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Summary of Exam Knowledge Needed:

List of Arthropod Classes that students will be required to recognize on sight, be familiar with the major groups included, their basic biology* & anatomy (below are some suggested references, but similar information can be found on numerous websites, if any of these links are broken):

- Arachnida (Spiders, Scorpions, Ticks, and relatives)
  [http://www.biokids.umich.edu/critters/Arachnida/](http://www.biokids.umich.edu/critters/Arachnida/)
  [http://entomology.ucdavis.edu/Faculty/Robert_B_Kimsey/Kimsey_Research/Tick_Biology/](http://entomology.ucdavis.edu/Faculty/Robert_B_Kimsey/Kimsey_Research/Tick_Biology/)
- Chilopoda (Centipedes)
- Collembola (Springtails)
- Diplopoda (Millipedes)
  [https://en.wikipedia.org/wiki/Millipede](https://en.wikipedia.org/wiki/Millipede)
  [http://www.earthlife.net/insects/diplopoda.html](http://www.earthlife.net/insects/diplopoda.html)
- Insecta (Insects)
  [http://www.earthlife.net/insects/orders.html](http://www.earthlife.net/insects/orders.html)
- Malacostraca (Crabs, Crayfish, Isopods, Pill bugs, and relatives)
  [https://en.wikipedia.org/wiki/Malacostraca](https://en.wikipedia.org/wiki/Malacostraca)

List of Insect Orders that students will be required to recognize and/or use a dichotomous key to identify and be able to recount basic biology*, life history (type of metamorphosis), and ecology (habitat, diet) of:

- Blattodea (Cockroaches & Termites)
- Coleoptera (Beetles)
- Dermaptera (Earwigs)
- Diptera (Flies)
- Ephemeroptera (Mayflies)
- Hemiptera (True bugs, Cicadas, Hoppers, and relatives)
- Hymenoptera (Ants, Bees, & Wasps)
- Lepidoptera (Butterflies, Moths, & Skippers)
- Mantodea (Mantises)
- Megaloptera (Alderflies, Dobsonflies, and Fishflies)
- Neuroptera (Antlions, Lacewings, and relatives)
- Orthoptera (Crickets, Grasshoppers, and Katydid)
- Odonata (Dragonflies and Damselflies)
- Siphonaptera (Fleas)

* Basic Biology refers to familiarity with the organism’s habitat, diet, type of metamorphosis, and ecological niche (free living, parasite, herbivore, etc).
List of specific species, or closely related groups of species, that students must be able to visually recognize and recount their taxonomy (what Class/Order they belong to), the scientific name (Genus + species), life history, ecology, and economic impact (how do they help or harm humans), or conservation status of:

- American Burying Beetle (*Nicrophorus americanus*)
- American Dog Tick (*Dermacentor variabilis*)
- Antlion (*Myrmeleon immaculatus*)
- Asian Longhorned Beetle (*Anoplophora glabripennis*)
- Black-legged Tick (*Ixodes scapularis*)
- Brown Marmorated Stink Bug (*Halyomorpha halys*)
- Bumble Bees (*Bombus spp.*)
- Eastern Carpenter Ant (*Camponotus pennsylvanicus*)
- Eastern Dobsonfly (*Corydalus cornutus*)
- Eastern Subterranean Termite (*Reticulitermes flavipes*)
- Emerald Ash Borer (*Agrilus planipennis*)
- German cockroach (*Blattella germanica*)
- Green Bottle Fly (*Lucilia sericata*)
- Gypsy Moth (*Lymantria dispar*)
- Honey Bee (*Apis mellifera*)
- Human Bed Bug (*Cimex lectularius*)
- Japanese Beetle (*Popillia japonica*)
- Karner Blue Butterfly (*Lygaeides melissa samuelis*)
- Monarch (*Danaus plexippus*)
- Multicolored Asian Lady Beetle (*Harmonia axyridis*)
- Paper Wasps (*Polistes spp.*)
- Pavement Ant (*Tetramorium sp.*)
- Viceroy (*Limenitis archippus*)
- Winter Crane Flies (*Trichocera sp.*)
- Yellow Jackets (*Vespula* and *Dolichovespula* spp.)

* This information can most easily be obtained by typing the scientific name into an internet search engine and looking at top results from trusted sources, such as Universities or Dept. of Natural Resources.

List of specific Concepts to Study

- How to use Identification Keys. Practice helps! (see pgs. 14-15 of this manual for Class ID)
- An easy to use key to insect orders: [http://www.knowyourinsects.org/index.html](http://www.knowyourinsects.org/index.html)
- Various methods of collecting arthropods and what specific tools/equipment are used in various habitats (see [macombo.org](http://www.macombo.org) website for document)
- Arthropod basic anatomy and body axes (see pgs. 9-11 of this manual)
- Insect Growth & Metamorphosis (see pgs. 16-20 of this manual)
- Pest Control Tactics (see pgs. 21-26 of this manual)
  - Mechanical Control [https://projects.ncsu.edu/cals/course/ent425/library/tutorials/applied_entomology/physical_mechanical_control.html](https://projects.ncsu.edu/cals/course/ent425/library/tutorials/applied_entomology/physical_mechanical_control.html)
Taxonomy of the Phylum Arthropoda

