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Bird census and survey techniques

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2.1 Introduction

In Chapter 1, we saw how it was possible to use simple methods to assess the species composition in an area and to give an idea of their relative abundances. Here, we consider methods that will allow us to derive estimates of population size or density or, where this is unnecessary or impossible, population indices. Armed with such information over a number of years, we can then track changes in population levels and, where appropriate, compare population levels between different sites. As described in Chapter 1, the distinction between a *census* and a *survey* is somewhat artificial, but here we use *census* to describe a particular type of *survey* that counts the total numbers in an area (Figure 2.1).

2.1.1 What are bird surveys and why do we need them?

If we need a reliable estimate or index of the population size of a particular species in a given area, then we must undertake a survey. There may be a number of reasons for wishing to do this. It may simply be that, as the owner of a nature reserve, we wish to know how many individuals of a particular species of bird are present, or we may need baseline information for an area, or a species, that is poorly known. If repeated at regular intervals, the counts allow us to track changes in bird populations. Alternatively, it may be because a piece of land is being developed (e.g. turned into an industrial area) and we need to undertake an assessment of the likely impact of the development on the nature conservation value of the land. Frequently, bird survey data are used to assess whether a piece of land should receive legal protection from governments and their agencies; such designations are important to conservation because they are intended to constrain potentially damaging activities. Information on population sizes of individual species can also be used to set priorities, allowing conservation effort to be focused on those species most in need of attention. In general, smaller population size is

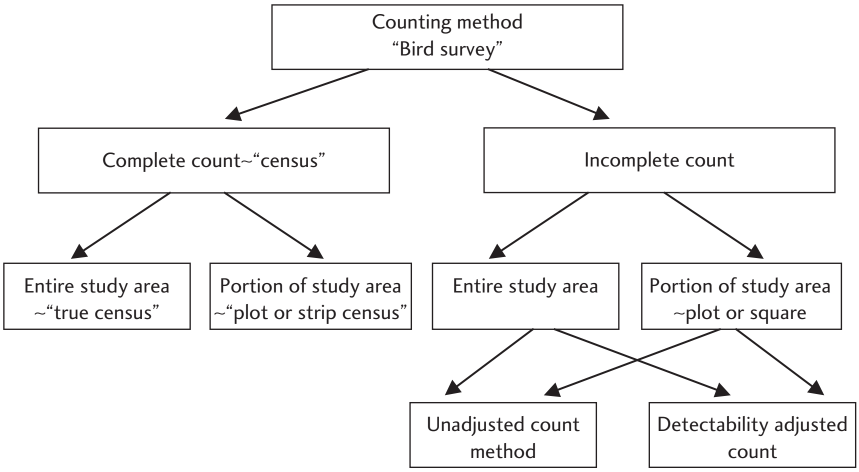

Fig. 2.1 Distinctions between surveys and censuses. Census counts, by their nature, require no correction for detectability. All other counts, here termed "incomplete counts," can be used in their unadjusted, raw form, or preferably with adjustment for detectability (adapted from Thompson 2002).

associated with greater risk of extinction locally, regionally, or globally. Such information is collected by undertaking surveys over varying geographical areas. The lists of globally threatened bird species (BirdLife International 2000) or of species of conservation concern in individual continents, countries or regions (e.g. Carter *et al.* 2000; Gregory *et al.* 2002; www.partnersinflight.org), are based largely on information on population size. In addition, surveys can be used to collect information on where birds are in relation to different habitats, and so assess habitat associations.

2.1.2 What is monitoring and why do we need it?

Monitoring is a simple step on from a survey, in that by undertaking repeat surveys we can estimate the population trend of a particular species over time. Here consistency of method is crucial to measuring genuine population fluctuations. Trend data are central to setting species conservation priorities. All other things being equal (e.g. population, range size and productivity), a species whose population is declining will be of higher conservation priority than one that is not. Monitoring has more uses than this, however. If a monitoring program is well designed, it can be a research tool in its own right providing that suitable environmental data (e.g. habitats, predators, food supplies, weather) are collected, or are available elsewhere. Frequently, such analyses provide early pointers towards the underlying causes of trends in species numbers. The monitoring of demographic parameters, considered in Chapters 3 and 5, can also yield clues about the underlying demographic mechanisms, for example, declining productivity or declining adult survival that may drive a decline in numbers. Monitoring also plays a role in ascertaining the success or failure of conservation actions by faithfully recording their outcomes—these actions might be the acquisition of land to protect particular species, the adoption of new management practices, species recovery programs, or the success of government environmental policies. Sadly, such monitoring is often neglected and the true efficacy of conservation actions is then hard to evaluate.

In some circumstances, birds can be excellent barometers of wider environmental health, particularly when such assessments use summarized data from a wide range of species (Bibby 1999, see also Niemi *et al.* 1997). Two of the best examples of such indicators are WWF's Living Planet Index (Loh 2002, www.panda.org/news_facts/publications/general/livingplanet/index.cfm), and the UK Government's headline indicator of wild bird populations (Figure 2.2; Gregory *et al.* 2003, www.sustainable-development.gov.uk/indicators/headline/h13.htm).

2.1.3 Useful sources of information

This chapter is an introduction to survey design. The following publications give more detail: Ralph and Scott (1981), Ralph *et al.* (1995), Bibby *et al.*

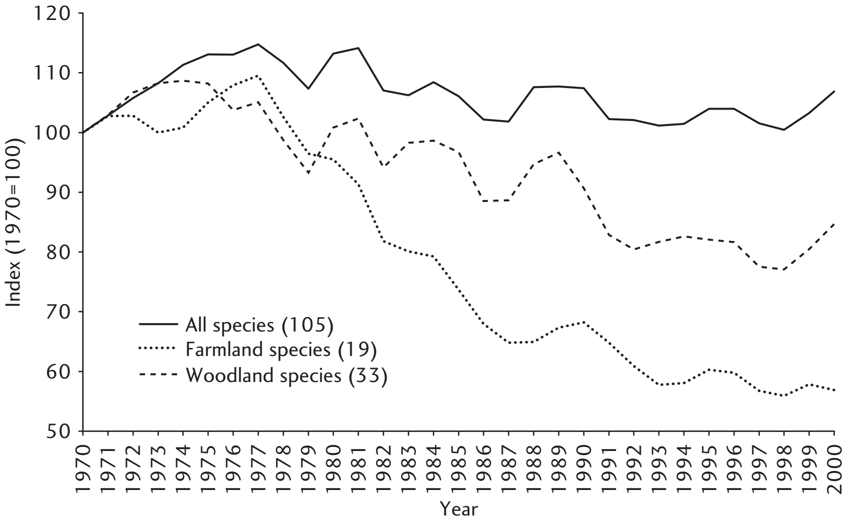

Fig. 2.2 The UK Government's *Quality of Life* indicator showing population trends among common native breeding birds.

(1998, 2000), and Bennun and Howell (2002). In addition, Gilbert *et al.* (1998) and Steinkamp *et al.* (2003) outline species-specific methods for many types of birds, while Greenwood (1996) introduces the underlying theory. Finally, Buckland *et al.* (2001) describe special methods for density estimation, known as *distance sampling* (see below), which use data from line or point transects.

2.1.4 Begin at the beginning

Before rushing into undertake a survey or set up a monitoring program, we first need to clarify our objectives and review our resources. This is a key stage in planning, and any ambiguity or uncertainty at this point could be fatal—wasting time and money, and limiting the usefulness of the results. A common mistake is to be overambitious and try to collect much more information than is strictly required to the point where this compromises quality and other activities. A useful technique here is to list your goals, the data required to fulfill them, the time required to collect these data, and then revisit and prioritize your aims. It is always tempting to ask a whole range of interesting questions, but in attempting to do so, you may fail to answer the key ones. This section outlines how to go about planning a survey; information on sampling strategies and field methods are developed in later sections.

The key decisions to take are:

- Do we want to estimate population size accurately or will an index meet our needs? In other words, are we interested in absolute or relative abundance?
- Where will we undertake the survey?
- Should we cover the whole area of interest, or only sample part of it?
- If we plan to sample, how should we select the study sites?
- What geographical sampling units will we use? Mapped grid squares, forest blocks, or other parcels of land?
- What field method will we use?
- What are the recording units for the birds: individuals, singing males, breeding pairs, nests or territories?
- How will the subsequent data analysis be carried out?
- How will the results be reported and used?

A useful way of planning a survey is to try to envisage clearly the finished product, even down to the details of what tables of data you wish to include in your report. This will clarify the various stages that you need to go through to collect these data.

2.1.5 Population size or index?

If the aim of our survey is to determine accurately the *population size* (=total numbers) of a species in a particular area, then a population index is insufficient for our needs. If, for example, we want to estimate the global population of the Raso Lark *Alauda razae* on its tiny island home, or the numbers of Sharpe's Longclaw *Macronyx sharpei*, on a particular grassland, then we must choose a method that yields an absolute measure of population size and where error can be estimated. If, however, we are not interested in having population size *per se*, only whether a population is increasing, decreasing or stable, then a *population index* would meet our objectives. The implicit assumption here is that there is a direct correlation between the population index and the true, but unknown, population size. A population index is a measure of population size in which the precise relationship between the index and population size is often not known. The index, however, should ideally be directly proportional to changes in population size, such that if the population doubles then so does the index. Population monitoring can be achieved by obtaining, over a period of years, repeated measures of population size or index; frequently the latter is much less resource-intensive than the former and a reliable index is preferable to a poor count. As we saw in the previous chapter, because we are often interested in quite large changes in populations to trigger conservation action (such as 25–50% declines: Gregory *et al*. 2002), then simple methods are often more efficient.

