THE ESTIMATION OF POPULATIONS OF SOME FARM GAME SPECIES

by

Louis Reams Hundley

Thesis submitted to the Graduate Faculty of the
Virginia Polytechnic Institute
in candidacy for the degree of
MASTER OF SCIENCE
in
WILDLIFE MANAGEMENT

APPROVED:

Director of Graduate Studies

Dean of Agriculture

APPROVED:

Head, Department of Biology

Major Professor

June 1953

Blacksburg, Virginia

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ACKNOWLEDGEMENTS

Without the cooperation and assistance of a great many individuals, this investigation and report could not have been undertaken and completed. The writer greatly appreciates the many services rendered.

The Virginia Commission of Game and Inland Fisheries, which with the United States Fish and Wildlife Service, the Wildlife Management Institute, and the Virginia Polytechnic Institute jointly sponsor the Virginia Cooperative Wildlife Research Unit, provided financial support and equipment.

The graduate committee, composed of Dr. Henry S. Mosby, the late Dr. Cecil F. DeLaBarre, Prof. A. B. Massey, Chairman, and Prof. J. J. Aulbach, for the first year of my graduate academic work, deserve special mention, Dr. Mosby in particular of organizing and supervising the project, and Prof. Massey for helping on the botanical aspects of the project.

The Town of Blacksburg, Dr. F. K. Lucas, Messrs. R. H. Martin of the Fish Division of the Virginia Commission of Game and Inland Fisheries, and Atlee Frazier of the Montgomery County Fire Department procured and loaned valuable and essential equipment.

Dr. Vincent Schultz, Assistant Unit Leader, gave many constructive criticism and suggestions during the writing of this paper. Dr. Robert D. Ross, Associate Professor of Biology, aided in identifying fish.

To , a V.P.I. graduate, and , two V.P.I. seniors, the writer wishes to express his thanks for their willing, voluntary work connected with the seining and draining of the fish pond.

To my fellow graduate students, , , , , , , , , , , , , , , , , and , the writer is indebted for their countless hours of effort, energy, and encouragement.

And to my fiancee, , I am grateful for her patience and understanding.

INTRODUCTION

Purpose of Study

Reasonably accurate estimates of animal populations are needed to evaluate sound wildlife management practices; it is preferable that the method of estimation not be too time consuming and laborious as well as provide a usable estimate. Indices of abundance such as number of shed antlers, number of fecal droppings, etc. are limited in applicability and accuracy (Allee, et al., 1949:269). A complete census or total count of all individuals, while giving a more precise figure, is probably never attained of a wild population; if such a census could be made, it would be expensive and time consuming in most cases. Thus, the primary objective of this investigation was to compare the accuracy of estimating game and fish populations by existing sampling techniques with estimates of the populations derived by more laborious and time consuming methods, i. e., by lengthy trapping periods or by fish pond drainage

Scope of Study

An estimate of fish and game populations does not have to be precisely accurate in order for it to be serviceable to wildlife managers. Instead, a reasonably accurate method of estimation would be a valuable wildlife management and research tool if the approximate limits of accuracy are known and if the method yields relatively uniform estimates of the true population. For example, if it is known that a cer-

tain population estimation method will always give a figure that is between say 45 per cent and 55 per cent of the true population, the method is usable.

This investigation was concerned primarily with the estimation of fish, rabbit, and squirrel populations in various areas on the Virginia Polytechnic Institute College Farms at Blacksburg, Virginia. Particular attention was given to the capture-recapture method and other related methods, and the evaluation, wherever feasible, of these methods by determining as accurately as possible the animal populations as determined by intensive trapping and pond drainage. Recommendations are made concerning the capture-recapture method and/or all other methods considered or developed in this study with regard to their use in wildlife management and research.

History

Monsieur P. S. Laplace (1783:693), French mathematician and scientist, established, from a sample, the ratios of human births in a year to the population producing those births in each urban and rural district of France. By multiplying the numbers of births by the ratio of population to births determined from the sample, he arrived at an estimate of the total population. He may have been the first to use a sampling ratio to estimate the population.

Lincoln (1930) suggested the banding returns as an index with which the waterfowl of North America, the most difficult group to census according to Leopold (1946:154), could be enumerated. Lincoln observed that an

average of twelve per cent of the total number of ducks banded at any one station were killed by hunters the first season after banding. He used the number of banded ducks as his marked population and the total kill by the hunters as his sample population. Assuming that the percentage of non-banded ducks killed is the same as the percentage of banded ducks killed, if every hunter would turn in a complete record of his annual bag and report all banded ducks killed, an annual population estimate could be made by dividing the total number of killed ducks by 0.12. Failure to report either banded or unbanded ducks which were killed would provide a source of error.

Wildlife research personnel, mammalogists, statisticians, and others have continued to experiment and to do research on estimating populations by the capture-recapture method.

The simplest case is one in which we have a population containing N members (unknown) which is known to contain T marked members. From this population a representative sample of n members containing t marked members is drawn. The total population has $U = N - T$ unmarked members, and the sample population has $u = n - t$ unmarked members. The term "representative" is used here to mean that the statistic computed from the sample will have a mean value in repeated samples equal to the population parameter. The total population is estimated by the equation $N = nT/t$.

The above equation is generally termed the Lincoln Index and has been used frequently such as in computing the total population of snowshoe hares (Green and Evans, 1940:223)

Several assumptions that are made in estimating populations by capture, mark, release, and recapture are: (1) the animals redistribute themselves in their original population as they were before being trapped, (2) no mortality factor can be connected with an animal caught in a live-trap or marked, (3) no animals become trap-shy or "trap addicts," and (4) no recruitment or abatement in population occurs by birth, death, immigration, or emigration during the trapping period.

In addition, inherent objections to any trapping project are: (1) all mammalogists are not equally skilled in setting traps, (2) the distance traps are set apart varies, (3) weather conditions undoubtedly influence the activity of animals and therefore the number coming in contact with the traps, (4) the several makes of traps vary in their effectiveness for different kinds of mammals, and traps themselves vary in efficiency depending on their previous use and exposure to weather, and (5) the number of animals caught usually decreases each night the trap line is set.

METHODS AND PROCEDURES

Selection and Description of Study Areas

Study areas were chosen to fit the following criteria: (1) each area had to be close enough to allow the investigator to visit it and the other areas at least twice a day, (2) each area had to be of sufficient size to contain a representative natural assemblage of game species, and (3) each area had to differ from all the others to the extent that they might on different farms.

The three wooded areas have been protected from hunting for over ten years, but some poaching has occurred. No fishing was allowed on Study Area I during the seining and draining; however, a few people continued to fish there until they were requested not to use the area even though "No Fishing" signs were posted. The writer feels that any abatement in populations caused by illegal hunting and fishing was not sufficient to void the data.

Study Areas II and III were trapped for the gray squirrel (Sciurus carolinensis leucotis Gapper) and the eastern cottontail rabbit (Sylvilagus floridanus mallurus Thomas); only gray squirrels were marked on Study Area IV.

