Subphylum: Hexapoda
(insects)

~1.1 M species; probably millions more
there are more species of insects than all other animal species
→ entire field of study = Entomology
most successful & widespread group of all life
adapted to land before most other terrestrial animals except for a few Chelicerates
(Devonian 390 MY)
adaptations to land (even deserts):
- waxy cuticle
- varnish layer can close spiracles
- extract & retain fluids from food and metabolism
  (some don’t need any liquid water at all)
- diapause & resistant eggs
had 40 MY to evolve and diversify before serious competition for space and resources from other animal phyla
→ still no birds around yet
→ still not a lot of parasites of insects yet
by carboniferous (~300MY ago ) there many different kinds of insects

need very little food to sustain themselves
range from < 1 mm to 25 cm
eg. Atlas moth of India has a wingspan of almost 1 foot
eg. Walkingstick of India is up to 15” long
insects invented agriculture & animal husbandry
→ many ants and termites cultivate fungi within their burrows
→ some ants guard aphids that let the ants ”milk” them for nectar-like secretion
may have been 1st to invent slavery
→ there are ~35 species of “slave making ants” that regularly raid the nests of other ant species and take young back to their own colony
there they work as they would in their home colony
- searching for food, raising young, etc
always very closely related species
ants will always do the work of whatever colony they are in when they emerge as adults
were the first animals to fly
→ 130 MY before pterosaurs

eg. roaches were the main insects of the time
eg. some dragonflies had 2’ wingspans
today insects have spread into all major habitats
dominant fauna of all freshwater and soil habitats
some live in deep underground caves
on top of world’s highest mountains
some insects live in unusual habitats:
some flies occur by the millions in brine lakes eg. Great Salt Lake, where hardly any other life forms are able to survive
some insects live in hot springs up to 120º F (49º C)
many species are found inside ice in antarctica
larvae of “petroleum flies” live in pools of petroleum around oil wells
a few insect species have been found breeding in brine vats holding human cadavers at medical schools
the “short-circuit” beetle bores into lead cables
but only a very few are truly marine; (Why?)
most are <2.5 cm (1/4”)
→ small size helps them escape enemies

A few kinds of insects have been semi-domesticated:
- honeybees
  3 trillion bees are kept and managed for pollination and honey production
- silkworms (moth larvae spin cocoons of silk)
each cocoon is made from over a half mile of silk
- mealworms & crickets are used to feed pets (or humans) or for fishing bait

Body Form
body in three parts: head, thorax and abdomen

Head
large compound eyes
several (usually 3) simple eyes (=ocelli)
1 pair of antennae
many kinds of antennae
eg. grasshoppers, crickets and cockroaches have long antennae
eg. butterflies have knob on end
eg. moths antennae are featherlike
antennae are very complex sense organs in which different segments control different aspects of an insect's life:

e.g. in ants:
one segment detects nest odor and helps prevent an ant from entering the wrong colony
another segment identifies offspring of a specific queen
another segment detects the ants own feeding trail
another segment helps detect what is needed by the immature ants it is tending

mandibles and other mouthparts for feeding

Thorax

divided into three segments (pro- meso- & metathorax)

→ each with sclerites:

   tergum, pleura, sternum

each thoracic segment bears 1 pair of legs

→ total 6 legs; thus hexapods

most insects also have 2 pairs of wings on thorax

eg. a bee can pick up 50 times its weight
eg. beetles are the strongest insects; up to 60 x's their weight

[but their small size relative to weight makes them only appear strong
→ if insects were as large as humans they would be little if any stronger than us]

A. Legs

great diversity of leg types:

insect legs are adapted for the same kinds of movements as vertebrates:

walking, running, jumping, swimming,

digging, climbing, grasping

legs in 5 segments

sometimes modified for

jumping (grasshoppers, crickets, fleas)
e.g. grasshoppers can jump 20 times length of body

→ equivalent jump for human would be 1/3rd length of football field

e.g. fleas are probably the best jumpers
can jump 8 " high and 13 inches in length

→ equivalent feat in human

storage of pollen (bees)

wings are extensions of cuticle formed by epidermis

Abdomen

segmented (10-11 segments)
reproductive organs

females have pincher like or syringe like ovipositor to lay eggs

in some social insects it is modified into a stinger

Insect Movement

most kinds of movement are created by muscular system (striated muscles like us)
insects have a more elaborate muscular system than any other invertebrate group

insects have more muscles than most animals including us

e.g. humans have ~700 individual muscles; some insects have 900 or more muscle organs; some caterpillars have 4,000

insects are remarkably strong, given their small size

swimming (diving beetles, many insect larvae)

B. Wings

most insects have two pairs of wings

some use both pairs to fly (e.g. butterflies)
some the 1st pair cover and protect second pair (e.g. beetles)
a few have only 1 pair (flies, mosquitoes)
a few are wingless (lice, fleas)

Insect Flight

insects were the first animals to fly

→ 130 MY before any other animal

unsure of evolutionary origin of wings:

