Supplemental instructor materials for
SCIENTIFICALLY THINKING
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Here are discussion activities based on photographic images. All photos are by the author, Stanley A. Rice, and can be used freely for classroom discussion. The instructor can show these images to students and ask them to discuss answers to the questions provided, or to other questions generated by the instructor (or the students). These discussions should not only promote scientific thinking in students but also enhance their habit of *noticing* things in the world around them. Each instructor will want to design his or her own discussion, but to aid in this process, the author has provided background information to the instructor separately from the discussion questions themselves. The author got the idea for classroom discussion of photos from renowned science educator Gordon Uno of the University of Oklahoma. Instructors, feel free to bring in your own photos for discussion!

Figures 1 and 2.

What kinds of scientific hypotheses could you test using tree rings? A tree forms a new ring of wood each year, outward from the center of the trunk. A ring consists of relatively large sap vessels produced in the spring (light-colored wood) and relatively small sap vessels produced in the summer (dark-colored wood). A ring is therefore a band of wood, half of which is light, and half of which is dark.

- About how many years old was the tree on the left when it died?
- One of these trunks is from the fast-growing red oak (*Quercus rubra*); the other is from the slow-growing post oak (*Q. stellata*). Which one is which?
- Can you tell exactly how old the tree on the right was when it died?
- What kind of information can you get from the fact that some of the rings are thicker than others? This is true of both examples, but is more easily seen in the sample on the left.

Instructor notes for Figures 1 and 2:

- Not all the rings are visible in either photo; students will have to estimate the number of rings. This is an important skill for students: to estimate, rather than just making a wild-assed guess.
- A thick ring of wood means a good year, a thin ring means a bad year, for tree growth. In a hot dry forest, a thick ring means a wet summer; in a colder, wet forest, a thick ring means a warm summer. You can discuss the construct validity (Chapter 11) of tree rings as a record of past climates.

Figure 3.

This is a “fairy ring” of mushrooms. According to folklore, magical little people dance in the middle of it. In order to generate a scientific hypothesis about how fairy rings form, you need some background information. In particular:

- Most of the fungus consists of invisible (to you) strands that grow through the soil and digest leaf litter and dead wood. After a few years, the strands deplete the soil of the nutrients that it needs, especially nitrogen. They get nutrients mainly at the leading edge of the growth of the strands.
- Mushrooms form when fungal strands fuse together, and they do so mostly in locations in which the soil is rich.
- Fairy rings form in woodlands, lawns (which is where you usually see them), and grasslands.

Given this information:

- Generate a scientific hypothesis for how a fairy ring forms.
- The fairy ring looks like it has formed around the base of a tree that is no longer present. Does this have to always be the case?

Instructor: This activity gives practice with hypothesis formation (Chapter 1).

Figure 4.

What happened here in this yard?

- Is it possible that this might be a fairy ring? Fungal strands, by digesting dead grass and wood, sometimes liberate enough mineral nutrients such as nitrogen that they cause the grass to become greener. You can sometimes see a fairy ring as a ring of green grass from which the mushrooms have not yet emerged. How would you test the hypothesis that this is a fairy ring?
- If this is not a fairy ring, what might it be? Be as specific as possible. Note that this picture was taken in a lawn next to apartment buildings, and note the cigarette butts. Your alternative explanation should include both why the ring is green *and* why the middle is barren.

Instructor: This activity provides practice with thinking of previously-overlooked factors to generate alternative hypotheses (Chapter 12). In leading the discussion, ask the students whether it was a male dog or a female dog.

Figure 5. The instructor can have students search online (or maybe even in a book??) for information about the life and work of George Washington Carver and share their discoveries with the class. The author's explanation for why Carver is his favorite scientist is in Chapter 20. See also the author's Darwin Channel video at: http://youtu.be/okynvvXcOGQ.

