AN ABSTRACT OF THE THESIS OF

Michael L. Morrison for the degree of Doctor of Philosophy

in Wildlife Science presented on 8 April 1982

Title: Response of Avian Communities to Herbicide-Induced Vegetation Changes, Western Oregon

Abstract approved: Redacted for Privacy
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The relationships between avian community structure and herbicide modification of vegetation were analyzed on early-growth clearcuts in western Oregon that had received phenoxy herbicide treatment 1 or 4 years previously. Only minor effects of herbicide treatment were evident 1-year after spraying, except for red adler (Alnus rubra), which still exhibited moderate to severe damage. Most plants showed no obvious signs of the treatment by 4 years post-spray. For both 1 and 4 years post-spray, vegetation development was greater in the second (1.0-3.0 m) and third (>3.0 m) height intervals on untreated (Control) sites; vegetation cover in the lowest (<1.0 m) interval did not vary between treated and untreated sites. All measures of vegetative diversity on untreated sites exceeded those on sprayed sites. Discriminant function analysis identified deciduous tree cover as of primary importance in separation of vegetation of treated and untreated sites. Overall density and diversity of birds were similar between treated and unntreated sites. Several bird species altered patterns of foraging behavior on treated sites. Differences in habitat use were identified for several species; birds using deciduous

trees were found to increase use of shrubs on treated sites. Deciduous tree cover usually functioned in ordination of the avifauna on both treated and untreated sites. The primary effect of herbicide application was a reduction in the complexity of vegetation on treated sites, a condition due primarily to the removal of deciduous trees. The substantial shrub cover on treated sites, however, apparently allowed maintenance of an overall avian density similar to that of untreated sites. Small patches of deciduous trees, scattered about on clearcuts treated with phenoxy herbicides can maintain an avian community that is similar to that on untreated sites.

RESPONSE OF AVIAN COMMUNITIES TO HERBICIDE-INDUCED VEGETATION CHANGES, WESTERN OREGON

by

Michael Louis Morrison

A THESIS

submitted to

Oregon State University

in partial fulfillment of

the requirements for the

degree of

Doctor of Philosophy

Completed: 8 April 1982

Commencement: June 1982

APPROVED:

Redacted for Privacy

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Date thesis is presented 8 April 1982

Typed by LaVon Mauer for Michael L. Morrison

ACKNOWLEDGMENTS

I was fortunate to be assisted throughout my doctoral studies by numerous individuals. My major professor, E. Charles Meslow, provided the guidance and critical overview that helped bring this study to a successful conclusion. Members of my doctoral committee -- D.S. deCalesta, G. Matzke, M. Newton, and J. Stevens -- offered invaluable suggestions and encouragement on all aspects of my studies. I am extremely grateful for their help. B.J. Verts and D. McIntire helped during the initial design of the study. K. Linquist, D. Burton, D. Chrostek, E. Forsman, C. LeFleur, D. Hardy, B. Hale, and H. Jones are thanked for field assistance during various stages of the study. I gained both professionally and personally through discussions with numerous staff members and fellow students, especially R.W. Mannan, R.G. Anthony, R.W. Frenzel, and G.A. Green. I am grateful to L. Mauer for typing numerous drafts of the thesis. The staff of the Patuxent Wildlife Research Center was extremely helpful during the design and analysis of the study -- I am especially grateful to N. Coon, H. Ohlendorf, C. Bunck, and C. Grue for their help and encouragement. J. Warner, Alsea Ranger District (UFSF), was instrumental in study site selection -- his help is gratefully acknowledged. J. Eckhardt, Hebo Ranger District, also assisted in site selection.

I will never be able to repay the support given my family by my mother, Jane Morrison -- her help was deeply appreciated. The support and encouragement of all of our relatives made the work more pleasant. Finally, I want to thank, with love, and dedicate this thesis to, my wife, Sherry Wagner Morrison, for seeing this project through with me. I realize it was not easy.

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PREFACE

The study reported herein concerns the effects of herbicides on plant and bird communities on early-growth clearcuts in western Oregon. Two study designs were involved: (1) the design, reported in the main body (text) of this thesis, concerns the effects of 2,4-D and 2,4,5-T (usually in a mixture) applied 1- and 4-years before study. Different pairs of sites (treated site and untreated site) were studied each of the 3 years of this study; (2) the design, reported in its entirety in the Appendix, concerns the effects of the herbicide glyphosate as applied to one site (and a untreated control site). Data were collected prior to, and for 2 years after, treatment.

Much of the data collected during this study were suitable for analyses not directly related to herbicide effects. As such, several other manuscripts that utilized parts of the basic data set were prepared as follows:

1) Morrison, M.L. 1981. The structure of western warbler assemblages: analysis of foraging behavior and habitat selection in Oregon. Auk 98:578-588. -- This paper analyzed the relation between three species of warblers occurring on clearcuts in western Oregon.

2) Morrison, M.L., R.W. Mannan, and G.L. Dorsey. 1981. Effects of number of circular plots on estimates of avian density and species richness. Pgs. 405-408 in Estimating the numbers of terrestrial birds (C.J. Ralph and J.M. Scott, eds.). Studies Avian Biol. 6. -- Includes data, among others, that were collected during bird censusing for the thesis projects. The objective of this paper was to identify the

minimum number of census points needed to obtain relatively stable density estimates of birds using the variable-circular plot census method.

3) Morrison, M.L., and E.C. Meslow. Bird community structure on early-growth clearcuts in western Oregon. In preparation. -- describes the community structure of birds nesting on clearcuts, both treated and untreated with herbicides, in western Oregon; does not discuss herbicide treatment directly.

4) Morrison, M.L., and E.C. Meslow. Avifauna associated with early-growth clearcuts in the Oregon Coast Range. In preparation. -- describes the density and frequency of occurrence of birds on clearcuts in western Oregon. Includes all clearcuts analyzed in the thesis, but does not separate those treated and untreated with herbicides; that is, considers the "typical" clearcut in the region.

RESPONSE OF AVIAN COMMUNITIES TO HERBICIDE-INDUCED VEGETATION CHANGES, WESTERN OREGON[1]

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Abstract: The relationships between avian community structure and herbicide modification of vegetation were analyzed on early-growth clearcuts in western Oregon that had received phenoxy herbicide treatment 1 or 4 years previously. Only minor effects of herbicide treatment were evident 1 year after spraying, except for red adler (*Alnus rubra*), which still exhibited moderate to severe damage. Most plants showed no obvious signs of the treatment by 4 years post-spray. For both 1 and 4 years post-spray, vegetation development was greater in the second (1.0-3.0 m) and third (>3.0 m) height intervals on untreated (Control) sites; vegetation cover in the lowest (<1.0 m) interval did not vary between treated and untreated sites. All measures of vegetative diversity on untreated sites exceeded those on

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[1]This study was conducted under the auspices of the Oregon Cooperative Wildlife Research Unit: Oregon State University, Oregon Department of Fish and Wildlife, U.S. Fish and Wildlife Service, and the Wildlife Management Institute cooperating. This study was funded by the U.S. Fish and Wildlife Service, Patuxent Wildlife Research Center, Cooperative Agreement 14-16-0009-78-977. Oregon State University Agricultural Experiment Station Technical Paper 6289.

sprayed sites. Discriminant function analysis identified deciduous tree cover as of primary importance in separation of vegetation of treated and untreated sites. Overall density and diversity of birds were similar between treated and untreated sites. Several bird species altered patterns of foraging behavior on treated sites. Differences in habitat use were identified for several species; birds using deciduous trees were found to increase use of shrubs on treated sites. Deciduous tree cover usually functioned in ordination of the avifauna on both treated and untreated sites. The primary effect of herbicide application was a reduction in the complexity of vegetation on treated sites, a condition due primarily to the removal of deciduous trees. The substantial shrub cover on treated sites, however, apparently allowed maintenance of an overall avian density similar to that of untreated sites. Small patches of deciduous trees scattered about on clearcuts treated with phenoxy herbicides can maintain an avian community that is similar to that on untreated sites.

J. Wildl. Manage. 00(0):000-000

Key words: birds, Oregon Coast Range, phenoxy herbicides, 2,4-D, 2,4,5-T, brush control, clearcutting, avian habitat use, avian foraging behavior.

Studies have shown that the avifauna of a forest selects habitats on the basis of vegetation structure (Johnston and Odum 1956, James 1971, Anderson and Shugart 1974, Whitmore 1975, Balda 1975, Roth 1976). These studies have also shown that, because of special habitat requirements, many bird species are restricted to a narrow range of structural types, or successional stages. It follows, then, that alteration of the vegetation pattern of a forest may affect the associated avian community.

Silvicultural practices that follow clearcutting of a forest often have a pronounced effect on the structure of the associated animal communities (Webb et al. 1977, Meslow 1978). Clearcutting, as the term is applied in the Oregon Coast Range, refers to the cutting-down of all, or nearly all, trees on a site. Commercially valuable species are removed, and residual species are cut and left scattered on the ground. Clearcutting is the most effective harvesting system for insuring conifer regeneration in this region (Williamson 1973). In the Oregon Coast Range, brushfields often form after clearcutting (Franklin and Dyrness 1973). These brushfields, usually composed of red alder (Alnus rubra) and various deciduous and evergreen shrubs, retard the growth of commercially valuable timber species, such as Douglas-fir (Pseudotsuga menziesii). Various mechanical and chemical methods are employed to suppress unwanted vegetation and thereby encourage conifer development (USDA Forest Service 1978). Avian species for which these early successional stages provide required needs, including feeding and nesting sites, would be expected to respond to alteration of their preferred habitat (Wight 1974, Meslow 1978).

In the Oregon Coast Range, herbicide use is the most common silvicultural method for maintaining dominance of conifer through the shrub stages (USDA Forest Service 1978). Following logging, application of an herbicide will enhance site preparation for planting of seedlings, and later, help reduce brush competition with developing conifers (release spraying). Despite the widespread use of herbicides for this purpose in the Pacific Norhtwest, there have been few studies on the effects of herbicide-induced vegetation changes on forest birds.

In the Sierra Nevada of California, no marked effects on overall bird density were noted 1 and 2 years after 2,4,5-T application to shrubs (Beaver 1976). Subtle differences in species abundance were evident, however, as several species exhibited greater or lesser abundance after the shrub cover was modified. In a spruce (Picea abies) forest in Norway, bird density decreased about 30% 1 year after a clearcut was sprayed with 2,4,5-T to reduce shrub coverage (Slagsvold 1977). Four years after treatment, numbers on the clearcut and sprayed area were still depressed. A marked reduction in the number of breeding birds was found on a 12-year old Jeffrey pine (Pinus jeffreyi) stand sprayed with 2,4,5,-T 6 years earlier (Savidge 1977, 1978). However, Savidge's study areas were small (5 ha), and the sprayed site was thinned 1 year prior to censusing. Osaki (1979) continued and expanded upon the work of Savidge, finding that although no overall difference in bird abundance was evidenced, several species declined in abundance after spray application. These studies have shown that herbicides induce changes in vegetation structure that may influence the density and diversity of the associated avifauna.

This study tested the hypothesis that the avian communities were similar between sites treated with, and sites not treated with, phenoxy herbicides. Specific objectives were to describe the vegetation structure of early successional forest communities, herbicide treated and untreated, and to compare the density, diversity, and patterns of habitat use of avian communities in relation to the vegetation structure on these sites. Differences in habitat use by a bird species between treated and untreated sites could then be related to modification of their habitats.

D.S. deCalesta, G.E. Matzke, M. Newton, P.H. Albers and J. Stevens are thanked for reviewing the manuscript. The assistance of N. Coon, C. Bunck, C. Grue, and H. Ohlendorf, Patuxent Wildlife Reserach Center, is appreciated. K. Linquist, D. Burton, and D. Chrostek assisted with field-work, and L. Mauer prepared the manuscript. J. Warner and J. Eckhardt, USDA Forest Service, helped with study site selection.

STUDY SITES

This study was conducted in the Douglas-fir region of the Oregon Coast Range on land administered by the USDA Forest Service, Siuslaw National Forest (Alsea and Hebo Ranger Districts). Study sites were located in Lane and Lincoln counties, except for 2 sites, which were in Yamhill and Tillamook counties, respectively. All study sites were as similar in size and topography as possible: 21-34 ha in area, 110-510 m in elevation, and of generally northern aspect. In this paper, site age refers to the number of years since conifer seedlings were planted. Planting (at 3-m spacings) usually takes place within 1 year of clearcutting. All sites had received similar pre-planting site preparation.

During each of the 3 years of study, two 4- or 5-year old sites were selected, one sprayed the previous year with 2,4-D and one untreated (Control) site -- these sites are referred to as 1 year post-spray. The actual date of application of phenoxy herbicides varied from spring to early summer because of logistic and weather related factors. Sites were thus studied the spring following herbicide treatment (i.e., 1 year post-spray). During each of the 3 years of study, two 6- to 8-year old stands were also selected, one sprayed about 4 years earlier with 2,4-D and/or 2,4,5-T and one untreated (Control) site — referred to as 4 years post-spray. Thus, two different pairs of sites were selected each of the 3 years of study. Control sites were selected from areas that were scheduled to receive release spraying (from a silvicultural view) but had not. The USDA Forest Service suspended silvicultural treatments on our study sites for the duration of this study. There were, of course, differences in plant composition between Spray and Control sites unrelated to treatment effects. Study sites (both Spray and Control) were selected from those available that represented the typical (average) site in need of herbicide treatment in the region.

