d) cryptic coloration or camouflage e) aposematic coloration f) agonistic behaviour g) home range h) interspecific competition i) intraspecific competition j) countershading k) disruptive coloration l) co-evolution m) Batesian mimicry n) Gause's competitive exclusion principle

4 a) camouflage or cryptic coloration b) it will be less likely to be eaten by predators c) moths that more nearly looked like their surroundings, in this case dead leaves, were less likely to be caught by predators, such as birds, and so were more likely to pass on their genes to their offspring resulting in evolution of the species

5 a) when grown separately both species increase in numbers until a stable population level is reached with *P. caudatum* being slightly lower in numbers than *P. aurelia;* when cultured together one species *(P. caudatum)* increases in numbers briefly, then decreases towards zero, whereas the other species increases to a maximum as before but not as high – competition between the two species is so intense that one species *(P. caudatum)* dies out when they are cultured together; they share the same ecological niche and the one that is slightly better adapted *(P. aurelia)* survives while the less well adapted species dies out

6 a) C-F-G-A-D-B-E-H b) a hierarchy is a linear dominance order in a social group of animals c) it reduces the amount of energy used in fighting and the potential risk to individual animals of continued tension and fighting over access to resources d) once the hierarchy has been established ritualised displays or body postures are usually enough to reinforce the dominance positions

Unit 6: Plant Orientation Responses

1 a) hormone b) stimulus c) phototropism d) thigmotropism e) coleoptile f) osmosis g) photoreceptor h) auxin i) geotropism j) tropism k) chemotropism l) turgor movement m) inhibitor n) hydrotropism o) nastic response

2 a) positive phototropism b) positive hydrotropism c) positive geotropism d) negative geotropism e) positive chemotropism

3 a) thigmotropism b) rubbing causes cells on one side of the tendril tip to produce an inhibitor that accumulates lower down the tendril on the rubbed side; the cells on the unrubbed side elongate more causing the tendril to curve around the object being touched

4 a) as a control/ to determine what happens to normal