In truth, the distinction between an estimate of population size and an index may be less we think, because in neither case do we actually know the real population size.

2.1.6 Survey boundaries

The decision on where to undertake the survey again depends on its objectives, which should guide the setting of *survey boundaries*. These boundaries are largely self-evident if we want to obtain an estimate of the numbers of one or more species in a discrete habitat area, such as a forest or marsh, or in a particular geopolitical (e.g. country) or geographical (e.g. island) area.

Survey efficiency, however, can be greatly improved if we further refine the boundaries within the area of interest, as it is likely that the species will not be present everywhere. It would be inefficient to cover large areas of clearly unsuitable habitat, but conversely little confidence could be placed on a study that excluded areas or habitats in which the species might be present. Boundary setting should be based on existing information, ideally previously available distributional data. If the general distribution of the species has been mapped by an atlas project (see Chapter 1), then set the boundaries of the survey to those shown by the atlas—but be aware of any limitations to the original data collection. If such information is not available—and for most parts of the world it will not be, or it is of uncertain provenance—then set your boundaries based on factors that you think might affect the species distribution, for example, altitudinal or habitat preferences. For example, Arendt *et al*. (1999), set the boundaries for their survey of the critically endangered Montserrat Oriole *Icterus oberi* on the known distribution of its favored habitat, humid and wet tropical forest, supplemented by knowledge of the bird's distribution from local foresters. Some areas outside this boundary were also checked, but no orioles were found.

Frequently, decisions on where to set survey boundaries, and on how to design the survey within those boundaries are closely linked. In many situations, our knowledge of a species' distribution and ecology is based on relatively scant and sometimes uncertain information. In this instance, we need to be more careful in defining our survey boundaries and be cautious of the received wisdom. The areas or habitats with uncertain information become particularly important when they are large in extent. The practical implication is that we will often need to collect data over a wider area than is apparent at first sight, although it is sensible to sample at a much lower intensity in peripheral areas. This is the basis of *stratification*, which will be discussed in more detail later. It is also sensible to count over a larger area when a bird is known, or suspected, to be expanding its range. Paradoxically, it can be as important to confirm that a bird does not occur in an area (and record a nil count), as it is to count it where it does occur.

2.1.7 Census or sample?

The next decision is whether to undertake a *true census* by attempting to count all birds, pairs or nests within the survey boundary, or to count in only a *sample* of areas within the survey boundary. While it might be tempting to census the whole area for the sake of completeness, it is often considerably more effective to census or survey representative sample areas and to extrapolate the results to obtain a figure for the total population with estimates of the likely error. Highly clumped and conspicuous species, such as breeding seabirds or non-breeding waterbirds, may be more amenable to counting most of the population at a limited number of sites. Where numbers are extremely large, however, within-site sampling may also be advisable. Rare birds with restricted ranges are often easier to count using a true census, because sampling might record too few birds to produce a reliable estimate. For more common and widespread species, it may be expensive and unnecessary to count the whole area, and it might be more cost-effective to census or survey a representative selection of areas.

It is possible to mix sample and census approaches within the same survey. Thus, in some areas or habitats a census of all birds is used, for example, where densities are high in limited geographical areas, yet in others only a sample of areas or habitats is counted, for example, where densities are low over wide areas.

2.1.8 Sampling strategy

If we decide to undertake a sample survey, we need to be very clear about the *sampling strategy*. We need to ensure that the areas in which we count are truly representative of the area within the survey boundaries. If they are not, our final estimate or index may be biased in an unknown manner. Strategies based on *random, random stratified* or *regular sampling* (also known as systematic sampling) are likely to be most robust. As this is such an important topic, it is outlined later.

2.1.9 Sampling unit

In tandem with our sampling strategy, we need to decide upon our *sampling unit*, the bits of the whole survey area we actually count birds in. This might be a grid square, the precise location and boundaries of which are available from maps. The area encompassed within the survey boundary can be subdivided into a large number of grid squares on a map, and a sample of these squares chosen at random for survey. While this approach is simple and statistically sound, it may not always be practical. It might be difficult to use, for example, when surveying birds living in fragmented forest plots of variable size surrounded by farmed land. In such circumstances, individual plots can become the sampling unit. In this case, unlike the grid squares, the individual sampling units are likely to vary in size.

2.1.10 Field methods

We now need to consider what *field method* we will use to count the birds. There are a variety of options and the one we choose will depend upon the species or group of species being counted, the habitats involved and the level of detail required. For some species, it is necessary to develop specially tailored methods (see Gilbert *et al.* 1998; Steinkamp *et al.* 2003). If we are trying to survey a number of species together, however, then we need a generic method that will encompass most species well. There are two principal methods for generic or single species surveys; *mapping* and *transects*. These methods, plus others with specific uses, are outlined below.

2.1.11 Accuracy, precision, and bias

The terms *accuracy, precision, and bias* have specific meanings when applied to scientific data, such as bird surveys, though *accuracy* and *precision* are generally interchangeable in common use. It is extremely important to understand these terms at the outset and to use them appropriately when we report survey results. As we will see, survey design essentially revolves around the twin aims of increasing accuracy and precision and reducing bias, but this is easier said than done.

Accuracy is a measure of how close our estimate is to the true population. For example, if our estimate is 510 parrots and the true population is 500, most people would accept that our estimate was quite accurate. If our estimate is 510 but the true population is 2000 parrots, then our estimate is patently inaccurate. Of course, the problem is that we usually do not know the actual numbers and so it is extremely difficult to measure accuracy. In most circumstances, it is practically impossible to count every last individual in a population, and even if it were technically possible, it would be prohibitively expensive. The only practical way to measure accuracy would be to carry out very intensive work in small areas and to calibrate the findings with a wider survey—but such studies are very time-consuming (e.g. DeSante 1981).

Precision is a measure of how close replicated estimates are from each other (and so it is unrelated to the true population size). This is the same as asking how much error is there around a mean estimate. Take the parrot example above; suppose that we have five counts during a period when the true population stayed the same, and we get estimates of 490, 495, 500, 505, 510. Because these estimates are close together, the difference between the extreme counts being just 4% of the mean, most people would accept that the estimates were relatively precise. Five counts of 300, 400, 500, 600, 700, with a difference between extreme counts of 80% of the mean, are imprecise. Coincidentally, the average of both sets of counts is accurate because it is close to the actual number of parrots, though of course this would not be known. A final set of counts of 990, 995, 1000, 1005, 1010, is exactly as precise as the first set, with again a difference of 4% of the mean between extreme counts, but hopelessly inaccurate. Hence, precision is independent of the true population size.

Unlike accuracy, precision can be measured in statistical terms (e.g. as a range, variance, standard error, 95% confidence limits, percentage error etc.) by looking at the differences in counts between the different sampling units. Be aware, however, that standard methods of calculating confidence limits assume that the counts follow a normal (or Gaussian) distribution, which is unlikely to be the case for bird counts. The way around this is to use distribution-free methods, such as bootstrapping, to derive confidence limits (see later). Precision is determined by two factors: the number of sample units visited (= numbers of sites and hence birds counted) and the degree of variation in the counts made in those sampling units.

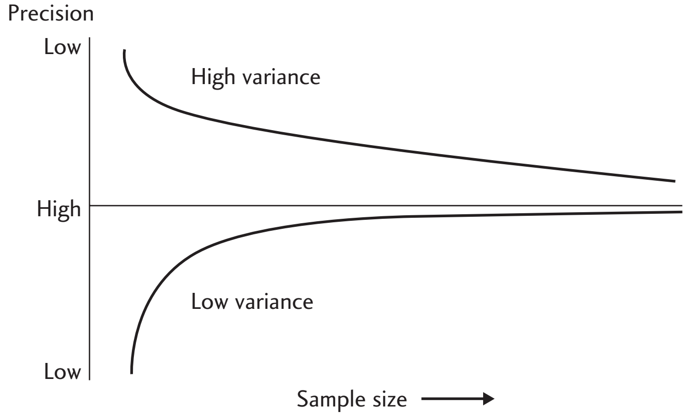

Fig. 2.3 The relationship between precision and sample size with high and low variance. Larger samples sizes deliver greater precision, but as sample sizes increase the benefit declines.

Multiple counts can be obtained by counting the same study site repeatedly in the same season, or by counting multiple study sites once. The first option tells us about temporal variation at sites within a season, the second about spatial variation across the sites—both may be important depending on the study aims.

The relationship between precision, sample size and variance is shown in Figure 2.3. This shows that precision rapidly increases with increasing sample size and that it does so more rapidly where there is little variance in counts between sampling units. As a good rule of thumb, the width of the confidence intervals is related to the number of sampling units *N*, as $N^{-0.5}$. With smaller sample sizes, great increases in precision can be achieved for relatively small increases in sample size. However, as sample sizes increase, so the additional precision gained declines, and when sample sizes become very large, we gain little in precision, even for very large increases in sample size. From a practical perspective, this tells us that if we wish to increase precision we need to take a larger sample of sites, but beyond a certain point, which we could think of as the optimum sample size, this produces diminishing returns. We can use pilot data to make an informed decision about the optimum sample size but, of course, there are often other more practical considerations (e.g. individuals and time available for fieldwork, survey time required within each plot, or the terrain), and the ultimate decision about sample size will be based as much upon these as on the theory.

