T H E S I S

A METHOD FOR INVESTIGATING AVIAN PREDATION ON THE ADULT BLACK HILLS BEETLE

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY PATRICK L. STALLCUP

ENTITLED A METHOD FOR INVESTIGATING AVIAN PREDATION ON THE ADULT BLACK HILLS BEETLE

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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INTRODUCTION

The use of insecticides is not in all cases a practical means of controlling destructive forest insects. An understanding of the natural factors affecting densities of populations of insects may lead to less use of chemical control. Information on the effects of birds on densities of populations of forest insects is needed not only because of its bearing on natural regulation of insects but because it also contributes to a further understanding of avian ecology.

The collection of various kinds of data is essential for investigating this aspect of forest ornithology. Information must be obtained on the kinds and numbers of birds that inhabit the area of the forest insects. An understanding of feeding habits and seasonal activities of these birds is necessary for determining those species that may be predators of the insects. Investigations must be made on the diets of the predatory birds in order to determine the proportions of the insects in their food. An understanding of the life cycle of the species of prey is necessary for determining in what stages of development the insects are available for predation by birds.

Avian predation on the Black Hills beetle, _Dendroctonus ponderosae_ Hopkins, a beetle that attacks ponderosa pine, Pinus ponderosa Douglas, has never been investigated, except by casual observations. The application and results of a sequence of operations for investigating the number of Black Hills beetles consumed by birds during the period of flight and attack of this insect is presented in this paper.

Life cycle of Black Hills beetle.

A brief description of the life cycle of the Black Hills beetle is presented here in order to show the temporal relationship of the period of flight of the adult beetles and their attack on the host tree to other stages in the life cycle of this insect.

During August the adult females bore into the bark of the host tree and construct egg galleries in the inner bark in which to lay eggs. Larvae develop from the eggs and mine laterally from the egg gallery for the remaining weeks of the summer. Pupation takes place the following summer in a pupal cell prepared by these larvae. Gradually the sclerotic exoskeleton of the pupa hardens and the adult form is reached by the first of July. These new adults start to emerge late in July and continue through August with some stragglers emerging throughout the year. Ponderosa pines infested by this beetle usually occur in groups of 2 or 3 to as many as 350 (Keen 1952:139).

Problem

To develop and test procedures of investigating avian predation on the adult Black Hills beetle during the periods of flight and attack of this insect.

Delimitations

The investigation extended from May of 1961 to May of 1963. The months of June, July, and August of both years were spent in the field. Two stands of ponderosa pine of about 50 acres each near Bailey, Park County, Colorado (Township 7 south, Range 72 west, Sections 19, 24, elevation, 8,000 feet above sea level) were used for field work. One stand was used for censusing the populations of birds, the other for collecting birds. The size of the population of Black Hills beetles was measured in both stands.

Chapter II

REVIEW OF LITERATURE

Various methods of determining proportions of populations of forest insects removed by birds have been developed within the last twenty years. One of the first attempts to evaluate the degree of predation by birds on forest insects was made by Kendeigh (1947). In his study of the interaction of populations of birds and the spruce budworm, he presented calculations on the proportion of the population of spruce budworm larvae consumed by birds. The number of birds per 100 acres was estimated by censusing singing males during the nesting period. The density of the population of spruce budworm larvae per 100 acres was calculated from estimates obtained from previous studies. He calculated that 4.3 per cent of the total population of larvae was eaten by birds during 45 days of the summer. This degree of predation was based on the estimate that each bird consumed 40 full-grown larvae per day (with slight adjustment for young birds) during this time.

In a study similar to Kendeigh's, George and Mitchell (1948) investigated avian predation on the spruce budworm. Through an unspecified method of censusing, the size of the population of birds was calculated to be about five per acre. They estimated that a bird of any age consumed 6 grams of spruce budworm larvae per day throughout a period of 40 days when these insects were freely available. They estimated that birds removed from 3.5 per cent to 7.0 per cent of the population of spruce budworm larvae.

Mitchell (1952) described a method of assessing the relative intensity of feeding on spruce budworm larvae of various species of birds. In one area of study, the population of birds was censused by counting the singing males during the nesting period. In another area birds were collected and the proportionate volume which spruce budworm larvae constituted of the total volume of food recorded from the stomachs of 826 birds was measured. Mitchell derived a relative index of predation for each species of bird by multiplying the proportion of spruce budworms in the stomachs by the number of birds per acre. The proportion of the spruce budworm population consumed by birds was not calculated.

Hutchison (1952) investigated the effects of woodpeckers on the Engelmann spruce beetle. The number of beetles removed by woodpeckers was estimated by measuring the surface area of bark that showed evidence of work of woodpeckers. He estimated that about 40 per cent of the population of beetles had been removed by birds during the winter months. The size of the beetle population was estimated by using calculations from previous studies made in different areas by other researchers. Hutchison examined the contents of stomachs of woodpeckers collected during his study and estimated that Engelmann spruce beetles made up 99 per cent of the woodpecker's diet at that time in the area of study.

Knight (1957) developed a method of measuring mortality of the Engelmann spruce beetle due to direct and indirect effects of woodpeckers. Wire screen was installed over a part of the bark of several spruce trees at the beginning of the winter to exclude the feeding of woodpeckers on this hibernating insect. In August of the following summer, the survival of the beetles which were available to woodpeckers under the unscreened bark was compared with that of the beetles protected from woodpeckers by the wire screens. Knight estimated that woodpeckers destroyed from 45 to 98 per cent of the hibernating population of Engelmann spruce beetle during the winter months.

An extensive study on the foods of titmice was conducted by Betts (1955) in Britain. She determined the number of pairs of nesting birds per acre by a total census of the study area. The abundance of defoliating insects was estimated by measuring the amount of frass produced by insects per hour. Many direct observations of the feeding of nestling birds were made. She estimated that nestlings were fed about seven food items per hour during 16 hours of the day. She assumed that adult birds consumed at least as much as the nestling birds and estimated that between 0.5 per cent and 2.6 per cent of the population of defoliating insects was removed by birds during the nesting period.

Inozemtsev (1961) studied the foods of nestlings of the Spotted Flycatcher (Muscicapa hypoleuca) in Russia. He calculated the number of invertebrates inhabiting a unit area of woodland of the hunting territory of the adult Spotted Flycatcher. By direct observation from a blind he tallied the number of various species or groups of invertebrates eaten by nestlings. He then calculated the "predatorial effect" of the Spotted Flycatcher on the various species and groups of invertebrates. Predatorial effect is the number of individuals of a species of invertebrate taken expressed as per cent of the total number of that invertebrate available. He calculated that less than one per cent of the total available invertebrates was removed by the Spotted Flycatcher; but up to 40 per cent of the population of an individual species of invertebrate were taken.

Various methods of assessing avian predation on forest insects have been discussed. All methods involved some means of estimating the size of the population of insects but not all methods involved estimates of the size of the population of birds. Estimates of the number of insects destroyed by birds have been based on various kinds of data. These data include calculations based on 1) measurements of the population of insects at various times of the year, 2) insect remains in the contents of the stomachs of birds, 3) direct observations of feeding habits of birds.

A review of the literature of avian predation on forest insects discloses that very few investigations have been made on avian predation of bark-beetles. Only the mortality of hibernating bark-beetles caused by woodpeckers has been investigated. Procedures for investigating avian predation on bark-beetles during the flight stage of these insects have not been developed.

Chapter III

MATERIALS AND METHODS

The procedures for investigating avian predation on the Black Hills beetle were developed and tested from May of 1961 to February 1963. The field work was conducted during the months of June, July and August of 1961 and 1962 in two stands of ponderosa pine of about 50 acres each near Bailey, Park County, Colorado (Township 7 south, Range 72 west, Sections 19, 24, elevation, 8,000 above sea level). Procedures of investigating this subject were not perfected until the summer of 1962, and only the procedures used at that time are presented.

The methods developed for investigating this problem will be presented and explained in the order they appear in the following outline.

A. Enumeration of Black Hills beetle.

1. Recording of all trees infested by Black Hills beetles.
2. Estimation of number of Black Hills beetles that flew from host trees.
3. Estimation of relative number of Black Hills beetles that emerged daily from representative infested trees.
4. Estimation of relative number of Black Hills beetles that emerged hourly from these trees.

B. Census of population of birds.

1. Recording of kinds of birds present, their abundance and location.

C. Estimation of the extent of feeding of birds on adult Black Hills beetles.

1. Collection of birds during flight period of Black Hills beetle.
2. Classification of birds into feeding-categories according to location and manner of feeding.
3. Examination of stomach contents of birds collected for remains of Black Hills beetles.
4. Estimation of the number of adult Black Hills beetles consumed by members of each feeding-category.
5. Estimation of the proportion of adult Black Hills beetle population consumed by members of all feeding-categories.

<u>Enumeration of Black Hills beetle</u>

Three kinds of information were needed to estimate the number of Black Hills beetles per acre that flew from their host trees and became potential prey of the birds of study: 1) number of infested trees per 10 acres, 2) area of infested bark per tree, 3) number of Black Hills beetles per square foot of infested bark.

