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Natural enemies of pests associated with prairie crops

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Natural enemies of pests associated with prairie crops

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Recommendations for pesticide use in this publication are intended as guidelines only. Any application of a pesticide must be in accordance with directions printed on the product label of that pesticide as prescribed under the Pest Control Products Act. **Always read the label.** A pesticide should also be recommended by provincial authorities. Because recommendations for use may vary from province to province, consult your provincial agricultural representative for specific advice.

Cover illustration
Ichneumonid wasp attacking bertha armyworm

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Preface

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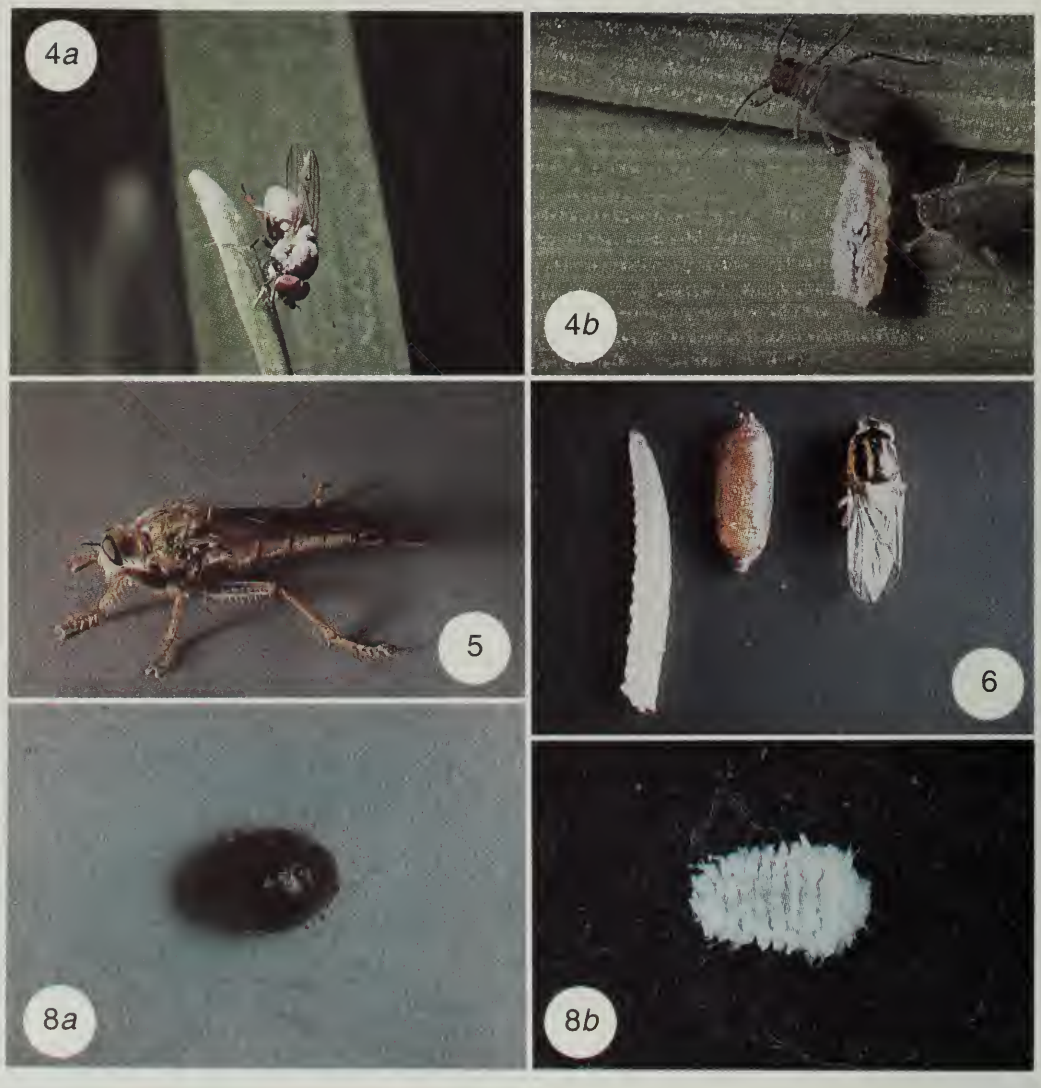

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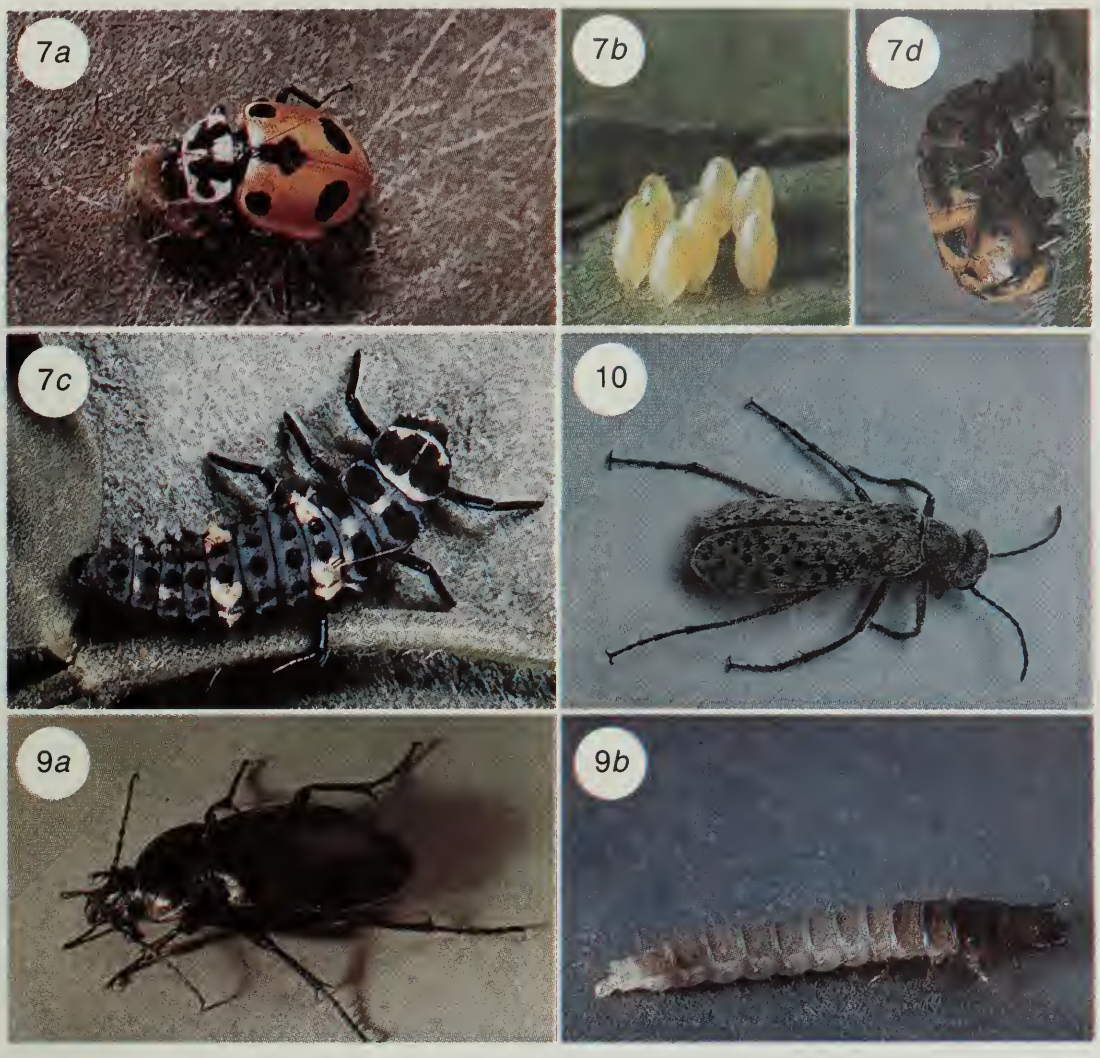

