NINE PRINCIPLES OF BIOMIMICRY

Summarizing the principles

Erasmus+

AGE RANGE

12–16

DURATION

Preparation:
about 20 min.

Activity:
about 90 min. / 2 lessons

SUBJECT(S)

- Science – *Biology, Chemistry, Physics*
- Design, Engineering and Technology
- Arts
- Mathematics

KEYWORDS

Biomimicry principles; function; diversity; energy; cooperation

SUMMARY

These activities provide an introduction to the 9 principles of biomimicry. These principles are the basis for biomimicry thinking which is important in all the modules. We also provide separate modules for each principle.

BIOMIMICRY PRINCIPLES

1 – Nature runs on sunlight
2 – Nature uses only the energy it needs
3 – Nature fits form to function
4 – Nature recycles everything
5 – Nature rewards cooperation
6 – Nature banks on diversity
7 – Nature demands local expertise
8 – Nature seeks balance
9 – Nature taps the power of limits

LEARNING OBJECTIVES

- Students understand how nature operates based on shared principles.
- Students understand how these principles are inter-linked to create a sustainable system.
- Students recognise that we can use biomimicry principles to solve human challenges.

LEARNING OUTCOMES

- Students explore biomimicry principles and how they link with each other.
- Students find connections between biomimicry principles.
- Students connect biomimicry principles into a system to explore sustainability.

BIOLEARN COMPETENCES

- Students are able to abstract principles of sustainability from the way the natural world functions.
- Students are able to identify functional design in nature, develop greater awareness and appreciation for design excellence in nature, and appreciate how nature works as a system which is elegant and deeply interconnected.

SUMMARY OF THE ACTIVITIES

	Activity Name	Short description	Method	Duration	Location
1	Explanation of the 9 principles	Presenting the principles 9_principles.ppt	• Teacher presentation • Discussion	70 (45+25)	Indoor
2	Connecting biomimicry principles	Searching for connections	• Group work	20	Indoor/ Outdoor

BACKGROUND FOR TEACHERS

The key idea of biomimicry is to learn from nature to solve human problems: learning how to solve human problems, how to invent new things (or at least think we need) and how to live sustainably. By observing nature carefully, we can discover its' principles, how everything is carefully self-regulated, and how different species and ecosystems provide solutions to the challenges faced by humans. The principles of nature that are important in biomimicry were gathered first by Janine Benyus (1997) in her book *"Biomimicry: Innovation Inspired by Nature".*

Principles of biomimicry:

1. Nature runs on sunlight
2. Nature uses only the energy it needs
3. Nature fits form to function
4. Nature recycles everything
5. Nature rewards cooperation
6. Nature banks on diversity
7. Nature demands local expertise
8. Nature seeks balance
9. Nature taps the power of limits

ACTIVITY DETAILS

LOCATION
Indoor

TOOLS AND MATERIALS

- PC, projector
- 9_principles.ppt
- student worksheet: W1.1
- teacher's page: T1.1

PREPARATIONS

Arrange the classroom for a presentation.

RESOURCES

Benyus, J. M. (2002): *Biomimicry – Innovation inspired by nature.* HarperCollins Publisher, New York, U.S.A.

Stier, S. (2014): *Engineering Design Inspired by Nature.* The Center for Learning with Nature, Coralville, U.S.A. https://www.learningwithnature.org/

Steven Vogel: *Comparative Biomechanics: Life's Physical World*, Second Edition June 17, 2013 (https://asknature.org/strategy/specialized-teeth-wear-down-but-remain-effective/#.XoRouHJS-Ht)

1| EXPLANATION OF THE 9 PRINCIPLES

» QUESTION

The 9 principles of biomimicry can be challenging to understand. The presentation 9_principles.ppt can help with understanding, supplemented with any of the other introductory modules as you think appropriate. Feel free to add more examples and discuss examples with your students. The presentation slides are explained in T1.1.

The presentation can be used as whole, but also can be used as an introduction to the modules about each principle individually, using only the relevant slide(s).

