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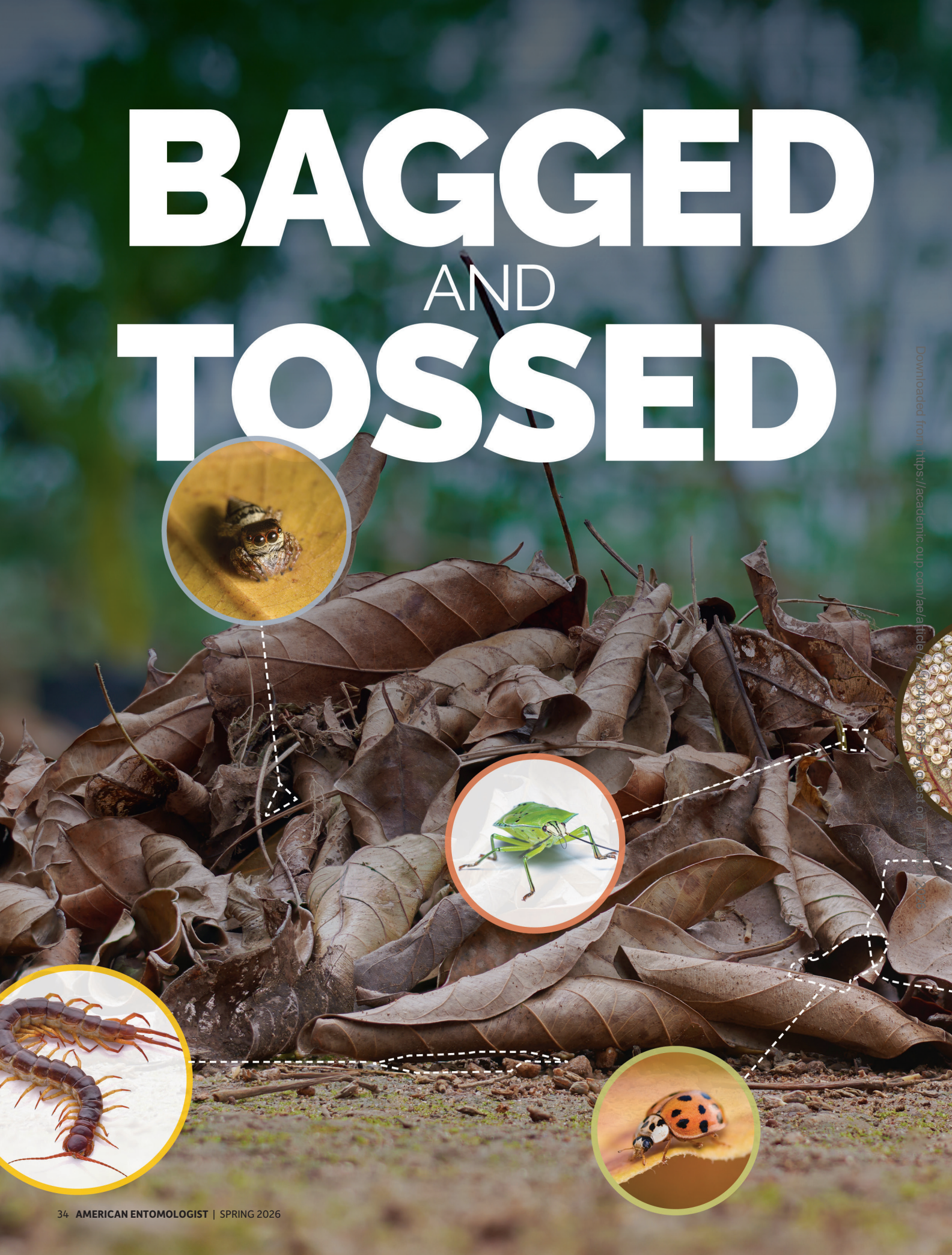

An Undergraduate Entomology Class Investigates the Insect Life Lost with Autumn Cleanup

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Over the last decade, a growing body of research has highlighted significant declines in insect abundance, bringing insect conservation to the forefront. While patterns vary across geographic regions and taxonomic groups, many studies show sharp declines in the abundance and biomass of many insects over the last 30 to 50 years, often at rates exceeding those of vertebrates (Dirzo et al. 2014, Forister et al. 2019, Wagner 2020). Numerous factors contribute to the current insect loss, including widespread use of pesticides and stresses associated with climate change. However, the leading driver of their decline is habitat loss through agriculture and industrial, urban, and suburban development (Dirzo et al. 2014, Schwägerl 2016, Forister et al. 2019, Wagner 2020).

