

# Ch. 14

## Introduction to survey sampling<sup>1</sup>

***“You can observe a lot by just watching”***  
**-- Yogi Berra**

### Questions to ponder:

- *What is the difference between abundance and density*
- *How are a census, a sample survey, and an index similar and different?*
- *How do ‘availability’ and ‘incomplete detection’ affect estimates of abundance or density?*
- *What types of surveys correct for incomplete detection or availability?*
- *Do I need to correct for incomplete detection or availability?*

### “Abundance” estimation: a background

One of the primary field techniques used in wildlife and fisheries research is some kind of survey that has the objective of either (1) counting a population or (2) estimating the density of the population or (3) obtaining some index to the relative population size. Biologists haul in nets of fish, walk forests and grasslands to count songbirds, use aerial photographs of seal colonies, conduct strip surveys for whales or dolphins, scuba along reefs to count moray eels (*Muraenidae*), listen at night on the edge of wetlands to frogs, collect unheard (by human ears) ultrasonic calls of bats, or conduct visual surveys of animals like black-tailed prairie dogs (*Cynomys ludovicianus*) or greater prairie-chickens (*Tympanuchus cupido*) on the breeding grounds. There is a method to try to count any species that exists, thus it is particularly important to carefully match the survey method with the biology of the species of interest.

We’ll identify  $C$  as the number of animals we count (or hear) in a particular area, and  $N$  is the true abundance—the number of individuals in that area. We know that in most cases, our count (even though we try very hard) does not equal the number of animals in the population.

---

<sup>1</sup> *With thanks for content to David Smith, Max Post van der Burg, John Carroll, Michael Conroy, and Gary White*

A bit about terminology:

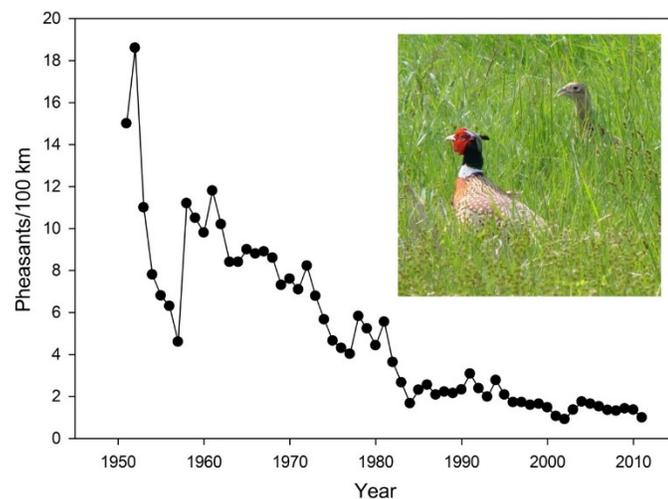
**Census** versus **abundance estimate**—a census is a full count of a population, which we assume to be complete. If our assumption is correct, there is no sampling or sampling error. So,  $C = N$ . In contrast, an abundance estimate is derived when a population is sampled by counting, so we assume  $C \neq N$ . But, we use the sample count to derive an estimate of  $N$ . We can think of the difference between  $C$  and  $N$ , loosely, as **detection error**.

*Typically, a census is only possible for small areas and/or limited populations (e.g., an endangered species on a small island).*

An **index** is obtained when a count is conducted, but detection rate is not measured. Because we don't know the detection rate, we don't know much about the exact relationship between  $C$  and  $N$ . But, we can say that  $C \leq N$ .

An example of an index would be the Rural Mail Carrier Surveys reported to Nebraska Game and Parks Commission each year by postal workers who are asked to note the number of ring-necked pheasants (*Phasianus colchicus*) they see. Since the 1950s, they have written down how many pheasants they see on their routes.

If we assume that the relationship between true pheasant abundance in Nebraska and this index remained the same over time, we would infer that the pheasant population has really decreased since the 1950s.

