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A METHOD OF STUDYING WILD BIRD POPULATIONS BY MIST-NETTING AND BANDING

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INTRODUCTION

A method of estimating avian populations is essential for clarifying the ecology of arthropod-borne viruses in wild birds. The activity of such viruses is being investigated by capturing birds in nets, banding and taking a blood sample, then recapturing a proportion of them later. A technique for estimating population densities incorporated into such studies will increase their value greatly. Such a technique also will be useful in general ornithological studies and in the evaluation of the effects of pest-control measures on birds. For these purposes, a method of population estimation should provide estimates for a maximum number of species and of individuals, birds of all ages and both sexes, breeders and nonbreeders; it should be applicable in all sorts of environments, in all seasons, and allow statistical evaluation of the dependability of data.

Quantitative studies on breeding populations of small wild birds have been of two types. First, the trapping and marking of a large proportion of a population of one or a few species, with detailed observation of individual birds over a long period (Kendeigh, 1934-44; Nice, 1937; Kluijver, 1951; Farner, 1955). Second, the estimation of breeding-bird populations by the Williams (1936) spot-mapping technique (*Aud. Field Notes*, 1950) which is based largely on territorial males. These methods have produced much useful and interesting information but also have emphasized the need for techniques more closely approaching the ideal outlined above. Recently, the introduction of the Japanese mist net has made available a highly nonselective method for taking larger numbers of a wider variety of species than by any other method in use (Austin, 1947; Low, 1957).

This paper reports progress toward development of a method of estimating numbers of small wild birds by combining mist-netting and banding, then calculating the population on the basis of recapture. Results obtained by this method are compared with those from a concurrent breeding-bird census made by the Williams spot-mapping method. The netting method was found to be practical for most species present and to yield results within useful statistical limits. The estimates obtained are, of course, based on the assumptions inherent in the recapture method.

LOCATION OF STUDY

The study was conducted at the Patuxent Wildlife Research Center near Laurel, Maryland. This area has been surveyed and permanent markers placed 330 feet apart on a grid. Nets were placed in a heavily-wooded deciduous forest, in and immediately adjacent to the flood plain of the Patuxent River in the Western Shore Section of the Oak-Pine Forest Region of Maryland (Stewart & Robbins, 1958), elevation is 95 to 105 feet. The study tract is surrounded by similar habitats for at least 4 miles upstream (NW), 4 miles downstream (SE), 400 yards to the northeast, and 150 to 350 yards to the southwest. Percentage distribution of the net locations by habitats (as described by Hotchkiss and Stewart, 1947) was 45% Terrace Forest (Beech, White Oak), 14% Bottomland Forest (Beech, Tulip-tree, Northern Red Oak [*Q. borealis*], Sweetgum), 14% River Swamp (Pin Oak, Overcup Oak [*Q. lyrata*], Red Maple, Sweetgum, Red Ash), 10% Transition Swamp, 7% Shrub Swamp, 5% Seepage Swamp, 2% Second Growth Swamp, and 2% Upland Oak Forest.

MATERIALS AND METHODS

Netting method.—Imported Japanese mist nets made of nylon (obtained from the Northeastern Bird-Banding Association, designated Type A: 4-shelf, 12-meter) were stretched between bamboo poles braced by 60-pound-test green linen fishline.

Nets were placed at 200-foot intervals along two 2000-foot lines that intersected at right angles at their midpoints. This arrangement was chosen because it represented about the maximum distance one person could walk, process the birds, and visit each net at least once every 2 hours. Within these limitations, this pattern offers the best sampling of habitat, intersects a maximum number of territories, and allows maximum detection of bird movement. The 200-foot interval was chosen on the basis of previous use of nets in woodland, where recaptures usually were made 400 to 600 feet apart. Thus, this interval should place two or three nets within the range of each bird. To set out the nets, survey lines were first located and flags placed at grid markers. Trails then were cleared. Net locations were determined by use of a 100-foot rope and a compass.

On March 31, 1959, 18 nets were placed parallel to the survey lines in the pattern described. Initially, no net was placed at the center position or at the first positions north and south of the center. On April 20, three nets were placed perpendicularly across the survey lines in these positions, and this arrangement was used through May 26. On June 3, each net was moved 100 feet south and 100 feet west to newly prepared lines and all of the nets were placed perpendicularly across the lines. These locations were used from June 4 through June 9. Ten nets that were somewhat damaged were replaced by new or slightly used ones when the arrangement was moved on June 3. All of the nets that were in place for the entire interval of 72 days were still in good condition at the end of this period.

