**MARK AND RECAPTURE**

**Summary:** Estimating the population size of animals is an important task for wildlife biologists, who can use the data to assess the health of a population. It requires diligent observation skills coupled with the ability to use empirical models that effectively determine the number of animals based on field surveys. The most common method for estimating the population size of animals is mark and recapture. This method requires capturing and marking individuals, followed by subsequent capture sessions. The number of individuals marked and unmarked in subsequent capture sessions are used to determine the population size. This case study introduces two empirical models for mark and recapture and applies one of the models in an application activity investigating the expansion of coyotes in urban areas.

**Introduction**

 Wildlife biologists are frequently tasked with the responsibility of estimating the population size of animals. Knowing whether a threatened or endangered population is increasing or decreasing is important in conservation management. However, it is often difficult if not impossible to obtain a complete count of animals in their natural environment. For this reason, biologists rely on methods to estimate their population size.

 The simplest method of estimating population size are counting individuals or their signs (e.g. bird calls or animal droppings) in randomly placed plots, where the plots may be quadrats or transects [5]. This method is popular with plants. For example, randomly assigned quadrats would be used if the field site was homogenous such as a wildflower meadow, whereas, transects would be used if the landscape was heterogenous such as a mountainous region where both south and north facing sides of the mountains were surveyed. Regardless of the method, at each quadrat or point along a transect plants would be identified, counted and percent cover estimated. The resulting estimate of the number of plants per unit area can then be converted into a population total by multiplying by the population area. This may be a reliable way of estimating the population size of non-mobile species such as plants but it is difficult to apply to animals that are prone to wandering about.

 Population estimates of animals range from quick and dirty methods such as counting all birds sighted along a roadside route one travels by car to more labor intensive methods such as radio tagging all elephants on the African plains. **Mark and recapture** is an example of a method that falls between the two extremes. The method involves marking a subset of a population, followed by later counts on the relative numbers of marked and unmarked individuals. This method is more precise than a crude census in which no animals are marked, but takes less time and expense than does an exhaustive marking campaign [3].

**Mark and Recapture Method**

 The Mark and Recapture method is the most popular way of estimating the size of a population. It is commonly used by fish and wildlife managers to estimate population sizes before fishing or hunting seasons. The method involves marking a number of individuals in a natural population, returning them to that population, and subsequently recapturing some of them as a basis for estimating the size of the population at the time of the marking and release. Marks can consist of metal bands (e.g., birds or bats), ear tags (e.g., mammals) fin clips (e.g., fish) or pen markings (e.g., invertebrates). Radio tags can also be used [4].

 The design of a mark and recapture study is important, and will determine what model is appropriate for estimating population size. For example, a wildlife biologist must make a decision about whether a population is open or closed. An **open population** is subject to animals leaving and entering the population through births, deaths, emigration and immigration. A **closed population** remains constant in size and composition throughout a study. Although all populations are subject to being open, it is possible to have closure by conducting a study over a short time frame, which is often desirable [4]. The two models that will be addressed in this case study are for closed populations. Analyzing data of open populations is more complicated because of animals leaving and entering the population, which may confound a biologist's ability to determine whether a marked individual not recaptured either emigrated out of the study area or was simply missed.

**Mark and Recapture Software**

 The standard program for estimating abundance of closed populations is the program, **Capture**. It was designed for use by wildlife biologists in 1978 and is still widely used today by federal and state agencies, including the U.S. Fish and Wildlife Service. The program can be downloaded for free or used online at *https://www.*

*mbr-pwrc.usgs.gov/software/capture.shtml* [8].

 Program **Mark** is a newer and more complete program for analyzing mark and recapture data for both open and closed populations. It was developed by Gary White at Colorado State University, but incorporates software and theory developed by many people. The program can be downloaded for free at *http://www.phidot.org/software/mark/* [7].

 Although Capture and Mark are often stressed as being easy and accessible, they are by no means trivial to use. It is recommended that anyone using the programs seek expert help to avoid making mistakes.

