Plant of the day!

*Ophrys* in Europe, 9 genera in Australia

Sexual deception where the flower attracts male pollinators by mimicking a female of the same species (e.g. scent, colour, “hair”)

Typically, pollination by sexual deception is highly specific and usually only involves one insect species

1/3 of the ~25k species of orchids are pollinated by deceit, giving no reward (only 400 are sexually deceptive)
What is co-evolution?

- What is co-evolution?
- Why is it important?
- Examples
Co-evolution: occurs when two (or more) ecologically interacting species exert reciprocal selection pressures on one another and the response is inherited

-trait centered
What is co-evolution?

Species A evolves an adaptation in response to species B

Species B evolves in response to the adaptation of species A
Species A has some trait unrelated to species B. Species B evolves in response to that trait in species A. This isn’t co-evolution.
What is co-evolution?

Co-evolved interactions are important
Mitochondria (Eukaryotes and bacteria-cellular energy)
Chloroplasts (Eukaryotes and cyanobacteria-photosynthesis)
Mycorrhizae (Plants and fungi-nutrition in plants)
Rhizobia (Plants and bacteria-nitrogen fixation in soil)
Pollination (Plants and animals-sexual reproduction in plants)
Seed dispersal (Plants and animals-sexual reproduction in plants)
Parasitism (Hosts and parasites)
Competition
Predators and prey

Complex organisms require coevolved interactions to survive and reproduce

Species rich ecosystems are dependant on coevolved interactions (especially mutualisms)
Important coevolved interactions in plants

Fabaceae host *Rhizobium* (bacteria) in their root nodules

They take up $N_2$ out of the air and convert it to a form of nitrogen that is usable to the host plant

This process is called nitrogen fixation

Mutualism - *Rhizobium* supply the usable nitrogen and plants give organic acids as an energy source

Why don’t the bacteria cheat?
A mycorrhiza is a symbiotic (mutualistic but can be pathogenic) association between a fungus and the roots of a plant.

The fungus colonizes the host plants' roots either intracellularly as in arbuscular mycorrhizal fungi (AMF), or extracellularly as in ectomycorrhizal fungi.

The fungus gets carbohydrates

The plant gets higher absorptive capacity for water and mineral nutrients (due to comparatively large surface area of mycelium:root ratio).
They were running hand in hand, and the Queen went so fast that it was all she could do to keep up with her: and still the Queen kept crying ‘Faster! Faster!’ but Alice felt she could not go faster, though she had not breath left to say so. The most curious part of the thing was, that the trees and the other things round them never changed their places at all: however fast they went, they never seemed to pass anything…

‘In our country,’ said Alice, still panting a little, ‘you’d generally get to somewhere else – if you ran very fast for a long time, as we’ve been doing.’ ‘A slow sort of country!’ said the Queen. ‘Now, here, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!’

Lewis Carroll’s Through the Looking Glass
Red Queen hypothesis

The continual evolutionary change by a species that is necessary to retain its place in an ecosystem because of ongoing co-evolution by other species.
Arms race: The escalating and reciprocal coevolution between the offensive ability of a predator/parasite and the defensive capability of its prey/host
THINK – PAIR - SHARE

How could you tell if an evolutionary arms race had occurred? What would be the signal and how would you detect it?
Darwinian extinction-a decline in mean fitness that occurs as a result of adaptation by natural selection which reduces the size of the population until it becomes inviable.

Example: increase in individual fitness for predator attack rates can lead to increased extinction risk for predator and prey.
Types of coevolution

**Specific:** one species interacts closely with another. Changes in one species induce adaptive changes in the other, and vice-versa.

**Diffuse:** selection imposed reciprocally by one interacting species on another is dependent on the presence or absence of other species.
Coevolution takes multiple forms and generates a diversity of ecological outcomes.

- Antagonistic interaction
- Mutualisms
- Plant herbivore interactions
- Plant pollinator interactions
- Plant pathogen interactions
- Competition
Plant-herbivore coevolution

- Plants produce toxic “secondary” chemicals (not directly involved in growth and reproduction such as terpenoids, alkaloids and phenols) that reduce herbivory

- Some herbivores have evolved to detoxify the toxic chemicals.
  - herbivores may specialize on the hosts whose defenses they have overcome
  - plants may evolve new defenses, and the cycle continues (Red Queen)
  - is there evidence of chemical escalation in plants?
Antagonistic interactions: plant herbivore interactions

*Bursera* spp. produce an array of terpenes that are toxic or repellent to insect herbivores. These terpenes decrease the survival and growth of their specialized herbivores, genus *Blepharida*. Some species even have pressurized resin canals and can entomb their attackers.
Antagonistic interactions: plant herbivore interactions
Did the number of new secondary chemicals in the genus increase over time?