During the last round of each day the nets were taken out of operation by slipping the end loops of each together at the middle of the poles and relaxing the bracing cords on one pole. When there were intervals

of one day or longer between netting, the mesh was fastened around the gathered shelf strings with pieces of cord by making ties at the center and about 6 feet from either end; loose mesh between ties was then wound around the shelf strings. When nets were used daily, the mesh of the net was not tied with cords but was wrapped around the shelf strings by a cranking motion from one end of the net after it had been slackened.

During active operation of the nets, all birds were first removed as rapidly as possible and placed in black cloth bags. (These bags are about 12 x 15 inches in size and are held flat and close by a corset stay sewed into each side 3 inches from the open end.) Five of these bags were carried while netting. Individuals of hard-biting and fighting species were placed in individual bags. Up to 5 birds of other small species were held satisfactorily in a single bag for short periods. Birds were identified, banded (if new), checked for brood patches, measured, released, and their net locations recorded, all within a few minutes of removal from the net.

The method used to estimate the population on the basis of recapture (Peterson, 1896) is based on the following reasoning. If a number of birds are banded and released, then the reciprocal of the proportion of banded birds in a subsequent sample times the number marked originally gives an estimate of the original population. This relationship is expressed in the formula:

$$N = \frac{Mn}{m}$$

N = the estimated number of birds present *during the marking period.*
M = the number of birds banded and released during the marking period.
n = the total number of birds captured during the sampling period.
m = the number of birds captured during the sampling period that were captured and released banded during the marking period.
The standard error of N is calculated from the formula:

$$\text{S. E.} = \sqrt{\frac{(M)^2 n\ (n-m)}{(m)^3}}$$

(Bailey 1951)

Population estimates made by this method are based on the following assumptions:

1. No loss or gain of marks.
2. No difference in mortality of marked and unmarked individuals.
3. Random distribution of marked and unmarked individuals or random sampling.
4. No recruitment, no difference in departures of marked and unmarked.
5. Behavior and catchability the same in marked and unmarked.

Assumptions 1, 2, and 3 probably are valid for the period of this study or at least the variations are inconsequential. However, information obtained shows that assumptions 4 and 5 are not valid in this study. Recruitment and net-shyness both tend to inflate population estimates and clearly do so in this study.

Spot-mapping Method.—Estimate of populations by the spot-mapping

procedure followed the Williams method, described in *Audubon Field Notes* (1950). The area in which the census was made lay within a square, 2,310 feet on each side, centered at the middle net. Instead of including the entire square of 122½ acres, an area of 22½ acres (990 x 990 feet) was omitted from the northeast corner and a strip containing 10 acres (330 x 1320) was omitted from the north edge. On the remaining 90 acres, previously surveyed lines running north-south and east-west at intervals of 330 feet were cleared, and marked with white tags. The area was censused by walking along these cleared trails on the following dates: May 21, 23, 26 (2 trips), 28, 30, and June 4, 6, 9, 1959. Trips started between 4:12 and 4:55 a.m. and ended between 8:00 and 9:35 a.m., except for one late morning trip from 9:05 to 11:40 a.m. The mean time per trip was 4 hours and 10 minutes.

During each census trip all birds seen or heard within 165 feet (half the distance between trails) of the census trails were plotted on a field map. Approximate positions of birds heard at greater distances also were mapped, and these positions were corrected later if the birds subsequently were heard closer to one of the other census lines. Symbols were used to designate sex, if known, and to indicate the positions of two birds of the same species that were heard singing simultaneously. At the conclusion of each day's trip, all records from the field sheets were transferred to separate sheets for each species. A different color was used on the species sheets for each day's records. Birds seen in the mist nets during the census trips were not mapped or included in the spot-mapping census in any way. Although a few records of singing birds were lost as a result of simultaneous netting operations, it was believed that inclusion of the netting data would distort the census figures considerably more than would omission of the netting data. Records from previous days were never taken into the field during census trips, as such a practice could have influenced the observer in his determination of positions.

After data from the nine field trips had been transcribed onto species sheets, it was assumed that clusters of spots of a given species color represented occurrences of a single male of that species on his singing territory. Thus approximate territories were sketched on the sheets on the basis of the clusters of records, and more especially from notations regarding different individuals heard singing simultaneously.

The number of territories in the 90-acre study area was obtained by adding to the number of territories that lay entirely within the 90 acres the fractional portions of those territories that lay only partly within the area. The number of territories per 100 acres was obtained by dividing the number per 90 acres by 0.90 and rounding off the quotient to the nearest whole number. The resulting number was multiplied by 2 to convert singing males to total individuals; this, of course, was done on the assumption that there were equal numbers of males and females in the area.

Estimates of the population by each method were made without knowledge of results by the other method.