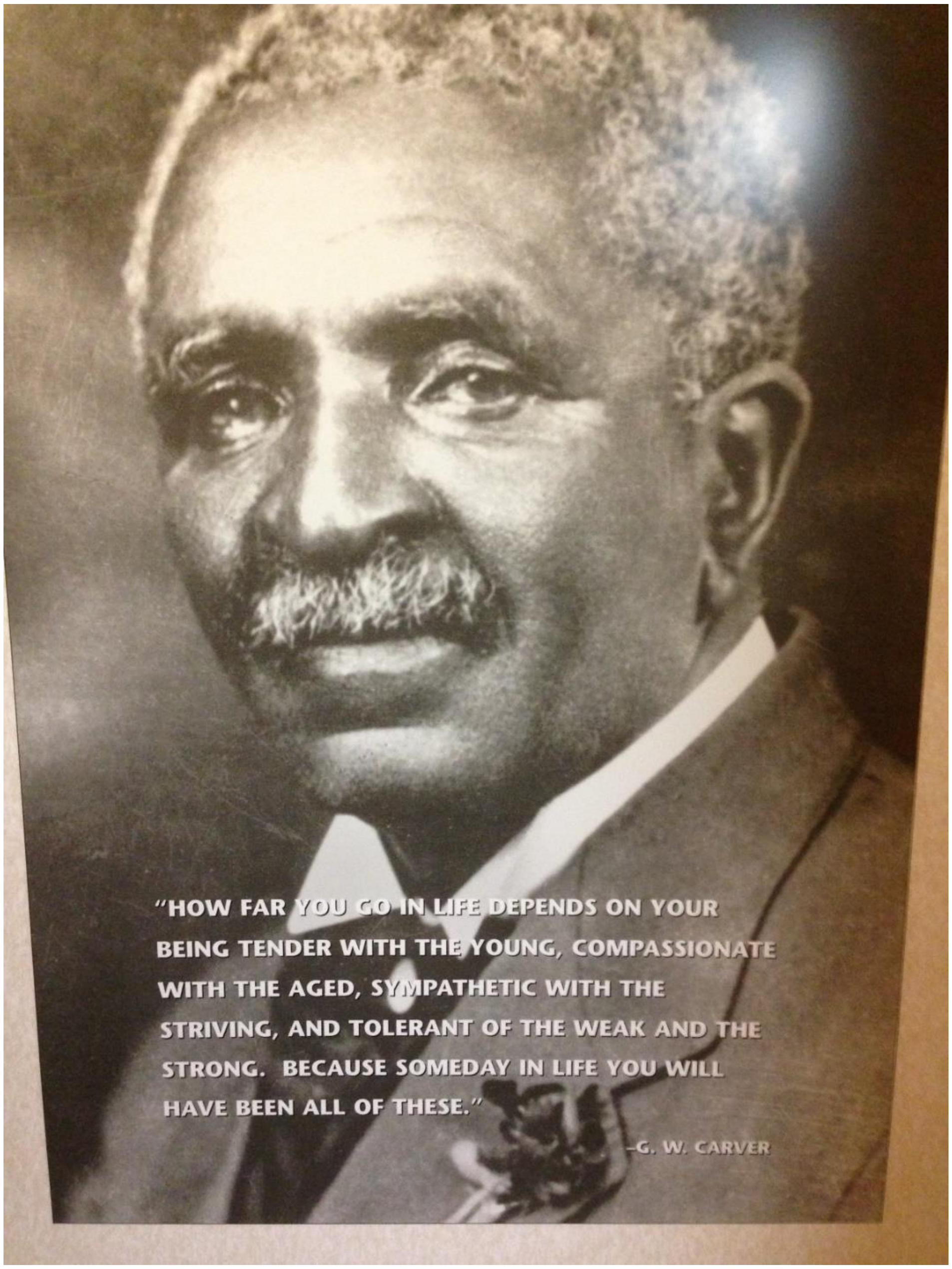


Figure 6. Fossilized bones of horses at Ashfall Beds State Historic Park in northeastern Nebraska. It's sort of an out-of-the-way place, but worth the time to visit! See the author's Darwin Channel video at: https://youtu.be/gSKaBEWrLy4.

