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entomology to the more abstract topic of ecological succession in a meaningful way. Many of the same mechanisms that drive succession on an ecosystem scale (i.e., abiotic factors, predator-prey dynamics, and environmental adaptation) operate on the level of insects colonizing a cadaver. Because of the smaller spatial and temporal scale, it is easier to explain to students how these factors influence the success of different organisms as the resource changes, which makes it easier for the students to grasp the importance of succession in the context of other ecological principles.

## ○ Methodology

Although I most often conduct the following exercises in college-level introductory courses, I have also used them with children as young as eight at summer science camps. It is important to consider the level and maturity of the class before using these exercises and to craft the discussion appropriately given the sometimes graphic visuals associated with forensic entomology.

I begin the exercise by defining ecological succession. I explain how different plant and animal groups are able to colonize a disturbed area through their interactions with the physical environment and the organisms already present there. Using images and illustrations, I present the classic large-scale examples of a forest after a fire or the aftermath of a volcanic eruption. Specifically, I mention Mount St. Helens in Washington, where an eruption in 1980 catastrophically disturbed the old-growth forest surrounding the mountain. Gary Rosenquist, an amateur photographer, captured images of the first few moments of the eruption, and these pictures are an excellent hook to catch students' attention (Tilling et al., 1997). Because a volcanic eruption is a very drastic example, it can also be informative to use local examples, such as new construction in the town or on campus.

I then ask the students to consider the similarities between a damaged ecosystem and a newly dead animal. Both represent an unused resource that attracts a specific and predictable progression of organisms, the former as it recovers and the latter as it decomposes. However, because of the large time scale involved in ecological succession, it is

## ABSTRACT

*Describing the progression of insects that arrive at a cadaver can be a useful and exciting tool for teaching students about complex concepts such as ecological succession.*

**Key Words:** *Forensics; entomology; teaching; ecology; succession; decomposition.*

One of the challenges in science education is making complicated topics interesting and relevant to students' experiences, particularly in the case of concepts that span large geographic or temporal scales. One such topic that I cover in undergraduate nonmajor science classes is the concept of ecological succession, or the patterns of change seen in communities of organisms following a disturbance (Gibson, 1996). This concept has been identified as one of the key components of fostering ecological literacy in American biology students (Gibson et al., 1999; Morrone et al., 2001); however, it is often difficult to convey to students why understanding successional patterns is important. Students perceive succession as something that happens in extraordinary circumstances (i.e., after a fire or large natural disaster) or happens so slowly that it has no relevance to their lives. Using smaller-scale examples can help students understand that succession is occurring all around them and on relevant time scales. In my classes, I use the example of forensic entomological succession to illustrate the larger concept of ecological succession. Even though forensic succession is a new topic for many students, discussing it teaches them about an important ecological concept at a manageable scale and can be used to explore some of the other underlying factors that drive succession.

Entomological forensic succession was described using the theories of ecological succession, so it is very relevant to the topic (Dadour et al., 2001). Although it is a relatively small field, forensic entomology has received increased media attention in recent years because of the success of television programs like *CSI: Crime Scene Investigation*. The exposure in the popular media has made the study of insects for solving crimes more accessible to students, and I am often surprised by how much they know about the subject before coming to class. This prior knowledge, coupled with the intrinsic fascination most students have for the subject, allows me to connect forensic

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generally more difficult for students to picture the changes or immediately grasp the importance of the patterns. Instead, I focus on the patterns of forensic succession, which occur within a more accessible time frame, have a very explicit significance, and, thus, are more accessible to the students.

I use examples of dead animals to demonstrate the patterns of forensic succession, although the format of the activity differs depending on the size, age, and circumstances of the class. Scenario 1, described below, is more appropriate for small groups and for younger students with limited knowledge, whereas Scenario 2 is better for large groups of older students who are more experienced. In both scenarios, whenever I use live materials or demonstrations, I take the class outside to avoid problems with odor and sanitation. These short “field trips” are a good strategy for breaking up lectures and making the class more interactive, although they work much better with smaller groups.

### ○ Scenario 1: “In the Flesh”

I begin the discussion of forensic succession by showing the group two dead animals, one that has died recently and another that has been dead for a long time. I choose the animals to enhance the contrast between them: the recently dead one still has flesh and is being consumed by a wide variety of insects, whereas the older one is mostly skin, fur, and bones. Pieces of meat from the grocery store or butcher can be used as an alternative to animals. During the summer months, I use actual specimens in an outdoor setting and allow the students to directly observe the cadavers and the insects on them. In the winter or when actual material is not practical, I use photographs or video depicting the diversity of insects. Although some resources exist online, I have found that an off-the-shelf digital camera with video capabilities is sufficient to collect high-quality still images and video of forensic insects in their natural environment. To continue the exercise, I ask the students to list differences between the cadavers and between the types of insects they see on them. After these informal observations, I ask the students to think about why different insects are found on the two cadavers, emphasizing that the animals have been dead for different amounts of time.