Subphylum Chelicerata (kuh-lis-er-a-da)
- Class Arachnida (uh-rak-ni-da) - Spiders, Harvestmen, Scorpions, Ticks, and others
- Class Merostomata - Horseshoe Crabs
- Class Pycnogonida - Sea Spiders

Subphylum Crustacea (kruh-stey-she-a)
- Class Branchiopoda
- Class Malacostraca (mal-uh-kos-truh-kuh) - Crabs, Crayfish, Isopods, and others
- Class Maxillopoda
- Class Ostracods

Subphylum Hexapoda (hex-ah-po-da)
- Class Insecta (in-sek-ta) - Insects
- Class Diplura - Bristletails
- Class Protura - Coneheads
- Class Collembola (kuh-lem-buh-luh) - Springtails

Subphylum Myriapoda (mir-euh-poh-da)
- Class Chilopoda (ky-luh-poh-da) - Centipedes
- Class Diplopoda (dip-luh-poh-da) - Millipedes
- Class Symphyla
- Class Pauropoda

Example of Linnaean Classification:

Kingdom Animalia
Phylum Arthropoda
Class Insecta
Order Coleoptera
Family Tenebrionidae
Genus Alphitobius
Species diaperinus

Classes highlighted in green are the only classes that students will be responsible to know for this event.
Introduction to the Adults of Class Insecta

The following is a brief introduction of the insect Orders you are responsible to know and some key characteristics to look for when identifying them. You will need to dig a little deeper on your own to learn about their basic biology (diet, habitat, type of metamorphosis, etc).

Blattodea (Cockroaches & Termites)

Historically Cockroaches and termites were considered separate orders (you may still see references to the Order Isoptera, which termites were previously classified) but more recent DNA evidence shows they are undeniably from the same lineage and belong in the same Order. In essence, termites are highly social, wood-eating cockroaches! This group will be soft bodied and have flexible cerci on either side of the tip of their abdomen. Wings may be present or absent in this order. Cockroaches have deflexed heads that aren’t fully visible from above and generally have very long antennae, sometimes as long as their body or more! Termites heads are generally pointing forward and their antennae are shorter and bead-like.

Coleoptera (Beetles)

Beetles are readily recognized by their hardened front wings, also called elytra. Their wings almost always completely cover their abdomen as a kind of hardened “body armor,” however some families have shortened elytra and may not at first appear to be beetles. Look for the elytra to meet in a straight line down their backs to know if it’s a beetle. Beetles also have membranous hind wings hidden under their elytra that many species use for flight. This is the most diverse order on animals on the planet, with over 350,000 described species of beetles currently known!

Dermaptera (Earwigs)

Earwigs look a little like a cross between a beetle and a cockroach. Earwigs have cerci at the tip of their abdomen, however, unlike the cockroaches these cerci are hardened and opposable (they can pinch!). This feature coupled with their unique wings make them easy to recognize. Dermapterans have four wings, with the front pair short, hardened and leathery and the back pair membranous and long. The hind wings are highly folded to fit under the short front wings. Though the wings are functional, earwigs rarely fly and some species may never fly.
Diptera (Flies)

Dipterans, as the Greek roots of their name implies (di = two, ptera = wing), have only two wings. This is a great characteristic for separating them from almost any other arthropod you will encounter. Their hind wings are reduced to little stubs that no longer function as wings, and are called halteres. This is another very diverse order, be warned, flies come in many shapes and sizes. There are many flies that mimic bees and wasps in appearance and are commonly mistaken for them! Flies generally have large compound eyes, short antennae, and compact bodies. Worldwide there are roughly 160,000 described species!

Ephemeroptera (Mayflies)

Adults may be quite small or quite large, but generally have four wings with the front wings much larger than the hind wings. Mayflies generally have large compound eyes, very short antennae, and three long “tails” protruding from the tip of their abdomen. They hold their wings over their backs when resting.

Hemiptera (True bugs, Cicadas, Hoppers, and relatives)

All Hemipterans have straw-like mouth parts, called a rostrum, which they use to puncture and suck fluids with. Their antennae are straight and often short with generally 4 or fewer antennal segments. Some species have antennae that resemble a tiny bristle (leafhoppers) and others may have longer antennal segments. You may run across some references that treat hemiptera (true bugs) and homoptera (hoppers, cicadas) as two separate Orders, but they are all considered Hemiptera now. They generally have 4 wings, though some are wingless, and the front and hind wings are approximately the same size in most species. The “true bugs” (Heteroptera) have wings that are leathery at the base and membranous at the tip, as shown on the above image.
Hymenoptera (Ants, Bees, & Wasps)

They generally have 4 wings (though some are wingless); when present, the front wings are much larger than the hind wings. The wing veins are quite sparse compared to many of the other Orders. Most members of this order also have a strongly narrowed “waist” or pedicel which is the first 2 or 3 segments of the abdomen strongly constricted. However, more ancient lineages, like the sawflies, do not have the constricted “waist.” Many adults have chewing mouthparts or modifications for sucking liquids, usually for sucking nectar out of flowers. This is another mega-diverse order with 115,000 known species worldwide, though many thousand more are thought to await discovery.