**Single Marking and Recapture, Closed Population Model**

 The simplest model involves two capture sessions. In the first capture session, a group of animals is caught, marked and released. The population is then re-sampled after an interval sufficient to allow dispersal of the marked animals through the population. This model was developed independently by Peterson in the 1890s to estimate the size of fish populations and by Lincoln in the 1920s to estimate wildlife populations. It is therefore called the **Peterson-Lincoln Index** [6]. The model is based on the principle that the proportion of marked individuals in the second sample is equivalent to the proportion of marked individuals in the total population so that [2]:

 m2/n2 = n1/N

 where, N = estimated population size

 n1 = number of individuals caught in the first capture session

 n2 = number of individuals caught in the second capture session

 m2 = number of marked individuals recaptured in the second capture session

 To estimate the size of a population, the following equation is used [2]:

 N = n1n2 / m2

 If sample size is small, the above model is biased. A modified version with less bias was developed in the 1950s by Chapman, called the **Chapman Index**,which remains to be the more widely used model for single marking and recapture sessions. The equation for the Chapman Index is [6]:

 N = [(n1+1)(n2+1) / (m2+1)] - 1

 The variance (V) of the estimate (N) is calculated using the following equation [6]:

 V = [(n1+1)(n2+1)(n1-m2)(n2-m2) / (m2 +1)2(m2+2)] - 1

 The 95% confidence interval (CI95%), which should be interpreted as "given the data and the calculated estimate of the population size, in 95 out of 100 cases, the true population size is within the boundaries of the confidence interval" is calculated using the following equation [6]:

 CI95% = 1.96√V

**Example:**

 A biologist nets 45 largemouth bass from a farm pond, tags their fins and releases them unharmed. A week later, the biologist nets 58 bass from the pond, including 26 with tags. What is the population estimate based on the Chapman Index?

 N = [(45+1)(58+1) / (26+1)]-1 = 100 largemouth bass

What is the 95% confidence interval?

 V = [(45+1)(58+1)(45-26)(58-26)) / (26+1)2(26+2)]-1= 80

 CI95% = 1.96√(80) = 18, which is reported as 100 ± 18

 Four assumptions must be met for the Chapman Index to be valid. First, all individuals must have the same probability of being caught. There is no birth, death, emigration or immigration during the study. Marked individuals are not lost. Lastly, the recaptured individuals must be an unbiased estimate of the proportion of marked to total individuals. This can be assured by carrying out the release and recapture sampling randomly, and by allowing sufficient time for dispersal of the marked individuals through the population [6].

**Repeated Marking and Recapture, Closed Population Model**

 The Chapman Index tends to overestimate the population size because it is difficult to generate sufficient recaptures in large populations. This is particularly true of large populations dispersed over a large area such as bee pollinators. An alternative to using the Chapman Index is a method that relies on repeated marking and recapturing, which is different from the one-time marking of the Chapman Index. This method is called the Schnabel Index. The **Schnabel Index** works by marking and releasing individuals on the first capture. On each subsequent capture, the number of marked recaptures is noted and the remaining individuals are marked and returned to the population. Thus, the total number of marked individuals increases through time. To estimate the size of a population (N), the following equation is used [6]:

 N = ΣniMi / Σmi

 where, ni = number of individuals caught in a capture session at time *i*

 Mi = total number of previously marked individuals at time *i*

 mi = number marked individuals recaptured in a capture session at time *i*

 The variance (V) of the estimate (N) is calculated using the following equation [6]:

 V = Σmi / (ΣniMi)2

 The 95% confidence interval (CI95%) is calculated using the following equation [6]:

 CI95% = N / [1±(N)(1.96)(√V)],

which gives two numbers for the lower and upper confidence intervals when 1 is added and subtracted in the denominator.