The other element to influence precision is the variation in counts between sampling units. If a bird is widely and evenly distributed, occurring in roughly

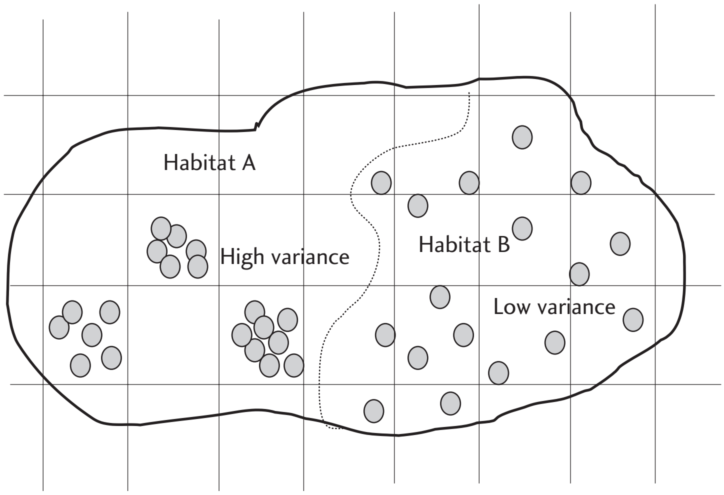

Fig. 2.4 An illustration of uneven variance between two habitats. The filled symbols represent birds.

similar numbers in different sampling units (as in Habitat B in Figure 2.4), then counts from different squares are likely to be similar and the estimates of population relatively precise. If a bird has a more clumped distribution, giving lots of variation between sampling units (as in Habitat A), then counts from different squares are likely to be dissimilar and have lower precision. Note that differences in the ability of the observers to make the counts can also lead to high variance even when the birds are actually evenly distributed.

Bias occurs when our estimates are either systematically larger or smaller than the true value. Put another way, inaccuracy is brought about by bias, which can arise from a poor sampling strategy (e.g. by only surveying the best areas) or an inappropriate field method (e.g. by counting around midday when a species is most active in the morning), or a combination of factors. A whole range of factors could lead to bias, for example, the field method, effort and speed of surveying, the habitat, the bird species and their density, the time of day, the season of the year, the weather conditions, double counting, the observer's skills, etc. The challenge is, first, to recognize all the potential sources of bias and, second, to standardize survey methods and improve standards where appropriate, to reduce bias as much as possible. That said, bias is an unpleasant and often unavoidable fact—and surveys should always consider the likely sources of bias and how they might influence the findings. We should never assume that our survey is free of bias.

2.2 Sampling strategies

We saw in the previous section that, if we are to obtain an unbiased measure of bird abundance (e.g. an estimate of absolute or relative population size), we will often need to count birds in a number of sampling units that are representative of the area within the survey boundaries. This raises two important questions; how many sampling units should we visit to count birds? And, crucially, which ones?

2.2.1 How many sampling units?

As we have seen, the larger the sample size (=number of areas and hence birds counted) the more precise our estimate. Sample size will therefore depend largely on the reliability we want to place in our estimate. If we want a very precise estimate, we need to have a larger sample of sites than if we just want a good approximation. Statistical methods, requiring the collection of some pilot data, are available for calculating sample sizes necessary to achieve predetermined levels of precision (Snedecor and Cochran 1980). In the real world, however, our sample sizes are generally influenced by financial and human resources, and, as these are generally low, we will rarely be at risk of having sample sizes that are much higher then we actually need. Instead, we need to ask ourselves whether our sample size will be sufficient to meet the objectives that we set ourselves at the outset.

2.2.2 Which sampling units to count?

Next, we need to determine which sampling units, out of all those available, should be visited. In other words, what is our *sampling strategy*? This is probably the most critical decision in a sample survey, as failure to use an appropriate sampling strategy could invalidate the results. Only when we are certain that our sampling strategy is appropriate should we start to think about how we will actually count the birds when we get into the field.

There is a tendency for fieldworkers to visit areas they expect to be good for their target species or for their particular study. *Free choice* of this kind can lead to a bias toward higher quality sites, or particular types of site. Remember that our sample must be representative of the whole area of interest if we are to extrapolate the results to areas that are not visited. So how can we select our sample without falling into this trap? The most frequently used methods, and the best, are *random sampling* and *regular sampling*. A definition of truly random sampling is that each sampling unit has an *exactly* equal chance of being selected. Contrast this to free choice, where better areas are far more likely to be selected than less good areas.

Sampling randomly is not as straightforward as it might seem. One might think that closing ones eyes and sticking a pin in a map would be random, but it

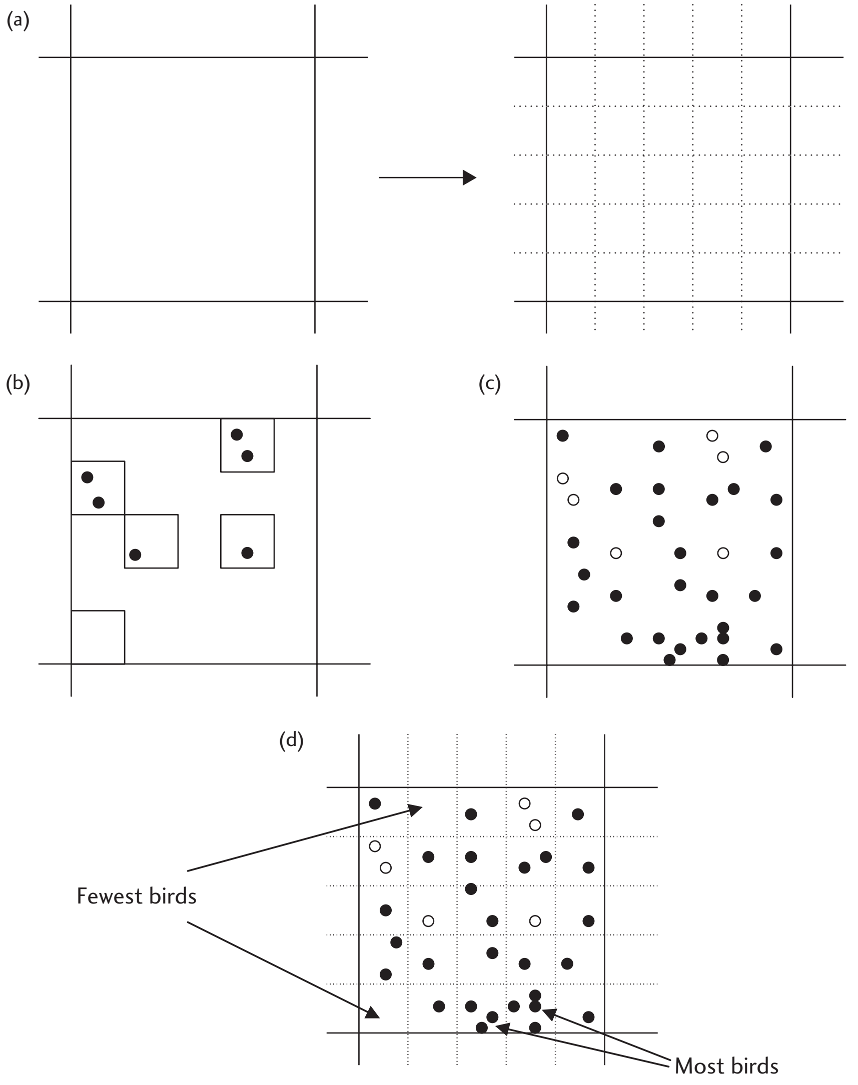

Fig. 2.5 Choosing the right sampling units to count from a grid. (a) First, break the whole area down into bits that can be counted—these are *sampling units*. In this example, we have the resources to count 5 of the 25 sampling units. (b) Next select your squares randomly (see text), count the birds (filled symbols) in these specially selected sampling units (and no others), and estimate the population. The estimate = number of birds counted divided by number of squares counted (= average density of birds per square) multiplied by the total number of squares. Thus, for example, population estimate = $6/5 \times 25 = 30$. Or, more correctly, add your census count to an estimate of the number of birds in the remaining un-surveyed squares = $6 + (6/5 \times 20) = 30$. This *extrapolates* data from areas

is not—squares toward the center of the map would be more likely to be selected than those around the edges. Trying to pick "random" squares by eye, or trying to guess "random" numbers, will be similarly biased. If we deliberately select squares we think might hold "average" numbers, this also biases our estimate of precision. There are a number of ways that sampling units can be selected randomly. Assigning each a different number, or using a grid in which each cell has unique coordinates, allows us to select sampling units using random numbers. Random numbers can be selected using random number generators from scientific calculators, from most database packages (such as Excel), or from statistical tables. Alternatively, bits of paper each with the grid coordinates of 1 square can be put into a hat and drawn out blind (this is only random if every square has a corresponding piece of paper). This low technology alternative is perfectly acceptable and scientifically robust. The power of random selection is that it does not matter if we miss the squares with most birds. In the example in Figure 2.5, the two "best" squares were missed, and one of only two squares where the species was absent was selected, but the estimate was still extremely close to the real population size.

The procedure for randomly sampling non-regular units, such as nesting colonies, lakes, forest blocks, etc., is similar. The key is to number or label each of the individual entities and then randomly sample from the whole set (so that each has an exactly equal chance of being picked). Note that for irregularly distributed sampling units, picking a point at random and selecting the nearest sampling unit does not produce a random sample, since sampling units that are more isolated from others are more likely to be selected using this method than sampling units close to others.