Is the increase lower in those species with mechanical means of defense?

Examined the number and relative concentration of chemical compounds in 70 Bursera species and used a phylogeny to determine if the number and complexity have increased over time

Becerra J X et al. PNAS 2009;106:18062-18066
Antagonistic interactions: plant herbivore interactions

Diversity of secondary compounds (Upper) and complexity of chemical mixtures (Lower) of extant species of Bursera over time.

Becerra J X et al. PNAS 2009;106:18062-18066
Antagonistic interactions: host and parasite systems

• Parasites are constantly evolving into new forms to avoid host resistance

• Hosts are constantly under selective pressure to evolve new resistance genes

• **Resistance** – the ability of the host to combat the parasite

• **Virulence** – the ability of the parasite to harm the host
Antagonistic interactions: host and parasite systems

Effector genes (E) of pathogens suppress host plant defenses

Resistance genes (R) in plants detect effectors eliciting a defense response

*Pseudomonas syringae pv. tomato*

Tomato near-isogenic lines

\[ pto / pto \]

\[ Pto / Pto \]

race 0
\[ avrPto \]

race 1

'S gene-for-gene' model of plant disease resistance
Antagonistic interactions: host and parasite systems

Results in balancing selection
Many R genes are diverse (much like S loci)

R1 plants have low infection rates
R1 rare
E1 common

E1 infect more plants

R1 rare
E1 common

Cost of resistance?

Selection for R1 allele

Selection against E1

Selection against R1

Jones & Dangl Nature 2006
Competition for pollination can lead to reproductive interference that imposes fitness costs

e.g. pollen loss to foreign stigmas and stigma blockage by foreign pollen

- specialization of pollinators
- differences in flowering time
- divergent flower morphology
Antagonistic interactions: competition

Bats visit *Burmeistera* spp. indiscriminately

Anther/stigma exertion influences pollen placement/deposition

Predictions:
Greater the divergence in exertion length between a pair of flowers, the less pollen that bats would transfer interspecifically

Observed differences in exertion length between sympatric species would be significantly greater than those of randomly generated null assemblages
Larger exsertion difference resulted in more conspecific pollen transfer (less interference)

Exsertion difference of sympatric populations was greater than chance (null assemblage)

Local adaptation via character displacement accounted for most of the exsertion difference between sympatric populations

Munchhala and Potts 2007
Mutualism: a symbiotic relationship where both species benefit from the interaction (e.g. the shrew and the pitcher plant)

Mutualisms represent one of the most influential of all biological interactions, with fundamental consequences for the evolution and maintenance of biotic diversity

The obligate mutualisms between flowering plants and their insect pollinators constitute extreme cases of interspecific mutualisms
Reciprocal co-evolution examples: plant pollinator mutualisms

The fig-wasp mutualism is ancient and diverse, originating ≈80-90 million years ago.

750 described species of *Ficus*

>300 wasp species

-One species of wasp thought to pollinate one species of fig (many exceptions)
Extreme specialization in mutualistic interactions is uncommon in free living species. Why?

The coevolutionary vortex!

Mutualisms among free-living species tend to draw other species in as other species try and exploit the interaction (convergent “one-sided” evolution)

Costa Rica: 65 hawkmoth species interact with 31 plant species all with similar floral traits (pollination guilds)
Interactions coevolve as constantly changing geographic mosaics

Coevolution is prominent in some areas (coevolutionary hotspots) but not others (coevolutionary cold spots) that the outcome of an interaction can vary between areas and that gene flow can affect the outcome of interactions.
Reciprocal coevolution and geographic mosaics: pines and crossbills

Benkman et al. 2003
Reciprocal coevolution and geographic mosaics: pines and crossbills

Thin scales
- Easy for crossbills
- Hard for squirrels

Thick scales
- Hard for crossbills
- Easy for squirrels
Reciprocal coevolution and geographic mosaics: pines and crossbills

- Pine + Squirrel + Crossbill = Pine Cone → More curved bill
- Pine + Crossbill = Pine Cone → Less curved bill
Coevolution: summary

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Coevolution takes multiple forms and generates a diversity of ecological outcomes.

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