Next, I provide a list of different types of forensically important insects and ask the students to work together to put them in the order in which they arrive at a cadaver (Figure 1). I usually provide laminated images of each of the types of insects so that the group can physically order them as they work. After the students have determined an order, I briefly describe some of the life-history characteristics of each of the insect groups and use those descriptions to correct and explain any errors that the students made in ordering them. For instance, it is common to place “predatory flies” before “carrion flies.” However, the larvae of carrion flies feed directly on dead tissues, whereas predatory fly larvae feed on other insects at the cadaver, which means that the predatory flies must arrive after the carrion flies; otherwise, they would not be able to eat.

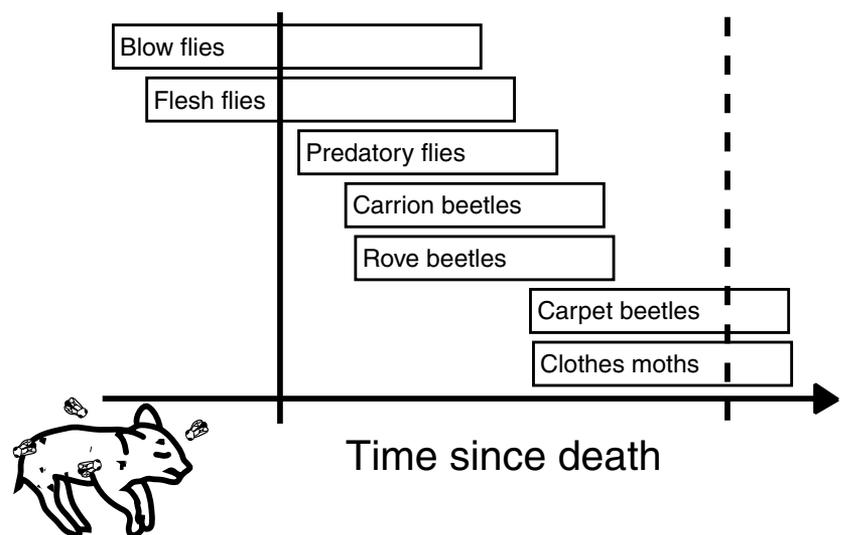
Scenario 1	Scenario 2
<ul style="list-style-type: none"> <li>• Carrion flies</li> <li>• Predatory flies</li> <li>• Carrion beetles</li> <li>• Predatory beetles</li> <li>• Hair and skin beetles</li> </ul>	<ul style="list-style-type: none"> <li>• Blow flies</li> <li>• Flesh flies</li> <li>• Predatory flies</li> <li>• Carrion beetles</li> <li>• Rove beetles</li> <li>• Carpet beetles</li> <li>• Clothes moths</li> </ul>

**Figure 1.** Lists of the forensically important insects used in both classroom scenarios for discussing entomological forensic succession.

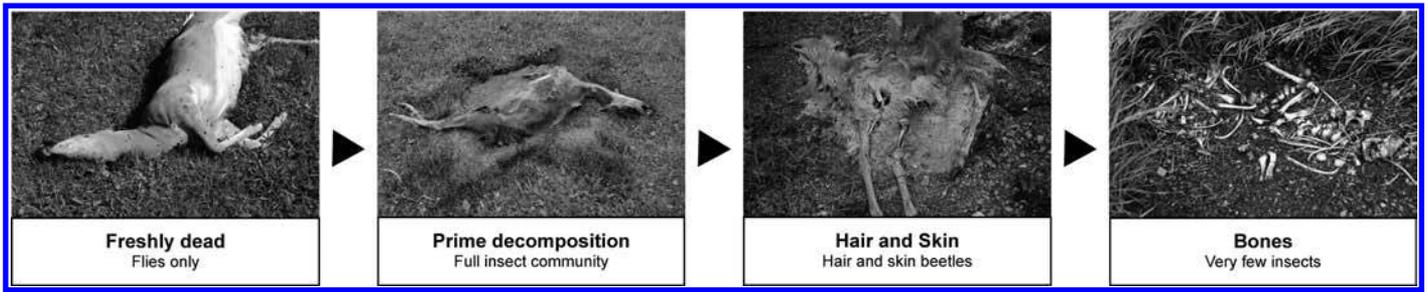
I conclude the exercise by once again highlighting the concept that insects arriving at a cadaver in a predictable progression (forensic succession) can be extended to larger time scales and circumstances, including ecosystems (ecological succession). The individual components may be different, but the theory behind both concepts is similar. Understanding the changes that take place over time at a new resource gives us important information about how long an animal has been dead (forensic succession) and how stable and healthy an ecosystem is (ecological succession). We also discuss some of the reasons (i.e., abiotic factors and physical adaptations) why succession occurs as it does, which demonstrates some of the ecological principles driving succession.