2.2.3 Using stratification

We can often use prior knowledge about a species or an area to be surveyed in order to sample more effectively. An important refinement is *stratification*, where

where we count (our sample) to those we do not count. (c) Random selection of sampling units almost always provides a good estimate of the true population. In this hypothetical example, our estimate was 30 and the "real" population was 33. Here, open circles represent birds that were counted and filled circles those that were not. (d) It may seem odd that our random sample has missed both the "best" areas for birds, (i.e. with most birds in them), and actually counted one of only two squares with no birds, but this does not matter. As we have seen above, the information we collect from our random sample allows us to estimate the population accurately. Had we based our counts on the best areas, our overall estimate would be a hopeless overestimate.

the area of interest is broken down into different sub-areas, known as *strata* (singular *stratum*). Two simple examples of stratification are shown in Figures 2.6 and 2.7. In the first case, there is prior information from a bird atlas that the species is largely absent, or at least very rare, in the southern part of our region. Randomly sampling across the whole region might, quite by chance, result in us selecting a high proportion of our samples in the area where the species is largely absent (Figure 2.6(a)). This would lead to an imprecise and inaccurate estimate and might lead to other problems, such as reluctance by fieldworkers to visit these areas because they expect to see so little. As an alternative, we could predetermine that, for example, 80% of our samples are drawn at random from the area we think is largely occupied, and only 20% of our samples from that thought to be largely unoccupied. In the second example, our area of interest is known to comprise two distinct habitats, which we expect to hold different densities of the species of interest. Once again, we can get a more precise estimate by using stratification, this time to allocate a predetermined 50% of our samples to each habitat (Figure 2.7(b)). Selection of strata clearly depends upon some knowledge or well-founded assumptions about the distribution of the study species.

We can stratify by habitat, climate, altitude, land use, bird abundance, accessibility of survey sites, administrative or geopolitical boundaries, and so forth. From

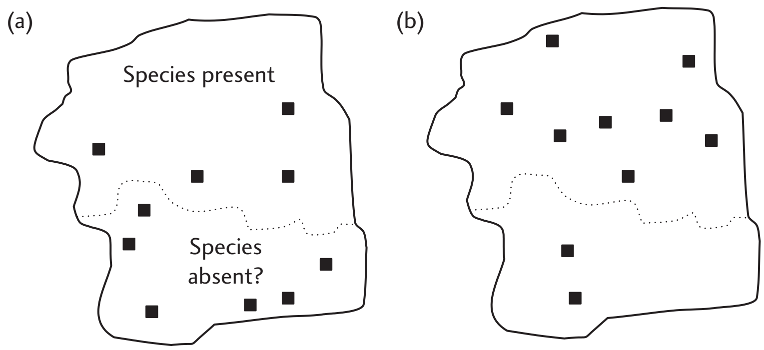

Fig. 2.6 Imagine we are surveying a bird in an area divided into two distinct habitats. (a) A pure random sample of the whole area could, by chance, result in 60% of our samples falling in the southern habitat—which we have reason to believe has very few, if any birds. The filled squares represent survey plots. This would be wasteful of time and resources. (b) Far better would be to use prior knowledge to stratify our sample and, say, take 80% of our random samples from the occupied habitat, and 20% from the habitat that is likely to be unoccupied (see text for further details). Note that, although the sample is smaller in the unoccupied area, it is still vital that it is surveyed.

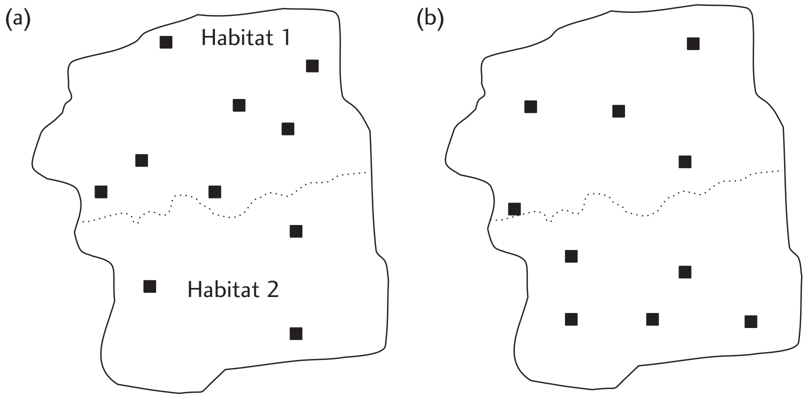

Fig. 2.7 Next, imagine our study area comprises two distinct habitats of roughly equal area, within which our chosen study species lives but at quite different densities. (a) A random sample across the whole area is quite likely to result in an uneven split of survey squares between the two habitats. If 70% of the squares happen to fall in one habitat then the population estimate for the whole area based on the 10 squares would inevitably be dominated, or biased, by that habitat. (b) The solution to this problem is to stratify so, for example, half the samples fall in each habitat—the data are then analyzed by strata and the results combined to give an unbiased estimate of population size (see text for further information on sampling within strata).

what we know about the ecology of birds, it will often make sense to stratify our sample by obvious factors, such as habitat and altitude. Where surveys rely on local observers, it might also make sense to stratify by their availability. Stratification by observer density might seem odd at first sight, but it provides an efficient way of maximizing the use of skilled volunteers when their distribution is uneven, as it often is. Stratification is strongly recommended because it can improve both precision and accuracy, and it ensures proper habitat coverage. Thankfully, there are simple rules that help us choose the most appropriate strata—and it turns out that, even when our prior assumptions about strata prove to be wrong, there is no detrimental effect.

In those situations where we have little information about the habitats used by a species, it makes sense to sample in proportion to the area of the different habitats. For example, if 80% of the area is forest and 20% farmed land, then 80% and 20% of our samples should be in forest and farms, respectively. When we know more about species density in different habitats there are some simple rules designed to improve precision. For example, Sutherland (2000) suggests that sampling should be proportional to the likely proportion of the species occurring in a habitat—so if preliminary information suggests 60% of a population lives in forest, then 60% of our sample should be in that habitat. Of course, there is an element of circularity in this, and it depends on the reliability of the original information. There is the added complication that numbers may be much more variable in one habitat than in another, requiring many more counts there to achieve the same level of precision.

In general, we can improve precision by choosing strata that minimize the variation between sampling units within a stratum while maximizing the variation between strata. This is quite easily achieved because birds generally occur at different densities in different habitats. As we have seen above, the simplest choice is proportional allocation of sampling units within strata, but if the costs of counting sampling units differs across strata, or the counts are more variable in some strata, we can adjust our sampling to optimize allocation (Box 2.1: Snedecor and Cochran 1980). The basic rule is to take smaller samples, compared to proportional allocation, in a stratum where sampling is expensive, and to take bigger samples in a stratum where the counts are more variable. Even rough estimates of variability and cost can help to improve sampling design.

Problems can arise if the number of strata is large relative to the total number of study plots (so that only a few sampling units are selected in each stratum). We recommend using a small number of strata; 2–6 is generally sufficient. One of the reasons for this is that a separate population estimate should be calculated for each stratum and these estimates must be added together to get an overall estimate of the total population. Likewise, confidence limits on these estimates have to be found by combining information from the strata (Box 2.2; see Wilkinson *et al*. 2002, Wotton *et al*. 2002).

In the real world, it may be very difficult to sample totally at random, for example, because you are unable to travel long distances to remote areas to count

Box 2.1 Choice of sample sizes within strata

1. Proportional allocation: Take the same fraction of sampling units from each stratum; that is, make n_h/N_h the same for all strata
2. Optimum allocation: Make n_h proportional to $N_h S_h/\sqrt{C_h}$. This delivers the smallest standard error around an estimate for a given cost.

Where: n_h is the sample size chosen in the hth stratum, N_h the total number of sampling units in the hth stratum, S_h the standard deviation of sampling units in the hth stratum, and C_h is the cost of sampling per sampling unit in the hth stratum.

Box 2.2 Analyzing stratified samples

The simple rule in analysing stratified samples is that each step of calculation needs to be carried out at the level of the stratum and the estimate then combined with those from all other strata. If we want to estimate the size of a bird's population and had collected data from three strata (e.g. low, medium, and high abundance, or farmland, scrub, and forest habitats), we would calculate the bird's density in each stratum separately based on our field counts, then multiply up by the area of each stratum, and then add these numbers together to give an overall population estimate. All very simple—and the same approach holds when calculating confidence limits using the bootstrap procedure, but here we add counts from the sampling units we visited to an estimate of the numbers from the remaining area of that stratum that was not visited. Thus, we re-sample at random with replacement from sample sites within strata, calculate an estimate of density and multiply by the area of the habitat that was not surveyed, and add to this the actual number of birds counted. We repeat this process to create 999 unique estimates of the number of birds within each stratum. For each replicate, (1,2,3, … ,999) the number of birds would then be summed across the strata (strata 1, replicate 1 + strata 2, replicate 1 + strata 3, replicate 1, etc.), to give 999 "bootstrapped" estimates of the overall population size. These totals are then sorted or ranked in size and the 25th and 975th values taken as the 95% confidence intervals.

birds. A more pragmatic approach is *semi-random* sampling, where sampling units are randomly selected within a predefined area. If, for example, you are able to travel a maximum of 50 km from your base to count birds, it is possible to select count sites at random from those available within this radius. An alternative is to define a larger area (which does not need to be contiguous) within which you are able to count, comprising say 5 or 10 km^2, and randomly select smaller sample squares from within this area. This is, however, liable to introduce bias. For example, a semi-random approach is likely to over-sample areas close to human population centers if that is where you live. Nevertheless, semi-random is better than just visiting areas that seem good for birds. By sampling a small number of genuine randomly chosen squares, it is also possible to check on the nature and degree of bias.

