BIO4102/BIO6102/MSB315

Evolutionary Ecology
(Varsha 2023)

Ullasa Kodandaramaiah

MODULE: PREY-PREDATOR INTERACTIONS

Photo: Science Photo Library / Rex Features

Location: Talakaveri WLS

http://imgur.com/gallery/gGALI

Hemeroplanes triptolemus?

Hawkmoth (Sphingidae)

Dan Janzen's caterpillar database

Hemeroplanes ornatus

Reflection points

- The resemblance in this case involves multiple traits – colour, size, shape, behaviour, etc
- What might have been the steps through which these traits evolved? Did they evolve together? Did one trait evolve first and then another? If so, what could the order have been?
- How can we test hypotheses of origin?
- Does the caterpillar 'know' that it resembles a snake? If so, how?

Mimicry

Evolution of a 'mimic' species to look similar to another unpleasant 'model 'species

Vespula spp (Wasp)
Trounce/Wikimedia Commons

Chrysotoxum cautum (Hoverfly)
Fritz Geller-Grimm

Left: *Vespula* wasp.
Right: Clearwing moth (Fam: Sessidae).

Photo: James Cassler

Model	Mimic
 *Micrurus tener* (Texas Coral Snake) LA Dawson, Wikimedia Commons	 *Lampropeltis triangulum* (Mexican Milk Snake) LA Dawson, Wikimedia Commons
 *Bungarus caeruleus* (Common Krait) Wikipedia/Wikimedia Commons	 *Lycodon* spp (Wolf snake)

Reflection

- Do the mimic and model need to be sympatric for mimicry to be effective?

Reflection

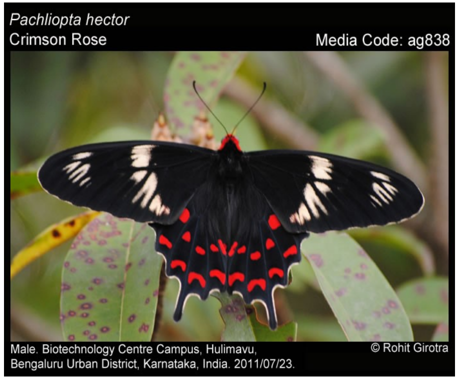
- When a non-venomous snake resembles a venomous one, in my experience, there is a strong tendency for humans to misidentify the non-venomous one as venomous (but it is relatively rare for venomous ones to be misidentified as non-venomous ones).
- Think of evolutionary reasons to explain the 'asymmetry' in the probability of misidentification

Batesian Mimicry (Henry Walter Bates)

The examples discussed so far are examples of a specific type of mimicry called ‘**Batesian mimicry**’, where a harmless mimic species mimics an unpleasant model species

Female limited Batesian mimicry

Mimic



Models

Mimic

Papilio polytes romulus
Indian Common Mormon
Media code: ab204
Female, form stichius. Chiplun, Ratnagiri District, Maharashtra, India. 2007/09/10
© Rohan Lovalekar

Model

Pachliopta aristolochiae aristolochiae
Indian Common Rose
Media code: ab170
Male. Baghmara, South Garo Hills District, Meghalaya, India. 2008/05/02
© Rohan Lovalekar

Alfred Russel Wallace

Mimic

female *Papilio memnon*

(Great Mormon)

Models

male *Papilio memnon*

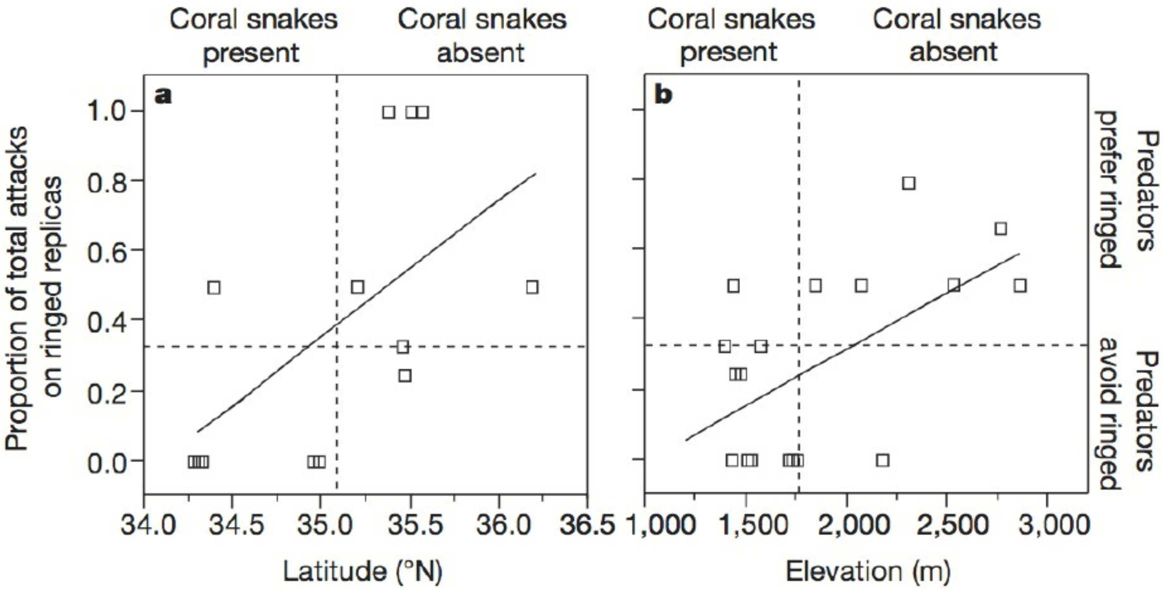
Reflection

- Why do you think Batesian mimicry in *Papilio polytes* & *P. memnon* is restricted to females?

Pfennig et al (2001) *Nature* 410, 323

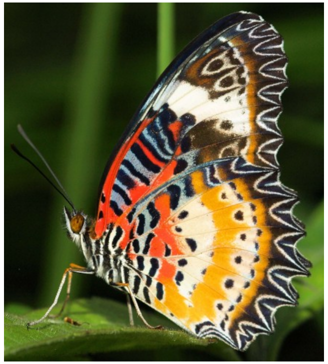
Replica

Mimic (Kingsnake)



Concept: Aposematism

Correlation between *conspicuous signals*, such as bright coloration, and prey *unprofitability*.



Cethosia cyane (Red Lacewing)

'Warning signals'

Dendrobatidae (Poison Dart Frogs)

Photo: Drzewołaz niebieski

Photo: Holger

Photo: Esteban Alzate

Photo: Olaf Leillinger

Photo: Olaf Leillinger

Photo: Geoff Gallice

Bradinus crepitans (Bombardier beetle)

Photo: Thomas Eisner

Mephitis mephitis (Striped skunk)

Source: www.birdphotos.com

Some common features of aposematic colouration

Contrast with background

Internal contrast

Repeated

How does aposematism help?

- *Learning*: Predators learn to correlate unpleasantness with conspicuous signals more rapidly than with cryptic signals

- *Remembrance*

- *Detection*: Distance detection hypothesis. Conspicuous signals are detected at greater distance by predators, giving the predator more time to evaluate suitability of prey.

- *Innate recognition*?

Reflection

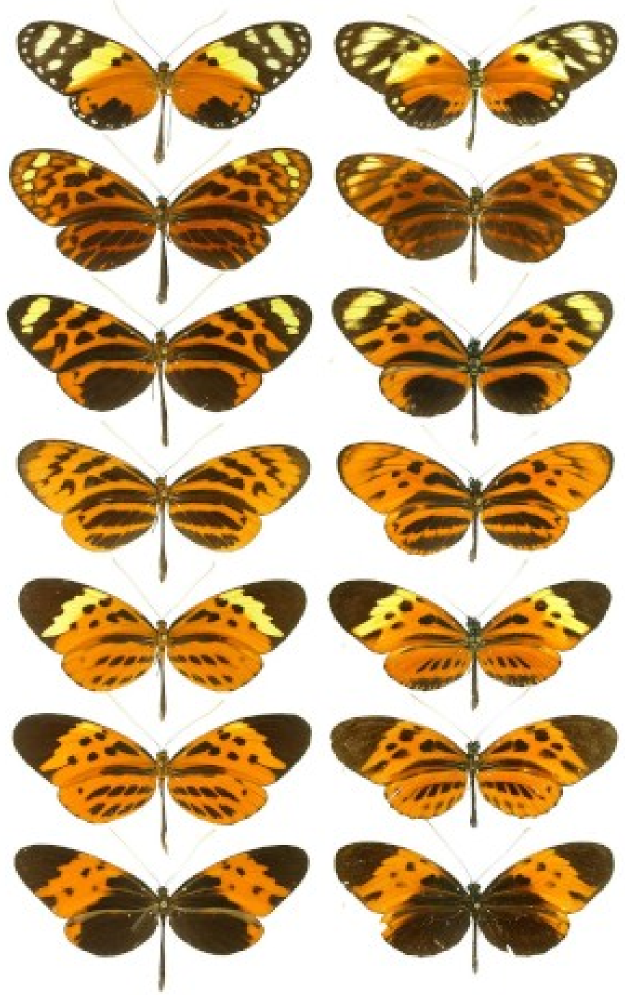
- A predator attacking a highly venomous snake such as a coral snake is likely to die. If so, the predator population cannot *learn* to avoid a particular colour pattern on the snakes.
- What could be the advantage of warning colouration (aposematism) for venomous snakes?