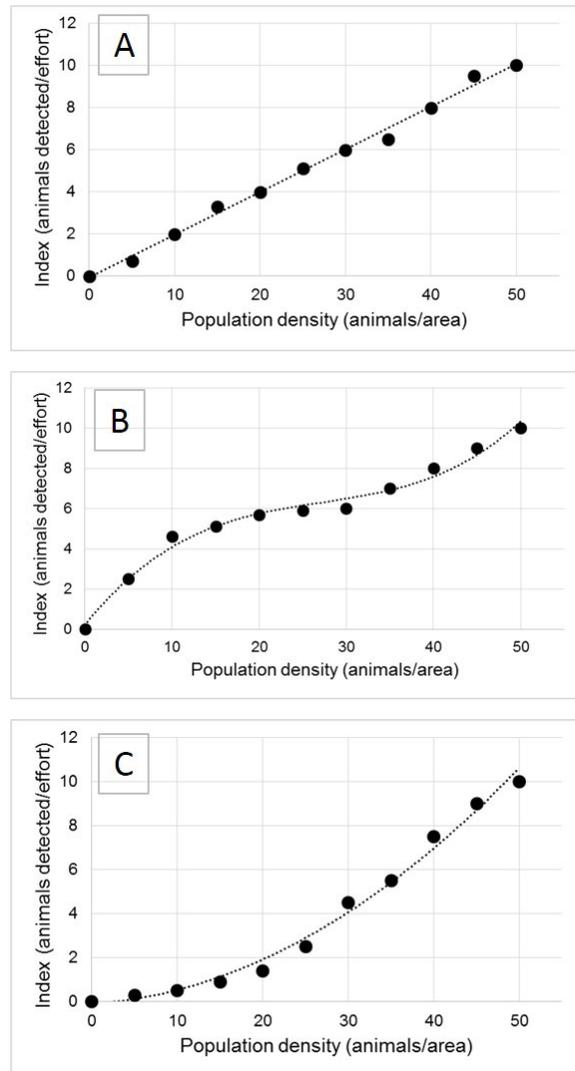


**Figure 14.1:** *The statewide index for ring-necked pheasants (*Phasianus colchicus*) in Nebraska, as determined by rural mail carrier surveys (number of pheasants per road distance traveled). Figure used with permission of Nebraska Game and Parks Commission. Photo of pheasant is a public domain image.*

But, indices have many possible relationships with true population density. Biologists usually assume a linear, positive relationship (A, Figure 14.2).

But, what if mail carriers became much more fastidious about looking for pheasants (their detection rates went up because they were hyper-vigilant; Figure 14.2B) as pheasant populations went down? Well, that would mean that their populations have actually decreased more than what the figure of pheasants/100 km shows. Or, what if mail carriers stopped looking for pheasants when populations were low—perhaps they felt that it wasn't worth their concentration and effort (Figure 14.2C). If detection rates were low at low population levels, the index shows a starker decline than really exists.

This is the problem with an index. Unless it is 'grounded' by some form of repeated-sampling to calibrate the index to give it rigor, these types of questions abound.



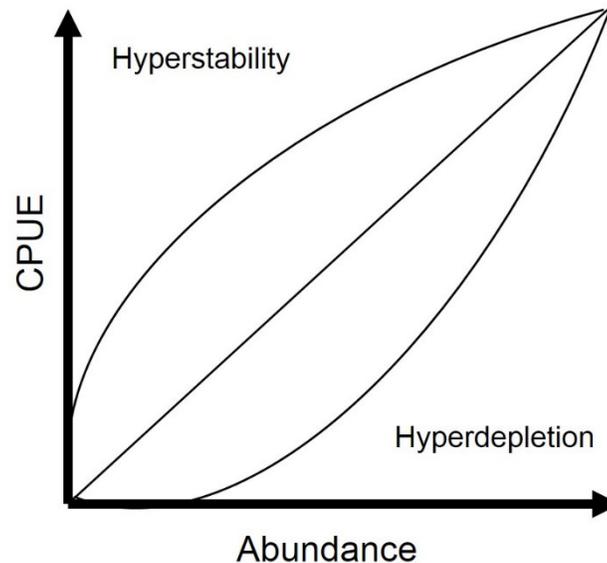
**Figure 14.2:** Possible relationships between an index and the actual population density (after Conroy and Carroll 2009).

Fisheries biologists think about indices a lot—perhaps more than wildlife biologists. **Catch-per-unit-effort (CPUE)** is a grand example of an index. CPUE is a measure of how many fish were caught per net-night (one net in a lake or stream for one night equals one **net-night**). But, most fisheries biologists are quite aware that many things can cause catch-per-unit-effort to change through time...even if abundance of the fish population stays the same.

Just as with bird survey indices, CPUE and abundance do not always have a linear relationship (Harley et al. 2001). Imagine a lake with a large population of fish. Sixteen nets are set out, and a CPUE is established for that population. Now, a disease goes through the population of fish and the population dramatically decreases in size (abundance declines, Figure 14.3). Those same

16 nets are put out again. If the fish move at random around the lake (like you might want to assume statistically), the CPUE might also decrease linearly. But, if those fish are spatially relegated to an area of the lake where you don't have your nets, your CPUE is going to decline dramatically...it could be zero when the population is not zero (*hyperdepletion* curve, Figure 14.3).

Alternatively, you might think of a situation where fish might move more if their competitors have been removed from the system. If abundance were to decline in the lake, the movement of the fish might keep the CPUE at almost the same level (the *hyperstability* curve in Figure 14.3), and a fisheries manager might not realize abundance had dropped. In fact, Harley et al. (2001) found evidence that the CPUE-abundance relationship is different for different species of fish in the same sampling scheme.



**Figure 14.3:** Possible relationships between catch-per-unit-effort indices and actual fish abundance (after Harley et al. 2001). *Hyperstability* occurs when catch per unit effort remains stable despite significant declines in fish abundance. *Hyperdepletion* is when CPUE declines faster than abundance and using these data in an assessment can produce overly pessimistic estimates of abundance.