Operation of nets.—Nets were operated on 23 days from March 31 through June 9, 1959. Eighteen nets were used on April 2, 4, and 6, and 21 nets on all subsequent days. The opening round was begun

at 7:00 a.m. on all days except April 2 (9:30), 21 (9:00), May 9 (6:00) and 16 (7:30). The closing round, although irregular through April 23, was started at 4:30 p.m. from April 25 through May 21 (except (5:00 on May 5 and 6:00 on May 9), and at 5:00 for the remainder of the study. Nets were visited at approximately 1½-hour intervals through May 21, and at exactly 2-hour intervals from May 23 though June 9. During a total of 4200 net-hours of operation 966 captures were made, yielding an average rate of 23.0 captures per 100 net-hours.

DESCRIPTION OF VEGETATION IN TERMS OF TREE COMPOSITION

Habitat.—The habitats in which these studies were conducted require description in terms that permit ready comparison with other areas in order that bird populations may be compared. Although plant ecologists have developed many methods of describing vegetation, the simplified scheme that was used requires only meager botanical knowledge and very little time. The essence of the procedure was to list the size and frequency of trees near each net by systematic sampling. The trees give a clear picture of the general aspect of the vegetation and can serve as a basis for comparison with other areas.

The trees to be measured were selected as follows. The first step was to place a 100-foot rope on the ground in line with the net and extending out from the east (or south) pole. The observer then stood at this pole facing east (or south) and selected the nearest tree that was within a quarter circle on each side of the rope. Thus he was choosing a tree within a half circle whose base was perpendicular to the direction of the

TABLE 1. Species of trees adjacent to nets

	Circumference in inches							
	4 or less	5-14	15-24	25-49	50+	Total trees	% of 525 trees	Present at % of nets
Pinus echinata (Shortleaf Pine)	—	—	—	1	—	1	—	4.8
Carya glabra (Pignut)	1	—	—	1	—	2	—	9.5
Carpinus caroliniana (Hornbeam)	93	14	1	—	—	108	20.6	66.6
Betula nigra (River Birch)	2	—	—	—	—	2	—	9.5
Alnus rugosa (Alder)	17	—	—	—	—	17	3.2	33.3
Fagus grandifolia (Beech)	58	14	5	9	1	87	16.6	76.0
Quercus alba (White Oak)	10	9	4	3	2	28	5.4	52.0
Quercus bicolor (Swamp White Oak)	—	—	1	—	—	1	—	4.8
Quercus palustris (Pin Oak)	—	4	2	3	2	11	2.1	33.3
Quercus phellos (Willow Oak)	—	3	1	2	—	6	1.0	19.0
Quercus velutina (Black Oak)	2	—	—	—	1	3	—	14.3
Ulmus sp. (Slippery Elm)	4	1	—	—	—	5	1.0	4.8
Magnolia virginiana (Sweetbay)	5	—	—	—	—	5	1.0	9.5
Liriodendron tulipifera (Tulip-tree)	1	1	—	1	—	3	—	9.5
Sassafras albidum (Sassafras)	3	—	—	—	—	3	—	9.5
Liquidambar styraciflua (Sweetgum)	30	13	13	22	2	80	15.3	81.0
Ilex opaca (Holly)	3	1	—	—	—	4	—	14.3
Acer rubrum (Red Maple)	29	23	22	8	1	83	15.8	76.0
Cornus florida (Flowering Dogwood)	14	2	1	—	—	17	3.2	14.3
Nyssa sylvatica (Blackgum)	12	14	9	6	—	43	8.2	66.6
Fraxinus pennsylvanica (Red Ash)	12	3	—	—	—	15	2.8	14.3

net. After this tree was measured a second was chosen by the same procedure using the tree rather than the pole as a base. Then subsequent trees were chosen until 25 had been measured at each net. Care was exercised to keep the base of the half circle perpendicular to the rope and so avoid "back-tracking."

Several arbitrary rules were observed. The trees were measured at breast height. All trees that had attained breast height were included. If multiple trees were separated at the base, each was counted as an individual. Shrubs were omitted even though some were more than breast high. Bent trees were included if the base was within the area.

The data for each net were recorded on individual sheets and then summarized (Table 1). Nomenclature follows Hotchkiss and Stewart, 1947. The relative importance of each species is indicated in two ways: the percentage of total trees and the percentage of net locations having at least one of each species. These two calculations give a clear impression of the habitat. The forest is just reaching maturity (many Beeches but few very large ones), has a definite understory (Hornbeam, Beech, Flowering Dogwood), is primarily a moist area (Red Maple, Willow Oak, Sweetgum) but has some dry parts (pines, Black Oak).