1. originated as small flaps that first allowed gliding = "flying squirrel theory"
2. were 1st used as solar collectors to raise body temperature
   later for gliding, then for flight
3. originated from gills of aquatic forms many have hinged gills on thorax

flying in most insects is like swimming for us due to size and relative density of air

wings are separate from legs and other
appendages

don't just move up and down
  → common pattern resembles "butterfly stroke" of human swimmers

direct and indirect flight muscles

the rate of wing beating varies considerably:

  fastest
    eg. midge >1000bps
    eg. housefly beat ~200bps
    eg. mosquito ~300bps
    eg. honey bee ~ 190bps

  more typical beat:
    eg. locust ~20bps
    eg. dragonfly ~25bps

slowly beating:
    eg. white butterfly ~12bps
    eg. swallowtail ~5bps

speed of insect flight also varies greatly:

from slowest insect flight speeds:

  eg. mosquitoes ~2mph
  eg. houseflies ~5 mph
  eg. butterflies ~6mph
  eg. honey bee ~7 mph

to quite fast

  eg. hawkmoth ~35mph
  eg. horse fly ~30mph
  eg. dragonflies ~25 mph

eg. the common housefly is one of most talented aerodynamicist on the planet

  → more maneuverable in flight than birds, bats or bees

eg. hoverflies are even better

  can make six turns a second
  hover, fly strait up and down, backwards, do somersaults, land upsiddown etc

yet: has brain smaller than a sesame seed

  has only a dozen muscles for flying

but are loaded with sensors

  compound eyes
  wind sensitive hairs
  antennae
  three light sensors = ocelli

flight greatly improved dispersal ability

some insects are able to migrate 1000’s of miles or fly at high altitudes:

  eg. monarch butterfly flies slowly (→ 6 mph)
  but can fly 100’s of miles at a time
  eg. painted lady migrates 4000 miles
  eg. some butterflies have been seen at 20,000’

some wings are only temporary structures

eg. males and queen ants use wings only for mating flight, then they drop off

eg. in houseflies the labium forms a sponge-like feeding structure to mop up liquids

c. others actually eat leaves, flowers and whole plants or animals

  eg. in many insects the mandibles are hardened into "jaws" that are used to snap off pieces of plant or animal matter
  eg. many caterpillars feed on specific plants

d. many feed on dead or decaying organic matter

  eg. houseflies have a sponge-like feeding structure

  eg. in biting flies the mouthparts resemble a beak for puncturing the skin

the digestive tract is a tube divided into 3 major regions:

  foregut → crop, salivary glands, stomach
  initial food processing & temporary storage

eg. in mosquitoes, most of the mouthparts together form a long hollow tube, the labium directs this tube through the skin to draw up blood

eg. in biting flies the mouthparts resemble a beak for puncturing the skin

feeding & nutrition

insects feed upon almost every kind of organic substance

  most feed on plant juices and tissues
    = phytophagous

  many feed on dead or decaying organic matter
    = saprophagous

  some are predaceous and attack other insects or smaller invertebrates

  some are parasitic and feed on blood or living tissues from temporary hosts

all insects share the same basic mouthparts:

  mandibles → jaws
  hypopharynx → tongue
  labrum, labium → lips
  maxillae → helps to manipulate food

the same basic mouthparts are modified in many ways to facilitate different methods of feeding:

a. most feed on plant juices and tissues

  eg. in butterflies the maxillae form a long coiled food tube for sucking nectar

b. some insects use spongelike mouthparts to lap up liquids

eg. in houseflies the labium forms a sponge-like feeding structure to mop up liquids

c. others actually eat leaves, flowers and whole plants or animals

  eg. in many insects the mandibles are hardened into "jaws" that are used to snap off pieces of plant or animal matter

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the digestive tract is a tube divided into 3 major regions:

  foregut → crop, salivary glands, stomach
  initial food processing & temporary storage
**Animals: Arthropods**

**Hexapoda**

*Ziser Lecture Notes, 2012.12*

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**Respiration**

- An insect's blood does not carry much oxygen. They don't have large gas-filled sacs taking up a larger part of their body for breathing.
- Oxygen is delivered directly to body cells through a system of tubes and passageways.

**Tracheal System with Spiracles**

- An adaptation to air: many spiracles have valves.
- The tracheal system is lined with cuticle that must be shed.
- Gas movement by **diffusion**
- Larger insects use some kind of **ventilation**
  - Eg. pumping movement of abdomen.
- Aquatic forms return to water:
  - Tracheal gills in cloaca eg dragonflies
  - Water bubbles

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**Sense Organs, Communication & Behavior**

- Insects are extremely active.
- They also have a rich supply of sense organs located all over the body.
- These contribute to a rich diversity of insect behaviors.
- Most insect sense organs are microscopic in size and are found on the body wall and various appendages:
  - Small hairs, small domes
- Keen senses but relatively simple circuits:
  - Eg. One signal usually results in one response for an insect.
  - In humans, one signal can result in many different responses.

