CHAPTER 5 - Classroom Mark-Recapture with Crickets

5.1 ABSTRACT

Mark-recapture techniques are commonly used by wildlife biologists and ecologists to estimate abundance of animals in naturally occurring populations and are therefore an important component of curricula that include population ecology. This lab activity teaches mark recapture techniques using crickets in a single 10-gallon aquarium and provides an inexpensive way to teach students about this commonly used technique in a real world context. This alternative teaching method for mark-recapture methods provided highly accurate estimates of cricket abundance and captured student's interest more than other classroom-based strategies for teaching the same material. This lab can easily be done in any classroom and has the advantages of allowing students to handle easily obtained live insects, without the potential drawbacks and uncertainty of teaching mark-recapture in a field setting. We successfully used this technique in a high school general life science course, but it could easily be adapted for use in undergraduate general biology and ecology courses.

5.2 INTRODUCTION

How many deer live in a particular county? How many fish live in the creek that runs near a school? And how have these numbers changed over time in the last 10 years? These are the questions of population ecologists. Population ecology is the study of changes in the abundance of organisms over time and space (Akcakaya et al. 1999). Temporal and spatial trends of animal abundance are commonly used to prioritize conservation and management efforts for various animals. For example, these trends are used to help determine the numbers of hunting permits that will be issued in a given year. Due to its central role for ecology and population biology, many high school and undergraduate biology courses include lessons on population ecology theory.

Curriculum pieces on population ecology theory often include investigations on methods used to estimate animal abundance. One commonly used technique to estimate the size of natural populations is single mark-recapture using the Lincoln-Petersen relative abundance model (Smith and Smith 2001). In this method, animals are captured, given an identifying mark such as a paint spot or a tag with a number, and then released back to their habitat. At a later date, traps are set again in the same places. The ratio of marked to unmarked animals during the second capture event can be used to estimate the size of the population. This method provides a simple means to estimate the population size of animals. The basic form of the Lincoln-Petersen model is mathematically straightforward and appropriate for teaching about mark-recapture methodology. The basic model also provides an ideal mechanism for integrating science and mathematics. More advanced students can explore many extension of this model that address violations of several key assumptions (see below).

Various strategies have been used to teach mark-recapture in high school and undergraduate classrooms. A common teaching strategy uses dried beans or plastic beads as model animals (e.g. Budnitz 1998). In this strategy, a subsample of beans or beads is taken out of a container, marked, and returned to the container. In a subsequent "recapture" event, another subsample of beans is collected and the proportion of marked beans relative to the number of unmarked beans is used to estimate the total number of beans in the container. While this is relatively simple to do in the classroom, we have found that it often does not work well because too many beans are in the containers to start with and this prevents students from marking a large enough proportion of the beans during the mark and recapture trials. Usually estimates are far from the true number of beans in the container. While this type of investigation illustrates very well one of the issues faced by population biologists that study hard-to-capture animals, we have found that it does not help the students firmly grasp population biology theory and furthermore, the inaccuracy of this method can erode student interest and enthusiasm. More importantly, this exercise does not present mark-recapture as it is used in practice and it is not as captivating for the students to handle beans as surrogates for live organisms.

Another teaching strategy involves the use of live animals, either in schoolyards (Anonymous 2002), or in a more natural field setting (Dussart 1991; Rollinson 2004). Handling live organisms provides a challenge to the students and provides a teaching opportunity about the natural history and biology of the organisms. This is an excellent option if large populations of easily captured organisms are available close to a school. Working with live animals is inherently more interesting to the students. Moreover, students get out of the classroom and into nature. On the other hand, working in a field setting requires significant planning and some uncertainty about the likelihood of successfully capturing enough animals. Furthermore, population estimates can be problematic if the assumptions of mark recapture models are not met.