In June of 1962 a survey was made of all trees infested with Black Hills beetles in the two areas of study. A map was made of the relative location of these trees, and their diameters at breast height were recorded. The average number of trees per 10 acres and average diameter of infested trees in the area of study were computed.

Three calculations were made in order to estimate the average area of bark infested by Black Hills beetles. All of these calculations were based on figures derived from the average diameter of infested trees. They included calculations of 1) circumference of the bole at the lower limits of infested bark, 2) length of infested part of bole, 3) circumference of the bole at the upper limits of infested bark.

The average circumference of the bole at the lower limits of infested bark was based on data gathered by Dr. G. Fechner (School of Forestry, Colorado State University, personal communication) in his study of taper of uninfested ponderosa pine in a comparable stand in the Black Hills of South Dakota. The average height above the ground of infested bark was computed from data developed by Massey (Height of Treatment of the Black Hills beetle in Ponderosa Pine and the Relationship of Height to Infestation, Roosevelt National Forest 1950. Unpublished report of 1951, Rocky Mountain Forest and Range Experiment Station). The average circumference of the bole at the maximum height above the ground of infested bark was calculated on the basis of Fechner's data.

From these data the total surface area of infested bark in the area of study was calculated using the formula for the curved surface of a frustum of a right cone. The result of this calculation was then converted to average surface area of infested bark per 10 acres.

The average number of Black Hills beetles per square foot of infested bark was calculated by computing the average number of Black Hills beetles under sections of bark (measuring 6 x 6 inches) removed from the north and south side of a sample of infested trees. The sampling of the beetle population for this computation was random and took place about two weeks prior to the flight period of this insect. Knight (1959) found that data obtained in the same way could be used for computing a reliable estimate of the average density of this insect per square foot of infested bark.

The average number of Black Hills beetles per acre in the area of study was computed by multiplying the average surface area of infested bark per 10 acres by the average number of beetles occupying a square foot of infested bark.

Prior to the flight period of the Black Hills beetle, 1½ x 4 feet wire screen cages were attached to the north side of the bole of three infested ponderosa pines in each of the two areas of study. A screw-top Mason jar was attached to the base of each cage so that insects emerging from the enclosed area of bark could be removed. These cages were checked every morning in order to determine the day that emergence of the Black Hills beetles started. After emergence had started, the total number of Black Hills beetles emerging each day from the six cages was recorded. This quantity was graphed to give an estimate of the relative intensity of emergence throughout the days of the summer.

Forest entomologists from the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, conducted investigations on the flight and attack characteristics of the Black Hills beetle in the same area of study. They collected and recorded the number of Black Hills beetles found hourly in the above cages every other day for a 10-day period during the greatest intensity of the emergence period. From these data, the relative intensity of Black Hills beetles emerging per hour in the area of study was estimated.

Census of bird populations

In June of 1962, a census transect was established in one of the areas of study. This transect coursed 27 chains north through various densities of forest and 23 chains south through a comparable area with some open brushland. Groups of infested ponderosa pine were present at various locations along the transect. Also, devices for attracting Black Hills beetles were installed near the transect by the forest entomologists working in the area. Figure 1 shows the location of the census transect in relation to trees that contain Black Hills beetles before the emergence in the summer of 1962 and trees that were attacked by this insect the same summer.

Birds were censused along the transect 54 mornings from June 21 to September 15. The censusing began no later than one hour after sunrise, and was completed in about 90 minutes. The species of birds observed during each census were recorded at intervals of one chain along the transect. Calculations of the total area censused for each species of bird were based on the greatest distance of recognition, which varied with density of forest and with conspicuousness of each species of bird. The area censused for each species was tabulated at the end of the summer, and the average number of birds per 10 acres was computed for five census periods consisting of 10 days each. Census data gathered during unfavorable weather conditions that revealed extremely low population densities of birds were not used in the final computation of the density of birds.

<u>Estimation of extent of feeding of birds on the adult Black Hills beetles</u>

In the summer of 1961, birds were shot with a .410 gauge shotgun during the period of flight of the Black Hills beetle. The results of the analysis of the stomach contents of these birds were used as a basis for determining the

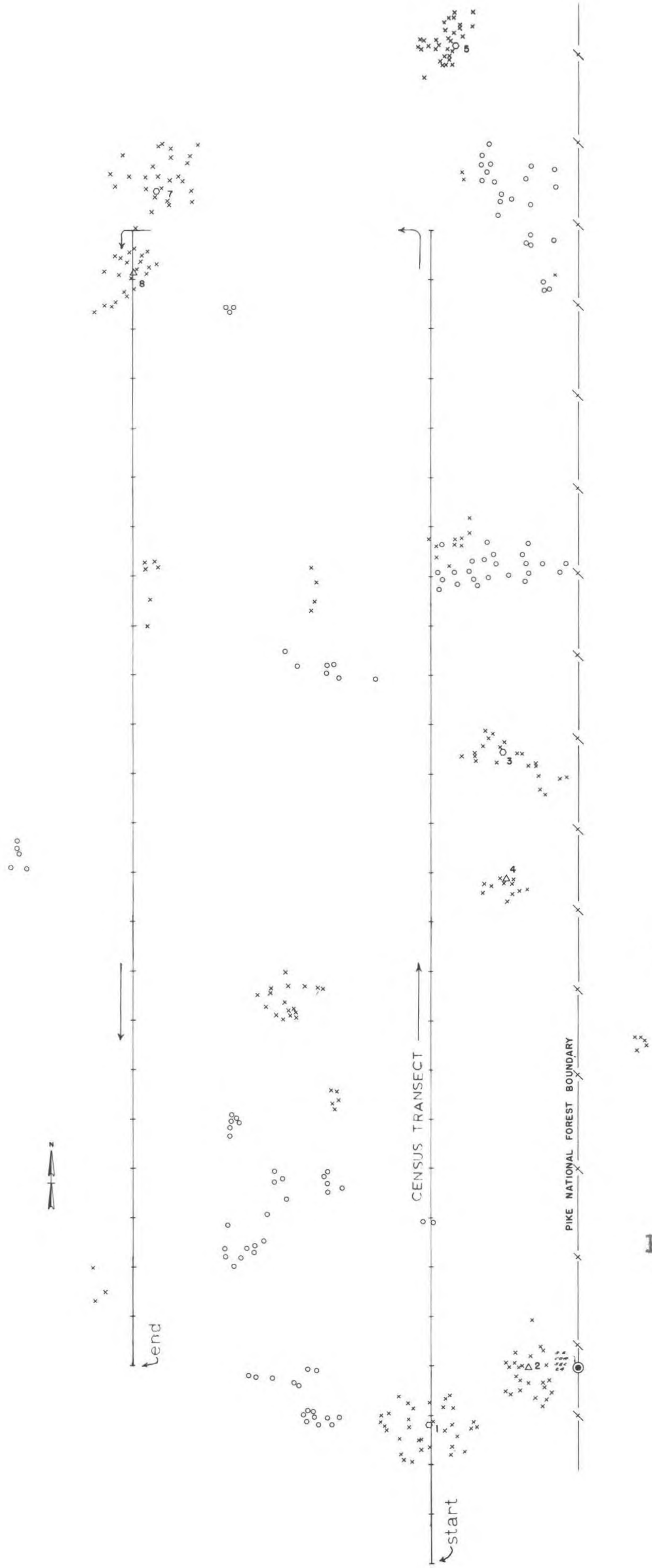

Figure 1.

BLACK HILLS BEETLE INFESTATIONS
1961 & 1962
BAILEY, COLORADO

SECTION - 24
T. 7 S.
R. 73 W.

LEGEND:
× 1962 ATTACKS
○ 1961 ATTACKS
—×— WIRE FENCE & FOREST BOUNDARY
△ CAGE ATTRACTANTS
○ BOLT ATTRACTANTS

⊢—⊣ = one chain

Prepared by the Rocky Mountain Forest and Range Experiment Station species of birds to be studied intensively in 1962.

During the summer of 1962 birds were collected in a stand of ponderosa pine comparable to the stand where the birds were censused, so that the population of birds in the area of censusing was not reduced. This area where birds were collected was situated about one third of a mile northwest of the area where birds were censused and was about 75 acres in size. Birds were collected from 8:00 a.m. until sunset during the last two census periods, in which most of the beetles emerged. In an attempt to obtain a random sample, each species of bird was collected unsystematically along an undetermined course within the area of the collecting plot. Some birds were collected in other areas of the forest. The time of day that these specimens were taken and their location relative to trees infested in 1961 or 1962 were recorded.

Species of birds collected in greatest quantities were classified into feeding-categories based on their location and method of feeding. The feeding categories were designated as:

1. Air-foliage feeders, consisting of birds that feed predominantly in air and occasionally in upper foliage of trees.
2. Foliage feeders, consisting of birds that feed predominantly in foliage of trees.

3. Stem-branch feeders, consisting of birds that feed predominantly on the main stem and occasionally on branches of trees.
4. Ground-foliage feeders, consisting of birds that feed predominantly on the ground and occasionally in foliage of trees and bushes.