- Usually fossils form in sediments at the bottom of rivers, lakes, or shallow seas. When this happens, the bones are usually disarticulated (that is, they fall apart from one another and scientists have to put them back together). But here, the bones are all in place. How did this happen? Hint: the matrix around the bones is volcanic ash.
- The volcanic ash is very fine. There are no coarse ash particles. What does this tell you about the location of the volcano that produced it? That is, how far away would the volcano have been, and would it have been to the east, or to the west?
- Okay, so the animals got buried in volcanic ash. But why did they all come to this one place to die? Hint: When an animal breathes fine volcanic dust, it gets very thirsty.

- This deposit formed 12 million years ago. At that time, the savannas of North America had many species of animals that are no longer native to the region, including hippopotamus and camel. What happened to these animals? Is this true even of the horses?
- There are five species of horses in Ashfall Beds. Some of them have multiple toes. How does this compare with modern horses, and what do the twelve-million-year-old skeletons of multiple-toed horses tell you?

Notes for instructor:

- The discussion about where the volcano was located involves a knowledge of prevailing winds (from the west) and the role of volcanoes in mountain-building in western North America. The volcano was actually located in what is now Idaho.
- You may also want to discuss radiometric dating, which gave us the figure of 12 million years. Uranium-to-lead radiometric dating can only be done on volcanic layers, and geologists use only the zircon crystals, not the whole layer of rock, to determine the radiometric age. The radiometric dating technique assumes that all of the lead came from the decay of uranium, an assumption that is true in a crystal, but not necessarily true in a rock layer. If your students know some chemistry, you can discuss with them why uranium and lead cannot coexist in a crystal when it first forms, because these two kinds of atom have different valence (number of outer electrons).
- For the discussion of what happened to the many animals that used to live in what is now Nebraska, including horses, please note that modern wild horses in America are the descendants of horses that escaped from the Spaniards about four hundred years ago.

Figure 7. Aspen trees *(Populus tremuloides)*, such as this tree in Wyoming, grow very rapidly. You can see, in this photo, one of the reasons. Notice the outer bark of aspen bark is thin, tight, and white, with a green layer of cortex underneath it. Do all trees have this adaptation?

Instructor: The chlorophyll in the cortex just underneath the bark produces extra food and allows aspens to grow faster. Most trees do not have this adaptation. The thin white bark is translucent.

Figure 8. This "leaf fossil" was formed 15 million years ago in what is today Idaho (at Fossil Bowl near the little town of Clarkia). This and thousands of other leaves like it were buried by sediments in a shallow lake. The water had little oxygen, so the leaves did not decompose very much. The loose sediments can today be pried apart with a knife, revealing the leaves. (You can see a video of the son of the land owner splitting open the sediment layers on the author's Darwin Channel; the direct link to the video is here [http://youtu.be/ml4oT5zuiBk]. The leaves are often reddish when first exposed to the air, after which exposure to oxygen rapidly turns them into black charcoal. Therefore, this leaf is not really a fossil; fossils form when minerals replace the original molecules of the dead organ or organism. But the carbon atoms of this leaf were actually *in the original leaf*. Most leaf fossils are just impressions that the now-decomposed leaf left in the sediments. This photo shows a leaf from an extinct species of sweetgum (three-lobed leaf below the author's thumb) and a beech leaf (inverted, upper right). Discussion questions are on the next page.

Discussion questions for Figure 8.