So, indices can be problematic to use and interpret in some cases. But, lest we throw out indices in favor of more complicated methods, one should read Johnson (2010), in which the author effectively argues “...although criticism of the thoughtless use of indices is welcome, their wholesale rejection is not.” Indeed, there is a level of intellectual snobbery from the quantitative elite (a club that you are on the path to membership, now!) towards indices. Your authors have been guilty of such thoughts in their careers as well. However, logistical and cost issues can sometimes prevent the use of more complicated methods. And, it is not hard to argue that effective management decisions have been made, worldwide, using indices as the information to feed into decision processes. The fact is that indices are typically cheaper to conduct, and they are used commonly in situations where funding is limited.

Johnson’s (2010) main point is that biologists often reject indices for their uncertain relations to true abundance in favor of estimation processes, but these estimation processes may also be fraught with their own issues (e.g., assumptions of closure for  $N$ -mixture models or 100% detection on the transect line or accurate distance estimation in distance methods) as you will see in future chapters. So, Johnson (2010) has a point: an index would be no worse than a poorly executed survey (i.e., one that grossly violates a method’s assumptions) used to estimate density, for example. Therefore, we should learn how to plan, conduct and analyze surveys (of any type) properly.

## Abundance estimation: from incomplete samples

We have postulated that our counts do not equal the population size in most situations ( $C \neq N$ ). We can formalize this a bit more as:

$$\hat{N} = \frac{C}{P_{\text{area}} \hat{P}_d}$$

Here, we correct the count ( $C$ , number of animals counted) with two proportions,  $P_{\text{area}}$  and  $P_d$ .

First, we can think of our sampling design. If we are sampling less than the entire area of interest, then we need to adjust our count by that proportion,  $P_{\text{area}}$ . So, if the population ( $N$ ) was known to cover 100 hectares, and we only sampled 50 hectares, we would logically assume that we would count half of the animals (assuming they are spread randomly throughout the entire area, and assuming we have perfect detection of animals in our sample area). This correction is called **design-based sampling**, because we can get this correction factor easily by looking at the design of our sampling (e.g., a map).

Now, what about **detection**,  $P_d$ ? What if our detection is not perfect? What if our capabilities only allow us to see 25% of the animals in our sample site? We need to correct for this, obviously. So, we need to inflate our count by an additional 75% to make up for the missing animals on the study site. This factor is not easily gotten, however. We are not privy to our personal detection rate! So, we have to estimate it from patterns in our data, in some manner. So, we call this correction factor **model-based sampling**.

### Design-based sampling

Many game counts in southern Africa are conducted by counting game in visible strips (the method is called **strip counts**). The width of the strips depends on how far a person can see in various habitats. This method can be used along roads, fairly easily. Obviously, you might end up ‘pushing’ animals ahead and some may remain unseen (so the count may be biased low). And, small game animals may have lower detection rates than larger game. But, if we assume that we see all the game in our strip, you simply ‘correct’ your count by extrapolating your count across the remainder of the study area.

$$N = nH/b$$

Where we define the following statistics:

- $N$  = Number of game of each type on the area
- $n$  = number of each type of game per strip
- $H$  = Surface area of farm/pasture/reserve
- $b$  = surface area of sampled strip

Fisheries biologists often use a similar design-based extrapolation when they sample a portion of a lake and extrapolate the count to the entire lake—just as the count in the strip is extrapolated to the pasture, above. We emphasize that this basic design-based sampling correction does not correct for animals missed because of incomplete detection.

## You try it!

Try your hand at a design-based correction to the following survey data:

Total area of pasture: 2110 ha

Total area of strips sampled: 791 ha

Survey data: we saw 88 impala (*Aepyceros melampus*) and 22 greater kudu (*Tragelaphus strepsiceros*)

How many impala and kudu are in the entire pasture? The answer is at the end of this chapter.

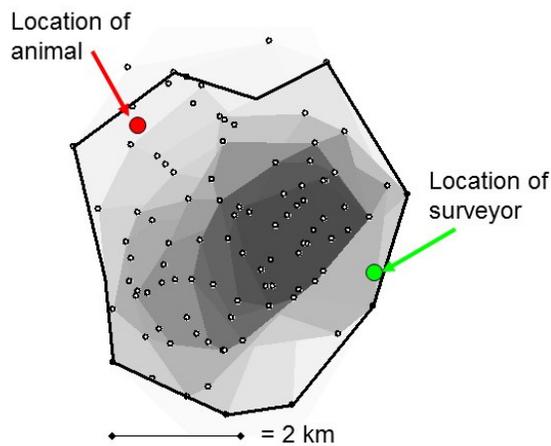
## Abundance estimation: generalized

Of course, life is always more complicated than we would like it to be. In fact, the **detection probability**,  $P_d$ , in the previous section really refers to three distinct probabilities:

$$\hat{N} = \frac{C}{P_{area} \hat{P}_d} \qquad \hat{N} = \frac{C}{P_{area} \hat{P}_{detection} \hat{P}_{availability} \hat{P}_{presence}}$$

**Presence probability:** the probability that an individual which uses the sample site during some portion of its life is at the sample site during a time of interest (such as when you survey it).