Pictures:

1. Nature runs on sunlight
   1. Tree
   2. Leaves
   3. Chloroplast
   4. Chloroplast drawing

2. Nature uses only the energy it needs
   5. Hunting cheetah
   6. Wild goose flying in V form
   7. Wolverine
   8. Grey squirrel

3. Nature fits form to function
   9. Teeth
   10. Skull
   11. Winged fruit (maple)
   12. Thistle
   13. Penguins
   14. Eagle

4. Nature recycles everything
   15. Autumn leaves
   16. Mushrooms
   17. Griffon vulture *(Neophron percnopterus)*
   18. Streptomyces albus
   19. Burying beetle *(Nicrophorus vespillo)*
   20. Rotting apple

ACTIVITY DETAILS

5. Nature rewards cooperation
    21. Insect pollination
    22. Lichens
    23. Lice and ants
    24. Buffalo and clean-birds
    25. Fish and cleaning-fish
    26. Yucca and yucca moth *(Tegeticula yuccasella)*

6. Nature banks on diversity
    27. Coral reef
    28. Monoculture
    29. Rainforest diversity
    30. Oak forest
    31. Robinia forest
    32. Damaged forest in High Tatras

7. Nature demands local expertise
    33. *Sempervivum sp.*
    34. Opened rocky grassland
    35. Forest on apron
    36. Arctic fox *(Alopex lagopus)*
    37. Fennec fox *(Vulpis zerda)*
    38. Pied avocet *(Recurvirostra avosetta)*
        38/a. beak of pied avocet
        38/b. foot of pied avocet

8. Nature curbs excesses from within
    39. Lotka-Volterra model
    40. Lynx and rabbit
    41. After fire
    42. Carrying capacity of the environment
    43. Lemming

9. Nature taps the power of limits
    44. Invasion of locusts
    45. Mice
    46. Cold rivers of lava
    47. Pioneer community
    48. Climax community
    49. A mother giraffe with her baby
    50. Forest trees

ACTIVITY DETAILS

LOCATION
Indoor / Outdoor

TOOLS AND MATERIALS
- W1.1 – one copy for each group
- paper per group
- pen/pencil

PREPARATIONS

Indoor: arrange as many tables as the number of the group. If outdoors, use the first extension activity.

2| CONNECTING BIOMIMICRY PRINCIPLES

» DISCOVER

Divide the class into groups of 3–4. Give each group a set of W1.1 (short description of biomimicry principles). Ask the groups to arrange the principles as a circle on their tables. Ask them to search for connections amongst the principles. Encourage them write down the links they discover.

Example:
- Interconnection between principle 1 (Nature runs on sunlight) and principle 3 (Nature fits form to function): leaves on a plant are designed to face the sun so they can capture solar energy more efficiently.

After student's finish searching for interconnections, put the principles onto flip chart/white board and ask each group to show and explain their results.

EXTENSION(S)

- You could deliver this activity using the webbing activity found in the modules about principle 6 and principle 7. Students (one per principle) stand in a circle and try to find connections among them. If they find something, they give the string to the connected person.
- Give one principle each to 9 groups of students during an excursion. Ask students to observe their surrounding during the excursion and find examples of their principle. Ask them to share their findings at the close of the excursion.

T1.1 EXPLANATION OF THE 9 PRINCIPLES

1st slide

INTRODUCTION

In the late 1990s, a revolutionary idea arrived on the scene, shepherded by an innovative thinker and nurtured by scores of curious and passionate individuals. In the book *"Biomimicry"*, Janine Benyus introduced the notion that we could be better off by simply mimicking the ways problems are solved in nature; this idea has proven transformative.

In the book, Benyus lists nine principles that govern and define how nature operates. Let's explore each of them in detail.

2nd slide

PRINCIPLE 1: NATURE RUNS ON SUNLIGHT

Nature uses sunlight as the main source of energy. Organisms use heat and UV radiation from this never-ending source. So, we can say that nature is powered by sunshine. Humans use fossil fuels, these sources are not renewable, and burning them creates CO_2 which is one of the gases causing climate change. Why don't we do the same and prevent the climate crisis? A wise person would mimic nature and rely on renewable power.

Photosynthesis is a chemical reaction that takes place inside a plant, producing food for the plant to survive. Carbon dioxide, water and light are all needed for photosynthesis to take place. Photosynthesis takes place in the part of the plant cell containing chloroplasts, these are small structures that contain chlorophyll. Photosynthesis takes place in two stages, the light reaction and the dark reaction. The light reaction converts the energy of sunlight into chemical energy (ATP – adenosine triphosphate and NADPH – nicotinamide adenine dinucleotide phosphate), and during the dark reaction chemical energy is converted to produce sugars from carbon dioxide (Calvin cycle).