**Example:**

 A biologist captures 45 largemouth bass from a farm pond, tags their fins and releases them unharmed. A week later, the biologist nets 58 bass from the pond, including 26 with tags (26 marked and 32 unmarked). In a third sample taken two weeks later, the biologist nets 49 bass from the pond, including 21 with tags (21 marked and 28 unmarked). What is the population estimate based on the Schnabel Index?

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***i*** | **ni** | **Mi** | **mi** | **niM1** |
| 1 | 45 |  0 |  0 |  0 |
| 2 | 58 | 45 | 26 | 2,610 |
| 3 | 49 | 77 | 21 | 3,773 |
| **Total (Σ) =** |  |  | 47 | 6,383 |

 - Note that Mi is the sum of all previously marked individuals (45 for *i* = 2 and 45+32 for *i* = 3)

 N = 6,383 / 47 = 136 largemouth bass

What is the 95% confidence interval?

 V = 47 / (6,383)2 = 1.2 x 10-6

 lower CI95% = 136 / [1+(136)(1.96)(1.1 x 10-3) = 105

 upper CI95% = 136 / [1-(136)(1.96)(1.1 x 10-3) = 192

 The four assumptions applied to the Lincoln-Peterson Index are the same for the Schnabel index. However, the Schnabel Index is a better predictor of population size because of the multiple marking and capturing sessions that provides more data, and thus, more precise estimates. The Schnabel Index also reduces the bias of the first assumption that all individuals must have the same probability of being caught. In repeated capture sessions, with only one marking session, the animals in the Chapman Index may become 'trap shy' and more difficult to capture over time. The Schnabel Index reduces the impact from repeated capturing of individuals by marking new individuals during each capture session [4].

**References**

1. Alonso, R.S., B.T. McClintock, L.M. Lyren, E.E. Boydston, and K.R. Crooks. 2015. Mark-recapture and mark-resight methods for estimating abundance with remote cameras: a carnivore case study. Plos One 10(3): doi:10.1371/journal.pone.0123032.

2. Cox, G.W. 1996. Laboratory manual of general ecology, 7th ed. Wm. C. Brown Publishers, Iowa.

3. Kell, J. 2017. A method of population estimation: mark & recapture. Radford University-Lab Exercises for Biology 103 (Environmental Biology). Accessed 9 August 2017. *http://www.radford.edu/~jkell/mark\_rec103.pdf.*

4. Lettink, M., and D.P. Armstrong. 2003. An introduction to using mark-recapture analysis for monitoring threatened species. Department of Conservation Technical Series 28, New Zealand, pp. 5-32. Accessed 12 August 2017. *http://www.doc.govt.nz/about-us/science- publications/series/doc-technical-series/*.

5. Schwarz, C.J., and G.A.F. Seber. 1999. Estimating animal abundance: review III. Statistical Science 14:427-456.

6. Seber, G.A.F. 1982. The estimation of animal abundance and related parameters, 2nd ed. Macmillan Publishing Co., New York.

7. White, G. 2017. Program Mark. Evan Cooch's Software Page-www.PhiDot.org. Accessed 12 August 2017. *http://www.phidot.org/software/mark/*.

8. White, G.C., K.P. Burnham, D.L. Otis and D.R. Anderson. 1978. Program Capture. Patuxent Wildlife Research Center Software Archive. Accessed 12 August 2017. *https://www.mbr- pwrc.usgs.gov/software/capture.shtml*.

9. Worrall, S. 2016. How the most hated animal in America outwitted us all. National Geographic. Accessed 15 August 2017. *http://news.nationalgeographic.com/2016/08/coyote-america-dan- flores-history-science/*.

**Discussion Questions**

1. What information is needed to determine if a population is an open or closed population? Discuss an example of a situation in nature that would result in a closed population.