Study Area I. The Upper Pond on the V. P. I. campus at Blacksburg, Virginia, was chosen for Study Area I. The pond has an area of two and a half acres as determined by a grid count made on a compass intersection map. The pond has an average depth of 3.22 feet (Bowman, 1951); however, Fig. 1 shows that there are deeper channels along the south-

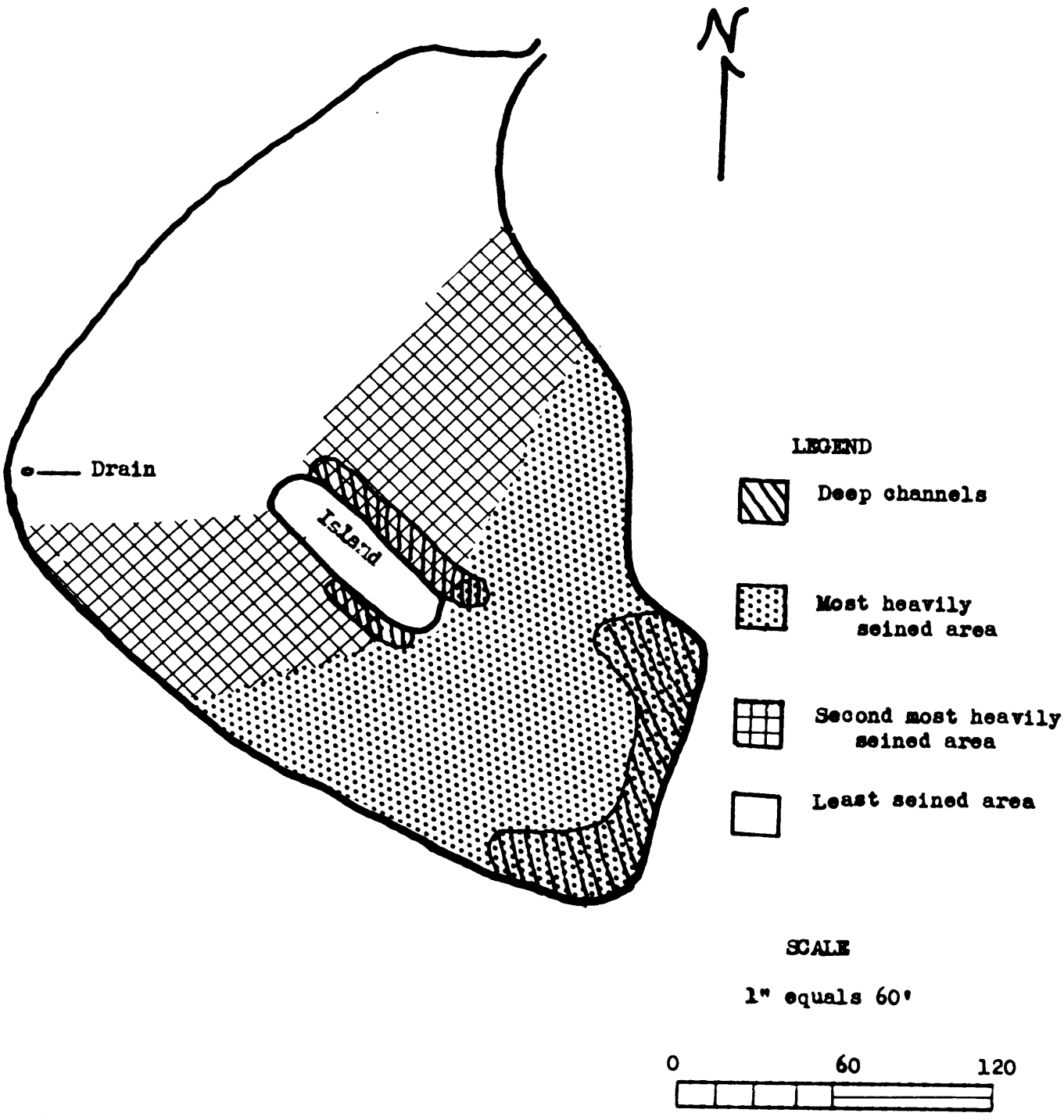

FIGURE 1. UPPER POND ON THE VPI CAMPUS.

eastern bank and on each of the longer sides of the island. During December 1949 the pond was stocked with largemouth bass (Micropterus salmoides Lacepede) and bluegills (Lepomis macrochirus Rafinesque) at the ratio of 1,000 bluegills to 200 bass fingerlings per acre of water. No other fish were known to be present in the pond at the time of restocking.

Study Area II. An ungrazed woodlot, similar to those on many Southwestern Virginia farms, known locally as North Crumpacker Woods, was chosen as Study Area II. Of the three woods used as study areas in this project, it is the least affected by human activities.

The forest type on this approximately eight acre woodlot is principally mature oak and hickory with an undergrowth of Rubus spp., grasses, and weedy annuals.

Fig. 2 shows the location of trap lines within this woods and the position of the woods with relation to the other study areas.

Study Area III. Crumpacker Woods, an approximately 14 acre grazed woodlot, was selected for Study Area III. It is of the mature Oak-Hickory Forest Type, with Cornus spp. and Crataegus spp. being the predominant shrubs. The ground cover of grasses and weedy annuals is heavily grazed.

Fig. 2 shows the position of the woods with relation to the other study areas and location of trap lines within the woods.

Study Area IV. An open, park-like woods on the V. P. I. campus known as President's Hill was selected as Study Area IV. Most of the 17.5 acres are covered with mature oak and hickory, but many orna-