Given that knowledge of the spatial and temporal distribution of animals is central to understanding important issues in ecology and conservation biology, we developed an activity to teach mark-recapture techniques using live animals in a classroom setting. We chose crickets living in 10-gallon aquaria habitats. Our approach shares the advantage of the bean exercise in that students conduct the investigation in the classroom so there is no uncertainty about finding enough animals. It shares the advantages of field-based investigations in that students work with live organisms, necessitating an understanding of the biology of the crickets. But most importantly, student's interest is captured by the challenge of handling these animals. We found that using crickets in this investigation captivates students in a similar manner as field-based techniques, but it is much more feasible to use in restricted time periods and classrooms.

5.3 OBJECTIVES OF THIS ACTIVITY

The general goal of this investigation is to complement instruction on population ecology and to teach mark-recapture theory and techniques that are used by population biologists to understand the distribution of animals in space and time. More specifically, students work collaboratively to learn: (1) mark-recapture techniques to estimate population size of naturally occurring organisms; (2) how to calculate a population estimate using equations (i.e. algebraic manipulation of simple ratios and solving equations for one unknown) and data they collect; (3) about the natural history and the handling of a common insect; and (4) to think critically about how wildlife biologists estimate population sizes and about popular press stories that feature abundance estimates of wild animal populations.

This investigation promotes science as inquiry and helps students develop skills in asking questions, collecting and interpreting data, and communicating the results with their peers. It maps easily onto the National Science Education Standards (NRC 1996). This semi-guided inquiry can lead to more open-ended investigations (content standard A) and it emphasizes student collaboration. Moreover, it emphasizes concepts related to population growth and natural resources (content standard F). Finally, students refine their ability to use models and equations to make estimates and predictions (content standard G).

5.4 COUNTING CRICKETS

Materials

Table 5-1 provides a list of the materials needed for this activity. We recommend using the same set of crickets for multiple classes and having students mark crickets multiple times on different body parts and with different colored paint pens. This minimizes set up time and forces the students to be careful with how and where they mark the crickets.

Investigation

This investigation can be completed within a 1 to 1.5 hour class period. There were two short periods of time for direct instruction and two periods where students capture, handle, and mark crickets. We designed an opening interactive lecture focusing on why it is important to estimate the population size of naturally occurring animals. Students then captured, marked, and collected data from crickets. During a second lecture, students learned the theory behind mark-recapture using the Lincoln-Petersen technique. The investigation and the transparencies that can be used for this investigation are available online at www.bioed.org/ecos/.

At the beginning of each class session, students received an investigation sheet that briefly explained the investigation and contained a data sheet for their mark-recapture data (Figure 5-1). Students worked in groups (we recommend three per group) and each group received one data sheet.

The introductory sampling lecture was designed to build on previous population ecology lessons and activities. In this lecture we addressed the following concepts: why it is important to estimate population sizes of naturally occurring animals, the basic idea behind mark-recapture techniques, the importance of understanding the biology and natural history of the animals we study, basic insect anatomy, specifically how to mark crickets, safety and ethical issues with working with live animals (there are minimal safety issues associated with this investigation but students should wash their hands after handling the crickets), and general logistics. More detailed information on these topics and a PowerPoint file with overhead masters are available at www.bioed.org/ecos. We waited to explain the details of the Lincoln-Petersen model until after the first capture session.

The first step in the investigation was for each group to observe the aquarium setting. We used one 10-gallon aquarium per class. One student from each group removed one "cricket castle", which was a small portion of an egg carton (Table 5-1), and gently shook the crickets from the egg carton into the plastic container. Each group returned to its table with its crickets (5 to 6 worked well). It is important to provide enough pieces of egg carton so that each group can use one and it is also helpful for the instructor to supervise the capture process so that groups overturn only one piece of egg carton. We observed a tendency for the students to overturn many of the pieces of egg carton and to disturb many of the crickets if we left them unsupervised. In addition, the instructor should monitor the approximate number of crickets collected. In general, abundance estimates tend to be close to the true number of animals if at least half of the animals receive marks.