The process is described by the equation $6CO_2 + 12H_2O + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$. The slide shows a tree, leaves and chloroplasts in cells seen through a light microscope.

It is worth mentioning that there are bacteria that do not use sunlight to generate energy. They use chemical compounds (e.g. hydrogen, ammonia, iron, sulphur compounds), this is called chemosynthesis. One of them is chemolithotrophs which use an inorganic electron donor for breathing. These bacteria usually live in anaerobic condition like ponds, or in extremely mineralized areas where sunlight is completely missing, e.g. iron geysers and springs, deep sea smokers (volcanoes). All autotrophs (they build up organic matter from inorganic materials in their environment) use carbon dioxide as the carbon source for photosynthesis to build up their organic matter. Heterotrophic organisms derive their energy from organic materials produced by autotrophic organisms.

3rd slide

PRINCIPLE 2: NATURE USES ONLY THE ENERGY IT NEEDS

Nature takes only what it needs. So why do we not do the same? Our economy is focused on maximizing output and is a big energy consumer. We transport food around the world because that is economically cheaper. Only money seems to count in a lot of decisions, not our energy consumption and the impact this has on the natural world. How can we learn to optimize the performance of goods and services to sip energy rather than gulp it?

Animals only take the nutrients they need; plants do not absorb more water than is necessary. The hamster stores as much grain as it needs over the winter; likewise, the squirrel collects sufficient hazelnuts for winter food. And if there are any seeds leftover, they become food for another animal or grows into a new tree.

The cheetah can run very fast, but only for a short distance. If catching the prey means using more energy than it puts into running, it stops running.

Predators only kill sufficient prey to meet their needs, leaving others for future meals. The wolf, for example, cannot eat a whole deer so it buries it to return and consume more later. Most people in society buy much more meat than they can consume. How much meat is stored unnecessarily in freezers? What will happen to it? How much energy and materials were necessary to produce this meat and how much energy needed to store it?

Migratory birds fly in a V-shape which creates an airflow that acts as a buoyancy force for the next bird, thereby maintaining speed and altitude with less effort. The V-shape helps birds save energy.

4th slide

PRINCIPLE 3: NATURE FITS FORM TO FUNCTION

A tree is rooted in the ground to draw water and nutrients from the soil; it spreads its branches and leaves wide to increase surface area and absorb the sunlight to produce energy and grow. Seeds are lightweight and some even come equipped with a sort of umbrella so they can float in the air. Nature creates designs for the function they provide, so should our buildings, transportation systems and schools.

“Grazing has perhaps elicited the most dramatic dental specializations in mammals. About twenty million years ago, grasses and grasslands appeared on earth. Grass provides poor fodder. It yields little energy relative to its mass, so a grazer has to process huge volumes. Much of that energy comes as chemically inert cellulose, which mammals hydrolyze only by enlisting symbiotic microorganisms in rumen or intestine. It's full of abrasive substances like silicon dioxide and has lengthwise fibres that demand cross-wise chewing rather than rapid tearing. Long-lived grazers, concomitantly, have special teeth, with their components typically layered side by side. This odd-looking arrangement ensures that, while teeth may wear down, they won't wear smooth. The harder material (enamel, most particularly) will continue to protrude as the softer materials (cementum and dentine) wear down between them.” (Vogel 2003:333)

The fruits and seeds of plants are designed to facilitate their propagation. They are designed to catch the wind, float in water, stick to animals etc to ensure they are spread far and wide. The fruit of the maple tree, for example, flies like a helicopter; this is made possible by the streamlined, slightly inclined 'wing'. The thistle seed has hook-and-loop parts that easily get caught in animal fur. Some plants even have a mechanism to 'shoot' their seeds away from the plant.

Birds also have a beak shaped for feeding on specific foods or prey. For example, predator birds have a hook on the beak that can easily tear their prey.

Penguin bodies are spindle shaped. This makes it difficult for them to move on land, but it is extremely streamlined in water; beside their bodies, the movement of the water is laminar, and turbulence occurs just behind their body, resulting in very low water resistance enabling them to swim faster.