RESULTS

A summary of daily captures, net-hours of operation, and captures per 100 net-hours is given in Tables 2 and 3. From March 31 through April 25 most of the birds captured were either winter residents or

TABLE 2. Summary of captures of breeding species 1 through 29*

Date 1959		Adult				Immature		Total
		New birds banded & released	Repeat from previous days	Repeat same day	Died (D) or Escaped (E) not banded	New birds banded & released	Repeat from previous days	
March	31	4	—	—	—	—	—	4
April	4	6	—	—	—	—	—	6
	6	4	1	—	—	—	—	5
	21	10	2	—	—	—	—	12
	23	3	1	—	—	—	—	4
	25	1	—	—	—	—	—	1
May	5	52	—	5	1D	—	—	58
	7	37	13	1	—	—	—	51
	9	41	13	2	—	—	—	56
	12	33	15	3	—	—	—	51
	14	26	16	1	1D	—	—	44
	16	20	21	1	1D	—	—	43
	19	36	16	1	2E	—	—	55
	21	33	20	2	1E	—	—	56
	23	16	16	2	1E	—	—	35
	26	21	15	2	—	—	—	38
June	4	31	30	4	—	—	—	65
	5	16	26	3	—	5	—	50
	6	10	28	2	—	1	—	41
	7	10	26	1	—	3	1	41
	8	10	10	1	—	1	1	23
	9	11	16	2	—	1	—	30
Total		431	285	33	7	11	2	769

*Listed in Table 5

permanent residents. Only 3 summer residents were banded during this period: A Louisiana Waterthrush* was taken on April 4, a Black-and-white Warbler on April 21, and a Blue-gray Gnatcatcher on April 23; all of these individuals were recaptured during May. As compared with May, the rate of capture during April was low and showed a sharp decrease on the 23rd and 25th. This trend reflects the lower density of the winter and early spring population and the departure of most winter-resident birds before the arrival of large numbers of summer-resident birds that had wintered farther south. Summer-resident breeding species apparently arrived in large numbers between April 25 and May 5.

The proportion of recaptured birds to new birds in daily totals tended to increase as more birds were banded. Immature birds were taken first on June 5 and they constituted 7 per cent of the captures from June 5 through June 9.

Eight birds were killed during the actual netting procedure, amounting to 0.8 per cent of captures. Also, four birds died when they became

TABLE 3. Summary of captures

	Winter Resident and Transient Species*					All Species		
Date 1959	New birds banded & released	Repeat from previous days	Repeat same day	Died (D) or Escaped (E) not banded	Total non-breeders	Total captures	Net-hours	Captures per 100 net-hours
March 31	47	—	—	1D	48	52	**	—
April 2	1	—	—	—	1	1	**	—
4	9	1	—	—	10	16	153	10
6	31	1	—	—	32	37	180	21
21	6	—	—	—	6	18	147	12
23	4	—	—	—	4	8	189	4
25	1	1	—	—	2	3	200	2
May 5	9	—	—	—	9	67	210	32
7	8	—	—	—	8	59	200	30
9	9	2	1	—	12	68	252	27
12	7	1	—	—	8	59	200	30
14	10	—	—	—	10	54	200	27
16	14	1	—	—	15	58	189	31
19	11	1	—	2E	14	69	200	35
21	6	—	—	—	6	62	200	31
23	7	—	—	—	7	42	210	20
26	3	—	—	1D	4	42	210	20
June 4	—	—	—	—	—	65	210	31
5	—	—	—	—	—	50	210	24
6	—	—	—	—	—	41	210	20
7	—	—	—	—	—	41	210	20
8	1	—	—	—	1	24	210	11
9	—	—	—	—	—	30	210	14
Total	184	8	1	4	197	966	4200	23

* Plus 1 Robin on May 12 and 1 Woodcock on June 8.
See Table 4 for list of winter residents and transients.
**Irregular operation; nets being placed.

*The names of bird species included in this paper follow the "Check-List of North American Birds" (5th ed.) prepared by a committee of the American Ornithologists' Union, 1957.

entangled in improperly tied nets between netting periods and this raised total mortality to 1.2 per cent of captures.

A summary of captures of non-breeding species is given in Table 4. Only 6 of 99, or 6 per cent, of the individuals of transient species were recaptured the next day or later, as compared to 38 per cent of adults of breeding species.

Data on 29 breeding species, including recaptures, movement, and a comparison of population estimates made by the recapture method and the spot-mapping technique are summarized in Table 5. Species are numbered to facilitate discussion of findings for various groups. Three breeding species (species 30, 31, 32) included in the spot-map census were not banded. (Two Ruby-throated Hummingbirds were captured in nets but released unbanded; no Barred Owls or Common Crows were taken in the nets.) Surprisingly few transient individuals of breeding species were captured; in fact, the American Goldfinch was the only breeding species for which transients are known to have been banded. Seventeen goldfinches banded on March 31 and 3 others banded on or before May 7 were assumed to be transients and were omitted from the breeding bird calculations. Also omitted were one American Woodcock and one Robin that were present in the area as post-breeding wanderers.