At their table, the groups used a paint pen to mark the crickets. One student held a cricket while another dabbed the specified body part with paint, and a third recorded the number of crickets marked (this is n_1 in the equation described below and in Figure 5-1). We used different colored paint pens for each class and marked either part of the thorax or one of the legs of crickets. Students also recorded data on their data sheet on whether or not the crickets have wings and the gender of each cricket. After all of the groups obtained crickets, the first groups were allowed to gently return crickets to the aquarium.

Once the crickets were back in the aquarium, we presented the Lincoln-Petersen method during another 15-minute lecture. This lecture focused on the variables in the Lincoln-Petersen index of relative abundance, the ratio used to calculate $\hat{N}$ (the estimate of population size), and the assumptions of the model. Overhead masters are available online for you to download at www.bioed.org/ecos. This break in activity allowed the crickets to settle back into their "traps".

The equation for the Lincoln-Petersen model is: $\frac{n_1}{\hat{N}} = \frac{m_2}{n_2}$ (1), where n_1 is the number of animals marked and released during the first session, n_2 is the number of animals captured during the second session, m_2 is the number of animals captured during the second session that are recaptures and were marked during the first session, and $\hat{N}$ is the estimate of population size. This equation can be algebraically manipulated to solve for $\hat{N}$, such that $\hat{N} = \frac{n_1 * n_2}{m_2}$ (2). This model makes the following assumptions: first, the population is closed (no births, deaths, immigration, or emigration). Second, marks are not lost or overlooked by the observer. Third, all animals are equally likely to be captured in each sample and over time. That is, it is assumed that there are no behavioral differences in preference or avoidance of the "trap" between individuals, and also that being trapped once does not make an individual more or less likely to be captured again. It is also assumed that things like weather changes or other environmental factors do not change the probability of trapping animals during the two trapping periods.

In addition to calculating $\hat{N}$, an optional extension for advanced students is to calculate the standard error of the estimate of population size using the following equation:

$S.E. = \hat{N}\sqrt{\frac{(\hat{N} - n_1)(\hat{N} - n_2)}{n_1 n_2 (\hat{N} - 1)}}$ (3). $\hat{N} \pm 2(S.E.)$ provides the 95% confidence interval about $\hat{N}$ (Smith and Smith 2001).

Finally, we predicted the types of factors that might lead to differences between our estimate of population size and the true population size. Through this discussion, students thought about the equation they had just learned and the consequences of violations of the assumptions of the model. For example, it the crickets lost their marks before the recapture session, this would lead to an upwardly biased estimate of the population size (because m_2 will be biased low and since this is in the denominator of equation 2, $\hat{N}$ will increase).

The recapture event followed this second lecture. Groups repeated the same process of capturing crickets described above. Students recorded m_2 (the number of marked crickets captured during this session) and n_2 (the total number of crickets their group recaptured). Students recorded all marks given during their class period (not just the marks given by their group). Each group reported n_1, n_2, and m_2 in a table made by the instructor on the board. The sum of each variable was used as the class total to calculate one value of $\hat{N}$ per class (Figures 5-1; Figure 5-2).

After students worked through the calculations of $\hat{N}$, a general discussion followed about how close the estimate was to the true value. Reasons why $\hat{N}$ might not be accurate were discussed, along with confidence intervals (optional), and potential violations of assumptions. We referred to the list of model assumptions to discuss each assumption and whether it may have been violated. For example, cricket escapes would violate the closed population assumption. Another possible source of bias could be related to the trapping method used in this investigation. $\hat{N}$ might be biased low because stressed crickets might crawl directly back into the castles to seek cover after the crickets are placed back into the aquarium. Thus, m_2 might be biased high, in turn causing $\hat{N}$ to be biased low. It is helpful to link violations of the assumptions explicitly to the equation to determine how $\hat{N}$ might be affected.