### 1. Vision

- Vision is the most important sense for most insects.
  - Eg. ~2/3rd's of a fly's nervous system is devoted to vision.
- Insects have two kinds of eyes:
  - Simple eyes that can detect light & dark.
  - Compound eyes with many individual lenses = **facets**
    - Simple eyes are called **ocelli**
    - Usually 2 or 3 on head.
    - Can detect only light vs dark.
  - **Compound eyes**
    - With many individual lenses = **facets**
      - Some as few as 9 facets.
      - Houseflies have 4,000.
      - Dragonflies have 28,000 facets.
    - Provide a wide field of view and particularly good at detecting movement.
      - Eg. This is another reason why many insects are hard to swat or capture.
    - **Color vision**
      - Eg. Plant eating insects are especially sensitive to green.
      - Eg. Butterflies that feed on red and yellow flowers are more sensitive to those colors.
      - (But most insects can't see red).
      - Eg. Some insects can see UV used during courtship.

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- Some insects communicate using light:
  - Number and duration of flashes produces unique signature for each species.

### 2. Touch

- Most sense organs that respond to touch are small **hairs** on epidermal **setae**.
- Most touching involves antennae and mouthparts.
  - A single antenna can have over 5,000 sensilla.
- These touch receptors can also pick up vibrations in air to respond to wind or gentle breeze.
  - Eg. A fly avoids a swat by feeling the air being pushed by your hand as you try to swat it.
- They can also detect temperature, humidity, gravity.
- Touch receptors are used in a variety of ways:
  - Eg. Mole cricket uses antennae to recognize nymphs in dark burrow.
  - Eg. Social insects can detect unwelcomed visitor to their nest and attack them.
  - Eg. Social insects often stroke and groom each other with antennae and mouthparts.
  - Eg. Waggle dance of honeybees involves touching to communicate location of pollen.
3. Hearing & Sound

insects have many different kinds of organs for hearing

the insects with the best developed hearing are those that communicate using sound

the simplest are hairs that respond to touch

many insects have hearing organs inside their legs that respond to vibrations passing through the ground or a plant
eg. ants come out of nest if you stomp on the ground

cicadas and crickets detect sound with an ear-like tympanum

moths, crickets, mantids etc can hear between 25,000 - 45,000 Hz

[humans hear sound waves from 20 - 20,000 Hz]

can detect ultrasonic signals of bats to avoid being eaten

sound may be used to individuals of the same species
eg. males and female mosquitoes are attracted to each other by sound of their buzzing wings

eg. tapping sound of death watch beetles (eat wood on old house - heard by those keeping watch over dead person before burial) used to attract a mate

many insects that can hear have structures for making various sounds to communicate with each other or to other species

some rub body parts together to make sounds = stridulation

eg. chirping sound of crickets, katydids, beetles and ants can be used to communicate with group or seek a mate

some have drum like membrane that can vibrate to make a sound

eg. cicadas are loudest of all insects
can be heard half mile away
songs differ for each species

hissing cockroach blows air out its spiracles to make sound

many insects can make supersonic sounds

4. Taste, Smell & Chemical Communication

both taste and smell are types of chemoreceptors they detect specific chemicals

smell → if the chemical is volatile and travels some distance

taste → if the insect is in direct contact with the source

smell is used to find suitable plant for laying eggs
used by flies to find dead animals

some parasitic wasps can track host species by smell

smell is also used to communicate within a species

eg. sex pheromones attract mates

eg. pheromones that cause grouping behavior

eg. ants release alarm pheromones if disturbed or threatened

eg. ants, caterpillars and other insects produce trail pheromones to map route to food

5. in addition to external senses insects also have a variety of proprioceptors
can monitor body positions, eg legs and wings, internal pressures
could not walk or fly without this information

Behavior & Communication

insects have keenly developed senses

can be used for communication and behavioral responses
insects communicate in a number of ways using their external senses

insect behavior is mostly instinctive (innate)
   eg. caterpillar is programmed to eat a certain plant
   eg. courtship, egg laying, migrations are preprogrammed
but they do have the ability to learn
   eg. bee dance
   eg. notice landmarks near nest or food
   eg. when Colorado potato beetles first attempt to mate, they are not very good at identifying their own species or even distinguishing head from tail; with repeated attempts they get better at it

Colonial Insects

many insect species exist as colonies
   eg. ants, bees, wasps, termites, some beetles
they can work much more efficiently as a group than as solitary insects
   they have a very structured division of labor
   highly dependent on each other
   generally unable to survive long on their own

eg. many crane flies, walkingsticks, grasshoppers
   immature insects that sacrifice a leg can often regrow it after several molts

2. quick reflexes

   as the most active invertebrates, most insects can easily avoid threats by quick escape; flying or running
most insects have sensitive hairs that can detect the change in air pressure of a fast moving hand
   eg. cockroaches can respond & escape from an approaching shoe in less than 50 milliseconds
   eg. resting houseflies can move to avoid a swat in 30-50 milliseconds

3. “hold your ground” or “play dead”

   some insects, when threatened, remain in place and adopt a defensive posture
   eg. tortoise beetles have strong adhesive pads on their feet; they lie flat against a leaf and hold on when threatened
   eg. cuckoo wasps curl up into a hard rigid ball like pill bugs for protection
   some insects simply “play dead”

   if on trees and shrubs; they release their grip and disappear into the undergrowth

