**GLOW** ***'Look, Capture and Create'***

**Session 4** ***Biodiversity and Beauty***

***Form and Function in Plants*** **with Neil Paterson Education Officer at the University of Dundee Botanic Garden**

“Biodiversity” is the word we use to refer to the numbers of different kinds of living thing in a particular place. We can talk about the biodiversity of a very small area, a whole country or even the whole world. Nobody knows how many different species there are. Scientists have named about 14 million but that may be only one tenth of the total! Compared to animals, bacteria and fungi, there are relatively few species of plants but, even so, there are around 300,000 different kinds of plant and 260,000 of those are flowering plants.

The likely reason for all this diversity is that organisms have been driven by competition to find more and more different ways of life to survive and these different ways of life require different adaptations – some of these adaptations involve shape and patterns.

Today I want to show you some shapes and patterns you can find in plants. My main interest is in how they connect with the life of the plant but the shapes often seem beautiful to us too.

**Cacti and life in deserts**

In this glasshouse we have a nice collection of desert plants. Because deserts are harsh environments with very little water, the plants have to be specially adapted to survive.

If you look at a cactus, the first thing to notice is that their bodies are thick and green and they don’t have leaves. They suck up water when it does rain and store lots of water in their green bodies so they can keep wet while they’re waiting for it to rain again. Now, because a cactus is full of water, thirsty animals will want to get at that water so the plant has to protect itself. It does this by growing spines and barbed hairs from points on the stem where its ancestors once grew leaves.

Cacti come in three main shapes (Fig. 1). There are ones with long columns of stems, ones with flat blades like Mickey Mouse ears and football-shaped ones called barrel cacti.

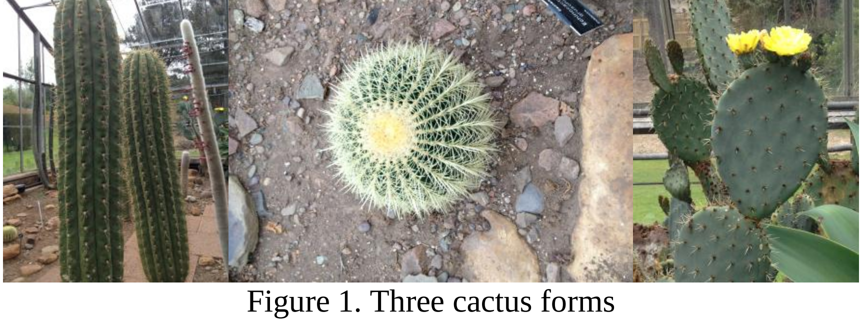

Figure 1. Three cactus forms

How do these forms help the plants survive in hot, dry environments?

Well, the football-shaped barrel cacti are minimising water loss because the greater the surface area of a plant, the more water it loses by evaporation.  Now, a sphere has the smallest possible surface area for a given volume so a football-shaped plant has reduced its surface as much as possible, helping keep water in.

The flat-blades are more-or-less standing upright.  This means that when the sun is high in the sky at midday and it's at its hottest, the blades receive as little light and heat as possible, so keeping the plant a little cooler than otherwise, which helps reduce evaporation of water.  In our cool climate, leaves tend to be held flat on to the sun to get as much light as possible.

Both the barrel cactus and the columnar cactus, like most cacti, have deep ridges on their stems.  When it's sunny you can see why this might be.  If the stem is round, half the stem will be shaded, but a ridged stem casts shadows on itself and so more than half is in shade at any one time, so keeping the plant cooler and reducing water evaporation.

Before we leave the cacti, I want to compare these two plants.  They both have thick, green succulent stems filled with water and you can see that they're protected by spines and that the stems are ridged.  They have other hidden similarities as well and most people would believe me if I said they were both cacti.  However, this one is a euphorbia, from Africa, while the cacti are an American plant family.

What's happened is that these two groups of plants, because they live in the same hot, dry kinds of habitat, have evolved the same solutions to the same problems, even though they're completely unrelated.  This is called convergent evolution.

A B C D

Figure 2.  Evolutionary convergence of cacti (A and C) and euphorbias (B and D)

**How leaves are arranged on a stem**

The word that plant scientists use to describe the arrangement of leaves on a stem is "phyllotaxis" which is made up from the Greek words for "leaf" and "order".

Leaves aren't just stuck onto a stem at random. They grow in definite arrangements which differ from species to species. Here's a sunflower (Fig. 3) which has leaves in pairs with each leaf opposite its neighbour on the stem. The next pair are also opposite to each other but they're rotated by 90 degrees compared to the first pair. This pattern continues down the stem. The effect of this arrangement is to reduce the shading of each set of leaves by the leaves above.

Figure 3. Sunflower phyllotaxis

Here's another example from a plant called *Aeonium*. Each rank of leaves is offset compared to the rank below and again this reduces the degree of overlap and shading of the lower leaves by the upper leaves.

Figure 4. *Aeonium* phyllotaxis

You should look at other plants and see how their leaves are arranged. You can also design your own plants – make sure that there's as little self-shading as possible.

**Some flowers – what do these different shaped flowers have in common?**

This spectacular flower is called Angels trumpets (Fig. 5). This beautiful red bottlebrush (Fig. 6) is made up of lots of tiny flowers and this last one is called Bird-of-paradise (Fig. 7). Their shapes are very complicated and quite different from each other.