We also had students reflect on their data on the number of males and females that had wings. These data were used to generate hypotheses regarding the observations. For the crickets we used in this investigation, females tended to be wingless while males had wings. One hypothesis is that females might not have wings because of the way they allocate their limited resources to growth versus reproduction. Because they use a lot of energy to make eggs, fewer energy-related resources may be devoted to growing wings during development. Males may need to allocate energy to the production of wings because they might disperse more than females, perhaps to find mates.

We used two follow up exercises to increase student comprehension. First, students were assigned the questions in Figure 5-2. This assignment takes the form of a follow up exercise to increase student comprehension. Second, we provided an extension activity where students estimated the population size of snowshoe hares from a valley in western Montana (Figure 5-3). For the students we worked with, this example was particularly relevant because snowshoe hares are the primary prey of Canada lynx (*Lynx canadensis*). The valley mentioned in this part of the investigation (the Swan Valley) is a stronghold of Canada Lynx in the lower 48 states of the United States (McKelvey et al. 2000). We created a fictitious data set that consisted of a series of n_1, n_2, and m_2 values for six consecutive years. Groups of students were assigned a year for which they calculated $\hat{N}$. Values of $\hat{N}$ for each year were written on the board and students were asked to graph the trend in population size. Once the data were combined, the overall population trend was discussed.

This portion of the exercise provided a link between the mark-recapture method just learned and a real-world use of this method. It also provided an opportunity to discuss potential violations of mark-recapture assumptions, the appropriate time interval between mark and recapture events, the best way to mark different types of animals, and methods of capture (snowshoe hares are trapped with wire Tomahawk live traps baited with alfalfa cubes in the winter or apples in the summer). In addition, because snowshoe hare and Canada lynx populations follow a boom and bust cycle, this portion of the exercise provided an opportunity to link the method the students just learned to relevant and exciting case studies in population ecology.

Extensions

Genetics techniques are now used to estimate the population size of animals. For example, biologists in Glacier National Park, Montana, use hair collected from special hair snagging stations to estimate the number of bears in this park (for more details see:

http://www.nrmsc.usgs.gov/research/glac_beardna.htm). Some of the techniques used to analyze genetic data use extensions of the Lincoln-Petersen model. Thus, after learning the basic theory and technique using the crickets, a further lesson could explore indirect genetic methods to estimate population size.

As another extension, after learning mark-recapture techniques through this investigation, students can design their own research investigation to use mark-recapture with naturally occurring populations of animals, perhaps as part of an independent project. This could be done in the schoolyard with insects using a similar technique described in this paper (e.g. pillbugs; Anonymous 2002). If a pond is nearby, frogs can be marked by clipping toes. Guidelines for toe-clipping can be found at: www.asih.org/pubs/ASIH_HACC_Final.pdf. For a discussion of the ethical aspects of this technique see Funk et al. (2005). If fish can be captured, individuals can be marked by clipping small portions of fins. Note that these more invasive techniques (e.g. clipping tissues) can only be performed with the consent of animal care committees and/or local fish and wildlife departments. We recommend contacting a local university or fish and wildlife department if students are interested in undertaking a project like this. There may be projects underway with opportunities for participation by volunteers.

Did this investigation provide a successful learning experience?

This investigation was tested with high school sophomores in their second year of a biology series. The teachers thought it was a substantial improvement over the bean exercise taught in the past for two reasons: 1) it was more accurate and 2) it better captured student interest. The classes' population estimates were close to the true value of 50 crickets in the aquaria and most estimates were within three of the true value; only one was off by eight from the true value. In contrast, the bean investigation often yielded results that were highly inaccurate, causing students to doubt the efficiency of the technique and, as a consequence, diminished their interest. Interestingly, the challenge of handling and marking live animals was a large part of the appeal of this exercise. Many students had to confront their fear of insects and most appeared to enjoy handling the crickets.