Given the urgency of addressing global insect decline, it is important for citizens to engage in conservation efforts. To foster meaningful participation, people must first be informed about the current state of insect populations and the major threats they face. One impactful setting for fostering this awareness is within college entomology courses. While these courses traditionally emphasize insect anatomy, physiology, taxonomy, and ecology, they should also highlight the importance of conservation. When students are educated about the challenges facing insect populations, they are more likely to take action and may share their knowledge with others in the community.

Fig. 1. Students picking through leaf litter in the laboratory.

In the U.S., most Americans live in suburban settings, and suburban populations continue to grow more than both rural and urban populations (Parker et al. 2018, Anderson 2020, Lerman et al. 2023). Many college students live in or are familiar with suburban environments, making them more likely to relate to the conventional landscaping practices commonly used in these settings. This familiarity creates an opportunity to discuss how everyday actions in one's backyard can contribute to broader conservation efforts. Suburban landscapes not only remove habitat for wildlife, but also often include practices such as expansive turf grass, pesticide use, mowing, and garden cleanup that can further exacerbate the impact of development on insects (Tallamy 2009). Collectively, residents of these suburban landscapes can have a positive impact if they adopt landscape practices that make their property more favorable for insects.

Many movements such as "No Mow May" and "Leave the Leaves" have been developed to promote insect success in suburban developments and have received much traction. The notion behind the "Leave the Leaves" movement is that the common practice of removing senescent leaves from yards in the fall may negatively affect insect populations in areas where they already have reduced viable habitat. Insects may be discarded alongside the leaves because they use leaves as a food source, shelter, breeding and oviposition habitat, and/or as an overwintering site in temperate regions (Eaton and Kaufman 2007, Tallamy 2009, Gullan and Cranston 2014). In 2018, U.S. residents discarded 35.4 million tons of yard waste, the majority of which is composted by the municipality (62.9%), followed by ending up in a landfill (29.7%) (EPA 2020). Thus, when individuals rake and bag their yard leaves in the fall for municipalities to pick up and remove, many insects may also be incidentally discarded along with the leaves and are not returned to a viable habitat.

Despite the popularity of the "Leave the Leaves" movement, it has not yet been evaluated what, if any, arthropods are present in leaf litter that is bagged and tossed from suburban yards each autumn. Evaluating discarded leaf litter from suburban landscapes within a college course offers a valuable hands-on opportunity to engage students directly with insect conservation. To that end, a small-scale study of such was conducted as part of an undergraduate entomology course of 25 students at Canisius University in Buffalo, NY.

Course Goals and Design

The class surveyed conventional 30-gallon paper yard waste bags containing leaves that were raked and bagged to evaluate the contents for any arthropods. The exercise aimed to deepen students' understanding of insect diversity, provide practical experience with insect identification, introduce elements of the scientific process, and foster a direct connection to insect conservation. This was the first time the activity was incorporated into the course, so it was uncertain whether any arthropods would be found.

Since the entomology course was offered during the spring semester, the leaves had to be collected during the previous fall. During that time, the instructor of the course put a call out for bags of raked leaves on social media and collected bags from individuals around the region who responded to the request. Of the bags collected, a total of eight bags were selected for the exercise. These bags were selected because they contained relatively dry leaf litter only and no other yard waste. The bags of leaf litter were stored in the instructor's garage for several months until the course began a few months later.

The exercise was conducted during the three-hour laboratory sessions of the course, which met once a week during the semester. Throughout the course, only six of the bags were searched due to time constraints, while the additional two bags were searched the following summer. Searching was performed on white bedsheets spread over laboratory benches to improve contrast. Leaves were picked through by hand and evaluated with the naked eye (Fig. 1). Each leaf had to be carefully checked for any eggs, larvae, or adults. Any specimen found was observed microscopically, and all members of the class had an opportunity to observe the specimen under the microscope. Pictures of each specimen were taken under a dissecting microscope eyepiece with cell phone cameras, requiring minimal equipment.