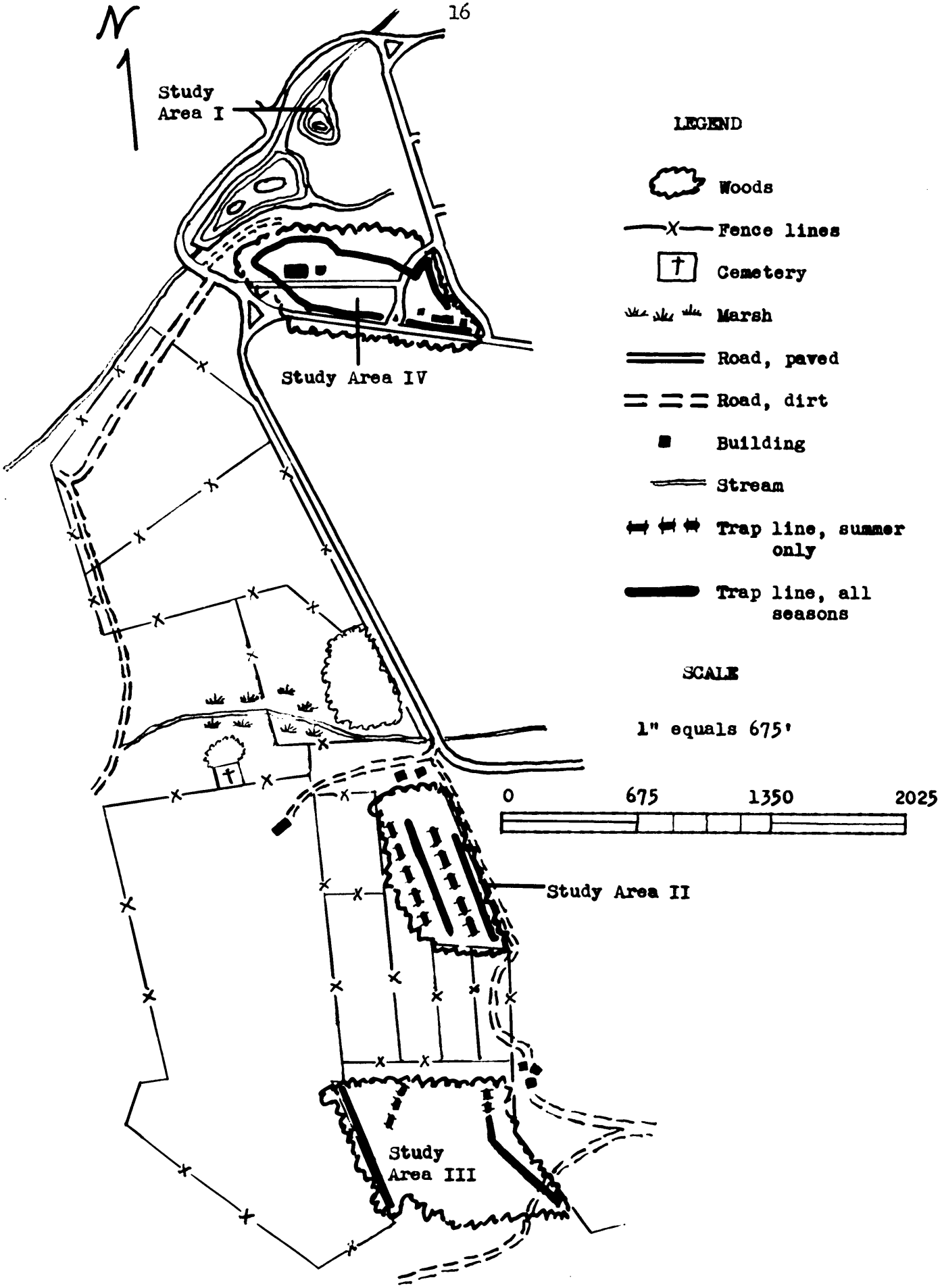

FIGURE 2. LOCATION OF THE FOUR STUDY AREAS ON THE VPI COLLEGE FARMS.

mental trees and shrubs are around the border of the area. The ground cover is chiefly blue grass (Poa spp.) and other perennial grasses.

Location of trap lines and the position of this area in relation to the other study areas is shown in Fig. 2.

Method of Trapping

Traps were laid out by pacing in North Crumpacker Woods (Study Area II) and Crumpacker Woods (Study Area III) at 50 feet intervals; on President's Hill (Study Area IV) traps were set at 75 feet intervals, again by pacing. Fig 2 shows that the traps were placed in approximately straight lines that either paralleled one another or were perpendicular to one another.

Generally, traps were checked twice a day, once early in the morning and again just before dusk in the evening. The author noticed that the morning catch, or trap-success during the night, appeared to vary with temperature, wind, and precipitation. Squirrel and rabbit catches were low on mornings following a dry, cold, windy night; rabbit catches in the morning were high when it had rained during the preceding afternoon and earlier part of the night, but the squirrel catch was low on mornings following rain. The author, while emphasizing that the above statements were based on personal observations and that no weather records were kept, believes that humidity and/or precipitation, wind velocity and direction, and temperature have a definite relationship to trapping success. This opinion concurs with findings resulting from work done on the squir-

rel (Shipley, 1941:17 - 25) and work done on other animals (Byrd, 1951:137; Richmond, 1952:202). Consequently, on mornings following cold, damp nights, the traps were occasionally not checked until as late as 11:00 a.m. No animals were found dead in the traps at this hour.

Shelled corn, which has proved successful (Shipley, 1941:116; Peery, 1948:89), was used for bait during the winter trapping. Half of the traps on Study Areas II and IV were baited, and all traps on Study Area III were baited. However, no greater trap success was noticed in baited traps than in unbaited traps. Apparently, scent left by previously trapped animals made the best lure, because once a trap had caught an animal, the trap usually continued to be successful.

Approximately 30 cc. of urine were collected from bladders of two squirrels killed by cars. This urine was divided into equal portions and used to bait six traps, none of which had caught a squirrel for over three months. Unfortunately, about six inches of snow fell the night after the urine lure was used; consequently, traps were not functioning and squirrels were not out of their dens. As soon as the snow was off the ground, an untagged squirrel was caught in one of the urine baited traps. Because of the unfavorable weather conditions at the time of using the urine, no definite conclusions can be drawn concerning it; nevertheless, the writer strongly believes that further work with squirrel urine as a lure will show that it is a very successful one.

Trapping and marking were discontinued after fourteen consecutive nights of trapping yielded no original captures.

Approximately 7,890 trap-nights were used in this study. Table 1 contains the approximate number of trap-nights per month for each of the three wooded study areas.

Table 1. Approximate number of trap-nights per month for each of the wooded study areas.

Month	Trap-nights on North Crumpacker Woods (Study Area II)	Trap-nights on Crumpacker Woods (Study Area III)	Trap-nights on President's Hill (Study Area IV)
July	400	440	—
Aug.	840	924	—
Sept.	320	852	—
Oct.	—	—	540
Nov.	—	—	204
Dec.	—	—	476
Jan.	80	120	510
Feb.	385	575	655
March	138	208	242
TOTALS	2,163	3,099	2,627

Handling Equipment and Techniques

Seining. In work on Study Area I, the pond, a 135' long, 16' wide, 3/4" mesh seine was used to capture the fish for marking purposes. The size of the mesh limited the catch to fish larger than approximately 1½ inches. The seine was pulled into the water by using a canoe and about 125 feet of rope; the seine was then hauled into shore, and all fish were removed. When the fish were counted, both pectoral fins were clipped closed to the base, and the fish were returned to the pond. A

record of the number of original captures and recaptures of each species was kept for each pass with the seine.

When at least 20% of the catch were recaptures for three consecutive hauls, seining and marking were stopped, and the pond partially emptied by draining and pumping. When the water was low enough to permit the use of small seines, approximately 10' long and 5' wide with a 3/4" mesh, fish were removed from the pond, placed into buckets, and taken to a checking station where they were separated by species into marked and unmarked fish and tabulated. Some bluegills and all bass were used for restocking purposes; the remaining fish were incinerated.

Trapping. The trap used for rabbits and squirrels was a modified Baumgartner box trap (Fig. 3) designed by Peery (1948:10). The traps were very serviceable, but were occassionally put out of commission by warping of the wood during damp weather. Also, staples would come out of the door if the traps were subjected to any rough handling; small eyelets screwed into the door in place of the staples would probably overcome this fault.

The holding funnel for squirrels (Fig. 4) was made from $\frac{1}{4}$" mesh wire commonly called hardware cloth. The larger end of the funnel was three inches in diameter, and the funnel tapered to a diameter of one and a half inches at the smaller end. A cloth sack was cut into a funnel-shaped pattern so that the larger opening would fit over the mouth of the trap, and the smaller opening could be wired to the large end of the wire funnel. As soon as the squirrel, prompted by blowing into

