Studies in Avian Biology No. 29:161–167

USE OF MIST NETS FOR STUDY OF NEOTROPICAL BIRD COMMUNITIES

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Abstract. I reviewed mist-netting protocols of 43 recent Neotropical bird inventory studies. Most studies had multiple objectives, which likely contributed to a broad range of protocols being used. Most studies used 36 mm mesh, 12 × 2.5 m nets set singly, ~25 m apart. Netting typically took place within the first 8 h of the day starting at sunrise, and was conducted for three consecutive days, but there was much protocol variation within and among studies. Tall forest and agricultural areas were the most frequently studied habitats. Number of captures is affected by effort, net type and distribution, number of net-hours per day, number of days netting at a station, and number of visits to a station within a season. Variation in protocols therefore makes it difficult to compare results among studies, although there are a few techniques for doing so. Inventory by mist nets of a large proportion of species may require an effort of 1,000 net-h, more than in most of the studies reviewed. Any inventory should include aural surveys as well.

Key Words: inventory methods, mist netting, Neotropical birds, Neotropical forest, survey methods.

Mist netting has been commonly used to study bird communities in the Neotropics (Karr 1981b). Because protocols often differ among studies, comparisons of results among mist-netting studies usually involve standardization of effort by expressing captures as birds per net-hour (1 net-h being one net open for 1 h; Ralph 1976). However, variation in other aspects of mist-netting protocols can also preclude direct comparison (e.g., Bierregaard 1990, Pardieck and Waide 1992, Ralph 1976, Remsen and Good 1996, Robbins et al. 1992). Here I review 43 Neotropical mist-netting studies that had species inventory as one of the objectives to illustrate the range of variation in mist-netting protocols and to indicate which factors influence capture rates.

METHODS

DATA SET

Studies reviewed here (Appendix) were selected from Keast and Morton (1980), Hagan and Johnston (1992), Gentry (1990), Wilson and Sader (1995), and from journals over the 16-year period 1986–2002 (including *Auk*, *Condor*, *Biotropica*, *Ecology*, *Ibis*, *Journal of Field Ornithology*, and *Wilson Bulletin*). I excluded studies with undefined mist-netting protocols, or that focused on migrating birds or food habits. The review included 43 Neotropical studies covering 194 sample locations. Studies resulting in multiple publications were included only once. When possible, I used data only from the period from December to March, because many Neotropical mist net studies take place in this period to survey residents and Neotropical migrants simultaneously. Most studies conducted surveys within one season or year. The seasonal restriction also reduced the effect of variation in capture rates caused by migration, or by seasonal shifts in the height strata used by different species (Karr 1981a,b).

For each study, I noted objectives, latitude, habitat (old field, scrub, secondary forest, tall forest, agricultural), canopy height (m), net mesh size (mm), net size (m), meters of mist net run per day, number of nets per net line (a net line being one or more adjacent nets set within 10 m of each other), distance between net lines (m), number of consecutive netting days, number of netting hours per day, use of other census techniques, total net-hours, number of species and of individuals caught, number of visits (periods of consecutive netting days), number of days between visits, and number of stations. "Stations," for the purposes of this paper, are defined as net arrays separated by habitat differences or >500 m. Habitats with canopy heights less than 15 m tall were classified as scrub habitat (including scrub forest).

ANALYSES

To determine which factors affected the number of species and of individuals captured in inventory studies, I used simple pairwise Pearson correlation of number of species and of individuals captured during the entire course of the study with the following as independent variables (Wilkinson 1990): distance between net lines, total net-hours, number of net lines surveyed, number of visits, latitude, number of consecutive days of mist netting during visits, canopy height (m), mesh size of net, meters of net per day, nets per net line, and hours of mist netting per day. I estimated correlations separately for forest stations (secondary and tall forest) and non-forest (old field, scrub, and agricultural) stations, because a preliminary analysis with habitat as a covariate indicated that capture rates may be differently affected by these variables in different habitats. Given the large number of tests (N = 52) and probable multi-collinearity of variables, it is likely that some significant results were spurious. Moreover, this statistical approach did not consider possible non-linear relationships. Nonetheless, results can be used as a preliminary indicator of the factors that affect numbers and kinds of species captured.

