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USE OF MIST NETS AS A TOOL FOR BIRD POPULATION MONITORING

Erica H. Dunn and C. John Ralph

Abstract. Mist nets are an important tool for population monitoring, here defined as assessment of species composition, relative abundance, population size, and demography. We review the strengths and limitations of mist netting for monitoring purposes, based on papers in this volume and other literature. Advantages of using mist nets over aural or visual count methods include ease of standardized sampling, low observer bias, ability to detect species that are often missed using other count methods, and opportunity to examine birds in the hand (providing information on condition, age, sex, and capture history). The primary limitation of mist netting, in common with most other survey methods, is from potential bias in sampling. However, there are many approaches to reducing or adjusting for bias, including standardization of netting methods, combining mist-net sampling with other survey types, and using mark–recapture techniques. Mist netting is an essential tool for species inventory, provides useful indices of relative abundance, and can be used to track temporal trends in abundance. It is also one of the most efficient methods of capture for mark–recapture studies.

Key Words: mark–recapture, mist net, population monitoring, sampling bias.

Mist netting is an important technique for population monitoring, helping to assess species composition, relative abundance, population size, and demography (productivity and survival). Whereas mist netting is time intensive and requires specialized training, it has certain advantages over visual and aural population monitoring techniques. Mist nets can sample species that are poorly detected by other means, counts are not subject to observer bias, netting effort is easily standardized, and each bird counted can also be examined in the hand. Capture allows birds to be aged, sexed, and marked to allow individual identification in future encounters. In addition, extra data can be collected that also contribute to population studies, such as breeding status or sub-species identification. Data can be collected for other research purposes at the same time (e.g., physiological state, molt, parasite loads, DNA sampling). Because mist netting is one of the most efficient means of capturing many bird species, especially those that are insectivorous, the technique is often used in mark–recapture studies.

In this paper, we discuss the strengths and limitations of mist netting for population monitoring applications, and summarize the literature in which population parameters based on mist-net captures were evaluated by comparing them with data from independent data sources. In addition, we review the main sources of potential bias in population indices based on numbers of birds captured, and discuss some ways to address such bias. Ralph et al. (*this volume a*) should be regarded as a companion paper to this one, because it recommends best practices in mist netting, accompanied by the reasons why recommended procedures will improve monitoring capability.

SPECIES COMPOSITION

Mist netting is often used as a tool to determine what species are present in a study area. The technique is a valuable component of species inventory because it detects more cryptic, ground-foraging, and non-singing birds than aural or visual surveys (Blake and Loiselle 2001, Rappole et al. 1993, 1998, Wallace et al. 1996, Whitman et al. 1997). Further, results are relatively unaffected by the bird identification skills of observers (Karr 1981a; although misidentification may still occur, Dale *this volume*). However, netting is often a less efficient means of species inventory than censuses such as point counts, in terms of species detected per unit effort (Ralph et al. 1995, Gram and Faaborg 1997, Whitman et al. 1997). Moreover, netting is known to under-sample or completely miss some species (such as aerial foraging swallows, or raptors), regardless of season (Wang and Finch 2002). As a result, most authors have recommended that mist netting be used as a supplement to visual or aural surveys when a species inventory is being prepared, rather than as a sole source of data (Faaborg et al. *this volume*, Whitman *this volume*). Kendall et al. (*this volume*) provide information on using mark–recapture techniques to estimate the total species present, even though only a proportion has been detected.

RELATIVE ABUNDANCE AND TRENDS

Mist-netting studies are commonly used to document differences in abundance indices among species, locations, years, or age classes (see next section), and to detect trends in population indices over the long term. No matter what count methods are used to obtain abundance indices, the proportion of the true population that is counted will likely vary over time and space, introducing bias, which we discuss below. Nonetheless, evaluation studies have shown that abundance indices derived from mist-net sampling often compare well to independent data on the parameters of interest.

For example, species rankings based on relative abundance in breeding season mist-net samples were usually correlated with abundance rankings based on point counts at the same locations (Table 1), although individual species' rankings sometimes differed markedly between count types (DeSante et al. *this volume*, Kaiser and Berthold *this volume*). Similar studies in wintering areas gave mixed results, in that agreement of species' rankings between methods was quite good for some data sets (e.g., Wallace et al. 1996 *this volume*), but very poor in others (Blake and Loiselle 2001). Faaborg et al. (*this volume*) found good correspondence for year-round residents but very little for wintering species, and Lynch (1989) found that level of correspondence differed among habitats. In the migration season, birds are perhaps less selective of specific habitat types (Moore et al. 1995). For example, Wang and Finch (2002) found good correspondence between mist-net and point-count abundance rankings of species during migration in all habitats studied.