4. spines, bristles and hairs

   eg. many predators will avoid a mouthful of spines and bristles found on many caterpillars
   eg. parasitic flies or wasps have more difficulty getting close enough to lay eggs in or on the potential host bearing spines and bristles

5. sound

   eg. hissing cockroaches emit a threatening hiss
   eg. some moths can mimic the sound of “bad tasting” moths to avoid being attacked by bats
   eg. tiger moths can detect the ultrasonic sounds made by bats if at low intensities (bat is relatively far away), they just change course and fly away
   at higher intensities (bat is much closer), they quickly drop from the air in an evasive looping dive

6. Color as warning or camouflage

   some insects have bright red or orange colors exposed only when they are threatened by predator that may scare predator away
   others with large eyespots that may intimidate
in other color and shape are used as camouflage

**camouflage** eg. walking stick

**mimicry** eg. viceroy butterfly

### 7. chemical defenses

many insects wage chemical warefare using noxious chemicals to ward off predators

in some cases they manufacture their own toxins

others use chemicals extracted from host plants

eg. stink bugs secrete a foul smelling chemical from glands in their exoskeleton when threatened

eg. some species of cockroaches and termites secrete a sticky substance from anal glands to immobilize ants, spiders, centipedes or other predators

some of these chemicals can be painful or cause temporary blindness

eg. **Bombadier beetle** shoots hot explosive secretions toward predator from glands in their abdomen

each gland has two chambers, one contains hydroquinones and hydrogen peroxide;

the other contains various enzymes;

when the two are mixed a series of explosive reactions occur

peroxide breaks down to oxygen and water and the concoction heats to boiling and blasts out as a toxic cloud

**stinging insects** use pain as an effective defense or a way to subdue prey

some insect toxins that cause pain are expelled by **hollow body hairs**

simply brushing against them causes them to break and release their painful chemicals

eg. saddleback caterpillars

eg. pus caterpillars

some social insects, usually infertile workers, have their ovipositors modified into stingers attached to poison glands

eg. bees, wasps, hornets, ants, etc

**sting-pain index based on human perception**

- **0. sting doesn't penetrate skin**
  - eg. fire ant sting

- **1. sharp, sudden, effect similar to a stray spark**
  - eg. honeybee stings
e.g. common wasps & hornets, acacia ant

- **2. a piercing pain**
  - eg. paper wasps, harvester ants

- **3. bold, caustic, burning and unrelenting**
  - eg. tarantual hawk, warrior wasps

- **4. blinding, fierce, excruciating and debilitating**
  - eg. tarantual hawk, warrior wasps

- **4+. worst sting: pure intense, brillian pain**
  - eg. bullet ant (**Paraponera clavata**) sting produces wave after wave of throbbing, all-consuming pain that continues unabated for up to 24 hrs

Fortunately, bullet ants are not aggressive except when defending themselves or their colony

Bullet ants are used by some indigenous people in their initiation rites to manhood:

- the ants are first knocked out by drowning them in a natural chloroform
- then hundreds of them are woven into sleeves made out of leaves, with stingers facing inward.
- when the ants awaken, boys slip the sleeves onto their arm.
- the goal of this initiation rite is to keep the sleeves on for a full ten minutes without showing any signs of pain
- when finished, the boys’ (now men) arms are temporarily paralyzed because of the venom, and they may shake uncontrollably for days

**malpighian tubules** (2-100’s) absorb metabolic wastes from blood and drain into intestine

### Reproduction & Life Cycles

wide range in life spans for adult insects: hours to years

eg. adult mayflies live for less than a day; do not eat sole purpose is to reproduce

eg. species with longest lifespan may be a tropical termite whose queen may live for 50 years

**Mating**

insects are **dioecious**

most have **internal fertilization**

mating is an important part of an insects behavior set to find mates

most use pheromones

some use light; eg. lightning bugs

others use sound or color

often have courtship rituals

internal fertilization

male must insert sperm into females seminal receptacles
eg. praying mantis courtship
females have predisposition to eat their mate before, during or after mating
eat head first → causes male to make concerted effort to mate with her
(during mating, the subesophageal ganglia (head) inhibit ventral ganglia from triggering intensive copulatory activity)
many females mate only once/lifetime and store the sperm
insects usually lay many eggs
eg. queen honeybee >1 M/lifetime
eg. termites lay 10,000 or more/day
eg. cockroaches can lay >1 million eggs in a year
but some only 1 egg per mating
eggs are sometimes enclosed in protective case
eg. roaches; praying mantis
some lay eggs on specific plant or animal
many insects "mark" plant with chemical to dissuade other females from depositing eggs there
→ ID of the chemical they use may be