RESULTS

Study Characteristics and Protocols

Of the 43 studies reviewed (Appendix), 12 had the sole objective of inventory (i.e., characterization of a community by numbers of species or individuals, proportion of migrants, or relative abundance of individual species). About three-quarters (31 of 43) had one or more additional objectives, including habitat use (measuring relative abundance of several species in more than one habitat), mark–recapture (estimating site fidelity, survival, or population size), and population trends (change in abundance at the same location across years). In only about one-third of the papers (15 of 43) did authors discuss biases associated with mist netting. Only one study was based on a pilot study (Robbins et al. 1992), and only four papers cited methodological studies that verified whether mist netting was the best technique to achieve the stated research goals. About one-quarter of the studies (12 of 43) also included aural censuses.

In most studies, researchers used nets of with a mesh size of 36 mm (Fig. 1A) and used nets of only a single mesh size (Fig. 1B). Nets were typically 2.5 m tall × 12 m long (Figs. 1C, 1D). Nets were set in lines ranging from 1 to 30 nets (Fig. 1E). Lines of nets were spread widely (median = 25 to 50 m; Fig. 1F). In most studies researchers netted between 5 and 12 h/day starting at sunrise (Fig. 1G), and netted for one to three days at a location (Fig. 1H).

Tall forest and second growth forest were the most frequently surveyed habitats (Fig. 2A). Most stations were visited only once (Fig. 2B). Most stations were sampled for greater than 500 net-h (Fig. 2C), usually with over 100 m of mist net (Fig. 2D). At 47 inventory stations with net-hour data, however, only about 25% (11) were netted for >1,000 net-h. Inventory stations were netted for a mean of 2,012 net-h (SD = 3,268). Stations commonly captured between 20 and 39 species (Fig. 2E) and up to 400 individuals (Fig. 2F).

Factors Related to Number of Captures

The protocol parameters affecting number of species and number of individuals captured differed between habitats (Table 1). In non-forest habitats, there were only two significant correlations: number of species captured increased with greater distance between net lines, and number of individuals captured decreased with increasing latitude.

Number of species captured in forested habitats was significantly correlated with many parameters. These included effort variables (total net-hours), equipment (mesh size), sample area (distance between net lines and number of net lines surveyed), amount of continuous effort at a station (number of visits and number of consecutive days of netting at each visit), and habitat structure (canopy height). In forest habitats, the number of species captured was not correlated with latitude or with amount of daily netting effort (meters of net per day, number of nets per net line, or hours of netting per day).

In forested habitats, several parameters were also correlated with number of individuals captured. These included parameters related to effort (total net-hours), sample area (distance between net lines and number of net lines surveyed), and amount of continuous effort at a station (number of visits). The number of individuals captured in forest habitats was not correlated with number of consecutive days mist netting, vegetation structure (canopy height), mesh size, amount of daily mist netting (meters of net per day, number of nets per net line, or hours of mist netting per day), or latitude.

Protocol Variation

Sampling protocols varied significantly within individual inventory studies. Two-thirds (25 of 43) of the studies did not use the same sampling protocol at each station, and only 17% (7) used the same protocols for all locations sampled (variation in the protocols of the remaining 11 studies was not reported). Two-thirds of the studies sampled different sized areas at some stations (N = 12), or used different net densities (N = 10).

DISCUSSION

Results in this paper indicated a high variability of mist-netting methods in the Neotropics both among and within inventory studies. Variation of this magnitude makes it very difficult to directly compare results among studies (Magurran 1988). Here I discuss some of the effects of that variation on inventory results.