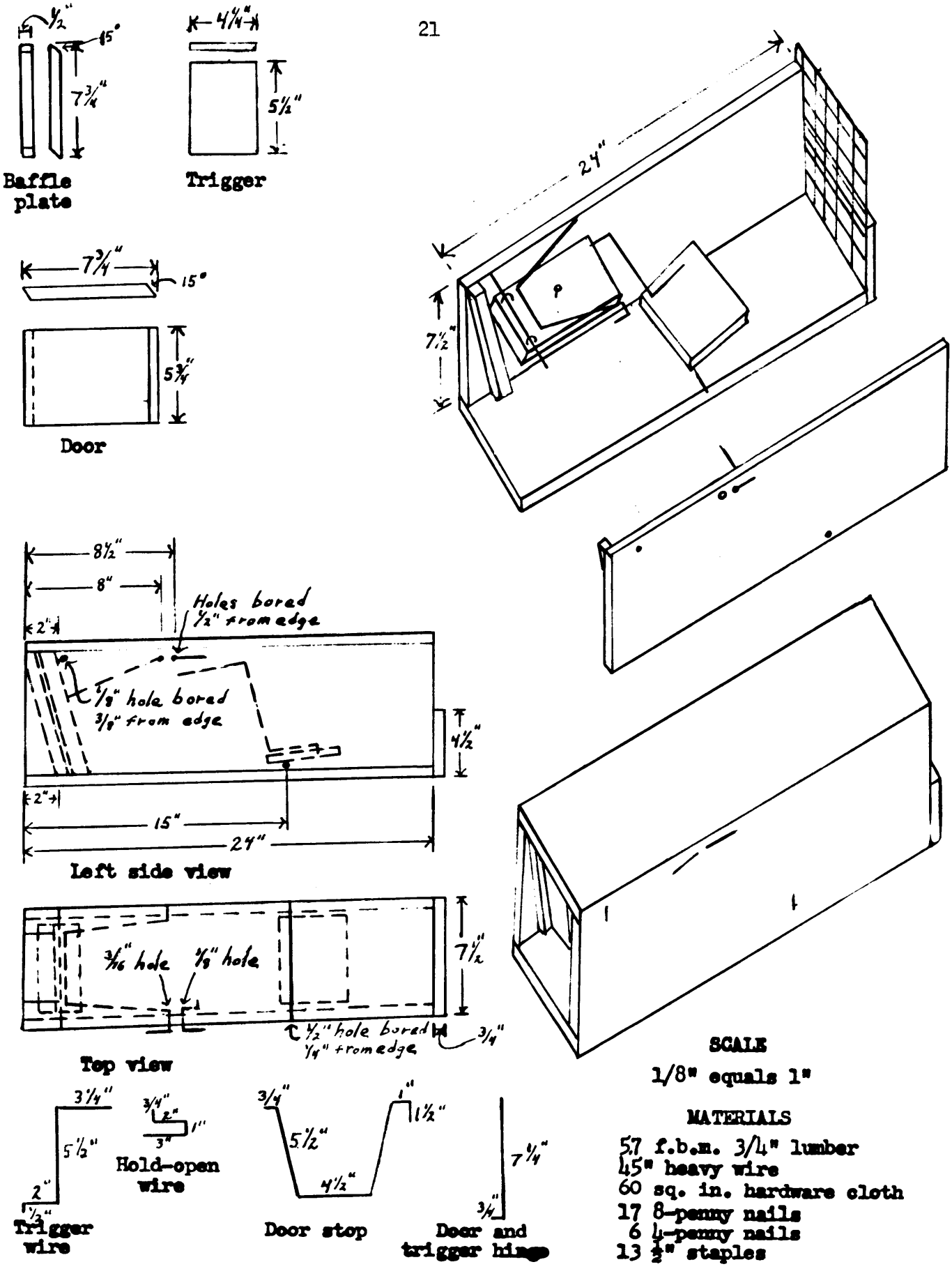

FIGURE 3. TYPE OF BOX TRAP USED. (SKETCHED AFTER PEERY, 1948)

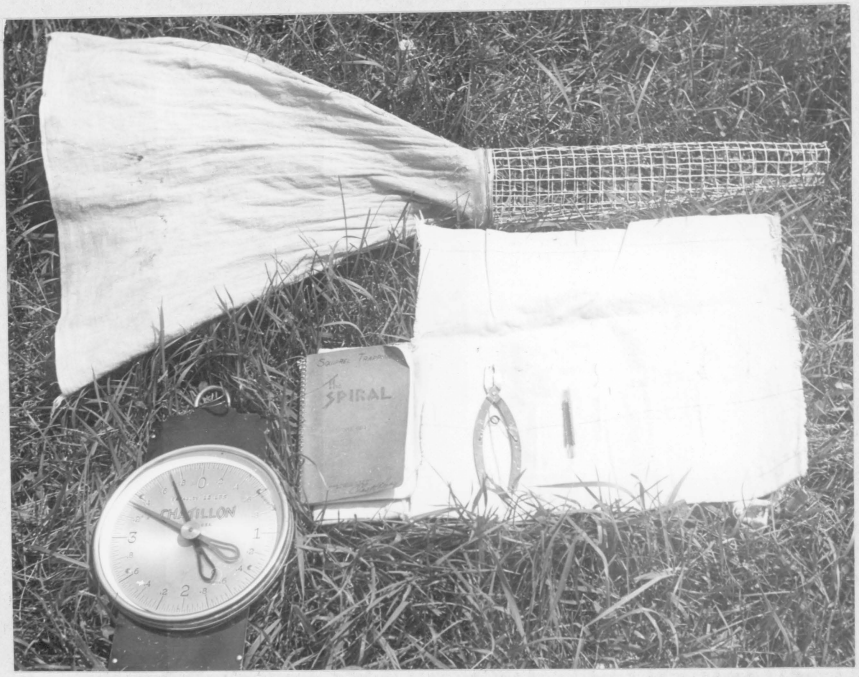

Fig. 4. Equipment used in handling, tagging, and releasing trapped squirrels. (Photo by J. L. Walthall.)

the back of the trap, entered the funnel, the sack was removed from the trap and forced into the funnel behind the squirrel thus immobilizing him so that he could be tagged, weighed, sexed, and otherwise examined.

The funnel for holding rabbits was made from 1" x 1½" mesh wire; overall dimensions were 30" by 8" by 4". The larger end fitted snugly against the mouth of the trap. Rabbits were removed from traps in a manner similar to that used for squirrels, and were immobilized in the funnel by stuffing a feed sack into the funnel behind the rabbit.

Both funnels had padding in the smaller ends to prevent the animals from injuring their heads when they ran into the funnel.

Monel Number 1 metal fish tags were placed in each ear of the animal once it was immobilized in the funnel. If tags are applied too loosely, they could be easily torn out and lost; if tags are applied too tightly, gangrene could set in, and the tag and part of the ear would be sloughed off. Consequently, great care was exercised in tagging animals, and each animal was tagged in both ears to minimize the chances of losing identifying marks.

Incidental data gathered. All animals were aged as adults or juveniles, sexed, weighed, and examined for external parasites. Squirrels were aged using the criteria of weight, thickness of ears, time of year it was first captured, and condition of reproductive organs. Rabbits were aged using general size and weight as criteria. Examination of external genitalia was sufficient to differentiate between sexes in squirrels, but this method was not always satis-

factory with rabbits. According to Nelson (1950:30-31), the clitoris of the female rabbit appears "acute at the apex with a fold of tissue running from the tip posteriorly and joining other vaginal structures. The clitoris is normally the size of the penis in the male and can be easily confused with this organ, but it is usually tipped with a pinkish color while the male organ is creamy white, blunt-tipped, devoid of lateral tissue and appears 'telescopic'." This observer had to rely on the presence of testes in the male and the possibility of lactation in the female in order to sex rabbits.

The sex ratios for squirrels in the three wooded study areas are shown in Table 2. Because the data on the sex of the rabbits were incomplete, no sex ratios are presented for them.

Table 2. Sex ratios for squirrels on three study areas.

Study Area II North Crumpacker Woods (30 individuals)	Study Area III Crumpacker Woods (50 individuals)	Study Area IV President's Hill (125 individuals)
173 males:100 females	158 males:100 females	95 males:100 females

Based on data presented by Chapman (1938:679), the sex ratio on Study Area IV is more nearly normal than that on the other two areas.

Home ranges were determined by taking the average distance that animals traveled from trap to trap as shown by the recapture records. Table 3 presents the average home ranges of squirrels and rabbits in the three wooded study areas as determined by this method.

Table 3. Home ranges in feet of squirrels and rabbits on three study areas. The numbers in parentheses refer to the number of observations.

	All rabbits		Squirrels					
		S.D.[1]	Male	S.D.	Female	S.D.	Average	S.D.
Study Area II	320 (12)	217	250 (10)	105	200 (4)	154	236 (14)	123
Study Area III	327 (16)	159	343 (7)	232	570 (5)	320	438 (12)	309
Study Area IV			289 (35)	176	240 (40)	40	263 (75)	177

[1] S. D. represents one standard deviation.