**nymph** resemble adult without wings
wings develop externally as budlike growths on thorax
grow by successive molts
eg. grasshoppers, cicadas, mayflies, stoneflies, dragonflies
c. a few have **direct development**
eg. silverfish, springtails
metamorphosis is regulated by hormones
3 major endocrine glands in insects:
\[
\begin{align*}
\text{brain} & \quad \text{produce} \\
\text{ecdysial gland} & \quad \text{juvenile hormone} \\
\text{corpora allata} & \quad \text{molting hormone}
\end{align*}
\]
Some insects overwinter as immature stage
→ don’t complete development until they are literally frozen in winter months

**Diapause**
some insects are able to enter a state of dormancy to survive adverse conditions; eg temp, humidity

**Development**
most insects also go through several distinct developmental stages as they grow from egg to adult
insects often have complex development including **metamorphosis**
a. 88% have **complete metamorphosis** (holometabolous):

\[
egg \rightarrow \text{larva} \rightarrow \text{pupa} \rightarrow \text{adult}
\]
**larva** usually has chewing mouthparts
**pupa** is a nonfeeding stage before metamorphosis; often in a **cocoon**
eg. butterflies: larva=caterpillar
eg. flies: larva=maggot
eg. beetles: larva=grub
once adult emerges it no longer molts
b. most of the rest have **incomplete metamorphosis** (hemimetabolous):

\[
egg \rightarrow \text{nymph} \rightarrow \text{adult}
\]

useful as a natural insect deterrent
some may care for young after hatching
**Ecological Impacts of Insects**

**insects are the most important organisms in most terrestrial ecosystems**

**without insects, most of the terrestrial life on earth would disappear**

**most of the rest of the world is literally helpless without them**

**vertebrates wouldn’t last more than a few months if all insects suddenly disappeared**

**invertebrates, especially insects, are “the little things that run the world”**

- EO Wilson

→ because of their number, variety and influence on larger organisms and whole ecosystems

**inverts are at the heart of healthy ecosystems:**

1. **inverts are an integral part of every landbased foodchain**

2. **Important in Recycling of nutrients**

   - eg. 90% of all dead animals (mainly insects) end up as food in ant nests
   - eg. 99% of human and animal wastes is decomposed at least partly by insects & other invertebrates

3. **insect pollinators are keystone species in some terrestrial ecosystems**

   - without a certain insect species to pollinate the dependent plant species will decline or go extinct

4. **Insect Symbioses**

   - insects have formed a wide variety of symbioses with virtually every major kind of living organisms

**Insect Symbioses**

**insects have formed a wide variety of symbioses with virtually every major kind of living organisms**

**Bacteria**

**almost all animals, including insects have bacterial symbionts**

some that live in digestive system are **mutualistic**

→ help break down hard to digest fibers and starches
→ make essential vitamins
→ protect from pathogens
→ provide additional nutrients from food eaten

**eg. cellulose digesting bacteria**

some species of bacteria, some protists, and most fungi are able to produce the proper enzymes to digest cellulose in plants

virtually no animal species can produce cellulose digesting enzymes

animals that are strict herbivores rely on cellulose digesting microorganisms to extract nutrients from plant materials

**eg. termites**

many species of cellulose digesting bacteria and protist that digest the bits of wood eaten by the termites

a diet restricted to wood only (not softer green parts of plants) is very low in nitrogen and termites also have nitrogen fixing bacteria that convert N₂ into useable nutrients for the termites

**Protozoa**

eg. **cellulose digesting flagellates in the gut of termites**

1/3rd to 1/2 of a termites weight are these symbiotic protozoa

work with bacteria to break down cellulose fibers

**Fungi**

**Animal “Fungus Farms”**

**eg. Atta ants (leafcutter ants)**

mounds up to 18 ft underground

the ants maintain active fungal gardens to feed larvae and adult in the colony

→ they cultivate fungi within their mounds
→ they feed the fungi bits of leaves, bark and other
plant material
g→ they weed out debris that might spoil their garden
→ have wheelbarrow-like depression on their backs
  for carrying spores
fungus is transferred from colony to colony by ants
freeliving cultures of fungus have never been found
fungus needs ants to provide them with food
in Central and South America leaf cutter ants are the dominant herbivores in food chains
→ consume 17% of total leaf production

e.g. African termites (Microtermitinae)
build chimneys up to 30 ft tall of feces and mycelia
eat mostly plant material but don’t have cellulose digesting microorganisms living in their gut
bring it home and eat it before entering mound
then go in and defecate
use their feces to grow fungi (Termitomyces)
all stages of termite readily eat the fungus
fungus never forms mushrooms in mound
but when rain is imminent
termites carry bits of mycelia out of mound
spread them around the ground
several days after rain mushrooms appear and produce spores
the termites reappear and collect the genetically mixed hyphae and take them back into the nest
abandoned mounds produce crops of mushrooms for several years after termites leave
→ African people consider them a rare delicacy

**Plants**

e.g. Pollination

a large part of the success of flowering plants is due to the variety of pollination
→ provides much better mixing of genes
flowering plants have coevolved with many kinds of animals through most of their history
this close relationship between plants and pollinators has resulted in **coevolution**
→ mutual adaptations for mutual benefits

**plant**: petals, scent, nectaries

**animal**: special body parts and behaviors

We like to think of animals as the most ‘evolved’ lifeforms
→ but plants lack brains, muscles, speech yet they don’t need them
  → they borrow animals to do their bidding

In some instances the relationships have become very specialized such that only a single species of animal can pollinate a particular species of plant.