Let us say we sample a portion of an animal's home range, but it is at the other edge of its home range during the sampling period (Figure 14.4). Theoretically, it should be enumerated as a member of the population, but we miss it because of this spatial problem.



**Figure 14.4:** Depiction of concept of presence probability. Animal is not always near the survey point, but uses the survey point.

Current statistical analyses of survey data do not adjust for the portion of animals that use a given site (at some point in the time period) that are not present when you survey. *This problem actually represents a mismatch between the scale of the animal's movements and the survey instrument.* Thus, the best way to eliminate this problem (goal: have the probability of presence be 100%) is to use a larger scale of sampling (e.g., transects instead of point counts) or to adjust the length of time that you survey (so an animal can move back to our sampling point). Alternatively, you might consider using a robust design approach (see Chapter 13) to account for the temporary emigration from your survey area.

**Availability probability:** the probability that an animal at your study site is available to be sampled.

An easy example of availability bias in a survey is to think about any animal that lives in a hole in a tree or in the ground. In the western United States, such a species is the black-tailed prairie dog (*Cynomys ludovicianus*; Figure 14.5).

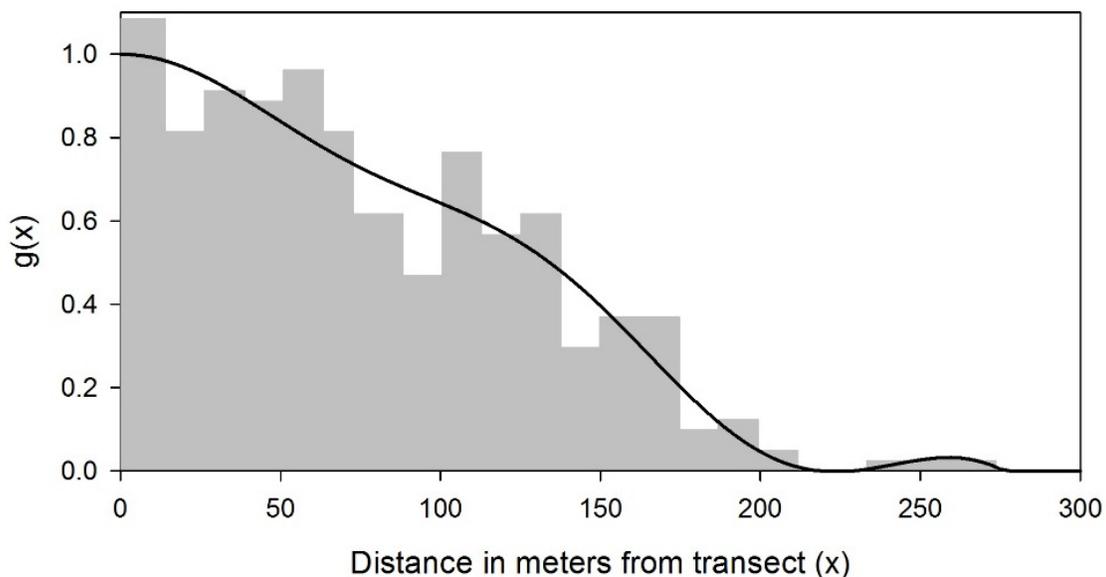
At any moment in time, even if you detect the animals above ground perfectly, a portion of the population is below ground. They are not available to be counted. And, that portion is obviously very important. Is 90% of the population above ground? Is it only 10% above ground? That's a big difference, and would affect our estimate of the population size.



**Figure 14.5:** Black-tailed prairie dog, photo by Ron Singer, US Fish and Wildlife Service (public domain image).

**Detection probability:** the probability of seeing/observing/hearing an individual, given that it is present and available at the sample point.

We can reference our prairie dogs again. Imagine that you are standing at the edge of a large colony (prairie dogs live in colonies of multiple burrows) and you are looking out across the colony. Prairie dogs are smallish creatures and they are brown—they blend in with the ground easily. As the distance from you to any prairie dog increases, odds are that you'll have a poorer chance of detecting the critter.