Methods Used in Estimating Populations

The Lincoln Index. The Lincoln Index has previously been explained. A period of trapping known as the precensus period was established during which time all animals caught were tagged, weighed, sexed, etc. The information was recorded in the field and later transcribed to a permanent form (Fig. 5). All capture-recapture records are on file at the Virginia Cooperative Wildlife Research Unit in Blacksburg, Virginia. After an appropriate interval, varying from two days to twenty-one weeks, another period of trapping known as the census period was established, and the number of recaptured individuals and the sample size were used to compute population estimates.

For estimates based on a long period of intensive trapping, all animals caught in 1952 constituted the precensus group and all animals trapped in 1953 the census group.

The Krumholz method. Krumholz (1943) suggested a formula for estimating fish populations. His formula is $P = SAB/SC$ where P is the total population, S is summation, A is the number of animals examined

Tagging Record

Species ..... Sex ..... Age ..... Tag No. .....

Date ..... Hr. .....m. Station No. .....

County ..... Locality .....

Tagged by ..... Remarks .....

Recovery Records

Date	Hr.	Station	Remarks	Initial

Fig. 5. Tagging record file card.

each day (or each pass of the seine, or each time the traps were checked), B is the number of marked animals in the study area, and C is the number of returns.

This formula was used in estimating the total population on all four study areas even though its use was designed primarily for estimating fish pond populations. On Study Areas II, III, and IV, it was used as a comparison with the Lincoln Index to see if the estimates given by the two methods were comparable.

As explained on the preceding page, estimates based on a long period of intensive trapping were made using the Lincoln Index, and estimates based on the same periods of trapping were made using the Krumholz formula. Data and estimates obtained by the latter method are shown in the Appendix, Table 1, 2, 3, 4, and 5. In making estimates with the Lincoln Index based on short periods of trapping, the total number of animals actually tagged, rather than the estimated total population, was used as a guide with which the short-term estimate was evaluated. It is thought that the number of tagged animals known to be on the area gives a reasonably accurate approximation of the animal population and therefore may be used as a "standard" by which the short-term estimate might be compared. These estimates based on short census and precensus periods were made in order to determine whether or not such short trapping periods would give a reasonable estimate of the total number of individuals that would be caught in the more lengthy, time-consuming, expensive, and intensive trapping period.

The Schumacher and Eschmeyer method. Schumacher and Eschmeyer (1943) used the formula $N = S\left[n^2 (m + u) \right] / S(nm)$ to determine the population of fish ponds in which N is the total population, S is summation, n is the number of marked fish in the pond, m is the number of recaptures in each sample, and u is the number of unmarked fish in each sample. Ricker (1937) believed that the efficiency of the formula was at a maximum when n/N equals 0.05. The formula was used as a comparison with the population estimate of Study Area I as given by the Krumholz method. Although n/N was much higher than 0.05 for all the species concerned, the two estimates agreed very closely.

Schumacher and Eschmeyer calculated the sampling variance, s^2, by the following formula, in which k stands for the number of samples taken from the pond:

$$s^2 = \frac{1}{k-1} \left[S \left(\frac{m^2}{m+u} \right) - \frac{1}{N} S(nm) \right]$$

The standard error of the population estimate was computed with the formula $S.E. = \sqrt{N^2 \left[Ns^2 / S(nm) \right]}$. The standard error of the population estimate for each genus is shown in Table 5.

Other methods. Estimating populations by a live capture, release, and recapture program is still time consuming. Therefore, it was hoped that some quick method could be used to give an acceptable estimate.

One of these quick methods used involved the counting of the number of squirrel leaf nests on a study area and, using the number of tagged squirrels, arrive at a squirrel:leaf nest ratio, and to see if this ratio for the three wooded study areas were comparable.

Another quick method of censusing used was to count the number of animals seen per hour per acre and to correlate the figures obtained from the three wooded study areas. However, data obtained by this method varied so greatly with the time of day the areas were surveyed and with the weather that this method was deemed unsatisfactory. Three, two, and no squirrels were seen at different fifteen minute surveys on Study Area II; four, six, and twenty-two squirrels were seen during surveys on Study Area III with the surveys being approximately the same length of time. The number of squirrels seen on Study Area IV varied from none seen during a twenty minute survey to twenty-four seen during a forty minute survey.

A third method substituted a harvest of squirrels on one of the study areas for the census period of trapping; i.e., kill data such as suggested by Lincoln was used instead of a second trapping period.

POPULATION ESTIMATES

Study Area I

Table 4 contains data and population estimates of bluegills in the V. P. I. Upper Pond. The two species of Lepomis were grouped together; although ten pumpkinseed were marked, none were recaptured, so no population estimate could be made for them. Also, it was very difficult to distinguish between the two species when they were recovered from the mud and slime resulting from draining.

Appendix Tables 6, 7, and 8 contain data and estimates for bass, golden shiner (Notemigonus crysoleucas crysoleucas Mitchell), and white crappie (Pomoxis annularis Rafinesque), respectively.

A comparison between estimated fish populations and counted fish populations is given in Table 5. If it is assumed that the same per cent of marked and unmarked fish escaped during the counting process, then the corrected population estimate for bluegills and pumpkinseeds would be 4,786/.873 or 5,482, which gives a 13.3 per cent deviation from the estimate arrived at by the Krumholz formula. (The per cents of deviation shown in the table were calculated in regard to the counted population.) Likewise, the bass population estimate would be corrected to 221/.906 or 244 which gives a per cent deviation of 47.0.

The shiners and crappies were not stocked in the pond but were probably placed there by well-meaning people after the pond was restocked in 1949.

Table 4. Data and estimates of the total population of bluegills and pumpkinseed in the V. P. I. Upper Pond as estimated by the Krumholz formula and the Schumacher and Eschmeyer formula.

Date	A		B			C		Estimated population	
	No. of fish examined	No. of fish marked	No. of marked fish in pond	Product A x B	Sum of products	No. of returns	Sum of returns	Krumholz	Schumacher and Eschmeyer
Sept.									
18	166	166	-	-	-	-	-	-	-
18'	66	65	165*	10,890	10,890	1	1	10,890	10,890
19	80	76	230	18,400	29,290	4	5	5,585	5,556
19'	155	147	306	47,430	76,720	8	13	5,901	5,814
22	52	48	453	23,556	100,276	4	17	5,898	5,840
22'	200	183	501	100,200	200,476	17	34	5,896	5,873
23	26	23	684	17,784	218,260	3	37	5,872	5,880
23'	201	160	706*	141,906	360,166	41	78	4,617	4,319
24	14	7	864**	12,096	372,262	7	85	4,379	4,011
24'	24	21	871	20,904	393,166	3	88	4,467	4,156
25	107	93	892	95,444	488,610	14	102	4,790	4,659
26	68	58	985	66,980	555,980	10	112	4,961	4,924
29	20	13	1,043	20,960	576,550	7	119	4,845	4,753
29'	28	17	1,056	29,568	606,118	11	130	4,663	4,501
29"	46	36	1,092	59,232	665,350	10	140	4,753	4,559

' Prime marks indicate days on which two passes were made with seine.
" Double prime marks indicate the day on which three passes were made with seine.
* One marked fish found dead in pond.
** Two marked fish found dead in pond.

Table 5. A comparison between the estimated fish population and the counted fish population in the V. P. I. Upper Pond.

Species	No. of marked fish in pond	No. of marked fish recovered in draining	Counted population	Estimated population (Krumholz)	Per cent deviation	Corrected estimate	Per cent deviation	Estimated population (Schumacher & Eschmeyer)	S. E.*
Bluegill sunfish and pumpkinseed	1,128	985 (87.3%)	4,786	4,753	0.69	5,482	13.3	4,559	497
Largemouth bass	32	29 (90.6%)	221	180	18.55	244	47.0	133	64
Golden shiner	19	16 (84.3%)	33	45	36.40	39	11.3	40	15
White crappie	2	2 (100%)	2	2	00.00			2	0

* Standard error of the population estimate.