During the laboratory sessions, students then went through the process of identification from the pictures using applications including Seek, Picture Insect, and Google Lens. The students focused on adult specimens for their identification, while immatures were identified later by the instructor. Following the species identification suggestion from the applications, the students performed additional research online to confirm

Table 1. Comprehensive list of specimens found in bagged leaves. Unknown specimens refer to those that were desiccated, damaged, or at an immature stage making accurate identification difficult.

Order	Family	Genus Species	Common Name	Stage	Feeding Guild
Isopoda	Oniscidae	*Oniscus* sp.	sowbug	Adult	Detritivore
Araneae	Cheiracanthiidae	Unknown	yellow sac spider (sp.)	Adult	Predator
Araneae	Lycosidae	*Pardosa* sp.	thin-legged wolf spider	Adult	Predator
Araneae	Philodromidae	*Philodromus* sp.	crab spider	Adult	Predator
Araneae	Salticidae	*Dendryphantes* sp.	jumping spider species #1	Adult	Predator
Araneae	Salticidae	*Hentizia mitrata*	jumping spider species #2	Adult	Predator
Araneae	Theridiidae	*Parasteatoda tepidariorum*	common house spider	Adult	Predator
Araneae	Unknown	Unknown	Unknown	Adult	Predator
Ixodida	Ixodidae	*Dermacentor variabilis*	American dog tick	Adult	Parasite
Scolopendromorpha	Scolopendridae	Unknown	centipede	Adult	Detritivore
Collembola	Entomobryidae	Unknown	slender springtail (sp.)	Adult	Detritivore
Psocodea	Psocidae	*Ectopsocus californicus*	bark lice species #1	Adult	Detritivore
Psocodea	Psocidae	Unknown	bark lice species #2	Adult	Detritivore
Psocodea	Psocidae	Unknown	bark lice species #3	Adult	Detritivore
Orthoptera	Tettigoniidae	Unknown	katydid	Adult	Herbivore (leaves)
Hemiptera	Aleyrodidae	*Aleurochiton forbesi*	whitefly	Pupae	Herbivore (sap sucker)
Hemiptera	Cicadellidae	*Helochara communis*	bog leafhopper	Adult	Herbivore (sap sucker)
Hemiptera	Coreidae	*Anasa tristis*	squash bug	Adult	Herbivore (sap sucker)
Hemiptera	Pentatomidae	*Chinavia hilaris*	green stink bug	Adult, Nymph	Herbivore (sap sucker)
Hemiptera	Pentatomidae	*Halyomorpha halys*	brown marmorated stink bug	Adult, Nymph, Eggs	Herbivore (sap sucker)
Hemiptera	Reduviidae	*Zelus luridus*	pale green assassin bug	Nymph	Predator
Hemiptera	Rhyparochromidae	*Myodocha serripes*	long-necked seed bug	Adult	Herbivore (seeds)
Hymenoptera	Cynipidae	Unknown	gall wasp	Adult	Herbivore (gall inducing)
Hymenoptera	Formicidae	Unknown	ant	Adult	Omnivore
Hymenoptera	Vespidae	Unknown	wasp species #1	Adult	Unknown
Hymenoptera	Vespidae	Unknown	wasp species #2	Adult	Unknown
Neuroptera	Chrysopidae	*Chrysoperla carnea*	common green lacewing	Adult	Predator
Neuroptera	Hemerobiidae	*Micromus posticus*	brown lacewing	Adult	Predator
Coleoptera	Carabidae	*Ophonus puncticeps*	ground beetle	Adult	Herbivore (seeds)
Coleoptera	Coccinellidae	*Harmonia axyridis*	multicolored Asian lady beetle	Adult	Predator
Coleoptera	Curculionidae	*Ischnopterapion virens*	white clover weevil	Adult, Larvae	Herbivore (stems, leaves)
Coleoptera	Staphylinidae	*Rugilus orbiculatus*	rove beetle	Adult	Predator
Diptera	Polleniidae	*Pollenia rudis*	cluster fly	Adult	Herbivore (nectar, sap)
Diptera	Syrphidae	Unknown	hover fly	Larvae	Predator
Diptera	Unknown	Unknown	Unknown	Pupae	NA
Lepidoptera	Crambidae	*Chrysoteuchia culmella*	garden grass-veneer	Adult	Herbivore (grasses)
Lepidoptera	Noctuidae	Unknown	owlet moth (sp.)	Pupae	Herbivore (leaves)

the identification. All identifications were recorded on a spreadsheet by the instructor and each specimen was placed in a vial, provided a number, and preserved in the freezer. After the course, the instructor confirmed the identification of each specimen using identification applications, identification guides, and online entomology forums to assist with identification of some of the immature larvae. Of the adults identified by the students during the laboratory, roughly 90% were identified correctly by the students. The numbers of orders, families, and (if possible) species were tallied across both insect and non-insect arthropods.