Müllerian mimicry (Fritz Müller)

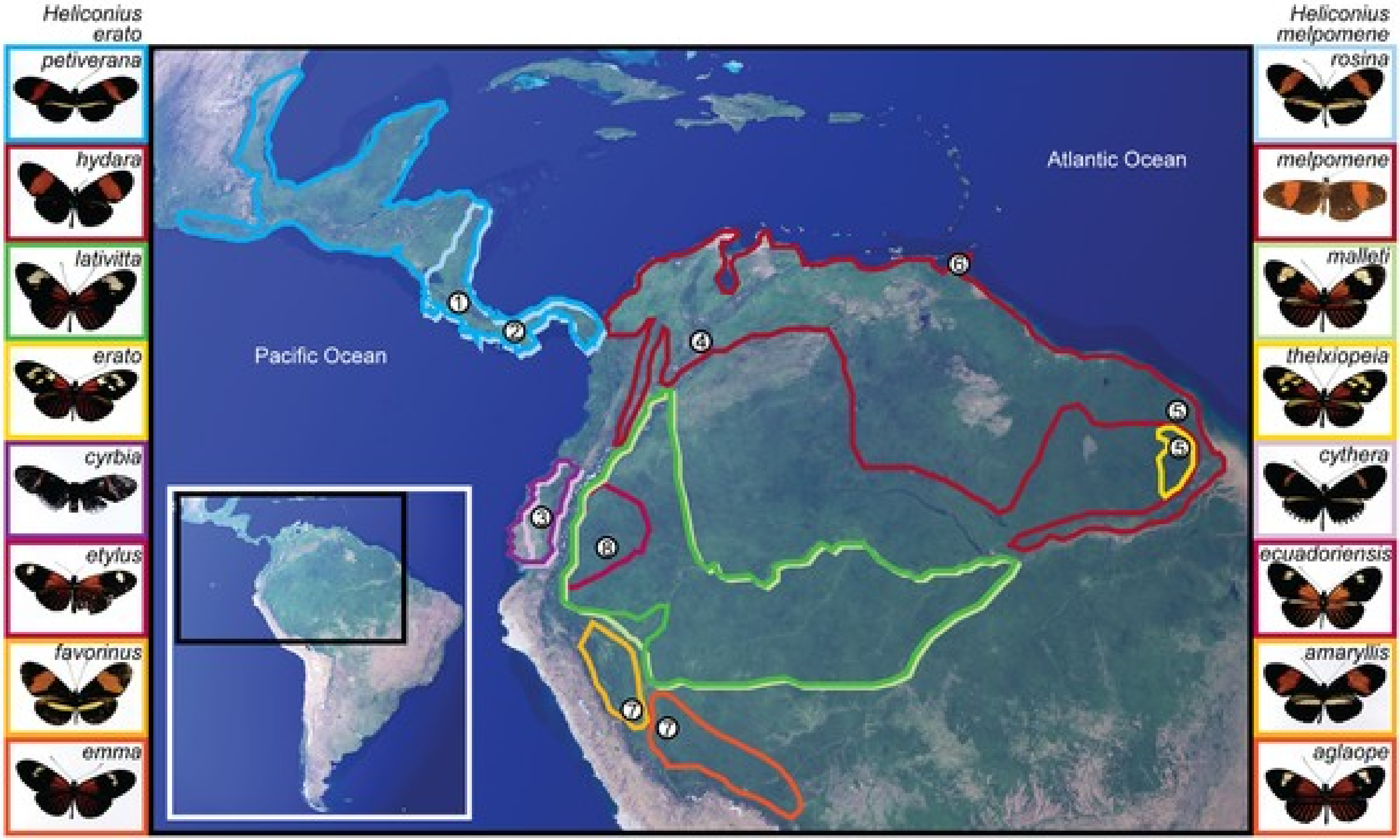
Two or more unpleasant species look similar to each other.

Species are both models and mimics, ie co-mimicry

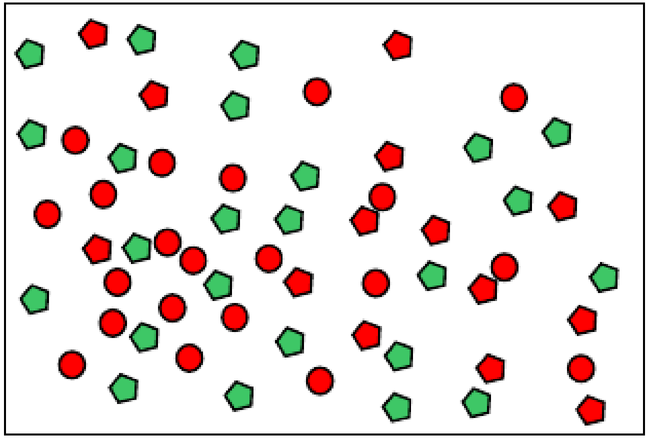
e.g. *Heliconius* & related butterflies



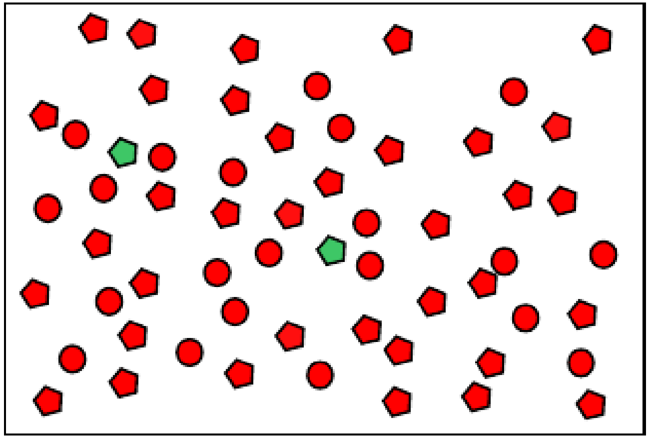
Wing patterns morphs and geographic distributions of the Müllerian co-mimics *Heliconius erato* and *H. melpomene*. Cuthill & Charleston (2012) PLoS ONE 7(5): e36464.



Mimicry rings
(> 2 spp)