Species 1 through 32 are divided into two groups for population estimation. The first group (species 1 through 16) includes 16 species of which 25 per cent or more individuals were recaptured; this group includes 85 per cent of all individuals of the 29 species banded. The second group (species 17 through 32) includes 13 banded species of

TABLE 4. Adults of winter-resident and transient species taken between March 31, and May 26, 1959

Species	Number banded and released	Number recaptured next day or later
Winter-resident species		
Yellow-shafted Flicker	3	
Brown Creeper	3	
Rusty Blackbird	1	
Slate-colored Junco	59	1
White-throated Sparrow	17	1
Total 5	83	2
Transient species		
Great Crested Flycatcher	1	
Catbird	1	
Swainson's Thrush	26	1
Gray-cheeked Thrush	12	1
Veery	3	
White-eyed Vireo	1	
Tennessee Warbler	1	
Magnolia Warbler	1	
Black-throated Blue Warbler	2	
Chestnut-sided Warbler	1	
Northern Waterthrush	16	3
Canada Warbler	8	
Indigo Bunting	3	
American Goldfinch (part)	20	
Swamp Sparrow	3	1
Total 15	99	6

which fewer than 25 per cent of the individuals were recaptured; this group includes 15 per cent of all individuals of the 29 species. In general, the species recaptured least frequently were those with the fewest individuals present, those having large ranges, or very small species (gnatcatchers), which the nets are least efficient in capturing. Recaptures for each species are listed only for the period May 5 through June 9, and captures made during this period are used in calculating distances between recaptures and in making population estimates. Earlier captures are excluded because differences probably exist in the amount of movement before and after birds are settled in breeding territories. A total of 301 recaptures of 165 birds of 20 species was made during this period.

Distances between recaptures were measured on a scale map of the netting arrangement. The "mean-maximum recapture distance" for each species was determined by measuring the greatest distance between recaptures for each individual of the species and averaging these distances. Birds recaptured only in the same net were not included in this calculation. For the 20 species concerned, mean-maximum recapture distances varied from 200 to 870 feet with an average of 550 feet. It should be noted that many of these recapture distances are based on only a few birds and a few recaptures, and all were influenced by the arrangement of the nets. The figures listed are, therefore, by no means definitive for the species.

Figures are listed for the probable number of birds in the area covered by the nets on the basis of the spot-map census. The numbers in the "available birds" column were obtained by determining on spot maps the number of birds whose territories fell in part within the species' mean-maximum recapture distance from the nets.

The recapture population estimates in Table 5 were calculated from two 6-day netting periods and are an average of 7 different estimates for these periods. The method of calculation and reasons for using these figures will be discussed later. Estimates are given for the Red-eyed Vireo and Wood Thrush and for the totals of species 1 through 16 and of species 1 through 29. The estimate for species 1 through 16 is given separately because 25 per cent or more of individuals of these species were recaptured and the standard error of the estimates on these species is, therefore, much smaller than that for all 29 species. Recapture estimates for the two groups of species and for the Red-eyed Vireo are higher than, but very close to, the figures obtained by the spot-map census. The recapture estimate of the Wood Thrush population, however, is nearly double the spot-map figure. According to the spot-map census, 86 Red-eyed Vireos and 42 Wood Thrushes were estimated to be available; the numbers of these species banded were 92 and 72, respectively. The proportion of number banded to number available for other species is generally what would be expected on the basis of the proportion of banded birds in daily captures (see Table 8).

Estimates of the population based on the recapture method discussed in the Materials and Methods section are presented in Tables 6 and 7. No estimates are made of the population present before May 5 because effort and catches were small before that date. Population estimates are given for all breeding species (Table 5, species 1 through 29); for those

TABLE 5. Summary of banding, recaptures, movement, and population estimates of breeding birds