Vegetation of Study Sites

The shrub layer was characterized by salmonberry (Rubus spectabilis), thimbleberry (R. parviflorus), vine maple (Acer circinatum), and salal (Galutheria shallon), with occassional patches of ceanothus (Ceanothus velutinus) and rhododendron (Rhododendron macrophyllum). Predominant plants in the low shrub-herb layer included sword-fern (Polystichum munitum), bracken fern (Pteridium aquilinum), tansy ragwort (Senecio jacobea), foxglove (Digitalis purpurea), and various grasses. Red alder provided the only significant deciduous tree cover. Only a few bigleaf maple (Acer macrophyllum) trees were present on each site. The number and cover of conifers (primarily Douglas-fir) varied among study sites. A thorough discussion of the successional patterns on early-growth clearcuts in western Oregon is given by Newton et al. (1968) and Franklin and Dyrness (1973).

Few quantitative data on the pre-spray coverage of shrubs and deciduous trees on the 4 years post-spray sites were available (unpubl. data, Alsea Ranger District). Visual estimates by forest service personnel prior to treatment indicated that herbicide treatment was necessary for shrub and/or hardwood control. Data for the pre-spray conditions of the 1 year post-spray sites were also limited. Information available indicated that our 1 year post-spray sites had required herbicide treatment to control: 20% vine maple and hardwood cover in 1979; 12% or more red alder, 16% vine maple, and 24% salmonberry and thimbleberry cover in 1980; and about 11 ha (or about 32% of the site) cover of red alder in 1981 (unpubl. data, Alsea Range District). The pre-spray presence of deciduous trees on the 1 year post-spray sites was also approximated by the presence of dead or severely damaged trees still evident on the site (i.e., standing dead material); reminants of damaged vegetation were scarse by 4 years post-spray (discussed later). Our visual estimate of the pre-spray coverage of red alder and other deciduous trees indicated that all spray sites had at least 10% deciduous tree cover prior to treatment.

METHODS

Vegetation Analysis

Plant vigor.--At each of 10 avian census stations (described later), 2 vegetation sampling points were placed 20 m from the station in 2 random directions. A visual estimate of the percent ground cover of plant species within a 5.0 m radius of each point was recorded. The vigor (see Table 1) of each species was listed.

Vertical complexity.--A 30 m line transect bisecting each vegetation sampling point in a randomly chosen direction was used to measure vegetation diversity and cover by height layers. Presence or absence of vegetation for each of 3 height layers (0-1 m, 1-3 m, and >3 m) was taken at 2 m intervals along the line. Foliage height diversity (H') (Shannon and Weaver 1949) and evenness (J') (Pielou 1966) were calculated for each site. Percent vegetation cover was the sum of percent covers in each layer over all layers of vegetation.

Habitat heterogeneity.--Habitat heterogeneity was determined in a manner similar to the "closest individual method" of Greig-Smith (1957). Heterogeneity was based only on plants that protruded above the shrub layer. The distance in 2 directions from each vegetation sampling point to the nearest tree and/or shrub greater than 2.0 m tall was measured. Plants > 2.0 m usually protruded above the otherwise ubiquitous shrub cover. Shrubs were defined functionally; that is, a contiguous clump of individuals of the same or different species of at least 5-m in one horizontal dimension was considered one "clump." Distance was measured to the middle of the clump. An index of heterogeneity (IH) was calculated using the standard equation for the coefficient of variation, $IH = 100\ SD/\bar{x}$, where SD is the standard deviation and $\bar{x}$ is the mean of the point-to-plant distances (Roth 1976).

Vegetation structure.--A comparison of the vegetation structure (physiognomy) of each pair of study sites (i.e., Control versus Spray sites) was based on data collected from fifty 5-m-radius plots on each site (stratified random placement based on the cover and distribution of shrubs and deciduous trees). An estimate of the number, cover, and height of the major plant types (i.e., shrubs, conifer, and deciduous trees) was made for each plot (Table 3). These data were subjected to discriminant function analysis, with sites used as the grouping variable (multivariate analyses described later).

Analysis of Avian Communities

Avian Census Technique.--The census technique used was the variable width circular plot method (Reynolds et al. 1980). Ten census points (stations) were established on each site. Stations were 70-100 m from the clearcut edge, and 70-100 m from the next census station. Beginning at sunrise, birds were censused at each station for 8 min. Each study site was censused 4 times per year (1 census per week) during the height of the breeding season (mid-May to July). Density estimates for each species were determined following Ramsey and Scott (1978) and Reynolds et al. (1980).

Bird species diversity (H'; Shannon and Weaver 1949) and evenness (J'; Pielou 1966) were calculated for each study site each year. To determine if the rank (order) of species by density was similar between 2 sites, Spearman's Rank Correlation (r_s) was computed (Steel and Torrie 1964:409). This statistic revealed if the order of numerical dominance of species was comparable. Because of removal during logging of most snags, primary and secondary cavity nesters were rare (<2 nesting pairs per study site) and were thus excluded from analysis.

Avian habitat use.-- Analysis of vegetation within the nesting territory of a bird has been used to describe the habitat requirements of that species (e.g., James 1971, Whitmore 1975, Conner and Adkisson 1977, Cody 1978). We characterized bird habitat by sampling vegetation in 5-m-radius plots centered on the song perch of males of species nesting on a site (James 1971). Measurements of the same vegetation characteristics used to describe study site vegetation structure were used to describe the habitats used by bird species on each site. For each study site, data were subjected to discriminant function analysis, with bird species serving as the grouping variables (multivariate analyses described later).

Foraging behavior and diversity.--Foraging behavior of nesting birds was determined by recording movements of individual birds once per min (to a maximum of 20 min). Data recorded were: species, sex, foraging location (e.g., foliage, trunk, ground), foraging height, and species and height of substrate.

Percent of time spent foraging at different height intervals (0-1.0 m, 1.1-3.0 m, and >3.0 m) was used to calculate an index of foraging height diversity (J'). Because there were essentially no differences in foraging behavior within treated and untreated sites between years, foraging data for each species were combined across years and reported as treated and untreated only. These data were used to determine if birds had altered their foraging behavior in response to herbicide-induced vegetation changes.

Index of habitat use.-- To determine if species were differentially using vegetation, we used the index (Jacobs 1974):

$$D_{hb} = \frac{r - p}{r + p - 2rp} .$$

D_{hb} is the index of habitat use or relative difference, r is the proportional use of a given habitat measurement (data from plots in nesting territories), and p is the proportional availability of that measurement (i.e., vegetation structure for each site). The relative difference, D_{hb}, varies from -1 to 0 for negative use and from 0 to 1 for positive use. The D_{hb} indices were categorized as follows: D_{hb} of ± (0.16 to 0.40) = + or - (slight preference or avoidance); ± (0.41 to 0.80) = ++ or -- (moderate preference or avoidance); ± (0.81 to 1.0) = +++ or --- (strong preference or avoidance). The percent use of different types of vegetation by a species on each Spray and Control site was not directly addressed. Rather, discussions will emphasize comparison of the use of habitat by birds relative to availability (through use of the index of habitat use, D_{hb}).

Multivariate Analyses

Prior to multivariate analysis, correlation coefficients (r) were calculated for all combinations of the original variables. Each variable retained for subsequent analysis had an r <0.7 with any other variable (Green 1971, Dueser and Shugart 1979). In addition, data were either log or arcsine (proportions) transformed in an attempt to improve the fit of data to a normal distribution. As such transformations did not significantly alter the results of discriminant analysis, nontransformed data were used in all analyses.

Data measuring site vegetation structure and bird habitat use were subjected to discriminant function analysis (DFA) with stepwise inclusion of variables using the Statistical Package for the Social Sciences (SPSS: Klecka 1975) computer program. Our data seldom met the assumption of equality of variance-covariance matrices, indicating that the multivariate representation of the groups in question differed in dispersion (Cooley and Lohnes 1971: 224). However, the test of equality of group centroids is fairly robust under departures from equality of group dispersions (Cooley and Lohnes 1971:228). In addition, we used DFA as a descriptive tool, and not as a formal test of the null hypothesis of no differences among species in habitat use (Johnson 1981). The discriminant program also computes F-statistics betweeen all pairs of groups (referred to herein as the F-matrix) based on the variables entered in the stepwise procedure. The F-matrix was used to give a general index of overlap in habitat use (niche breadth) for species on an ordination.

RESULTS

Plant Vigor

1 year post-spray.--Only minor effects of herbicide application were evident 1 year after treatment for most plants, except red alder, which showed moderate to severe damage (vigor code 3 or 4) on all Spray sites (Table 1). _Ceanothus_, a target (along with other shrubs and red alder) of herbicide treatment on the 1980 site, showed heavy damage. This cover of _Ceanothus_ was concentrated in only one corner of the Spray site; shrub cover on the remainder of the site (i.e., salmonberry, thimbleberry, and rhododendron) was similar (in distribution) to that on the Control site for this comparison. Most (90%) salmonberry and thimbleberry appeared essentially normal 1 year after treatment on all sites.

4 years post-spray.--Red alder, salmonberry, and thimbleberry, the primary targets of herbicide application, retained little if any signs of damage 4 years after treatment (Table 1). Vine maple showed moderate damage from treatment only on the 1979 site; on all other Spray sites it evidenced only light damage. However, most vegetation severely damaged or killed by herbicides (especially red alder) had fallen-over before 4 years post-spray (pers. obs.), resulting in an underestimate of the effectiveness of treatment. Unfortunately, records of the USDA Forest Service (USFS) made immediately following treatment were too incomplete for direct comparison with our results. Records indicated that treatment met at least minimum standards set by the USFS: that is, conifer were in a "free-to-grow" condition (Unpubl. data, Alsea Ranger District).

Vegetation Analysis

1 year post-spray.--Vegetative cover was greater in the middle (1.0-3.0 m) and highest (>3.0 m) intervals on the Control sites relative to the Spray sites; for all years (comparisons) during the study (Table 2). Vegetative cover in the lowest (0.0-1.0 m) interval did not vary between Spray and Control sites. Total vegetative cover was also greater on the Control sites for all comparisons, although this difference was statistically nonsignificant. The distribution of cover between layers was more even on the Control sites, as reflected in the higher values for foliage height diversity and evenness (J'). Horizontal diversity, or patchiness, was also greater on the Control sites relative to the Spray sites.

Few differences in vegetation were evident between Control and Spray sites for most measures of vegetation structure (Table 3). Shrub development (cover and height) was greater on the Spray sites for 2 of 3 comparisons, but did not vary significantly between Spray and Control sites for the overall comparison. Likewise, no distinct pattern in conifer development was noted--the cover and number of conifers was slightly greater on the Spray sites, but the height was greater on the Control sites. The only measure with an overall statistically significant difference between Spray and Control sites was deciduous tree cover--values on the Control sites were nearly twice those on the Spray sites; this relation held for all 3 comparisons. Discriminant function analysis (based on data in Table 3) identified deciduous tree cover as the variable of primary importance in separating the Spray and Control sites (Table 4).

4 years post-spray.--All measures of overall (i.e., 3-year means) vegetative cover by height intervals, and vertical and horizontal diversity, were greater on the Control sites relative to the Spray sites (Table 2). In addition, all measures were greater on the Control sites during all 3 comparisons, except for plant coverage in the lowest height interval for 1 comparison.

Measures of shrub and deciduous tree development were consistently greater on the Control sites relative to the Spray sites (Control sites > Spray sites for 2/3 or 3/3 comparisons, Table 3). All measures of conifer development were greater on the Spray sites compared with the Control sites although the overall comparison was statistically nonsignificant. Discriminant function analysis identified measures of deciduous tree and shrub development as the variables of primary importance in separating Spray and Control sites by vegetative structure (Table 4).

Avian Density and Diversity

1 year post-spray.--Overall total density (i.e., the 3-year mean for the total density of all species per site) was slightly higher on the Control sites relative to the Spray sites; this difference was statistically nonsignificant (Table 6). Diversity (H') and evenness (J') were slightly higher on the Spray sites for both the overall and yearly comparisons; richness (S) did not vary between Spray and Control sites. Spearman's rank correlation (r_s) showed a significant correlation for the relative order by density of species between Spray and Control sites (Table 7).

The white-crowned and song sparrows and MacGillivray's and Wilson's warbler (scientific names in Table 9) had higher densities on the Control sites relative to the Spray sites for all 3 comparisons (Table 6). The willow flycatcher, American goldfinch, Swainson's thrush, and orange-crowned warbler had higher densities on the Control sites for 2 of the 3 comparisons. However, only the goldfinch had a higher overall density on the Control sites.

The rufous-sided towhee and dark-eyed junco had higher densities on the Spray sites for all comparisons; overall density was also higher on the Spray sites for these species. The rufous hummingbird showed slightly higher overall density on the Spray sites, and were more abundant on Spray sites for 2 of the 3 comparisons. Densities for the Bewick's wren, American robin, and black-headed grosbeack were too low for meaningful comparisons to be made between sites.

4 years post-spray.--Overall total density was nearly identical between Spray and Control sites (Table 8). Diversity and evenness were slightly higher on the Control sites, but species richness did not vary between Spray and Control sites. Diversity was higher for all 3 comparisons on the Control sites. The rank order of species by density (r_s) was significantly correlated during 1980 and for the overall comparison (Table 7).

The towhee, junco, hummingbird, and Wilson's warbler had substantially higher overall densities on the Control sites relative to the Spray sites; differences for the towhee and warbler were statistically significant (Table 8). These species showed higher densities on Control sites for all 3 comparisons, except for the junco, which was higher for 2 comparisons. The flycatcher, thrush, song sparrow, and MacGillivray's and orange-crowned warblers had similar overall densities between Spray and Control sites. The goldfinch and white-crowned sparrow were the only species with obviously higher overall densities on the Spray sites; the difference for the white-crowned sparrow was statistically significant (Table 8). The goldfinch had a higher density for 2 of the 3 comparisons, and the white-crown had a higher density for all 3 comparisons, on the Spray sites. Here again, densities of the wren, robin, and grosbeak were too low for analysis.