The census data for different species of birds were segregated by feeding-categories, and the latter were analyzed as single entities.

The contents of each stomach were spread out uniformly in a calibrated watch glass and examined for remains of Black Hills beetles. The average proportion of these beetles in the food of the members of each feeding-category was determined visually. These proportions were converted to the equivalent weights that they constituted of the estimated weights of food consumed by the members of each feeding category during the two census periods. The weight of food consumed daily was based on the assumption that these birds ate daily quantities of food equivalent to about 25 per cent of their body weight (Lack 1954:131). The average weight of beetles consumed by members of each feeding category was converted to equivalent numbers of beetles.

In order to calculate the number of beetles taken per 10 acres by members of each feeding-category, the average number of birds per 10 acres for each category was multiplied by the average number of beetles in their diet.

The total number of beetles consumed by birds of all categories was calculated by summing the total number of beetles eaten by birds of each feeding-category.

The proportion of the population of adult Black Hills beetles consumed by members of all feeding-categories was expressed as the mean number eaten per 10 acres.

Chapter IV

PRESENTATION OF DATA

Enumeration of the Black Hills beetle population

The number of Black Hills beetles per 10 acres in the area of study was derived from the following sequence of operations.

The map of infested trees in both areas of study was arbitrarily subdivided into 12 sectors equivalent to 10 acres each. The trees infested in 1961 within each sector were counted, and their average number was calculated to be 21.85 per 10 acres. Thirty-one per cent of all trees infested in 1961 was sampled for Black Hills beetles. From this sample the average number of beetles that emerged during the summer of 1962 was estimated to be 27.96 per square foot of bark, with a standard error of 3.52.

The measurements used in computing the surface area of infested bark were interpolated from measurements of diameters taken at breast height. The mean diameter of 298 trees infested in 1961 was calculated to be 9.4 inches with a standard error of 0.2. The height of the infested bole for trees with diameters of 9.5 inches was estimated to be about 23 feet above the ground, based on Massey's (*op. cit.*, p. 11) study of the relationship of diameter and height of infested bark of ponderosa pine. Mortality of the beetles was extremely variable, as indicated by samples of bark taken at various heights above six feet on the bole. No measures were taken to evaluate the extent of this mortality.

Data gathered by Fechner (op. cit., p. 11) in a comparable stand of uninfested ponderosa pine show that trees with diameters between 9 and 10 inches taper to about 7.4 inches at 23 feet above the ground. The surface area of the bole was computed between 1 and 23 feet above the ground, since the density of Black Hills beetles below one foot is extremely low. The diameter at one foot above the ground was interpolated from Fechner's data to be 11.0 inches.

The surface area of infested bark for trees of average diameter was computed to be 52.99 square feet, and the average surface area of infested bark per 10 acres was calculated to be 1,157.83 square feet.

Assuming that the length of the infested bole of the average tree was 22 feet and that the number of beetles from samples of bark removed at breast height were representative of the mean size of the population, the average number of beetles per 10 acres was calculated to be 32,373. This figure was used as the estimate of the maximum number of beetles that emerged in July and August of 1962.

The number of Black Hills beetles emerging per day was recorded from counts of beetles taken from the cages on 6 trees (Figure 2). The results from the hourly counts of beetles from these cages are presented in Figure 3.

Census of bird population

Forty-nine censuses were used during this study. They were grouped into five census periods consisting of about 10 days each (Table 1).

TABLE 1.--DATES OF CENSUS PERIODS

Census period	Dates included	Number of censuses taken a/
I	June 23 to July 5	13 (10)
II	July 6 to July 20	10 (10)
III	July 21 to August 3	10 (10)
IV	August 4 to August 18	13 (10)
V	August 23 to September 14	9 (9)

a/ Number in parentheses represents number of censuses used.

Records were made at intervals of one chain along the census transect of the greatest distance of recognition of each species of bird. From these data the total area censused for each species was computed. The area censused for species encountered infrequently was not computed. Because of the difficulty of identifying birds of the genus *Empidonax*, all members of this genus were analyzed as a

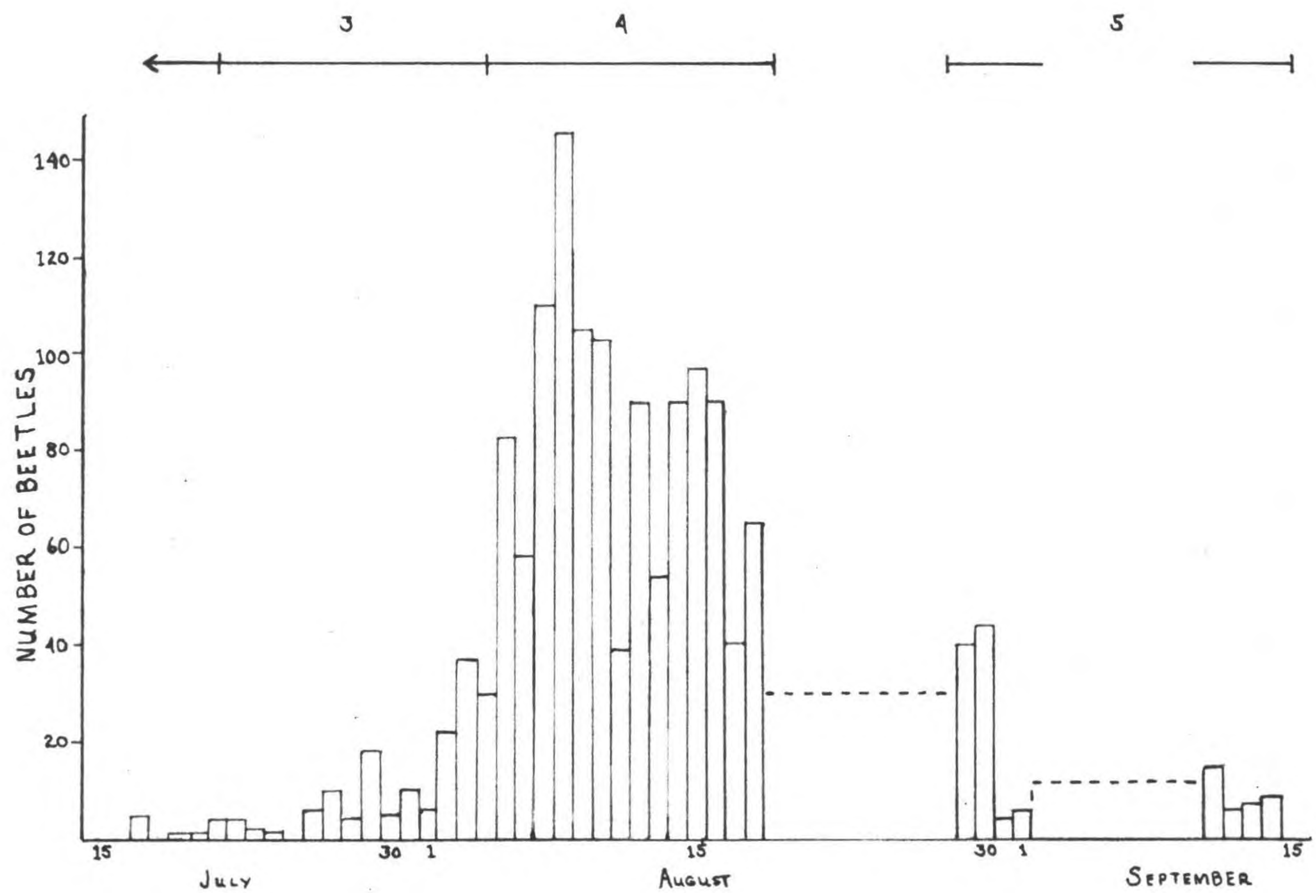

Figure 2.--Histogram of total number of Black Hills beetles collected from six cages at 9:00 a.m. daily. Dotted lines represent average number of beetles per day during times when they were not collected daily. Distance between hatches of horizontal line above represents length of census periods.