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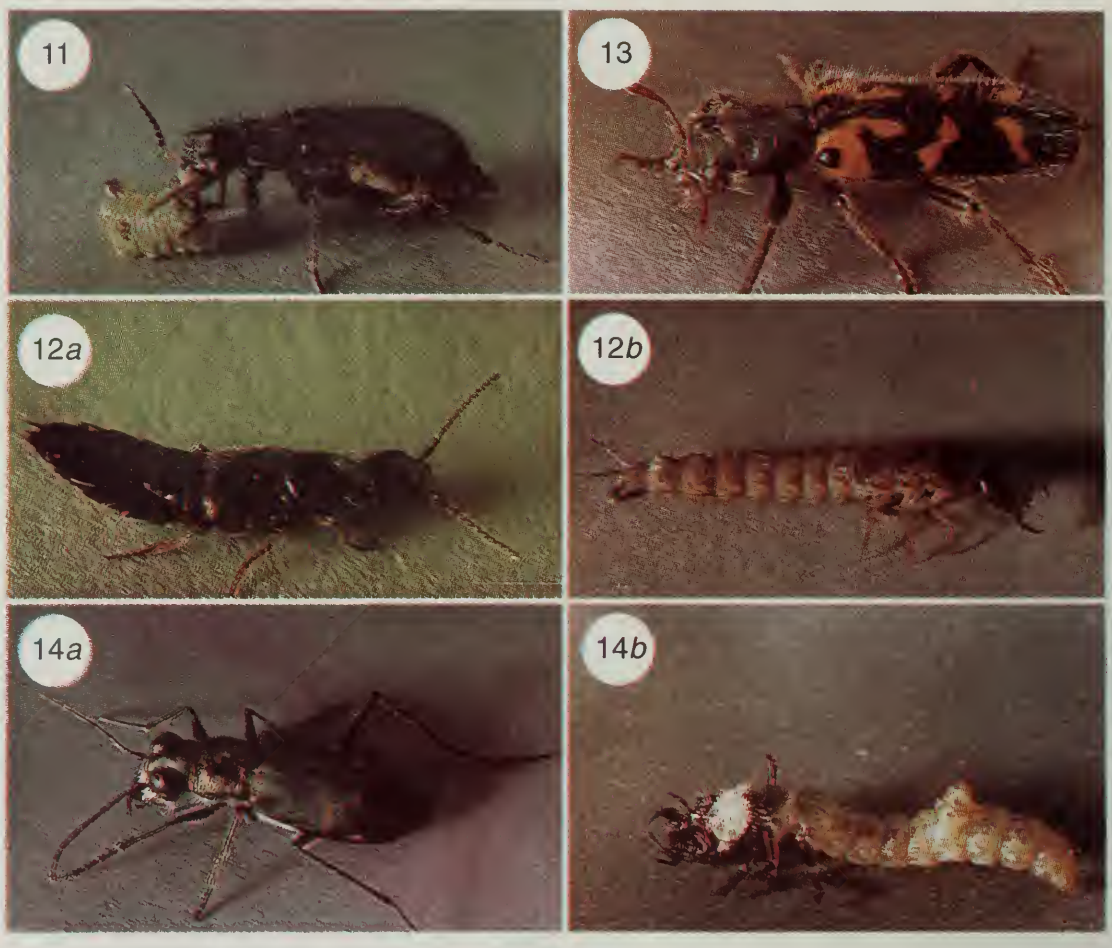

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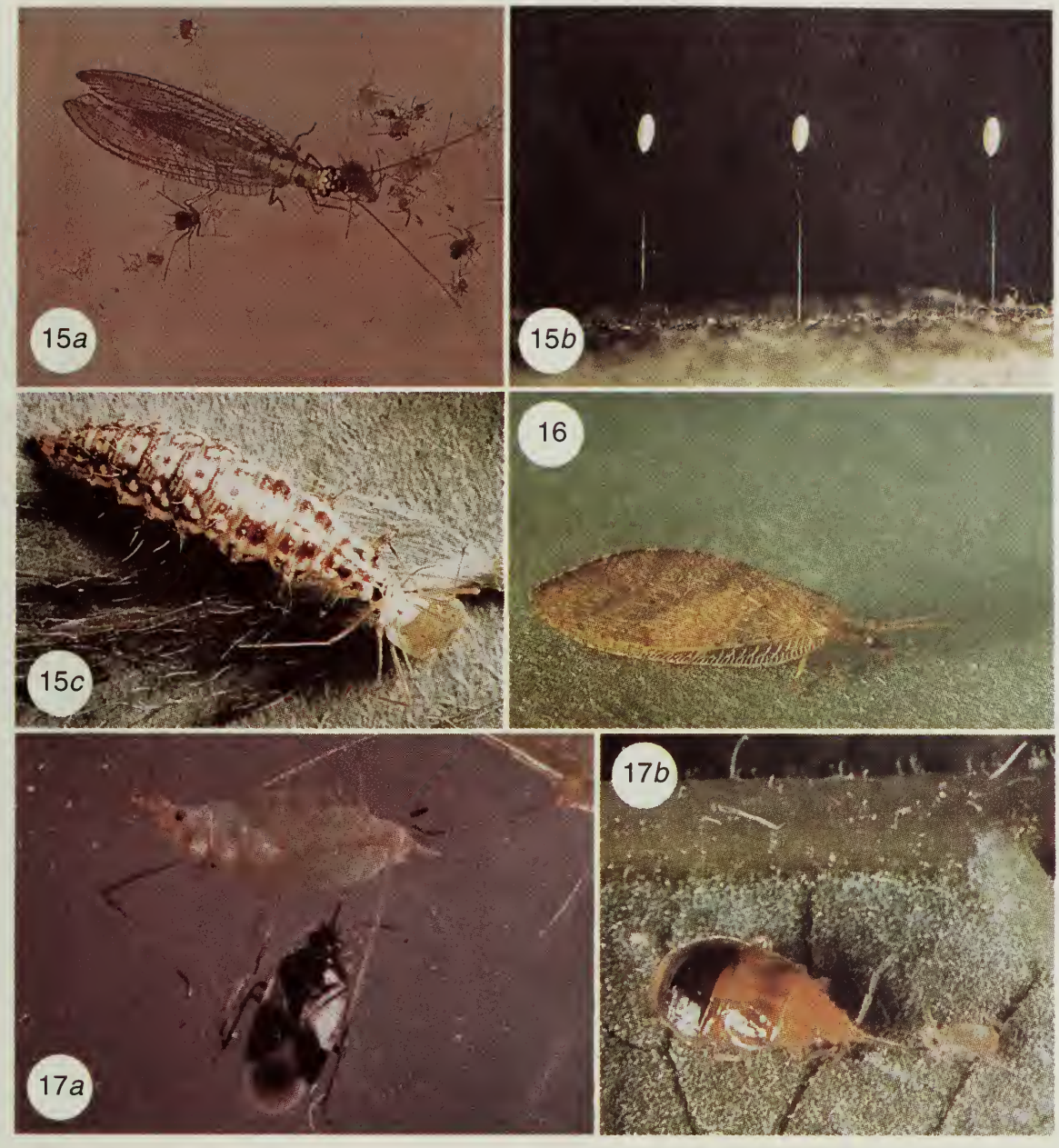