Figure 5. Angels trumpets with drops of sweet nectar

What do they have in common? First they make spectacularly visible displays with their bright colours. Second, they all produce lots of sweet nectar, packed with sugars. Third, they don't smell. What these flowers are doing is attracting animals to take pollen from one flower to another so they can make seeds and reproduce. Pollination can be done by wind, water, bats and, especially, insects like bees and butterflies. These flowers are pollinated by birds.

Figure 6. Bottlebrush

Birds have no sense of smell and forage by sight so the colours make the flowers conspicuous to birds. But the most important thing that bird-pollinated flowers have in common is their sweet nectar. Birds, even small ones, are relatively heavy flying machines and they need enormous amounts of energy to keep flying. Only a flower that gives them a seriously high energy meal can get them interested.

Figure 7. Bird-of-paradise flower with thick sweet nectar being squeezed out (right)

You can see the drops of nectar dripping down the inside of the petals on the Angels trumpets and I can squeeze very thick nectar from the Bird-of-paradise. And with the bottlebrush, if you squeeze the little flowers, your fingers get sticky with the sweet sugary nectar.

Incidentally, it's a very special kind of bird which pollinates the Angels trumpets. Because the flower hangs down like this, there's no place for a bird to stand while it's feeding so this flower especially attracts hummingbirds which can hover while they're feeding.

**Plant shapes and maths**

We've already seen a connection between maths and shapes in the barrel cacti where using a ball shape minimises the surface area for a given volume. I want to look at two more examples of maths and plant shapes.

1. **Fractal shapes**

Fractal shapes are strange mathematical objects which show what is called self-similarity. This means that if you look at a close-up of the shape, you can see the same shape again, only smaller. This process can go for ever with the same shape always appearing but getting tinier and tinier for as long as we want to go on. Figure 8 shows a mathematical pattern called the Mandelbrot set. Each of the small blobs off the big blob is a copy of the big blob and they in turn have smaller blobs which are also copies and so on for as long as we can be bothered to continue.

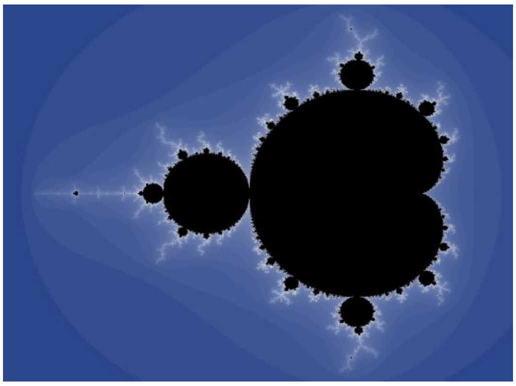

Figure 8. The Mandelbrot set – infinite self-similarity

Now approximate self-similar fractal shapes are found in nature. They don't go on for ever like pure mathematical fractals though, because the physical objects involved end up too small to show the shapes.

Think of how a branch of a tree is like a miniature version of the whole tree and how littler branches are like smaller copies of bigger branches.

Look at this fern. The big frond – fern leaves are called fronds – is made up of smaller similar units and each of these is made up of even smaller similar units. I think that we have four levels of self-similarity here.

Figure 9. Four levels of fractal-like self-similarity in a fern frond

You can find computer applications for drawing fractal shapes. Try making a tree-like shape where each branch is the same as the bigger branch it comes from.

2. **Fibonacci numbers in daisy-like flowers**

Plants from the daisy family, like daisies, dandelions and sunflowers are called composites because they have flowering heads made up of two different types of flower. On the rim what looks like petals are actually female flowers while in the middle is a disk of lots of tightly-packed little flowers each of which is both male and female.

Before we look at the flower heads I want to write down a list of numbers. I'll start with a 1, then another 1 and, from now on, each new number will be the previous two numbers added together. So 1 + 1 = 2, 2 +1 = 3, 3 + 2 = 5, 5 + 3 = 8, and so on:

**1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, …**

(the dots mean we can carry on as long as we want)

This is called a Fibonacci series after the Italian mathematician who invented it more than 800 years ago in 1202. But what's it got to do with flowers?

Well, let's look at the middle of this sunflower's flowering head – Fig. 10 also shows the same effect in another daisy family plant *Doronicum*. Can you see that the little flowers are arranged in spirals, some running right to left and the others left to right. If you can count the spirals in the two directions, you should find that there are more running to the right than to the left and that they turn out to be two consecutive numbers from the Fibonacci series. Also, if you count the female flowers on the rim, they come out as a Fibonacci number, like 34 or 55.

Figure 10. Spirals in the disk of *Doronicum*

The best way of counting the spirals is to take a photo and print it out and laminate it. Then you can mark out the spirals with a suitable pen and then count them. What I'd like you to do is to count spirals and rim flowers from a number of flowering heads and send your results to us at the Garden – we'll put the results together and see what we all come up with.  Remember to say which types of plant you use.

I'm afraid I can't go into exactly why Fibonacci numbers turn up in sunflowers.  The overall reason though is that growth patterns that avoid these numbers will produce flowering heads where the little flowers aren't packed together as efficiently as possible – evolution by natural selection has found the best solution and that solution has to involve Fibonacci numbers.  I've written a brief explanation for teachers to explore if they want to know how this works.

I hope that you've found these plant shapes interesting as well as beautiful.  When you see an interesting shape in any living thing, remember to ask yourself whether the shape could have a function in helping it survive better in its environment.