- What could you learn from this leaf that you could not from just a fossil impression? (Note that the organic molecules quickly turn to charcoal upon exposure to air.)
- This leaf is from a now-extinct species of sweetgum tree. Today, sweetgums do not grow in Idaho. They grow in Asia and eastern Europe, and in southeastern North America. Why did they become extinct in Idaho during the last 15 million years? Think about how the climate is different in Idaho from these other places, in terms of moisture and temperature.
- What caused Idaho's climate to change? Note: the Cascade Mountains to the west are volcanic and have risen mostly in the last 15 million years.
- How do we know that these leaves were buried 15 million years ago?
- What evidence might you expect to verify the hypothesis that the leaves were buried in sediments with very little oxygen? Note that these sediments still smell like hydrogen sulfide when they are first exposed.

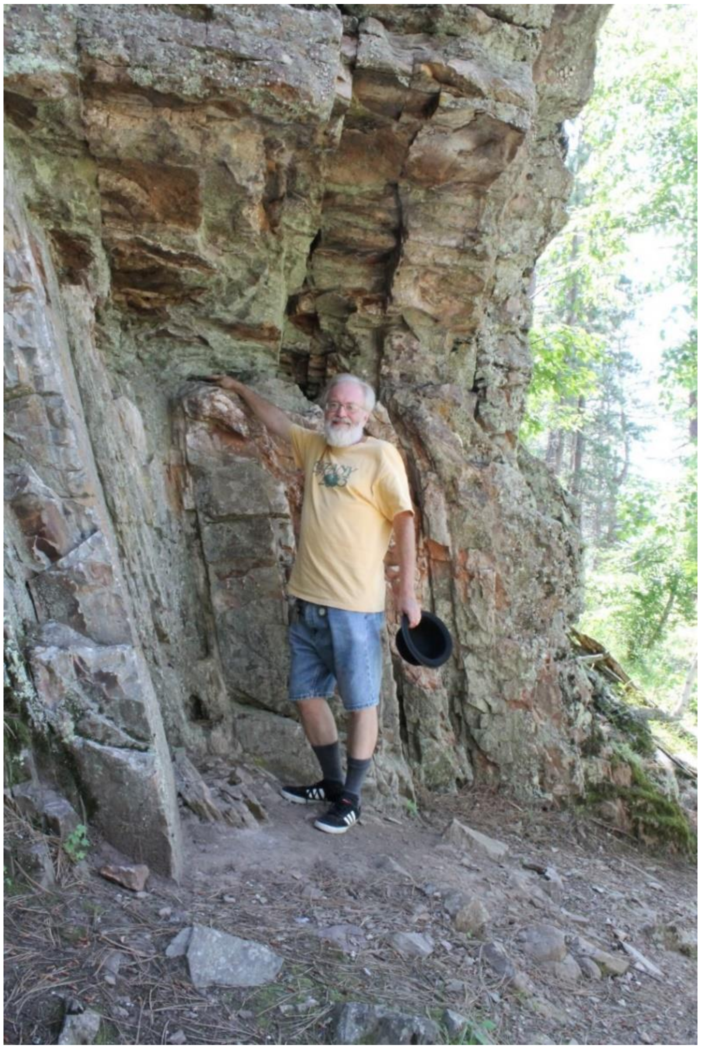
Instructor:

- Today, Idaho is mostly high elevation and is too cold for sweetgums to grow. Also, the Cascade Mountains, to the west, were formed by volcanic eruptions mostly during the last 15 million years. The Cascade Mountains form a rain shadow, which makes most of the rain fall on the Pacific slope rather than on the east side of the mountains.
- Volcanic dust can be found in some of the sediment layers at Fossil Bowl. The discussion about how we know the leaves are 15 million years old is similar to the discussion of Figure 6.
- Hydrogen sulfide forms under anaerobic conditions and is frequently the nasty smell of a swamp.

Figures 9 and 10. This is a close-up of petrified wood from Petrified Forest National Park in Arizona. Over 250 million years ago, this was the wood of a living tree that fell into water and decomposed slowly. Today, it consists of rock minerals, which includes metal ions that create colors that were not originally present in the wood. You can still see the wood grain. There are entire logs of petrified wood. The trees, genus *Auracarioxylon*, are now extinct. See the author's Darwin Channel video at: http://youtu.be/-NGZ3YlvxWY.