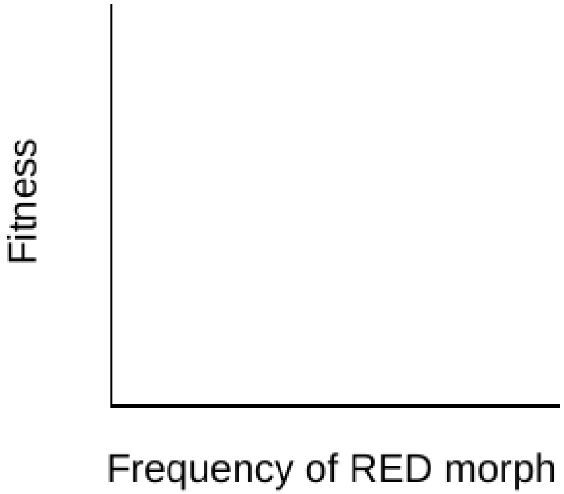
Low frequency of RED morph

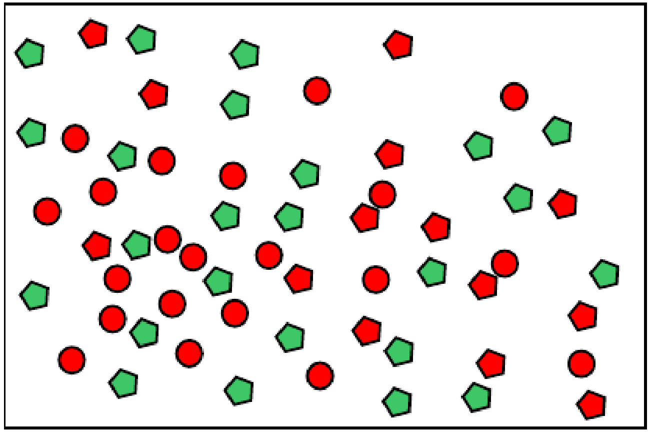


High frequency of RED morph

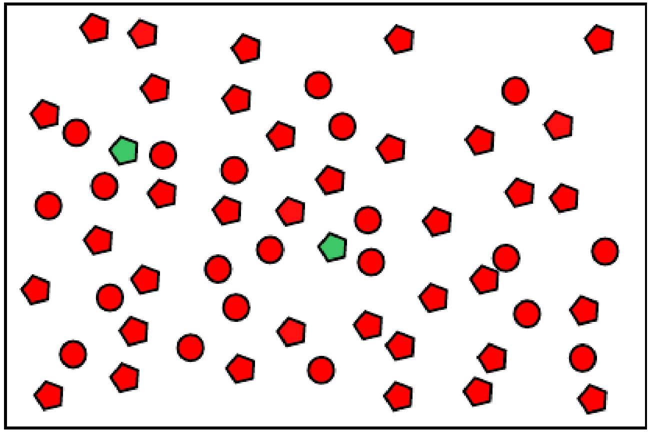
BATESIAN MIMICRY

- ○ Toxic model
- ⬠ Edible mimic





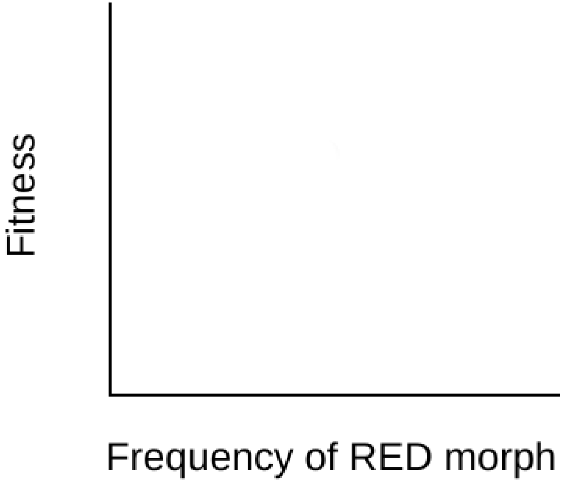
Low frequency of RED morph



High frequency of RED morph

MÜLLERIAN MIMICRY

○ Toxic species
⬠ Toxic species

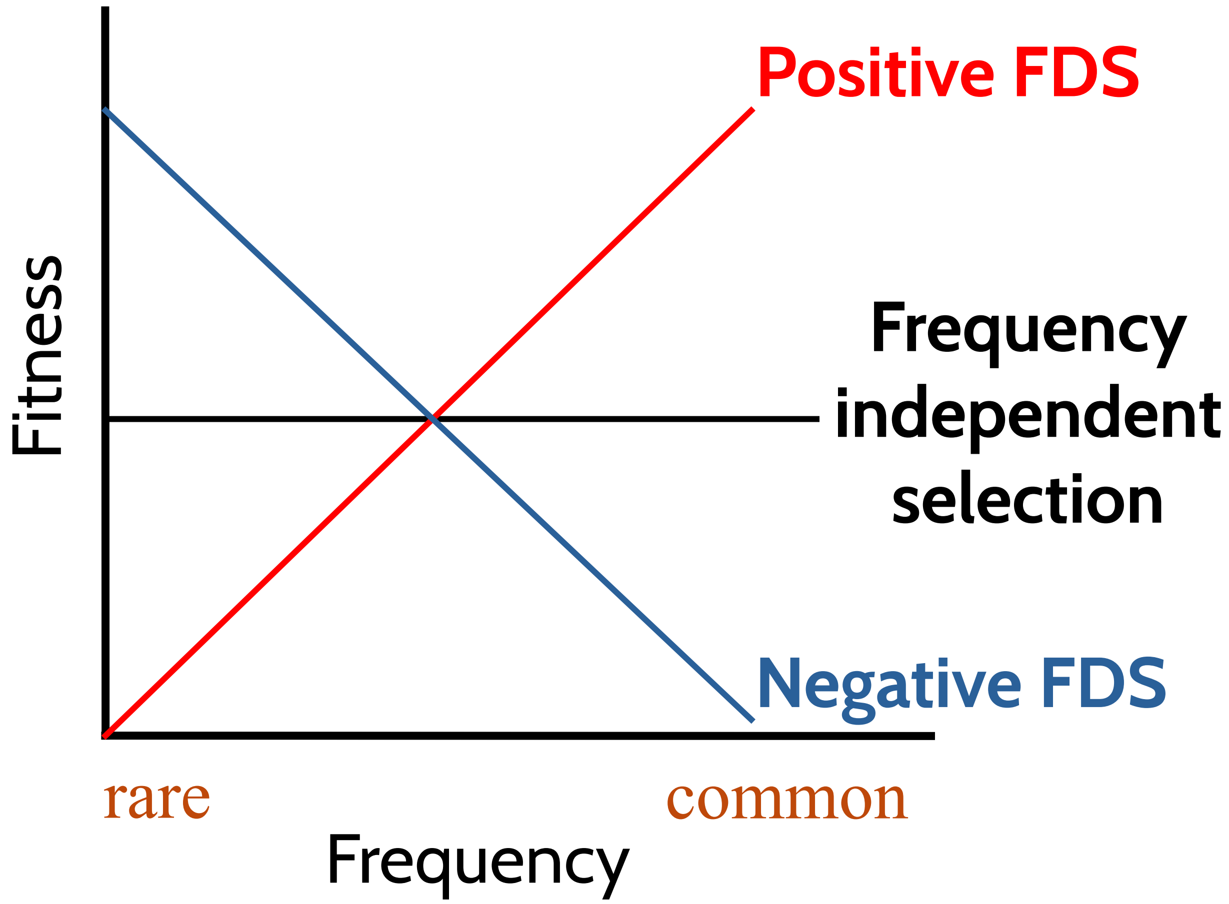


Concept: Frequency dependent selection

FDS: selection where fitness of a phenotype depends on its relative frequency

- **Negative FDS**: fitness of a phenotype *decreases* with increase in relative frequency

- **Positive FDS**: fitness of a phenotype *increases* with increase in relative frequency


Positive FDS
Fitness
Frequency
independent
selection
Negative FDS
rare
common
Frequency

Frequency dependent selection in the cichlid *Peridossus microlepis*

Fig. 1. The handedness of mouth opening of a Lake Tanganyikan scale-eating cichlid, *P. microlepis*. A right-handed (upper) and a left-handed (lower) individual are shown from both sides. [Photo provided by H. Yamasaki]

Hori 1993 *Science*. 260:216-9

P. microlepis – scale eater (feeds on scales from living fish)

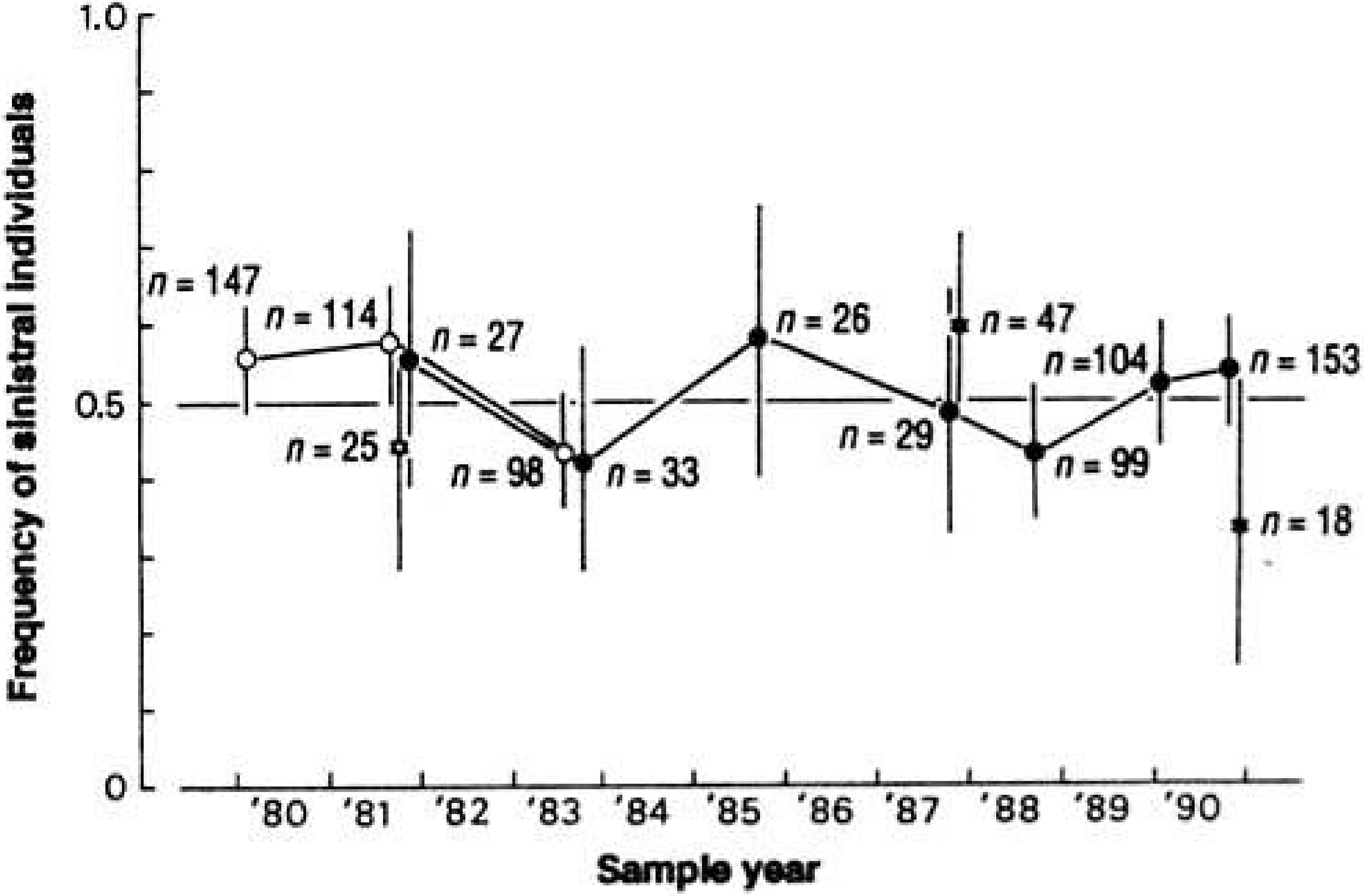
Asymmetrical mouth: left- or right-mouthed (genetically determined)

- Right-mouthed (dextral) – attack from left

- Left-mouthed (sinistral) – attack from right

- Study site: Lake Tanganyika (2 sites)
- Monitored populations for 11 years, sampling at 1-2 year intervals

fluctuations in the frequency of left-mouthed fish



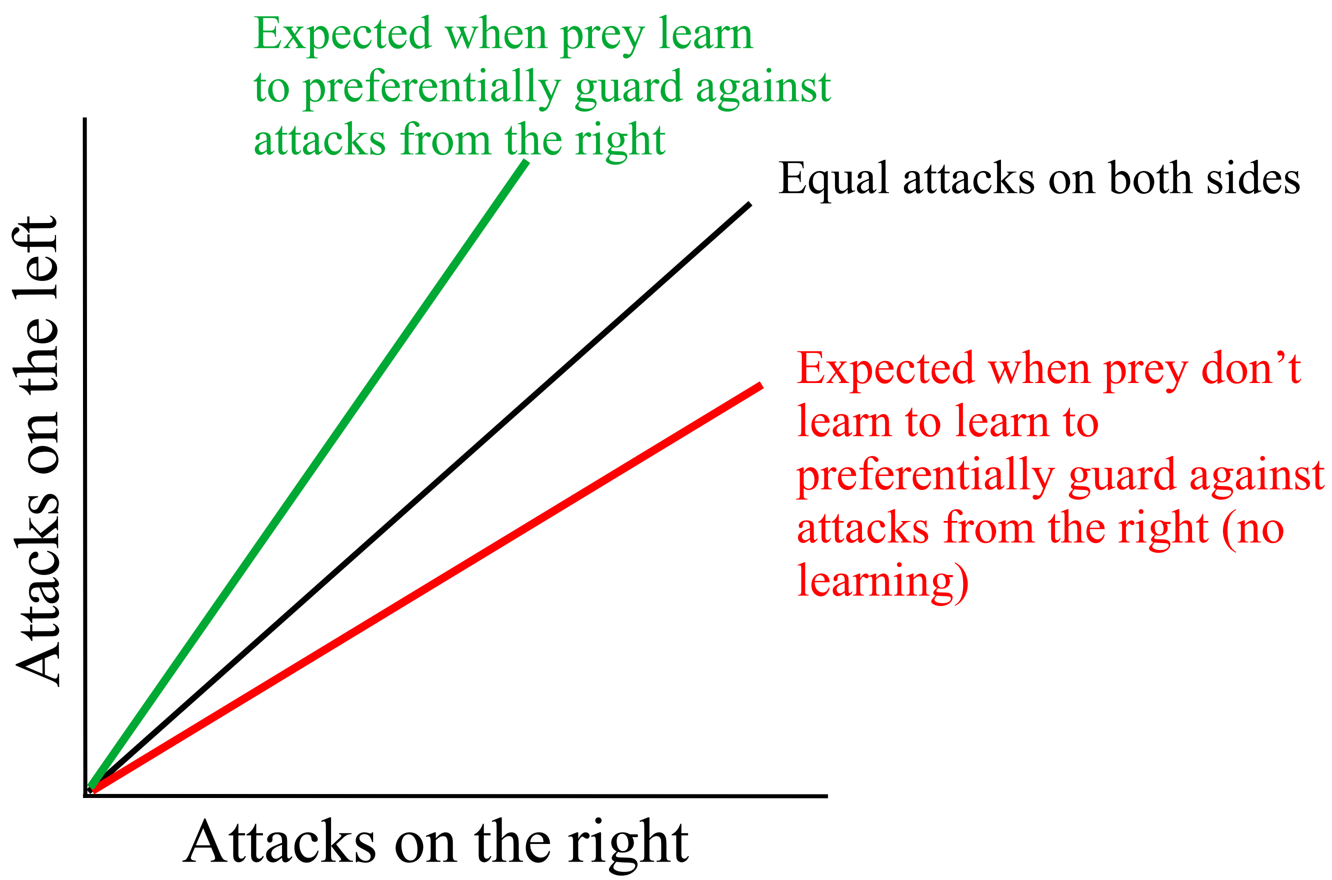
explanation: prey fish learn which side to protect, depending on which morph of *P. microlepis* is common