5th slide

PRINCIPLE 4: NATURE RECYCLES EVERYTHING

There is no 'away' to throw things. Everything produced in nature is biodegradable, there is no waste. There can still be abundance, look at all the blossom on a cherry tree, but that all serves a purpose and will be food and nutrients for others. Once the natural life of a pinecone has come and gone, it breaks down into essential elements that are repurposed into new life.

The combination of plants, herbivores, predators and decomposers maintain a cycle of natural materials. In this system plants get their energy from the sun, which then becomes food for other organisms in the food chain. All minerals are recycled and are returned to the soil by decomposers. A dynamic balance is maintained. Humans do things differently; raw materials are mined and manufactured into products for consumption. During and at the end of this process, natural resources are transformed into new materials which do not easily biodegrade. These waste materials create pollution and damage the balance of natural systems.

When we hear of decomposers, mushrooms often come to our mind. However, many more groups of living organisms are involved. For example, large vertebrates such as crows and vultures, insects such as beetles, and many bacteria living in soil are members of this group.

The soil (= storage layer) in a rainforest is thin because the process of digestion and the recycling of mineralized biomass is very fast. Deforestation, therefore, quickly results in the destruction of the soil layer which is difficult to regenerate.

6th slide

PRINCIPLE 5: NATURE REWARDS COOPERATION

We see competition in nature, but only when it's impossible to avoid; in general, competition costs too much energy. On the other hand, very little in nature exists in isolation. Plants cooperate with pollinators to disperse seeds, and the pollinators feed on nectar. Ladybirds feed on aphids and help plants to stay healthy. Nature favors cooperation because it maintains the health of the whole system.

In all habitats, populations of different species live together influencing each other's life processes and functions, and therefore interacting with each other. It can be positive, negative or neutral. Here are some examples:

Commensalism (table community) – when one species benefits another species but does not interact. An example of this are sparrows nesting in a stork's nest; they receive food without disturbing the stork.

Antibiosis – the presence of one species is clearly harmful to another species. It is predominantly micro-organisms, the metabolism of one species adversely affecting the other. A typical example is penicillin, a substance that inhibits the growth of bacteria.

Competition – harmful to both species, but sometimes necessary. This happens when, for example, food or habitat is not sufficient for all populations living there. Typically, one species disappears. Another example is when plants out compete each other for light.

Predation (catching prey) – herbivores eat plants, predators eat the flesh of herbivores, decomposing organisms eat dead plant and animal parts.

Parasitism – there is a host organism and a parasite that feeds on it. Living together is beneficial for the parasite but it is harmful for the host organism, even if it does not die immediately. An example of this is the downy mildew on vines or tapeworms in vertebrates.

Mutualism – one of the most typical relationships that benefits both species. There are many examples of this relationship between plants and animals. In obligatory mutualism, the two species cannot live without each other, while optional mutualists can. Symbiosis means close and lasting coexistence, whereas other forms of mutualism do not necessarily involve the continuous coexistence of partners.

Examples:

- Azotobacter (nitrogen-fixing bacteria) in the root tissue of *Papillonaceae* fix ammonia from nitrogen in soil-air for the plant.
- Mycorrhiza – root connections between fungi and plants; the former helps in the absorption of inorganic substances, the latter provides organic compounds to the fungi.
- Lichen – coexistence of algae and fungi.
- Vitamin-producing bacteria living in the human intestine.
- Insects pollinate plants – there are plants that can be pollinated by several species, and some that have special flowers, so only a certain species can pollinate them.

- Ants and aphids – the latter absorb the sap of the plants and pick out the dew which the ants prefer to consume, in return the ants protect the aphids and carry aphids from one plant to another.
- Cleaning fish and their host fish – smaller fish remove parasites from the mouth of larger fish.
- Cellulose-degrading bacteria in ruminants.
- Hydrates live in symbiosis with green algae; algae are not digested, algae produce organic matter and oxygen from hydra-produced materials, which is good for the hydra.

7th slide

PRINCIPLE 6: NATURE BANKS ON DIVERSITY

Diversity is one of nature's best insurance policies. When one food source is unavailable, others can be found. Plants use several different strategies to spread seed or defend against predators. We know that species with limited genetic diversity have more difficulty adapting to environmental change, and that ecosystems rich with diversity are more stable.