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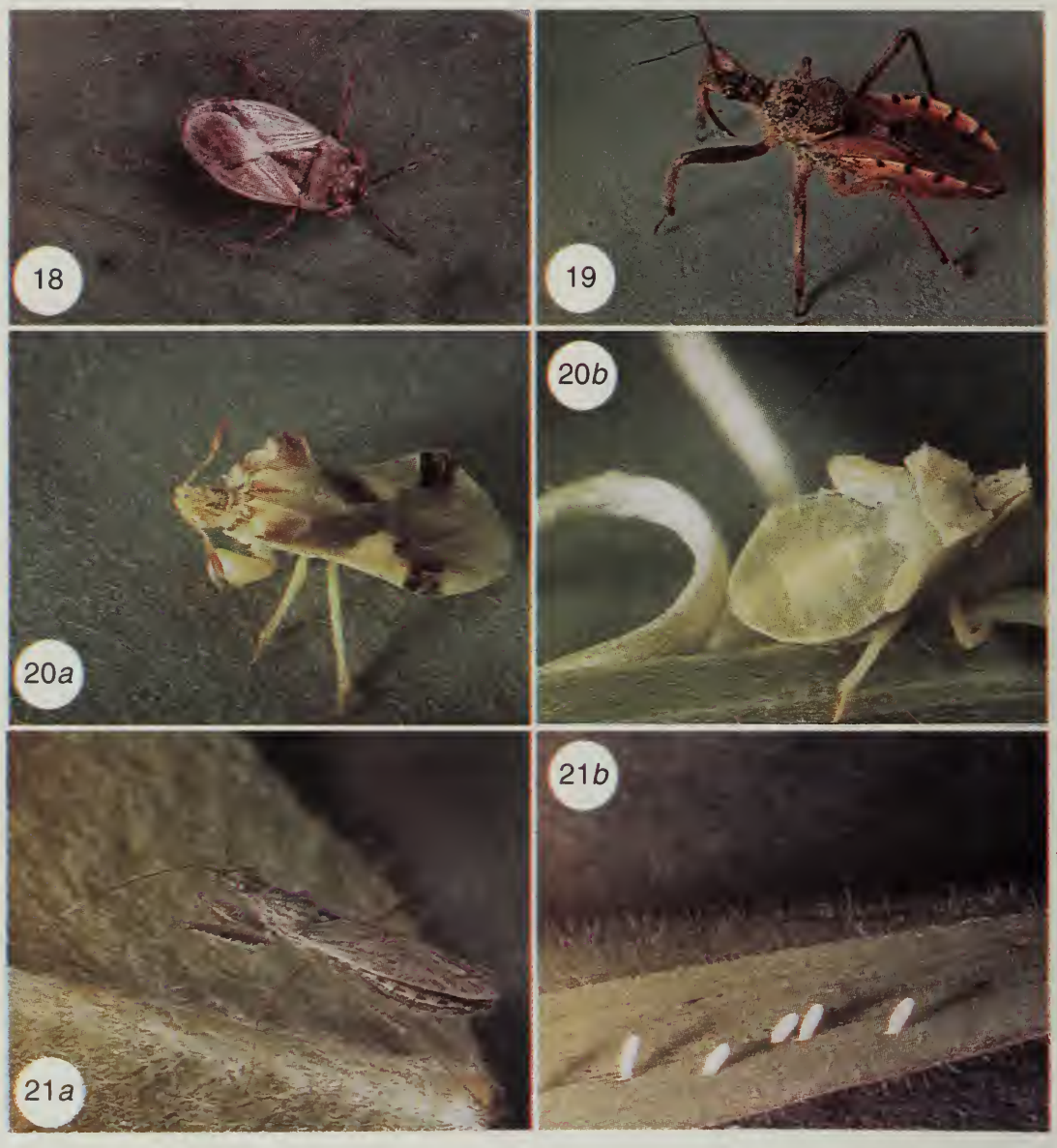