This exercise accompanied the conventional anatomy and diversity lessons taught in the laboratory portion of the course. Early in the semester, the class reviewed both external and internal anatomy of insects in the laboratory. The course lab then continued with several diversity lab sessions, during which the course surveyed the diversity of several orders of insect and non-insect arthropods. The diversity laboratory sessions included a short lecture reviewing the major orders and families along with some regionally important species provided by the instructor, followed by observing teaching specimens in those respective groups. The diversity of all arthropod groups was divided across six laboratory sessions.

The "Leave the Leaves" project was introduced in the fourth week of the laboratory and lasted for four weeks, with the class sifting through the leaves during the final hour of the laboratory session. An additional two-hour period of searching through the leaves during a later laboratory session was also provided. In total, the class searched the contents of six conventional yard-waste bags of leaves over the course of six hours and identified the specimens as they were found. As mentioned, the additional two bags were searched by the faculty member and a student the following summer. This exercise allowed students to observe the diversity of the structures learned in the anatomy portion of the course, such as different types of wings, forelegs, and antennae. It also allowed them to apply their knowledge of diversity and gave them experience with the identification process.

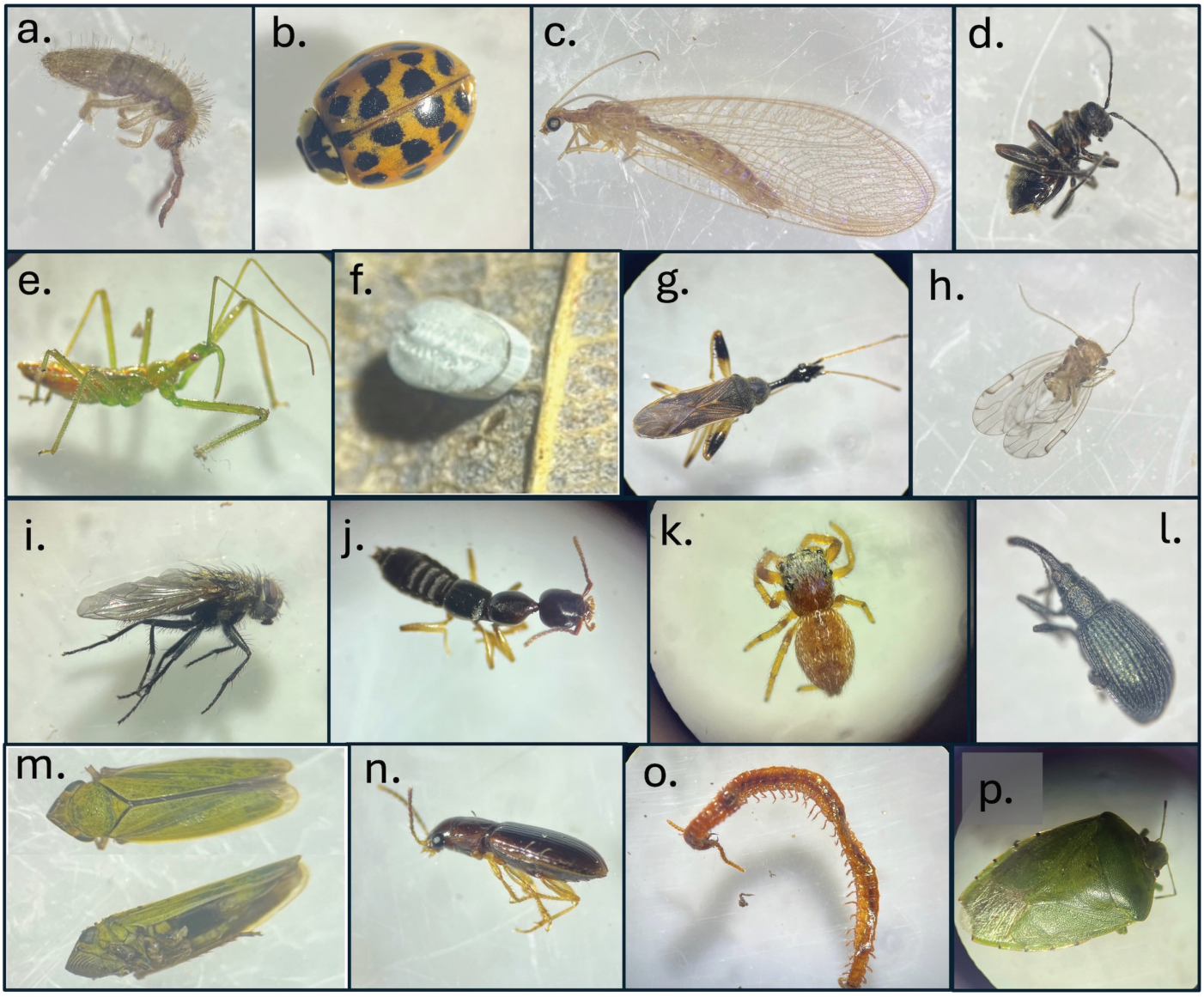

Fig. 2. Sample of diversity found in the leaves: a) slender springtail; b) multicolored Asian lady beetle; c) common green lacewing; d) gall wasp; e) pale green assassin bug; f) whitefly; g) long-legged seed bug; h) barklouse; i) common cluster fly; j) rove beetle; k) jumping spider; l) white clover weevil; m) bog leafhopper; n) ground beetle; o) centipede; p) green stink bug. Magnification varies across images.

What's Left in the Leaves

During this exercise, many different arthropods were found within the bags of leaves, including nine different species of non-insect arthropods representing nine different families and four orders (spiders, centipedes, sowbugs, and ticks). Spiders were the most abundant and diverse non-insect arthropods. We identified 25 different species of insects representing 23 different families and nine orders, including springtails, barklice, grasshoppers, true bugs, beetles, lacewings, flies, wasps, butterflies, and moths (Tables 1 and 2; Fig. 2). Insects from all developmental stages were found (Fig. 3), and the diversity of arthropods represented many different feeding guilds playing several roles in ecosystem function, including various predators of insects, parasites, and different forms of phytophagous insects such as sap suckers, gall makers, leaf and stem chewers, and nectar feeders that also serve as pollinators (Table 1).