Fig. 6. Recovery of fish during the draining process. Note bottom mud and slime in which some fish were lost. (Photo by G. H. Brown.)

Fig. 7. Separating fish into marked and unmarked groups, by species, at a check station. A covering of mud and algae made careful inspection necessary and may have been the source of error in separating marked and unmarked fish. (Photo by G. H. Brown.)

Fig. 8. Saving bluegill fry for restocking.

Data in Table 5 indicate that the methods of sampling used are reliable for populations as large as that of the bluegills in the pond. The writer believes that the low bass population and/or the difficulty in catching bass by a seine caused the estimated population to have as high a per cent deviation as it did.

A letter was sent to Dr. Louis A. Krumholz explaining the seining procedure and containing all of Table 5 except the last two columns. In his letter of reply he stated, "The data which you enclosed in the letter seem to be fairly adequate and I can think of no particular reason why your estimates are not valid. The reliability of data gathered by using a seine instead of traps is not generally to be questioned."

Fig. 6, 7, and 8 are photographs taken of the pond during the draining and fish recovery period.

Study Area II

Rabbits. The total number of tagged rabbits in North Crumpacker Woods was 31. Table 6 contains data and estimates based on short pre-census and census periods. These data indicate that such short trapping periods in which only a few animals are caught do not give sufficient information upon which a sound estimate can be made.

Appendix Table 1 contains data for the latter half of the trapping period for rabbits in this study area. Both the Lincoln Index and the Krumholz formula gave estimates of the total population of

rabbits in this woodlot to be 55. Calculating the population confidence limits at the 95% confidence level as described by Adams (1951: 16), the upper and lower limits are 214 and 27, respectively.

Table 6. Three Lincoln Index population estimates of rabbits in North Crumpacker Woods based on short trapping periods.

Precensus period	Census period	T*	u*	t*	n*	N*
7/15/52 - 8/3/52	8/4/52 - 8/22/52	9	4	3	7	21
7/15/52 - 7/21/52	7/22/52 - 8/4/52	6	3	2	5	15
7/15/52 - 9/5/52	1/29/53 - 2/4/53	16	8	5	13	42

* Lincoln Index symbols of formula N = nT/t

Squirrels. Twenty-six squirrels were tagged in Study Area II, giving a counted population of approximately 3.3 squirrels per acre. The population estimates were 30 (3.8 squirrels per acre, approximately) and 41 (5.1 squirrels per acre, approximately) as obtained by the Krumholz formula and the Lincoln Index, respectively. (See Appendix Table 2.) The upper population confidence limit at the 95% level for the Lincoln Index estimate was 67; the lower, 28. Estimates based on shorter trapping periods, as given in Table 7, again indicate that not enough animals were caught to give a useable estimate.

The number of leaf nests seen on Study Area II was two; this gives a ratio of marked squirrels:leaf nest of 13:1.

Table 7. Four Lincoln Index population estimates of squirrels in North Crumpacker Woods based on short trapping periods.

Precensus period	Census period	T*	u*	t*	u*	N*
7/15/52 - 7/18/52	7/19/52 - 7/22/52	4	2	1	3	12
7/15/52 - 7/21/52	8/24/52 - 8/30/52	6	6	5	11	13
7/15/52 - 7/21/52	8/24/52 - 9/8/52	6	10	5	15	18
1/29/53 - 1/30/53	2/2/53 - 2/11/53	6	5	4	9	28

* Lincoln Index symbols of formula N = nT/t

Study Area III

Rabbits. Twenty-eight rabbits were marked in Crumpacker Woods during the trapping periods that lasted from July 15 through September 4, 1952 and from January 29 through March 24, 1953. (These dates were also the trapping periods on Study Area II.) The Krumholz formula gave an estimate of 37 rabbits (Appendix Table 3); the Lincoln Index estimate was 55 rabbits with the upper confidence limit being 300 and the lower being 22 at the 95% level. As in Study Area II, population estimates based on shorter periods of trapping gave no reasonable estimate of the population as can be seen in Table 8.

Squirrels. The total number of tagged squirrels in Study Area III was 43 or approximately 3.1 squirrels per acre. There were an estimated 63 squirrels on the area (4.6 squirrels per acre, approximately), as calculated by the Krumholz method (Appendix Table 4), and an estimated 74 squirrels (5.3 squirrels per acre, approximately) as computed by the Lincoln Index. The upper and lower population confi-

dence limits at the 95% level for the latter estimate are 144 and 50, respectively.

Table 8. Three population estimates, using the Lincoln Index, of rabbits in Crumpacker Woods based on short trapping periods.

Precensus period	Census period	T*	u*	t*	n*	N*
7/15/52 - 7/21/52	8/2/52 - 8/8/52	7	1	1	2	14
7/15/52 - 8/2/52	8/4/52 - 9/4/52	8	4	3	7	19
7/15/52 - 9/4/52	1/29/53 - 2/5/53	12	13	1	14	168

* Lincoln Index symbols of formula N = nT/t

Table 9 contains the data and estimates based on short precensus and census periods; these data indicate that the information obtained was insufficient for making a sound estimate.

Table 9. Four population estimates, using the Lincoln Index, of squirrels in Crumpacker Woods based on short trapping periods.

Precensus period	Census period	T*	u*	t*	n*	N*
7/16/52 - 8/24/52	8/25/52 - 9/4/52	16	9	4	13	52
7/16/52 - 8/24/52	8/25/52 - 9/7/52	16	9	9	18	32
7/16/52 - 9/4/52	1/29/53 - 1/31/53	21	14	5	19	80
1/29/53 - 1/31/53	2/2/53 - 2/11/53	19	6	4	10	47

* Lincoln Index symbols of formula N = nT/t

Three leaf nests were seen on Study Area III. The marked squirrels: leaf nest ratio is 14.3:1.

After 23 squirrels had been marked, 16 squirrels of which 4 were marked were killed in a harvest. Substituting the kill data for a census period of trapping gives a population estimate of 92, a higher and probably more inaccurate estimate than by any other method used. The upper and lower fiducial limits on the kill data at the 95% confidence level are 230 and 49, respectively.

Study Area IV

One hundred and thirty-one different squirrels were trapped on President's Hill, giving a counted population of seven and a half squirrels per acre. The Krumholz formula gave an estimated population of 166 (Appendix Table 5) or 9.5 squirrels per acre; the Lincoln Index estimated population was 172 or 9.8 squirrels per acre. The upper and lower limits of the Lincoln Index estimate at the 95% confidence level were 236 and 143, respectively.

Estimates based on shorter periods of trapping, as shown in Table 10, are reasonably constant and are close to the actual number tagged. This is probably due to the large number of individuals caught during the short periods.

Ten leaf nests were counted on the area giving a marked squirrel:leaf nest ratio of 13.1:1.

Table 10. Three Lincoln Index population estimates of squirrels on President's Hill based on short trapping periods.