Lepidoptera (Butterflies, Moths, & Skippers)

The name of this order from the Greek roots literally means “scale wing.” This is a great identifying characteristic, as almost all butterflies and moths have large wings completely covered with small scales, much like shingles cover a roof. Almost all species have four wings, though there are a few wingless species. A few species don’t have functional mouthparts as adults, but most have a long tube-like proboscis that remains coiled under their heads when not in use. This Order contains roughly 300,000 known species, the vast majority of these being moths! Butterflies account for only roughly 5% of Lepidopteran species.

Mantodea (Mantises)

These insects are often quite large, though often go unnoticed because of their camouflage and ability to sit and wait long periods to ambush prey. They usually have a very narrow pronotum (the first segment of the thorax), with a pair of powerful raptorial legs attached. They have a large moveable head, with prominent compound eyes. Antennae are often short, generally not extending to the abdomen.
Megaloptera (Alderflies, Dobsonflies, and Fishflies)

This group is usually medium or large in size with long slender bodies, and clearly visible antennae. The Megalopterans have very large front and hind wings; the hind wing has an extra fold (called the anal fold) which is distinctive. The mouthparts are of the chewing type, though some adults don’t eat, and some species have very prominent mandibles.

Neuroptera (Ant lions, Lacewings, and relatives)

This Order resembles smaller Megalopterans, but their hind wings do not have an anal fold and the wings tend to have more cross veins. They often have prominent compound eyes on the head, and have chewing mouthparts. Antennae may be rather short or nearly as long as the body. There is quite a bit of anatomical diversity in the Neuroptera, with some species having raptorial front legs and strongly resembling small mantises.

Orthoptera (Crickets, Grasshoppers, and Katydid)

Most Orthoptera species are recognized by their greatly enlarged hind legs which they mainly use for jumping away from predators. Species in this group generally have four wings, which often completely cover the abdomen. The wings have many cross-veins, and are leathery to the touch. Their mouthparts are adapted for chewing. The Orthoptera includes many common species that can be heard calling (chirping) on warm summer nights. The chirping sounds are made by stridulatory organs, ribbed body parts that are rubbed together to produce the sound. Grasshoppers create the sound by rubbing a rasp on their hind leg against the adjacent wing, while cricket and katydids chirp by rubbing special bumpy areas of their wings together.
Odonata (Dragonflies and Damselflies)

Medium to large sized insects, they have long needle-like bodies and four large wings, with front and hind wings the same size. They have large heads dominated by a pair of compound eyes, equipped with chewing mouthparts, and short bristle-like antennae. Dragonflies tend to keep their wings outstretched while resting, whereas the damselflies will bring their wings together straight above their backs when resting. Some species can be quite bright and colorful!

Siphonaptera (Fleas)

Fleas are very distinctive creatures! Their bodies are highly compressed laterally, much like a coin standing on edge. They are wingless, with backwards directed hairs on their bodies making them tough to remove from a furry animal, like a pet. Fleas are all ectoparasites of animals meaning the adults live on and feed on the outside of a host, generally a bird or a mammal. They feed on the host’s blood, so have mouthparts adapted for piercing and sucking. Their hind legs are powerful and built for jumping; but rather than using their legs for escape, they will jump towards a host that has moved in front of them.
Arthropod Body Axes (ak-seez)

When describing arthropods it’s sometimes necessary to refer to regions of the body and their relation to other regions of the body. Anatomists use a series of axes, or imaginary lines, which can be thought of as crossing through an organism in X, Y, and Z coordinates. In scientific literature these terms will show up when talking about all organisms, not just arthropods. Some of these terms even make it into everyday speech. For instance, you may have heard of someone jokingly referring to a person’s posterior after they sat in a puddle of water or otherwise messed up their backside.

In short, things towards the head (or front) of the animal are referred to as **anterior**, while things towards the back are referred to as **posterior**. Things on top are called **dorsal** (you may have heard of the dorsal fin on a fish) and things under are called **ventral**. Things towards the outside of the body are **lateral** (think shoulder blades) and towards the center line—the dashed line on the image below—are **medial** (think belly button). For appendages, the further away from the body is **distal** (also called **apical**), like our hands, while closer to the body is called **proximal** (or **basal**).

![Arthropod Body Axes Diagram](image_url)

*Fig. 1: A vinegar fly (or small fruit fly) standing on the surface of a table grape with the major body axes superimposed.*
Basic Arthropod Anatomy

Similar to body axes there are some technical anatomical terms for arthropods that you will need to learn to be able to properly discuss and identify them. There may also be some supplemental anatomy for specific groups found in the website links on pages 1-2.

Arachnida:
- Two main body segments, the cephalothorax and the abdomen. The cephalothorax is essentially a face plastered onto a thorax (kind of like Mr. Potato head)! There is no separate head.
- Always have 8 legs and 2 pedipalps attached to the cephalothorax. Pedipalps may take the form of "pinchers" as in scorpions.
- The mouthparts are called chelicera.
- Can have various numbers of eyes, but they are always simple (single faceted) eyes.

Malacostraca:
- May have 2 or 3 main body segments. The specimen shown has three the head, thorax, and abdomen. In species with two tagma, they will only have a cephalothorax and abdomen.
- The thorax has all of the legs attached to it, different species will have different numbers, but all have at least 5 pairs of legs.
- The abdomen will often have some specialized structures on it used for movement (as in the tail on shrimp) or reproduction.
Insecta & Collembola:
- Three main body segments (tagma) the head, thorax, and abdomen.
- Many sensory organs and the mouthparts are found on the head.
- Have both simple and compound eyes. Compound eyes allow excellent color vision, simple eyes are generally thought to tell only light vs. dark and be involved in circadian rhythm.
- All 6 legs and all wings (either 0, 2, or 4) attach to the thorax.
- The abdomen contains most of the digestion, reproductive, and defensive organs.