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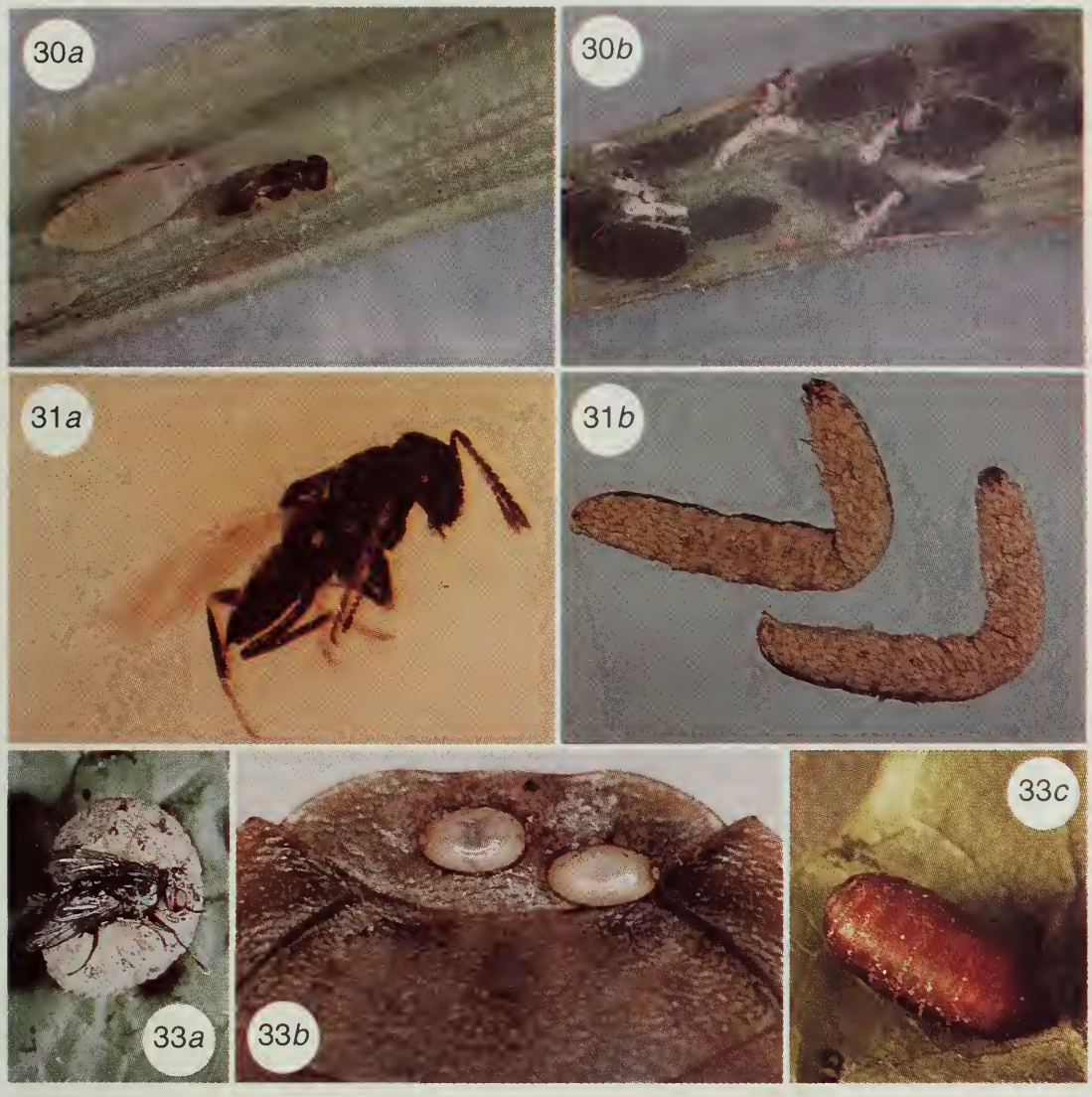

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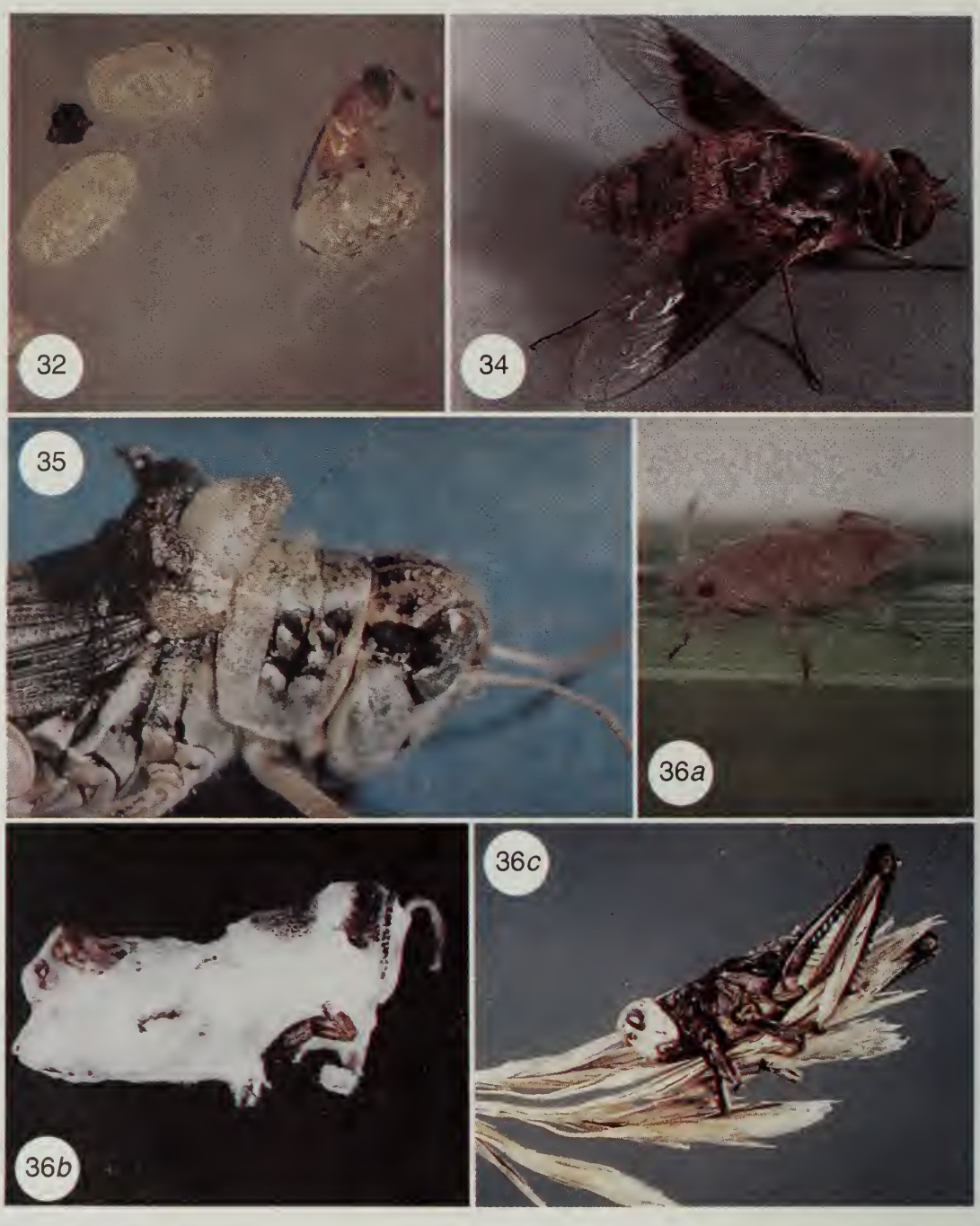

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Introduction

Natural enemies of agricultural pests are organisms that prey on, parasitize, or infect insects and mites that compete with us for food. They play an important and often unrecognized role in suppressing pest populations, thereby reducing the frequency and severity of pest outbreaks. To ensure that they continue to provide natural control of agricultural pests, it is important to know which they are and what their role is. Only then can we provide an environment suited to conserving them and enhancing their ability to protect our crops.