Species number	Species	Number banded	Number recaptured	Number of recaptures*	Maximum distance between captures in feet	Mean-maximum recapture distance in feet	Available birds	Birds per 100 acres spot-map	Population estimates by recapture
1	Red-eyed Vireo	93	43	80	810	337	86	100	108
2	Acadian Flycatcher	26	9	13	870	330	40	50	
3	Wood Thrush	72	32	75	1200	501	42	41	85
4	Hooded Warbler	24	11	34	1600	573	32	38	
5	Scarlet Tanager	25	8	11	900	530	36	31	
6	Ovenbird	20	9	18	860	497	30	29	
7	Tufted Titmouse	26	13	17	1180	648	30	22	
8	Kentucky Warbler	19	8	15	1070	660	32	22	
9	Red-bellied Woodpecker	10	5	7	1140	463	20	19	
10	Downy Woodpecker	19	8	11	710	570	20	18	
11	Cardinal	12	5	6	900	460	16	16	
12	Louisiana Waterthrush	6	5	8	1110	753	14	9	
13	Eastern Wood Pewee	3	1	1	600	600		8	
14	Black-and-white Warbler	2	1	0	—	—		7	
15	White-breasted Nuthatch	6	2	1	700	700		4	
16	Rufous-sided Towhee	4	1	1	500	500		2	
1 through 16		367	161	298				416	435
17	American Redstart	10	1	1	200	200		18	
18	Blue-gray Gnatcatcher	6	1	0	—	—		17	
19	Carolina Chickadee	12	1	1	710	710		9	
20	Hairy Woodpecker	11	1	1	870	870		7	
21	Brown-headed Cowbird	4						9	
22	Parula Warbler	1						7	
23	Yellowthroat	2						7	
24	American Goldfinch (part)	4						7	
25	Blue Jay	6						6	
26	Yellow-throated Vireo	5						4	
27	Pileated Woodpecker	1						3	
28	Red-shouldered Hawk	1						2	
29	Mourning Dove	1						1	
1 through 29		431	165	301				513	528
30	Ruby-throated Hummingbird	0						4	
31	Barred Owl	0						2	
32	Common Crow	0						2	
1 through 32		431	165	301				521	

*Recaptures are listed only for the period May 5 through June 9. This explains why "Number of Recaptures" is less than "Number Recaptured" for species 14, 15, and 18.

TABLE 6. Estimates of breeding population on the basis of recaptures

Marking period	Sampling period	Species 1 through 16*					Species 1 through 29*				
		M	n	m	N	S.E.	M	n	m	N	S.E.
May 5, 7, 9	May 12, 14, 16	123	102	27	465	76	134	114	27	566	95
"	May 19, 21, 23	123	112	24	574	104	134	128	24	715	122
"	June 4, 5, 6	122	116	39	363	47	133	128	39	437	58
"	June 7, 8, 9	122	74	21	430	80	133	78	21	494	92
May 12, 14, 16	May 19, 21, 23	100	112	21	543	105	112	128	21	683	136
"	June 4, 5, 6	99	116	27	442	76	111	128	26	546	96
"	June 7, 8, 9	99	74	13	556	142	111	78	13	666	169
May 19, 21, 23	June 4, 5, 6	108	116	25	501	89	124	128	27	588	100
"	June 7, 8, 9	108	74	10	799	233	124	78	10	967	286
June 4, 5, 6	"	115	74	28	304	45	127	78	29	342	50
June 7, 8, 9	None	54					58				
May 5-16	June 4-9	194	162	65	484	46	217	177	65	591	58
May 14-26	"	180	162	55	530	58	209	177	57	649	71

* See Table 5 for relation of species numbers to species

TABLE 7. Estimates of Red-eyed Vireo and Wood Thrush populations on the basis of recaptures

Marking period	Sampling period	Red-eyed Vireo					Wood Thrush				
		M	n	m	N	S.E.	M	n	m	N	S.E.
May 5, 7, 9	May 12, 14, 16	30	36	10	108	29	31	14	6	72	22
"	May 19, 21, 23	30	23	4	173	79	31	24	8	93	38
"	June 4, 5, 6	30	31	11	85	20	30	18	7	77	23
"	June 7, 8, 9	30	20	8	75	21	30	20	4	150	67
May 12, 14, 16	May 19, 21, 23	34	23	8	98	28	14	24	4	84	38
"	June 4, 5, 6	34	31	8	141	40	14	18	4	63	26
"	June 7, 8, 9	34	20	5	136	53	14	20	3	93	50
May 19, 21, 23	June 4, 5, 6	23	31	5	143	58	23	18	5	83	31
"	June 7, 8, 9	23	20	1	460	450	23	20	4	115	51
June 4, 5, 6	"	31	20	7	89	27	18	20	10	36	8
June 7, 8, 9	None	20					20				
May 5-16	June 4-9	54	44	19	125	22	38	28	10	106	27
May 14, 26	"	45	44	15	132	28	33	28	8	116	35

species of which 25 per cent or more individuals were recaptured (Table 5, species 1 through 16); and for the Red-eyed Vireo and Wood Thrush, the two species captured in greatest numbers. Twelve different estimates are presented in Tables 6 and 7 to illustrate variations in estimates when different periods of time are employed in the calculations. These separate estimates also demonstrate the degree of consistency in trends observed in all breeding species and in three components of this total.

The percentage of unbanded birds in the totals captured on successive days is shown in Table 8 for species 1 through 16, and for Red-eyed Vireos and Wood Thrushes.