Precensus period	Census period	T*	u*	t*	n*	N*
10/2/52 - 10/8/52	10/9/52 - 10/15/52	44	15	8	23	126
10/2/52 - 10/5/52	10/6/52 - 10/9/52	13	35	4	39	127
10/2/52 - 10/11/52	10/12/52 - 10/21/52	47	13	8	21	123

* Lincoln Index symbols of formula N = nT/t

SUMMARY AND CONCLUSIONS

1. This investigation was concerned primarily with the estimation of fish, rabbit, and squirrel populations on various areas on the Virginia Polytechnic Institute College Farms at Blacksburg, Virginia. Particular attention was given to the capture-recapture method and other related methods of population estimation, and the evaluation, wherever feasible, of these methods by determining as accurately as possible the animal populations as determined by intensive trapping and pond drainage.
2. A total of 1,181 fish were marked during a period of 12 days. Fifty-nine rabbits and 200 squirrels were marked during a period of approximately 7,890 trap-nights.
3. Both the Krumholz method and the Schumacher and Eschmeyer method give a reasonably accurate and certainly usable estimate of fish pond populations.
4. The Krumholz method, as used in this study for a comparison with the Lincoln Index estimates of mammal populations, is not suited for use in calculating estimates when the number of captures and recaptures has been low for an area.
5. The number of animals seen per hour per acre varies greatly with the habitat, season, and the time of day; however, this technique could be a useful index to abundance when such records have been kept for a considerable period of time for the same area.
6. The efficiency and accuracy of population estimates based on short precensus and census periods are not constant because the number

of individual captured and recaptured varies too greatly with the species and its environment. Table 11 is a summary of the population estimates of squirrels and rabbits on the three wooded study areas.

Table 11. Summary of population estimates of squirrels and rabbits on three study areas. The estimate at the top of the Lincoln Index column for each species and for each study area is based on a 1952 precensus period and a 1953 census period; all other Lincoln Index estimates are from preceding tables.

Study area number	Rabbits			Squirrels		
	Total tagged individuals	Krumholz estimate	Lincoln Index estimates	Total tagged individuals	Krumholz estimate	Lincoln Index estimates
II	31	55	55 21 15 42	26	30	41 12 13 18 28
III	28	37	55 14 19 168	43	63	74 52 32 80 47
IV				131	166	172 126 127 123

7. The Lincoln Index method of population estimation, when applied to data obtained through four or more months of continuous squirrel trapping yielded an estimate that varied from 1.31 to 1.72 times the number of animals tagged on the area. The average variation was 1.537 with a standard deviation of 0.278. The Lincoln Index

estimates of the rabbit populations varied from 1.78 to 1.96 times the number of animals tagged on the area. The average variation was 1.868 with a standard deviation of 0.0925. When this method of censusing is used, the variation should be kept in mind, and any population figure based on the Lincoln Index should also contain a statement as to whether or not the figure was adjusted.

8. The use of kill data from a squirrel harvest substituted for a census period of trapping yielded an estimate that was probably more inaccurate than that obtained by any other method. However, it is entirely possible that an insufficient number of animals had been marked prior to the harvest in order to obtain an acceptable estimate by this method.

9. The ratio of marked squirrels per leaf nest was fairly constant. If the four marked squirrels that were removed by hunting on Study Area III were not included in the total number of tagged animals on that area, the marked squirrel:leaf nest ratio would be 13:1 on Study Areas II and III and 13.1:1 on Study Area IV. The leaf nest counts were made in mid-April, after the nests had been subjected to the snow, sleet, and wind of winter. However, a leaf nest count made in mid-December on one study area gave the same number as the later count. The only disadvantage to using this method is that it should be used at a time of year when there are no leaves on the trees in order to insure a complete count.

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APPENDIX

Appendix Table 1. Data and estimates of the total population of cottontail rabbits in North Crumpacker Woods as estimated by the Krumholz formula.

Date	A		B			C		Estimated population
	No. of animals examined	No. of animals marked	No. of marked animals in area	Product A x B	Sum of products	No. of returns	Sum of returns	
Jan.								
29	2	2	15	30	30	-	-	-
30	6	4	17	102	132	2	2	66
31	3	2	21	63	195	1	3	65
Feb.								
2	1	1	23	23	218	0	3	73
3	4	2	24	96	314	2	5	63
4	1	0	26	26	340	1	6	57
7	6	5	26	156	496	1	7	71
8	1	0	31	31	527	1	8	66
12	3	0	31	93	620	3	11	55

Appendix Table 2. Data and estimates of the total population of gray squirrels in North Crumpacker Woods as estimated by the Krumholz formula.

Date	A		B			C		
	No. of animals examined	No. of animals marked	No. of marked animals in area	Product A x B	Sum of products	No. of returns	Sum of returns	Estimated population
Jan.								
29	4	3	16	64	64	1	1	64
29'	1	0	19	19	83	1	2	42
30	2	2	19	38	121	0	2	61
30'	2	1	21	42	163	1	3	54
31	2	0	22	44	207	2	5	41
Feb.								
1	2	0	22	44	251	2	7	36
2	1	0	22	22	273	1	8	34
2'	4	1	22	88	361	3	11	33
3	1	0	23	23	384	1	12	32
4	1	0	23	23	407	1	13	31
5	3	1	23	69	476	2	15	32
6	2	0	24	48	514	2	17	30
7	2	0	24	48	572	2	19	30
8	2	0	24	48	620	2	21	30
9	2	0	24	48	668	2	23	29
10	1	1	24	24	692	0	23	30
11	3	1	25	75	767	2	25	31
23	2	0	26	52	819	2	27	30
March 23	2	0	26	52	871	2	29	30

' Prime marks indicate days on which animals were in traps in the morning and evening.

Appendix Table 3. Data and estimates of the total population of cottontail rabbits in Crumpacker Woods as estimated by the Krumholz formula. On January 29, 1953, two animals escaped before they were marked.

Date	A		B			C		
	No. of animals examined	No. of animals marked	No. of marked animals in area	Product A x B	Sum of products	No. of returns	Sum of returns	Estimated population
Jan.								
29	4	2	12	48	48	-	-	-
30	3	2	14	42	90	1	1	90
31	3	2	16	48	138	1	2	69
Feb.								
1	2	2	18	36	174	0	2	87
2	3	2	20	60	234	1	3	78
3	1	1	22	22	256	0	3	85
4	3	2	23	69	325	1	4	81
5	3	0	25	75	400	3	7	57
7	2	1	25	50	450	1	8	56
11	2	0	26	52	502	2	10	50
12	5	2	26	130	632	3	13	49
13	3	0	28	84	716	3	16	45
24	1	0	28	28	744	1	17	44
25	5	0	28	140	884	5	22	40
26	1	0	28	28	912	1	23	40
27	3	0	28	84	996	3	26	38
28	1	0	28	28	1,024	1	27	38
March								
23	1	0	28	28	1,052	1	28	38
24	1	0	28	28	1,080	1	29	37

Appendix Table 4. Data and estimates of the total population of gray squirrels in Crumpacker Woods as estimated by the Krumholz formula.

Date	A No. of animals examined	No. of animals marked	B No. of marked animals in area	Product A x B	Sum of products	No. of returns	C Sum of returns	Estimated population
Jan.								
29	1	1	18	18	18	-	-	-
30	7	4	19	133	151	3	3	50
30'	2	2	23	46	197	0	3	66
31	8	5	25	200	397	3	6	66
31'	2	1	30	60	457	1	7	65
Feb.								
2	4	2	32	128	585	2	9	65
3	1	0	34	34	619	1	10	62
4	2	1	34	68	687	1	11	62
5	2	0	35	70	757	2	13	58
6	1	0	35	35	792	1	14	57
7	2	0	35	70	862	2	16	54
9	1	1	35	35	897	0	16	56
10	1	0	36	36	923	1	17	54
11	1	1	36	36	959	0	17	56
23	2	2	37	74	1,033	0	17	61
March								
23	1	1	39	39	1,072	0	17	63

' Prime marks indicate days on which animals were in traps in the morning and evening.

Appendix Table 5. Data and estimates of the total population of gray squirrels on President's Hill as estimated by the Krumholz formula.