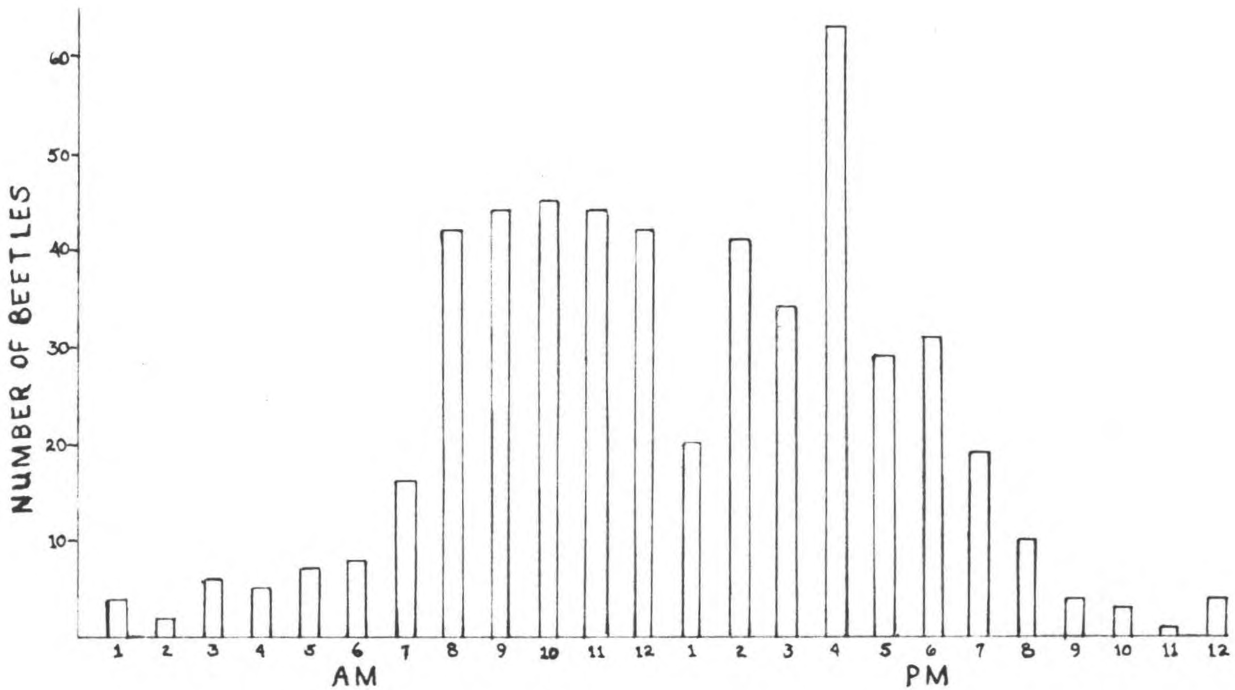

Figure 3.--Average number of Black Hills beetles collected hourly from six cages in 1962, August 7, 9, 11, 13, 15.

single entity. A summary of all species of birds encountered along the transect and the area censused for each is presented in Table 2.

The average number of birds per 10 acres for each census period for birds in which the area censused was computed is shown in Table 3. The frequency of observations during each census period for scarcer birds not computed on a 10 acre basis are presented in Table 4.

Species of birds censused that were collected in large quantities were classified into feeding-categories. The members of these categories are presented in Table 5. Birds observed in the area but not classified into feeding-categories were:

Sparrow Hawk	Hermit Thrush
Great Horned Owl	Virginia's Warbler*
Common Nighthawk	Townsend's Warbler*
Broad-tailed Hummingbird	Western Tanager
Red-shafted Flicker	Pine Siskin
Williamson's Sapsucker	Green-tailed Towhee
Hairy Woodpecker	Chipping Sparrow
Clark's Nutcracker	Savannah Sparrow*
Red-breasted Nuthatch*	Golden-crowned Kinglet*
Brown Creeper	Gray Jay
House Wren	

The asterisk (*) indicates birds that were collected. The average number per 10 acres of the members of each feeding-category for the five census periods is shown in Figure 4.

TABLE 2.--SPECIES OF BIRDS ENCOUNTERED AND AREA CENSUSED FOR EACH

Species a/	Area in acres
Sparrow Hawk, *Falco sparverius*	not computed
Great Horned Owl, *Bubo virginianus*	"
Common Nighthawk, *Chordeiles minor*	"
Broad-tailed Hummingbird, *Selasphorus platycercus*	"
Red-shafted Flicker, *Colaptes cafer*	15
Williamson's Sapsucker, *Sphyrapicus thyroideus*	15
Hairy Woodpecker, *Dendrocopos villosus*	15
Empidonax flycatchers	10
Western Wood Pewee, *Contopus sordidulus*	15
Violet-green Swallow, *Tachycineta thalassina*	30
Gray Jay, *Perisoreus canadensis*	not computed
Steller's Jay, *Cyanocitta stelleri*	15
Clark's Nutcracker, *Nucifraga columbiana*	30
Mountain Chickadee, *Parus gambeli*	14
White-breasted Nuthatch, *Sitta carolinensis*	14
Red-breasted Nuthatch, *Sitta canadensis*	not computed
Pigmy Nuthatch, *Sitta pygmaea*	13
Brown Creeper, *Certhia familiaris*	not computed
House Wren, *Troglodytes aedon*	14
Robin, *Turdus migratorius*	15
Hermit Thrush, *Hylocichla guttata*	not computed
Townsend's Solitaire, *Myadestes townsendi*	15
Golden-crowned Kinglet, *Regulus satrapa*	14

TABLE 2.--Continued

Species a/	Area in acres
Solitary Vireo, Vireo solitarius	not computed
Virginia's Warbler, Vermivora virginiae	"
Audubon's Warbler, Dendroica auduboni	14
Townsend's Warbler, Dendroica townsendi	not computed
Western Tanager, Piranga ludoviciana	14
Pine Siskin, Spinus pinus	14
Green-tailed Towhee, Chlorura chlorura	14
Savannah Sparrow, Passerculus sandwichensis	not computed
Grey-headed Junco, Junco caniceps	14
Chipping Sparrow, Spizella passerina	not computed

a/ Scientific names are from the A.O.U. Checklist of North American Birds, 5th ed., 1957.

TABLE 3.--THE MEAN AND STANDARD ERROR OF NUMBERS OF BIRDS PER TEN ACRES FOR THE FIVE CENSUS PERIODS

Species of birds	Census periods I	II	III	IV	V
Red-shafted Flicker	0.8 ± 0.2	0.5 ± 0.2	0.5 ± 0.2	0.1 ± 0.1	0.5 ± 0.2
Williamson's Sapsucker	0.5 ± 0.2	0.6 ± 0.2	0.7 ± 0.1	0.0	0.0
Hairy Woodpecker	0.2 ± 0.1	0.1 ± 0.1	0.0	0.0	0.4 ± 0.2
Empidonax Flycatchers	0.0	0.0	0.0	0.1 ± 0.1	0.2 ± 0.1
Western Wood Pewee	0.2 ± 0.2	0.3 ± 0.1	0.1 ± 0.1	0.6 ± 0.3	0.3 ± 0.2
Violet-green Swallow	3.7 ± 0.5	5.3 ± 0.7	6.0 ± 0.4	2.2 ± 0.6	0.0
Steller's Jay	0.3 ± 0.1	0.7 ± 0.1	0.0	0.2 ± 0.2	0.4 ± 0.2
Clark's Nutcracker	0.0	0.0	0.0	0.1 ± 0.1	0.0
Mountain Chickadee	0.5 ± 0.2	0.9 ± 0.6	4.9 ± 1.5	4.6 ± 0.8	3.1 ± 0.7
White-breasted Nuthatch	0.9 ± 0.3	0.3 ± 0.2	0.5 ± 0.3	0.7 ± 0.3	0.5 ± 0.2
Pigmy Nuthatch	4.8 ± 0.9	8.9 ± 1.9	10.7 ± 1.2	12.7 ± 1.0	12.3 ± 2.1
House Wren	0.6 ± 0.3	0.0	0.6 ± 0.2	0.4 ± 0.2	0.0
Robin	1.1 ± 0.5	1.0 ± 0.4	0.4 ± 0.2	0.9 ± 1.2	0.0
Townsend's Solitaire	0.8 ± 0.3	0.3 ± 0.1	0.0	0.4 ± 0.2	0.1 ± 0.1

TABLE 3.--Continued

Species	Census periods				
	I	II	III	IV	V
Solitary Vireo	0.0	0.2 ± 0.1	0.0	0.3 ± 0.2	0.6 ± 0.2
Audubon's Warbler	0.1 ± 0.1	0.0	0.3 ± 0.2	0.0	1.7 ± 0.3
Western Tanager	0.7 ± 0.3	0.9 ± 0.3	0.3 ± 0.3	0.0	0.0
Pine Siskin	0.4 ± 0.3	0.2 ± 0.1	0.0	0.1 ± 0.1	0.0
Green-tailed Towhee	0.1 ± 0.1	0.1 ± 0.3	0.0	0.0	0.1 ± 0.1
Grey-headed Junco	5.6 ± 1.6	7.5 ± 1.3	7.1 ± 1.1	9.0 ± 0.2	6.3 ± 2.3

TABLE 4.--NUMBER OF DAYS BIRDS WERE OBSERVED IN EACH CENSUS PERIOD FOR BIRDS IN WHICH THE AREA CENSUSED WAS NOT COMPUTED ON A 10-ACRE BASIS

Species	Census periods				
	I	II	III	IV	V
Sparrow Hawk	0	1	0	0	0
Great Horned Owl	0	0	0	1	0
Common Nighthawk	6	8	1	0	0
Broad-tailed Hummingbird	2	1	7	4	0
Gray Jay	0	0	0	0	1
Red-breasted Nuthatch	0	0	0	0	1
Brown Creeper	0	0	0	0	1
Hermit Thrush	0	0	0	0	2
Golden-crowned Kinglet	0	0	0	1	0
Virginia's Warbler	0	0	0	0	1
Townsend's Warbler	0	0	0	0	1
Savannah Sparrow	0	0	0	1	0
Chipping Sparrow	0	0	0	0	1