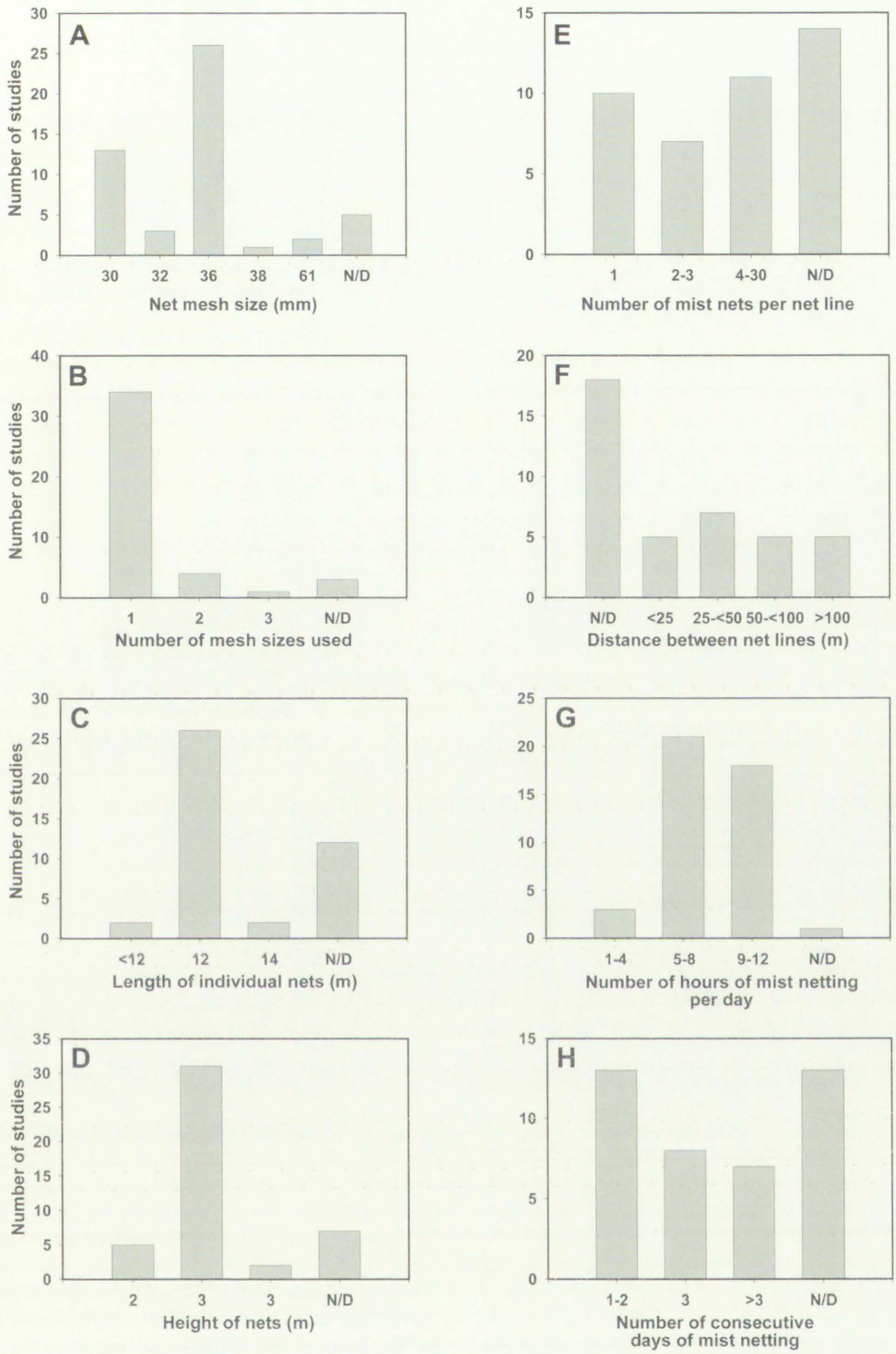

FIGURE 1. The frequency of studies (N = 43) using different: (A) net mesh sizes, (B) numbers of mesh sizes used, (C) length of individual mist nets, (D) height of individuals mist nets, (E) number of mist nets per net line, (F) distance between net lines, (G) number of hours of mist netting per day, and (H) number of consecutive days of mist netting at a visit. N/D = studies in which a variable was not described.