null hypothesis: success of the two morphs of *P. microlepis* is either equal or proportional to their frequency (no learning by prey)

alternate hypothesis: the common morph will have lower success than the rare morph

- Tested by measuring success rates at times when each morph is common

Sinistral dominant year (*more attacks from the right*)



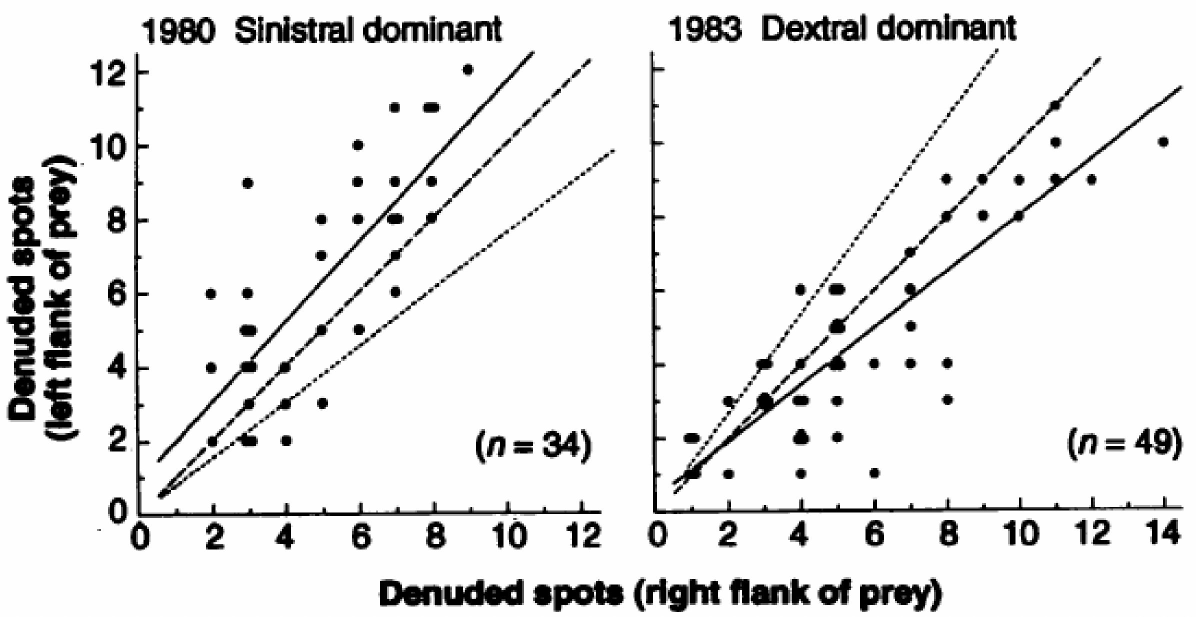


Fig. 3. Denuded spots on each flank of a prey species during two opposite phases of phenotype abundance of *P. microlepis*. The number of denuded spots on each flank of *C. furcifer* taken from Luhanga during the sampling of *P. microlepis* was measured in 1980, when the sinistral phenotype was dominant, and in 1983, when the dextral phenotype was dominant. An experiment with the use of live fish demonstrated that a successful attack by a scale-eater left a characteristic scar, with several scales missing in two adjacent clusters. As scale-eaters other than *P. microlepis* were very rare at this study site (*11*), all such scars were regarded as being caused by this species. The solid lines indicate the regression line of the plotted data points; the broken lines represent an equal number of attacks on right and left flanks—that is, an exact inverse relation to the actual frequency of the two phenotypes in the population. The dotted lines represent attacks to flanks proportional to the actual frequency of the two phenotypes—that is, the prey guard both sides equally, irrespective of the frequency of attack. In 1980, prey species suffered more scale-eating from dextral individuals, as indicated by the greater number of scars on left flanks ($P < 0.001$, normal distribution test). Conversely, in 1983 prey suffered more scale-eating on their right flanks ($P < 0.001$).

Photos: Abhijith Viswananthan

CRYPSIS (CAMOUFLAGE)

Range of strategies to prevent *Detection* or *Recognition*

Crypsis through ***Background Matching***

- Blending with background (visual, non-visual)
- Primarily prevents **detection**
- **Colour pattern cryptic if it resembles a random sample of the background**
- One of the most common anti-predator strategies
- Strong experimental evidence

Hemidactylus leschenaulti (Bark gecko)


YouTube/CakesStepbyStep
CAKE


Mother and Me
Creative Cakes
adidas

Crypsis through ***Masquerade***

- Resemblance to inedible objects (e.g., leaf, twig, bird dropping)
- Works primarily by preventing **recognition**

Uroplatus phantasticus
(Satanic Leaftail)

© ardea.com

Tropidoderus childrenii
(Children's stick insect)

Flickr.com/© petrichor

Reflection

- Can background matching enhance the effectiveness of masquerade?

Assumption: Predators able to *detect*, but unable to *recognize* the prey

How do we know that predators confuse prey with inedible objects?

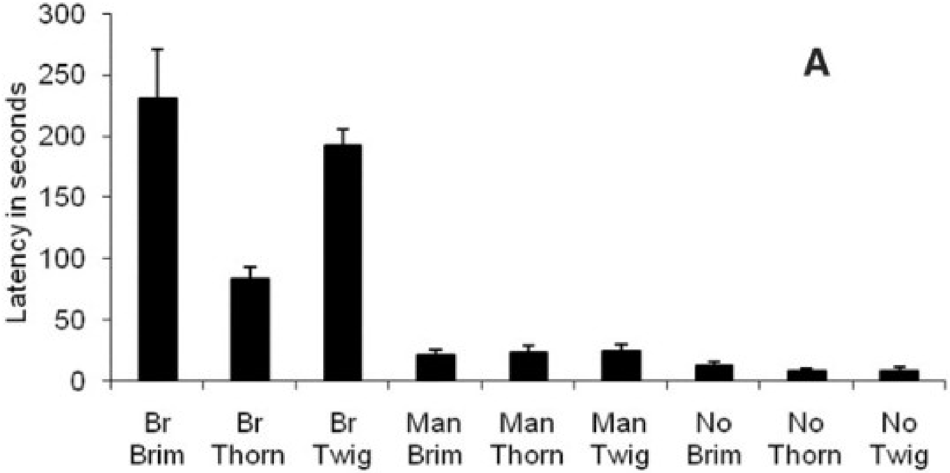
Could they not have simply failed to spot the prey?

Skelhorn *et al* (2010) *Science* 327: 51

Opisthograptis luteolata (Brimstone moth).
Photo: www.pyrgus.de

Selenia dentaria (Early Thorn moth).
Photo: www.pyrgus.de

- Hawthorn tree: host plants for both
- Predator: Naive (inexperienced) domestic chicken



<u>3 Groups (EXPERIENCE)</u>

<u>Br</u>: Hawthorn branch

<u>Man</u>: Manipulated hawthorn branch (purple coloured)