TABLE 5.--SPECIES OF BIRDS OF EACH FEEDING-CATEGORY

Species of birds	Feeding-category
White-breasted Nuthatch Pigmy Nuthatch	I Stem-branch feeders
Empidonax flycatchers Western Wood Pewee Violet-green Swallow	II Air-foliage feeders
Mountain Chickadee Solitary Vireo Audubon's Warbler	III Foliage feeders
Steller's Jay Robin Townsend's Solitaire Gray-headed Junco	IV Ground-foliage feeders

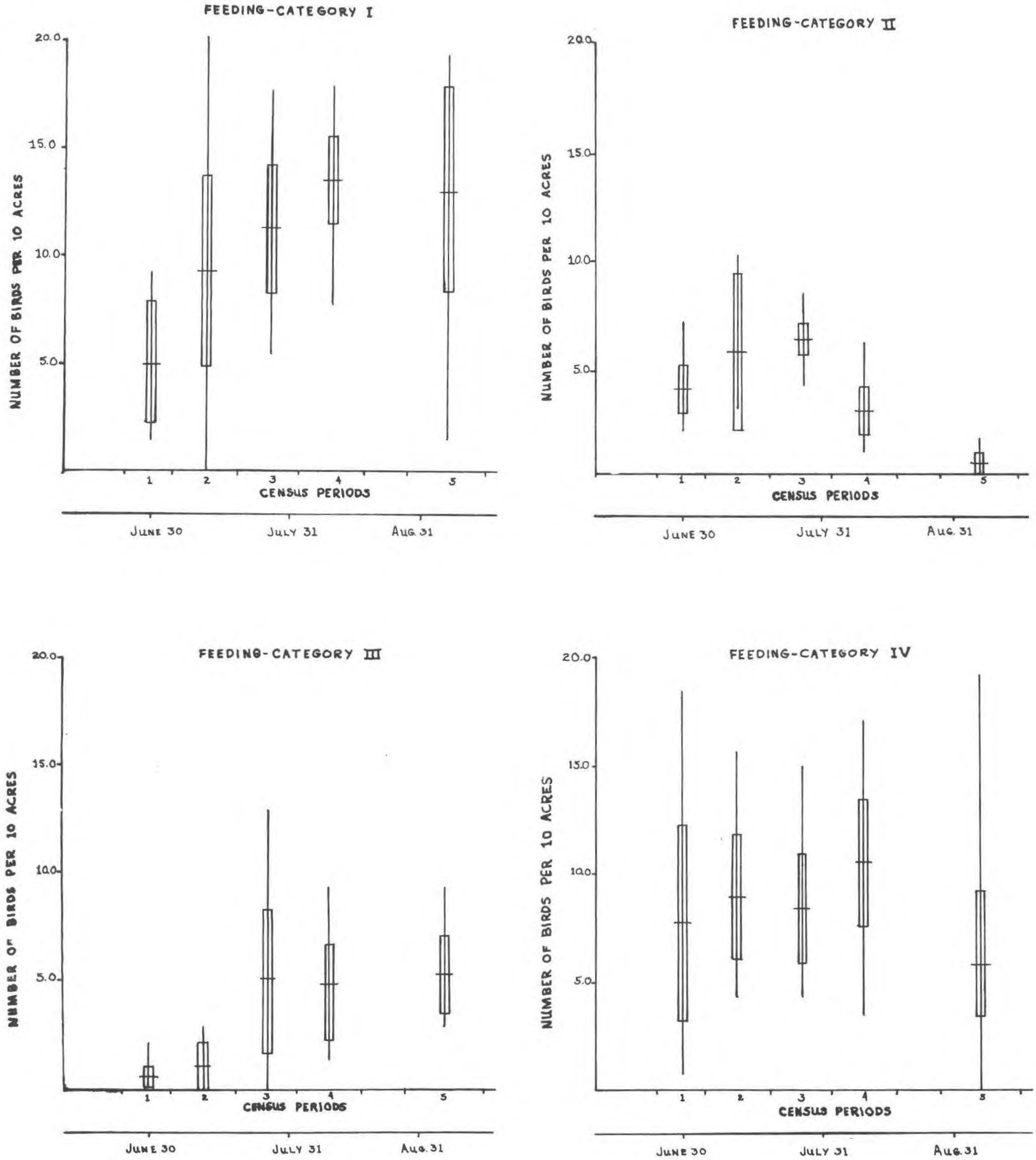

Figure 4.--Number of birds per ten acres in Feeding-categories I, II, III, IV, for all census periods. The vertical lines represent the ranges, the horizontal lines represent the means, the rectangles represent the 95 per cent confidence interval of the mean.

<u>Extent of feeding of birds on the adult Black Hills beetle</u>

The frequencies of occurrence of fragments of Black Hills beetles found in the stomachs of birds collected during the summer of 1961 are tabulated in Table 6.

Four out of six stomachs of Hairy Woodpeckers collected in 1961 contained adult and pupal Black Hills beetles. Methods for determining whether the beetles in stomachs of woodpeckers were eaten before or after the emergence of this insect have not been developed. For this reason no members of the woodpecker complex were collected in 1962.

The occurrence of fragments of Black Hills beetles in the stomachs of birds collected in 1962 is presented in Table 7.

Measurements of hourly emergence (Figure 3) are the best estimates available of hourly activity of beetles which have emerged. If the hourly activity of emergent beetles is related to the conspicuousness of these insects to birds, the probability of a bird eating a beetle before 6:00 a.m. and after 7:00 p.m. should be lower than in the afternoon. Also, it may be assumed that beetles are most likely to be eaten by birds which forage in areas of infested trees. In recognition of the possible different opportunities for feeding on beetles, the stomachs of each feeding-category were further classified according to time of day and nearness to infested trees.

TABLE 6.--FREQUENCY OF OCCURRENCE OF STOMACHS WITH FRAGMENTS OF BLACK HILLS BEETLES FOR BIRDS COLLECTED IN 1961

Species of bird	Specimens	
	Number examined	Number with fragments of Black Hills beetles
Common Nighthawk	2	0
Broad-tailed Hummingbird	1	0
Red-shafted Flicker	6	0
Williamson's Sapsucker	3	0
Hairy Woodpecker	6	4
Empidonax flycatcher	1	0
Western Wood Pewee	5	4
Olive-sided Flycatcher	1	1
Violet-green Swallow	2	0
Steller's Jay	3	0
Clark's Nutcracker	2	1
Mountain Chickadee	10	1
White-breasted Nuthatch	4	1
Pigmy Nuthatch	23	4
Robin	9	1
Townsend's Solitaire	7	3
Audubon's Warbler	5	2
Pine Siskin	1	0
Gray-headed Junco	5	0
Chipping Sparrow	1	0

TABLE 7.--OCCURRENCE OF BLACK HILLS BEETLE FRAGMENTS IN STOMACHS OF BIRDS COLLECTED IN 1962

Species of birds	Census period	Number of birds collected	Number of stomachs with beetle fragments	Proportion of stomach contents represented by beetle fragments, in per cent
	Feeding-category I			
Pigmy Nuthatch	IV	21	3	5, 5, 10
	V	21	2	5, 15
White-breasted Nuthatch	IV	7	2	70, 95
	V	6	0	0
	Feeding-category II			
Violet-green Swallow	IV	3	0	0
	V	0	0	0
Western Wood Pewee	IV	6	3	10, 40, 50
	V	2	1	5
Empidonax sp.	IV	1	1	15
	V	3	0	0
	Feeding-category III			
Mountain Chickadee	IV	18	1	5
	V	23	0	0
Audubon's Warbler	IV	2	0	0
	V	6	0	0
Solitary Vireo	IV	1	0	0
	V	2	0	0
	Feeding-category IV			
Gray-headed Junco	IV	13	0	0
	V	16	0	0
Robin	IV	7	0	0
	V	0	0	0
Townsend's Solitaire	IV	2	0	0
	V	4	0	0
Steller's Jay	IV	4	1	trace
	V	2	0	0
	Species of birds not classified into feeding-categories			
Brown Creeper	IV	0	0	0
	V	1	1	25

TABLE 7.--Continued

Species of birds	Census period	Number of birds collected	Number of stomachs with beetle fragments	Proportion of stomach contents represented by beetle fragments, in per cent
Red-breasted Nuthatch	IV	0	0	0
	V	1	0	0
Virginia's Warbler	IV	0	0	0
	V	1	0	0
Ruby-crowned Kinglet	IV	0	0	0
(*Regulus calendula*)	V	2	0	0
Townsend's Warbler	IV	0	0	0
	V	1	1	trace
Savannah Sparrow	IV	0	0	0
	V	1	0	0

The four time-location classes used were:

A. Collected between 6:00 a.m. and 7:00 p.m., and less than one chain away from infested trees.

B. Collected between 6:00 a.m. and 7:00 p.m., and greater than one chain away from infested trees.

C. Collected before 6:00 a.m. or after 7:00 p.m., and less than one chain away from infested trees.

D. Collected before 6:00 a.m. or after 7:00 p.m., and greater than one chain away from infested trees.

The numbers of specimens of each feeding-category in each time-location class are shown in Figure 5.