Instructor: Have your students explain how this petrified wood formed (slow decomposition in mineral water, in which minerals fill the space once occupied by living cells).

Figure 11. The author is standing beside the Great Unconformity in the Black Hills of South Dakota. Notice that the bottom layers are tilted about sixty degrees, while the top layers are horizontal. This formation is solid rock and is now at approximately four thousand feet of elevation above sea level. See the author's Darwin Channel video at: http://youtu.be/X4ZP9NtpPEA.



- How did the bottom layers of sediments form? What was their orientation when they formed?
- What caused the layers to turn sixty degrees on their sides?
- Did the sediments have to be solid rock at the time this happened? Note that no sediments were accumulating at the time this happened.
- Then what happened to form the upper layers of sediments?
- What happened after the upper layers were formed?

Instructor: There are about a billion years of missing history where the author's finger is pointing. The sequence of events, which the students can figure out, was roughly this:

- Sediments accumulated at the bottom of a shallow sea and were compressed into rock by sediments above them.
- Continental movements raised the rocks, and the upper layer of sediments eroded away. This is a good chance to discuss continental drift.
- Continental movements also twisted the rock, causing the layers to tilt.
- The sediments had to be rock at the time they tilted, since the law of gravity would make loose sediments squish downward rather than retaining their tilt.
- The rock layers subsided back down into the ocean.
- New sediment layers accumulated on top of them and were compressed into rock.
- Continental movements raised them again, where we see them today.
- Sea levels were also changing, but not by four thousand feet!

Figure 12. This is the oak tree *Quercus gravesii,* the Graves' oak, here shown in the Chisos Mountains of Big Band National Park. It grows only in ravines and at the bottoms of cliffs high in the desert mountains of extreme southwest Texas and nearby areas of northern Mexico (see the Wikipedia distribution map). At lower elevations in these mountains, and all around these mountains, the landscape is desert shrubland. The gray oak, *Quercus grisea,* has a similar story, as told in the author's Darwin Channel video at: http://youtu.be/EKtx05KUh4E.

How did this oak get to the top of desert mountains? Note that (1) the climate has gotten drier during the last ten to twenty million years; (2) the closest relatives of this species, red oaks, grow in the deciduous forests of the United States. You can also find populations of limber pine (an alpine species of pine found mostly in the western mountains of North America), and sugar maple in the Chisos Mountains.

Figure 13. These sugar maples are growing near Tulsa, Oklahoma. Sugar maples are very rare in Oklahoma. They are abundant in the eastern deciduous forest north and east of Oklahoma. Why are sugar maples found in this particular location? Note that they are growing at the base of north-facing cliffs. Think of as many reasons as you can. Consider that maple *seedlings* cannot tolerate hot dry conditions.

Figure 14. Why is this twig melting into the snow? Explain the steps that have caused this to happen. Does snow absorb very much sunlight? Does the twig absorb very much sunlight? Note that the sun is shining in this photo.

This photo can also accompany a discussion of Chapter 9 of *Scientifically Thinking*. Global warming can cause snowmelt, which can result in a "vicious circle" of global warming and snowmelt. This photo allows students to notice something that many of them have seen but never thought about and which confirms the vicious-circle aspect of global climate change.

Figures 15 and 16. These are the *Phacelia strictiflora* wildflowers that grew abundantly after the forest fire as described in Chapter 1 of *Scientifically Thinking*. These are the plants on which we tested the hypothesis that smoke chemicals are necessary for seed germination. The instructor can discuss the experimental procedure with students. Part of this experimental procedure is to produce smoky water in which to germinate the seeds. See how this was done in the Darwin Channel video at: http://youtu.be/1bnJa7yYkyM.

