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

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 anarctica

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

→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

insects: 330 MY(SN04); carboniferous
reptiles: 200 MY pterosaurs; late jurassic ,
birds: 150 MY; coexisted with pterosaurs for~90MY
bats: 54 MY (Eocene)

A few kinds of insects have been semi-domesticated:

honeybees

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

silkworms (moth larvae spin coccoons of silk)

each coccoon 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 insects life:

eg. 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

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**

<u>Insect Movement</u>

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

eg. 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

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)

eg. grasshoppers can jump 20 times length of body

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

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

→ equivalent feat in human → leap tall bldg in a single bound

storage of pollen (bees)

swimming (diving beetles, many insect larvae)

B. Wings

most insects have two pairs of wings

some use both pairs to fly (eg. butterflies)

some the 1st pair cover and protect second pair (eg. 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 upsidedown 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

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 snip 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

e. some are **predaceous**

eg. dragonflies, some beetles have large strong mandibles

f. some are **parasitic**

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

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

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

midgut → usually has sac-like **gastric caecae**
enzyme secretion and absorption of nutrients

hindgut → **intestine** and **rectum**
rectum for water and nutrient absorption;

Respiration

an insects blood does not carry much oxygen

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 system of tubes and passageways

tracheal system with spiracles → adaptation to air

many spiracles have valves

tracheal system is lined with cuticle → must be shed

gas movement by **diffusion**

larger insects use some kind of **ventilation**

eg. pumping movement of abdomen

aquatic forms returned to water:

→ tracheal gills in cloaca eg dragonflies

→ water bubbles

→ return to surface to breath

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

and compound eyes that are especially effective in detecting movement

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

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

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

chemoreceptors are found on all parts of the insects body

→on setae, antennae, mouthparts, legs

→but are mainly on antennae and feet

→ wasps and crickets know where to lay eggs because they have chemoreceptors on their ovipositors

receptors for taste and smell have a pore that receives the chemical to be detected

eg. a single sense organ on the antenna of a polyphemus moth has 18,000 pores for chemicals to enter

most insects have 4 of the same **taste sensations** as do humans: sweet, sour, bitter and salty

organs of **smell** do not detect as many different odors as does a human nose

but it is tuned more finely

→ can detect differences between very similar chemicals and in much lesser amounts

some can detect airborne chemicals 5 miles away

eg. male of lesser emperor moth can smell the pheromone of the female up to 6 miles away

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

<u>**Behavior & Communication**</u>

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, termintes, 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

→ they work almost as a single individual

eg. ants

in relative size ants have one of the larges brains among insects

→ each ants brain consists of 250,000 cells with the processing power equivalent to a Mac II computer

→ as a colony of 40,000 individuals, the colony has a processing power equivalent to the brain of a mammal

eg. bees

a queen is selectively bred in a special queen cell.

She is fed "royal jelly" by worker bees to induce her to become sexually mature

she makes a mating flight with about a dozen drones

the drone that succeeds in impregnating her plugs her genital opening with his broken off penis after insemination to insure that no other males can copulate with her.

Insect Defenses & Weaponry

1. hard exoskeleton

the hard exoskeleton of insects serves as an effective defense against many dangers

eg. large beetles, including weevils, have a particularly thick exoskeleton

some insects have a "fracture line" in each appendage that allows the leg to break off easily if caught by a predator

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 insets 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 camoflage

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 camoflage

camoflage 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 concotion 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

<u>sting-pain index based on human perception</u>

0. sting doesn't penetrate skin

1. sharp, sudden, effect similar to a stray spark

eg. fire ant sting

2. a piercing pain

eg. honeybees, common wasps & hornets, acacia ant

3. bold, caustic, burning and unrelenting

eg. paper wasps, harvester ants

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 sleeve onto their arm.

the goal of this initiation rite is to keep the sleeve 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

<u>Excretion</u>

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

<u>Reproduction & Life Cycles</u>

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

<u>Mating</u>

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

useful as a natural insect deterrent

some may care for young after hatching

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→larva→pupa→ 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→nymph→ adult

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**

egg → juvenile → adult

eg. silverfish, springtails

metamorphosis is regulated by hormones

3 major endocrine glands in insects:

brain
ecdysial gland
corpora allata
} produce juvenile hormone & molting hormone

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

if this dormancy is for an extended period and triggered by daylength = **diapause**

Ecological Impacts of Insects

insects are the most important organisms in most terrestrial ecosystems

without insects, most of the terrstrial 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

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<u>Bacteria</u>

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 converte N_2 into useable nutrients for the termites

<u>Protozoa</u>

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

<u>Fungi</u>

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

→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

eg. 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

<u>Plants</u>

eg. Pollination

a large part of the success of flowering plants is due to the variety of pollenation

→ 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)

flowers generally **shallow** (short mouthparts)

honeybees are attracted to **nectar**
they also gather pollen

flowers often **delicately sweet** and **fragrant**

flowers often have lines or distinctive markings that function as "**honey guides**"
→ lead bees to nectar

some of these markings are only seen in **UV** light
→ invisible to us, not bees

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 *Tetrastigma* (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**

heavy fragrance

open at night, closed in daylight

eg. yuccas, night blooming jasmine, night blooming cereus

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. 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

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 6^{th} 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 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 <u>$57 Billion</u> 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 pollenation 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 pollenators:
- 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 coccoons of silk)

eg. **silk**

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

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

before making a coccoon, 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 coccoon is made from over a half mile of silk

the coccoons are collected and plunged in boiling water to kill the silkworm and remove the sticky glue that holds the coccoon 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 ono cactus → dyes

7. Venomous Insects

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

some caterpillars have poisonous hairs or spines

that are attached to poison gland

with any contact spine penetrates skin and injects poison

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 (infect 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

eggs = nits, deposited on hairs or clothing

eg. head lice
prefer fine hair of head

eg. body lice
generally live on clothing when not feeding
a female can lay 80-100 eggs at a time

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
afterwords, most fleas return to mom and comlete 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

blow fly larvae are used as surgical aids
only eat dead tissues → clean wound
they destroy bacteria
wound heals much quicker

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/cm^2 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

Future Applications

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 engineerred to produce silk

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

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 extracrt.

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 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

→ 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