**insect pollinators**

petals colorful and large
often with **nectaries**
much less pollen produced
insects can be attracted by showy flowers, smell &/or nectar

a. bee & wasp pollinated

pollenate more flowers than any other group
20,000 different species of bees are important pollinators for many plants
bees pollenate mainly spring flowers
bees have very **good vision**
→ flowers are generally **brightly colored**
predominately **blue or violet markings**
rarely pure red (pure red appears black to them)

b. beetle pollinated

flowers generally **large** and open
usually **white** or dull in color
(beetles cant see as well as bees)
flowers tend to have a **strong** yeasty, spicy or fruity odor, sometimes unpleasant to us
secrete no nectar but may supply food as pollen or in special storage cells in petals
most eat parts of the flower
  eg. magnolias, lotus

c. carrion flies

tend to be **dull red** or brown or white
often have **foul odors** resembling rotting meat
  eg. skunk cabbage
eg. carrion flower = Rafflesia
a parasitic flowering plant of SE Asia
early botanists thought it might be a fungus
parasitic plant with no true roots or leaves
parasitic on vines in genus Tetrasigma (Vitaceae)
produces a huge speckled flower on little stem
with no leaves
largest known flower:
flower bud size of basketball
flower up to 1 m across; weighs up to 10 kg
smells like rotting meat
fruit is eaten by three shrews and other mammals
d. butterflies
prefer sweet fragrance and provide nectar
fused petals force insect to crawl into flower for nectar
nectaries are usually at bases of deep spur that
only butterflies and moths can reach with their
mouthparts
some butterflies can detect red flowers
eg. daisy family: butterfly bush = Buddelias,
goldenrods, blazing star
eg. monarchs pollenate milkweeds
e. moth pollinated
white or yellow large tubular flowers

eg. Plant Galls
galls are any deviation from the normal pattern of
plant growth on a particular organ or part due to
the presence of another organism
all plant organs are attacked: roots, stems, leaves,
flowers and fruits
→ leaves are most common organ attacked
many galls superficially resemble plant parts such as berries,
nuts and other fruit types
some galls look like fungi and for years some were misidentified
as a fungal species
some galls resemble strange sea urchins and coral polyps
galls on trees and shrubs often appear in the spring
when the leaves first appear
→ when they are highest in food quality
plant galls have been known since antiquity (350 BC)
eg. plant galls were known and used extensively in medicine,
industry and as human food for over 1000 years in China,
India and parts of Europe
plant galls can be produced by a variety of organisms
but mainly various species of insects
→ ~13,000 gall forming insects are known
(2% of all known insects)

70% of galls are produced by flies & wasps
most insects are highly host and organ specific
insects especially form leaf galls
gall forming insects are highly specialized
plant feeders:
tend to be sedentary and feed only on certain cells
they induce the plant tissue to grow rapidly inside the
gall to provide adequate food
the stimulated growth created by the insect
produces a high protein, nutritious meal
much more nutritious than eating typical leaves,
stems or roots.
the gall insect typically becomes trapped inside the
gall and becomes a victim for a diversity of
parasites itself
→ creates a complex insect community
within the gall.
eg. some oak galls support as many as
22 species
eg. another kind of gall had 75 different
species present
a gall appears to be a parasitic relationship
→ the gall is formed as the insect attacks and
wounds the plant

f. ants
dense clusters of small flowers near ground
sticky pollen
with nectar
eg. some composites, poppies,
h. wasps
wasps have very good vision
flower preferences similar to bees
but wasps pollenate mainly in summer
wasps are much less "hairy" so not very good pollenators
flowers are generally brightly colored
predominately blue or violet markings
flowers generally shallow (short mouthparts)
flowers often delicately sweet and fragrant with nectar
or fruit juices
eg. fig wasps exclusively pollenate almost 1000
species of tropical fig trees
eg. some species of orchids resemble certain wasp
females that attract only one species of wasps
**eg. Ant/Plant Symbioses**

**eg. ants and acacia trees**

one species of acacia tree is always found with a colony of a particular ant species associated with it

the tree is small (5'-6') and its branches are covered with pairs of sharp thorns up to 3' long.

No acacia of species *Acacia drepanolobium* has been found that did not contain colonies of the ant species, *Crematogaster mimosae* and *C. nigriceps*.

these ants live only on these trees; up to 20,000/tree

ants get room and board:

at every 6th pair of thorns is a swelling (=pseudogall) which is a hollow space inhabited by the ants

at base of each leaf are nectaries that exude a sugar solution similar to flower nectar

acacia trees get protection from herbivores

→ grab intruder with strong mandibles and sting it

eg. antelope gets a face full of stings and leaves

**eg. ants and tropical epiphytes**

some epiphytes have swollen knobby tuber with hollow chambers inside inhabited by ants

ants accumulate humus and their excretions nourish the plants

in some species the ants collect seeds of various epiphytes and plant them in their nests to create "hanging gardens"

they collect animal feces to nourish seeds

some epiphytes reward the ants by producing starch grains or sugary secretions

**eg. ants and rattan vines**

certain rattan (*Korthalsia*) vines have swollen areas that house ants

if a mammal accidentally brushes against plant the ants make a rattling noise by beating their mandibles on the hollow chambers and scare the animal off