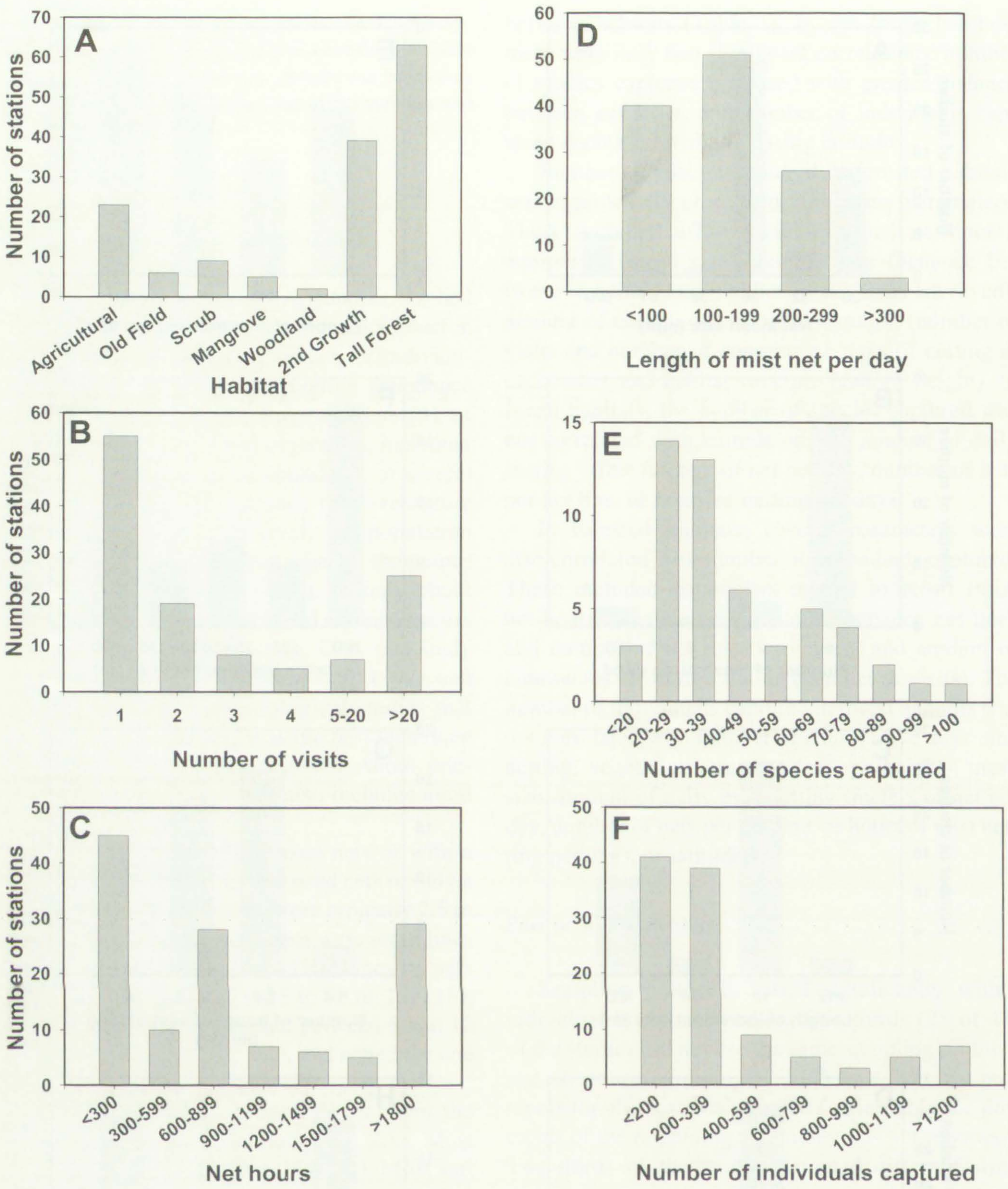

FIGURE 2. The frequency of stations (N = 194) with different: (A) habitats, (B) numbers of visits (netting sessions of one or more consecutive days), (C) net hours, (D) length of mist net operated per day, (E) numbers of species captured, and (F) number of individuals captured.

Overall Effort

Karr (1981a) concluded that for the purposes of species inventory, capture of 100 individuals was an adequate compromise between effort and quality of results. Most studies reviewed here met that objective (Fig. 2C). However, it should be recognized that such studies may not yield accurate assessment of species evenness (Bierregaard 1990), or reveal the presence of uncommon species. In agricultural and shrub habitats, a sample of 700 net-h may be needed to detect most individuals and species (Petit et al. 1992, Borges and Stouffer 1999), whereas in forest habitats, a sample of 1,000 net-h may be needed (Blake and Loiselle 2001, Petit et al. 1992, Lopez de Casenave et al. 1998). Most studies in this review had <1,000 net-h (Fig. 2C).