<u>No</u>: Empty

<u>EXPOSED TO</u>

<u>Brim</u>: Brimstone moth

<u>Thorn</u>: Early thorn moth

<u>Twig</u>: Twig of hawthorn tree

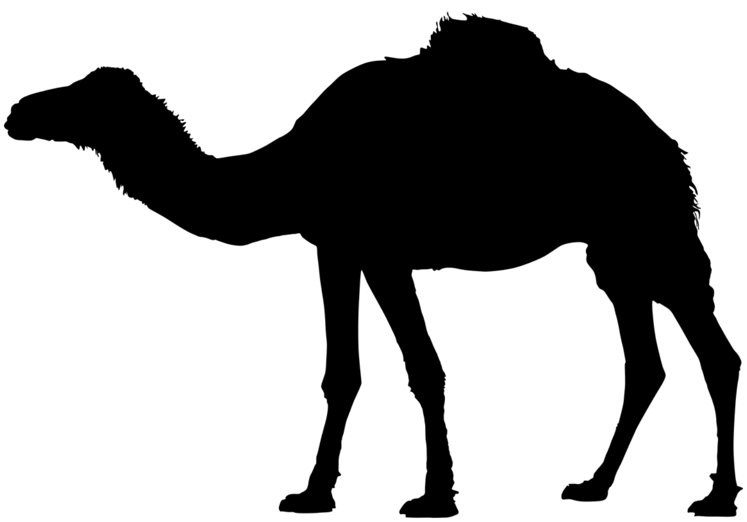


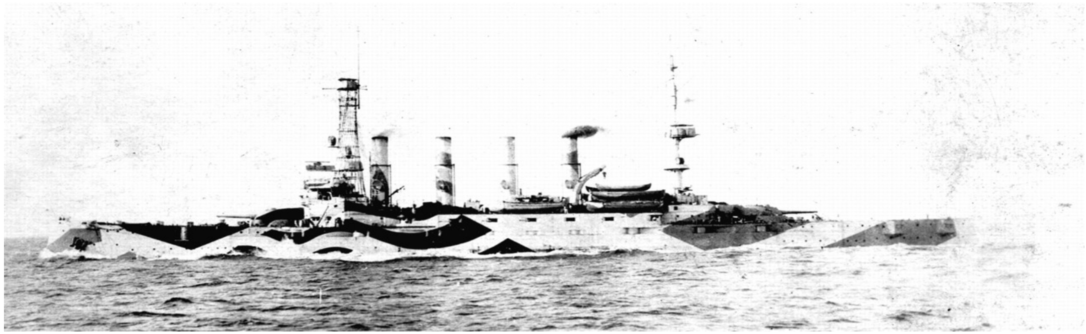
Illustration: Chris Fagbayi

Illustration: Jussi Paju

Crypsis through *Disruptive colouration*

- Breaks up the outline (i.e., edge)
- Creates false edges

  Hampers **recognition**



Credit: Roy R Behrens

Photo: Steve Irvine,
MyShot/National Geographic

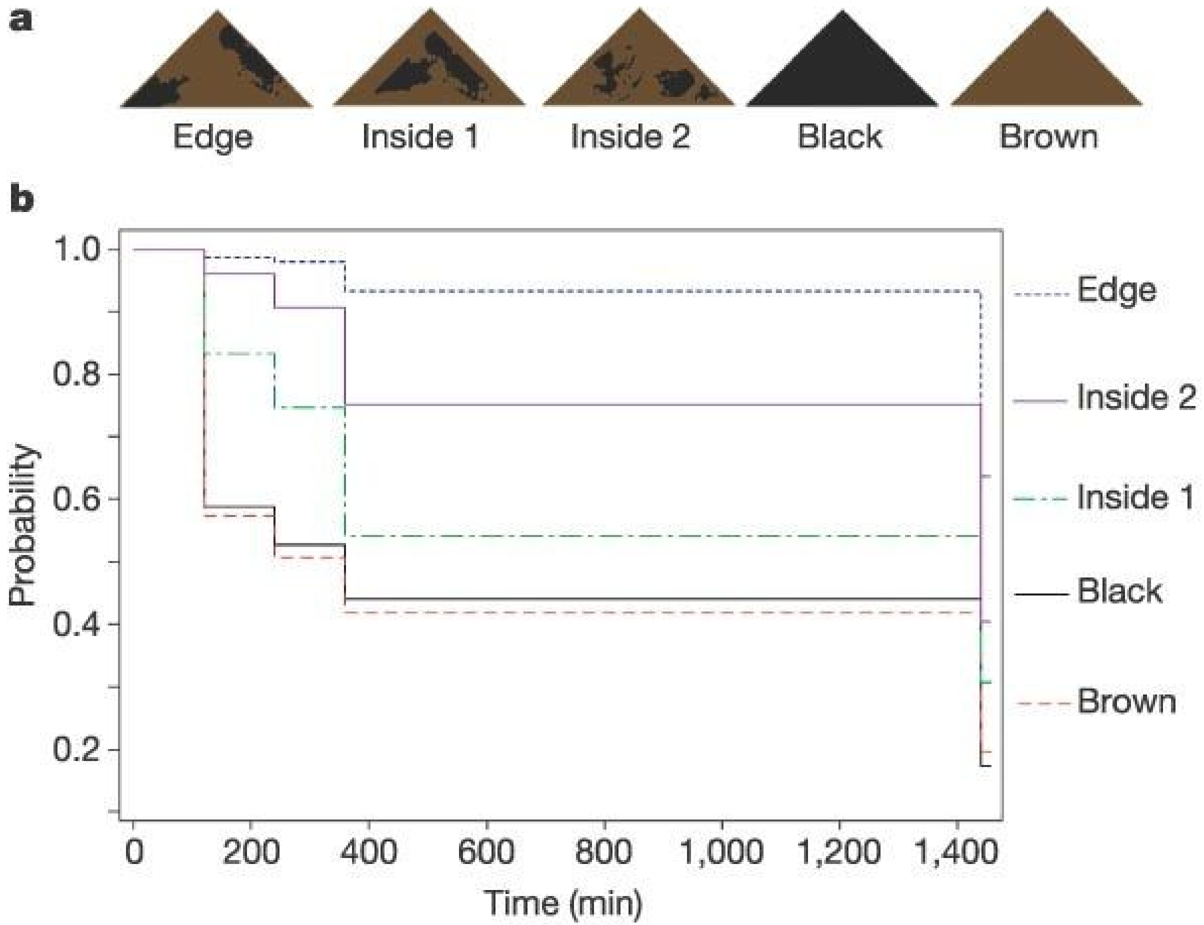
Dascyllus aruanus (Humbug damselfish)

Photo: www.australianmuseum.net

Photo: http://gardenofeaden.blogspot.in/

Lagopus leucura (White-tailed Ptarmigan): female & 5 chicks

Photo: Paxson Woelber



Survival analysis

Cuthill *et al* 2005. Nature 434: 72-74

Reflection

- Can background matching enhance the effectiveness of disruptive colouration?

Crypsis through *Countershading*

- Gradation in shading and colouration, usually darker on dorsal surface compared to ventral surface (sometimes sharp transition)

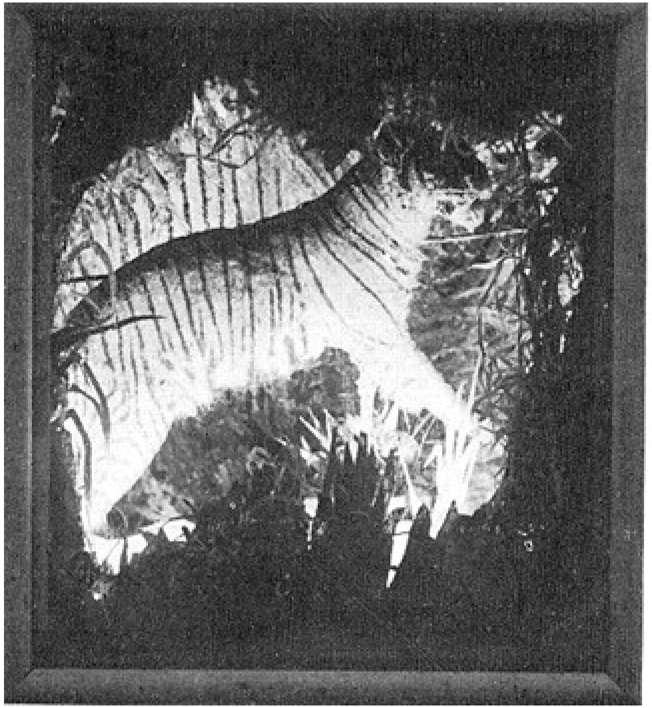
Hypotheses:

- Counteracts effect of shadows when illuminated from above
- In aquatic organisms, when viewed from below, darker dorsal patterns may blend in with dark below & lighter ventral may blend in with light above

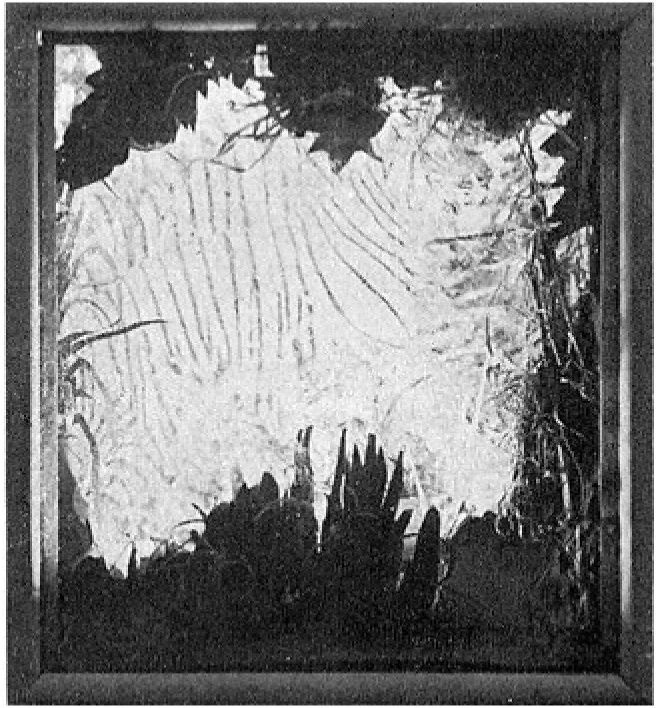
Photo: Broken Inaglory (Wikimedia Commons)