Avian Foraging Ecology

1 year post-spray.--Only minor differences in foraging height diversity were noted between the Spray and Control sites for most species (Table 5). MacGillivray's warbler concentrated foraging activities in the middle height interval on the Spray sites; foraging was concentrated in the lowest foliage layer on the Control sites. The more even apportionment of foraging activities by the MacGillivray's warbler on the Spray sites resulted in a higher diversity value on these sites relative to the Control sites. Wilson's warbler showed greater use of the lowest height interval, and a lesser use of the middle and highest intervals, on the Spray sites relative to the Control sites.

4 years post-spray--Analysis of foraging behavior showed no differences in foraging height diversity for most species between Spray and Control sites (Table 5). Although foraging height diversity

remained essentially unchanged, the Wilson's warbler showed a greater use of the lowest foliage layers, and a lower use of the highest layer, on the Spray sites relative the Control sites.

Avian Habitat Use

1 year post-spray.--Indices of habitat use (D_{hb}) showed few distinct patterns of use of vegetation relative to availability (Table 9). The 3 species of warbler showed a greater use of shrub cover on the Spray sites compared with the Control sites. The hummingbird and junco, however, used relatively denser shrub cover on the Control sites. Results for use of conifer were inconclusive, due primarily to the low availability and use of conifer by all species; the white-crowned sparrow and junco were the only species showing positive use of conifers.

The MacGillivray's warbler had greater use of deciduous tree cover on the Spray sites relative to the Control sites. Although showing avoidance of deciduous trees on the Control sites, the junco, white-crowned and song sparrow, and hummingbird showed lower avoidance of this substrate on the Spray sites (e.g., showing -- on the Control sites but 0 on the Spray sites). The thrush and Wilson's warbler showed moderate positive use, and the orange-crowned warbler slight positive use of deciduous trees on both Spray and Control sites.

Discriminant function analysis (DFA) of habitat use showed measures of deciduous tree development to be of primary importance in ordinating the avifaunas on both Spray and Control sites (Table 10). For both Spray and Control sites, species near the upper (negative) end of the discriminant axis used areas typified by various amounts of shrubs and coniferous tree, but little to no deciduous tree cover (Fig. 1). Species in the middle and lower (positive) end of the ordinate occupied areas of increasingly dense deciduous tree cover.

For both Spray and Control sites, a group of species (sparrows, junco, towhee) was clumped near the extreme upper (negative) end of the axis. The remaining species on the ordinate for the Control sites were spread along the continuum of increasing deciduous tree cover, with the Wilson's warbler occupying the densest deciduous tree cover. Several species located at the negative end of the axis overlapped in habitat use with several species near the center and upper end of the ordinate. The Wilson's warbler was the only species not showing overlap in habitat use on the Control sites. Except for the Swainson's thrush and Wilson's warbler, all species on the Spray sites were clumped (and overlapped in habitat use) near the extreme negative end of the ordinate.

4 years post-spray.--The Swainson's thrush and Wilson's warbler showed greater relative use of shrub cover on the Spray sites, as measured by the index of habitat use (D_{hb}; Table 9). Both species showed avoidance on the Control sites, but positive use on the Spray sites, of shrubs. In contrast, the hummingbird, MacGillivray's warbler, towhee, and white-crowned sparrow had slightly greater use of (former 2 species), or at least lower avoidance of (latter 2 species), shrub cover on the Control sites relative the Spray sites.

Little differential use of conifer was shown by species on the Spray and Control sites. The orange-crowned warbler and towhee showed slight positive use, and the thrush slight avoidance, of conifer on the Spray sites. The orange-crowned warbler moderately avoided deciduous trees on the Spray sites. By contrast, the MacGillivray's warbler showed greater use of deciduous trees on the Spray sites. On both Spray and Control sites, the hummingbird, towhee, and white-crowned and song sparrow showed strong avoidance, and the thrush and (especially) the Wilson's warbler strong positive use, of deciduous trees.

The discriminant axis for the Control sites was identified as a continuum of increasing (toward the positive end of the axis) deciduous tree cover (Table 10). Three somewhat distinct, albeit overlapping, groups were evident when the bird species were plotted on this axis (Fig. 1). The sparrows, hummingbird, and MacGillivray's warbler were identified with areas of relatively little or no deciduous tree cover--such areas were typified by relatively open areas of (sometimes dense) scattered shrubs, herbs, and conifer. In contrast, the thrush and Wilson's warbler were placed on the extreme positive end of the axis, thus identifying these species with areas of dense deciduous tree cover. The willow flycatcher, and especially the orange-crowned warbler, were placed between these first 2 groups. These final 2 species thus occupied areas of intermediate deciduous tree cover (and thus intermediate shrub and conifer cover).

The ordinate for the Spray site was identified as a continuum of increasing (towards the positive end of the axis) deciduous tree cover and shrub height (Table 10 and Fig. 1). As on the Control site, the F-matrix identified 3 somewhat distinct groups of species--there was greater overlap, however, between groups on the Spray sites. The sparrows, flycatcher, hummingbird, and orange-crowned warbler occupied areas of low shrub height. The hummingbird, song sparrow, and orange-crowned warbler, which overlapped with species towards the center of the axis, were thus somewhat separated from the flycatcher and other species in this first group. The Wilson's warbler was placed near the extreme positive end of the axis, thus identifying this species with greater shrub height and deciduous tree cover than any other species on the Spray sites. The thrush and MacGillivray's warbler overlapped with the Wilson's warbler on the positive end, and the hummingbird, song sparrow, and orange-crowned warbler on the negative end, of the ordinate. The thrush and MacGillivray's warbler were thus intermediate in use of shrubs and deciduous trees relative to the remaining species on the Spray sites.

DISCUSSION

Habitat selection in passerine birds is apparently influenced by the physical structure of the available vegetation (e.g., Anderson and Shugart 1974, Whitmore 1975, Roth 1976). Correlations have been found between avian community structure and vegetation heterogeneity -- the complexity of the avian community increased with increased patchiness of vegetation, especially in shrublands (Wiens 1974, Roth 1976). Therefore, one would intuitively anticipate a change in avian communities following alteration of vegetation. In the following discussion, emphasis is placed on species showing a change in density and a change in habitat use or foraging behavior.

This study showed the primary effects of application of phenoxy herbicides to be a reduction in vegetative complexity on treated sites. Such simplification in vegetation was due primarily to the reduction of deciduous tree cover (mainly red alder). Although rapid re-growth of shrubs was evident following treatment, deciduous trees remained suppressed through at least 4 years post-spray.

The effects of herbicides on vegetation noted in this study were consistent with results of other studies in western Oregon (e.g., Stewart 1974, Gratkowski 1975, Newton and Knight 1981, M. Newton, pers. comm.). Red alder colonizes sites shortly after clearcut logging (Newton et al. 1968, Franklin and Dyrness 1973). Alder is mostly unable to re-invade a clearcut after removal by herbicides, however, because of the presence of shrubs and herbaceous plants already established or re-established (M. Newton, pers. comm.). Our results also identified the inability of alder to re-colonize sites following application of phenoxy herbicides.

Total density of nesting birds varied only slightly between treated and untreated sites (both 1 and 4 years post-spray). The majority of birds nesting on our study sites were characteristic of shrub-dominanted habitats. The total area covered by shrubs, which was essentially equal between treated and untreated sites, may have been the best indicator of total density of birds on the early-successional communities we studied. Osaki (1979) found similar overall density of birds between sites treated with phenoxy herbicides and untreated sites in the Sierra Nevada, a result he too attributed to shrub and conifer cover remaining after treatment.

We showed that the Wilson's warbler concentrated activities in deciduous trees. Although the Wilson's warbler altered patterns of habitat use and foraging behavior on treated sites to include use of a higher proportion of shrubs, it had densities that were 2 to 3 times lower on the Spray sites for all comparisons. Similarily, species using significant cover of deciduous vegetation (e.g., yellow warbler, *Dendroica petechia*) declined in abundance following alteration of their habitat by 2,4,5-T in the Sierra Nevada (Savidge 1977, 1978, Osaki 1979).

The MacGillivray's warbler had lower densities on Spray sites relative to Control sites at 1 year post-spray. This species substantially increased use of the small amount of deciduous trees remaining on the treated sites at 1 year post-spray in an apparent attempt to compensate for loss of habitat following defoilation of shrubs. This species is known to use areas of dense shrubs for foraging and nesting (Bent 1953, Griscom and Sprunt 1979), and is apparently sensitive to even short-term defoliation of shrubs (Morrison and Meslow, unpubl. data). The increased use of shrubs on the Spray sites by 4 years post-spray suggested that shrubs had developed sufficiently to supply adequate habitat for this warbler. Alternatively, the white-crowned sparrow had higher densities on the Spray sites by 4 years post-spray. This result was predictable given the avoidance of deciduous trees, and apparent preference for scattered shrubs and conifers, shown by this species. Thus, the reduction of deciduous tree cover on the treated sites apparently enhanced habitat for the white-crowned sparrow, and was apparently responsible for the increased density of this species. The remaining species on the sites showed no readily discernable changes in density that could be related to changes in either habitat use or foraging behavior.

In summary, this study showed the primary effects of application of phenoxy herbicides to be a reduction in deciduous tree cover and the temporary defoliation of shrubs. This effect was reflected by those birds shown to concentrate activities in deciduous trees --their densities were lower on treated sites. Conversely, species utilizing shrub habitats were barely affected by spraying, especially after shrubs recovered from initial defoliation. Total density of birds was similar between treated and untreated sites, and no bird species was eliminated from a site after application of phenoxy herebicides. Our results indicated a direct relationship between the vegetation of a clearcut and the density and behavior of the associated bird community; that is, birds were responsive to differences in vegetation between sites. We also showed that the application of phenoxy herbicides was responsible for the major differences in vegetation between sites (e.g., deciduous tree cover). The spray-vegetation relationship was not as strongly demonstrated as the bird-vegetation relationship because of the somewhat tenuous information on pre-spray vegetation (especially for 4 years post-spray). Our study did identify, however, the major effects of herbicides on vegetation and bird communities in the Oregon Coast Range.

MANAGEMENT IMPLICATIONS

This study indicated that minor alterations in bird communities will result from reduction of deciduous tree cover. Reductions in populations of the Wilson's warbler, as well as the MacGillivray's warbler and several other species, were also anticipated by forest management agencies following habitat modification by silvicultural practices (USDA Forest Service 1979:206-208).

By 4 years post-spray, deciduous tree cover was three times greater on the Control sites relative the Spray sites. The absolute difference in deciduous tree cover, however, averaged only 8.3% between these sites (calculated from Table 3). Results for (especially) habitat use indicated that even this small difference in deciduous tree cover played a critical role in formation of the bird communities. However, these results also indicate that only a small increase in deciduous tree cover on Spray sites would result in a bird community similar to that on Control sites.

On our Control sites, deciduous trees were primarily located along small creeks that bisected each site, along the edges of logging spur roads and landings, and in areas of unstable soil on steep slopes. Conifer seedlings planted in such areas usually experience significant damage and mortality through animal browsing, loss of surface soil, or even vehicular damage (pers. obs.). If the goal is maintenance of similar bird communities on treated and untreated sites, deciduous trees could be retained in certain of these areas on herbicide-treated sites without severely impacting the growth of most conifers.

Deciduous trees (i.e., riparian vegetation) are currently maintained primarily along major streams (that usually do not bisect clearcuts) by forest management agencies to avoid degradation of water quality (USDA Forest Service 1979). Riparian zones are usually predominated by mixtures of mature deciduous and coniferous trees, a plant community atypical of early-successional clearcuts. Retention of deciduous trees in riparian zones cannot directly influence avian communities on the sites we studied. If bird communities characteristics of untreated (by herbicides) clearcuts are desired throughout the area of interest, deciduous trees should be maintained on the majority of clearcuts, rather than concentrated in only a few locations.

The USFS projected that about 2500 ha, or 1%, of the Siuslaw National Forest would be treated with herbicides each year during the 1980's for release of conifers from competing vegetation (USDA Forest Service 1979:v). The USFS also anticipated, however, that 64% of the area that was clearcut logged each year would be treated for release of conifers between 3 and 10 years post-planting. Thus, while the total area sprayed each year is small, the majority of early-successional forest-communities in this region are projected to receive treatement with herbicides.

This study does not address, however, the spatial scale at which different types of vegetation should be maintained throughout an area. Decisions are needed concerning the distribution of vegetation throughout an area. That is, should a heterogeneous mixture of deciduous trees, shrubs, and conifers be maintained on all, or only a fraction, of clearcuts in a forest? Or should such mixtures of vegetation be confined solely to riparian zones? The scale at which it is desirable to maintain different types of vegetation remains a subject of biological research and a point of concern for management agencies. Unfortuantely, little is known concerning the effect that changes in bird communities induced by forest management practices have on the entire community of forest plants and animals.

Table 1. Effects of application of phenoxy herbicides on plants on the Spray sites 1 and 4 years post-spray.[a,b]

Species	1979 vigor	1979 % cover	1980 vigor	1980 % cover	1981 vigor	1981 % cover
1 YEAR POST-SPRAY						
Douglas-fir	1 (1.0)	1	1 (1.0)	3	1 (1.0)	5
Red Alder	4 (1.0)	5	1 (0.4) 3b (0.1) 4 (0.5)	2	1 (0.5) 3b (0.3) 4 (0.2)	15
Vine maple	1 (0.8) 3a (0.2)	3	1 (0.9) 2 (0.1)	7	1 (0.9) 2 (0.1)	12
Salmonberry	1 (0.9) 4 (0.1)	26	1 (0.9) 2 (0.1)	5	1 (0.9) 2 (0.1)	6
Thimbleberry	1 (0.9) 3b (0.1)	4	1 (0.9) 2 (0.1)	17	1 (0.9) 2 (0.1)	8
Ceanothus	np[c]		1 (0.1) 2 (0.1) 3a (0.1) 4 (0.7)	13	np	
4 YEARS POST-SPRAY						
Douglas-fir	1 (1.0)	16	1 (1.0)	8	1 (1.0)	6
Red alder	1 (1.0)	+[d]	1 (1.0)	8	1 (0.5)	4
Vine maple	1 (0.4) 3a (0.3) 3b (0.2) 4 (0.1)	5	1 (0.9) 2 (0.1)	5	1 (0.9) 2 (0.1)	10
Salmonberry	1 (1.0)	5	1 (0.9) 2 (0.1)	15	1 (1.0)	4
Thimbleberry	1 (1.0)	8	1 (1.0)	3	1 (1.0)	4

[a] Vigor = code (frequency).