Chilopoda & Diplopoda:
- Have two main body regions, the head and thorax (often called the trunk).
- Most species have small collections of ocelli on their heads, so technically they can be called compound eyes, though their vision is considered very poor.
- The name centipede implies 100 legs and millipede implies 1,000 legs, though no known species actually have this many legs!
- Chilopods have a set of venom fangs, called forcipules, instead of their front pair of legs. They can bite with these if handled, so be careful! Both diplopods and chilopods possess chewing mouthparts, though have very different diets.
Using Identification Keys

When dealing with arthropods it’s very important to be able to identify what you are finding! For instance, is the specimen a spider, a beetle, or a butterfly...? For this event we are most interested in identifying specimens to the “Class” and “Order” levels. It is unrealistic to expect anyone but a professional specialist to be able to give identifications at the Genus and species levels for all specimens collected. Please don’t attempt to do this!

When identifying specimens an identification key is used. For this event there are two main keys to utilize, one is included on the following pages of this manual and can be used to identify things to the Class level. The other key, can be used to identify insect specimens to the Order level, and is found online (see the second link from the top on page 2). The following is a description of how to best use an identification key, this passage is quoted from the Encyclopedia of Entomology:

“Keys are arrangements of taxa (a group of organisms that is sufficiently different from other groups to be considered a unique group), with similar taxa—usually based on external morphology, or appearance—clustered together. Thus, insects with wings may be in one cluster, wingless in another. Then within one of these clusters, some other character such as antenna length is used to segregate individuals further: those with wings and long antennae in one cluster, those with wings and short antennae in another. Extended far enough, this process can lead to species-level determinations. Keys usually require the user to make a choice between only two characters at a time: so-called “dichotomous keys.” The choices are usually numbered, and the user is referred to various sections of the key by number.

In almost all cases, keys begin with a large taxon (e.g., arthropods or insects), and work down to smaller and smaller groups. Often insect keys segregate Orders, and then there are separate keys for each Order that separate Families, then other keys to distinguish among the Genera in the Families, and then finally keys to species, which sometimes are integrated with keys to the Genera. A common, but incorrect, assumption is that Order or Family keys are easier to use than species keys. The opposite is true. Keys to larger taxa must accommodate a great deal of variation, and sometimes it is difficult to find unifying characteristics.

Illustrated keys have a major advantage in that they graphically display the characters of interest. It is much easier to understand differences among contrasting characters when they are illustrated. It also helps to have the key graphically displayed in a flow-chart arrangement. This gives the user better opportunity to see at a glance where the key is headed, and to easily work backward if diagnosis proves difficult.
A few pointers on use of keys follow:

- Do not attempt to skip through a key, or to take short-cuts. Start at the beginning and work through the key methodically.
- Read the descriptions carefully; a large percentage of errors are caused by careless reading, or by the user not understanding the meaning of the words. Terminology may differ between taxa, so if you are not familiar with a taxon it is advisable to look up the exact meaning of terms. Illustrations are immensely helpful.
- You will be asked to make a series of decisions, usually making the “best” choice among two options. Your specimen should fit one of the two choices; if not, perhaps you made an incorrect decision earlier in the key.
- If more than one character is provided for you to examine, the first character is usually the most important. The others are secondary, or apply only in part.
- It is helpful to examine more than one specimen. It may be difficult to see a key character on certain individuals, or there may be sexual differences in the degree of expression.
- When you arrive at a final destination, do not automatically accept it. Always seek a more complete description of the organism to ascertain that the specimen seems to match.”

To verify an identification consider using the website links found on pgs. 2-3 to see if your identification seems to match other known examples of that group.

Reference:

Key to Classes of common Adult Arthropods *

1. Adult arthropod specimen
   a) Specimen does NOT have antennae or wings AND has 8 legs plus one pair of leg-like or claw-like appendages (pedipalps) .................................................. Class Arachnida

   b) Specimen has one or more pair(s) of antennae, legs variable ......go to step 2

2. Specimen with antennae
   a) Specimen has six legs (may have other tails, spines, or appendages not primarily used for walking) ................................................................. go to step 3

   b) Specimen has more than six legs ................................................................ go to step 4

3. Specimen with six legs
   a) Tiny specimens (0.5 - 6 millimeters long), never with wings, always with a cylindrical specialized organ (collophore) on the ventral side near the hind legs, and often have a flexible organ (furcula) used for jumping ........................................ Class Collembola

   b) Size variable (1 mm - 4 inches long), may have wings, tails, or other abdominal protrusions, but never with a specialized jumping organ or cylindrical collophore on the ventral side of the abdomen ........................................ Class Insecta

* Make sure that specimen is in good condition, any broken or missing legs, wings, or antennae may invalidate your identification.
Key to Classes of common Adult Arthropods (cont.) *

4. **Specimen with more than six legs**
   a) Specimen has fewer than 9 pairs of legs and has an abdomen. **Class Malacostraca**
   