A potential problem with random sampling, particularly when sample sizes are low, is that, just by chance, our samples might be concentrated in one part of the survey area that is particularly good for a species, or might miss an area in which we were particularly interested (Figure 2.8(a)). If we are using stratification, this is less of a problem; we can, for example, stipulate that every grid square, or every stratum, contains a fixed number of sampling units (Figure 2.8(b)). An alternative to random sampling that gets around this problem is *regular* or *systematic sampling*. This involves selecting the sampling units by choosing them in a regular pattern (Figures 2.8(c) and 2.9(a)). We can use random numbers to help us do this. If we want a 10% sample from 100 squares, we can select a random number, say 7, then take every 10th square from a list in standard order; 7, 17, 27, 37, . . . , 97. Alternatively, we could simply decide to sample every 1-km square in the north-east corner of every 10-km square and so forth to achieve a predetermined sample size. There are advantages to regular sampling compared to a random design:

- Regular samples are easier to select—a single random number is all that is required.
- It samples evenly over the area of interest; there is 'built-in' stratification that ensures that samples are taken from across the whole area of interest.
- In consequence, it is often more accurate.
- It can be used to create maps and atlases.
- It is easy to understand and explain to others.

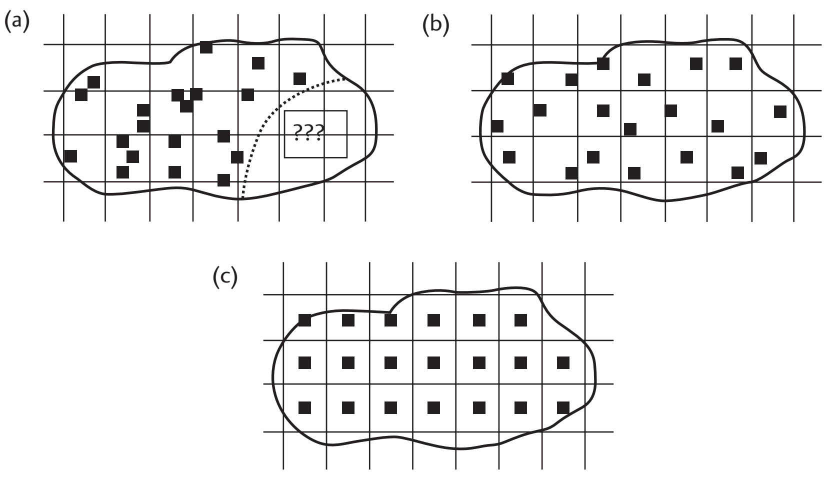

Fig. 2.8 There are certain situations, in which a pure random sample can, by chance, miss an important part of the study area, which could lead to serious under- or overestimation of a population depending on its distribution. In this example, a random sample (a) under-samples the southeast corner of the study area. A stratified random approach (b) could alleviate this problem by requiring a survey point in every grid square in the study area. Similarly, a regular sample (c) overcomes this problem because survey points are located in the center of every grid square. Here the filled circles represent sampling units ($n = 20$) within a study area defined by the bold border.

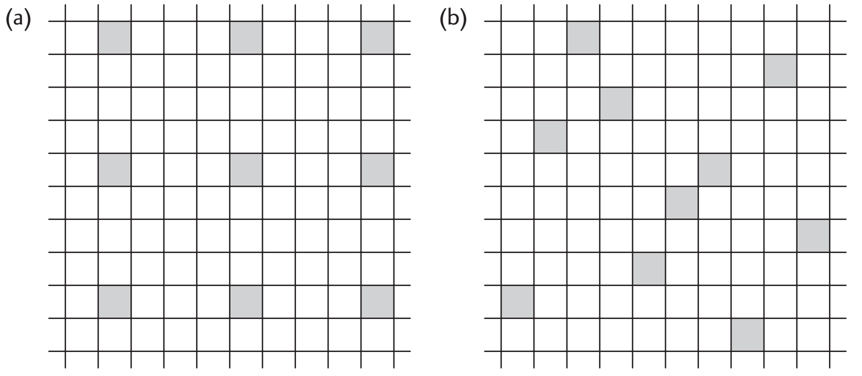

Fig. 2.9 (a) An example of a regular sampling method, and (b) a randomized Latin square design. Survey squares are shaded.

Stratification can be used alongside regular sampling too. For example, we could take every seventh square from a stratum where a bird is thought to be common, but every fourteenth square from a stratum where it is thought to be rare (see Nemeth and Bennun 2000 for a similar approach).

There is, however, a possible bias in systematic sampling, in that this method might over- or under-sample certain features that are regularly distributed in the landscape. For example, it might be that parallel roads are the same distance apart as our lines of samples, leading to over- or under-sampling of areas near roads. In reality, however, such biases are very rare, although we need to be aware of them. In summary, regular sampling has much to recommend it and it has probably been under-used in the past.

An attractive alternative is to integrate the strengths of random and regular sampling by using a *randomized Latin square* design (Figure 2.9(b)), in which each column and each row holds one, and only one, sampling unit. Sampling units are drawn randomly from the rows and columns on the condition that every row and column can only contain a single square, which ensures balanced coverage of the area. This pattern of sampling can be repeated across the study area and within larger sampling units.

2.3 Field methods

In the section above, we considered the key question of how we choose where to make our counts. Now we must consider how to choose between counting methods. Although we have presented survey design as a linear process, in reality, there should be a strong feedback loop in which the sampling strategies and

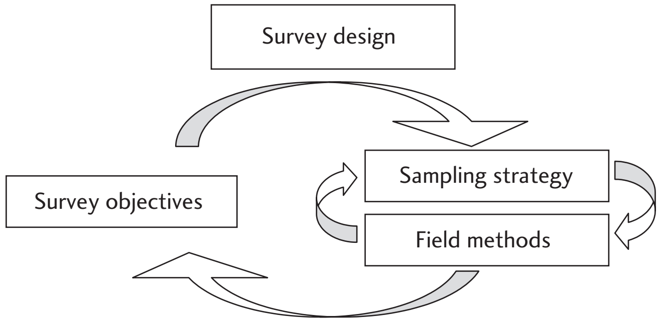

Fig. 2.10 Feedback loops operating in survey design between the survey objectives, sampling strategy, and field methods.

field methods influence and alter each other, and they will in turn influence and potentially alter the survey objectives (Figure 2.10). For example, if the required survey method for a particular species, or habitat, is labor intensive, this might dictate that a smaller number of census plots could be covered. Equally, if the sampling strategy dictated that survey effort needed to be spread across several potential habitats because of uncertainty over the true habitat requirements of a scarce species, this might lead us to re-define and simplify our survey objectives.

There are some general issues to consider in planning fieldwork:

- The season and the time of day the survey is to be carried out.
- The size of the survey plots.
- The number of visits to be made to each sample plot or area (commonly around 10 visits for territory mapping, 2–4 for transects, see below).
- The recommended search effort, for example, walking speed (this is particularly important for line transects) or count duration (for point counts), and general counting protocol for the observers.
- The recording units and behavior of the birds to be noted (ages, sexes, nests, singing, calling males, etc).

The three most common field methods are mapping, and line and point transects; each of these is discussed in turn below.

2.3.1 Mapping

During the temperate zone breeding season, many individual birds are restricted to relatively small areas, actively defending a territory or spending much time around a nest. If a number of visits are made to an area, and the exact location of birds plotted on maps, it becomes possible to identify clusters of sightings and so to estimate directly the total number of pairs or territories of each species present.

An essential component of this method is the use of activity codes to describe bird behavior in the field. These allow observers to record simultaneous observations of territory-holding birds, different forms of territorial behavior and other factors that later allow an analyst to approximate the boundaries between adjacent bird territories. This is the method of *territory* or *spot mapping*. Examples of these codes, and of the way that maps can be analyzed, are given in Marchant *et al.* (1990), Gibbons *et al.* (1996), and Bibby *et al.* (2000). At first sight, this would appear to be an extremely accurate and precise method, but this is not always the case and one needs to be aware of the underlying assumptions about territoriality. An obvious advantage of the method is that it produces a detailed map of the distribution and size of territories, allowing us to link bird distribution with habitats. For certain purposes, for example, habitat management on a nature reserve, such information can be invaluable. The method does, however, have a number of disadvantages:

- It requires high quality maps of the study area.
- It is time consuming, requiring up to 10 visits to each site to be able to identify territories (though fewer visits could be made if only one species is being surveyed—a minimum is around four). The time required for mapping can be up to seven times that of transects.
- Because of the intensity of recording, only small areas can normally be covered, generally 1–4 km^2 (though again this depends on whether a single species is being studied and its ecology, and how much time is available).
- Mapping requires a high level of observer skill in identifying and recording birds.
- Interpretation of the results can be difficult, subjective, and requires the application of consistent rules, particularly when territory densities are high. Territories at the edge of a plot are troublesome and require arbitrary rules.
- It is an inefficient method for recording non-territorial species, semi-colonial species, those that sing for brief periods, or those that are not monogamous.
- It is difficult to use in dense or featureless habitats (e.g. thick forests, flat deserts) or when bird densities are high.
- It is difficult to compare results across studies unless common standards of territory analysis have been applied.

Despite these limitations, territory mapping has proved a useful method of surveying birds in temperate situations and the results have proved a valuable data source for ecological research. In those situations where it is critical to map individual territories, and sufficient resources exist to do this, it is the method of choice. When used appropriately, it allows fine-scale habitat associations to be studied and probably provides relatively accurate estimates of population size (although precision, and especially accuracy, are not easily measured). Mapping methods can also be usefully combined with nest finding, radio telemetry, mist netting etc. in research projects. Mapping has seldom been used in the tropics, largely because breeding is more asynchronous and many species have complex social behaviors.

2.3.2 Transects

There are two types of transect most commonly used in bird surveying, *line transects* and *point transects*. The latter are often termed point counts. Both are based on recording birds along a predefined route within a predefined survey unit. In the case of line transects, bird recording occurs continually, whereas for point transects, it occurs at regular intervals along the route and for a given duration at each point. There are a number of variations on this theme where birds are recorded to an exact distance (variable distance) or within bands (fixed distance) from the transect point or line. The two methods can also be combined within the same survey. While there are important differences between the line and point transects, and choosing between them is an important decision in survey design, there are also many practical and theoretical similarities.