[b] Codes: 1 = crown leafed-out > 75% (normal); 2 = crown leafed-out 25-75%; 3 = crown leafed-out < 25%; 4 = plant dead, no evidence of sprouts. Subscripts added to codes 1-3: a = sprouts on stems; b = sprouts on base. For example, a code of 2a = crown leafed-out 25-75% with sprouts on damaged stems (modified from Kelpsas 1978).

[c] np = not present.

[d] + = less than 1% cover.

Table 2. Vegetation structure by height intervals and structural diversity for the 1 and 4 years post-spray study sites.

	1979		1980		1981		Frequency	Overall[a]	
	Control	Spray	Control	Spray	Control	Spray	Control > Spray	Control	Spray
1 YEAR POST-SPRAY									
Layer coverage (%)									
0.0 - 1.0 m	90	92	83	80	86	89	1/3	86 (3.5)	87 (6.2)
1.0 - 3.0 m	30	11	30	27	35	31	3/3	32 (2.9)	23 (10.6)
> 3.0 m	12	1	8	3	10	5	3/3	10 (2.0)	3 (2.0)*
Cumulative % cover	132	104	121	110	131	125	3/3	128 (6.1)	113 (10.8)
Foliage height diversity (FHD)	0.82	0.39	0.78	0.67	0.82	0.72	3/3	0.81 (0.02)	0.60 (0.18)
Evenness (J')	0.746	0.355	0.710	0.610	0.746	0.655	3/3	0.734 (0.021)	0.540 (0.162)
Habitat heterogeneity (IH %)	64	42	58	47	47	38	3/3	57 (8.4)	43 (4.5)
4 YEARS POST-SPRAY									
Layer coverage (%)									
0.0 - 1.0 m	86	79	93	92	84	91	2/3	88 (4.7)	87 (7.2)
1.1 - 3.0 m	41	25	53	42	35	19	3/3	43 (9.2)	29 (11.9)
> 3.0 m	8	5	17	9	11	4	3/3	12 (4.6)	6 (2.6)
Cumulative % cover	135	109	163	143	130	114	3/3	143 (17.8)	122 (18.4)
Foliage height diversity (FHD)	0.82	0.71	0.92	0.82	0.85	0.60	3/3	0.86 (0.05)	0.71 (0.11)
Evenness (J')	0.746	0.646	0.844	0.746	0.773	0.546	3/3	0.788 (0.051)	0.646 (0.100)
Habitat heterogeneity (IH %)	68	50	65	51	43	39	3/3	59 (13.9)	47 (7.0)

[a]Values represent $\overline{X}$ (S.D.) of yearly data (n = 3).

*$P < 0.05$, *t*-test.

Table 3. Comparison of vegetation on the 1 and 4 years post-spray study sites (sample size = 50 5 m radius plots per site per year).[a]

Variable	1979 Control	1979 Spray	1980 Control	1980 Spray	1981 Control	1981 Spray	Frequency[b] Control > Spray	Overall[c] Control	Overall[c] Spray
1 YEAR POST-SPRAY									
Shrub cover (%)	36.8 (25.14)	51.9* (25.26)	49.3 (17.32)	58.4 (15.20)	61.9 (22.47)	44.4* (23.00)	1/3	49.3 (24.24)	51.6 (20.46)
Shrub height (m)	0.9 (0.37)	1.1* (0.30)	1.2 (0.30)	1.2 (0.36)	1.1 (0.35)	1.0 (0.42)	1/3	1.1 (0.38)	1.1 (0.36)
Conifer cover (%)	6.4 (6.44)	3.9* (4.48)	3.0 (1.77)	3.9 (1.96)	5.5 (2.97)	7.8* (4.54)	1/3	5.1 (4.18)	5.2 (3.38)
Number of Conifer	4.6 (2.94)	3.8* (2.24)	3.2 (1.57)	5.3* (1.32)	2.6 (1.18)	3.2* (1.62)	1/3	3.5 (2.24)	4.1 (1.81)
Conifer height (m)	1.3 (0.64)	0.8* (0.45)	1.9 (0.38)	1.7 (0.23)	1.9 (0.35)	2.3* (0.27)	2/3	1.8 (0.48)	1.6 (0.68)
Deciduous tree cover (%)	19.2 (26.38)	9.3* (13.83)	5.5 (9.88)	1.3* (2.97)	11.1 (20.05)	8.3 (20.21)	3/3	11.9 (23.64)	6.3* (16.15)
Number of deciduous trees	4.9 (6.70)	2.0* (2.52)	3.0 (4.20)	3.1 (3.94)	2.8 (4.53)	2.6 (6.32)	2/3	3.6 (6.04)	2.7 (4.77)
Deciduous tree height (m)	2.2 (1.55)	1.7* (1.77)	2.1 (2.02)	2.3 (1.62)	2.1 (1.85)	2.1 (1.62)	1/3	2.1 (1.79)	2.0 (2.89)
Herbaceous cover (%)	--[d]	--[d]	55.9 (14.35)	36.8* (16.47)	50.4 (19.97)	57.8 (20.08)	1/2	53.2 (17.10)	47.3 (18.20)
Total cover damaged by spray (%)	--[e]	--[d]	--[e]	15.7 (15.46)	--[e]	12.6 (14.78)	--[e]	--[e]	14.2 (15.10)
4 YEARS POST-SPRAY									
Shrub cover (%)	45.5 (27.02)	34.5* (23.41)	54.4 (22.56)	54.1 (24.38)	55.9 (20.74)	52.6 (20.73)	3/3	53.0 (22.98)	47.9 (23.31)
Shrub height (m)	1.0 (0.41)	0.8 (0.39)	1.0 (0.49)	1.3* (0.33)	1.0 (0.39)	0.8* (0.32)	2/3	1.0 (0.44)	0.9 (0.47)
Conifer cover (%)	8.0 (6.07)	22.1* (13.14)	19.9 (10.08)	6.1* (3.52)	3.9 (2.10)	6.4* (4.17)	1/3	10.8 (9.60)	12.1 (11.79)
Number of Conifer	5.0 (2.24)	9.3* (5.21)	8.9 (3.37)	4.6* (2.19)	2.3 (0.85)	3.4* (1.81)	1/3	5.8 (3.65)	6.5 (5.36)
Conifer height (m)	1.9 (0.79)	2.4* (0.82)	2.5 (0.43)	2.3 (0.53)	1.9 (0.30)	2.0 (0.49)	1/3	2.1 (0.60)	2.4 (0.70)
Deciduous tree cover (%)	18.3 (21.62)	2.2* (8.27)	9.6 (15.53)	2.3* (6.93)	10.7 (17.12)	5.8 (15.05)	3/3	12.6 (17.77)	4.3* (16.57)
Number of deciduous trees	3.4 (3.33)	0.4* (1.50)	1.9 (2.44)	0.5* (1.25)	3.1 (5.13)	2.0 (4.82)	3/3	2.8 (3.81)	1.2* (3.19)
Deciduous tree height (m)	2.5 (1.82)	0.4* (1.03)	2.2 (2.29)	0.7* (1.49)	2.1 (1.95)	2.3 (2.54)	2/3	2.3 (1.97)	1.1* (1.97)
Herbaceous cover (%)	--[d]	--[d]	27.5 (17.85)	55.3* (18.88)	56.4 (18.13)	42.2* (22.84)	1/2	42.0 (18.00)	48.8 (20.80)
Total cover damaged by spray (%)	--[e]	--[d]	--[e]	0.2 (0.32)	--[e]	0.0 (0.00)	--[e]	--[e]	0.1 (0.20)

Table 3. Continued

[a]Values = $\overline{X}$ (S.D.).

[b]Frequency values for Control greater than (>) Spray.

[c]Values based on data combined across all years, 1979-81 (n = 150).

[d]Not measured.

[e]Not applicable.

*$P < 0.05$, *t*-test.

Table 4. Summary of 2-group discriminant analyses as applied to general site vegetation on the 1 and 4 years post-spray study sites.

Characteristic	1 year Post-Spray	4 years Post-Spray
Eigenvalue	0.0135	0.1725
Relative % of eigenvalue associated with function	100.0	100.0
Wilk's lambda	0.9867	0.8529
Chi-square for significance of function	3.975	47.174
Significance (d.f.)	$\underline{P} < 0.05$ (1)	$\underline{P} < 0.001$ (3)
Equality of group covariance matrices (Box's M)	21.106	44.400
Significance (d.f.)	$\underline{P} < 0.01$ (15, 26612.0)	$\underline{P} < 0.001$ (6, 64310.0)
Variable(s) entered in DF procedure & standardized discriminant coefficients	Deciduous tree cover 1.0000	Deciduous tree height 0.7569 Shrub cover 0.4699 Shrub height 0.4658

[a]Data combined for all comparisons, 1979-81; n = 50 5-m-radius plots/site/year.

Table 5. Percent of time spent foraging in each of 3 height intervals and an index of foraging height diversity (J') for bird species nesting on the 1 and 4 years post-spray study sites; data combined for all comparisons, 1979-81.

Species	Sample Size[a]		% use (0.0-1.0 m)		% use (1.1-3.0 m)		% use (>3.0 m)		Diversity (J')	
	Control	Spray	Control	Spray	Control	Spray	Control	Spray	Control	Spray
1 YEAR POST-SPRAY										
Rufous hummingbird	184	94	61.0	50.5	35.0	45.5	4.0	4.0	0.73	0.76
Orange-crowned warbler	202	252	44.1	45.6	38.1	42.5	17.8	11.9	0.94	0.89
MacGillivray's warbler	184	127	83.7	69.1	14.1	28.6	2.2	2.4	0.46	0.64
Wilson's warbler	180	164	25.0	59.0	61.0	37.0	14.0	4.0	0.84	0.73
White-crowned sparrow	241	146	61.4	63.0	33.6	37.0	5.0	0.0	0.74	0.60
Song sparrow	175	121	74.0	76.9	24.0	23.1	2.0	0.0	0.59	0.49
American goldfinch	110	85	43.0	57.0	48.0	31.0	9.0	12.0	0.85	0.85
Rufous-sided towhee	60	71	85.0	89.0	15.0	11.0	0.0	0.0	0.38	0.32
4 YEARS POST-SPRAY										
Rufous hummingbird	120	98	54.5	61.7	37.9	33.3	7.6	4.9	0.81	0.74
Orange-crowned warbler	242	240	38.3	46.4	45.1	41.2	16.5	12.4	0.93	0.89
MacGillivray's warbler	166	146	81.2	76.0	18.8	20.9	0.0	3.1	0.44	0.59
Wilson's warbler	149	163	27.9	50.8	51.4	42.2	20.7	6.8	0.93	0.81
White-crowned sparrow	191	200	64.0	69.6	33.7	28.3	2.2	2.2	0.67	0.63
Song sparrow	110	121	71.0	79.0	29.0	21.0	0.0	0.0	0.55	0.47
American goldfinch	90	90	42.0	38.1	46.0	48.2	14.0	13.7	0.91	0.90
Rufous-sided towhee	136	66	79.3	83.3	20.7	16.7	0.0	0.0	0.46	0.41

[a] Number of observations; see Methods.

Table 6. Density (birds/40.5 ha) and diversity for bird species on the 1 year post-spray study sites; values are $\bar{x}$ (S.D.).

Species	Density - 1979		Density - 1980		Density - 1981		Frequency[a]	Overall Density[b]	
	Control	Spray	Control	Spray	Control	Spray	Control > Spray	Control	Spray
Willow flycatcher (Empidonax traillii)	39 (23.6)	69 (20.9)	10 (3.4)	4 (2.3)	54 (20.9)	38 (14.4)	2/3	34 (22.4)	37 (32.5)
American goldfinch (Carduelis tristis)	95 (21.5)	56* (20.5)	26 (2.3)	18 (6.0)	23 (7.4)	25 (9.7)	2/3	48 (40.7)	33 (20.2)
Rufous-sided towhee (Pipilo erthrophthalmus)	16 (7.9)	60* (12.5)	35 (9.6)	46 (10.7)	15 (7.4)	33 (8.6)	0/3	23 (10.4)	46 (13.5)
Dark-eyed junco (Junco hyemalis)	12 (3.9)	21 (11.2)	8 (5.4)	12 (2.5)	19 (9.7)	31 (7.3)	0/3	13 (5.6)	21 (9.5)
White-crowned sparrow (Zonotrichia leucophrys)	116 (21.1)	66* (20.7)	44 (22.8)	28 (4.2)	56 (13.5)	24* (4.0)	3/3	72 (38.6)	39 (23.2)
Song sparrow (Melospiza melodia)	57 (10.4)	45 (11.7)	52 (9.2)	34 (10.5)	70 (3.7)	55* (4.4)	3/3	60 (9.3)	45 (10.5)
Bewick's wren (Thryomanes bewickii)	10 (2.1)	24* (6.4)	4 (1.4)	6 (1.7)	-	-	0/2	7 (4.2)	15 (12.7)
American robin (Turdus migratorius)	11 (2.6)	5* (2.1)	4 (2.4)	3 (0.6)	8 (3.2)	7 (2.1)	3/3	8 (3.5)	5 (2.0)
Swainson's thrush (Catharus ustulatus)	63 (22.2)	41 (14.5)	48 (5.8)	54 (6.1)	80 (0.0)	61 (13.7)	2/3	64 (16.0)	52 (10.1)
MacGillivray's warbler (Oporornis tolmiei)	36 (17.7)	28 (10.2)	23 (7.8)	9* (2.0)	29 (0.0)	23 (4.6)	3/3	29 (6.5)	20 (9.6)
Black-headed grosbeak (Pheucticus melanocephalus)	9 (1.2)	4* (1.1)	1 (0.0)	1 (0.0)	2 (0.0)	14* (3.5)	1/3	4 (4.4)	6 (6.6)
Orange-crowned warbler (Vermivora celata)	20 (9.9)	39 (15.0)	40 (24.4)	36 (4.3)	29 (12.7)	21 (3.5)	2/3	30 (10.0)	32 (9.6)
Wilson's warbler (Wilsonia pusilla)	25 (7.1)	23 (8.9)	17 (0.5)	10* (4.1)	33 (4.3)	18* (5.2)	3/3	25 (8.0)	17 (6.6)
Rufous hummingbird (Selasphorus rufus)	37 (14.3)	62 (20.0)	49 (7.8)	65 (10.9)	44 (17.3)	18* (0.0)	1/3	43 (6.0)	48 (26.3)
TOTALS	546	543	361	326	465	368	2/3	460	416
Richness (S)	14	14	14	14	13	13	0/3	14	14
Diversity (H')	2.33	2.46	2.35	2.26	2.34	2.43	1/3	2.41	2.49
Evenness (J')	0.883	0.932	0.890	0.856	0.914	0.949	1/3	0.913	0.943

Table 6. Continued

[a]Frequency Control site density greater than (>) Spray site density.