Figure 17. This rock is gypsum (calcium sulfate) that formed millions of years ago at the bottom of a shallow sea that once covered northwestern Oklahoma. Gypsum is white and translucent (that is, light can shine through thin layers of it). What is the green layer just below the surface of the gypsum? Note that it is not inorganic (e.g. it is not an inorganic copper compound) but is organic and consists of living photosynthetic cells. What are the cells? Why do they grow just underneath the gypsum surface?

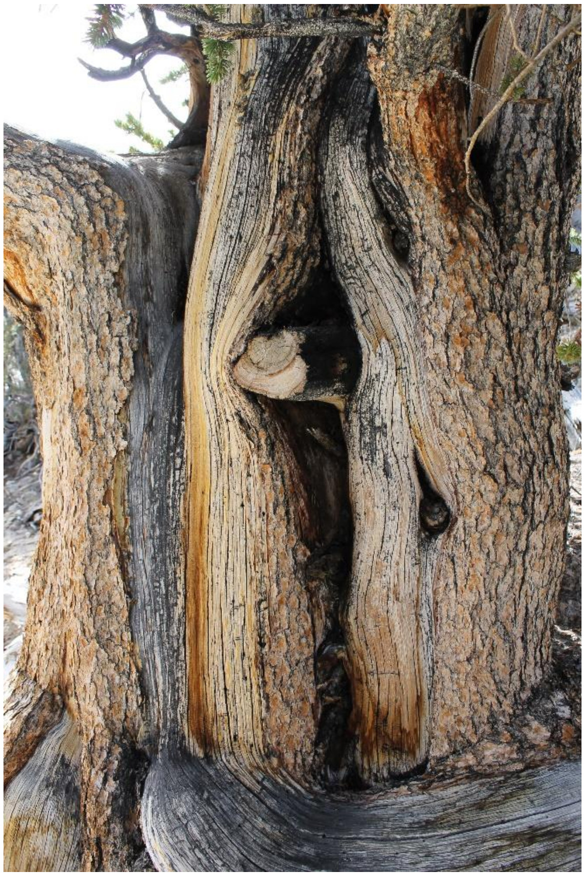
Figure 18. What are the fuzzy balls on these post oak leaves? The leaves have been shed by the tree.

- Grubs of parasitic wasps have formed these “insect galls.” The adult wasps hatch from the galls. But the galls do not consist of insect tissue. The grubs release molecules that affect plant growth. Now, explain how these fuzzy balls formed.
- What would be the advantages to the wasp grub to stimulate gall formation, rather than just eating the leaf tissue?
- What can the tree do to get rid of the galls?

Figure 19. This kind of caterpillar eats the leaves of black cherry trees. They form a dense tent of webs and hide inside of them during the day. They come out at night to eat the leaves. Why, then, are these four caterpillars outside of the tent, while the others are all inside? Note: these caterpillars would occasionally twitch.

Instructor: Have your students read about parasites that alternate between caterpillar and bird hosts, then have them explain what happened to the caterpillars and the advantage that this provides to the parasite. The daytime exposure and twitching would make the caterpillars more visible to birds, the alternate host.

Figures 20 and 21. Bristlecone pines *(Pinus longeava)* such as this one live in the White Mountains of California, where the winters are long and cold, the summers cool and dry, and the soil is very poor. How do these trees survive? See also the Darwin Channel video at: http://youtu.be/eTmSI_QwtR8.



Figures 22 and 23. Figure 22 shows the Sierra Nevada mountains in California from Owens Valley on the dry east side. The peaks in this view include Mt. Whitney, which is the tallest mountain in the United States outside of Alaska. At this same elevation on the moist west slope, there is a thick forest of conifers, as shown in Figure 23, which also includes Mt. Whitney. But on this east slope, there is only desert. Have your students explain why the two sides of the mountain are so different. Hint: Where does the rain and snow come from? See also the Darwin Channel video at: http://youtu.be/uyD32fMfTLM.