Another way of evaluating the effort required

TABLE 1. PEARSON CORRELATION COEFFICIENTS BETWEEN THE NUMBER OF SPECIES OR OF INDIVIDUALS CAPTURED AND VARIOUS INVENTORY PROTOCOL PARAMETERS, IN NON-FOREST AND FOREST HABITATS

	Non-forest habitat			Forest habitat		
	Number of species	Number of individuals	Number of studies	Number of species	Number of individuals	Number of studies
Distance between net lines (m)	**0.598**	0.437	12	**0.918**	**0.990**	9
Total net-hours	0.337	0.325	22	**0.830**	**0.925**	13
Number of net lines surveyed	0.233	0.147	17	**0.717**	**0.801**	12
Number of visits	-0.007	0.364	25	**0.544**	**0.760**	17
Latitude (°)	-0.132	**-0.568**	26	-0.098	-0.396	18
Consecutive days of netting	-0.251	-0.127	25	**0.506**	0.442	14
Canopy height (m)	-0.190	-0.006	16	**0.574**	0.263	15
Mesh size of net (mm)	0.329	-0.275	26	**0.597**	0.221	15
Meters of net per day	0.241	0.022	17	0.433	0.385	12
Nets per net line	0.314	-0.007	26	0.302	0.480	15
Hours netted per day	-0.084	0.055	23	-0.013	0.172	16

Notes: Correlation coefficients in boldface were significant ($P < 0.05$).

for useful species inventory is to look at number of individuals captured. A high proportion of species was detected after capture of at least 500 individuals, whether in forest (Lynch 1989) or non-forest habitats (Borges and Stouffer 1999, Lynch 1989, Mallory and Brokaw 1993). However few studies included this many individuals (Fig. 2F), and an essentially complete survey in forest habitats may require a sample of 1,000 individuals (Blake and Loiselle 2001, Karr et al. 1990b). Although capture of more than 500 individuals usually does not detect many additional species, the new species will be ones that are rare. Thus, samples comprised of few captures will have low proportions of rare species and greater species evenness, as compared to samples with many captures.

Aural surveys detect many species better than mist netting (and hence more species and individuals; Blake and Loiselle 2001, Lynch 1989, Rappole et al. 1998, Wallace et al. 1996), but they are affected by observer bias (Faanes and Bystrak 1981, Levey 1988, Verner 1985). Mist netting, on the other hand, detects a few common bird species better than aural surveys, is not affected by observer bias, and may yield greater counts of individuals for some species (Blake and Loiselle 2001, Rappole et al. 1993, 1998, Wallace et al. 1996, Whitman et al. 1995). Therefore, thorough studies of Neotropical bird communities may require both aural surveys and mist netting.

NETTING PROTOCOL

Increasing mesh size correlates with increasing capture rates for larger species, so restriction of mesh-size biases inventory results (Heimerdinger and Leberman 1966, Pardieck and Waide 1992). In this review, 36-mm mesh nets were by far the most commonly used, and few studies used more than one size. Karr (1981a) suggested using 36-mm mesh nets as a good general mesh size for catching most species 8 to 100 g. However, 36-mm nets will catch up to 50% fewer individuals of small (<20g) species than will 30-mm mesh nets (Heimerdinger and Leberman 1966, Pardieck and Waide 1992).

Most researchers preferred distributing their nets uniformly within a study plot to eliminate observer bias in station selection. Some researchers argue for maximizing capture rates by placing nets at "good" locations that have many species, but this introduces observer bias, especially in the capture rates of individual species (Karr 1979, Whitacre et al. 1993), and may make statistical comparisons among stations inappropriate.

Spacing nets >50 m apart may maximize the numbers of unique individuals and species captured (e.g., Karr 1981a). However, for a fixed sample area, nets placed along a transect will cross more microhabitats and bird territories than nets placed in a grid, and therefore will capture more species and new individuals.

In Neotropical studies, number of sequential days of netting at a station has been shown to strongly influence capture rates (Robbins et al. 1992, Faaborg et al. *this volume*). The number of birds caught declines after the first day because the proportion of the population captured increases with each passing day, and captured birds avoid mist nets after being caught (Bierregaard 1990, Robbins et al. 1992, Terborgh and Faaborg 1973). Thus, a mist-netting study conducted on a single day may not be comparable to a study conducted on several days, unless the raw data are available and the analyses are restricted to data in common.