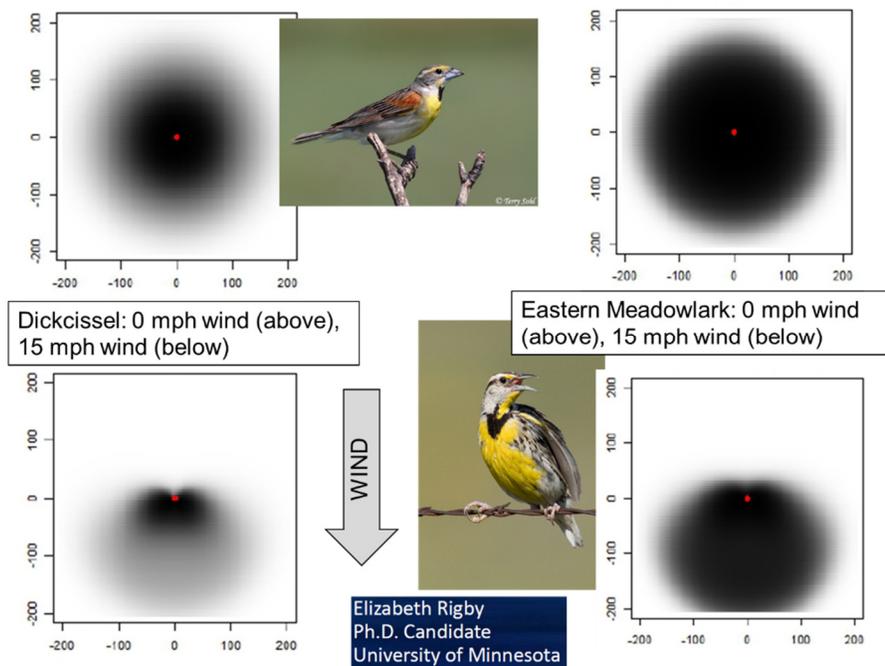
**Figure 14.6:** Count data (gray bars) and detection function,  $g(x)$  for western meadowlarks shown as distance from a transect line in a grassland habitat increases (Kempema 2007).

The count data in Figure 14.6 (gray bars) are for a loud-singing, yellow-breasted grassland bird, the western meadowlark (*Sturnella neglecta*). These data are from line transects through grasslands in Nebraska, USA (Kempema 2007). Unless meadowlarks were hanging out near the transect line in higher numbers than in other spaces in the pastures (very unlikely!), this figure shows a stark decrease in detectability as distance from the line increases. In fact, the problems with distance occur even for big animals...like kangaroos, deer, and whales (Buckland et al. 2001).

Here is a list of other potential reasons that detectability may not be 100% on a survey:

- Secrecy/crypsis – cannot see/hear animals easily
- Observer ability – lack of training or skills prevent detection
- Visual obstructions – grass/trees get in the way
- Wind – animals are harder to hear when windy, and less active so harder to see
- Weather – animals less/more active because of temperature or precipitation
- Time of year – breeding vs. brooding affects activity or color of animal

Detection can be a fairly complicated dynamic in the real world. As an example, Rigby (2014; USFWS teleconference transcript, used with permission) provided some very unique depictions of the spatial variation of probability of detection of a grassland bird around a point count during conditions of high and no wind (Figure 14.7). At higher winds and with the observer upwind from the bird, both dickcissel (*Spiza americana*) and eastern meadowlark (*Sturnella magna*) had very low probabilities of detection. Such dynamics can be accounted for with analyses and/or accounted for with survey design or protocols (e.g., no surveys conducted during high wind speeds).



**Figure 14.7:** Spatial depiction of model predictions of variable detectability (darker shows higher detection probability) for two grassland songbirds, eastern meadowlark and dickcissel, under no-wind and 15-miles per hour (~24-km per hour) wind conditions. Wind direction is shown by arrow. At high wind speeds, the birds were virtually undetectable when the observer was upwind. From Rigby (2014), used with permission.

## How to select a survey method

One should always have a goal. So, what is the goal for your survey? Do you want to estimate population size? Should you consider a closed mark-recapture approach? Or, is a survey better?

Is density (number of individuals per unit area) your interest? We should note that density is often hard to estimate. For example, if you use a trap grid to estimate abundance ( $N$ ) of small rodents using mark-recapture, how can we find the density? Well, we could approximate the size of the area trapped, right? Well, what is that area? What is the ‘effective’ size of the grid? How far did rodents come to be trapped? See the problem? It is hard to determine the appropriate area to use to calculate density.

Abundance or relative abundance is often easier to estimate. But, density allows direct comparisons among studies.

Effective sampling begins with clearly defined study objectives and a good understanding of the species being sampled (biology, natural history, etc.). Some survey or research questions might be as follows:

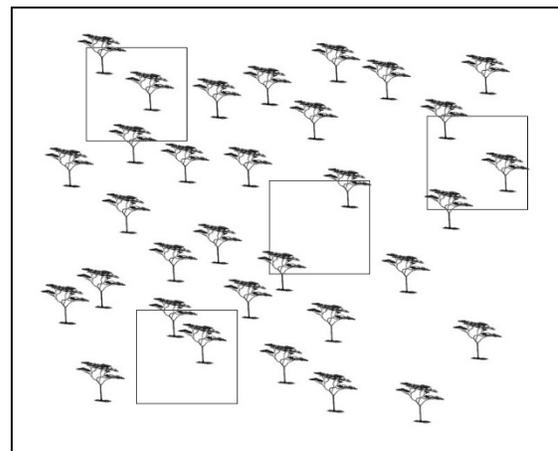
- What is the current density of an endangered species in an area of potential impact?
- What is the recent trend in abundance of a species in an area of interest?
- Why is abundance changing?

We might be doing a survey because we have management needs to make decisions based on monitoring. Perhaps we need to provide information on the current state of a system. Will we be evaluating management performance based on changes in population size or density?