**eg. ants and Barteria tree**

in West Africa

ants (*Pachysima*) defend the tree against herbivores by potent stings

sting can penetrate elephant hide and can numb small mammals (and humans) for several days

**Economic Impacts of Insects**

in the US a 2006 study estimates that insects directly or indirectly contribute more than $57 Billion to our economy

1. as nutrition for wildlife, insects contribute ~$50 Billion/yr to US economy from fishing, hunting, hiking, and enjoying wildlife

2. pest control

   insects often prey on agricultural pests saving up to $4.5 billion/yr in crops and pesticides

   $50 Million worth of beneficial insects are sold worldwide per yr; esp in greenhouses

   eg. ladybugs

3. Pollination services

   without pollinators many plants cannot be fertilized to produce seeds

   90% of worlds flowering plants are animal pollinated

   → including 80% of world’s 1330 cultivated crop species

   → 1/3rd of US agricultural crops are insect pollinated

   in US → responsible for pollinating over $20 Billion worth of agricultural products in 1998

   economic value of insect pollinators worldwide is $217 Billion/yr (08)

   in US, excluding honey bees, other insect pollinators contribute ~$3 Billion/yr to agriculture

4. dung beetles burying animal dung help to recycle nutrients, fertilize the soil, and reduce flies and disease carrying insect on grazing land at a value in US of $380 million/yr

5. A few kinds of insects have been semi-domesticated:

   **eg. honeybees**

   3 trillion bees are kept and managed for pollination and honey production

   honeybee pollination services are 60-100x’s more valuable than the honey they produce

   **eg. Honey Production**: 1999 $126 Million worth of honey was produced in US

   eg. in 2000, beekeepers worldwide harvested 125 million pounds of beeswax (US goes for $1-2.10/lb)
in US ~1/2 of honeybee colonies have been lost in last 50 years → 25% in last 5 yrs alone

since 2007, thousands of bee hives have been decimated

threats to pollinators:
- habitat loss & fragmentation
- loss of nesting and overwintering sites
- intense exposure to pesticides and herbicide
- introduction of exotic species
- newest threat is a parasitic fly that kills entire hives

eg. silkworms (moth larvae spin cocoons of silk)

eg. silk

in 2000 silk producers harvested 225 Million lbs of silk from domesticated silkworms

China, worlds largest silk producers (150 Million lbs/yr) had silk exports worth $2.8 Billion in 1999

before making a cocoon, silkworms are fattened up on a diet of mashed mulberry leaves.

the worms then anchor a thread onto a branch and reel the silk from a tiny hole in their mouth

each cocoon is made from over a half mile of silk

cocoons are collected and plunged in boiling water to kill the silkworm and remove the sticky glue that holds the cocoon together

workers find the end of the filament and thread it onto a bobbin and collected as long filaments

silk can also be reconstituted into its original jelly-like form and respun using a variety of techniques to produce the thype of thread required or poured into molds, cast into transparent films or freeze-dried to make sponge or foam

eg. mealworms & crickets

used as animal foods and bait

6. commercial products

eg. chitin

second most abundant organic polymer

can be used to coat fruits to slow ripening

eg. shellac

made from lac → a resin produced by insects

eg. dyes

cochinile bugs on cactus → dyes

7. Venomous Insects

ants, bees, wasps, hornets, blister beetles, etc

some caterpillars have poisonous hairs or spines

can suck on blood intermittently for hours at a time

usually feed at night

eg. asp or pus caterpillar

spines remain poisonous even after they are shed

8. Parasites & Diseases & Vectors

eg. mosquitoes

besides being blood parasites are also vectors for malaria, yellow fever, dengue fever, elephantiasis, etc

mosquitoes indirectly kill more people each year than any other cause (infest up to 1 Billion each year and kill up to 3 million)

eg. bed bug

4-5mm

nocturnal

feed on blood

in day, hide in bedding and cracks and crevices anywhere in room

in large infestations produces distinctive “bedbuggy smell” can live up to a year even without food

eg. Lice

looked on today with disgust and loathing but:

high proportion of some populations (50%) esp children have them

common in jails, camps, etc

in some countries lice are believed to be an indication of robust health and fertility

can suck on blood intermittently for hours at a time

usually feed at night

eg. head lice

prefer fine hair of head

eg. body lice

generally live on clothing when not feeding

head and body lice can spread:

- typhus
- trench fever
- relapsing fever

eg. crab louse

mainly in coarse hairs of body:

- pubic area, armpits, beard, eyebrow, eyelashes

- almost exclusively confined to caucasians

- almost always venereally transmitted

each female can lay 25 eggs at a time

eg. Fleas

over 1000 species of fleas

ectoparasites of birds and mammals (warm blooded)

larvae live in nests

have compressed bodies and backward spines and bristles to help them move through fur piercing, sucking mouthparts

long powerful legs → enormous jumping power

eg. human flea (Pulex irritans; really a pig flea) can jump 13” horizontally

7.75” vertically
equivalent jump for human:
450’ broad jump
275’ high jump
most breed and lay eggs in nests of hosts
cat and dog fleas lay eggs in fur of host
cat, dog, rat fleas readily attack humans

most fleas suck blood wherever they can find it

some species can survive up to 2 years without food

fleas are fairly indiscriminant in host choice

→ since they change hosts easily they easily transmit diseases: typhus, plague, etc

David Harum: “A reasonable amount of fleas is good for a dog, they keep him from broodin’ on bein’ a dog”

eg. Rabbit Flea (*Spilopsyllus*)
parasite’s ovaries develop in response to corticoid hormones of pregnant host’s reproductive cycle

→shortly after rabbits are born

levels of pituitary hormones in young stimulate fleas to copulate and lay eggs

afterwards, most fleas return to mom and complete regression of their gonads occurs

eg. Flies
eg. blood sucking flies → blackflies, sandflies, no-see-ums, horseflies, stable flies

eg. myiasis
some flies lay eggs in flesh and maggots feed on tissue until they molt into adults

1. Insect and spider silk is being investigated for a variety of purposes

20x’s stronger than steel
it does not trigger an immune response
can be easily produced at low temperatures and pressures compared to other similar polymers

is biodegradable

organisms such as bacteria, potato and tobacco plants and goats have been genetically engineered to produce silk

eg. silk is already used to make underwear for British and American troops in Afghanistan

much more resistant to shrapnel injuries, doesn’t tear

→ even if the shrapnel enters the body it is enclosed in the silk and therefore much easier to extract.

especially important for a part of the body that is often of most concern to the soldiers when injured

eg. films of silk have been used to produce artificial corneas

→ “its amazingly transparent”

eg. may one day be used as scaffolding to get stem cells to mend bones and muscles

eg. controlled releases of antibiotics and other medicines inside the body

2. Insects as food

in industrialized world we often react in disgust at the thought yet we eat insects all the time

eg. FDA allows up to 60 insect fragments/100 grams of chocolate; up to 30 pieces/100g of peanut butter;

in many parts of the world, insects are considered delicacies

eg. central African children eat ants and grubs as they play

eg in SE Asia street vendors are thronged for their fried crickets

eg. in africa a certain species is sought after so much that biologists are concerned about its extinction

eg Aborigines in Australia will travel several hours to find a cache of honey ants to eat

113 nations eat bugs

we happily eat crabs, shrimp, and lobster; the “insects of the ocean” but are repulsed by the thought of grilled cicadas

gram for gram many insects are more nutritious than beef or pork

eg. 3 crickets could provide an individuals daily iron requirement

eg. many insects have a fairly high concentration of essential amino acids

9. Medical applications

eg. *maggots* used to clean wounds by eating dead tissue from wounds

secrete a fluid containing enzymes that speed healing

certain species of blowfly larvae; 5-10/cm² for 2-3 days

will eat and remove ONLY the dead and damaged tissues and leave the healthy tissues alone

heal some kinds of wounds much more effectively and much more quickly than other treatments

have produced a prototype gel that healed wounds more quickly

hope to produce wound dressings impregnated with the enzymes

10. Chinese Herbal Medicine

weaver ants are pulverized into a powder used to treat asthma

powdered cockroach are used for stroke

silkworm feces is used to treat typhus

bee venom, honey and other bee products are used to treat miscellaneous ailments

dried cicadas are boiled in a soup to improve eyesight
eg. and the fats in bugs are considerably healthier than the fats in meat

eating insects would be considerably “greener” than our current meat diet

and it’s a sustainable industry that causes much less destruction of the environment

3. blood sucking insect, *Dipetalogaster maximus*, is used as a high tech syringe
can take up to 4 ml in one meal
donor doesn’t feel a thing
used as a way to get blood samples from wild animals that are difficult to sample in other ways
eg. can measure stress hormone levels in nesting terns without having to capture them

eg. used to survey rabies infections in bats
removes blood sample using a needle; they recover quickly

4. insects as chemical detection devices
insects have extremely sensitive olfactory senses
military and security services need ultra sensitive, flexible and portable odor detectors

sniffer dogs
cost ~$15,000 each,
takes 6 months to train
require dedicated handler

“wasp hound” = a portable hand held odor detector
with a team of black wasps as its sensor
so far the wasps have learned to respond to just about any odor tried
wasps show coiling behavior when they detect food molecules
other insects (eg. bees) when they detect food they stick out their tongues
they can detect an odor at concentrations of a few ppt
\[ \text{equivalent to finding a grain of salt in a swimming pool} \]
after a couple day stint as sniffers they are returned to hive and a new batch is trained
can also be used to assure food quality,
check for contaminants
maybe even help diagnose diseases such as cancer or TB

5. Scientists hope to harness the activities of termite bacteria to break down cellulose to produce ethanol and biofuels