DISCUSSION

In this study the most obvious sources of error in recapture population estimates are recruitment and net-shyness. For adult birds of species breeding in the season and locale of this study, there are three sources of recruitment. First, the arrival of new individuals that establish breeding territories, mainly in the beginning of the breeding season; second, later arrival of individuals that are unable to establish breeding territories and constitute a surplus population which presumably moves randomly about the area; and third, transient individuals. The data gathered in this study allow a number of approaches to assessing recruitment; observation of trends in daily rate of capture (Table 3), trends in recapture population estimates, and in the various factors that enter into the formula when successive periods of time are employed in calculations (Tables 6 and 7), variations in these trends between individuals species and groups, and trends in the percentage of unmarked birds in daily totals (Table 8). Net-shyness is expected to be manifest in a progressive decline in catch per effort and to be reversed and again show its effect when nets are moved. Trends in observations would be expected to display the effects of an interplay of

TABLE 8. Per cent of unbanded birds in totals captured on successive days

Date 1959	Species 1 through 16*		Red-eyed Vireo		Wood Thrush	
	Total	% Unbanded	Total	% Unbanded	Total	% Unbanded
May 5	51	100	6	100	16	100
7	46	78	11	91	16	69
9	46	74	17	82	6	67
12	40	70	18	67	5	60
14	38	63	9	44	6	50
16	38	45	16	50	5	40
19	39	64	13	62	8	63
21	50	60	13	46	9	67
23	32	50	4	0	8	50
26	28	46	7	57	7	43
June 4	56	48	14	43	11	45
5	36	31	10	60	9	33
6	35	20	9	33	3	0
7	35	26	12	17	6	17
8	17	41	3	33	7	43
9	27	41	6	50	9	33

* See Table 5 for relation of species numbers to species

recruitment and net-shyness. For example, the increase in rate-of-capture on May 19 (Table 3) was probably the result of a wave of migration. This conclusion is supported by independent observation—"North of Washington there was a mild wave on April 26, another on May 4 and 5, and the most pronounced on May 18 and 19." (Scott, 1959.) The trend of decrease in rate-of-capture on May 19th through 23rd and June 4th through 8th was probably the result of the development of net-shyness and was interrupted by relocation of the nets.

Further evidence of recruitment and net-shyness can be deduced from trends in the various factors entering into the recapture population estimates (Tables 6 and 7). The value of M for successive marking periods tends to decrease except for the period including May 19, when the wave of migration occurred. The decreasing trend is most marked when the period May 19, 21, 23 is compared with June 7, 8, 9. The value of m and its proportion to n for a given sampling period generally become smaller when used with successively later marking periods until the nets were moved; they then show a sharp increase. The population estimate (N) and its standard error (S.E.) increase sharply at the time when heavy recruitment by migration into the area is known to have occurred, progressively increase as net-shyness would be expected to exert its influence, and decrease when the nets were moved.

If all of the assumptions involved in the recapture method of population estimation (listed in the Materials and Methods section) were valid, the percentage of unbanded birds in the totals captured on successive days (Table 8) would show a steady decline. Such a trend is observed from May 5 through May 16; this trend is reversed on May 19. This observation is consistent with the expected effect of the arrival of a substantial number of new birds in the area on May 19 and independent evidence that this did occur has been cited. A trend toward reduction in the per cent of unbanded birds again appears after May 21 but a reversal is noted in all groups between June 7 and 8. The failure of this trend to continue is probably due to net-shyness.

It is realized that a cause and effect relationship has not been established between recruitment and net-shyness and the trends observed. A great deal more detailed study will be necessary to accomplish this. However, if further work validates the conclusions, it should be possible to develop mathematical manipulations to remove the effects of these two sources of error (Parker, 1955). Estimates for groups of species are complicated by assuming (as was done in calculations in this paper) that all species are similar in respect to the assumptions listed in the Materials and Methods section. Data presented here indicate that species are not similar in these respects. Further complications will arise in comparing studies in different areas because the proportions of the various species present will differ.

The locality in which this study was conducted offered a number of advantages that will be difficult to achieve in other areas. No interference was experienced from humans or domestic animals, no net was exposed to wind, and only one was exposed to direct sunlight. In areas where conditions are less favorable, the 2-hour interval between visits to nets would not be feasible. During the course of this investigation the weather was phenomenally good. Each day of operation

used in the recapture-population estimates was so much like every other one that weather variation is not believed to have biased the netting results. Erratic weather conditions and their possible effect on activity of birds and effectiveness of nets may be expected to complicate interpretation of data in the future.