Within species, annual abundance indices have been shown to fluctuate in parallel with indices based on other data sources (Table 1). Repeated mist netting throughout the breeding season gave indices that paralleled abundance data derived from spot mapping, in 3 of 4 species studied by Silkey et al. (1999, from a single netting station) and in 9 of 21 species studied by Peach et al. (*this volume*, pooling data from many locations). No comparable studies have been conducted during the wintering season. For the migration season, Dunn et al. (*this volume a*) showed that annual abundance indices based on daily mist-net samples were strongly correlated with indices based on a standardized daily census in 73% of 64 species.

Several comparisons have been made between long-term trends in abundance indices based on netting data and trends from independent sources (Table 1). Pooled data from constant-effort mist netting at many locations during the breeding season corresponded with regional population trends based on spot mapping in 15 of 21 species (Peach et al. 1998, *this volume*). Trends in numbers of migrants captured were often correlated with Breeding Bird Survey trends from regions to the north where the migrants were assumed to have originated (Hagan et al. 1992, Dunn and Hussell 1995, Dunn et al. 1997, Francis and Hussell 1998, Berthold *this volume*, Rimmer et al. *this volume*). Correlations were strongest when statistical techniques were used that compensated for variation in daily bird numbers caused by weather and date in the season, and precision of long-term trends has been shown to improve when netting at a single station is more frequent (Thomas et al. *this volume*). However, as noted by Rimmer et al. (*this volume*), birds from diverse portions of the breeding range are typically sampled at a single location, making direct comparisons between mist-net capture rates and Breeding Bird Survey trends difficult.

DEMOGRAPHIC MONITORING

Monitoring of productivity is a special case of abundance monitoring, in which abundance of adult and young birds is assessed separately. Because capture probabilities differ between age classes (Ballard et al. *this volume*, Burton and DeSante *this volume*, Nur et al. *this volume*), the relative proportions of young to adults cannot be regarded as absolute measures of the number of young produced per adult, but rather are indices of productivity (Bart et al. 1999). Productivity indices from constant-effort mist netting in the breeding season have been compared to the numbers of nestlings found during intensive nest monitoring (Table 1). In some, but not all species, these estimates fluctuated in parallel between years (Nur and Geupel 1993b, du Feu and McMeeking *this volume*). Discrepancies may have resulted from post-fledging dispersal of young (e.g., Anders et al. 1998, Vega Rivera et al. 1998), so that mist-net samples represented local productivity in some species and regional productivity in others. Differences in mist-net based productivity indices among stations within a region (as found by Ralph et al. *this volume b*) could therefore result from true differences in local productivity, or from post-fledging redistribution of birds. Therefore, unless pilot work has demonstrated that productivity indices from mist netting accurately reflect local productivity in the target species, site-specific indices of productivity based on mist netting should at least be augmented by intensive nest monitoring (e.g., Gates and Gysel 1978, Roth and Johnson 1993).

In contrast, it has been demonstrated that collecting data from multiple netting stations is a good means of tracking regional productivity (Bart et al. 1999; Table 1). Cooperative programs that pool data from constant-effort sampling at many mist-net stations in a region include MAPS (Monitoring Avian Productivity and Survivorship; DeSante et al. *this volume*), the British Trust for Ornithology's

TABLE 1. COMPARISON OF POPULATION DATA COLLECTED BY MIST NETTING WITH DATA FROM INDEPENDENT SOURCES

Parameter	Season	Source of data for comparison	Correspondence of parameter between data sets	Source
Relative abundance of species	Breeding	Point counts	Correlated at 34 of 37 locations	DeSante et al. *this volume*, Kaiser and Berthold *this volume*
	Winter	Point counts	Roughly correlated in some data sets; not in others	Lynch 1989, Wallace et al. 1996, Blake and Loiselle 2001, Faaborg et al. *this volume*
	Migration	Point counts	Correlated in all habitats	Wang and Finch 2002
Annual abundance indices for individual species	Breeding	Spot mapping	Often correlated, but not in all species	Silkey et al. 1999, Peach et al. *this volume*
	Migration	Transect	Correlated in 73% of 64 species	Dunn et al. *this volume a*
Daily abundance indices	Migration	Point counts	Corresponded only roughly	Simons et al. *this volume*
	Migration	Radar	Corresponded only roughly	Simons et al. *this volume*
Population trends	Breeding	Spot mapping	Corresponded in 15 of 21 species	Peach et al. 1998, *this volume*
	Migration	Spot mapping	Often corresponded	Berthold *this volume*
	Migration	Breeding Bird Survey	Often corresponded	Hagan et al. 1992, Dunn and Hussell 1995, Dunn et al. 1997, Francis and Hussell 1998, Rimmer et al. *this volume*
Local productivity	Breeding	Nest monitoring	Corresponded in 4 of 4 species	du Feu and McMeeking *this volume*
	Breeding	Nest monitoring	Corresponded in 1 of 2 species	Nur and Geupel 1993b
Regional productivity	Breeding	Nest monitoring	Corresponded in 1 of 2 species	Nur and Geupel 1993b
	Breeding	Population model[a]	Corresponded (1 species studied)	Bart et al. 1999
Survivorship	Breeding	Resighting	Corresponded (1 species studied)	Nur et al. *this volume*
	Breeding	Band recoveries	Corresponded roughly (5 species studied)	Peach and Baillie *this volume*
	Breeding	Correlation with causal factor	Several examples	Peach et al. 1991, 1999
Sex ratio		Shooting	No correspondence (2 species)	Mawson 2000
Capture rate	Breeding	Other trap types	Does not always correspond	Bauchau and Van Noordwijk 1995, Collister and Fisher 1995