   ![Malacostraca Image](image1)
   
   b) Specimen has 9 or more pairs of legs and no abdomen. **go to step 5**
   
   ![Millipede Image](image2)

5. **Specimen with 9 or more pairs of legs and no abdomen**
   a) Specimen has 1 pair (2 legs) per body segment. **Class Chilopoda**
   
   ![Chilopoda Image](image3)
   
   b) Specimen has 2 pairs (4 legs) per body segment. **Class Diplopoda**
   
   ![Diplopoda Image](image4)

* Make sure that specimen is in good condition, any broken or missing legs, wings, or antennae may invalidate your identification.
**Arthropod Growth & Metamorphosis**

All arthropod development is comprised of three major phases: **egg**, **immature**, and **adult**. That’s right, all of these creatures start life off as an immobile egg which hatches (**ecloses**) into a very small immature form. When an arthropod first leaves the egg it is called a **first instar**, this stage is generally quite active and able to fend for itself but rarely seen because of its small size.

To help keep the various types of metamorphosis distinct, different terminology is used for the immature stage; see if you can spot the 4 different terms for immature stages in the figures below (but they are all referred to generically as first instars).

The first instar will take in nutrients by eating and beginning to grow. However, as all arthropods have their “skeletons” (hard parts of their body) on the outside and their muscles and other soft tissues inside, they must **molt** before growing any larger and entering the second instar stage. The hard outer covering of arthropods is known as the **exoskeleton**, which must be broken down and partially dissolved so that the first instar can break through it when molting. While the old exoskeleton is breaking down underneath it the new, and larger, one is forming inside. For anyone familiar with Russian nesting dolls, or Matryoshka dolls, you know that you can’t put a larger doll inside of a smaller one, but that’s essentially what arthropods are doing when they molt! This is possible as the new exoskeleton of the second instar hasn’t fully hardened yet when emerging from the molted skin of the first instar.

Often newly emerged arthropods are confused as being albino individuals as many appear as a very light whitish color. Once they crawl out of their old skin they will expand slightly before the new exoskeleton hardens and again takes on its characteristic darker coloration. The visible molting process is known as **ecdysis** and is usually complete within a few hours or less. This same process will repeat as the arthropods grows larger and larger, all of these instars taken together are known as the immature stage.

Eventually the arthropod is a full grown adult that is capable of reproduction, i.e. mating, and if it’s a female, laying eggs of its own to start the **lifecycle** over again. Adults often have features slightly or drastically different from the immature stages, this is where the term **metamorphosis** comes into play.

The term, **metamorphosis**, when used in biology describes how an arthropod (usually only used when discussing an insect) develops and what morphological, or anatomical, changes it undergoes while maturing. The word comes from the Greek roots “meta” and “morphe,” which literally mean a changing of form. Metamorphosis is often described in slightly different ways and by using differing numbers of categories depending

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*Amazing Arthropods Study Guide – Version 4, October 16, 2017*
on the author. Here we will use the following four categories: **Without**, **Gradual**, **Incomplete**, and **Complete** metamorphosis.

Developing **Without metamorphosis** looks a lot like what it sounds like, there are no drastic changes from the first instar to the adult! The only difference is that the adult stage is larger and sexually mature, otherwise it looks just like an immature. Some arthropods in this group actually continue to grow and molt even after they’ve reached the adult stage!

![Fig. 6: A lifecycle diagram of a silverfish, which develops Without metamorphosis](image)

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Gradual metamorphosis looks very similar to developing without metamorphosis, in that the nymphs and the adults very strongly resemble each other. However, adults are clearly different from the nymphs as they have fully developed wings (in species that are winged) in addition to being sexually mature. Species that undergo gradual metamorphosis are very common in the environment and undoubtedly having winged adults helps a species to move into new areas and find a wide array of food resources.
Incomplete metamorphosis is where things start to get really interesting. All insect Orders that mature in this manner are aquatic species when immature and they do NOT resemble the adult forms, which fly around in terrestrial environments. This is truly a transformation! The adults and immatures do not even inhabit the same environment! The aquatic naiad must crawl out of the water or float to the surface in order for the winged adult to emerge and fly away.

Fig. 8: A lifecycle diagram of a dragonfly, which develops by Incomplete metamorphosis
You’ve probably all viewed the lifecycle of a butterfly, beginning as a tiny egg, then hatching into a caterpillar, which grows and pupates into a chrysalis, and eventually emerges as a butterfly. This is known as **Complete metamorphosis**. What you may not know is that most insects develop in this fashion, including things like beetles, flies, and ants. This is considered the pinnacle of insect development as so many successful species are included in this group. It is thought that insects developing through complete metamorphosis are so successful because they often don’t have to compete with their offspring for food and habitat needs; the immatures and the adults often lead very different lives, eat different things, and live in different places.

It’s important to note that this type of metamorphosis includes a “resting” stage before the adult stage that is generically know as a **pupa**. Pupa generally don’t move and have reduced metabolic rates, making them environmentally resilient. Some species can remain as pupae for many months and can wait until favorable conditions before emerging as adults. Many insect species in Michigan spend the long cold winter in the pupal stage.