The most diverse insect groups were the true bugs (Hemiptera) and beetles (Coleoptera), while the most abundant groups were barklice (Psocodea) and gall wasps (Hymenoptera). There were, however, some specimens in the exercise that could not be properly identified, such as cocoons, eggs, and immature larvae. Data on abundance of each group was not reported, as students admitted they did not report every specimen of commonly found taxa such as spiders and barklice, which were likely represented by more than 50 individuals. It is also very likely that many smaller specimens of particular orders such as springtails were missed with the methods used.

When this exercise was developed, it was uncertain whether any arthropods would be found in the leaf litter. Surprisingly, the diversity observed exceeded expectations, especially considering the unsystematic methods of collecting and searching for specimens with minimal equipment. The leaf bags examined in this study were collected by individuals who responded to the

Table 2. Summary of diversity found in bagged leaves. A plus sign indicates when additional specimens at immature stages could not be identified down to species and therefore could not be concluded to be the same or different than one previously identified.

Non-Insect Arthropods			
Order	**Group of Arthropods**	**# Families**	**# Species**
Scolopendromorpha	Centipedes	1	1
Isopoda	Sowbugs	1	1
Ixodidae	Ticks	1	1
Araneae	Spiders	6+	6+
4 Total		**9+**	**9+**
Insects			
Order	**Group of Insects**	**# Families**	**# Species**
Collembola	Springtails	1	1
Psocodea	Barklice	1	3
Orthoptera	Grasshoppers, crickets, katydids	1	1
Hemiptera	True bugs (cicadas, leafhoppers, stink bugs)	7	8
Hymenoptera	Bees, wasps, ants	3	4
Neuroptera	Lacewings	2	2
Coleoptera	Beetles	4	4
Diptera	Flies, hover flies	2+	3+
Lepidoptera	Butterflies, moths	2	2
9 Total		**23+**	**25+**

social media request and represented neither a broad spatial sample of the Western New York region nor much diversity of leaf litter types, mostly comprising various species of maples, oaks, and American beech. In addition, all leaves were raked and bagged during the same 30-day period (mid-October to mid-November). Taken together, these factors suggest that this exercise likely captures only a subset of suburban leaf litter and does not represent the full range of arthropods that may be raked, bagged, and discarded each autumn. Nonetheless, it was an effective teaching tool that contributes to a better understanding of how everyday landscape practices impact insect populations.