Photo: www.asdp-samra.blogspot.com

Lit from below



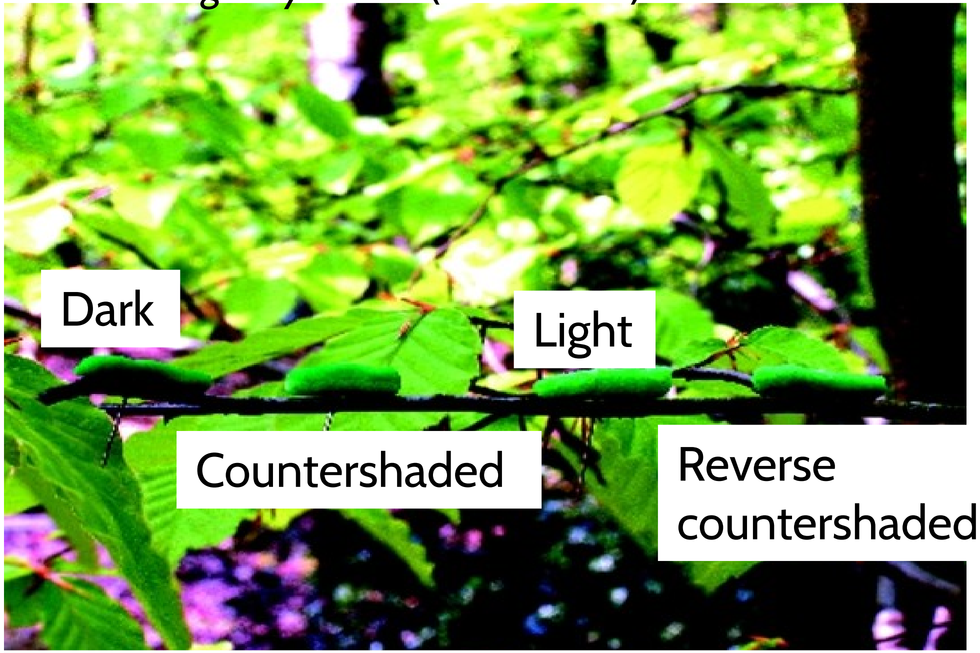
Lit from above

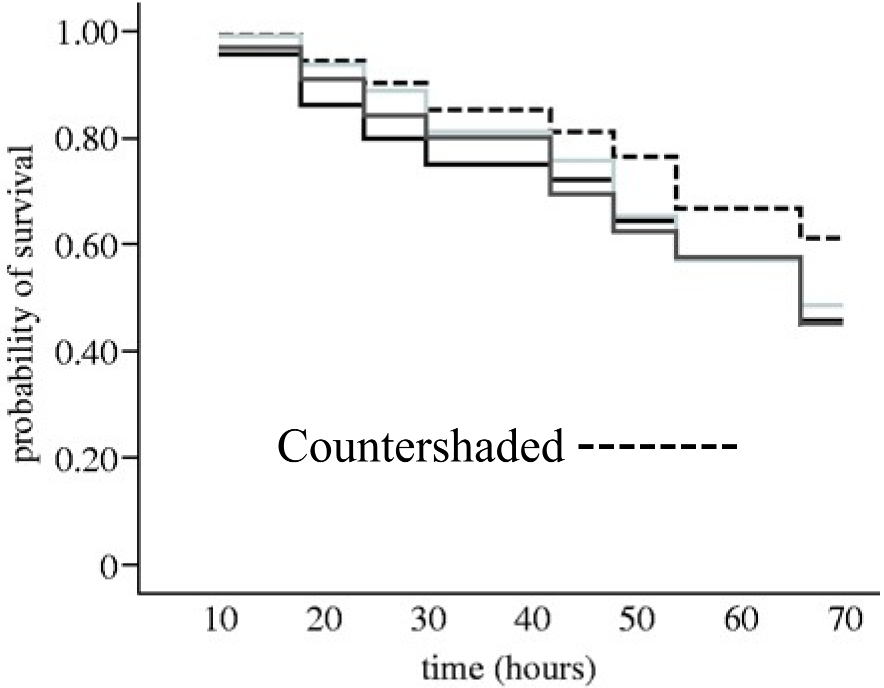


Abbott Thayer's installation (now at Harvard)

Rowland *et al* (2008) *Proc R Soc B* 275: 2539-2545

Artificial pastry prey pinned to the upper surface of a *Fagus sylvatica* (beech tree) branch.





When illuminated from above ventral shadows are cast onto the body of light, dark and reverse-shaded prey, but countershading counterbalances the effects of dorsal illumination and has reduced shadowing.

Reflection

What principle(s) of crypsis is(are) are used by this owl and the snake in the next slide?

(*Strix nebulosa*) Great Gray Owl

Photos: Allen Murphy

Source: Twitter.com (@dm_ynwa)

Spot the badger

Photo: Wikimedia commons/Killianwoods

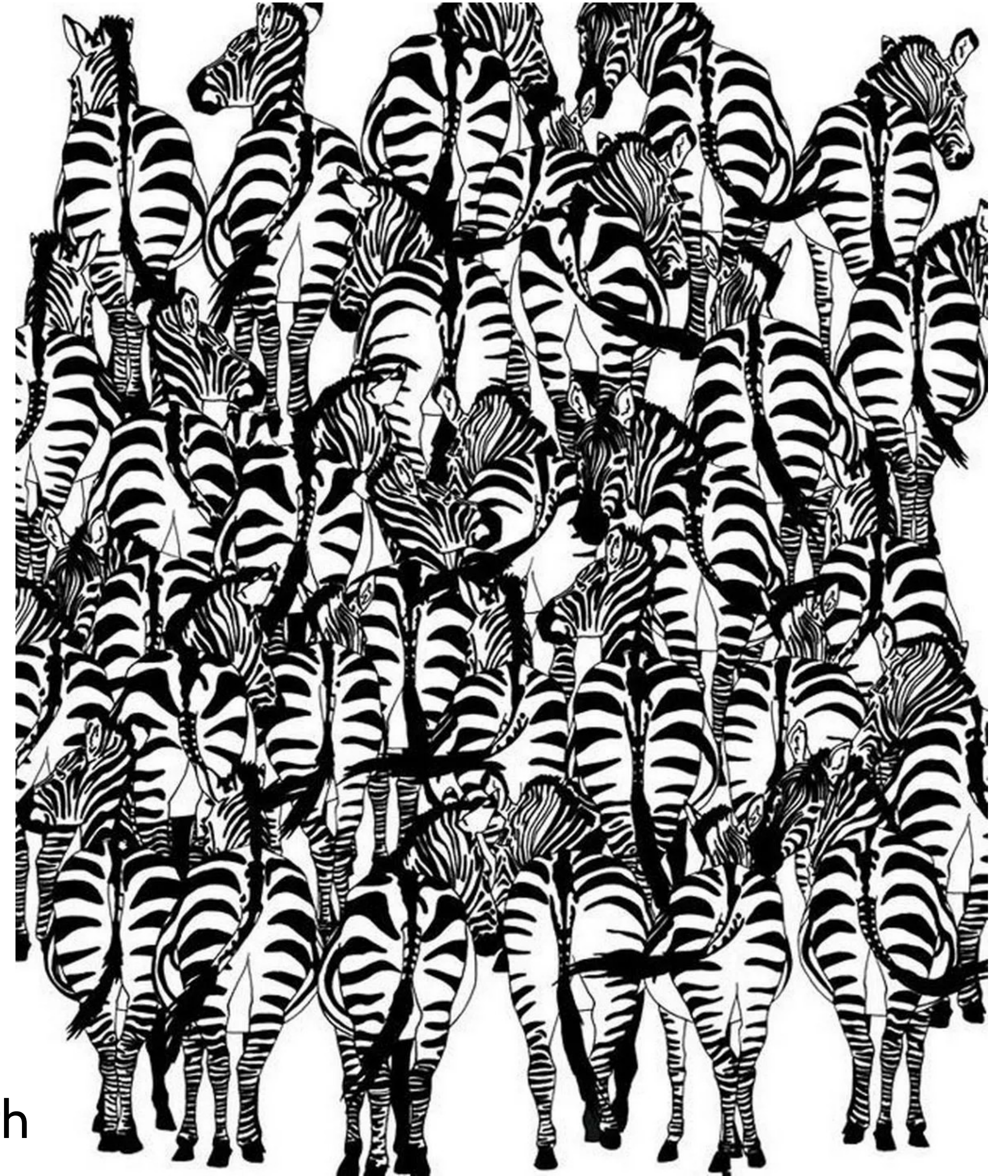


Image: BBC Earth

Transparency

Cithaerias spp?

Photo: Rick Stanley

Greta diaphana (Hispaniolan Clearwing Butterfly)

Photo: Miguel Landestoy

Uncommon

Deflection

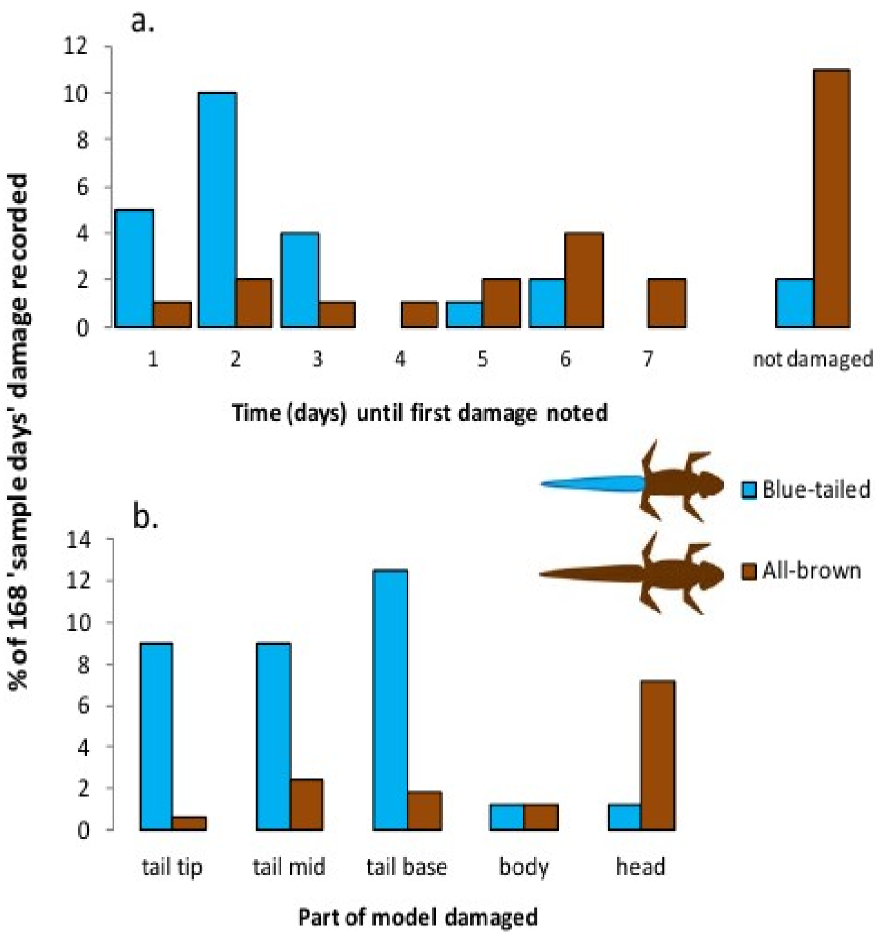
- Diverting/deflecting attacks towards less vital parts of the body

  e.g. lizard tails which can regrow (*caudal autotomy*)