We also examined how well students performed on the assessment problems and questions (Figures 5-2; Figure 5-3). Overall students answered most of the questions correctly and we conclude that the students gained an overall understanding of mark-recapture theory and technique. In general, students successfully manipulated equations, were able to think critically about assumptions of the Lincoln-Petersen model, and gave thoughtful responses regarding the broader importance of estimating the size of natural populations. We observed that some students had difficulties with using and manipulating the equations (equations 1 and 2, we did not use equation 3 for the standard error) and there was wide variation among answers related to assumptions of the model. We found that these concepts were important to revisit, through additional problems, questions, and class discussion. In summary, this investigation provided a great foundation from which we could increase student understanding of mark-recapture and population ecology concepts.

5.5 CONCLUSIONS

This population ecology investigation provides an inexpensive way to teach students, in a real world context, about a technique commonly used in field biology and ecology. This approach for teaching about mark-recapture methods provided highly accurate estimates of cricket abundance and appeared to capture student's attention more than the typical bean or bead counting strategies for teaching the same material. This investigation is easily done in any classroom setting. Moreover, it has the advantages of allowing students to handle live insects without the drawback, uncertainty, and time necessary to teach mark-recapture in a field setting. Most importantly, students demonstrated they could think critically about how wildlife biologists estimate population sizes and about popular press stories that feature abundance estimates of wild animal populations.

5.6 GLOSSARY

Sampling terminology

*Closed population***:** a population where no births or deaths occur and individuals do not enter (immigrate) or leave (emigrate) during the time of study

Confidence Interval (C.I.): The range in which you expect 95% of all estimates to lie.

Lincoln-Petersen model: a specific mark-recapture technique that requires two sessions where animals are captured. This is a basic technique that forms the basis for more complicated population estimation methods. The equations for the model is: $\frac{n_1}{\hat{N}} = \frac{m_2}{n_2}$, where n_1 is the number animals marked and released during first session, n_2 is the number of animals captured during the second session, m_2 is the number of animals captured during second session that are recaptures from the first session, and $\hat{N}$ is the estimate of population size.

Mark-recapture techniques: a set of techniques used to estimate the population size of animals. All of the techniques involve an initial marking event where animals are captured, marked, and released. Animals are recaptured a second time and the proportion of marked to unmarked animals is used to estimate the population size.

Standard Error (S.E.): a measure of variation about the mean population estimate.

Subsample: a smaller group collected from within a larger population of objects.

Cricket anatomy (Borror et al. 1992)

Head: the anterior body region, which bears the eyes, antennae, and mouthparts

Thorax: the body region behind the head, which bears the legs and wings

Abdomen: the posterior of the three body divisions

Ovipositor: the egg laying apparatus; the external genitalia of the female

Cercus (plural *cerci*): one of a pair of appendages at the posterior end of the abdomen

Table 5-1. Materials for cricket investigation. Numbers of a given item required are in parentheses.

- 10-20 gallon aquarium (1)
- Pet store crickets (~50)
- Cardboard "traps" ("cricket castles"). We used egg cartons and cardboard packing material from an electronic device (~10)
- "Painters" acrylic non-toxic paint pens (Hunt Inc.; number of colors depends on number of participating classes)
- Chopped apple (food and water for crickets)
- Large (32 oz.) plastic containers (1 per group of students)

Figure 5-1. Description of investigation and data sheet.

Figure 5-2. Questions and problems that accompany this investigation.

Figure 5-3. Extension exercise using fictitious snowshoe hare mark recapture data.

Figure 5-4. Cricket in a small yogurt container. The thorax of this cricket has been painted by students with a white paint pen. The cerci extend from the back of the abdomen. The ovipositor is at the very tip of the abdomen.

Figure 5-5. Crickets on a cricket "castle". The castle is a cardboard insert to an electronic appliance. Notice the paint on some of the crickets, particularly the white on the back and purple on the leg of the cricket to the right.