[a] A model containing results from annual range-wide counts and annual survival rates was used to estimate range-wide productivity in Kirtland's Warbler (*Dendroica kirtlandii*).

CES Scheme (Constant Effort Sites; Peach et al. *this volume*), the German MRI Program (Mettnau-Reit-Illmitz-Program; Kaiser and Berthold *this volume*), and the STOC program in France (Suivi Temporel du niveau d'abundance des populations d'Oiseaux terrestres Communs; Vansteenwegen et al. 1990). An evaluation of CES productivity indices (Peach et al. 1996) showed that although there was variation in capture rates and age proportions among locations, annual changes in age proportions at individual stations were similar in direction and magnitude across habitats and regions (Peach et al. 1996). Productivity indices based on pooled data also were similar among a cluster of stations in California (Ralph et al. *this volume b*), and pooled data from CES stations had acceptably low standard errors (Peach et al. *this volume*).

Migration data also may be useful for tracking regional productivity, as represented by the proportion of young birds in fall mist-net samples. However, this hypothesis has been little tested (Hussell *this volume*). It will be difficult to validate productivity indices that are based on capture of fall migrants, because independent productivity data from the breeding grounds will rarely be available (because breeding locations are unknown or unstudied). Nonetheless, some approaches to evaluation have been suggested for future research (Dunn et al. *this volume b*).

MAPS, CES, and the other cooperative demographic monitoring programs mentioned above are designed to collect information not only on productivity, but also on apparent survival rates. Whereas survival rates could be estimated for any season in which birds are site faithful and relatively sedentary, these cooperative studies estimate annual survival between breeding seasons. Average survival can also be estimated for individual netting stations, although sample sizes are usually too low to document annual differences (Faaborg and Arendt 1995, Hilton and Miller 2003).

There are fewer validation studies of survivorship estimates than of productivity indices, because independent estimates of survivorship are harder to obtain. Nur et al. (*this volume*) showed that survivorship of one species estimated from mist-net recaptures was similar to estimates based on resighting of marked individuals. Peach and Baillie (*this volume*) found that across five species, there was an overall (but non-significant) relationship between survivorship estimates based on CES and those based on band recoveries. Survival rates from CES were lower, probably because birds that emigrate from a station cannot be distinguished from birds that die, but the authors presented cogent arguments supporting the usefulness of CES estimates as indices of survival. There have also been several studies showing that change in annual survival rates was correlated with events likely to have had a strong effect on mortality (Peach et al. 1991, 1999).

POTENTIAL BIAS IN MIST-NET SAMPLES

As with bird counts obtained through visual and aural surveys, the numbers of birds captured in mist nets are indices of abundance, rather than total counts. Use of standardized, constant effort protocols will reduce variation in capture rates caused by uneven effort or net avoidance (Ralph et al. *this volume a*). However, even completely standardized operations capture only a proportion of all birds present, and that proportion will vary with species, habitat, weather, and other factors unrelated to true population size. Sauer and Link (*this volume*) showed that capturing different proportions of the true population could lead to false conclusions in comparison of samples, so it is important to investigate the potential for bias and to estimate its magnitude.

Capture rates at all seasons are affected by a multitude of factors, including distribution of nets with respect to territory size (Remsen and Good 1996, Ballard et al. *this volume*, Nur et al. *this volume*), mesh size of nets (Heimerdinger and Leberman 1966, Pardieck and Waide 1992, Jenni et al. 1996), season (Pagen et al. 2002), species (Jenni et al. 1996, Wang and Finch 2002), age class (Ballard et al. *this volume*, Burton and DeSante *this volume*, Nur et al. *this volume*), factors affecting movement rates (e.g., whether birds are incubating or molting), activity height (Remsen and Good 1996), and vegetation and habitat structure (Pagen et al. 2002, Ballard et al. *this volume*, Kaiser and Berthold *this volume*, Mallory et al. *this volume*, Whitman *this volume*).