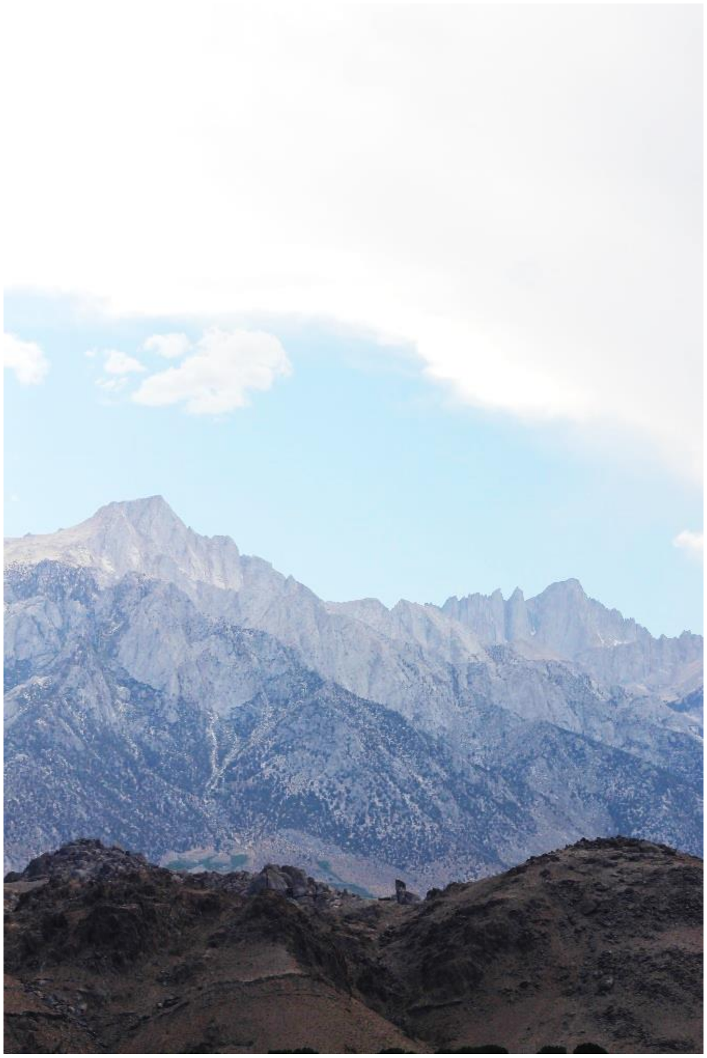
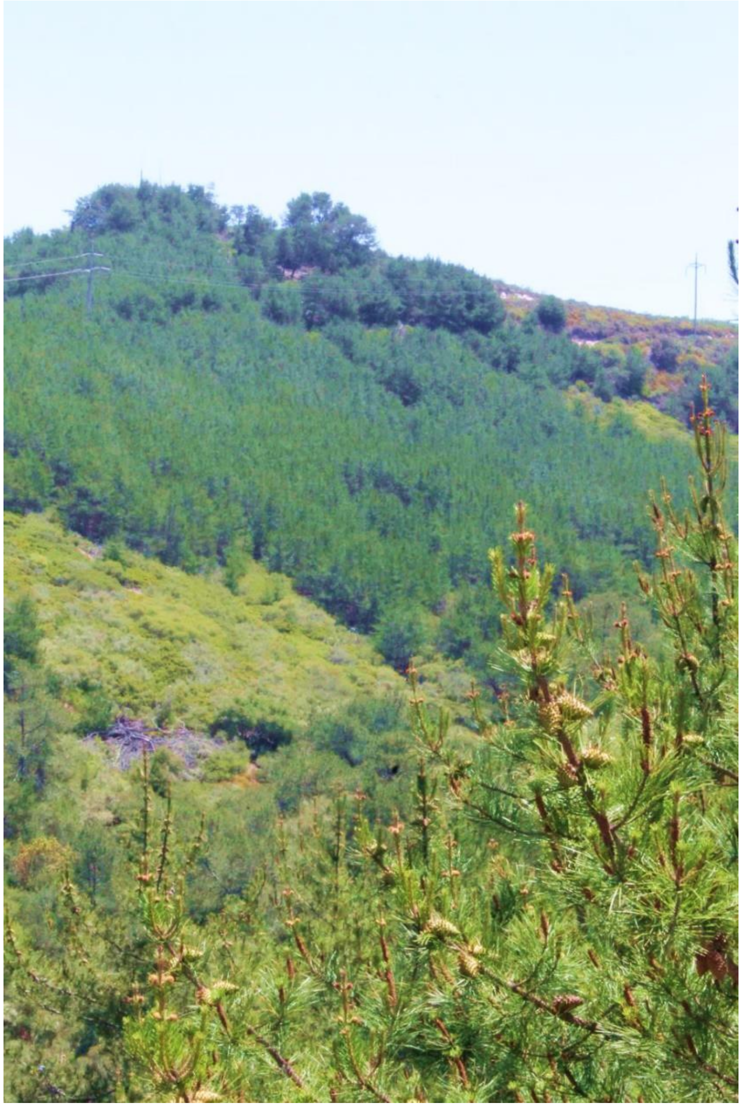