All of these questions are important as we plan for the type of survey we need—a census, an index, or an estimation method.

### Simple surveys: assuming 100% detection

**Quadrat sampling** represents the simplest type of sampling—identify some areas that can be defined (squares in Figure 14.8). Then, the number of organisms in the quadrats is counted (a complete count, or local census, within the sample area). This is a spatial sampling approach, and the true abundance can be estimated by extrapolating the abundance ( $n$ ) from the quadrats (as in our southern Africa example). Plant biologists use this method often, and they assume that detection is not a problem.



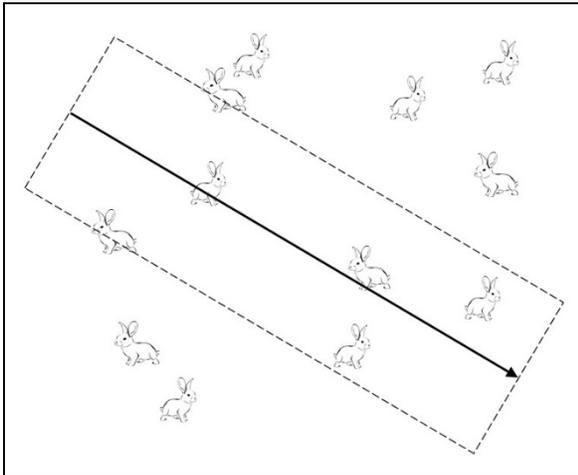
**Figure 14.8:** *A population of trees sampled with four quadrats (squares).*

Density, in a quadrat survey, can be quickly calculated as:

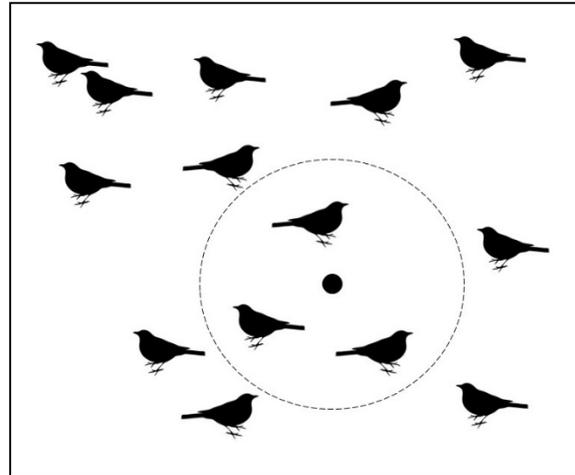
$$\hat{D} = \frac{n}{\text{area}}$$

The next step in surveys was to extend the quadrat in space along a route that was walked or traversed in some other way (Figure 14.9). This survey is called a **fixed-width transect census**. Animals are counted from the transect (of length:  $L$ ) to a certain width,  $w$ . For example, an avian biologist can walk through the woods and count woodpeckers within 20 meters of a trail. Or, a fisheries biologist can electroshock along a transect of a width covered by the electrical current from the boat. The fish are collected and counted. The width of the strip is typically chosen to attempt to assure 100% detectability within the strip. Density is estimated as:

$$\hat{D} = \frac{n}{2Lw}$$



**Figure 14.9:** A population of animals is sampled as a complete count (census) along a transect with a fixed width and known length.



**Figure 14.10:** A population of animals is sampled with a complete count (census) from a point location using a sample circle of fixed radius.

A similar method to the fixed-width transect approach is the **fixed-radius point count**. These are used often by avian biologists. A radius,  $r$ , is chosen, to which the biologist feels comfortable that they can see/count all birds (Figure 14.10). Density is calculated as:

$$\hat{D} = \frac{n}{\pi r^2}$$

## Imperfect detectability



**Figure 14.11:** Comparison of visibility during a survey of birds on a coastal beach in Washington, USA, during normal (left) and foggy (right) conditions. Photos by L. Powell.

We've already established that detectability can be an issue. It is usually easy to assume that some factor will prevent the surveyor from detecting all the animals in an area. In fact, sometimes detectability changes during a survey. For example, the photos in Figure 14.11 were taken during a survey of peregrine falcons (*Falco peregrinus*) and bald eagles (*Haliaeetus leucocephalus*) along the beaches of coastal Washington. Fog rolled in during the survey and dramatically changed the distance at which birds could be seen from the car. And, as you might expect, the surveyors counted fewer birds when they were in the fog.

So, what kind of survey methods can help when detectability is an issue? You have several choices, and each has its advantages and constraints.

The **known component method** is one of the simplest methods. It requires the use of a 'known component' that can be used to correct the count for the detection problem.

This is another method used in southern Africa. Let us suppose that 114 plains zebra (*Equus quagga*) were introduced to a farm during the week before a survey was conducted (i.e., the "known component"). During the road strip survey, 78 zebra were counted along with 283 Cape buffalo (*Syncerus caffer*).