![Fig. 9: A lifecycle diagram of a flea, which develops by Complete metamorphosis](image-url)
Pest Management

Introduction:

We are all part of the ecosystem of planet earth. While it’s intriguing to think about the ways that humans are inherently different from all other forms of life on the planet, we are for the most part much the same; we are made of the same stuff, we eat things that were grown here, and we live here. We compete with many other species (many of them arthropods) to continue to survive and live here.

While we cherish those groups that benefit humans, like the bees that help pollinate our plants, we tend to despise the groups that bite us, spread disease, infest our structures, eat our food, or just plain annoy us. We collectively call these arthropods pests. A pest is simply a human designation for these undesirable species. Fortunately, the vast majority of arthropod species are NOT pests, fewer than 1% of species are pests. What we consider to be a pest will change over time. For instance, carpet beetles and clothes moths feed on many animal proteins like hair, fur, and skin; in nature they help to break down old animal carcasses. In the past, clothes were often made of wool and things like horse hair was used to insulate homes—so it’s no surprise that many people had problems with carpet beetles and clothes moths infesting their homes and ruining their belongings. Nowadays most of our clothing and insulation is made from non-edible, synthetic fibers, so these insects aren’t very common pests anymore.

It is also important to remember that simply because people don’t like a certain arthropod it may, in fact, have a very important ecological role to play. This is one reason why the term “extermination” has largely been replaced by “pest management.” Rarely is it beneficial (or possible) to completely exterminate a species! Rather we strive to manage pests, so that their numbers don’t get out of control, or to keep them away from resources we want to protect (crops, buildings, pets, etc.). Integrated pest management is the use of a variety of methods to effectively and economically manage pests. Generally, using multiple strategies improves control, reduces costs, and makes it less likely that pests will develop resistance to the methods used.

History:

As long as humans have walked the earth there has been a need for pest management to combat species that feed on blood such as mosquitoes, ticks, lice, and many others. However, with the dawn of agriculture and land settling suddenly a whole host of organisms became...
pestiferous to humans that previously had not been very important. The majority of animals on the planet require at least some plants as a source of dietary nutrition and arthropods are no exception. Once humans domesticated plants and became farmers many arthropods became pests. Even today approximately 80% of pest management dollars are put towards protecting our crops from pests.

Throughout history there are many examples of attempts to manage pests, but most were either based on complete superstition or had variable effectiveness. Pests were often seen as punishment from the gods, and not something that could be controlled. Yet there were some useful strategies developed even in ancient times. One of the earliest records of pest management is the use of predatory ants by the ancient Chinese (~1200 B.C.) to protect fruit trees. Ropes and sticks would be placed so that every tree could be easily accessed by the ants, which could then hunt for caterpillars and other pestiferous larvae for their food. This is quite ingenious, but also not terribly effective, as many plant pests, like aphids, are actually protected by ants. The first recorded use of a pesticide was the burning of sulfur in Greek homes to fumigate structural pests (~1000 B.C.). Sulfur continued to be a valued pesticide into the 1900s and is still used occasionally today. Egyptian fishermen were credited as using their fishing nets to sleep under at night to keep the mosquitoes from reaching them (~450 B.C.). This practice also has been carried into the present as the use of treated mosquito bed nets is one of the most effective tools in the fight against malaria transmitting mosquitoes in Africa. However, some ideas were clearly ineffective like the Roman Consul Mucianus who wore a live fly sewn into his clothes to protect against diseases.

It wasn’t until the modern sciences, particularly chemistry, came along in the late 1700s that pest management really started to become an effective discipline. Not only from the creation and use of more effective pesticides, but also an ability to understand insect’s biochemical machinery including how they develop and how they communicate. The various methods of pest management discussed below all benefitted from this scientific approach.

**Biological Control:**

Biological control (sometimes called “biocontrol”) is the use of other organisms to control pests. These control agents (or “natural enemies”) may be something that eats, parasitizes, or outcompetes a pest and may be as small as bacteria or as large as a bird. In many ways it is the ideal form of pest management as the organisms can continue to persist and control pest populations in perpetuity once they've been established at no additional cost and with no environmental degradation. However, it doesn’t always work out exactly as intended! Hundreds of insects have been introduced for biocontrol in the United States and only 20%, or so, have been outright successes. Others never became established, failed to control the pest population, or in the worst-case scenarios became pests themselves!

Biological control has been responsible for some fantastic successes as well as some ecological disasters. Many pest species can now be found worldwide because they are
accidentally moved around with human commerce, but their natural enemies may still only be found in the region where the pest originated. This means that often biocontrol species are imported from other countries and their environmental impact in the new areas they are introduced into aren’t known with certainty. One of the first and also the most successful releases of a natural enemy was the Vedalia beetle, a type of lady beetle, which was intentionally brought into California citrus groves in 1889 to control the cottony cushion scale. Another famous lady beetle, the Multicolored Asian Lady beetle, introduced more recently as a biocontrol agent wasn’t a huge success. You will read more about this insect when you research this species in more depth. Try to find at least three reasons why this insect turned out to be a poor choice for biocontrol.