Figure 24. The California pine forest in the distance consists of a single species of pine *(Pinus muricata)* and all the trees are the same age (about 17 years old). How did this happen? And how are the pines adapted to take full advantage of the cause of this event? Note that the cones (on the tree in the foreground) are very dense and they do not open up and drop seeds out the way most pine cones do, unless the event that created this forest occurs. See also the Darwin Channel video at: http://youtu.be/xowPbBi5bl0.



Instructor: The event is fire. A 2005 fire created this forest as seen in 2012. The cones will not open without fire. Mature cones remain unopened on the trees for many years until a fire, nearly inevitable in these dry coastal mountains, comes through. The pine trees at the top of the hill are older than 17 years. The cones do not open immediately as the fire passes through, but fall to the ground after it has cooled off. The role of fires in releasing fertilizer into the soil can also be discussed.

Figure 25. This is a savanna of California black oaks *(Quercus kelloggii)* and grasses below Sequoia National Park in California. Most of the trees are growing on just one side of the hills. Which side are the trees growing on and why? (Hint: grasses tolerate drought better than oak trees do.)

Figures 26 and 27. This tiny wildflower *(Linanthus montanus)* grows only on gravelly granite outcrops in the Sierra Nevada Mountains of California where the soil is very shallow. Why do they not grow in areas with deeper soil?

Figures 28 and 29. These giant saguaro cacti in Arizona produce their large flowers only at the very top of the column. Can you think of an advantage this might provide to them? (Hint: pollination is only effective if pollen is carried from the flower of one plant to the flower of another plant of the same species.) What do you think the pollinator might be? (Note: the flowers are open for a short period, but this includes both day and night. The daytime pollinators might be different from the night-time pollinators.)

Instructor: bats pollinate the flowers at night. These bats are not blind. The white color helps them find the flowers.

Figures 30 and 31. This is a mulberry tree in early spring. Or is it? Look at the photo of the base of the trunk.

Instructor: The students will easily figure out that this is (at least) two mulberry trees, not just one. But you can lead them to further discussion.

- Why do two or three trees, growing together, look like one tree? Consider in which direction a branch is most likely to grow: toward the other tree, or away from it.
- How are several mulberry seeds likely to get deposited at the same spot on the ground? Consider that mulberries have many seeds per fruit (it is actually a composite fruit) and dispersed by birds.
- This is also a good chance to discuss how birds disperse seeds. The seeds have hard coats and can survive in a bird's digestive tract. What advantage does the mulberry tree get from having birds disperse its seeds? Specifically, what advantage might there be for getting the seeds far away from the parent? There is more than one answer to this question.
- In some cases, trees even fuse their trunks together. Is this more likely to occur in trees of different species, or of the same species? And would close genetic relatives be more likely to fuse together than trees that are not closely related, even within the same species?