The average proportions of the Black Hills beetle components in the stomachs of members in each time-location class of each feeding-category for Census Periods IV and V were computed (Tables 8 and 9). Because members of Feeding-categories III and IV had only traces of Black Hills beetles in their stomachs, only members of Feeding-categories I and II were considered in the computation of the number of beetles consumed.

The average weight of Black Hills beetles in the foods of members of Feeding-categories I and II was computed under the assumption that these birds consumed daily a quantity of food equal to about 25 per cent of their body weight. The average body weights of members of these feeding-categories are presented in Table 10. From these weights

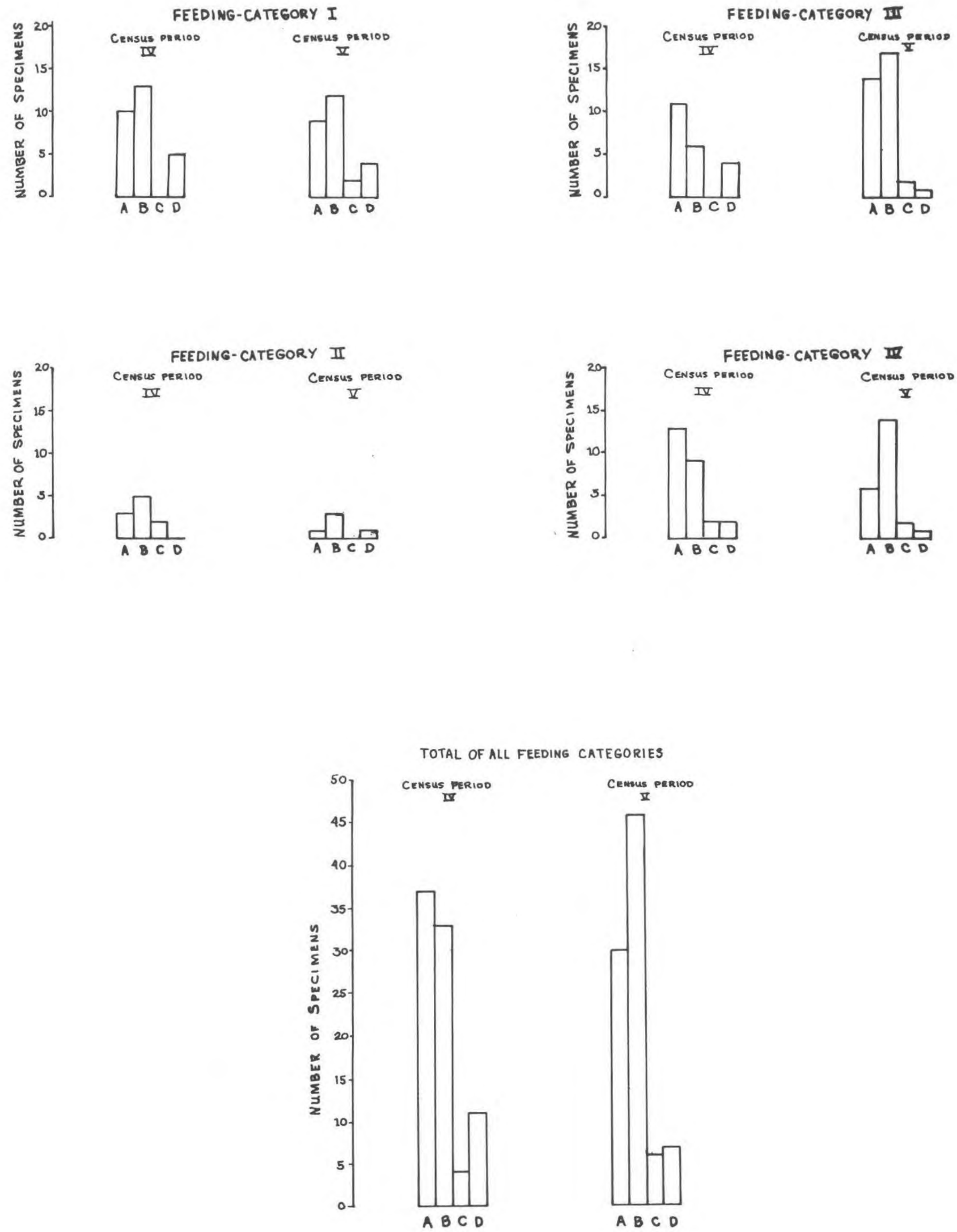

Figure 5.--Number of specimens of Feeding-categories I, II, III, and IV in each time-location class for Census Periods IV and V.

TABLE 8.--AVERAGE PROPORTION OF FRAGMENTS OF BLACK HILLS BEETLES IN STOMACHS OF MEMBERS OF EACH TIME-LOCATION CLASS FOR ALL FEEDING-CATEGORIES COLLECTED DURING CENSUS PERIOD IV

Time-location class a/	Number of specimens	Specimens with beetle fragments	Σ% beetle fragments	$\bar{X}\% \pm s\bar{x}$ b/ beetle fragments
		Feeding-category I c/		
A	10	4	180	18.00±11.96
B	13	1	5	0.39± 0.17
C	0	0	0	0
D	5	0	0	0
Total	28	5	185	6.85± 4.10
		Feeding-category II		
A	3	3	100	33.33±14.72
B	5	1	15	3.00± 3.00
C	2	0	0	0
D	0	0	0	0
Total	10	4	115	11.50± 5.31
		Feeding-category III		
A	12	1	1	trace
B	6	0	0	0
C	0	0	0	0
D	4	0	0	0
Total	22	1	1	trace
		Feeding-category IV		
A	13	1	1	trace
B	9	0	0	0
C	2	0	0	0
D	2	0	0	0
Total	26	1	1	trace

a/ Time-location class described on page 36.

b/ The symbols $\bar{X} \pm s\bar{x}$ indicate the mean plus or minus one standard error of the mean.

c/ Feeding-category described on page 30.

TABLE 9.--AVERAGE PROPORTION OF FRAGMENTS OF BLACK HILLS BEETLES IN STOMACH CONTENTS OF MEMBERS OF EACH TIME-LOCATION CLASS FOR ALL FEEDING-CATEGORIES COLLECTED DURING CENSUS PERIOD V

Time-location class	Number of specimens	Specimens with beetle fragments	Σ% beetle fragments	$\bar{X}\% \pm s\bar{x}$ beetle fragments
		Feeding-category I		
A	9	2	20	2.22±1.69
B	12	0	0	0
C	2	0	0	0
D	4	0	0	0
Total	27	2	20	0.74± .58
		Feeding-category II		
A	1	1	5	5.00±0.00
B	3	0	0	0
C	0	0	0	0
D	1	0	0	0
Total	5	1	5	1.00±1.00
		Feeding-category III		
A	14	0	0	0
B	17	1	1	trace
C	2	0	0	0
D	1	0	0	0
Total	34	1	1	trace
		Feeding-category IV		
A	6	0	0	0
B	14	0	0	0
C	2	0	0	0
D	1	0	0	0
Total	23	0	0	0

TABLE 10.--MEAN WEIGHT OF SPECIES OF BIRDS INCLUDED WITHIN FEEDING-CATEGORIES I AND II

Species of bird	Number weighed	$\bar{X} \pm s\bar{x}$ of weight in gms.
	Feeding-category I	
White-breasted Nuthatch	12	17.9 ± 0.3
Pigmy Nuthatch	38	10.3 ± 0.1
	Feeding-category II	
Empidonax	3	11.6 ± 0.7
Western Wood Pewee	7	13.2 ± 0.3
Violet-green Swallow	3	15.4 ± 0.3

it was calculated that each member of Feeding-categories I and II ate about 3.5 grams of food per day.

Black Hills beetles collected in 1961 from a stand of pine 25 miles west of Fort Collins had a mean weight of 0.017 grams (data obtained from William McCambridge, Forest Entomologist, Rocky Mountain Forest and Range Experiment Station). This figure was derived from the mean weight of 790 beetles weighed in groups ranging from 16 to 21 beetles each. The standard deviation of the weights of the groups was 0.001 grams.

From these data, the average weights of beetle fragments in the stomachs were calculated by the methods explained on page 17 for birds in Feeding-categories I and II. These weights were converted to equivalent numbers of Black Hills beetles (Table 11).

The estimate and the 95 per cent confidence interval of the number of beetles consumed by these birds during the last two census periods are shown in Table 12. The proportion of the beetle population consumed by these birds during those census periods was calculated to be 8.5 per cent. The 95 per cent confidence interval on this figure is from zero to 43.3 per cent.