In tall forest, additional visits may increase the number of species and individuals captured as long as there are at least three weeks between visits. A three-week interval may sufficient to minimize net shyness (Bierregaard 1990), although other researchers suggests that much longer intervals may be necessary (J. Faaborg, pers. comm.).

Addressing Variation in Protocols

When mist nets are used to conduct inventories and accomplish other objectives as well, more than one sampling protocol may be necessary. For example, the chief goal of an inventory is to catch as many different species as possible, which includes minimizing effort spent on recapture. Mark–recapture studies have the opposite goal, that is, to maximize the number of recaptures. Simple comparisons of species richness among locations can be accomplished by using species accumulation curves from each station (Herzog et al. 2002) even when different protocols were used. If the original data are available and protocols do not differ significantly, bootstrap analysis can be an effective technique for eliminating the effect of unequal sampling effort on results (Karr et al. 1990b). However, use of standardized protocols whenever possible should help make results of mist netting studies more comparable.

ACKNOWLEDGMENTS

I thank G. R. Geupel, J. Faaborg, M. Kasprzyk, J. R. Karr, E. P. Mallory, C. J. Ralph, J. Hathaway, and E. H. Dunn for their generous comments.

Appendix. Location, habitat, number of survey stations, and objectives of reviewed studies

Study	Country(s)	Habitats[a]	Number of stations	Objectives[b]
Bierregaard 1990	Brazil	Tall forest	1	I, M, P
Blake 1989	Panama	Tall forest	3	I
Blake and Loiselle 1992	Costa Rica	Secondary and tall forest	5	H, I M
Borges and Stouffer 1999	Brazil	Old field	6	H, I
Lopez de Casenave et al. 1998	Argentina	Tall forest	1	H, I
Gonzalez-Alonso et al. 1992	Cuba	Shrub	1	I
Greenberg 1992	Mexico	Tall forest	5	H, I M
Karr 1990	Panama	Tall forest	1	I, M
Kricher and Davis 1992	Belize	Secondary and tall forest	3	H, I
	Belize	Old field	3	H, I
Lefebvre et al. 1992, 1994	Venezuela	Mangrove	1	I, M
Lopez de Casenave et al. 1998	Argentina	Tall forest	2	I
Lynch 1992	Mexico	Old field, scrub	2	H, I, P
Malizia 2001	Argentina	Tall forest	2	H, I
Mason 1996	Venezuela	Tall forest	14	H, I
Martin and Karr 1986	Panama	Secondary forest	1	I, M
Machado and Da Fonseca 2000	Brazil	Tall forest	4	I
Mills and Rogers 1992	Belize	Agricultural	5	I
Murphy et al. 1988	Bahamas	Low secondary forest	3	I
	Bahamas	Mangrove	2	I
	Bahamas	Old field, scrub	5	I
Poulin et al. 1993	Venezuela	Scrub, woodland	3	H, I
	Venezuela	Tall forest	3	H,I
Rappole et al. 1998	Mexico	Tall forest	10	H, I
	Mexico	Secondary forest	10	H, I
	Mexico	Agricultural/old field	10	H, I
Robbins et al. 1992	Puerto Rico	Agricultural	8	H, I
	Jamaica	Tall forest	8	H, I
	Belize	Tall forest	8	H, I
	Costa Rica	Tall forest	8	H, I
Robinson and Terborgh 1990	Peru	Tall forest	1	I, M, H
Stouffer and Bierregaard 1995	Brazil	Tall forest	9	I

APPENDIX. CONTINUED

Study	Country(s)	Habitats[a]	Number of stations	Objectives[b]
Thiollay 1994	French Guiana	Tall forest	1	I
Waide 1980	Mexico	Old field, tall forest	5	H, I
Waide 1991	Puerto Rico	Tall forest	1	I, P
Wallace et al. 1996	Cuba	Secondary forest	6	H, I
		Low secondary forest	9	H, I
		Scrub	2	H, I
		Mangrove	1	H, I
Whitman et al. 1995	Belize	Tall forest	1	I, H
Will 1991	Nicaragua	Tall forest	1	I
Wunderle 1995	Puerto Rico	Tall forest	1	H, I, P
Young et al. 1998	Costa Rica	Tall forest	20	I

[a] Tree crops include citrus, coffee, cacao, mango.

[b] H = habitat use, I = inventory, M = mark–recapture, P = population monitoring.