Natural enemies can be divided into three categories: predators, parasitoids, and pathogens.

Predators capture prey and consume it immediately or use it to provision their young. Included in this category are lacewings, predacious beetles, flies, thrips, vespid and sphecoid wasps, spiders, and carnivorous mites. Predators are usually habitat-specific, that is they hunt in a specific or preferred habitat devouring any prey that they are able to capture. If the immature stage is predacious, the adult female lays her eggs in locations where suitable prey is likely to be plentiful. Most predators are general feeders, that is, they consume whatever is available, so they have a suppressing effect on pests in general although they generally concentrate on the most abundant prey.

Parasitoids are insects that lay their eggs on, or into, an insect of another species, and the ensuing larvae consume the host tissues, killing the host in the process. Some families of flies and all families of parasitic wasps are included in this category. They tend to be host-specific and can only survive if appropriate hosts are present. Therefore, specific parasitoids can be used selectively against specific pests without adversely affecting other organisms. They are also good at locating hosts and are effective even when the host population is low.

Pathogens are microorganisms that infect and multiply in the cells and tissues of the host. They include fungi, protozoans, bacteria, and viruses. They infect insects by ingestion with food or penetration through the integument; in some cases they can be transmitted from the female to her offspring. Under certain conditions, widespread outbreaks of disease (epizootics) can almost eradicate pest populations. Pathogens are more prevalent when pest populations are high and are often responsible for terminating outbreaks.

International commerce has led to many pests being transported to foreign lands. Freed of the natural enemies that have evolved with them, they often cause considerable damage to agricultural crops in their new habitat. The importation of natural enemies to control these introduced pests has become an important technique in biological control. This process involves determining the place of origin of the pest and identifying the major natural enemies present there, determining the most suitable natural enemy to import, and establishing the imported natural enemy in those areas where the introduced pest has become a problem. Parasitoids, because of their host-specificity, are usually the

natural enemies of choice, but predators have also been used with success.

To be effective, both imported and native natural enemies must be conserved within the agricultural environment. The intelligent use of pesticides can alleviate the detrimental effect of these chemicals on natural enemies. Using pesticides only when necessary, using spot applications where feasible, and, if possible, applying pesticides when the natural enemies are least vulnerable can reduce losses of natural enemies due to pesticides. Some herbicides and fungicides also have an adverse effect on natural enemies by repelling them from their hosts or reducing their fecundity. Appropriate cultural methods can conserve and enhance natural enemies. For example, the timing and method of harvesting of some crops, such as forages, can sometimes be altered to reduce the destruction of natural enemies. Minimum tillage not only conserves crop residues and reduces wind erosion but also provides a habitat more favorable for many natural enemies. Studies have shown that populations of predacious ground beetles are significantly higher in no-tillage fields than in conventionally tilled fields. Field margins and windbreaks are a source of alternate hosts and provide shelter for many natural enemies. In fact, some natural enemies can survive only if these ancillary environments are present. Also the nectar and pollen provided by the diverse vegetation in these environments attract and sustain the adult stage of many natural enemies, which otherwise would disperse elsewhere in search of food. The adult females of many natural enemies need a source of carbohydrates, such as nectar, to mature their eggs. Some weeds have been shown to fulfill a role as providers of carbohydrate. Absolutely clean fields, devoid of all weeds, may not be the ultimate goal in sustainable agriculture.

Some natural enemies can be mass-produced and released to control a specific pest. This approach is comparable to chemical control except that the active ingredient is a biological agent. The ideal natural enemy for this purpose is one that can kill the pest before any damage is done and that can be produced economically in large quantity. *Bacillus thuringiensis*, a pathogen, has been produced commercially since 1960 to control various lepidopterous pests (moths and butterflies). Soon after ingestion of *B. thuringiensis*, the pest stops feeding, and death occurs within 12–72 h. Another organism often used for inundative release is a tiny parasitic wasp, *Trichogramma*, which is mass-reared to control European corn borer and spruce budworm. The female wasp lays her egg into that of the pest, killing the host egg in the process. The inundative release method has been shown to be as effective as chemical control in certain circumstances and has none of the adverse side effects of chemical pesticides.

Predators

Predatory wasps and ants (Hymenoptera)

Sphecoid wasps (Sphecidae)

Most species of these large, solitary wasps, are more than 25 mm in length (Plate 1, Fig. 1). They nest in the soil and provision their nests with grasshoppers, crickets, caterpillars, and spiders as a food store for their young. For example, females of *Odynerus dilectus* use alfalfa weevil larvae to provision their nests.

Hornets and yellow-jackets (Vespidae)

These large, social wasps are from 10 to 25 mm in length (Plate 1, Fig. 2). They build nests out of chewed up wood and foliage. The larvae are fed by the workers on masticated caterpillars, weevil larvae, and other insects. The queens overwinter and start new colonies in the spring.

Ants (Formicidae)

Ants are the most numerous insects in the world. They are social insects living in colonies of queens, males, and workers. Their feeding habits range from plant feeders to scavengers and general predators. Some species are agricultural pests because they protect aphid colonies and scale insects against other natural enemies. Some species are useful natural enemies of agricultural pests. In fact, the first recorded case of biological control was the use of ants to control citrus pests in China in the 3rd century A.D. Certain species of ants are still reared and released to protect crops in China.

Predatory flies (Diptera)

Syrphid flies (Syrphidae)

The adults resemble small bees or wasps with a black and white or black and yellow abdomen (Plate 1, Fig. 3*a*). Most are active in the daytime and can often be found hovering over flowers. The oval, white eggs (Plate 1, Fig. 3*b*) are laid singly amongst aphid colonies. The larvae are elongate grubs, each with a pointed head and two breathing tubes (spiracles) at the posterior end. They vary in color from brown to yellow or green and have whitish or mottled markings (Plate 1, Fig. 3*c*). The adults feed on honeydew, nectar, and pollen and are also important pollinators. Syrphids overwinter as pupae (Plate 1, Fig. 3*d*) on foliage, among debris, or in the soil. Although the larvae of hover flies appear to be important in the natural control of aphids, their effectiveness in reducing aphid populations to below economic level has not been determined with certainty.

Aphid flies (Chamaemyiidae)

These small flies are usually grayish in color with black spots on the abdomen (Plate 2, Fig. 4*a*). Eggs are laid singly near suitable hosts. The larvae (Plate 2, Fig. 4*b*) resemble those of hover flies except that the two posterior breathing tubes are wider apart. The larvae feed primarily on aphids, scale insects, and mealy bugs. Overwintering may be by second- or third- instar larvae or in the pupal stage. Because of their small size, flies of this group have the potential to control aphids that are found in the more secluded habitats, such as Russian wheat aphids within rolled leaves.