Line and point transects are the preferred survey methods in many situations. They are highly adaptable methods and can be used in terrestrial, freshwater, and marine systems. They can be used to survey individual species, or groups of species. They are efficient in terms of the quantity of data collected per unit of effort expended, and for this reason they are particularly suited to monitoring projects. Both can be used to examine bird–habitat relationships (though generally less well than territory mapping), and both can be used to derive relative and absolute measures of bird abundance. Transects can be usefully supplemented and, to some degree, verified in combination with other count methods such as sound recording, mist netting, and tape playback (e.g. Whitman *et al.* 1997; Haselmayer and Quinn 2000).

There are a series of issues to consider when using transects in the field. The recommended walking speed is particularly important for line transects, as are the counting instructions for the observers. A further important consideration is whether to use full distance estimation, that is, estimating distances from the center of the point count or from the transect line, to all birds heard or seen, or to use estimation within distance bands or belts. In the latter case, one needs to decide on the specific distance bands.

We would always recommend recording some measure of the distance to each bird seen or heard because this provides a useful measure of bird detectability in the habitat concerned and allows species-by-species density estimation (see *Detection probabilities*). It is always preferable to record the exact distance to birds, or failing this, distance within many belts, but in reality, this will often prove to be impractical. As range-finders become increasingly affordable, they open the way for simple and accurate distance estimation, especially for single species surveys.

2.3.3 Line transects

At its simplest, a line transect involves traveling a predetermined route and recording birds on either side of the observer. The distance a bird is seen or heard from the transect line is normally recorded as an absolute measure, or in distance bands. Distances should be estimated perpendicular to the transect line (rather than the distance from the bird to the observer). Distance estimation of this kind is key to the estimation of bird densities. Perpendicular distances can be estimated in a number of ways:

1. Distance is estimated by eye from the line, given practice and periodic checking against known distances; fixed distances can also be marked unobtrusively in the field using marker posts or colored tape to aid recording.
2. Observers may be able to visually mark the position of a bird when detected and then use a tape or range finder to measure the distance when they are perpendicular to where the bird was recorded.
3. Bird observations can be plotted on to high quality maps and the distance measured subsequently. This requires good mapping skills and is helped by having fixed markers in the field.
4. Observers can use a sighting compass to estimate the angle (θ) between the transect line and a line from the observer to the bird, and use a tape or range finder to measure the distance (d) from that point to the bird. The perpendicular distance is then calculated as $d \cos \theta$.

The sampling strategy chosen for a particular survey determines the sample square or unit to be surveyed, but there is still the choice of line transect routes within this area. There are several options, and some flexibility is advisable. For example, a regular or systematic approach could be used with parallel transects orientated north to south, or a series of transects oriented along the long axis of the study area. A random approach, for example, with starting points and directions of transects selected randomly, could be used. One could even use a stratified random approach, for example, with the starting points and direction of transects selected at random, but where each lies within an individual habitat stratum. In reality, topography, watercourses, roads, certain land uses, and access permissions, might all limit access, so that the actual routes counted will differ to some degree from the ideal routes—but such deviation cannot be avoided. In some cases, it might be necessary to substitute a piece of transect for one that cannot be covered, providing it is equivalent in habitat.

The survey design of the Breeding Bird Survey in the United Kingdom, which uses a line transect approach, provides a useful model that can be adopted elsewhere for breeding birds (Gregory 2000; Gregory and Baillie 1998, www.bto.org/survey/bbs.htm). This survey is based on two counting visits to a square each breeding season, with one previous visit to set up a route, and uses three distance bands, 0–25, 25–100, and over 100 m. In general, and for ease of comparison across studies of terrestrial breeding birds, we recommend a minimum of two visits to a plot each season and a maximum four visits. We recommend, as a minimum, 2 distance bands, 0–25 and over 25 m for line transects, and preferably three (as above) or more.

Observers often differ in their ability to record birds and other data. If more than one observer is available, bias can be reduced by matching observers to particular tasks they suit (e.g. one spotting and identifying birds, one estimating distances, one acting as data recorder), and by incorporating training. Inter-observer differences in bird identification can be monitored and compared (e.g. by plotting the decline in the percentage of bird records unidentified through time).

Line transects are highly adaptable; they have been used to survey seabirds from ships, and waterbirds and seabirds from the air, although these are specialized and expensive applications.

2.3.4 Point transects

Point transects differ from line transects in that observers travel along the transect and stop at predefined spots, allow the birds time to settle, and then record all the birds seen or heard for a predetermined time, ranging, at the extremes, from 2 to 20 min. Again, we have three choices in deciding where to site point counts within the study plot. There are, of course, many variations on this theme and the counting stations do not need to follow a set route. One could select individual points at random, or by a stratified random design, and access each of them individually—in fact, this is one of the strengths of point transects because they do not require access across the whole survey area. As with line transects, practical barriers might limit the degree to which the ideal routes can be followed, but equivalent points can be substituted with a little care.

If the point transect is the chosen method for a particular survey, then the same set of considerations outlined above would apply. In addition, for point counts one needs to decide on a settling time once the counting station is reached, and on the duration of the count itself. For ease of comparison across studies of terrestrial breeding birds, we recommend the minimum number of visits to a plot is two and a maximum four. We recommend a 5- or 10-min count period plus an initial settling time of 1 min. For the longer period, we suggest that birds recorded in the first and second 5 min are noted separately (allowing some check on double counting, on whether birds are attracted to the observer, and allowing comparison with 5-min counts). We recommend a minimum of two distance bands, 0–30 m and over 30 m, better still would be 3 bands, 0–30, 30–100 and over 100 m. Lastly, we suggest a minimum of 200 m between counting stations. Ralph *et al.* (1995) review point count methods and provide practical recommendations for their use.

The North American Breeding Bird Survey, which is a continent-wide survey, involves point counts along randomly selected road transects (Sauer *et al.* 2001; www.mbr-pwrc.usgs.gov/bbs/).

2.3.5 Rules for recording birds in the field

The aim is to record all birds identified by sight or sound with an estimate of distance when first detected. It might be helpful to indicate whether a bird is detected by sight or sound on a recording form. Birds that are seen flying over the census area (aerial species) are recorded separately because they cannot be included in standard density estimation. For such mobile species, it is best to make an estimate of their numbers along each section of transect, or at each point. If birds fly away as you are counting, record them from the point you first saw them. We recommend that birds flushed as you approach a point count station should be recorded from that point and included in the point count totals (but you must make this plain in the write-up). Try to avoid double-counting the same individual birds at a point count or within a transect section by using careful observation and common sense. It is, however, correct to record what are likely to be the same individual birds when they are detected from subsequent point counts or transect sections.

2.3.6 Choosing between line and point transects

There is little to choose between line and point transects because they are so adaptable to species and habitats, but each is better suited to particular situations (Table 2.1). The strengths and weaknesses of the methods need to be matched against your survey objectives.

Both methods require a relatively high level of observer skill and experience because a large proportion of contacts and identifications will be by song or call.

Table 2.1 *A comparison of line and point transects*

Line transects	Point transects
Suit extensive, open, and uniform habitats	Suit dense habitats such as forest and scrub
Suit mobile, large or conspicuous species, and those that easily flush	Suit cryptic, shy, and skulking species
Suit populations at lower density and more species poor	Suits populations at higher density and more species rich
Cover the ground quickly and efficiently recording many birds	Time is *lost* moving between points, but counts give time to spot and identify shy birds
Double counting of birds is a minor issue, as the observer is continually on the move	Double counting of birds is a concern within the count period—especially for longer counts
Birds are less likely to be attracted to the observer	Birds may be attracted to the presence of observers at counting stations
Suited to situations where access is good	Suited to situations where access is restricted
Can be used for bird–habitat studies	Better suited to bird–habitat studies
Errors in distance estimation have a smaller influence on density estimates (because the area sampled increases linearly from the transect line)	Errors in distance estimation can have a larger influence on density estimates (because the area sampled increases geometrically from the transect point)

Some thought needs to be given to surveying birds that are non-territorial, semi-colonial species, those that sing for brief periods, and those that have unusual mating systems; but this is less of a concern than in territory mapping. A potential disadvantage of both transect methods for some purposes is that they tend to follow paths, tracks, or roads and so may not be representative of the area as a whole. A practical way around this using point counts is to establish counting stations at right angles to the transect, and say 30 or 50 m into the habitat.

2.3.7 Detection probabilities

Having conducted a survey of a species in a particular habitat, it makes sense to compare the results with those of other similar studies in order to place your findings in context. This is often easier said than done, however, because to do so using the raw, or "unadjusted counts," you must assume that the probability of detecting birds is the same for each data set that is compared. It is an inescapable fact that some birds present in your study area will go undetected regardless of the survey method and how well the survey is carried out. Detectability is a key concept in wildlife surveys and we neglect it at our peril. Thus, comparison of "unadjusted counts" will only be valid if the numbers represent a constant proportion of the actual population present across space and time. This assumption is often questionable and has been a matter of much debate (Buckland *et al.* 2001; Rosenstock *et al.* 2002; Thompson 2002). To be clear, this could affect comparisons between different habitats surveyed at the same time, and between the same or different habitats surveyed at different times.