TABLE 11.--NUMBER OF BLACK HILLS BEETLES IN DIETS OF MEMBERS OF FEEDING-CATEGORIES I AND II DURING CENSUS PERIODS IV AND V

Census period	Weight of food consumed per day	$\bar{X} \pm s_{\bar{x}}t_{.05}$[a] of proportion of beetles in diet per day	$\bar{X} \pm s_{\bar{x}}t_{.05}$ of equivalent weight in gms. of beetles in diet per day	$\bar{X} \pm s_{\bar{x}}t_{.05}$ of equivalent number of beetles in diet per day
		Feeding-category I		
IV	3.5	6.85±8.41	0.24±0.53	13.87±44.51
V	3.5	0.74±1.19	0.03±0.07	1.73± 5.78
		Feeding-category II		
IV	3.5	11.50±12.01	0.40±0.82	23.12±70.52
V	3.5	1.00± 2.26	0.40±0.11	2.31± 8.67

a/ The symbols $\bar{X} \pm s_{\bar{x}}t_{.05}$ represent the mean plus or minus the 95 per cent confidence interval of the mean.

TABLE 12.--SUMMARY OF COMPUTATION OF NUMBER OF BEETLES CONSUMED BY MEMBERS OF FEEDING-CATEGORIES I AND II DURING CENSUS PERIODS IV AND V

Census period	No. of days in census period	$\bar{X} \pm s_{\bar{x}} t_{.05}$ of number of birds per 10 acres	$\bar{X} \pm s_{\bar{x}} t_{.05}$ of number of beetles in diet	Estimates of the number of beetles consumed per 10 acres		
				Minimum	Mean	Maximum[a]
			Feeding-category I			
IV	10	13.4±2.0	13.9±44.5	0	1,863	8,994
V	9	12.9±4.8	1.7± 5.8	0	197	1,195
			Feeding-category II			
IV	10	2.9±1.1	23.1±70.5	0	670	3,744
V	9	0.5±0.5	2.3± 8.7	0	10	99
			Total	0	2,740	14,032

a/ Mean, minimum and maximum values are based on the means and 95 per cent confidence intervals of the number of beetles in the diets and the number of birds per 10 acres.

Chapter V

DISCUSSION

The operations developed for investigating this problem will be discussed in the order in which they were performed, so that their independent validity and usefulness as a whole may be evaluated. In addition, suggestions will be made for modifying these operations for adapting or refining their use according to particular requirements in future studies.

Enumeration of Black Hills beetle population

The degree of accuracy desired in this study did not warrant the direct taking of all measurements used in calculating the proportion of the population of beetles consumed by birds. Consequently, appropriate inferences from the results of other researchers and certain assumptions were employed in computing the size of the population of this insect.

The best approximations of the average taper and length of the infested bole of trees in the area of study were derived from data obtained by Massey (*op. cit.*, p. 11) and Fechner (*op. cit.*, p. 11). The stand of ponderosa pine from which Fechner gathered his data was estimated by forest entomologists of the Forest and Range Experiment Station in Fort Collins, Colorado, to be comparable in taper to the stand of trees in Bailey, Colorado. The only data available on the lengths of the infested boles of ponderosa pines were those data gathered in 1950 by Massey in the Roosevelt National Forest.

Samples of bark taken from the stand in Bailey in 1962 at various heights on the bole of several infested trees indicated that the survival of the Black Hills beetle above 10 feet from the ground was extremely variable. The variable survival of this insect was assumed by forest entomologists to be caused by the severe cold weather of the previous winter. For this reason, the computation of the surface area of infested bark (based on the length of infested bole derived from Massey's data) is probably an overestimate of the actual surface area of infested bark in the area of study.

In future research of this kind, a more accurate estimate of the surface area of infested bark could be obtained by taking actual measurements of the length and taper of the infested bole from a sample of infested trees in the area of study.

The reduction in the numbers of beetles under the bark between the date in which these insects were sampled and the time of their flight was not considered in estimating the number of beetles that emerged in the summer of 1962. However, for the degree of accuracy desired in this study it was felt that the mortality of the beetle during this time did not significantly reduce the estimate of the number of beetles that emerged per 10 acres. Further refinements for correcting this source of error cannot be made until more is known about the degree of mortality at this stage of the life cycle of the beetle.

The ratio of trees attacked by Black Hills beetles in 1961 to trees attacked in 1962 was 1.0 : 2.1. This increment of the number of infested trees agrees with the prediction of the trend of the infestation made from the results of a sequential sampling of the population of beetles taken in July of 1962 according to methods developed by Knight (1960). Consequently, the flight of beetles into the area of study from adjacent locations was assumed to be in equilibrium with the flight of beetles out of the area of study. No techniques are available for adjusting the estimate of the population of beetles in the event of a large immigration or emigration of this insect. For this reason, the estimate of the proportion of the population of this insect removed by birds has to be based on the existing population in the area of study.

Census of bird population

The procedures used in censusing birds in the area of study can be compared to the "variable-width-strip" method of censusing tested by Amman and Baldwin (1960) in their evaluation of various methods for censusing woodpeckers. They utilized the greatest distance at which each species of woodpecker was noticed in order to determine one half the width of his census strip. They computed the number of each species of woodpecker per acre separately, They found that the results of this method compared best to the results of a 100 per cent census of the study plot.

The procedures of censusing used in this study differed from the preceding in that the greatest distance of recognition for each species of bird was considered for each interval of one chain along the census transect. This modification was necessary because of the variable distance of visibility at different locations along the census transect due to various densities of forest.

The average number of birds censused in the area of study was computed on a 10 acre basis, because this unit of area corresponds closely to the actual area censused for each species of bird (Table 2). The adjustment of census data to the unit of area (100 acres) suggested by Lack (1937) may not be valid if the habitat of the area censused is not representative of the habitat of 100 acres in the same area of study. In further studies of this kind the unit of area could be modified to correspond to the approximate area censused.

The number of birds per 10 acres was derived from average counts from census periods of 10 days each, except for Census Period V (which consisted of nine days). The results of the computation of the number of birds per 10 acres were variable from one census period to the other. This can be explained in part by the fact that this study was conducted during the nesting season of many birds. An increase recorded for many species of birds was probably due to an actual increase of fledglings. The decline and subsequent absence of Violet-green Swallows in the area was due to the pre-migratory flocking of this species near the North Fork of the South Platte river located one mile south of the area of study.

Variation in number of birds computed during different census periods could also be due to their uneven distribution in the forest. In further studies, a more precise estimate of the average number of birds per 10 acres could be made by increasing the number of days from which this average is computed.

Estimate of the extent of feeding by birds on the adult Black Hills beetle.

Inferences were made on the avian predation on Black Hills beetles in one area of study from the occurrence of beetles in the stomachs of birds collected in another area. This procedure presupposes that foods of each species of bird were similar in both areas of study. This assumption seems justified in that no apparent ecological boundary separated the two areas, and no important differences were observed in the complex of avian species of either area.

It is difficult for one investigator to collect a sample of birds of sufficient size for analyzing the feeding on Black Hills beetles by each species of bird separately. Classifying the samples into feeding-categories and analyzing each of these categories as a single entity is a useful means of increasing the size of the samples. A further classification of collected specimens into time-location classes can be used for analyzing birds with greater or lesser probabilities of having eaten Black Hills beetles.

The classification of specimens of each feeding-category into time-location classes (page 36 and Figure 5) reveals that more specimens were collected of Time-location Classes A and B. This shows that collecting of birds was biased, because more specimens were collected between the hours of 6:00 a.m. and 7:00 p.m. The results of the analysis of stomach contents show that birds of Time-location Classes A and B were the only birds that had fragments of beetles in their stomachs. This may indicate that specimens of birds of Time-location Classes A and B had greater opportunities for feeding on beetles. However, larger samples of birds would have to be collected in order to give this statistical significance. The attempts to take random samples can be improved in future studies by spending equivalent lengths of time collecting at times of the day and areas that correspond to each time-location class.

The number of samples of birds of each time-location class of each feeding-category will vary with the distribution of birds. This may result in the collecting of inadequate numbers of birds for analyzing statistically. Larger samples could be obtained by more workers collecting in several comparable stands of forest.

One difficulty that arises in the analysis of food in the stomachs of birds is the continued digestion of these foods after death of the bird. Koersveld (1951) suggests that this continued digestion of foods after death may be stopped by dissecting the stomach immediately after killing the birds and using 10 per cent formalin to preserve the stomach contents. In the present study, the stomachs of the birds collected were filled with a solution of 35 per cent alcohol by use of a pipette via the esophagus. All specimens collected were frozen within five hours after being collected In January of 1963, the stomachs were removed and their contents examined.

Detailed volumetric methods for measuring the proportionate volume of fragments of Black Hills beetles in the stomachs of birds are impractical because the volume of the stomach contents in most species of bird is very small. Thus, the visual estimate as described on page 17 seems to be the best method for measuring the volume of beetle fragments in the stomach contents.

Several assumptions were necessary in order to calculate the number of beetles consumed daily from the proportion of fragments of beetles in the stomachs: 1) the average per cent of fragments of beetles in the stomachs can be used to determine the daily consumption of beetles, 2) the different foods in the stomachs of birds of the same feeding-category have approximately equal weights for the same volumes (specific gravity), 3) all foods of birds of the same feeding-category are digested at approximately the same rate. Using these assumptions, the proportions of beetle fragments in the stomachs were converted to equivalent weights that they constituted of the estimated weights of food consumed by these birds daily. These weights were then converted to equivalent numbers of beetles consumed daily.