Biodiversity – the diversity of the plants and animals, which may include the whole of the Earth's wildlife (species, genetic richness, habitat diversity) or the ecosystem of a particular area (e.g. the Carpathian Basin).

A more diverse ecosystem is more resilient and less vulnerable. When the environment changes, individuals who are able to adapt to the changes will survive and multiply. The greater the diversity the greater the opportunity for adaptation. This process is also evident on a larger scale; habitats with high species diversity are more able to adapt to change.

The existence of biodiversity is important for ecosystem services (e.g. pollination, soil fertility, climate control) as our food, clean water and air could not exist without it. Therefore, protecting biodiversity is critical to our future.

Tropical rainforests – terrestrial ecosystems have the largest biodiversity. Two thirds of all the species on Earth are in rainforests. Unfortunately, the area of tropical rainforest is reducing rapidly. Trees are cut down mainly to create space for agricultural production, i.e. monocultures are created on the site of what was once a species rich area.

Coral reef – the largest biodiversity in the marine ecosystem. They are home to 25% of species living in marine habitats. Overfishing and pollution are the biggest threats to the marine ecosystem, and global warming can lead to the destruction of coral reefs. Corals live in symbiosis with single-celled algae which are sensitive to high water temperatures and pollution. Increasing carbon dioxide levels in the air increases the acidity of water, and causes the coral vase to dissolve.

Monoculture – the less biodiversity in an ecological system the more vulnerable the system is, and the less flexibility it has in response to change. That is, the fewer species the system has (e.g. agricultural monocultures), the more likely it is that a small change will have a big impact (e.g. the appearance of a pest).

Oak forest and robinia forest – the diversity of the oak forest is higher than of a robinia forest. The former is home of more species.

Many people were appalled by the news when in November 2004 a major storm swept the pine forests in the High Tatra. One of the reasons is that since the 19th century spruce was planted (monoculture, which means one species in the same age), which is not a native species in the Tatra. The rapid breeding of death-watch beetle in the collapsed trees made matters worse. It was extended to the still standing trees increasing the rate of destruction.

8th slide

PRINCIPLE 7: NATURE DEMANDS LOCAL EXPERTISE

Nature's systems are inherently local. Certain species thrive under specific conditions; local and regional weather patterns matter, as do other conditions such as soil, air quality and water temperature. Relationships are created locally and local resources are used. Of course, some birds travel long distances but have you seen them take their food with them?

Climatic adaptation – some organisms live in varying climates and have strategies to adapt. Hares adapt from the warm summer to the cold winter by thickening their fur and also changing its colour to match with snow.

Extrazonal adaptation – due to local climatic conditions, some species appear outside their usual habitat zones. For example, beech appears on the northern slopes and in cold valleys due to the micro- and meso-climatic features there.

Intrazonal adaptation – within zonal vegetation types, there are intrazonal habitats that are frequently associated with variations in environmental conditions, and that have a microclimate which deviates from the general macroclimate associated with the zone. For example, in an oak woodland, bluebells come into flower before oak trees come into leaf; in this way they take advantage of the light available on the wood-land floor before the oak leaves block it out.

Examples (pictures in ppt)

- Debris slopes forests – on steep and rocky hillsides, the main species is the European ash *(Fraxinus excelsior)* and small leaved lime *(Tilia cordata)*, they have a roll in soil conservation.
- Open rock lawn – drought-tolerant grasses, succulents (*Sempervivum* and stonecrop species).
- *Sempervivum sp*. – they live on sunny rocks and stony places in the mountain. It is possible because they are able to store water in their thick leaves.
- Arctic fox *(Alopex lagopus)* – they are native throughout the Artic tundra biome. They adapted well to living in cold environments. They have thick, warm fur which is used also as camouflage. Their rounded body shape minimizes the escape of body heat.
- Fennec fox *(Vulpis zerda)* – they are native in the desert of North-Africa and Arabian. They have unusually large ears to serve to dissipate heat. Their kidney, ears and coat functions have adapted to high-temperature, low-water, desert environments.
- Pied avocet *(Recurvirostra avosetta)* – they have long, bluish legs used to step in the shallow brackish water. They have long, upturned beaks. They use it to mow from side to side in water, which is a unique feeding technique. With the help of this movement they eat crusanceans and insects feom the shallow water.

The plant species can be classified by ecological indicators.