Handout for Cricket Mark-Recapture Investigation

Name: **Period:**

Date:

For this investigation, we will estimate the population size of crickets in aquariums. You will work in teams of two to catch, mark, release, and recapture crickets. Each team will take a plastic container to the aquarium and capture crickets by scooping crickets out once. This is your first sample. Take the crickets in your container to your desk and mark all of these crickets on their back with a paint pen. Fill in the number of crickets caught during your first sample for n_1 in the data table.

Once everyone has caught and marked crickets, each team will return the marked crickets to the same aquarium. We will wait 15 minutes. Then each team will take a second sample of crickets. Again, take the container of crickets to your desk and record the total number of crickets caught. Also record the total number of crickets with marks. The total number of crickets you caught the second time is n_2. The number of crickets you caught the second time with marks is m_2. Fill these in below. Also record whether each cricket is male or female and whether it has wings or not. Fill in the total number of males and females with and without wings in the table at the bottom of the page.

Your group's totals:

n_1 = _______________

n_2 = _______________

m_2 = _______________

As a class, we will pool our cricket samples to estimate the abundance of crickets in the aquarium.

Class totals:

n_1 = _______________

n_2 = _______________

m_2 = _______________

Fill in the data on sex and wings in this table:

Cricket #	Sex (M/F)	Wings (Y/N)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Fill in the total number of males and females with and without wings in this table:

Winged/wingless	**Males**	**Females**
Wings		
Wingless		
Total		

Figure 5-1

Questions for Cricket Mark-Recapture Investigation

1) Use the class data to estimate the population size of crickets in the aquarium ($\hat{N}$). Show your work below and use this equation: $\hat{N} = \frac{n_1 * n_2}{m_2}$.

2) Which assumptions of the Lincoln-Petersen model might we have violated?

3) How would the violations you mentioned effect your estimate of population size ($\hat{N}$)?

4) If the class estimate was close, does this guarantee that we didn't violate any assumptions of the Lincoln Petersen model?

5) What is the value of estimating the size of naturally occurring populations?

Figure 5-2

Extension Activity

Snowshoe hares are important food sources for Canada lynx; so many people are very interested in the population size. We would like to know if a population of snowshoe hares in Seeley Lake is increasing or decreasing. We conducted a 2-day trapping session once a year for 6 years. Each team will estimate the population size for **ONE** of the years. Once we tell your team which year to estimate, circle the year and estimate the population size. Once everyone has estimated the population size for their year, we will put it all together and graph the population size over time.

2004: On day 1, we caught and marked 18 animals. On day 2 we caught 23 animals, of which 12 were marked.
2003: On day 1, we caught and marked 12 animals. On day 2 we caught 15 animals, of which 6 were marked.
2002: On day 1, we caught and marked 16 animals. On day 2 we caught 19 animals, of which 12 were marked.
2001: On day 1, we caught and marked 20 animals. On day 2 we caught 24 animals, of which 19 were marked.
2000: On day 1, we caught and marked 13 animals. On day 2 we caught 15 animals, of which 9 were marked.
1999: On day 1, we caught and marked 14 animals. On day 2 we caught 15 animals, of which 11 were marked.