Over the years researchers have found that certain biological traits make a species more likely to be a successful biocontrol agent:

1. **Narrow Host Range** — Ideally it should only attack the pest species and nothing else. Polyphagous species (those that can use many organisms as a food source) often will attack non-target species that aren’t pests.
2. **Synchrony with the Host** — Both the pest and the biocontrol agent must be present and developing at the same times so that they can interact.
3. **High Reproductive Potential** — The more offspring the biocontrol species can leave behind the faster they will control the pests.
4. **Efficient Search Ability** — The biocontrol must be able to find the pest species to eat it or parasitize it.
5. **Persistence at Low Host Density** — In order for the system to be self-sustaining the biocontrol generally shouldn’t destroy all of the pests, but should have population fluctuations in sync with them.
6. **Compatibility with Existing Natural Enemies** — Ideally the organism will be able to complement the other natural enemies and not have a negative impact on their populations.

It is even possible to use insects as biocontrol against their own species! In the 1950s the Sterile Insect Technique was developed and used to eradicate screw-worm flies from the U.S. and parts of Central and South America. Large numbers of screw-worm flies were raised in captivity and the males were sterilized with X-ray radiation then released into the wild so that they would mate with females, thus preventing the females from producing more offspring in the wild.
Chemical Control:

Pheromones

A pheromone is a chemical compound produced by an animal that changes the behavior on another animal of the same species. Pheromones are quite common in nature and many arthropods use them to communicate with each other. There are many different ways that species can use pheromones including:

Aggregation Pheromones – are emitted to draw more individuals (both male and female) to an area. This may help improve the chances for group survival by predator confusion or resource conservation. For instance, the human bed bug can conserve water and mature more quickly when in a tight cluster of individuals.

Alarm Pheromones – Are used to communicate that a member of the species is being attacked. This alarm may lead other nearby individuals to flee the area or to mount a counter attack (as in yellow jackets).

Sex Pheromones – These are used by one gender to attract the other when they are receptive to mating. Typically females will use sex pheromones to “call” to nearby males. In some extreme cases females may be unable to move and need the male to seek her out.

Trail Pheromones – These are used by many social insects, like ants, to mark paths from a food source back to their nest. This trailing behavior makes it easier for other nest mates to quickly find the food source and to help bring it back.

Typically aggregation and sex pheromones are the two types used to manage pests. Sex pheromones are used to either disrupt mating by flooding an area with pheromone so that males and females can’t find each other or to monitor for the presence of pests by mimicking a calling female and catching the males in a trap as they are called in. Aggregation pheromones can be used to lure large numbers of arthropods into a trap or an area that was treated with a pesticide.

Pesticides

A pesticide is defined in the U.S. as any substance or mixture of substances intended to prevent, destroy, repel, or mitigate a pest. This is a broad definition that can apply to things that target insects (insecticides), weeds (herbicides), fungi (fungicides), and many more. Many
people think of an aerosol can of ant or wasp spray when they think of a pesticide, in other words, a liquid spray that kills on contact; but as you can see from the definition, many other types of products are considered pesticides. This includes mosquito and tick repellents, lice and flea shampoos, and even some biological control agents that are formulated as sprays or pellets (like a mosquito dunk, which uses bacteria to kill mosquito larvae). Here are a few ways that pesticides are used against pests:

Contact Sprays – These are short-lived liquid products, like wasp spray, that are intended to be applied directly to the pest. The same product may be effective against a wide-array of pests, from spiders to fleas. However, once the spray has dried it will no longer kill arthropods.

Residual Sprays – These liquid products will kill on contact but will also continue to be effective once dried. Many years ago residual sprays could last for decades, these days residuals are intended to lose their effectiveness after a month or two. This makes them more environmentally friendly, but also means they may need to be applied multiple times throughout the year for continued control.

Insect Growth Regulators (IGRs) – These products don’t kill quickly, but will disrupt a population’s ability to reproduce successfully over time. They may prevent eggs from hatching or prevent immature insects from correctly molting into adults. These products work by being chemically similar to hormones in the arthropod’s body that regulate growth and molting. This makes them very attractive pesticides to use, as people and pets don’t have these same hormones in our bodies. IGRs tend to be used against insects that go through gradual or complete metamorphosis, such as cockroaches, flies, and pantry moths or beetles.

Baits – A bait is a product that is intended to be eaten by the pest. This makes the products highly effective as the pests may actively seek out the pesticide to consume and eating the material will give the individual a much larger dose than merely walking over it. However, baits don’t exist for all types of pests, e.g. there is no such thing as a spider or bed bug bait. They also tend to be selective, so that an ant bait may not be attractive to a cockroach.

Repellents – These materials are offensive to the pest and are used to keep them off of areas where they are unwanted. Repellents may be used to protect our skin from biting insects, protect our plants from herbivores, or protect a structure from invading arthropods. Repellents are often short-lived and may need to be reapplied after a few hours or a few days.
Pesticides are regulated by federal law and approved by individual States for use. One of the provisions of the federal law is that pesticides must be used according to their package directions, which is referred to as the product’s label (The label is the law). So if you’ve ever heard of someone mixing a pesticide at a rate stronger than the label says is allowed, they are technically committing a federal crime. The label will also tell the user the name of the substance that is actually affecting the arthropod, called the active ingredient. The rest of the contents are often not considered harmful and are called inert ingredients. For instance, the food components in a bait are inert ingredients.

**Arthropod Specimen/Photography Collection Rules**

You must make an arthropod collection, but may choose to use actual pinned specimens OR by photographing specimens (preferably when alive). The following apply to both collection types:

- All specimens should be adults or nymphs of species that undergo gradual or without metamorphosis (no caterpillars, maggots, or other immatures of incomplete or complete metamorphosis groups will be accepted), local in origin (from the Midwestern U.S.), and collected or photographed within a year of the Science Olympiad competition date by the team members.