The main contribution of this study is its illustration that a combination of mist-netting and banding with a definite pattern of arrangement and schedule of operation will produce information on bird populations not obtainable by other techniques. It produces a mass of well-integrated data from which information on population density, dynamics, movement, and behavior can be derived. The data gathered in this study have not been completely analyzed and cannot be fully evaluated until comparisons with similar studies in different areas can be made. The main findings are presented now to obtain the advantage of criticism and with the hope of encouraging additional studies. Only one method of the many available for estimating populations from banding data is discussed here. Some other method may prove to be more useful.

It was demonstrated in this study that the home-range of some species of passerine birds (*e.g.*, Wood Thrush) is considerably greater than the singing territories of the males. This conclusion has important implications in population studies and in the evaluation of effects of insecticides and other pest-control measures. These findings will be more completely analyzed and discussed in a subsequent publication (Robbins & Stamm).

Evaluation of this method and its comparison with other techniques will be aided greatly if some standardized method of operation and analysis is generally adopted by those conducting such studies. It is quite likely that some other arrangement or number of nets may be superior to that used here. This can be demonstrated best if such variations are tested simultaneously with the present arrangement in the same habitat. Studies in different habitats, seasons, and populations with different densities and species and age composition will produce a variety of results. Such differences can be evaluated only if a thoroughly standardized technique is employed. It is suggested that, where possible, the present arrangement and number of nets be used. Some modifications will be mandatory in certain situations as, for example, in areas where it is not possible to avoid or is desirable to include edge. It is suggested that, in applying the present method to include forest edge, a 2,000-foot line be located parallel to and just inside the edge and that 700 feet from either end of this line a 1,000-foot line extend into the forest at right angles to the edge. Such a pattern actually entails 800 feet less wasted distance per circuit than that used here and will largely preserve the sampling of habitat, numbers of territories intersected, and detection of movement inherent in the arrangement used in the present study.

A standardized schedule of operation also will aid in comparing different studies. On the basis of findings in this study the following is tentatively suggested. It appears that two 6-day periods of netting with relocation of the nets between periods will be most satisfactory. This schedule of operation will allow the estimation of the population

on a recapture basis by employing successive periods in calculations. The first 3-day period can be used in calculations with three succeeding 3-day periods, the second 3-day period with 2, and the 3rd with 1. The first 6-day period then can be used with the last 6-day period. The 7 estimates thus obtained can then be averaged to yield a definitive estimate. Such a procedure minimizes the effects of chance variation. This method was used in arriving at the estimates in Tables 6 and 7.

This method of obtaining information on a bird population is especially well adapted to studying the activity of agents such as arthropod-borne viruses. Birds can be bled from the jugular vein and, by virus isolation and serologic studies, information on the activity of the agent can be obtained on a current basis as well as by revealing differences between successive study periods and between different localities. For example, if one considers the first and last 6-day periods for which population estimates were made, 22 per cent of the birds captured during the first period or 13 per cent of the total population present was recaptured during the second period. Many of the recaptures were made after an interval sufficiently long to show conversion from negative to positive on serologic tests.

SUMMARY

1. Progress is reported toward development of a method of bird-population study based on mist-netting and banding. A definite pattern of arrangement and schedule of operation are presented.
2. Nets were operated for a total of 4200 net-hours during which 966 captures were made (23.0 birds per 100 net-hours). A total of 431 adult breeding birds were banded and 38 per cent of them were recaptured.
3. A breeding-bird census was made simultaneously in the same area by the Williams spot-mapping technique.
4. Estimates of population by recapture agreed closely with the spot-mapping census.
5. Some birds are demonstrated to have overlapping home-ranges much larger than their singing territories.
6. Recruitment and net-shyness distort recapture estimates of population but the method allows detection and assessment of their influence in the population dealt with here.
7. The method produced integrated information on population density and dynamics, movement and behavior.
8. The procedure is especially well adapted to studies of disease agents in bird populations.
9. A simple scheme for description of the habitat in terms of relative abundance and frequency of occurrence of tree species was used.

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A METHOD OF MIST NETTING WOODCOCKS IN SUMMER*

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The purpose of this paper is to describe a technique of capturing American woodcocks *(Philohela minor)* with Japanese mist nets during the summer months in central Massachusetts. Low (1957) has thoroughly described mist netting techniques, mostly for passerines. Woodcocks present a unique netting problem requiring certain specific refinements of the technique heretofore described. It is possible that methods described here could be productive for other species as well.

Liscinsky and Bailey (1955) described a method of catching limited numbers of woodcocks in summer and fall by erecting funnel nets in favored summer feeding and resting areas. During the summers of 1953 and 1954, approximately 25 woodcocks were captured in similar traps set primarily for ruffed grouse by personnel of the Massachusetts Cooperative Wildlife Research Unit in central Massachusetts. Summer observations of evening behavior of woodcock led to the discovery of certain open fields where woodcocks light at dusk. The regularity and

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