Although it is widely understood that leaf litter provides food, habitat, and an overwintering site for insects, the impact of removing senescent leaves in the fall is just beginning to be recognized. In a previous study, it was found that in plots where senescent leaves were removed in the fall, the emergence of arthropods the following spring was significantly reduced and the community composition was altered, with lower diversity in many groups (Ferlauto and Burghardt 2025). Although removing the insulating layer of leaf litter can reduce survival of subterranean overwintering insects in the soil, our study indicates that insects themselves are indeed removed and discarded along with raked leaves.

Many phytophagous insects feed on live or senescent tree leaves as a resource, such as the several lepidopterans, hemipterans, and gall wasps found in our study. It is likely that the spiders, centipedes, springtails, barklice, and many beetles found were raked up with the leaves that shelter them and provide their complex habitat. In addition, many insects overwinter on or in the leaves themselves as eggs, larvae, or pupae, such as the lepidopteran and dipteran pupae found in the bags we examined (Eaton and Kaufman 2007, Gullan and Cranston 2014, Black 2020). These findings suggest that the raking and removal of autumn leaves does remove insects that utilize leaf litter for food, shelter, and overwintering habitat.

Altogether, the class activity found evidence supporting the ecological basis of the "Leave the Leaves" movement, and that arthropods really are tossed out with bagged leaves each autumn. We hope that this evidence, combined with that of other studies (e.g., Ferlauto and Burghardt 2025), will provide more motivation for suburban residents to keep senescent leaves in their yards through the winter, as this small practice can have a positive impact on insect populations. Any change to autumn leaf removal can have a positive impact, such as only removing a portion of the leaf litter or raking leaves into designated areas such as along garden beds or under certain trees within the yard until the spring. Additionally, other simple land practice changes such as refraining from using pesticides, planting natives, and reducing mowing frequency can help mitigate the impact suburban development has on insect populations.

Impact on Students and Beyond

This exercise was extremely successful in the course in that it captivated the students,

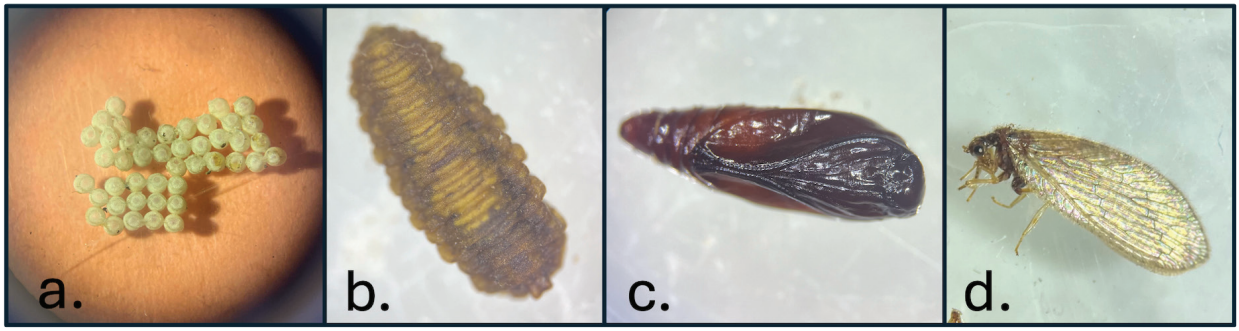

Fig. 3. Specimens found in leaves representing all life stages: a) stink bug eggs; b) hover fly larva; c) owlet moth pupa; d) brown lacewing adult. Magnification varies across images.

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allowed them to apply and expand their knowledge of arthropod diversity, and involved them in a study that is important to insect conservation. The students thoroughly enjoyed the experience, and it was a pleasure to see their wonder and passion grow as a result. Sofia Russo, a student in the course, shared, "I loved the excitement and curiosity that erupted when someone discovered something new. It was really cool to work as a class and try to identify the specimens, whether that was standing over a microscope, reverse image searching a photo we took of it, or consulting with Dr. Costanzo for her expert opinion." Another student, Grace Caraco, stated, "I enjoyed viewing the different insects under the microscopes to view their features. This helped greatly in learning to identify common species for the project or improve upon insect identification in general. Also, it was encouraging to know this data was contributing to the important cause of conserving insect species!"