Robber flies (Asilidae)

These elongated, bristly flies have a tapered body (Plate 2, Fig. 5). The top of the head is depressed between the eyes, and the face has a bearded appearance. The adults capture their prey in flight and are noted for their rapacious attacks on other insects. They inject saliva into the prey to immobilize it and to liquify the tissues. The fly then sucks its victim dry. Prey includes grasshoppers, wasps, aphids, and midges. The larvae live in soil, where they feed on the larvae of other insects. Larvae of some species feed on grasshopper eggs.

Chloropid flies (Chloropidae)

The adults are small, chunky, smooth flies, and some species are brightly colored with yellow and black (Plate 2, Fig. 6). Although some chloropids are plant-feeding pests of cereal crops, one species, *Thaumatomyia glabra*, is a very effective predator of the sugarbeet root aphid. Eggs are laid in the soil at the base of infested plants. The immature stage is a white maggot (Plate 2, Fig. 6), 1–7 mm in length, which feeds on the aphids by sucking out the body fluid. Pupation occurs in the soil, and the adult emerges the following spring.

Stiletto flies (Therevidae)

These medium-sized flies are somewhat hairy, with a pointed abdomen. The adults are diurnal and feed on nectar and plant exudate. The larvae move in the soil in a snakelike fashion and are predators of root-feeding larvae, cutworms, and grasshopper eggs. They produce one generation each year and overwinter as mature larvae.

Beetles (Coleoptera)

Lady beetles (Coccinelidae)

The adults have an oval, rounded shape and are usually brightly colored in yellow, red, or orange with distinctive patterns of black dots (Plate 3, Fig. 7*a*). The yellow, elongate eggs are laid in clusters on the underside of

leaves (Plate 3, Fig. 7*b*). The larvae are often black or bluish in color with spots or bands of bright colors and have elongate bodies—they look like tiny, fat alligators (Plate 3, Fig. 7*c*). The pupae are attached to leaves, stems, or other surfaces (Plate 3, Fig. 7*d*). Both adults and larvae feed on aphids, insect eggs, small insect larvae, and mites. Lady beetles hibernate as adults, frequently in large aggregations, in sheltered areas on the ground. There is usually one generation per year. Lady beetles are effective predators of aphids and mites and are an important natural enemy of pests in the agricultural environment.

Black lady beetles (Coccinelidae)

The adults have the shape of the typical lady beetles but are tiny (about 2 mm in length) and are usually dull black or brown with hairy wing covers (Plate 2, Fig. 8*a*). The eggs are laid singly in the prey colony. The larvae are dark brown to nearly black and covered with hairs that give them a white, velvety appearance (Plate 2, Fig. 8*b*). Both adults and larvae are predacious on aphids and mites and have several generations per year. Because of their small size, they are probably quite effective in controlling aphids that have secluded habits, such as Russian wheat aphid.

Ground beetles (Carabidae)

This large group of beetles has some 2500 species in North America. Adults are usually dark, shiny, and somewhat flattened, with striations or punctations on the wing covers (Plate 3, Fig. 9*a*). They are commonly found under stones or debris or are observed running about on the ground. When disturbed, they run rapidly but seldom fly. They normally hide during the day and feed at night. The larvae are elongate and wormlike (Plate 3, Fig. 9*b*) but can move quickly. Both adults and larvae are predacious on other ground-dwelling insects, such as cutworm larvae. They also feed on grasshopper eggs. Some adults are active even in the winter and may live for 2–3 years.

Blister beetles (Meloidae)

Blister beetles are so named because the body fluid of some species contain a substance that irritates and blisters the skin. The adults are usually rectangularly elongate, with soft, flexible wing covers (Plate 3, Fig. 10). Eggs are deposited in deep burrows in moist, firm soil. The larval stages undergo several dramatic changes, developing from an active, long-legged hatchling larva to a short-legged grub and then to a legless nonfeeding stage. Larvae of some species are predacious on grasshopper eggs and, when abundant, may destroy up to 80% of grasshopper egg pods. Larvae of other species are parasitic on wild bees. The adults of several species of blister beetles are sometimes minor pests, feeding on potatoes, sugarbeet, cabbage, canola, fababean, and turnips, but control is seldom necessary.

Soft-winged flower beetles (Melyridae)

These elongate-oval, soft-bodied beetles are 10 mm or less in length (Plate 4, Fig. 11). Many are brightly colored with red and blue. Adults feed on pollen or other insects and larvae are predacious on larvae of flea beetles, alfalfa weevil, and various other insects.

Rove beetles (Staphylinidae)

Rove beetles form one of the largest family of beetles with about 2900 species in North America. Rove beetles are elongated beetles with short wing covers extending only partway down the body (Plate 4, Fig. 12*a*). They run rapidly, frequently with the tip of the abdomen raised. The larvae resemble the adults except for the absence of wings (Plate 4, Fig. 12*b*). Both adults and larvae are predacious on root maggots and other small insects.

Checkered beetles (Cleridae)

These elongate, hairy beetles are mostly 5–12 mm in length. Many are brightly colored (Plate 4, Fig. 13). Both adults and larvae are predacious on other insects and larvae of some species develop in egg pods of grasshoppers.

Tiger beetles (Cicindellidae)

Adult tiger beetles are brightly colored insects that are usually disruptively marked to blend with the surroundings (Plate 4, Fig. 14*a*). They run rapidly on the ground and take flight quickly when frightened. The adults are predacious on any insect that is small enough for them to subdue. The larva has powerful, upward-bending jaws and a S-shaped body (Plate 4, Fig. 14*b*). They occupy burrows that are usually located in dry, sparsely vegetated areas. Spines on the back of the abdomen function to anchor the larva inside the burrow as it reaches out to grab any prey that comes within reach. The larva overwinters in the soil below the frost line.

Lacewings (Neuroptera)

Green lacewings (Chrysopidae)

The adults have green net-veined wings, long antennae, and gold or copper-colored eyes (Plate 5, Fig. 15*a*). They give off an unpleasant odor when handled. The eggs are laid on foliage on top of a silk thread (Plate 5, Fig. 15*b*). The larvae, called aphidlions, resemble tiny light-colored alligators with sicklelike jaws (Plate 5, Fig. 15*c*). They feed on aphids, flea beetles, and insect eggs. The pupae are enclosed in round, silken cocoons usually attached to the underside of leaves. Most adults feed on aphid honeydew and plant fluids, but some are predacious.

Brown lacewings (Hemerobiidae)

These insects resemble the common green lacewing but are brown instead of green (Plate 5, Fig. 16). They are smaller and less common than the common green lacewing and are usually found in wooded areas. Eggs are usually laid singly or in small group on leaves, twigs, and bark. Both adults and larvae feed on aphids, small insects, and insect eggs. They are sometimes one of the more abundant natural enemies in corn fields.