[b]Mean (S.D.) of yearly data, 1979-81.

*$P < 0.05$, t-test.

Table 7. Spearman's Rank Correlation (r_s) for comparison of the relative order by density of birds on the 1 and 4 years post-spray study sites (Control versus Spray sites).

	1 year post-spray				4 years post-spray			
	1979	1980	1981	Overall[a]	1979	1980	1981	Overall[a]
Correlation (r_s)	0.725	0.874	0.573	0.725	0.452	0.702	0.520	0.672
Significance (P)	<0.006	<0.001	<0.050	<0.010	>0.050	<0.010	>0.050	<0.050
Sample size (n)[b]	13	13	13	13	13	13	14	14

[a]Values based on mean of yearly density estimate for each species.

[b]Degrees of freedom = n - 2, where n is the number of paired comparisons.

Table 8. Density (birds/40.5 ha) and diversity for bird species on the 4 years post-spray study sites; values are $\bar{x}$ (S.D.); footnotes in Table 6.

Species	Density - 1979		Density - 1980		Density - 1981		Frequency[a]	Overall Density[b]	
	Control	Spray	Control	Spray	Control	Spray	Control > Spray	Control	Spray
Willow flycatcher	26 (10.7)	23 (5.1)	28 (10.2)	6* (0.0)	33 (1.8)	49 (27.7)	2/3	29 (3.6)	26 (21.0)
American goldfinch	21 (11.2)	31 (7.6)	18 (10.4)	12 (8.6)	30 (0.0)	60* (2.5)	1/3	23 (6.2)	34 (24.1)
Rufous-sided towhee	47 (10.8)	32* (3.9)	43 (7.9)	20* (8.8)	44 (11.9)	33 (8.0)	3/3	45 (2.1)	28* (7.2)
Dark-eyed junco	45 (19.0)	9* (1.5)	8 (2.3)	4 (3.4)	5 (4.6)	6 (1.8)	2/3	19 (22.2)	6 (2.5)
White-crowned sparrow	20 (4.1)	66* (7.8)	26 (10.0)	88* (17.8)	23 (15.9)	73* (13.1)	0/3	23 (3.0)	76* (11.2)
Song sparrow	21 (5.8)	32 (7.3)	48 (2.0)	66* (7.4)	53 (18.4)	45 (15.3)	1/3	41 (17.2)	46 (17.2)
Bewick's wren	12 (4.0)	-	5 (0.0)	15 (10.9)	16 (4.0)	6* (4.0)	2/3	11 (5.6)	11 (6.4)
American robin	5 (2.1)	8 (2.0)	6 (2.5)	2* (0.0)	6 (5.5)	6 (4.0)	1/3	6 (0.6)	5 (3.1)
Swainson's thrush	34 (19.7)	25 (10.6)	59 (20.1)	35 (10.4)	33 (21.8)	60 (35.1)	2/3	42 (14.7)	40 (18.0)
MacGillivray's warbler	25 (5.8)	12* (3.2)	22 (17.8)	24 (4.4)	19 (21.8)	27 (4.6)	1/3	22 (3.0)	21 (7.9)
Black-headed grosbeak	7 (1.2)	6 (1.0)	2 (1.5)	2 (1.5)	10 (6.4)	15 (12.9)	1/3	6 (4.0)	8 (6.6)
Orange-crowned warbler	63 (11.8)	38* (11.0)	13 (2.5)	31* (4.7)	27 (11.1)	11 (6.0)	2/3	34 (25.8)	27 (14.0)
Wilson's warbler	47 (15.0)	12* (2.4)	31 (6.2)	16* (4.1)	32 (1.6)	8* (3.3)	3/3	37 (9.0)	12* (4.0)
Rufous hummingbird	95 (25.8)	79 (20.9)	80 (23.2)	55 (16.5)	41 (9.0)	28 (7.4)	3/3	72 (27.8)	54 (25.5)
TOTALS	468	373	389	376	372	427	2/3	410	390
Richness (S)	14	13	14	14	14	14	1/3	14	14
Diversity (H')	2.41	2.31	2.33	2.23	2.48	2.36	3/3	2.46	2.39
Evenness (J')	0.913	0.902	0.883	0.845	0.939	0.894	3/3	0.932	0.905

Table 9. Vegetation used by avifauna (from 5-m-radius plots in nesting territories), and indices of habitat use (D_{hb}), on the 1 and 4 years post-spray sites. Values based on overall data, 1979-81.[a,b]

Species	Shrub cover (%)		Conifer cover (%)		Deciduous tree cover (%)	
	Control	Spray	Control	Spray	Control	Spray
1 YEAR POST-SPRAY						
Rufous hummingbird	60.9 (23.98) +	54.1 (23.68) 0	4.7 (2.45) 0	4.4 (2.08) 0	2.6 (4.27) --	3.0 (5.92) -
Willow flycatcher	43.8 (22.12) 0	42.9 (16.50) -	5.9 (4.46) 0	5.9 (5.20) 0	10.9 (14.12) 0	8.2 (10.31) 0
Swainson's thrush	60.0 (24.39) +	60.4 (20.86) +	2.9 (2.29) -	4.4* (3.09) 0	28.1 (28.60) ++	32.2 (23.68) ++
Orange-crowned warbler	48.7 (23.46) 0	63.7* (18.47) +	6.3 (7.98) 0	3.4 (2.08) -	19.3 (28.32) +	10.3 (11.79) +
MacGillivray's warbler	52.2 (23.98) 0	61.9 (22.02) +	5.8 (3.92) 0	4.9 (3.20) 0	6.0 (9.28) -	9.2 (11.46) +
Wilson's warbler	49.8 (24.56) 0	62.9* (21.85) +	2.7 (1.63) -	3.6 (2.92) -	38.1 (29.84) ++	35.2 (25.18) ++
Rufous-sided towhee	45.7 (22.22) 0	53.1 (22.60) 0	5.2 (3.39) 0	5.1 (4.26) 0	5.5 (8.54) -	3.5 (5.04) -
Dark-eyed junco	57.3 (19.15) +	30.6* (25.49) -	6.8 (4.47) +	7.1 (3.75) +	4.0 (3.49) --	6.9 (5.74) 0
White-crowned sparrow	33.9 (19.42) -	41.2 (19.10) -	8.2 (6.12) +	6.0 (4.61) 0	3.6 (7.50) --	2.9 (4.76) -
Song sparrow	49.4 (26.53) 0	44.9 (20.81) 0	5.3 (4.24) 0	6.2 (5.00) 0	7.0 (13.67) -	7.5 (10.57) 0
American goldfinch	39.6 (24.86) -	35.5 (20.64) -	6.1 (3.93) 0	6.4 (5.81) 0	16.3 (25.15) +	7.4 (10.25) 0

Table 9. Continued.

	Shrub cover (%)		Conifer cover (%)		Deciduous tree cover (%)	
Species	Control	Spray	Control	Spray	Control	Spray
4 YEAR POST-SPRAY						
Rufous hummingbird	65.0 (22.86) +	43.9* (23.70) 0	8.3 (7.41) 0	9.2 (6.85) 0	4.7 (7.51) --	0.5* (1.26) ---
Willow flycatcher	46.7 (26.64) 0	50.6 (26.69) 0	12.1 (8.79) 0	11.8 (8.23) 0	14.4 (18.97) 0	5.0 (7.50) 0
Swainson's thrush	44.1 (21.47) -	61.7* (23.67) +	12.9 (11.05) 0	9.0 (10.06) -	30.9 (24.31) ++	11.8* (20.87) +
Orange-crowned warbler	47.6 (24.30) 0	43.9 (22.50) 0	9.8 (8.57) 0	16.3* (12.43) +	16.5 (18.43) +	2.5* (5.34) --
MacGillivray's warbler	62.1 (22.85) +	42.6* (23.54) 0	10.0 (8.33) 0	10.4 (10.80) 0	5.9 (7.75) -	13.3 (26.66) +
Wilson's warbler	42.0 (22.13) -	57.9* (27.50) +	11.1 (11.08) 0	10.2 (14.66) 0	33.6 (25.15) ++	19.7 (28.21) ++
Rufous-sided towhee	53.6 (26.64) 0	37.9* (22.05) -	9.8 (8.49) 0	20.0* (17.82) +	5.2 (8.43) --	0.5* (2.00) ---
White-crowned sparrow	51.3 (21.10) 0	32.9* (21.22) -	9.7 (8.85) 0	12.9 (11.05) 0	3.9 (6.01) --	1.6 (6.49) --
Song sparrow	59.5 (22.57) 0	44.9* (23.52) 0	10.6 (10.89) 0	13.8 (10.84) 0	3.8 (4.25) --	0.1* (0.21) ---

[a]Values = $\overline{X}$ (S.D.); D_{hb} values given directly below S.D.

[b]See explanation of D_{hb} values in text; in general, 0 = no preference, - = avoidance, + = preference.

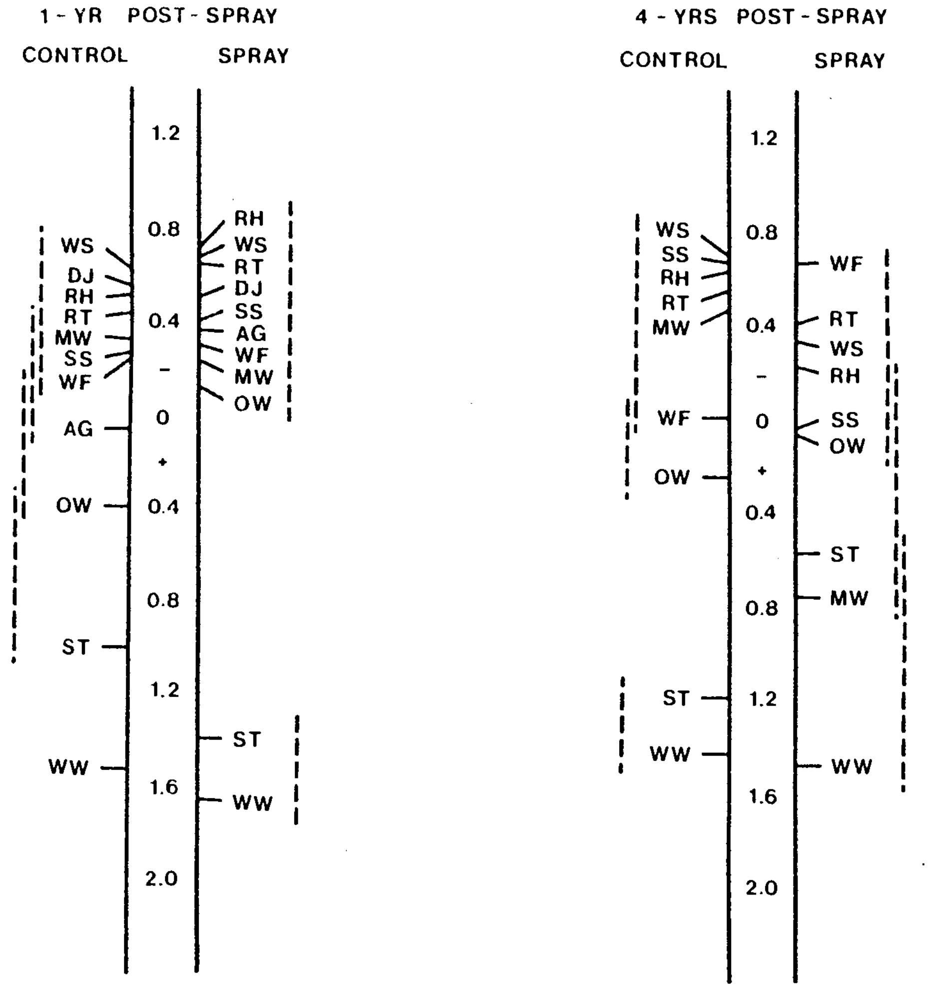
*$P < 0.05$, t-test.