- T-rate – shows the temperature claim of the species (wide tolerance species, tundra, taiga, coniferous and deciduous mix forest, deciduous tree, sub-Mediterranean deciduous forest, Mediterranean, Atlantic evergreen forest) – except for wide tolerance species the plants are on own climatic area.
- W-rate – shows the water demand of the species, and the place where the plant is most frequently found (extremely dry – fresh – aquatic) – the succulents live dry place, their leaves are dick with reservoir tissue; the tissue of aquatic plants adapted to their habitat.
- R-rate – shows the pH claim of the species, means that acid-calcareous soil type where the species live (wide tolerance species, acid-neutral-calcareous) – the acid soil is liked by e.g. fungi, sphagnum; the soil in the coniferous tree are acidic; the plant living in a open rock lawn prefer calcareous soil.
- N-rate – shows the nitrogen claim of the species (poor in N, reach in N, neutral species) – e.g. nettle and elderberry prefer the soil reach in N.
- Z-rate – shows the degradation tolerance of the species (not tolerant, good tolerant, degradation-phile).

9th slide

PRINCIPLE 8: NATURE SEEKS BALANCE

Ecosystems will always try to keep in balance. More mice? Then you will see more owls to feed on the mice and keep the population in balance. Forest fires are a great example of a natural phenomenon that renews and refreshes, reducing excessive growth and allowing for regeneration. Every natural system has a tipping point, a carrying capacity or a state of disequilibrium that triggers a change to a different state.

Ecosystems are self-regulating, maintaining a dynamic balance free from extreme fluctuations. For example, every fourth year increases in lemming numbers create a shortfall in food availability. This results in mass migration of lemmings to seek new food sources and the local population to reduce back to sustainable levels.

Predator control on prey population (Lotka-Volterra model)
If the number of prey species increases, so does the number of predator species; this results in a decrease in the number of prey animals, which in turn will reduce the number of predator species. This basic mechanism was described by two mathematicians: Alfred J. Lotka (American) and Vittorio Volterra (Italian). An example is the interaction between Canadian lynx and polar rabbit (changes occur over a period of about 10 years). This cyclicality could only be detected in the Arctic, where few species of prey live, so the predator cannot switch from one prey to another.

In reality, the predator-prey relationship is much more complicated. It has many components, including multiple prey and predators, the impact of weather conditions and availability of food for prey organisms. Most predators are actually polyphagic, meaning they consume a variety of foods. As a result, their headcount changes are much smaller. In the case of a complex food web there is a high degree of stability, resulting a smaller curve swing (amplitude).

Carrying capacity of the environment
If a species lives in the right conditions, it will produce more than two offspring during its lifetime (i.e. the father and mother will not replace only themselves). If we imagine an ideal population where the individuals are not affected by the environment, then the number of individuals would increase exponentially, that is to say, a dramatic change in the number of individuals. In nature, however, environmental factors prevent this exponential growth (e.g. weather, food, predators, disease). As the density of individuals increases, density-dependent limiting factors appear, for example as the number of individuals increases the amount of food per individual decreases; disease and parasites can spread more easily. So, the growth of the population slows down and stops.

The density of a population above which the population cannot permanently be greater is called the environmental maintenance capacity. The number of individuals in a given habitat must not permanently exceed its carrying capacity. In species-rich habitats, the numbers of individuals in a population are not prone to extreme fluctuations, while in species-poor associations (e.g. monoculture) there may be extreme fluctuations.

Stability of natural communities = resistance to disturbance
If a system is exposed to external influences, it may provide a resistant or a resilient response. In the first case it prevents the attack, in the second case it successfully adapts to the new conditions and a new system emerges. Resilience is also an organizing force. In shock, the system shifts from its original equilibrium and then reorganizes and recovers at another level.

10th slide

PRINCIPLE 9: NATURE TAPS THE POWER OF LIMITS

Unlimited growth on a finite earth is not a good idea. All living things are governed by limitations; age, climate, population density and many other factors determine how species and systems develop. Nature has found ingenious ways to work within these limits to be as productive as possible over the long run.

Succession
Ecological succession is the process of change in the species structure of an ecological community over time. It is a one-way process in which the populations that make up a community are completely or partially exchanged. During succession, pioneer species appear first. The closing of the succession process is the appearance of a climax (closing) community.