The only requisite for the first of these assumptions is the collection of an adequately large sample of specimens for each time-location class in each feeding-category to satisfy the statistical level of accuracy desired. The large standard error calculated for the mean proportions of beetle fragments demonstrates the extreme variation in proportions of these fragments in the stomachs. Larger samples might result in a more accurate estimate of the proportion that beetles constitute of the diets of birds. However, larger samples might not affect greatly the relative size of the confidence interval of the mean if the feeding of birds on Black Hills beetles is inherently highly variable.

The assumption of approximately uniform specific gravity for foods of birds in the same feeding-category can be used if the members of the feeding-categories are found to eat similar kinds of foods, as is the case with the members of Feeding-categories I and II in this study. However, if birds classified into the same feeding-categories in future studies had extremely varied diets, adjustments would be required for the weights of different foods for computing the weights of beetle fragments from volumetric measurements.

The rate of digestion of various foods (for birds of the same feeding-category) could be analyzed in future studies. Hartley (1948) suggests an experimental method for making allowances for the speed of digestion of various foods in which groups of experimental animals are fed meals of single kinds of food. The animals are killed at intervals and the degree of digestion of the foods in the stomachs is recorded. In this way, each kind of food can be given a numerical value representing its rate of digestion that can be used for evaluating the diets of animals from the examination of their stomach contents. However, the assumption of a uniform rate of digestion for birds that eat similar foods (birds of the same feeding-category) seems justified for attaining the degree of accuracy desired in this preliminary study.

The weight of the adult Black Hills beetles in the area of study was approximated by use of the weight of beetles collected from infested trees located about 100 miles north of the area of study. In the event of local differences in weights of beetles, a more accurate estimate could be obtained by weighing beetles collected from the area of study.

The number of adult Black Hills beetles computed per 10 acres is probably an overestimate because of the great mortality of this insect in the tree above 10 feet from the ground. For this reason, the proportion calculated in this study of the beetle population consumed by birds during Census Periods IV and V is considered to be an underestimate.

Assuming no survival of beetles above 15 feet on the bole of infested trees, the population of beetles would have been calculated as 23,575 per 10 acres. This figure is about 72 per cent of the value calculated under the methods previously described (page 12 and 20). The proportion of the population of beetles removed by birds using this latter figure would be 11.6 per cent. The 95 per cent confidence interval on this figure is from zero to 59.5 per cent.

The frequency of occurrence of a given proportion of beetle fragments in the contents of the stomachs (Table 7) resembles that of a Poisson distribution. However, an analysis of goodness of fit did not demonstrate this to be true. If it can be shown in future research that the occurrence of beetle fragments in the stomachs of birds does approximate this kind of distribution, a more precise confidence interval on the mean proportion of fragments might be computed. The small samples collected in this study made it necessary to accept low precision in the confidence interval for the mean proportion of beetle fragments in the stomachs. Regardless of the form of the distribution of these proportions, the mean is the best parameter from which the number of beetles eaten can be estimated.

The methods developed in this study apply only to avian predation on the Black Hills beetle during the flight period of this insect. However, some of these procedures may be employed for investigating avian predation on other forest insects. It is difficult to compare the methods used in this study with those used for investigating avian predation on other forest insects. However, the utilization of certain empirical data in the present study offer an improvement over previous investigation. These improvements include:

1. Measurements of the relative abundance of the insect prey throughout the summer.
2. The computation of density of the population of birds throughout the summer from average counts derived from census periods of several days each. This permitted the detection of changes of numbers of birds over a considerable length of time which may be used in future studies for correlating fluctuations of both populations of birds and insects.
3. The calculation of the number of insects eaten by birds from the actual occurrence of fragments of these insects in the stomachs. This permits the evaluation of variation in feeding on the insect and could also be used in future studies for investigating possible patterns of feeding on other foods. The frequency of

occurrence of other foods in the stomachs may contribute to our knowledge of the quantities of other foods consumed by birds throughout the summer.

Various suggestions have been made for refining the methods developed for this investigation. These refinements may only result in computing these various data with more precision. Previous to this study, no information was available on the number of Black Hills beetles consumed by birds during the flight period of this insect. It is felt that the procedures developed and tested in this study offer a substantial means for estimating this value.

Chapter VI

SUMMARY

Procedures for investigating avian predation on the adult Black Hills beetle during the period of flight and attack of this insect were developed and tested. Field work was conducted during the months of June, July and August of 1961 and 1962 in two stands of ponderosa pine of about 50 acres each near Bailey, Colorado. One stand was used for censusing the population of birds, the other for collecting birds.

The density of the population of beetles per 10 acres was computed from average number of beetles found in samples of infested bark. The relative intensity of beetles emerging and flying per day was determined from counts of beetles collected from cages installed on infested trees.

Birds were censused along a census transect. The total area censused for each species was calculated based on the greatest distance of recognition of the birds. This distance varied with density of forest and conspicuousness of each species of bird. The average number of birds per 10 acres was computed from 49 censuses taken throughout the summer.

During the period of flight of the Black Hills beetle, birds were collected in an adjacent stand. The collected specimens were classified into feeding-categories and the stomach contents of each member of each category was examined for fragments of Black Hills beetles. Each feeding-category was analyzed as a single entity. The average proportion of fragments of beetles in the food of members of each feeding-category was estimated visually. These proportions were converted to equivalent weights that they constituted of the estimated weights of food consumed by these birds daily. These weights of fragments of beetles were converted to equivalent numbers of beetles.

The average number of beetles eaten by members of each feeding-category during the period of most intense emergence of the beetle was computed. This computation was based on the number of birds of each feeding-category censused per 10 acres and the average number of beetles consumed by them.

The proportion of the population of beetles consumed by birds was calculated to be 8.5 per cent. The 95 per cent confidence interval of this figure is from zero to 43.3 per cent.

Field observations indicated that mortality of the Black Hills beetle during the previous winter of 1961-62 was abnormally high. Considering this high winter mortality, the proportion of the population of beetles removed by birds was computed to be 11.6 per cent. The 95 per cent confidence interval on this figure is from zero to 59.5 per cent.

The frequency of occurrence of a given proportion of beetle fragments in the contents of the stomach appeared to resemble a Poisson distribution; however, an analysis of goodness of fit at the 95 per cent level of significance, failed to demonstrate this kind of distribution of the data. The relatively few numbers of specimens collected in this study made it necessary to accept a small degree of precision in the confidence interval of the mean proportion of the population of beetles consumed by birds. If the form of the distribution of the occurrence of beetle fragments in the stomach of birds can be approximated in future research, a more precise confidence interval on the mean proportion of the population of beetles removed by birds might be computed. Regardless of the form of this distribution, the mean was the best parameter from which the number of beetles consumed by birds could be estimated.

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ABSTRACT OF THESIS

A METHOD FOR INVESTIGATING AVIAN PREDATION

ON THE ADULT BLACK HILLS BEETLE

Procedures for investigating avian predation on the adult Black Hills beetle, Dendroctonus ponderosae Hopkins, during the period of flight and attack of this insect were developed and tested. Field work was conducted during the months of June, July, and August of 1961 and 1962 in two stands of ponderosa pine of about 50 acres each near Bailey, Park County, Colorado.

The density of the population of beetles per 10 acres was computed from average number of beetles found in samples of infested bark. The relative intensity of beetles emerging and flying per day was determined from counts of beetles collected from cages installed on infested trees.

Birds were censused along a census transect. The total area censused for each species was calculated and based on the greatest distance of recognition of birds which varied with density of forest and conspicuousness of each species of bird. The average number of birds per 10 acres was computed from 49 censuses taken throughout the summer.

During the period of most intense emergence of the Black Hills beetle, birds were collected in an adjacent stand. The collected specimens were classified into feeding-categories and the stomach contents of each member of

each category were examined for fragments of Black Hills beetles. Each feeding-category was analyzed as a single entity. The average proportion of fragments of beetles in the food of members of each feeding-category was estimated visually. These proportions were converted to equivalent weights that they constituted of the estimated weights of food consumed by these birds daily. These weights of fragments of beetles were converted to equivalent numbers of beetles.

The average number of beetles eaten by members of each feeding-category during the period of most intense emergence of the beetle was computed. This computation was based on the number of birds of each feeding-category censused per 10 acres and the average number of beetles consumed by them.

The proportion of the population of beetles consumed by birds was calculated to be 8.5 per cent. The 95 per cent confidence interval of this figure is from zero to 43.3 per cent.

Field observations indicated that mortality of the Black Hills beetle during the previous winter was abnormally high. Considering this high winter mortality, the proportion of the population of beetles removed by birds was computed to be 11.6 per cent. The 95 per cent confidence interval on this figure is from zero to 59.5 per cent.

Patrick L. Stalloup
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