- Duplicates (two or more specimens of the same species) will NOT count as multiple specimens. For instance, if two (or more) ants from the same colony are collected and mounted they will only receive 1 specimen point total—essentially they will be treated as a single pinned specimen.

- All specimens/photos must bear collection data, associated with each individual specimen. Collection data should be on a paper card below pinned specimens and as a digital insert on or immediately below a photo, see examples below. Labels must consist of the following data:

  1. Date collected
  2. Location collected (State, County, & nearest City)
  3. Brief behavior/habits observed during collection. *For instance, you could say it was eating a leaf, or swimming in a pond.*
  4. Name of collector (this should only be you or your teammate!)
• All specimens should be identified to Class. Then all specimens in Class Insecta should be identified to Order. Specimens should be grouped by Class first, then sub-grouped by Order (insects only). No further identification below this level is needed (or wanted!) for this event.

• Please refer to the published rules for clarification on collection scoring.

• For tips and techniques on finding a wide variety of arthropods for your collection please consult the document “Advanced Entomological Techniques” available for download from the macombso.org website.

• Please remember the “Designed and Built by the Student Policy”
  o The intent and practice of our policy is to let students have the experience. Please resist the temptation for perfection, or the need to win at all costs.
  o Our priorities:

    1) Your student should be safe. There may be a few instances where a tool is required that is too advanced for your student to operate. Cutting a piece of wood might be a good example of this. Even so, you should involve the student in the planning and design work, and confirmation that the item turned out as planned.

    2) Your student should do the work. That doesn't mean you should stand back and let your student flounder. Coaches have an important role in teaching skills. Organize your work so you can demonstrate a skill, and then give your student the opportunity to practice. You might need a few extra bugs to pin to learn from.

    o It is not acceptable for you to do the same work as your student, in parallel, and then submit the coach's effort as the student's. For instance, if the student doesn't take as good of a photograph as the coach, it is not acceptable to substitute the coach's. Digital photography is almost costless, so let your student practice.
The following rules pertain only to Pinned Specimen Collections:

- Collections should be housed in a sturdy cardboard or wooden box with a lid, not to exceed 16.5” x 19” (this size is called a “Cornell box”). Styrofoam or similarly porous and flexible material should be placed on the bottom for the pins to stick into. Professional insect drawers may be purchased (see sources below), but are not required.

- Freezers are your friend! Live specimens can be placed in a bag or container and placed in a freezer for a couple of days, killing them so they can be mounted (you’ll want to thaw specimens before mounting or they may crack). Be sure to check with an adult before putting bugs in the freezer!

- Be sure to consult the manual “Preserving Your Insects” available on the macombso.org website for rules on proper pinning. Note: spreading specimens is welcome, and may help your team win in a tie-breaker situation, but is not required. Soft bodied specimens (like spiders, springtails, aphids, etc.) are generally stored in alcohol by professionals, but for the purposes of this event should be pinned or pointed (mounted by a drop of glue to a small triangle of cardstock that is then pinned, see Fig. 12 below).

- Insect pins, for mounting specimens, can be obtained from any number of biological/entomological supply stores. Professional insect pins must be used as they work much better than sewing pins for insect collections. They come in multiple sizes, but a size #2 is appropriate for general use and should be the only size needed for this project.

- Here are a few insect pin suppliers to consider:

  - Bioquip Products
    - https://www.bioquip.com/
  - Indigo Instruments
    - www.indigo.com/
  - Amazon
    - www.amazon.com

![Fig. 12: A pointed specimen](image1)

![Fig. 13: An example of a high scoring pinned specimen collection](image2)
The following rules pertain only to Photographic Collections:

- The collection should be housed in a photo album or combined onto a poster (not to exceed 24”x36”) or otherwise professionally put together. For instance, a bunch of printed pictures paper clipped together is NOT acceptable.

- In the collection you must describe what camera you used to take the pictures and what lenses you used (if you are using a camera body that can accept multiple lenses or aftermarket lenses designed to fit over equipment like a mobile phone). If you use a number of cameras/lenses list them all.

- Photos must be in focus and allow for proper identification of the specimen, which means they must show necessary features, like number of legs, wings, etc. (based on info needed in the identification keys). Blurry images or photos taken from too far away will not be counted.

- Freezers are your friend! You may want to pop a very active specimen (or one prone to flying away from you) into a freezer for 1-5 minutes to chill it before returning it to its habitat, allowing for better pictures to be taken. Don’t worry they will recover!

- If you have multiple images of the same specimen and no single shot is adequate for identification you may use multiple images in your collection. If multiple images of the same specimen are used please clearly indicate this, and of course, these multiple images will only count for one specimen! For instance, if you need to see the head and number of wings to make a proper identification and you have 2 photos one with the head in focus and one with the wings in focus, you may use both images to count for one specimen.

- Images should be cropped to emphasize the subject and not include a lot of blank space or unnecessary background.

- Photos must be of only one specimen! For instance, a picture of a spider with a fly in its web does NOT count for two specimens. But it would be a welcome image demonstrating what a spider does ecologically!

ACCEPTABLE

NOT Acceptable