Date	A		B			C		
	No. of animals examined	No. of animals marked	No. of marked animals in area	Product A x B	Sum of products	No. of returns	Sum of returns	Estimated population
Oct.								
2	3	3	-	-	-	-	-	-
3	9	8#	3	27	27	-	-	-
4	4	4	11	44	71	-	-	-
6	12	12	15	180	251	-	-	-
7	14	12	27	378	629	2	2	317
8	8	5	39	312	941	3	5	189
8'	4	3	44	176	1,117	1	6	147
9	1	1	46*	46	1,163	0	6	195
9'	4	2	47	188	1,351	2	8	169
13	4	3	49	196	1,547	1	9	173
14	10	8	52	520	2,067	2	11	188
14'	2	0	60	120	2,187	2	13	168
15	3	2	60	180	2,367	1	14	169
15'	2	0	62	124	2,491	2	16	156
16	2	0	62	124	2,519	2	18	146
21	3	2	62	186	2,801	1	19	148
21'	2	0	64	128	2,929	2	21	139
22	3	1	64	192	3,121	2	23	136
22'	1	0	65	65	3,186	1	24	133
23	2	0	65	130	3,316	2	26	128
24	4	3	65	260	3,576	1	27	133

Appendix Table 5. Data and estimates of the total population of gray squirrels on President's Hill as estimated by the Krumholz formula. (Continued.)

Date	A		B			C		
	No. of animals examined	No. of animals marked	No. of marked animals in area	Product A x B	Sum of products	No. of returns	Sum of returns	Estimated population
Oct.								
29	1	1	68	68	3,644	0	27	135
30	6**	3	69	414	4,058	2	29	140
31	6**	5	72	432	4,490	0	29	155
Nov.								
1	4	2	77	308	4,798	2	31	155
1'	4	4	79	316	5,114	0	31	165
2	4	2	83	332	5,446	2	33	165
3	3	1	85	255	5,701	2	35	163
4	4**	0	86	344	6,044	3	38	159
Dec.								
3	1	0	86	86	6,131	1	39	157
4	2	2	86	172	6,303	0	39	161
4'	11	6	88	968	7,271	5	44	165
5	3	1	94	282	7,553	2	46	164
8	8**	4	95	760	8,313	2	48	173
9	4	1	98*	392	8,705	3	51	171
10	4**	2	99	396	9,101	1	52	175
10'	3	0	101	303	9,404	3	55	171
12	3	1	101	303	9,707	2	57	170
12'	3	1	102	306	10,013	2	59	170
13	3	1	103	309	10,322	2	61	169
14	3	1	104	312	10,644	2	63	169
15	1	0	105	105	10,749	1	64	168

Appendix Table 5. Data and estimates of the total population of gray squirrels on President's Hill as estimated by the Krumholz formula. (Continued.)

Date	A No. of animals examined	No. of animals marked	B No. of marked animals in area	Product A x B	Sum of products	No. of returns	C Sum of returns	Estimated population
Dec.								
16	1	1	105	105	10,854	0	64	170
17	1	0	106	106	10,960	1	65	169
Jan.								
6	5**	3	106	530	11,490	2	67	171
7	2	1	108	216	11,706	1	68	172
7'	3	1	109	327	12,033	2	70	172
8	3	3	110	330	12,363	0	70	177
8'	2	0	113	226	12,589	2	72	179
9	5	2	113	565	13,154	3	75	176
10	3	1	115	345	13,499	2	77	175
11	2	1	116	232	13,731	1	78	176
12	2	1	116*	348	14,079	1	79	178
13	2	1	117	234	14,313	1	80	179
14	2	1	118	236	14,549	1	81	180
16	2	0	119	238	14,787	2	83	177
30	1	1	119	119	14,806	0	83	177
31	2	0	120	240	15,046	2	85	177
Feb.								
1	1	0	120	120	15,166	1	86	176
2	3	0	120	360	15,526	3	89	174
3	1	0	120	120	15,646	1	90	174
4	1	0	120	120	15,766	1	91	173
6	1	0	120	120	18,886	1	92	173

Appendix Table 5. Data and estimates of the total population of gray squirrels on President's Hill as estimated by the Krumholz formula. (Continued.)

Date	A		B			C		
	No. of animals examined	No. of animals marked	No. of marked animals in area	Product A x B	Sum of products	No. of returns	Sum of returns	Estimated population
Feb.								
8	3**	0	120	360	16,246	2	94	173
10	3	2	120	360	16,606	1	95	175
11	4	0	122	488	17,094	4	99	173
24	4	0	122	488	17,582	4	103	171
25	1	0	122	122	17,704	1	104	170
March								
1	3	0	122	366	18,070	3	107	168
4	2	0	122	244	18,314	2	109	168
20	1	0	122	122	18,436	1	110	168
21	1	0	122	122	18,558	1	111	167
22	2	0	122	244	18,802	2	113	166
23	1	0	122	122	18,924	1	114	166

\# One animal escaped before it was marked.
' Prime marks indicate days on which animals were in the traps in the morning and evening.
* One marked animal found dead.
** One unmarked animal found dead.

Appendix Table 6. Data and estimates of the total population of largemouth bass in the V.P.I. Upper Pond as estimated by the Krumholz formula and the Schumacher and Eschmeyer formula.

Date	A		B			C		Estimated population	
	No. of fish examined	No. of fish marked	No. of marked fish in pond	Product A x B	Sum of products	No. of returns	Sum of returns	Krumholz	Schumacher and Eschmeyer
Sept.									
18	2	2	-	-	-	-	-	-	-
18'	7	7	2	14	14	-	-	-	-
19	3	3	9	27	41	-	-	-	-
19'	4	4	12	48	89	-	-	-	-
22	1	1	16	16	105	-	-	-	-
22'	2	2	17	34	139	-	-	-	-
23	1	1	19	19	158	-	-	-	-
23'	5	5	20	100	258	-	-	-	-
25	2	2	25	50	308	-	-	-	-
26	4	3	27	108	416	1	1	416	304
29	2	2	30	60	476	0	1	476	370
29'	2	0	32	64	540	2	3	180	133

' Prime marks indicate days on which two passes were made with the seine.

Appendix Table 7. Data and estimates of the total population of golden shiners in the V. P. I. Upper Pond as estimated by the Krumholz formula and the Schumacher and Eschmeyer formula.

Date	A		B				C	Estimated population	
	No. of fish examined	No. of fish marked	No. of marked fish in pond	Product A x B	Sum of products	No. of returns	Sum of returns	Krumholz	Schumacher and Eschmeyer
Sept.									
18	5	5	-	-	-	-	-	-	-
19	4	4	5	20	20	-	-	-	-
22	1	1	9	9	29	-	-	-	-
22'	7	6	10	70	99	1	1	99	88
23	1	0	16	16	115	1	2	58	44
25	3	1	16	48	163	2	4	41	35
26	1	1	17	17	180	0	4	45	40

' Prime mark indicates day on which two passes were made with the seine.

Appendix Table 8. Data and estimates of the total population of white crappie in the V. P. I. Upper Pond as estimated by the Krumholz formula and the Schumacher and Eschmeyer formula.

Date	A		B				C	Estimated population	
	No. of fish examined	No. of fish marked	No. of marked fish in pond	Product A x B	Sum of products	No. of returns	Sum of returns	Krumholz	Schumacher and Eschmeyer
Sept.									
19	2	2	-	-	-	-	-	-	-
22	1	0	2	2	2	1	1	2	2
23	1	0	2	2	4	1	2	2	2
26	1	0	2	2	6	1	3	2	2
29	1	0	2	2	8	1	4	2	2