Eumeces fasciatus (Five-lined skink)

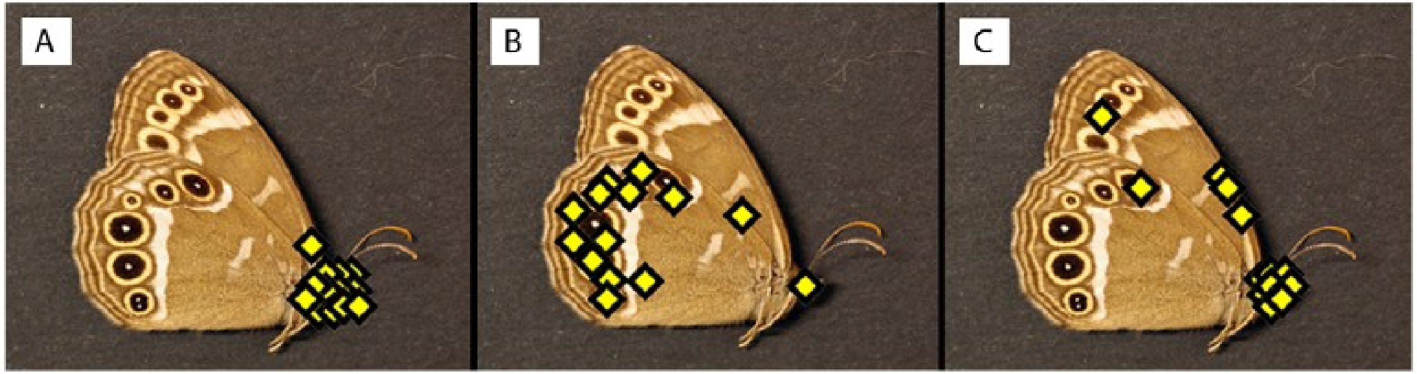
Photo: Richard Butler

Bateman *et al* 2014 *Current Zoology*



Marginal eyespots

e.g . *Lopinga achine* (Olofsson et al 2010 PloS One e10798)



Olofsson *et al* (2013) *BJLS* 109: 290-297

Video of *Cyanistes caeruleus* (Blue Tits) birds attacks a butterfly with and without eyespots

False head in butterflies

Parazanclistius hutchinsi (Short boarfish)

Photo: David Muirhead

Chaetodon capistratus (Foureye butterflyfish)

Reflection

Raja binoculata (Big Skate)

Photos: Port Townsend Marine Science Blog

Could the eyespots on this animal be an example of deflective markings?

Aggressive mimicry

- Predator/parasite resembles a non-threatening species/object to gain access to prey/hosts

Lamsilis ovata (Freshwater mussel)

Photo: Dick Biggins (Wikimedia Commons)

Crab spider (Thomisidae) with *Junonia lemonias* (Lemon Pansy)

VIDEO: Frog fish using a lure http://www.youtube.com/watch?v=8DHTC2i-x5s

Wignall & Taylor (2011) *Proc R Soc B* 278: 1427-1433

Do assassin bugs (*Stenolemus bituberus*) use aggressive mimicry to lure spider prey?

Compared responses of spiders to bugs with responses to prey, courting male spiders and leaves falling into the web

- Vibrations by bugs similar to vibrations by prey
- Spider response: prey = bug

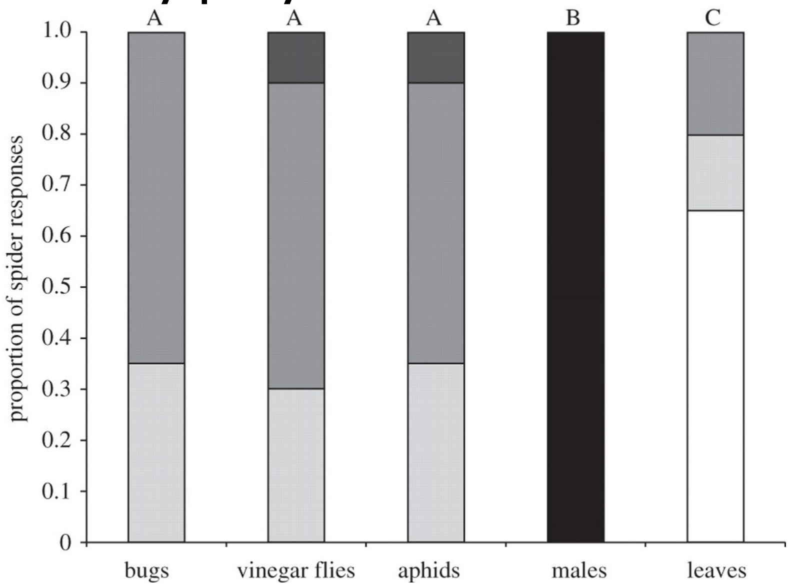


Fig 1: Responses of spiders to each vibration source. Significant differences are indicated by different letters (Fisher's exact tests). Black bar: orient, pause, copulatory position. Dark grey bar: direct approach. Grey bar: orient, pause, approach. Light grey bar: orient, no approach. White bar: no response.

Pollinator/Floral mimicry

- e.g. 'Batesian floral mimicry': Flowers with no reward resemble other flowers that offer reward.

- e.g Bee orchid flowers use visual, tactile and *olfactory stimuli* to attract male bees and get them to 'mate'

Ophrys epiphera (Bee orchid)

Photo: Ian Capper

Bee mating with *Ophrys arachnitiformis*
Photo: Nicolas Vereecken/BBC News

VIDEO: Orchid pollination through sexual deception

http://www.youtube.com/watch?v=HUMzVEjT0y4

Startle/Deimatic display

- Sudden display of conspicuous features
- *Surprise*

  e.g. Inachis io (Peacock butterfly)

  >> wing-flicking to display eyespots, sounds

www.sensoryecology.com

Photo: W. Schön (Wikimedia Commons)

Photo: Korall (Wikimedia Commons)

Blue tits (*Parus caeruleus*) as predators

Photo: Francis Franklin/Wikimedia

No eyespots

5/10 survived

P=0.03; Fishers Exact Test

Eyespots

9/9 survived

Vallin, Jakobsson, Lind and Wiklund (2005) *Proceedings of the Royal Society B*

Kodandaramaiah, Vallin & Wiklund (2009) *Animal Behaviour*

Anti-predatory function of eyespots: Testing the ***Intimidation Hypothesis***

Junonia almana – Peacock pansy

Two-choice test

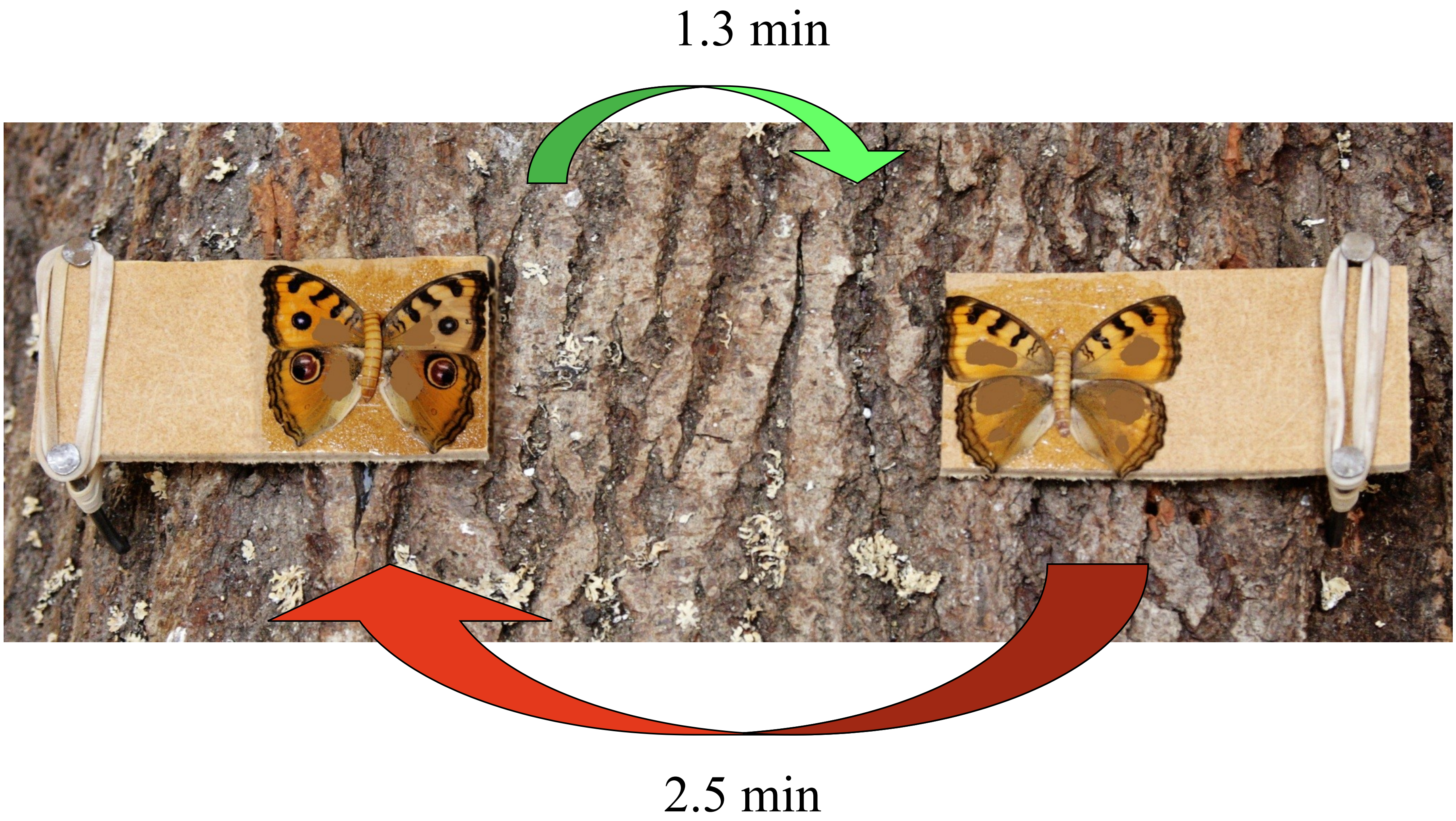
Parus major (Great Tit / Grey Tit)