For this method, we can establish the following statistics:

- $N_x$  : Unknown population size of species  $x$
- $N_y$  : Population size, known, of species  $y$
- $n_x$  : Number counted of species  $x$
- $n_y$  : Number counted of species  $y$

If we assume that both species have equal detection rate, we can use the fact that we counted 78 of the 114 zebras (68%) to help estimate the number of buffalo. This method would not work well for predator (low detection) vs. herbivore (higher detection). And, of course, the requirement is that you know the number of one of the species being surveyed, which is rarely the case.

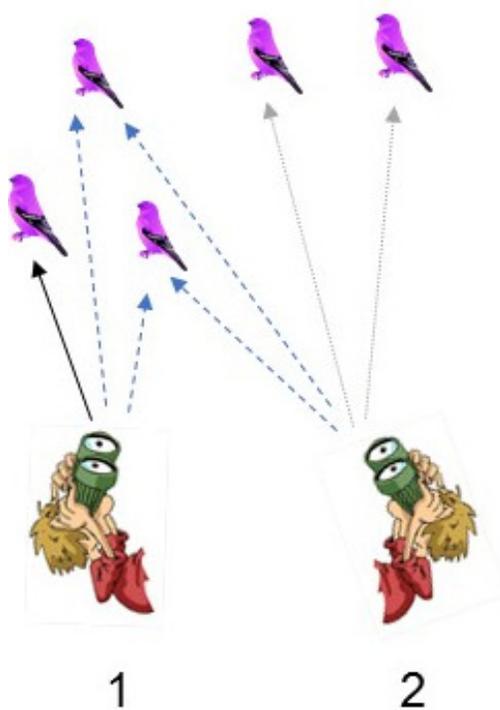
But, if the situation allows, we can estimate:

$$N_x = \frac{(N_y)(n_x)}{n_y}$$

A version of the known component method has been used to correct aerial surveys of waterfowl in North America. You can imagine flying over a wetland in an airplane, trying to count the number of ducks. By putting a known number of duck decoys ( $N_y$ ) out in a certain area (the number of decoys not known to the person counting from the airplane of course!), the known component method can be used to estimate the population size of real ducks in the area ( $N_x$ ) if we assume the counts of ducks ( $n_x$ ) and decoys ( $n_y$ ) are susceptible to the same probability of detection.

**Distance sampling** was developed to account for the declining detectability with increasing distances away from a transect line, as shown with the meadowlark example earlier in this chapter.

Using distance sampling, a surveyor walks a transect line, as in the transect census method. But, in this method we do not assume we count all of the animals. In fact, we assume we will miss some individuals, as seen in Chapter 19 with elephants. The data collected are simply the number of animals seen, and (for each animal seen) the perpendicular distance from the transect to the animal ( $x$ ). The pattern of observations allows us to estimate a detection probability, so we can adjust our count to reflect the density of animals near our transect line. This method can also be used with point counts, as we will demonstrate in Chapter 19.



The **double-observer method** uses two observers (Figure 14.12), and the analysis uses the pattern of imperfect observations from both observers to estimate the detection probability. We assume that both observers may not see all of the animals. Both observers record ‘seen’ animals, and they then reconcile which animals both observers saw. As we will discuss in Chapter 16, the analysis is based on mark-recapture theory—you might think of each animal observed as having a ‘capture history’ where the 1’s and 0’s show whether observer #1 (first column of capture history) saw the animal and whether observer #2 saw the animal (second column of capture history). For example, a capture history of “11” indicates that both observers saw the individual.

**Figure 14.12:** Depiction of potential results of a double-observer survey in which animals can be sighted by either or both observers.

Double-observer survey possible results	Represented as capture history	Number of individuals with capture history ( <i>Figure 14.12</i> )
#1 yes, #2 no	10	1 individual ( <i>dark arrow</i> )
#1 no, #2 yes	01	2 individuals ( <i>gray arrows</i> )
#1 yes, #2 yes	11	2 individuals ( <i>dashed lines</i> )

Fisheries and small mammal biologists have been using **removal methods** (“*Zippin depletion method*”) for decades. The method uses repeated samples, one after another during a very short time span, and might result in capturing all the animals in the area if sampling were to continue for long enough. Animals are “removed” (not replaced) after sampling.

Avian biologists have extended the removal sampling method to bird surveys, by using 3-4 time intervals during the point-count survey as individual sampling occasions. The logic is that you will begin to see fewer and fewer ‘new’ birds as the survey goes through time (point-counts are often 5 or 10 minutes long). Birds not initially ‘available’ (hiding in the grass) will eventually pop up. So, this method accounts for both availability and detection, as we will discuss in Chapter 17.

A typical set of “removal” data might look like this:

- Time interval 1: 10 new individuals
- Time interval 2: 5 new individuals
- Time interval 3: 4 new individuals
- Time interval 4: 1 new individual

**N-mixture methods:** this method also estimates abundance by using multiple visits to the same points and multiple samples at the study area (envison a grid on which each point is sampled multiple times). By visiting within a short time period (so that we can assume ‘closure’ of the population), we can develop a count history with the site samples as rows and the visits as columns:

	Visits			
Site A	0	1	2	0
Site B	0	0	0	0
Site C	0	2	0	0

Here, we know (for Site A, the top row) that the minimum number of animals on-site is 2. We also know that we missed at least one animal during the previous visit (we only saw 1), and we missed all (at least 2) animals during the first and last visits. With this information, a corrected count is developed. We will discuss this method in Chapter 18.