Capture rates of migrants are also affected by most of these factors. Weather has a particularly strong effect on migrant numbers, because it influences rate of daily influx and departure from a location, and weather effects may be especially marked at stations near the edges of migration routes (Simons et al. *this volume*). In addition, during migration there will be daily variation in the proportion of birds migrating past the study site that actually stop there (Dunn and Hussell 1995). Migrating birds may be less selective of habitat during migration than are breeding birds, however, so habitat biases may be lower during migration than in other seasons.

After a review of sources of bias in mist-net captures, Remsen and Good (1996) concluded that unadjusted capture rates should not be used in quantitative comparisons of relative abundance, either among species, or within species among habitats. On the other hand, there is much evidence that a strong signal can be obtained from standardized index counts (Table 1). Whereas descriptive, non-qualitative results alone can be useful for land managers (e.g., Humple and Geupel 2002), information on relative abundance can add a great deal of value, particularly when conclusions are tempered by explicit discussion of the potential for bias and its possible magnitude. Moreover, long-term trend monitoring will not be compromised by the fact that numbers captured are only a proportion of true population size, as long as there are no temporal trends in the capture proportions themselves. In most studies such stability is assumed rather than directly tested, but Dugger et al. (2000) found that capture proportions in a neotropical study area remained relatively stable over time within species and locations. However, relatively small changes in a species' mean peak of activity can have a large effect on capture rates (Remsen and Good 1996). Long-term habitat change is the most likely source of systematic bias in long-term trends based on mist netting (Ralph et al. *this volume a*), and such change may be difficult to prevent even with regular management of the vegetation (Kaiser and Berthold *this volume*).

Mark–recapture methods can help to reduce the potential for bias caused by variation in capture proportions among mist-net samples (Sauer and Link *this volume*). Mark–recapture modeling estimates the proportion of all birds that is actually captured, which can then be used to estimate total population size (e.g., Kaiser and Bauer 1994, Kaiser and Berthold *this volume*). Peach and Baillie (*this volume*) and Kendall et al. (*this volume*) provided background on the uses of mark–recapture for this purpose, as well as for estimating adult survival, recruitment, and proportion of transients in a sample. The technique may have more limited value for migration studies, because the high rate of turnover in the birds present at a study location precludes using recapture rates to estimate population size. It should be noted that capture–recapture estimates of population size and capture probability are model-based, and the assumptions associated with any model must be considered when interpreting results.

Another means of addressing biases that may exist in mist-net samples is to adjust numbers of birds captured according to independent data on abundance. Although no count methods are completely problem-free, a few techniques have been developed that produce relatively unbiased estimates of density (Buckland et al. 2001, Bart and Earnst 2002, Thompson 2002). These methods can be used in combination with mist-netting studies to evaluate the presence and potential magnitude of bias in the mist-net samples. Once capture proportions have been quantified, the density estimation data can be used to adjust the mist-net samples during analysis.

FUTURE RESEARCH

The strengths and limitations of mist netting for population monitoring have received considerable attention in recent decades, but much remains to be learned. We suggest the following topics as priorities for research:

- The factors affecting the proportion of the true population captured need to be better quantified in a wider variety of species. In particular, more work is needed on effects of vegetation structure, habitat, and net avoidance.
- For programs that pool data from many stations, more work is needed on the most appropriate number and distribution of stations to ensure representative sampling at chosen geographic scales, the effects on results of frequency of operation, and on effects of station turnover.
- Additional validation studies are needed on abundance and demographic indices based on mist netting (including fall age ratios in migrating birds), and on population trends of temperate migrants sampled in their wintering areas.
- There is little information on age- or sex-specific differences in dispersal and habitat preference, or on degree of annual variation in these factors. Such knowledge is important for interpreting spatial and temporal differences in productivity indices.
- Mark–recapture methods are improving rapidly, but better models are needed to address dispersal of juveniles or previous breeders, and for pooling of data from multiple stations (especially when there is turnover in the sample of stations). Use of mark–recapture for migration studies also needs further investigation.

CONCLUSIONS

Mist netting as an extremely valuable tool for many kinds of population monitoring, not only for detecting the presence of species and counting individuals, but as an efficient means of capture to age individuals and mark them for future identification. It is almost unique among methods in providing demographic estimates in all seasons, for many species of birds. Although mist netting is especially effective as a monitoring technique when used in mark–recapture studies, it can also provide valuable indices of relative abundance. In addition, mist-net samples can be used to track long-term trends in abundance and productivity.

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