True bugs (Hemiptera)

Minute pirate bug (Anthocoridae)

These small, oval bugs are usually black with white markings and about 3–5 mm in length (Plate 5, Fig. 17*a*). The eggs are inserted into soft tissue of plants. Newly hatched nymphs are phytophagous, but later instars (Plate 5, Fig. 17*b*) and adults are carnivorous, feeding on aphids, mites, thrips, and eggs and young larvae of armyworm, corn earworm, and European corn borer. After impaling the prey with its beak, it injects an anesthetizing fluid to paralyze the prey. The prey is then sucked dry. Adults overwinter in sheltered locations on the ground.

Big-eyed bugs (Lygaeidae : Geocorinae)

The lygaeid bugs usually have enlarged grasping forelegs, however most species feed on plants. Exceptions are the adults and nymphs of the big-eyed bugs (Plate 6, Fig. 18) which feed on aphids and flea beetles.

Assassin bugs (Reduviidae)

These medium- to large-sized insects have a black or brownish body. The head is narrow and elongated, and the abdomen is usually widest at the middle (Plate 6, Fig. 19). Many will inflict a painful bite if carelessly handled. In the tropics some species are bloodsuckers and are vectors of human diseases, but all our species are predators of other insects. They inject saliva into the prey to cause paralysis and then suck the prey dry. Both adults and nymphs are predacious, and their prey includes plant bugs and other alfalfa pests. Overwintering may occur in any life stage, depending upon the species.

Ambush bugs (Phymatidae)

These attractively colored, stout-bodied bugs have grasping forelegs (Plate 6, Fig. 20*a*). They can be differentiated from the assassin bugs by the clubbed antennae. They are active in the daytime, usually lying in ambush on flowers. Both adults and nymphs (Plate 6, Fig. 20*b*) are predacious on caterpillars, plant bugs, and various other insects.

Damsel bugs (Nabidae)

These small, dull-colored bugs have a body that tapers towards the head (Plate 6, Fig. 21*a*). Some are nocturnal and are attracted to lights. They insert eggs in plant stems (Plate 6, Fig. 21*b*). Both adults and nymphs are predacious on a variety of insects including aphids, flea beetles, and small caterpillars. Most damsel bugs overwinter as adults.

Stink bugs (Pentatomidae)

These bugs have a shield-shaped body that is often brightly colored or conspicuously marked (Plate 7, Fig. 22*a*). They produce a disagreeable odor when handled. Eggs of stink bugs are usually barrel-shaped and laid in clusters (Plate 7, Fig. 22*b*). Some species are plant feeders, but others are predacious on aphids, Colorado potato beetle larvae, caterpillars, and other soft-bodied insects. They feed by injecting saliva into their prey and sucking out the liquified body contents. Most stink bugs overwinter as adults.

Thrips (Thysanoptera)

Banded thrips (Aeolothripidae)

These small, slender-bodied insects have white bands on the wings (Plate 7, Fig. 23). The adults are about 1.6 mm in length. The larvae are yellowish, shading into orange posteriorly. Both adults and larvae feed on other thrips, aphids, mites, and alfalfa weevil eggs.

Mites (Acari)

Predacious mites (Phytoseiidae and Anystidae)

Mites are minute, wingless arthropods with an oval, compact body and eight legs (Plate 7, Fig. 24*a*) (except the first-instar larva that has only six legs). Predacious mites are important in controlling phytophagous mites, which are sometimes serious agricultural pests. Eggs are deposited on the underside of leaves close to the prey. All stages of the predacious mites are carnivorous, but sometimes they supplement their diet with pollen. Usually only the mated females overwinter. Some species of predacious mites are mass-reared for use in greenhouses to control mites and thrips. Other mites are ectoparasites of insects and, if present in high numbers, have a debilitating effect. Grasshoppers are often infested with red mites (Plate 7, Fig. 24*b*).

Spiders (Araneida)

All spiders, both immatures and adults, are general predators of insects and other arthropods. They are widely distributed and are present in

most habitats. Because of their abundance and voracious appetite, they play an important role in reducing insect populations.

Crab spiders (Thomisidae)

These crablike spiders typically walk sideways or backward with a slow, deliberate motion (Plate 7, Fig. 25). They do not construct webs and usually lie in ambush among foliage. Some can change color to blend with the foliage.

Wolf spiders (Lycosidae)

These large spiders hunt on the ground for their prey. The species found in Canada do not spin webs. Eggs are carried about by the female until they hatch. The young may stay on her back for a while. Most Canadian species apparently overwinter as adults.

Orb-weavers (Araneidae)

These spiders build orb webs to catch their prey (Plate 7, Fig. 26). The structure of the webs vary with the subfamilies of orb-weavers. Insects as large as grasshoppers may be caught and devoured. Egg masses are enclosed in silken sacks in which they overwinter.

Parasitoids

Parasitic wasps (Hymenoptera)

Ichneumonid wasps (Ichneumonidae)

This family of insects is one of the largest, having more than 4600 species in North America. The adults vary considerably in size and color, but most resemble slender wasps (Plate 8, Fig. 27*a*). Some have very long ovipositors, which enable them to parasitize concealed hosts. The adult females need a source of nectar to mature their eggs. The eggs are laid singly either in or on the insect host. When the egg hatches, the larva begins feeding on the host, eventually killing it. These wasps are very important in the control of agricultural pests. For example *Bathyplectes curculionis* parasitizes alfalfa weevil larvae (Plate 8, Fig. 27*b*), *Banchus flavescens* parasitizes bertha armyworm and *Spilichneumon superbus* parasitizes cutworms. Other pests attacked include loopers, beet webworm, horn fly, wheat stem sawfly, and many forestry pests. Some ichneumonids overwinter as mature larvae (*B. curculionis* and *B. flavescens*), but others overwinter as adults (*S. superbus*).

Braconid wasps (Braconidae)

This family is also large with about 1700 species in North America. These wasps are usually smaller than ichneumonid wasps and rarely exceed 15 mm in length (Plate 8, Fig. 28*a*). Their habits are similar to ichneumonids except that many species emerge from the host to pupate in silken cocoons (Plate 8, Fig. 28*b*). Braconids are important parasitoids of a wide variety of pests, including cutworms, cabbage butterfly larvae, hornworm, beet webworm, alfalfa caterpillar, wheat stem sawfly, flea beetles, alfalfa weevil, and sweetclover weevil.

Aphidiid wasps (Aphidiidae)

These small wasps specialize in attacking aphids and play an important role in reducing the frequency and severity of aphid outbreaks. The adults (Plate 8, Fig. 29*a*) are predominantly black or dark brown, with yellowish, orangy brown, or yellowish brown patterns. The female wasp lays an egg inside a host aphid and the larval stage completely consumes the inside of the aphid. Some larvae pupate within the remnant of the aphid shell, forming a 'mummy' from which the adult wasp emerges (Plate 8, Fig. 29*a*), whereas others form a separate cocoon beneath the dead host aphid (Plate 8, Fig. 29*b*). *Aphidius smithi* is an important biological control agent of aphids in alfalfa.