## Counting too many animals?

To this point, we have assumed that our counts are equal or less than the number of animals in the population. And, this is almost always true. However, there is one type of survey for which the count is usually greater than the number of animals ( $C > N$ ): surveys of waterholes.

Here's how a waterhole survey typically works: biologists sit in a blind (also called a "hide" if you are in southern Africa) and they count all animals seen in 48 hours (Figure 14.13). The time period of 48 hours is chosen because all animals are assumed to come to drink at least once during 48 hours. Sampling occurs during the full moon for night viewing and counting.



**Figure 14.13:** *The view of a waterhole at Waterberg National Park in Namibia during the dry season. Photo taken by L. Powell from the blind. Salt blocks are scattered between the waterhole and the blind to encourage rhinoceros to come closer at night for better individual identification.*

Of course, some animals come to drink more than once during the 48 hours, so you end up with more animals counted than are in the population. So, you must use the drinking frequency ( $H$ , hours between drinks) of each species to correct the count (relative to the number of hours,  $H_{sampled}$ , during which you counted).

$$N = C \cdot \frac{H_{\text{betweendrinks}}}{H_{\text{sampled}}}$$

For example, if you count 50 giraffe (*Giraffa camelopardalis*) in 48 hours, and giraffes drink once every 24 hours, then there are 25 giraffes in the population:  $50 \times (24/48) = 25$

Similarly, if you count 15 rhino in 48 hours and rhino drink once every 48 hours, then there are 15 rhino in the population:  $15 \times (48/48) = 15$

## Conclusion

We will cover, in more detail, many of these model-based survey methods in the following chapters. There is not a "best" survey method. The method used should be based on your objectives and the natural history of your study species. And, each survey process will have constraints. For example, if you are the only person available to do surveys, you cannot use the double-observer method. Below is a comparison of the main methods we have introduced in this chapter.

Method	Accounts for incomplete detectability	Accounts for incomplete availability	Requires >1 person	Requires >1 visit	Simple data recording
Strip census					X
Distance	X	X <sup>a</sup>			
Double-sample	X		X		X
Double-observer	X		X		
Removal	X	X			
N-mixture	X	X <sup>b</sup>		X	X

<sup>a</sup>Advanced form of distance analysis with removal sampling accounts for availability; typical distance sampling does not.

<sup>b</sup>Advanced, multi-season form of N-mixture model estimates availability; single season N-mixture model does not.

## Answers: You Try It!

Total area of pasture: 2110 ha  
 Total area of strips sampled: 791 ha  
 Survey data: we saw 88 impala and 22 kudu.

How many impala and kudu are in the entire pasture? First, we come up with the multiplier to use to extrapolate our counts to obtain the population size:  $2110 \text{ ha} \div 791 \text{ ha} = 2.67$ . That is, our pasture is 2.67 times as large as our sample area. So, we multiply species' counts by 2.67.

$$2.67 \times 88 \text{ impala} = 235 \text{ impala}$$

$$2.67 \times 22 \text{ kudu} = 59 \text{ kudu}$$

## References

Buckland, S. T., et al. 2001. *Introduction to Distance Sampling: estimating abundance of biological populations*. Oxford University Press.

Conroy, M. J., and J. P. Carroll. 2009. *Quantitative Conservation of Vertebrates*. Wiley-Blackwell: Sussex, UK.

Harley, S. J., R. A. Myers, and A. Dunn. 2001. Is catch-per-unit-effort proportional to abundance? *Canadian Journal of Fisheries and Aquatic Sciences* 58: 1760-1772.

Johnson, D. H. 2008. In defense of indices: the case of bird surveys. *Journal of Wildlife Management* 72: 857-868.

Kempema, S. L. F. 2007. The influence of grazing systems on grassland bird density, productivity, and species richness on private rangeland in the Nebraska Sandhills. MS Thesis, University of Nebraska-Lincoln, Lincoln, NE.

### **For more information on topics in this chapter**

Bart, J., S. Droege, P. Geissler, B. Peterjohn, and C. J. Ralph. 2004. Density estimation in wildlife surveys. *Wildlife Society Bulletin* 32: 1242-1247.

Thompson, W. L., G. C. White, and C. Gowan. 1998. *Monitoring vertebrate populations*. Academic Press, San Diego.

Williams, B. K., J. D. Nichols, and M. J. Conroy. 2002. *Analysis and management of animal populations*. Academic Press, San Diego.

### **Citing this primer**

Powell, L. A., and G. A. Gale. 2015. *Estimation of Parameters for Animal Populations: a primer for the rest of us*. Caught Napping Publications: Lincoln, NE.