n_1 = ______________
n_2 = ______________
m_2 = ______________

$\hat{N}$ = ______________

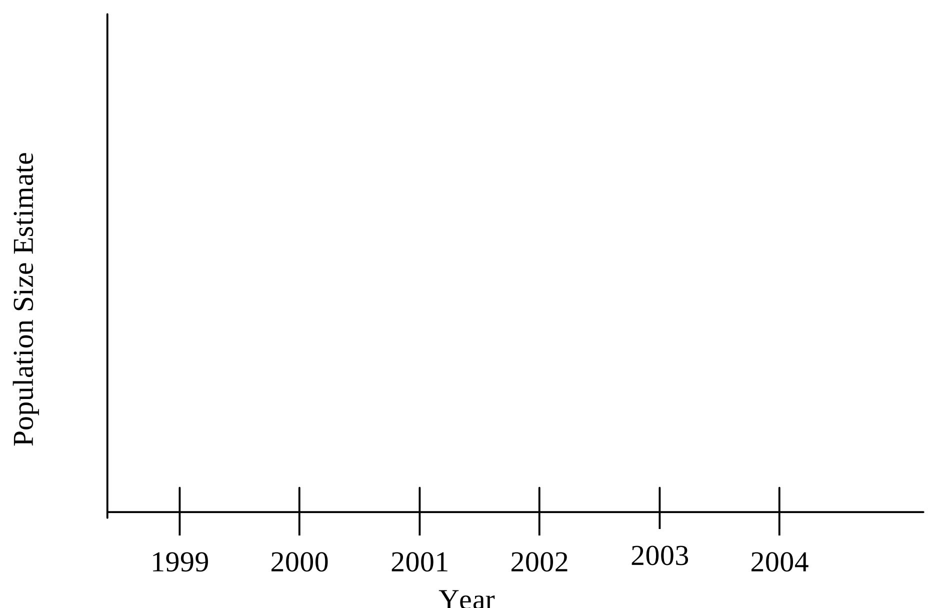

Figure 5-3

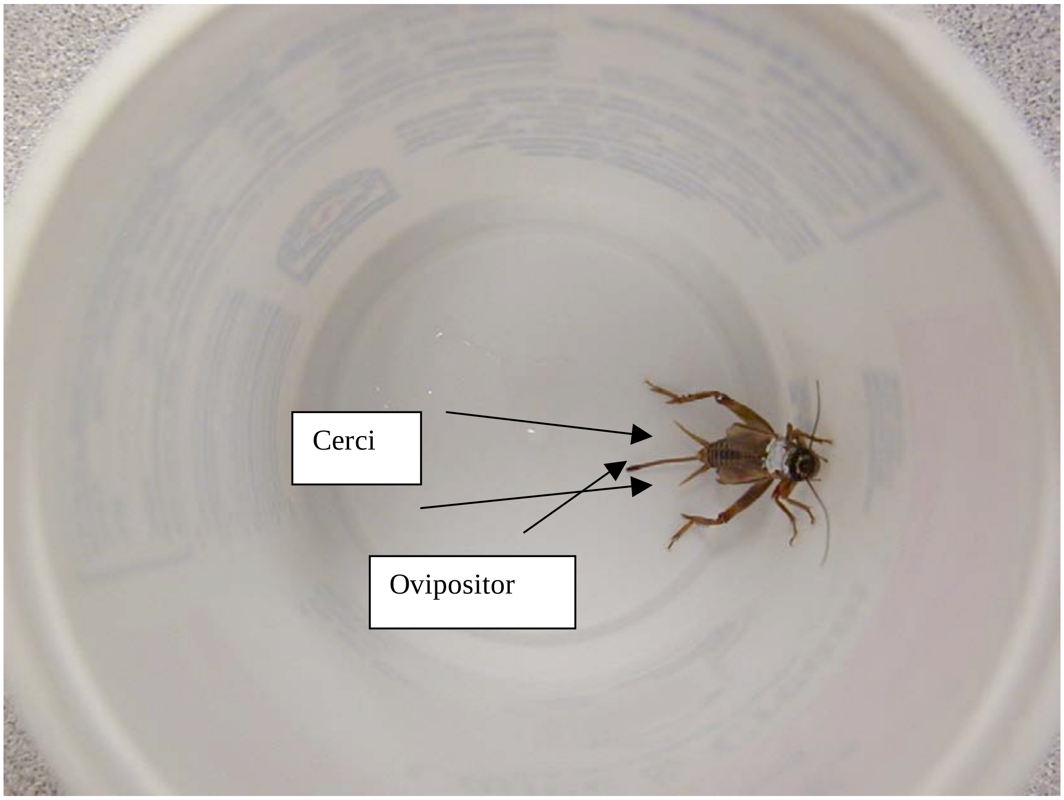

Figure 5-4


Figure 5-5