Table 10. Discriminant function analysis of avian habitat use (data = 5-m-radius plots in nesting territories) on the 1 and 4 years post-spray study sites; only the first disciminant function (DF I) is presented for each site.[a]

Characteristic	1 year Post-Spray		4 years Post-Spray	
	Control	Spray	Control	Spray
Eigenvalue	0.742	0.945	0.944	0.816
Relative % of eigenvalue associated with function	72.1	76.4	92.2	60.6
Wilk's lambda	0.437	0.390	0.476	0.335
Chi-square for significance of function	281.26	328.59	198.310	290.120
Significance (d.f.)	$\underline{P}<0.001$ (50)	$\underline{P}<0.001$ (52)	$\underline{P}<0.001$ (30)	$\underline{P}<0.001$ (72)
Equality of group covariance matrices (Box's M)	604.79	430.97	236.03	630.51
Significance (d.f.)	$\underline{P}<0.001$ (150, 31495.9)	$\underline{P}<0.001$ (120, 18328.1)	$\underline{P}<0.001$ (60, 15140.7)	$\underline{P}<0.001$ (147, 19374.1)
Variable(s) entered in DF procedure & standardized discriminant coefficients	Deciduous tree cover 0.957	Deciduous tree cover 0.853	Deciduous tree cover 1.036	Deciduous tree cover -0.808 Shrub height -0.754

[a]Values based on data combined for all comparisons, 1979-81.

Fig. 1. Ordination of birds according to first disciminant function of habitat relationships (data from 5-m-radius plots in nesting territories combined for all 3 comparisons). All axes represent increasing deciduous tree cover towards the positive (lower) end of the ordinate, except for the 4 years post-spray treated site, which represents a continuum of increasing deciduous tree cover and shrub height (see Table 10). Mnemonics and samples sizes (1 year post-spray sites -- Control, Spray; 4 years post-spray -- Control, Spray) for birds are: white-crowned sparrow (WS -- 54, 41; 26, 47); song sparrow (SS -- 44, 47; 22, 45); dark-eyed junco (DJ -- 11, 16; -, -); rufous hummingbird (RH -- 33, 23; 30, 22); rufous-sided towhee (RT -- 27, 34; 43, 31); MacGillivray's warbler (MW -- 36, 27; 27, 21); orange-crowned warbler (OW -- 23, 26; 28, 28); Wilson's warbler (WW -- 46, 38; 38, 19); willow flycatcher (WF -- 17, 26; 15, 17); American goldfinch (AG -- 23, 20; -, -); Swainson's thrush (ST -- 29, 37; 29, 24).


1-YR POST-SPRAY
CONTROL
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4-YRS POST-SPRAY
CONTROL
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Figure 1

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APPENDIX

Effects of the Herbicide Glyphosate on Bird Community Structure, Western Oregon

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E. CHARLES MESLOW

ABSTRACT: We report on an exploratory study of vegetative changes induced by the herbicide glyphosate on habitat use and foraging behavior by birds nesting on 2 clearcuts in western Oregon. About 23 percent of total plant cover was intitially damaged by aerial application of glyphosate. By 2 years post-spray, however, the vigor of most plants improved. Several measures of vegetation on the treated site decreased relative to the untreated site 1 year after treatment. By 2 years post-spray, vegetation on the treated site had recovered to near pre-spray status. Virtually no difference in total

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density of nesting birds was evident between treated and untreated sites during all years of study. Several species of birds decreased use of shrub cover, and increased use of deciduous trees 1 year after treatment. By 2 years post-spray, many species had returned to pre-spray use of most measured habitat components. Several species increased foraging height diversity following treatment. Most species, however, returned to near pre-spray foraging behavior by 2 years post-spray. Results indicated that glyphosate application modified the density, habitat use, and foraging behavior of at least 4 species of birds.

FOREST SCI. 00:000-000.

ADDITIONAL KEY WORDS. Avifauna, habitat modification, bird density and diversity, bird habitat use, clearcuts.

The structure of bird communities in forests primarily is influenced by the successional stage of the vegetation (Johnston and Odum 1956, Balda 1975, Roth 1976, Meslow 1978). Silvicultural practices which alter the successional stage could have a pronounced effect on nesting birds; the application of herbicides following clearcutting of a forest is such a practice.

In western Oregon, application of herbicides is commonly used to remove plant species that compete with young conifers during the first 10 years after planting (USDA Forest Service 1978). Herbicide application is intended to shorten the "brush" stage of succession.

Of the herbicides available, 2,4,5-T and 2,4-D (i.e., phenoxy herbicides) have received extensive use.

Since about 1976, however, the application of 2,4,5-T has been restricted due largely to public concern over dioxin contamination. Alternatives to 2,4,5-T will likely gain in use in the future. One such herbicide is glyphosate, also known as Roundup. Glyphosate is one of the most effective means for controlling deciduous brush in forest stands (Sutton 1978, Newton and Roberts 1979).

No studies were available that described the use by forest birds of vegetation treated by glyphosate. Studies of the effects of phenoxy herbicides on bird communities have generally found that densities were altered by spray treatment (Beaver 1976, Slagsvold 1977, Savidge 1978, Osaki[1]). However, as density was the primary means of assessing treatment effects, few insights into the impact of habitat change induced by herbicides on bird behavior were gained from there studies.

This study was designed to identify the characteristic habitat used by birds nesting on clearcuts in the Oregon Coast Range before and after application of glyphosate. Our objective was to determine if any post-treatment shifts in habitat use, foraging behavior, and density by a species could be related to habitat modifications. The study was intended as a preliminary exploration of the effects of

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[1]Osaki, S.K. 1979. An assessment of wildlife populations and habitat in herbicide-treated Jeffrey pine plantations. Unpubl. M.S. thesis, Univ. California, Berkeley. 83 p.

glyphosate on plant and bird community structures -- study sites were not replicated. As such, results reported herein are descriptive in nature and only provide insight into changes that might be expected following application of glyphosate in the manner described herein.

STUDY SITES

Our study was conducted on the Siuslaw National Forest, Alsea Ranger District (Lane and Lincoln counties), in the Oregon Coast Range. This area is characterized by subclimax Douglas-fir (*Pseudotsuga menziesii*) and climax western hemlock (*Tsuga heterophylla*) (Franklin and Dyrness 1973:71). Two early-growth (less than 7 years post-planting) clearcuts were selected for study, 1 designated by the USDA Forest Service (USFS) as in need of release-treatment with the herbicide glyphosate (referred to herein as the Glyphosate site; 36 ha), and 1 unsprayed (Control; 21 ha) site. The Control site was scheduled by the USFS for herbicide treatment to promote conifer growth; treatment was postponed for the duration of this study.[2] The 2 sites were about 15 km apart, similar in topography, of northern aspect, and 275-375 m in mean elevation. After clearcutting (which removed all standing wood, coniferous and deciduous), both sites received similar pre-planting site preparation (which corresponded to the standard silvicultural procedures in the Siuslaw National Forest). Seedling Douglas-fir were hand planted over the entire clearcut at 3 m spacing

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[2]Personal communication with J. Warner, USFS Siuslaw Natl. Forest, Alsea, Oregon.

about 6 months after site preparation (1-2 years after logging) and about 4.5 years before this study.

The treated site was sprayed on 11 and 13 October 1979 at a rate of 1 qt (0.9 l) of glyphosate in sufficient water to equal 10 gal (37.9 l) of spray per acre (0.4 ha). About 25 ha of this 36 ha site were treated with the intent to reduce the salmonberry (*Rubus spectabilis*) that was overtopping and thus supressing conifer growth. As the Glyphosate site was treated following the first season of field work (1979), results for 1979 served as "pre-spray" data, while those for 1980 and 1981 provided 1 and 2 year "post-spray" data, respectively.

Vegetation on our study sites was characterized as follows: The shrub layer was dominated by salmonberry, thimbleberry (*R. parviflorus*), and vine maple (*Acer circinatum*). Dominants in the low shrub-herb layer included sword-fern (*Polystichum munitum*), bracken fern (*Pteridium aquilinum*), tansy ragwort (*Senecio jacobaea*), foxglove (*Digitalis purpurea*), pearly everlasting (*Anaphalis margasritacea*), Oregon oxalis (*Oxalis oregana*), and various grasses. Red alder (*Alnus rubra*) and a few scattered big-leaf maple (*Acer macrophyllum*) provided the only deciduous tree cover on the study sites.

METHODS

Vegetation Analysis

Plant vigor.--Twenty sampling points were established on each site. At the 10 bird census stations (described later), 2 vegetation sampling points were placed 20 m from the station in 2 random directions. A visual estimate of percent ground cover and vigor (see Table 1) of plant species damaged by glyphosate within a 5.0-m-radius of each point were recorded.

Vertical complexity.--A randomly oriented 30 m line transect bisecting each of the 20 vegetation sampling points (described above) was used to measure cover by height layers. Presence or absence of live vegetation for each of 3 height classes (0-1.0 m, 1.0-3.0 m, > 3.0 m) were taken at 2.0 m intervals along the length of the transect. Foliage height diversity (H' or FHD; Shannon and Weaver 1949) and evenness (J'; Pielou 1966) were calculated. Percent vegetation cover was the sum of percent covers in each layer for all layers of vegetation.

Habitat heterogeneity.--The horizontal component, or "patchiness", of habitat structure can also be an important predictor of the animal community being studied (MacArthur 1964). Habitat heterogeneity was determined in a manner similar to the "closest individual" method of Greig-Smith (1957:46-49). The distance in 2 directions from each of the 20 vegetation sampling points to the nearest group of trees and/or shrubs greater than 2.0 m tall was measured. Vegetation over 2.0 m in height protruded above the low shrub-herb layer on both sites; distance was measured to the middle of the group. The index of habitat heterogeneity (IH) was calculated as the coefficient of variation: $IH = 100\ SD/\bar{x}$ (Roth 1976).

Vegetation structure.--Fifty plots of 5.0-m-radius were placed on each site following a stratified random placement based on estimated gross cover and distribution of shrubs and deciduous trees. At each plot, the general vegetation structure (physiognomy) on each site was measured by visually estimating the vegetation measures given in Table 12. Deciduous vegetation was considered a "tree" when it exceeded 2.0 m in height; all conifers were recorded regardless of height.

Bird Community Analysis

Bird census technique.--The census technique used was the variable-width circular plot method (Reynolds et al. 1980). Ten census stations were established on each site. Stations were located 70-100 m from the clearcut edge and 70-100 m from the next station. Birds were censused at each station for 8 min; birds on each site were censused once a week for 4 weeks during the peak of the nesting season (mid-May to July). Bird species diversity (BSD or H') and evenness (J') were calculated for the avifauna on each site. To determine if significant ($P < 0.05$) changes in bird density occurred following treatment, the 3 yearly density estimates were compared using a 2-way factorial analysis of variance (ANOVA) design. Significant site by year interaction would indicate that yearly changes in density on the Glyphosate site were not parallel to yearly changes in density on the Control site.

Bird habitat use.--We obtained vegetation data from 5-m-radius plots within the territory of nesting birds; singing males and nest sites were the center of each 5-m plot (James 1971). A visual estimate of the vegetative measures used to describe site vegetation structure (Table 12) was made for each plot. In an attempt to avoid double-sampling of individuals, a particular area (patch of habitat) on a study site was visited only once during each year. Preliminary analysis indicated that all substantial changes in habitat use by birds after treatment with glyphosate could be expressed through examination of use of shrub and deciduous tree covers; discussion of univariate analysis of habitat use thus concentrated on these measures of habitat.

Foraging behavior and diversity.--Foraging behavior of bird species was determined by recording movements of individuals during the nesting period. Data were recorded once per min for a minimum of 5 min to a maximum of 20 min depending upon visibility of the bird. Data recorded were: species, foraging location (e.g., foliage, trunk, ground), foraging height, and height and species of foraging substrate. As females were rather secretive during nesting, only data for males were analyzed. Percent of time spent foraging at different height intervals (0-1.0 m, 1.1-3.0 m, > 3.0 m) was used to calculate an index of foraging height diversity (evenness, J'). These data were used to determine if birds altered their foraging behavior in response to herbicide-induced vegetation changes.

Data Presentation

Data for bird density and habitat use, and general site vegetation, were collapsed into one figure as follows: for each year, data on the

Glyphosate site were divided by the corresponding value on the Control site (Slagsvold 1977). These adjusted values (indices) were used as a qualitative aid in interpreting changes in the parameters between years; no statistical analyses were performed on these indices. Throughout this paper, "relative change" refers to changes in measurement on the Glyphosate site as compared to (relative to) changes for the measurements on the Control site. Such a design was necessary, rather than analyzing data for the Glyphosate site alone, as it was likely that some of the variation in data between years on the Glyphosate site was caused by site differences and observer error independently of treatment effects.

RESULTS

Vegetation Analysis

Plant vigor.--Approximately 23 percent of the total cover on the Glyphosate site evidenced damage by glyphosate 1 year following application (Table 12). Two predominant plant species, salmonberry and thimbleberry, were the most heavily damaged by the treatment, 75 percent and 60 percent respectively, (Table 11). However, only 5 percent of each of these species were killed; the majority of individuals developed leaf sprouts (along stems) that were small, curled, and discolored, but still alive. Berry production on these plants was reduced following treatment. We estimated that total berry production was less than 25 percent of the normal (pre-spray) on the site 1 year after treatment. None of the remaining species evidencing damage by glyphosate treatment experienced direct mortality (i.e., red alder, vine maple, and elderberry had minor loss of leaves).

About 15 percent of the total cover on the Glyphosate site continued to exhibit obvious (external) signs of herbicide damage 2 years after treatment (Table 12). Although the total cover showing damage did not change appreciably between 1 and 2 years post-spray, the vigor of all plants improved. Except for dead individuals, normal appearing leaves were evident on the stems and base of most plants. Additionally, berry production appeared to return to near pre-spray levels; plants still showing moderate damage (vigor code = 3, Table 11) 2 years post-spray produced berries.