The first step toward meaningful citizen participation in insect conservation is education and heightened awareness. It is essential that conventional entomology courses include conservation and environmental stewardship as part of the curriculum to play an active role in the solution. The health and stability of our ecosystems rely on insects, as they play critical roles as pollinators and in food webs, decomposition, and natural pest control. The current decline of insects is deeply alarming, and we can no longer rely solely on public agencies and conservation organizations to address this loss. Students who have a deep understanding of insect conservation issues are empowered to make positive changes themselves and educate others in their community.

Incorporating this "Leave the Leaves" exercise into an entomology course allows the students to engage directly with the material and deepens their understanding of the current threats to insects. "What I enjoyed the most about the 'Leave the Leaves' project was being able to discover first-hand what could be found within just several bags of leaves over the course of a few weeks," explained senior Anders Florek. "The project assisted in helping me describe to other individuals about what exists in our yards and how leaving the leaves could be beneficial to the ecosystem residing there."

Because the students were directly involved in discovering insects within the leaf litter, they felt more motivated to engage with insect conservation than they might have through classroom learning alone. As Anders continued, "While lecture discussions are necessary to understanding the broader array of insects within our environment, conducting investigations into the insects within our own backyards specifically led to a closer connection to the topic."

As such, this hands-on experience fostered a more personal connection to insect conservation and inspired the students to change their behaviors and educate their family and friends to support insect populations. Sofia explained, "After conducting this lab, I convinced my lawn-obsessed father to leave the leaves throughout the end of May. I even got him to go one step further and participate in No Mow May this year!" Another student, Ashley Battaglia, shared, "This is my first year as a homeowner with a yard of my own and our leaves will be staying right where they are," and Grace said, "My father is now only going to move the leaves to the woods along our property instead of bagging them."

Furthermore, the exercise has inspired students to carry their knowledge and awareness into their professional lives. Anders, who also works in landscaping and design, explained, "I have already used this experience to further my explanations of landscape practices to other individuals as well as landscape clients with my job. Providing explanations with detailed anecdotes from the lab about what exists right in our own backyard helps me convey the importance of leaving the leaves to others. I hope that by continuing to share the findings of our lab in my everyday life, as well as my professional life we can reach a wider audience and get more people excited about conserving our tiny friends." Ashley, who aspires to make a career out of promoting healthy landscape practices, said, "My dream is to open up a landscaping business to help benefit the native ecosystem while balancing clean and beautiful landscaping."

Because of its success, this exercise will be a part of the entomology course each time it is offered. After running through it once, the instructor has some suggestions

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on how it could be refined. This exercise could be completed during the semester with the course, during which time five or six bags could be examined, given the class size and hours available. The instructor or a graduate student should confirm the identifications during the course and the class can review the results at the end of the semester. Other variables could be examined during the study, including whether the type of leaf litter or landscape use of the property (suburban, urban, rural) affects the level of diversity found. If incorporated into an entomology course, the following learning objectives can be achieved through this exercise:

1. Describe the ecological rationale behind the "Leave the Leaves" approach in insect conservation and test this hypothesis through observational study.
2. Demonstrate proper techniques for effectively searching for, isolating, and observing specimens microscopically.
3. Apply knowledge of insect anatomy and diversity to specimens observed.
4. Apply insect identification tools (e.g., Seek, Google Lens) to identify specimens and evaluate the reliability of these identifications with instructor confirmation.
5. Collaborate with peers during the collection and identification process, fostering communication and collaboration skills in scientific inquiry.
6. Reflect on how human behavior and landscaping practices impact insect conservation.

This exercise provides student-collected evidence that raked and bagged autumn leaf litter from suburban landscapes hosts a surprising diversity of arthropods that play various ecological functions. By physically finding and identifying these organisms, students experienced first-hand the importance behind the "Leave the Leaves" initiative. It is a relatively easy activity to add to a course and requires very little equipment. The exercise complemented the diversity and anatomy lessons of the course well, while incorporating the scientific process of discovery. Most importantly, this activity engages students with insect conservation, with hopes that the impact will extend beyond the classroom. As student Alexa Gioia explained, "This project (and this class) was one of the highlights of my college career. It helped me to better remember certain species and identify insects in the field and it helped me become more aware of suburban residents' role in the conservation of insects. I will most certainly use my experience from this project to inform others of how landscape practices affect insect populations."

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