- The pioneer community consists of highly adaptable, broad-tolerant, one-year r-strategist species.
- The climax community is the most versatile community with the highest productivity under given climatic conditions. K-strategist species predominate and narrow-tolerant species also appear.

The two types of succession:

- Primary succession occurs where there has not been life in the area before. For example, after volcanic eruption, landslide or glacial moraine.
- Secondary succession occurs when the succession process is re-launched in an association which is stable for a long time. For example, recharging of standing water, mowing stops in a mountain meadow or after a forest fire.

Climax communities are generally resistant but have moderate resilience, whereas primary or intermediate communities have less resistance but greater resilience.

r and K strategists
Animals can be classified into r and K strategists.

- r-strategist species reproduce very quickly under the right environmental conditions, reaching a maximum value, which quickly reduces due to the depletion of environmental resources. If the environmental conditions are favourable again, rapid reproduction occurs. They live in unpredictable environments (desert, tundra, periodically flooded areas). Examples of r-species include mice, rabbits, weeds and bacteria, which have a lot of offspring, but a short life expectancy.
- K-strategist species have longer lifespans, large body size, with fewer offspring, low mortality rate, stable population size, and frequently have a defined territory. The number of individuals corresponds to the carrying capacity of the environment. Examples of K-strategist species include birds, larger mammals (such as elephants, horses, and primates), and larger plants.

W1.1 EXPLANATION OF THE 9 PRINCIPLES

Short description of nature principles

1. Nature runs on sunlight
Nature uses sunlight as the main source of energy. Organisms use heat and UV radiation from this never-ending source. So, we can say that nature is powered by sunshine. Humans use fossil fuels, these sources are not renewable, and burning them creates CO_2 which is one of the gases causing climate change. Why don't we do the same and prevent the climate crisis? A wise person would mimic nature and rely on renewable power.

2. Nature uses only the energy it needs
Nature takes only what it needs. So why do we not do the same? Our economy is focused on maximizing output and is a big energy consumer. We transport food around the world because that is economically cheaper. Only money seems to count in a lot of decisions, not our energy consumption and the impact this has on the natural world. How can we learn to optimize the performance of goods and services to sip energy rather than gulp it?

3. Nature fits form to function
A tree is rooted in the ground to draw water and nutrients from the soil; it spreads its branches and leaves wide to increase surface area and absorb the sunlight to produce energy and grow. Seeds are lightweight and some even come equipped with a sort of umbrella so they can float in the air. Nature creates designs for the function they provide, so should our buildings, transportation systems and schools.

4. Nature recycles everything
There is no 'away' to throw things. Everything produced in nature is biodegradable, there is no waste. There can still be abundance, look at all the blossom on a cherry tree, but that all serves a purpose and will be food and nutrients for others. Once the natural life of a pinecone has come and gone, it breaks down into essential elements that are repurposed into new life.

5. Nature rewards cooperation
We see competition in nature, but only when it's impossible to avoid; in general competition costs too much energy. On the other hand, very little in nature exists in isolation. Plants cooperate with pollinators to disperse seeds, and the pollinators feed on nectar. Ladybirds feed on aphids and help plants to stay healthy. Nature favours cooperation because it maintains the health of the whole system.

6. Nature banks on diversity
Diversity is one of nature's best insurance policies. When one food source is unavailable, others can be found. Plants use several different strategies to spread seed or defend against predators. We know that species with limited genetic diversity have more difficulty adapting to environmental change, and that ecosystems rich with diversity are more stable.

7. Nature demands local expertise
Nature's systems are inherently local. Certain species thrive under specific conditions; local and regional weather patterns matter, as do other conditions such as soil, air quality and water temperature. Relationships are created locally and local resources are used. Of course, some birds travel long distances but have you seen them take their food with them?

8. Nature seeks balance
Ecosystems will always try to keep in balance. More mice? Then you will see more owls to feed on the mice and keep the population in balance. Forest fires are a great example of a natural phenomenon that renews and refreshes, reducing excessive growth and allowing for regeneration. Every natural system has a tipping point, a carrying capacity or a state of disequilibrium that triggers a change to a different state.

9. Nature taps the power of limits
Unlimited growth on a finite earth is not a good idea. All living things are governed by limitations; age, climate, population density and many other factors determine how species and systems develop. Nature has found ingenious ways to work within these limits to be as productive as possible over the long run.