The solution is to "adjust" counts to take account of detectability, and a number of different methods have been proposed (Thompson 2002). For example, the "double-observer" approach uses counts from primary and secondary observers, who alternate roles, to model detection probabilities and adjust the counts (Nichols *et al.* 2000). The "double-sampling" approach uses the findings from an intensive census at a subsample of sites to correct the unadjusted counts from a larger sample of sites (Bart and Earnst 2002). The "removal model" assesses the detection probabilities of different species during the period of a point count and adjusts the counts accordingly (Farnsworth *et al.* 2002). Finally, "distance sampling" models the decline in the detectability of species with increasing distance from an observer and corrects the counts appropriately.

Distance sampling is a specialized way of estimating bird densities from transect data and of assessing the degree to which our ability to detect birds differs in different habitats and at different times (Buckland *et al.* 2001; Rosenstock *et al.* 2002). The software and further information to undertake these analyses are freely available at: www.ruwpa.st-and.ac.uk/software.html. *Distance sampling* takes account of the fact that the number of birds we see or hear declines with distance from the observer. The shape of this decline, the distance function, differs among species, among observers and, importantly, among habitats—birds within open grassland are detectable over greater distances than those within dense forest—even when they occur at the same densities. *Distance sampling* models the "distance function" and estimates density taking into account both the birds that were observed, plus those that were likely to be present but were not detected. This method is strongly recommended.

Distance sampling provides an efficient and simple way of estimating bird density from field data. It allows for differences in conspicuousness between habitats and species (though not observers), enabling comparisons to be made between and within species, and across different habitats at different times. Density estimates improve with the number of birds recorded—a minimum of about 80 records is recommended. The method relies on a number of assumptions which need to be evaluated carefully in the field and steps taken to lessen their effects (Buckland *et al.* 2001). The key assumptions of distance methods are that all the birds actually on the transect line or at the counting station are recorded (for cryptic and shy species this may not be true), and that birds do not move in response to the observer prior to detection.

2.3.8 Colonial birds

Around 15% of bird species nest in colonies, either on cliffs, in trees, on the ground, in caves or in burrows. In some ways, this makes them easy to count, since birds are concentrated in generally conspicuous aggregations. However, counting birds in colonies also poses problems:

- Numbers may be huge, making counting difficult; it may be necessary to sample parts of the colony (using strategies described above) and extrapolate.
- Breeding may not be synchronous. At any time, part of the population might be elsewhere, and the birds present on the second visit might not necessarily be those present on the first; individual marking of birds may be necessary.
- There may be large numbers of non-breeders or "helpers" present, or birds might be absent from the colony for long periods; it may be better to count nests rather than individuals.
- Old nests might appear to be active; it might be advisable to count apparently active or occupied nests only.
- Colony attendance might vary greatly during the day and over the year; it may be necessary to make a number of counts at different times.

A critical step is to decide what it is that you want to count. Is it the total number of birds present, the number of breeding pairs, the number of apparently active nests, or the number of occupied burrows? This decision will help to determine the count method used.

Counts of large colonies often involve breaking the colony down into smaller units for ease of counting. In the case of cliff colonies, photographs can be used to divide the cliff into counting units, or even to count the birds directly. Cliff colonies should always be counted from opposite the colony rather than from above when nests are more easily missed. Aerial photography has been used to estimate numbers of large colonial birds, such as Gannets *Morus bassanus*. Tree-nesting colonies can be counted in a similar fashion, with nests in either all trees being counted or just a sample of trees. Large colonies of ground-nesting birds can be subdivided into smaller counting units by using a grid system marked out with string. The counters can then visit all, or a random stratified or regular sample of grid squares. Alternatively, densities of nests can be estimated using *distance sampling* (see above) and extrapolated for total colony area. Burrow-nesting seabirds are particularly difficult to count, many of them return to land after dark, and burrows may be occupied by more than one pair, or they may be unoccupied. It is possible to assess whether burrows are occupied using playback methods (although you need to know or measure the response rate), endoscopes, smell, or by planting toothpicks around the entrance to the burrow and seeing whether these get knocked over (but beware pre-breeding birds that are prospecting for nest sites). Multiple occupancy of burrows is difficult to detect and remains a problem. Steinkamp *et al.* (2003) provide a practical and detailed review of survey methods for seabirds and colonial waterbirds.

2.3.9 Counting roosts and flocks

Counting large aggregations of birds away from breeding colonies poses many of the same problems as counting birds in colonies, but with some additional considerations:

- If disturbed by the counter, birds are unlikely to return to the same place; observers need to maintain a distance.
- Birds may be closer together than when they are in nesting colonies where they tend to space themselves out, so great care is needed to count those present.
- Flocks often contain several species; it is necessary to count each separately.
- Some aggregations, such as roosting flocks, form for only short periods, often when light conditions are poor. Counts of nocturnal roosts often require the use of photography or of counts of groups of birds joining the roost.

Stationary flocks of up to 500 birds can be counted directly with relative ease if conditions are good. For larger flocks, and for rapidly moving flocks, photography or estimation methods are needed. A common method when estimating very large flocks is to count, say, 10, 20, 50, 100, or 500 birds and then estimate what proportion of the flock this represents. An important consideration when using this method is that birds in flocks do not tend to be evenly distributed, with higher densities in the center of the flock and lower densities at the periphery. Alternatively, for wading birds feeding on open mudflats and waterbirds on lakes, the flock can be broken down into smaller counting units using natural features of the habitat or distant landmarks. When birds are in dense groups, accurate counts are only possible by counting from above, or by counting them as they enter or leave an area. Care is needed so that counting does not disturb the birds; count from concealed or raised positions. The exception to this rule is the *flush* method in which birds are deliberately flushed into the air in order to get a better count of numbers (see Steinkamp *et al.* 2003). Coastal birds might be more easily counted at particular stages of the tide, for example, at high tide roosts, than when more dispersed over a larger area. Photography is a useful method, but in tightly packed flocks, many birds may be obscured. For larger birds, aerial or even satellite photography gets around this problem, although identification may be difficult. A general consideration when counting flocks is that observers show a natural tendency to overestimate small flocks and underestimate large flocks, although the extent to which different observers do this varies greatly. Furthermore, most observers estimate the size of larger flocks far less accurately than smaller flocks. It is always helpful for individual counters to repeat their own section counts and compare them with those from another observer.

For flocking species that disperse to feed over wide areas, it is often advisable to count the birds as they enter or leave roost sites at dawn or dusk, particularly where the sites are used traditionally and predictably.

2.3.10 Counting leks

In a small proportion of birds (around 150 species), males gather in communal gatherings, known as leks, to display and compete for females during the breeding season. At this time, a high proportion of males can be detected at a relatively small number of often traditionally used sites. One or two counts of the leks may be sufficient to give a reasonable and efficient census of the local population. There are downsides to this method however. For example, you need to be sure that all the leks present in an area have been detected, as birds can move between leks, and the smaller they are, the harder they are to find. Counts restricted to the largest traditional leks may well sample a specific group of birds and we do not know the area from which the birds came. In addition, some males may not choose to visit leks and this is particularly true for younger males. Finally, lek counts provide a poor means of surveying female birds.

2.3.11 Counting migrants

Counting large, diurnal migrants, such as raptors, cranes, storks, and pelicans, where they pass through migration bottlenecks, is often more efficient and easier than trying to count them when dispersed over huge breeding or wintering grounds, although this only samples birds that are low enough to be seen. In Israel, counters are arranged in a line across the front of migration and use radios to ensure that no more than one observer records each large flock of migrating birds. As migration can take place at great heights, observers often count in teams, continually scanning the sky and working together. Similar coordinated raptor counts occur across North America where their potential for population monitoring has been explored (Lewis and Gould 2000).

Estimation of the numbers of smaller nocturnal migrants is particularly difficult, but considerable progress has been made in this field (www.birds.cornell.edu/brp). Many smaller migrants call as they migrate, allowing at least minimum numbers to be assessed and species to be identified. Recently developed methods use microphones and complex computer programs to try to estimate total numbers of calling birds passing, as well as their height and speed (Evans and Rosenberg 2000, www.birds.cornell.edu/brp). Radar has been used to not only detect passing flocks, but also to estimate their numbers, direction of flight, speed, altitude, and even wing beat rate, but not their specific identity. This method requires access to extremely sophisticated, and usually militarily sensitive equipment and is generally beyond the reach of most researchers. Counts of migrants passing in front of the moon, or passing through the beams of bright lights, are of limited use, because only a small proportion of birds can be seen and most cannot be identified. A further indirect method of measuring changes in numbers of migrants, although not the absolute numbers, is ringing (banding), and a high proportion of ringing effort is concentrated at migration stopover points (Dunn *et al.* 1997). These methods are described in detail in Chapter 7.

2.3.12 Capture techniques

Because most species of bird tend to be visible and vocal, methods to survey them generally rely on observers seeing or hearing them. Occasionally, however, this may not be the case, as in species that live in dense undergrowth, or in the forest canopy, which may be rarely seen or heard. Under such circumstances, one way to census them is to catch them using mist nets. Capture techniques have been widely used in the tropics where they can be usefully combined with other census methods (e.g. Whitman *et al.* 1997). Broadly, two separate approaches can be used; either *capture-mark-recapture* (also known as mark-release-recapture, MRR) which allows estimations of population size, or *catch per unit effort* which can be used to produce population indices.

Capture methods can be time consuming and require substantial training to develop the skills necessary to catch, handle, and mark birds. The safety and welfare of the birds are always of paramount importance. In many countries, these techniques are licensed, and anyone considering using them should apply to the relevant authority well in advance. As we have seen in the previous chapter, mist netting is a relatively poor method for surveying birds. Further information on methods of capture and marking are given in Chapter 4. Despite these disadvantages, capture techniques yield much information besides population size and trend estimation. In particular, they can provide valuable information on demographic parameters, such as survival and breeding success, in addition to information on bird movements. Chapter 5 covers these issues in detail.