Vegetation structure.--Most measures of vegetation structure on the Glyphosate site decreased relative to the Control 1 year after herbicide treatment, except for herbaceous cover (HERB), which increased on the Glyphosate site (Table 12). Changes in vegetation, especially for shrub cover (SHBCV), and deciduous tree height (DECHT) and cover (DECCV), resulted from a relatively large increase (growth) of vegetation on the Control site compared to the Glyphosate site. There was a rapid invasion of herbaceous plants on the Glyphosate site in areas of heaviest vegetation damage; herbaceous vegetation was especially prevalent under standing, but dead, salmonberry.

Most measures of vegetation increased on the Glyphosate site relative to the Control site between 1 and 2 years post-spray; but DECHT and number of conifer (CONNO) declined slightly on the Glyphosate site (Table 12). The decline in CONNO was due to the decreasing number of surviving conifer seedlings for all 3 years of study on the Glyphosate site. The decline in DECHT between 1 and 2 years post-spray (both sites) was caused not by an actual decrease in tree height, but resulted from relatively small saplings being included in sampling for the first time 2 years post-spray (i.e., plants just reaching 2 m).

Vertical vegetation diversity (H' and J') was essentially equal for all pre- and post-spray comparisons (Table 13). Horizontal vegetative diversity, however, showed a relative decrease 1 year after treatment on the Glyphosate site. Because of defoliation of plants in the shrub layer, cover in the first (0.0-1.0 m), and especially second (1.1-3.0 m) height intervals decreased on the Glyphosate site relative to the Control site. The decrease in cumulative cover on the Glyphosate site was a reflection of reduced cover in the first 2 height layers. All measures of structural diversity and cover by height intervals increased on the Glyphosate site relative to the Control site between 1 and 2 years post-spray -- vegetative cover in the lowest and heighest intervals, and cumulative cover, showed the largest relative gains during this period (Table 13).

Bird Community Analysis

Bird density.--Total density and diversity of nesting birds were similar on the Glyphosate site relative to the Control site during all 3 years (Table 14). Individual species declining in relative density on the Glyphosate site 1 year after treatment were the rufous hummingbird (*Selaphorus rufus*), MacGillivray's (*Oporornis tolmiei*) and

Wilson's (*Wilsonia pusilla*) warbler, rufous-sided towhee (*Pipilo erthrophthalmus*), and white-crowned sparrow (*Zonotrichia leucophrys*); species increasing in density on the Glyphosate site were the willow flycatcher (*Empidonax trallii*), orange-crowned warbler (*Vermivora celata*), dark-eyed junco (*Junco hyemalis*), and American goldfinch (*Carduelis tristis*). Although these species showed at least 25.0 percent change in density, only the site by year interaction for change in density for the towhee and goldfinch were significant at $P < 0.05$; the interaction for the MacGillivray's warbler was $P = 0.08$. Densities for the Bewick's wren (*Thryomanes bewickii*), American robin (*Turdus migratorius*), and black-headed grosbeak (*Pheucticus melanocephalus*) were low on both study sites (< 10 birds/40.5 ha), making comparisons for these species between sites inappropriate.

All species that declined in relative density on the Glyphosate site between pre-spray and 1 year post-spray showed relative increases in density between 1 and 2 years post-spray (Table 14); the increases for the MacGillivrays' warbler, white-crowned sparrow, and towhee were significant. Conversely, all species on the Glyphosate site that showed positive changes in density between pre-spray and 1 year post-spray decreased by at least 20 percent in relative density between 1 and 2 years post-spray. The changes for the organge-crowned warbler and goldfinch were significant.

Habitat use.--Use of shrub cover (SHBCV) on the Glyphosate site decreased relative to the Control site between pre- and 1 year post-spray for all species, except for the American goldfinch, which increased use of SHBCV (Table 15). Most species exhibited an increased use of deciduous tree cover (DECCV) on the Glyphosate site relative to the Control site 1 year post-spray. The MacGillivray's warbler was the only species which substantially decreased relative use of DECCV. The Swainson's thrush (Catharus ustulatus) and Wilson's warbler showed virtually no change in relative use of DECCV on the Glyphosate site during this period.

Between 1 and 2 years post-spray, all species except the rufous-sided towhee increased relative use of SHBCV on the Glyphosate site. The use of DECCV showed relative decreases for all species on the Glyphosate site, except the song sparrow (Melospiza melodia) and the flycatcher, which increased use of deciduous trees.

Foraging behavior.--Foraging height diversity (FHD) increased for 4 species on the Glyphosate site relative to the Control site between pre- and 1 year post-spray (Table 16). Increased FHD resulted from a more even apportionment of foraging time between the first 2 height intervals, with the rufous hummingbird, MacGillivray's warbler, rufous-sided towhee, and song sparrow increasing use of the middle height layer (Table 17). Although not reflected in FHD, the Wilson's warbler also increased foraging time in the middle foliage layer 1 year post-spray (Table 17). All species that increased FHD 1 year post-spray returned to near pre-spray diversity 2 years following glyphosate treatment. The Wilson's warbler returned to near pre-spray use of the lowest foliage layer 2 years post-spray.

DISCUSSION

When drawing conclusions on the response of birds to habitat alterations, it is important to evaluate all of the parameters measured. It is difficult to determine the reasons for a change in density for a species if this change is not accompanied by a change in foraging behavior, habitat use, or some other measure of resource use. Therefore, in the following discussion, emphasis will be placed on those species experiencing directional trends in density and one or more aspect of resource use. Given the lack of replication of study sites, our results are only directly applicable to the specific glyphosate treatment and sites described herein.

The overall effects of glyphosate treatment in this study were described as "fair to moderate" by USDA Forest Service personnel.[3] The main target of spray application, salmonberry, showed the most damage 1 year after treatment. By 2 years post-spray, however, the study site returned to about the condition present prior to spray application. Based on the visual estimates of plant vigor made herein, and the pattern of vegetation development in western Oregon (Franklin and Dyreness 1973:82-88), it appears that glyphosate prevented increased development of target vegetation for about 2 years on our study site. It is important to remember that our results are based on the fact that while shrub development generally ceased on the Glyphosate site for 2 years, plants on the Control site continued along a course of apparently normal succession.

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[3]See footnote 2.

Most birds declining in relative density on the Glyphosate site 1 year post-spray primarily used shrub cover for foraging and nesting -- the Wilson's warbler was associated with patches both of shrubs and red alder. The MacGillivray's warbler, for example, decreased use of shrub cover following treatment. This warbler apparently required dense, vigorous shrub cover, and would not use damaged plants. In an apparent attempt to compensate for loss of shrub cover, rufous-sided towhees increased use of deciduous tree cover 1 year post-spray -- towhees were observed foraging in and around the dense foliage in lower portions of red alder. The MacGillivray's warbler, rufous-sided towhee, and rufous hummingbird increased vertical foraging diversity, making a wider use of foliage layers following glyphosate treatment; the Wilson's warbler increased use of the middle foliage layer. Thus, elimination of a portion of these birds primary foraging substrate (i.e., salmonberry) apparently caused a shift in the range of substrates used. Even with shifts in habitat use and foraging behavior, however, these species were not able to maintain pre-spray densities.

All species declining in density 1 year post-spray increased in density 2 years after treatment on the Glyphosate site. Most species increased use of shrubs during this period. The return to use of shrubs paralleled the increased vigor and cover of salmonberry 2 years after treatment on the Glyphosate site, and was apparently responsible for the increased density of species initially declining in numbers after glyphosate treatment.

The decline in relative density for the Glyphosate site 2 years post-spray by species initially increasing in density is difficult to explain. It is possible that these species responded favorably to habitat modifications following treatment (e.g., increased herbaceous cover). The return to near pre-spray habitat conditions may have caused the relative decline of these species 2 years after treatment. A more effective treatment with glyphosate might have allowed herbaceous plants to attain greater distribution and cover, and maintain relative development for more than 1 year post-spray (concomitant with a decrease in shrub cover.)[4]

Concluding remarks.--Results of this exploratory study indicated that the herbicide glyphosate, through alteration of vegetation, can affect the density and behavior of bird species. Further studies are thus indicated that assess the response of plant and bird comunities to the full range of effects that can be anticipated through use of this herbicide.

When properly applied, glyphosate is an effective agent for control of deciduous shrubs (Sutton 1978, Newton and Roberts 1979). For maximum effectiveness in the Oregon Coast Range (i.e., retardation of shrub growth for over 2 years), glyphosate should be applied during the period of maximum nutrient translocation to the roots (August or

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[4]Personal communications with M. Newton, Forest Res. Lab., Oregon State Univ., Corvallis, Oregon.

early September in western Oregon), rather than in October as in this study.[5] Therefore, a more effective application of glyphosate could cause alternations in bird communities different from those noted herein.

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[5]See footnotes 2 and 4.

Table 11. Effects of glyphosate application on plant vigor on the Glyphosate site 1 (Post-1; 1980) and 2 (Post-2; 1981) years after treatment (data = from 20 vegetation sampling points centered on bird census stations).

Species	Total % damaged[a]		Vigor code (%)[b]	
	Post-1	Post-2	Post-1	Post-2
Salmonberry	75	64	1 (25) 2a (20) 3a (50) 4 (5)	1 (36) 2a,b (50) 3a,b (10) 4 (4)
Thimbleberry	60	53	1 (40) 2a (35) 3a (20) 4 (5)	1 (47) 2a,b (41) 3a,b (9) 4 (3)
Red alder	20	5	1 (80) 2a (20)	1 (95) 2a (5)
Vine Maple	15	5	1 (85) 2a (15)	1 (95) 2a (5)
Elderberry	5	5	1 (95) 2a (5)	1 (95) 2a (5)

[a]Sum of vigor codes 2 to 4.

[b]Vigor codes: 1 = crown leafed-out greater than 75% (normal); 2 = crown leafed-out 25-75%; 3 = crown leafed-out less than 25%; 4 = plant dead, no evidence of sprouts; a = sprouts on stem; b = sprouts on base.

Table 12. Vegetative structures (fifty 5-m-radius plots/site/year) on the Control (CONT) and Glyphosate (GLY) sites before (Pre.; 1979) and 1 (Post-1; 1980) and 2 (Post-2; 1981) years after treatment.

Variable Site	$\bar{X}$ (S.D.) Pre	Post-1	Post-2	Relative change[a] Pre vs Post-1	Post-1 vs Post-2
Shrub Cover (%)					
GLY	48.8 (26.08)	50.3 (19.12)	63.9 (16.85)	-17.8	25.8
CONT	41.2 (25.75)	52.1 (22.90)	52.4 (22.22)		
Shrub height (m)					
GLY	0.9 (0.35)	1.1 (0.26)	1.1 (0.30)	-21.0	7.6
CONT	0.9 (0.37)	1.4 (0.46)	1.3 (0.31)		
Conifer cover (%)					
GLY	3.9 (4.58)	3.4 (2.75)	7.3 (4.45)	-18.4	8.1
CONT	5.1 (5.31)	5.5 (3.05)	10.9 (5.72)		
Number of conifer					
GLY	4.5 (2.67)	4.1 (2.19)	3.2 (1.69)	-14.8	-5.3
CONT	5.1 (2.65)	5.5 (1.91)	4.5 (1.54)		
Conifer height (m)					
GLY	1.3 (0.45)	1.6 (0.34)	2.2 (0.36)	-6.2	6.6
CONT	1.6 (0.50)	2.1 (0.39)	2.7 (0.37)		
Deciduous tree cover (%)					
GLY	3.2 (10.19)	3.4 (9.41)	4.7 (8.75)	-19.0	41.2
CONT	15.6 (21.10)	19.6 (26.09)	19.8 (26.71)		
Number of deciduous trees					
GLY	0.9 (2.70)	1.1 (2.70)	1.1 (1.84)	0.0	0.0
CONT	2.4 (3.82)	2.9 (3.19)	2.9 (3.34)		
Deciduous tree height (m)					
GLY	2.0 (1.52)	2.0 (1.69)	1.6 (2.25)	-18.5	-17.0
CONT	3.1 (1.62)	3.8 (1.82)	3.6 (2.67)		
Herbaceous cover (%)					
GLY	40.0 (17.32)	45.4 (18.49)	61.8 (16.44)	23.0	37.3
CONT	66.1 (21.13)	60.2 (19.85)	60.0 (19.91)		
Damaged vegetation (%)[b]					
GLY	0.0 (0.00)	23.3 (18.49)	15.0 (9.72)	nc[c]	
CONT	0.0 (0.00)	0.0 (0.00)	0.0 (0.00)		

[a] % change based on index values (GLY/CONT); see text.

[b] Percent of total vegetation cover damaged by spray.

[c] nc = could not be calculated.

Table 13. Vegetation analyses by height intervals (vertical complexity) and habitat heterogeneity for the Control (CONT) and Glyphosate (GLY) sites before (Pre.; 1979) and 1 (Post-1; 1980) and 2 (Post-2; 1981) years after treatment (data = from 20 vegetation sampling points centered on bird census stations).

	Value			Relative Change[a]	
	Pre	Post-1	Post-2	Pre vs Post-1	Post-1 vs Post-2
Layer coverage (%)					
0-1.0 (m)					
GLY	88	78	92	-16.3	11.0
CONT	90	95	101		
1.1-3.0 (m)					
GLY	22	20	23	-31.5	2.0
CONT	30	40	45		
over 3.0 (m)					
GLY	2	3	6	11.8	57.9
CONT	12	16	20		
Cummulative % Cover					
GLY	112	101	121	-21.2	9.0
CONT	132	151	166		
FHD (H')					
GLY	0.58	0.63	0.67	0.0	2.8
CONT	0.81	0.88	0.91		
Evenness (J')					
GLY	0.528	0.573	0.610	0.0	2.8
CONT	0.737	0.801	0.828		
Habitat heterogeneity (%)					
GLY	49.6	51.1	53.2	-6.4	8.2
CONT	63.9	70.0	67.2		

[a]% change based on Index values (GLY/CONT); see text.