2. Conduct literature research on how biologists capture and mark two different types of animals. Discuss your findings.

3. Complete the table below, which discusses the consequences of ignoring the assumptions for the mark and recapture methods. The impact on estimated population size for the first assumption is answered for you.

|  |  |  |
| --- | --- | --- |
| **Assumption Violation** | **Example** | **Impact on Estimated** **Population Size** |
| Some individuals are less likely to be caught, resulting in marked individuals having higher capture probabilities. | Some insects have an age-biased dispersal, with adult males most active in the morning, juvenile males and females most active midday and adult females most active in the afternoon. If you mark individuals in the morning you will capture and mark mostly males. | under estimated |
| Death or emigration of individuals that have been marked results in fewer recaptures. | Clipping too much of the fins on fish can affect their swimming, making it easier for predators to capture them. |  |
| Individuals lose their marks. | Mammals can wiggle out of their radio collars. |  |
| Marked individuals do not randomly mix with the larger population.  | A short sampling period that prevents marked turtles from mixing among unmarked turtles, resulting in the recaptured turtles being overrepresented in a second capture session.  |  |

**Application Activity**

 Coyotes (*Canis latrans*), in the absence of larger predators (e.g., wolves), have become the defacto apex predator in some of the largest cities of North America in the last several decades. Prior to the settlement of western North America, the coyote's range included the arid grasslands and deserts of the Great Plains region. By the close of the 20th century, the coyote expanded its range across the Mississippi River to include all of North America. During their expansion, some of them discovered a new refuge in cities. Cities are places where people do not trap, poison or shoot them; and where wolves cannot persecute them. Coyotes survive on the abundance of rodents and garbage left unattended on streets in urban areas, making their rounds at night to avoid detection. Coyotes in rural regions live on average two to three years but in cities they can live to be 13 years old [9].

 As the coyotes moved west, they encountered two remnant species of American wolf: the red wolves of the south and the eastern wolves of the north. Through interbreeding, they have created a new hybrid for modern America, called the 'coywolf,' which is 70 percent coyote but has wolf genes and even the genes of domestic dogs [9]. The coywolf name is a term used for the hybrid, which are still of the coyote species. It is this hybrid that frequents rural and urban areas alike east of the Mississippi River. In an effort to estimate the population size of coyotes in cities to better understand how they live, remote cameras can be used in conjunction with mark and recapture methods. Biologists "capture" animals via photograph and identify individuals by their pelt pattern or other natural markings. After the first capture, animals are considered marked base on unique natural characteristics. Encounter histories for marked individuals are constructed for a series of repeated mark and recapture sessions from which abundance can be estimated [1].

 This assignment applies the Schnabel Index to estimate the population of coyotes in a hypothetical city. Calculate the population size and confidence intervals of the coyotes and answer the following questions. Assume that multiple cameras were dispersed throughout the city so that each date in the table below is a compilation of all cameras. Also, assume that the natural markings on the coyotes used for marking them were visible in all the photographs taken.

|  |  |  |  |
| --- | --- | --- | --- |
| **Dates of** **Remote Camera Capture Sessions** | **Number of coywolves caught on camera** | **Total number of previously marked coywolves** | **Number of marked coywolves recaptured** |
| 7 April 2016 | 84 | 0 | 0 |
| 21 June 2016 | 95 | 84 | 46 |
| 3 July 2016 | 34 | 133 | 12 |
| 16 September 2016 | 67 | 155 | 34 |
| 10 November 2016 | 79 | 188 | 29 |

Questions:

1. Using the data in the table above, estimate the population size using Schnabel’s Index and calculate the confidence intervals of coyotes in a hypothetical city. Show all work including the use of another table if used in your calculations.

2. Using the data in the table above, estimate the population size using Chapman’s Index; only using the data in the first two capture sessions (7 April 2016 and 21 June 2017) for your calculation. Also, calculate the confidence interval. Show all work.

3. How do your population estimates compare between Chapman’s Index and Schnabel’s Index. Why would they be different and which estimate is more reliable?

4. For each assumption that applies to the Chapman and Schnabel Index, discuss whether they would be likely violated in this study and what could be done to reduce the bias in each assumption.