### ○ Scenario 2: “Pinky the Pig”

To accommodate a larger group, the second scenario is less hands-on, but it progresses similarly and still captures the core ideas while eliciting student involvement. I present an image of “Pinky the Pig” and the groups of forensically important insects (Figure 1) and ask the students to suggest which group they think arrives first at the newly dead Pinky. I divide the groups of forensically important insects more finely in this scenario because the audience is usually older and more experienced. Following a suggestion of an insect group, I ask for a show of hands to determine a class consensus and list it on the board. The activity progresses until all the insect groups have been ordered. Then I present detailed information on the life histories of each of the insect groups, once again emphasizing how their characteristics affect the order in which they can colonize the cadaver and correcting any errors in the class-determined order of progression. Collecting specimens, such as maggots or beetles, and preserving them in vials of alcohol, which can be passed around, can provide a more realistic exposure to the organisms involved if taking the students outdoors is impractical. The best preservative is 70% ethanol, but if it is not available any clear liquor that is at least 100 proof, such as vodka or rum, is an acceptable substitute. I emphasize that knowing what insects are present at a cadaver provides important information about how long that animal has been dead (Figure 2). As in Scenario 1, I conclude by restating the connection between forensic succession and the larger concept of ecological succession and discuss what factors drive the patterns in both instances.



**Figure 2.** Progression of forensically important insects in the second scenario. The widths of the boxes represent the relative time after death when different forensically important insects are present at a cadaver. The communities of organisms are very different at the early time (solid line) as compared to the later time (dotted line).



**Figure 3.** Stages of decay in cadavers. Images were collected in early July in Pennsylvania from road kill.

## ○ Assessment & Application

One of the strengths of these activities is that they provide an interactive scenario in the classroom. In Scenario 1, asking the students to work as a group reinforces team-building skills. In 3 years of summer camps, no group has failed to reach consensus on an order of progression. In the larger classes in which Scenario 2 is appropriate, asking for student input and participation helps break up the class period and re-engages the students' interest in the topic. Including live or preserved insects in both scenarios gives students a chance to observe organisms that they are unlikely to have encountered before, which increases interest and can contribute to retention of the information presented.

The difficulty in using these activities is gauging the proper level to discuss the forensic information. Some students may be repulsed by the thought or depiction of a dead animal, which may block their understanding of the topic. Warning the students when potentially disturbing images will be displayed eliminates some of this distraction. Also, explicitly stating the relationship between forensic and ecological succession is important to reinforce the similarities between the two concepts because the exotic forensic information sometimes overshadows the ecological connection, despite its effectiveness in creating interest in the topic.

Regardless of the scenario used, though, there appears to be high retention and comprehension of the concept. Repeat students in the classes and camps often remember the correct order for the forensically important insects, even if it has been years since it was first presented to them. Additionally, when I ask the students to think of examples of how succession can be applied or provide useful information, many students are able to suggest good ideas (e.g., conservation work). I believe that the retention is linked to the exotic nature of the topic; most students have not directly encountered forensic examples, and the information is intriguing and memorable. Presenting the topic at the smaller, forensic scale also makes the underlying concept, succession, easier for students to grasp and extend to other levels.

Both scenarios provide information to the students about the biology and life history of the forensically important insects. This information can serve as a springboard for discussions of why successional patterns develop and what other factors are involved in shaping how organisms colonize and use a resource. One of the key factors that drives forensic succession is the moisture content of the cadaver; the physical environment of the cadaver changes drastically as the tissue dries (Figure 3), and this directly influences what organisms are able to utilize this resource. It is easier for students who have seen a soft-bodied maggot and the moist environment it inhabits within a cadaver and compared this with the dried bones left at the end of forensic succession to understand how important abiotic factors are in shaping an ecosystem. They are then able to extend that concept to large scales and describe why, for example, deserts are dominated by very different species than rainforests.

The examples of forensic succession are also a good tool for connecting other ecological concepts, such as predator-prey dynamics or evolution, into the larger conceptual framework of succession. For

example, predatory beetles are an important part of the community associated with a cadaver. However, their prevalence is linked to the availability of prey, such as maggots. If the maggot population is insufficient to support the beetle population, the community that assembles on the cadaver will be very different from one that assembles on a cadaver with abundant maggots. Predatory beetles also have adaptations that make them effective hunters (e.g., developed eyes and long legs for rapid movement), whereas maggots are essentially eyeless and are well adapted to sedentary feeding on decaying flesh. Asking students to consider how changes in one population affect another population and what factors – such as temperature, moisture content, and physical adaptations – drive those changes gives them a concrete example of succession as a dynamic process that is ongoing in the face of changing environmental conditions, whether at the cadaver or ecosystem scale.

Overall, describing the practical example of forensic succession is a useful tool for increasing students' understanding of the larger, more theoretical concept of ecological succession. Using this strategy allows me to educate my students about an interesting, novel topic while connecting that topic to the larger body of scientific theory.

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