Table 14. Bird density estimates (birds/40.5 ha) on the Control (CONT) and Glyphosate (GLY) sites before (Pre.; 1979) and 1 (Post-1; 1980) and 2 (Post-2; 1981) years after glyphosate application.

Species	Site	$\bar{X}$ density estimate (S.D.)			Relative change[a]	
		Pre	Post-1	Post-2	Pre vs Post-1	Post-1 vs Post-2
Rufous hummingbird						
	GLY	74 (33.14)	54 (9.42)	63 (21.05)	-25.0	6.7
	CONT	37 (21.17)	37 (7.13)	40 (11.84)		
MacGillivray's warbler						
	GLY	24 (5.96)	10 (3.32)	44 (17.84)	-57.1	300.0**
	CONT	36 (17.71)	33 (10.37)	37 (9.96)		
Wilson's warbler						
	GLY	11 (2.17)	10 (2.83)	13 (1.92)	-25.0	15.6
	CONT	25 (7.31)	31 (8.12)	35 (5.72)		
Rufous-sided towhee						
	GLY	35 (7.99)	17 (3.42)	75 (17.59)	-40.9*	38.5**
	CONT	16 (7.34)	13 (5.32)	41 (4.82)		
White-crowned sparrow						
	GLY	86 (21.57)	33 (8.53)	56 (12.01)	-28.6	90.0*
	CONT	116 (21.05)	62 (5.37)	59 (12.63)		
Willow flycatcher						
	GLY	31 (19.04)	14 (8.54)	24 (3.94)	75.0	-57.1
	CONT	39 (23.74)	10 (5.91)	40 (23.66)		
Orange-crowned warbler						
	GLY	56 (5.09)	63 (10.40)	34 (7.64)	50.0	-64.3**
	CONT	20 (9.89)	15 (4.18)	22 (13.42)		
Dark-eyed junco						
	GLY	30 (11.80)	14 (8.22)	31 (20.02)	33.3	-7.1
	CONT	14 (8.76)	5 (1.26)	12 (1.83)		
American goldfinch						
	GLY	42 (10.75)	40 (10.22)	30 (13.10)	111.1**	-50.5*
	CONT	48 (10.57)	21 (3.11)	32 (11.45)		

Table 14. Continued

Species / Site	$\bar{X}$ density estimate (S.D.)			Relative change[a]	
	Pre	Post-1	Post-2	Pre vs Post-1	Post-1 vs Post-2
Swainson's thrush					
GLY	27 (10.03)	28 (11.24)	83 (21.10)	0.0	50.0
CONT	63 (22.11)	63 (21.68)	131 (30.17)		
Song sparrow					
GLY	58 (3.14)	32 (8.73)	81 (15.09)	0.0	-20.0*
CONT	57 (10.27)	31 (5.07)	102 (11.45)		
Bewick's wren[b]					
GLY	4 (1.22)	3 (1.10)	6 (1.00)		
CONT	2 (1.55)	8 (2.61)	4 (1.30)		
American robin[b]					
GLY	5 (4.02)	3 (1.22)	6 (0.84)		
CONT	7 (4.29)	3 (1.10)	13 (3.32)		
Black-headed grosbeak[b]					
GLY	5 (2.06)	1 (0.58)	10 (0.00)		
CONT	11 (5.02)	2 (1.00)	20 (5.36)		
TOTALS - Density					
GLY	488 (25.88)	322 (19.37)	556 (27.69)	-3.0	-1.0
CONT	491 (29.86)	334 (20.12)	588 (35.15)		
BSD (H')					
GLY	2.37	2.30	2.40		
CONT	2.33	2.31	2.35	-2.0	2.0
Evenness (J')					
GLY	0.898	0.872	0.909	-2.0	2.0
CONT	0.883	0.875	0.890		

[a]% change based on index values (GLY/CONT): see text.

[b]Relative change and ANOVA not calculated because of low densities for these species on both sites.

* $\underline{P} < 0.05$; ** $\underline{P} < 0.01$; ANOVA.

Table 15. Vegetative measure for birds nesting (data = 5-m-radius plots in nesting territories) on the Control (CONT) and Glyphosate (GLY) sites before (Pre.; 1979) and 1 (Post-1; 1980) and 2 (Post-2; 1981) years after glyphosate treatment. Sample sizes given in Table 18.

Species Site	% Shrub cover[a]			Relative change[b]		% Deciduous tree cover[a]			Relative change[b]	
	Pre	Post-1	Post-2	Pre vs Post-1	Post-1 vs Post-2	Pre	Post-1	Post-2	Pre vs Post-1	Post-1 vs Post-2
Willow flycatcher										
GLY	61.4	45.0	62.5			6.4	6.9	10.0		
	(21.16)	(21.41)	(13.89)			(17.00)	(9.44)	(8.45)		
				-35.4	197.6				12.0	103.6
CONT	47.2	53.8	25.0			12.8	12.3	8.8		
	(28.07)	(22.48)	(3.78)			(18.70)	(6.76)	(9.54)		
Swainson's thrush										
GLY	38.8	41.3	59.4			35.0	21.3	16.3		
	(30.10)	(19.78)	(14.00)			(40.40)	(14.08)	(14.08)		
				-19.3	36.6				-3.8	-46.1
CONT	44.0	59.3	61.3			33.0	20.9	29.9		
	(29.03)	(20.22)	(22.56)			(35.99)	(20.53)	(21.72)		
Orange-crowned warbler										
GLY	49.3	51.9	64.1			9.9	14.7	5.1		
	(27.18)	(22.94)	(14.63)			(14.61)	(22.02)	(9.35)		
				-18.3	34.2				150.0	-83.7
CONT	52.8	68.6	63.0			18.4	10.9	22.9		
	(24.25)	(15.20)	(24.97)			(36.10)	(7.71)	(31.67)		
MacGillivray's warbler										
GLY	67.9	53.6	69.5			7.6	6.3	6.0		
	(25.55)	(14.64)	(21.27)			(11.54)	(4.07)	(10.22)		
				-37.5	5.0				-30.2	-41.8
CONT	42.3	53.8	65.9			7.9	9.4	15.5		
	(23.76)	(24.12)	(10.68)			(10.82)	(13.02)	(23.71)		
Wilson's warbler										
GLY	66.3	62.5	71.8			28.4	22.7	16.5		
	(23.11)	(13.59)	(15.21)			(13.51)	(25.64)	(16.01)		
				-36.8	11.7				-3.6	-53.7
CONT	35.4	50.4	53.5			50.5	41.7	65.0		
	(25.61)	(29.19)	(13.75)			(29.03)	(21.57)	(19.86)		

Table 15. Continued.

Species / Site	% Shrub cover[a]			Relative change[b]		% Deciduous tree cover[a]			Relative change[b]	
	Pre	Post-1	Post-2	Pre vs Post-1	Post-1 vs Post-2	Pre	Post-1	Post-2	Pre vs Post-1	Post-1 vs Post-2
Rufous-sided towhee										
GLY	50.5	60.4	57.9			0.1	0.6	0.1		
	(26.08)	(14.36)	(21.30)	-7.1	-11.5	(0.58)	(1.66)	(0.60)	500.0[c]	-95.0[c]
CONT	36.3	46.3	50.5			12.5	0.6	2.2		
	(22.16)	(18.85)	(21.63)			(10.00)	(1.19)	(3.33)		
Dark-eyed junco										
GLY	46.4	27.3	40.0			0.7	3.3	0.0		
	(23.04)	(13.28)	(10.00)	-27.6	6.0	(1.89)	(5.77)	(0.00)	241.7	-100.0[c]
CONT	40.0	32.4	45.0			6.0	8.1	10.0		
	(18.01)	(11.21)	(5.00)			(7.12)	(12.42)	(5.00)		
White-crowned sparrow										
GLY	41.7	36.9	52.5			1.5	1.0	0.0		
	(23.80)	(14.62)	(16.04)	-32.9	64.5	(2.85)	(1.61)	(0.00)	72.0	-100.0[c]
CONT	24.8	32.3	27.9			6.0	2.3	1.8		
	(13.53)	(23.42)	(23.13)			(9.56)	(3.56)	(3.25)		
Song Sparrow										
GLY	46.6	52.7	70.7			1.6	2.1	2.1		
	(24.84)	(17.84)	(12.99)	-3.5	3.6	(3.50)	(3.39)	(3.03)	166.7	15.0
CONT	41.0	47.8	62.0			10.5	5.2	4.6		
	(28.28)	(19.06)	(12.29)			(17.60)	(5.40)	(3.98)		
American goldfinch										
GLY	43.1	42.1	47.5			14.3	10.2	2.5		
	(29.61)	(25.54)	(18.53)	34.6	20.6	(24.51)	(21.87)	(3.71)	296.2	-78.6
CONT	32.9	24.0	22.5			27.1	4.8	5.5		
	(29.58)	(20.74)	(8.66)			(31.00)	(8.67)	(6.35)		

[a]Values = $\bar{x}$ (S.D.)

[b]% change based on index values (GLY/CONT); see text.

[c]Approximate change only.

Table 16. Indices of foraging height diversity (J') for birds nesting on the Control (CONT) and Glyphosate (GLY) sites before (Pre.; 1979) and 1 (Post-1, 1980) and 2 (Post-2; 1981) years after glyphosate treatment.[a]

Species	Foraging diversity (J')			Relative change[b]	
	Pre	Post-1	Post-	Pre vs Post-1	Post-1 vs Post-2
Rufous hummingbird					
GLY	0.317	0.779	0.609	106.3	-46.1
CONT	0.394	0.472	0.682		
Orange-crowned warbler					
GLY	0.750	0.886	0.918	15.7	2.1
CONT	0.904	0.920	0.935		
MacGillivray's warbler					
GLY	0.260	0.505	0.380	81.5	-30.6
CONT	0.484	0.515	0.556		
Wilson's warbler					
GLY	0.735	0.787	0.842	5.9	-9.3
CONT	0.728	0.737	0.864		
Rufous-sided towhee					
GLY	0.113	0.296	0.122	147.4	-62.8
CONT	0.296	0.315	0.351		
White-crowned sparrow					
GLY	0.318	0.591	0.595	-1.1	-12.8
CONT	0.334	0.627	0.728		
Song sparrow					
GLY	0.113	0.437	0.491	124.2	-35.3
CONT	0.181	0.315	0.546		
American goldfinch					
GLY	0.722	0.829	0.866	-23.7	11.5
CONT	0.632	0.955	0.896		

[a]Sample sizes given in Table 17.
[b]% change based on index values (GLY/CONT); see text.

Table 17. Percent of time spent foraging in each of 3 height intervals for species nesting on the Control (CONT) and Glyphosate (GLY) sites before (Pre.; 1979) and 1 (Post-1; 1980) and 2 (Post-2; 1981) years after glyphosate treatment.

Species	Sample size[a]			% use (0.0-1.0 m)			% use (1.1.0 m)			% use (> 3.0 m)		
	Pre	Post-1	Post-2	Pre	Post-1	Post-2	Pre	Post-1	Post-2	Pre	Post-1	Post-2
Rufous hummingbird												
GLY	99	88	51	88.9	59.9	74.3	11.1	33.3	22.3	0.0	6.8	3.4
CONT	130	62	43	84.1	85.0	71.1	15.9	10.0	22.8	0.0	5.0	6.1
Orange-crowned warbler												
GLY	172	78	56	68.1	51.3	45.0	21.9	35.9	40.1	10.0	12.8	14.9
CONT	129	76	60	46.0	40.0	34.3	40.5	45.0	47.7	13.5	15.0	18.0
MacGillivray's warbler												
GLY	135	46	36	91.7	80.4	85.3	8.3	19.6	14.7	0.0	0.0	0.0
CONT	140	61	47	83.0	80.0	74.6	14.3	18.0	24.3	2.8	2.0	1.1
Wilson's warbler												
GLY	78	85	76	68.4	24.7	51.0	23.7	64.7	40.0	7.9	10.6	9.0
CONT	104	76	81	13.5	68.0	34.2	71.2	23.7	54.1	15.4	8.3	11.7
Rufous-sided towhee												
GLY	31	63	48	97.0	90.0	87.3	3.0	10.0	12.7	0.0	0.0	0.0
CONT	135	40	61	88.0	89.0	87.0	12.0	11.0	13.0	0.0	0.0	0.0
White-crowned sparrow												
GLY	150	74	51	89.0	75.0	71.7	11.0	22.2	26.8	0.0	2.8	1.5
CONT	53	32	73	95.0	54.5	59.1	5.0	45.5	37.3	0.0	0.0	3.7
Song sparrow												
GLY	117	89	71	97.0	81.4	80.0	3.0	18.6	19.0	0.0	0.0	1.0
CONT	72	53	61	54.5	89.0	75.0	45.5	11.0	24.0	0.0	0.0	0.9
American goldfinch												
GLY	65	75	46	67.7	42.1	51.5	26.2	50.0	37.5	6.2	7.9	11.0
CONT	20	52	37	90.0	35.0	47.1	10.0	45.0	40.0	0.0	20.0	12.9

[a]Number of observations; see Methods.

Table 18. Sample sizes (number of 5-m-radius plots) for analysis of bird habitat use on the Control (CONT) and Glyphosate (sites).

Species	Pre-spray (1979)		1 year Post-spray (1980)		2 years Post-spray (1981)	
	CONT	GLY	CONT	GLY	CONT	GLY
Willow flycatcher	9	7	8	7	8	8
Swainson's thrush	5	5	18	8	15	8
Orange-crowned warbler	9	22	7	16	10	11
MacGillivray's warbler	20	17	16	7	11	10
Wilson's warbler	14	8	12	10	10	11
Rufous-sided towhee	8	10	8	13	12	19
Dark-eyed junco	3	7	3	5	3	5
White-crowned sparrow	29	15	18	8	18	8
Song sparrow	24	22	9	22	10	14
American goldfinch	12	18	5	12	5	12