Photo: Adrian Vallin

Experimental setup

10 25

(Binomial test, ***p*= 0.0017**, n=35)



Mann-Whitney U test, ***p= 0.019***, n=22

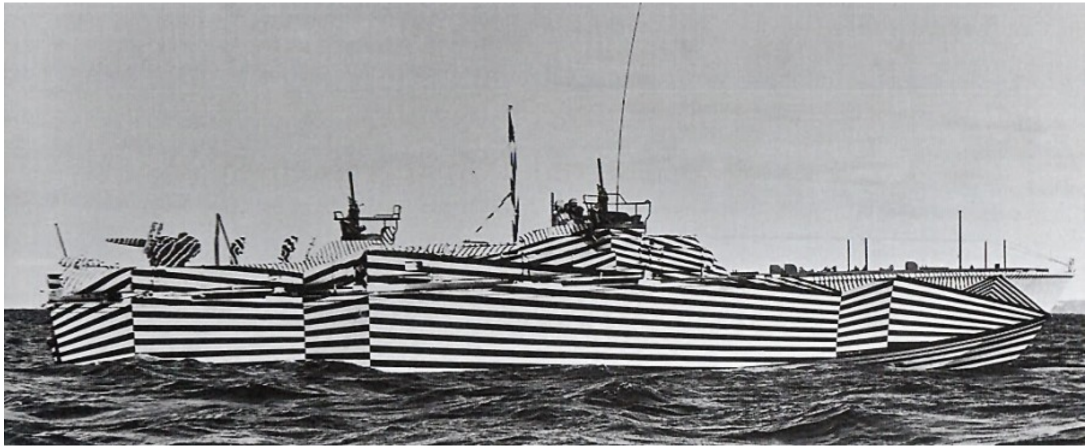
Reflection

- Some experiments on antipredatory colour patterns involved using a single predator species under laboratory conditions. Some other studies relied on outdoor experiments with multiple, unknown predators. What could be advantages and disadvantages of of the two approaches?

‘Motion Dazzle’ patterns

Salient (conspicuous) colour patterns involving strong internal contrast. e.g. stripes, zigzags

- Effective when the prey is moving
- Thought to hinder perception of speed or trajectory



http://www.graphicine.com/wp-content/uploads/2014/02/razzle_Dazzle-camouflage_ship4.jpeg

Evidence from experiments with human 'predators' and virtual prey on a touchscreen

- E.g., Murali & Kodandaramaiah (2016) *Royal Society Open Science.*
  - Anterior stripes on lizards can function as motion dazzle patterns that redirect attacks towards the dispensable tail

Source: http://studydroid.com

Anti-herbivory defenses in plants

- Some of the oldest plant fossils have evidence of herbivory

Fossil of *Viburnum* leaf with insect damage. Photo: Wilson44691/Wikimedia Commons

Acknowledgment: Some content for slides on plant defenses based on slides by Amy Zanne, and http://www2.mcdaniel.edu/Biology/botf99/herbnew/aintro.htm

Types of plant defenses

<u>Constitutive</u>:

- Always present

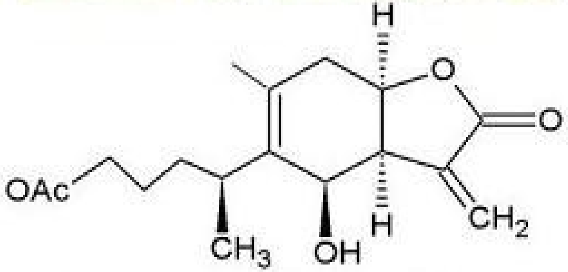
<u>Induced</u>:

- Produced or mobilized after exposure to an herbivore

Chemical defenses

- >25,000 secondary metabolites found in plants

  Secondary: not used for metabolic pathways and are often byproducts.



1-O-actylbritannilactone (2)

3 major types of compounds

A) *Nitrogen-based*: alkaloids, cyanogenic glycosides and glucosinolates

Alkaloids (>3000): from amino acids

e.gs nicotine, caffeine, morphine, strychnine, quinine, ergoline

B) *Terpenoids or isoprenoids* (>10,000):

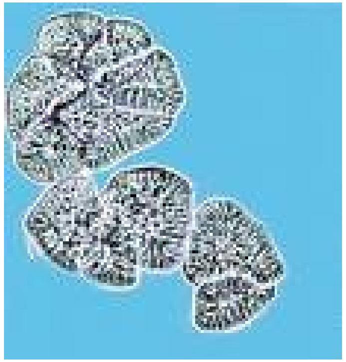
volatile essential oils, iridoids, latex, resins, sterols, glycosides, etc

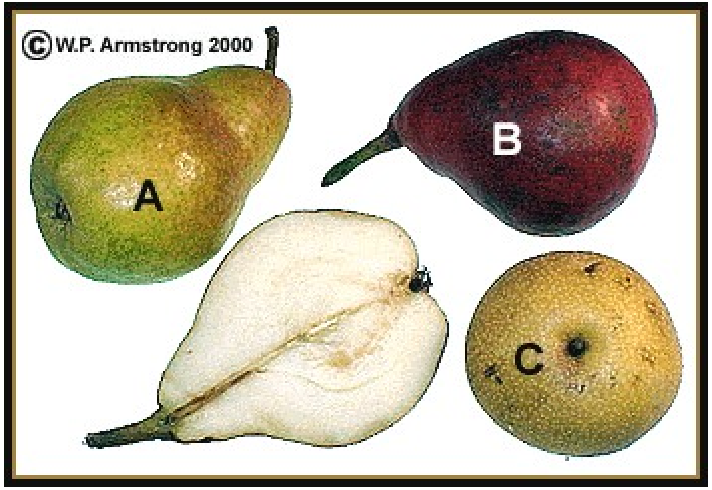
C) *Phenolics or phenols*

e.g. tannins, flavonoids

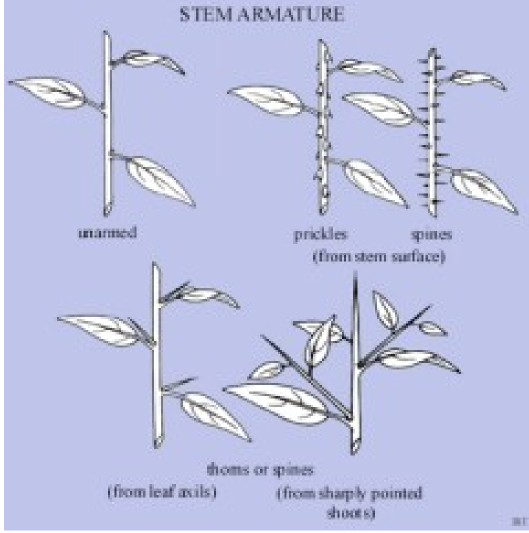
Indigestible chemicals

– Lignin, silica, stone cells (sclereids)





Mechanical defenses



- External chemicals: resin, lignin, silica, wax, gums
- Physical
    - Spines: Vascularized, modified leaf or stipule
    - Prickles: Several cells thick, not vascularized
    - Thorns: Modified stem, usually dead
    - Trichomes: Epidermal outgrowth, e.g., hair
    - Thick protective layers

<u>Thigmonasty</u>: respond to touch. *Mimosa pudica*

<u>Mimicry</u>: Eg. 'egg-mimicry' in *Passiflora*.

Hostplants of *Heliconius* butterflies.

Cannibalism avoidance?

Passiflora boenderi

Photo: J.M. MacDougal

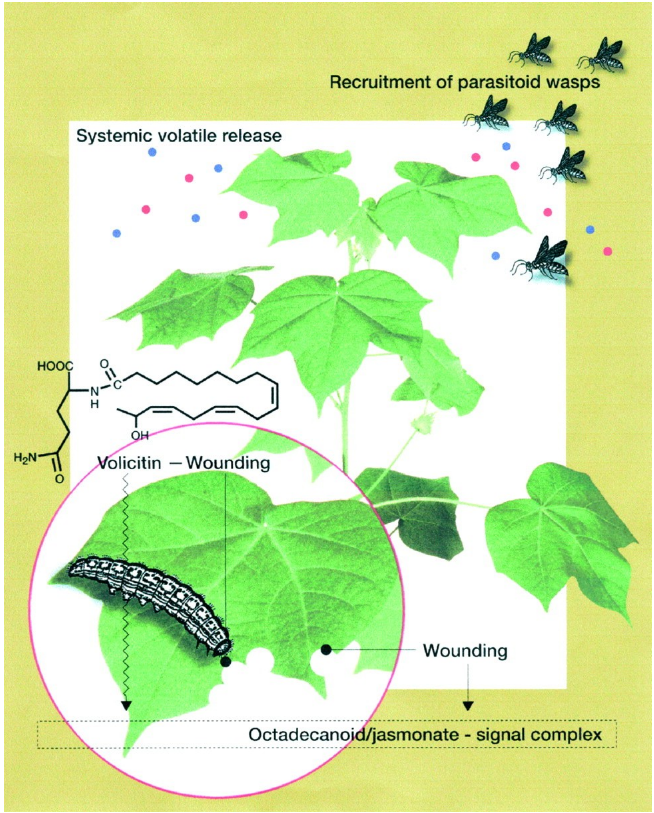
Passiflora davidii

Source: flickr.com/user *cpf1*

Recruitment of predators of herbivores through chemical cues

Example

Schematic representation indicating an increase of volatile compounds released by plants in response to insect feeding triggered by an interaction of elicitors such as volicitin in the oral secretions of insect herbivores with damaged plant tissue.



Paré & Tumlinson (1999) *Plant Physiol* 121:325-332

Reflection

- Which of these – herbs and trees - do you expect to have more secondary metabolites? Why?