The principle behind standard effort *capture-mark-recapture* is that, if birds are caught and individually marked (e.g. with rings or bands), then from the ratio of marked to unmarked birds subsequently recaptured, population size can be estimated. Imagine that on the first day of capture at a site, 100 birds of a particular species were caught in nets, marked, and released. A week later, the nets were put back up. This time 50 of the same species were caught, 25 of which had been marked on the first day. If we assume that the population is closed and the original 100 birds caught had become fully mixed back in the population over the intervening week, then the total population size of the species on the site is 200. That is, we assume that the proportion of birds caught on the second date that were marked (25/50 or 50%) is the same as that in the total population on the site. Because we know that the number of marked birds is 100, then the total population is twice that, that is, 200. Expressed mathematically: the total population size, $P = n_1 n_2 / m_2$ where n_1 is the number caught, marked, and released on the first date, n_2 the number caught on the second date, and m_2 is the number of those caught on the second date that were marked. In practice, there is no need to actually catch birds on the second date, as they could be recorded by walking around the site trying to see as many birds as possible and recording those that were marked.

While the capture-mark-recapture approach may seem simple, it is in practice fraught with problems because it relies on a suite of assumptions, many of which may be untrue. For example:

- It assumes that birds mix freely within the population and this may rarely be the case.
- It assumes that the population is closed and that no birds enter or leave the population, either through births, deaths, or movements.
- It assumes that marking does not affect the probability that a bird will be recaptured, and that marked birds have the same probability of survival as unmarked birds.
- It assumes that marks do not fall off or become less visible.

While many of these assumptions may be broken, it is possible to plan fieldwork to minimize their influence on the results. For example, if the first and second capture dates are reasonably close together, the study site is well defined, and the study is undertaken outside of the breeding and migration periods, then the population will more approximate a closed one.

An array of mathematical models has been developed to analyze data from capture-mark-recapture studies. While it is not within the scope of this chapter to go into these methods, a range of approaches is available. The simplest of these, which is known as the Lincoln index (or Petersen method) assumes one capture and one recapture (or re-sighting) event only, and that the population is closed. The calculations for this model are essentially those described above. More complex models allow for multiple capture (re-sighting) events, and for open populations. The latter types of model, generally known as Jolly-Seber models, provide information on both population size and survival rates. Further information on these models is given in Chapter 5.

The principle behind *standard effort capture* is that populations of birds can be reliably monitored by capture methods if capture effort is kept constant over time, and done at the same season each year. Several programs for monitoring birds with this method exist, but perhaps the best known is the Constant Effort Sites scheme of the British Trust for Ornithology (Peach *et al.* 1996, www.bto.org/ringing/ringinfo/ces/index.htm), which is being followed by an increasing number of European countries. The Monitoring Avian Productivity and Survival (MAPS: www.birdpop.org/maps.htm) program is a similar initiative in North America.

Catch per unit effort data can be used to:

- Monitor population trends of adult birds, based on the numbers caught.
- Estimate absolute population size using the capture-mark-recapture methods outlined above.
- Monitor changes in productivity using the ratio of juveniles to adults caught late in the season.
- Estimate adult survival rates from between-year re-traps of ringed (banded) birds (see Chapter 5).

For the Constant Effort Sites scheme, the capture method involves placing the same types (e.g. mesh size) and lengths of mist nets (see Chapter 4), in the same positions, for the same length of time (about 6 h per visit) over a series of 12 visits during May to August. These methods are held constant from year to year. All birds caught are identified, aged, and sexed, and all un-ringed birds are ringed. While it might be tempting to vary net lengths from visit to visit, particularly if the number of fieldworkers varies from visit to visit, this could influence the catches. Simply calculating the number of birds per 10 m of net is insufficient, because doubling net lengths does not necessarily double the number of birds caught. Similarly, catching for twice as long with half the length of nets on some visits is not advised as capture success may vary with time of day.

Constant effort ringing is commonly used in dense habitats (scrub, reed beds, undergrowth, etc), but it can also be used in forest canopies, with nets raised high above the ground using pulleys or telescopic poles. Because some dense habitats, such as scrub and reed bed, can be successional, care needs to be taken to ensure that population trends reflect real changes in bird numbers rather than local habitat change around the nets. Although the Constant Effort Sites scheme uses mist nets, any accepted capture technique (Chapter 4) can be used, providing that effort is standardized (same number of traps, places, time periods, etc).

As a general survey or monitoring tool, catch per unit effort has some limitations, such as requiring specialist equipment and training and thus being expensive to maintain.

2.3.13 Tape playback

Some species of bird are particularly difficult to see or hear. Examples of such species are those that have skulking behavior, live in dense habitats, are nocturnal or crepuscular or nest down burrows. The probability of detecting these species can sometimes be increased by the use of tape playback, in which the taped call or song of a bird is played, and a response listened for. Recordings of the calls and songs of many species are now commercially available, and can be copied to tape. Ideally, use a tape loop, so that a short length of call can be repeated continuously for as long as is required. The call can be broadcast from a simple hand-held loudspeaker but care is needed to keep disturbance to a minimum and not to affect the bird's natural behavior.

The results from census work involving tape playback need careful interpretation. If the aim is simply to determine whether a given species is present in an area, then tape playback may simply increase the chance of finding it. If, however, the aim is to estimate population size or to produce a population index, then more care is needed. To generate a reliable population index, the probability of birds responding to the tape needs to be held as constant as possible. This can be helped, for example, by standardizing the manner in which the tape is played (same volume, recording, playback length, time of day, season, etc), and ensuring that the tape is not played to any one individual too frequently, causing it to habituate and respond less frequently. Tape playback has been used widely for monitoring populations of marsh birds, owls and raptors (Gibbons *et al.* 1996; Newton *et al.* 2002; Lor and Malecki 2002).

Estimating absolute population size from tape playback is more complex, as the probability of the average bird in the population responding to playback needs to be known. Frequently, detailed additional work will be required to determine response probabilities. Such work has been undertaken on owls and nocturnal burrow-nesting seabirds. For example, Brooke (1978) has shown that responses to playback of their call were obtained only from half of all occupied Manx

Shearwater *Puffinus puffinus* burrows. Detailed observations on incubating birds showed that this was because males and females shared incubation equally, but that only males responded to playback. Playing the tape into numerous burrows, counting the number of responses, and doubling this number could thus yield an estimate of the overall population. Unfortunately, response probabilities are not always constant. In their studies of Storm Petrels *Hydrobates pelagicus* Ratcliffe *et al.* (1998) have shown that response probabilities vary among years and colonies, and the cause of this variation is unknown. To estimate population size, it is thus necessary to determine year-specific and colony-specific response probabilities.

2.3.14 Vocal individuality

The songs and calls of many bird species are unique and often identifiable at the level of an individual, if not by ear, then from a sonogram. Acoustically distinct calls of this kind have considerable potential in monitoring and conservation, particularly for birds that occur in dense vegetation or are otherwise difficult to observe, but this potential has not always been realized (McGregor *et al.* 2000). The method involves recording songs or calls with a directional microphone and examining sound spectrograms using freely available software. The spectrograms from an individual bird are often recognizable by eye and discrimination can be formalized using statistical techniques.

Work on Bitterns *Botaurus stellaris*, in Britain has shown that their booming calls are individually quite distinct. This has allowed their numbers to be monitored more accurately and their year-to-year survival to be estimated (Gilbert *et al.* 2002). In a study of the Corncrake *Crex crex* information gained from vocalizations increased census estimates by some 20–30% (Peake and McGregor 2001), and showed that males called less frequently than was previously thought. The churring call of male European Nightjar *Caprimulgus europaeus*, a mainly nocturnal and mobile species, has been shown to differ between individuals (Rebbeck *et al.* 2001). The pulse rate of calls and the phase lengths together allow identification of nearly 99% of males. Interestingly, males were shown to move some distance within a breeding season, but return to the same territory year after year. It is hard to see how these insights could have been gained by other methods. One can also apply *capture-mark-recapture* methods to re-sightings based on vocalizations to estimate population size. In contrast, although the calls of Black-throated Diver *Gavia arctica* are distinct, the method proved impractical as a monitoring tool because calls are infrequent and difficult to record (McGregor *et al.* 2000). In each case, quantitative rules were developed to help discriminate one bird from another, but this is not always straightforward and, in some cases, ambiguity remains.

An advantage of this method is that it is non-intrusive, which might be particularly useful in studying rare and endangered species. The disadvantages are: that it requires high quality recording of birds that often live at low densities across scattered sites; ideally, one needs an independent means of identification, such as marking or radio tracking, to corroborate the findings; it requires specialist and quite expensive equipment; it often tells us only about breeding males; and it can be time-consuming, unless the analysis is automated (see Rebbeck *et al*. 2001).

2.4 Conclusions

A whole variety of different approaches can be used in surveying birds, but a series of questions need to be asked before work can begin. For example, are we interested in relative or absolute abundance, or a population index instead of a population estimate? As we have seen, it is vital to establish the objectives of the survey at the outset and consider their practicality and relative priority. The survey objectives will interact with, and be influenced by, the sampling strategy (choosing where to count) and the field method (how to count); these taken together define our survey design. A number of generic rules help us decide how to select our survey plots; random stratified and regular sample designs are best. Stratification should always be considered. Furthermore, a number of rules allow us to choose between survey methods and apply them in an appropriate fashion. We recommend line and point transects as the two most adaptable and efficient methods for most surveys. While each survey must be tailored to a particular situation, the common application of field methods will greatly enhance our ability to compare across studies; and we make some practical suggestions. A number of specialized and often more intensive techniques are available for survey and research purposes.

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