Aphelinid wasps (Aphelinidae)

These small to minute wasps are usually less than 1 mm in length (Plate 9, Fig. 30*a*). Availability of nectar from flowers of weeds and other plants greatly increase the longevity and fecundity of these wasps. The female wasp lays her egg either in or on the host. One or more larvae can develop in each host. Aphelinids are important parasitoids of aphids, scale insects, and whiteflies. An aphelinid, *Encarsia formosa*, is reared in large numbers for use against whiteflies in greenhouses. *Aphelinus varipes* has been imported into Canada and released for control of the Russian wheat aphid (Plate 9, Fig. 30*b*).

Encyrtid wasps (Encyrtidae)

These tiny wasps are about 1–2 mm in length (Plate 9, Fig. 31*a*). Many are parasitoids of scale insects, but some are important natural enemies of lepidopterous (moths and butterflies) pests. *Copidosoma bakeri* is a common parasitoid of redbacked and army cutworms. The female wasp lays an egg inside the cutworm egg, but development of the parasitoid is delayed until the host has become a nearly mature larva. During this time a single *Copidosoma* egg divides into several thousand embryos, which develop into larvae that completely devour the host's body tissues. The parasitoid larvae pupate within the remnant host cuticle (Plate 9, Fig. 31*b*). One to two thousand wasps usually emerge from each parasitized cutworm.

Trichogrammatid wasps (Trichogrammatidae)

These minute wasps are about 0.2–1.6 mm in length and specialize in attacking the eggs of other insects (Plate 10, Fig. 32). The wasp completes development within the host egg. It tends to be habitat- rather than host-specific and will attack the eggs of a wide range of insect pests. Some *Trichogramma* species can be easily reared in large numbers on substitute hosts (e.g., meal moth eggs) and then released for biological control of lepidopterous pests (e.g., European corn borer and spruce budworm). They are ideal biocontrol agents because they kill the host before it causes any damage whatsoever.

Parasitic flies (Diptera)

Tachinid flies (Tachinidae)

This large family of parasitic flies has about 1300 species in North America. The adults are medium to large in size, bristly, and sometimes beelike (Plate 9, Fig. 33*a*). Some species deposit an egg directly on the body of their host (Plate 9, Fig. 33*b*). Upon hatching, the larva burrows into the host and feeds internally. When fully developed, it leaves the host and pupates nearby (Plate 9, Fig. 33*c*). Other tachinids deposit tiny eggs on foliage, which are then eaten by host larvae. The egg hatches in the host's gut and the larva penetrates into the body cavity. In these species development is usually completed within the host pupa. *Athrycia cinerea* is an important parasitoid of the bertha armyworm. Other hosts include cutworms, grasshoppers, stink bugs, June beetles, and sweetclover weevil.

Bee flies (Bombyliidae)

These hairy flies are medium to large (Plate 10, Fig. 34). Many have long, protruding mouthparts and patterned wings. Most are fast fliers and are able to hover in mid air. The adults feed on nectar and pollen. The female fly apparently oviposits in loose sand or dust. The first-instar larva is wormlike and adapted to move through the soil to search for its hosts, usually cutworms, armyworms, and hymenopterous larvae. It develops inside the host, which is killed when the larva matures. The fly larva then leaves the host and pupates close to the soil surface. Larvae of some species of bee flies (e.g. *Systoechus oreas*) are predators of grasshopper eggs and have been credited with destroying up to 30% of the egg pods on some occasions.

Flesh flies (Sarcophagidae)

The adults are about the size of a house fly and are generally black with gray thoracic stripes. They are strong fliers and need nectar and honeydew for survival. Female flies give birth to live larvae, which are deposited on or near the host. A single larva then penetrates into the host

body where it develops to a mature larva (Plate 10, Fig. 35), which then leaves the host to pupate in the soil. Hosts include grasshoppers, imported cabbageworm, beetles, and spiders.

Pathogens

Fungi

An insect becomes infected by germinating spores that penetrate the integument and adhere to, or are ingested by, the insect. Once inside the body cavity, the fungus grows rapidly destroying the internal tissues of the insect. The remnant of the insect becomes a hard, brittle mummy, sometimes covered with fungal mycelium (Plate 10, Fig. 36*a*). A common fungus is *Beauveria bassiana,* which can infect many insects including grasshoppers (Plate 10, Fig. 36*b*), sweetclover weevil, and European corn borer. This fungus can be cultured in large quantity and is being studied for use in biological control of grasshoppers. Other fungi, such as *Entomophaga* (Plate 10, Fig. 36*c*) and *Entomophthora* spp., infect aphids, grasshoppers, alfalfa weevil, horn fly, and canola root maggot.

Viruses

These tiny intracellular organisms are not visible with the ordinary light microscope. They enter the host by ingestion and commonly cause disease epizootics in larvae of moths and sawflies. The infected larva becomes discolored and flaccid, and its internal tissues disintegrate, giving the body contents a fluid consistency. Some of the pests affected are alfalfa looper, bertha armyworm, and cutworms. Some virulent viruses have been produced commercially for use as biological insecticides against cabbage looper and sawflies.

Bacteria

Bacteria enter the insect in its food. *Bacillus thuringiensis*, which is the most commonly used bacterium in biological control, contains a toxin that is activated in the insect gut. There are different strains specific to different groups of insect pests. *B. thuringiensis* has been produced in commercial formulations for the control of cabbage looper, imported cabbageworm, gypsy moth, spruce budworm, alfalfa looper, and diamondback moth.

Protozoans

These pathogens can be either transmitted via the egg from adult to the next generation or ingested in food contaminated with spores. Infection

significantly reduces longevity and fecundity and may cause death if the infection occurs in an early instar. Natural infestations of microsporidia in grasshoppers and European corn borer are sometimes high and contribute significantly to reduction of pest populations. *Nosema* spp. have been mass-produced and used for control of grasshoppers.

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W.G. Wellington, University of British Columbia: Figure 2.

Van Waters & Rogers Inc.: Figures 3*b*, 25.

J.R. Byers, Lethbridge Research Station: Figures 3*c*, 15*a*, 22*b*, 31*b*, 33*b*.

J.F. Doane, Saskatoon Research Station: Figures 4*a*, 4*b*.

A.M. Harper, Lethbridge Research Station: Figures 6, 8*a*, 8*b*, 10, 17*a*, 18, 23, 28*a*, 29*a*.

Lethbridge Research Station: Figures 7*a*, 7*c*, 15*b*, 15*c*, 29*b*.

D.L. Johnson, Lethbridge Research Station: Figures 24*b*, 35, 36*b*, 36*c*.

Winnipeg Research Station: Figures 27*a*, 31*a*, 33*a*.

D.S. Yu, Lethbridge Research Station: Figures 30*a*, 30*b*, 32.

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