ncasi
NATIONAL COUNCIL FOR AIR AND STREAM IMPROVEMENT

FOREST HERBICIDE EFFECTS ON PACIFIC NORTHWEST ECOSYSTEMS: A LITERATURE REVIEW

TECHNICAL BULLETIN NO. 970
DECEMBER 2009

by
Laurie A. Clark
NCASI Western Wildlife Program
Tenmile, Oregon

Gary J. Roloff, Ph.D.
Michigan State University
East Lansing, Michigan

Vickie L. Tatum, Ph.D.
NCASI Southern Regional Center
Newberry, Florida

Larry L. Irwin, Ph.D.
NCASI Western Wildlife Program
Stevensville, Montana

Acknowledgments

We wish to extend special thanks to Dr. Mike Newton for critically reviewing an early draft of this document and providing valuable advice on content, context, and formatting. We also extend our appreciation to Dr. Thomas Sullivan, Dr. A.J. Kroll, Tony Melchiors, Dr. Darren Miller, Dr. John Cook, Dr. George Ice, Dr. Alan Lucier, Stu Farber, Jeff Light, Matt Higgins, Steve Wickham, Jerry Breland, Conner Fristoe, and Marshall Jacobson for providing critical manuscript reviews. All of your comments and edits greatly improved this manuscript, and for this we are grateful. We express our gratitude to Judith Adamski for assistance with literature acquisition. Funding for this project was provided by NCASI, and member companies of the Washington Forest Protection Association, Oregon Forest Industries Council, and the American Forest Resource Council.

For more information about this research, contact:

Larry L. Irwin, Ph.D.
Principal Research Scientist
NCASI Western Wildlife
P.O. Box 68
Stevensville, MT 59870
(406) 777-7215
llirwin@bitterroot.net

Alan A. Lucier, Ph.D.
Senior Vice President
NCASI
P.O. Box 13318
Research Triangle Park, NC 27709-3318
(919) 941-6403
alucier@ncasi.org

For information about NCASI publications, contact:

Publications Coordinator
NCASI
P.O. Box 13318
Research Triangle Park, NC 27709-3318
(919) 941-6400

Cite this report as:

National Council for Air and Stream Improvement, Inc. (NCASI). 2009. *Forest herbicide effects on Pacific Northwest ecosystems: A literature review*. Technical Bulletin No. 970. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

PRESIDENT'S NOTE

Herbicides are important tools for sustaining the health and productivity of forests. For example, herbicides have critical roles in controlling invasive weeds and enabling cost-effective forest regeneration after timber harvest. In comparison to alternatives, use of herbicides to control vegetation has important ecological advantages with positive feedbacks to ecosystem sustainability and water quality. These advantages include avoiding effects of ground-based equipment on soil physical properties; avoiding nitrogen losses associated with burning; reducing on-site soil and organic matter displacement; and minimizing soil erosion and sediment transport to streams.

Advantages notwithstanding, stakeholders and critics of the forest industry continue to express concerns about the effects of herbicides on wildlife and biodiversity in managed forests. This report reviews scientific aspects of those concerns with emphasis on studies conducted in the Pacific Northwest. A substantial body of research shows that direct toxic effects to wildlife are not expected when herbicides are used in accordance with legal requirements. Much less is known about indirect effects of habitat modifications associated with herbicide use in wood production systems. Suggested research priorities include studies on long-term responses of plant and animal communities to herbicide use in forested landscapes.

Appendices in this report will be of use to anyone interested in learning more about specific aspects of the scientific literature on silvicultural herbicides and their ecological effects in the Pacific Northwest. Appendix A contains synopses of 86 studies of wildlife responses to herbicides. Appendix B contains lists of scientific papers on responses of mammals and birds to silvicultural applications of herbicides.

This report is a product of the industry's Western Wildlife Program (WWP) and its research initiative on biodiversity in managed forests in the Pacific Northwest. The initiative includes several ongoing field studies conducted in collaboration with universities, agencies, and timber companies. The WWP is managed by NCASI on behalf of four industry associations that provide core funding support (American Forest Resources Council, Oregon Forest Industries Council, Washington Forest Protection Association, and NCASI).

Ronald A. Yeske

December 2009

MOT DU PRÉSIDENT

Les herbicides sont un outil important pour le maintien de la santé et de la productivité des forêts. Par exemple, les herbicides jouent un rôle crucial pour le contrôle des plantes envahissantes tout en permettant une régénération rentable de la forêt suite à la récolte. Par comparaison aux autres solutions possibles, l'usage d'herbicides à des fins de contrôle de la végétation offre des avantages écologiques importants et des rétroactions positives pour le maintien des écosystèmes et la qualité de l'eau. Parmi ces avantages, on compte : l'évitement des effets négatifs sur les propriétés physiques des sols causés par l'utilisation des équipements au sol, l'évitement des pertes d'azote causées par les feux, réduction des déplacements de sols et de matières organiques, minimisation de l'érosion des sols et du transport de sédiments vers les cours d'eau.

Peu importe leurs avantages, les parties intéressées ainsi que les critiques de l'industrie forestière continuent d'exprimer leurs inquiétudes à propos des effets des herbicides sur la faune et la biodiversité des forêts aménagées. Le présent rapport présente une revue des aspects scientifiques relativement à ces inquiétudes en mettant une emphase particulière sur les études réalisées dans la région du nord-ouest du Pacifique. Un nombre important de recherches démontrent qu'on ne s'attend pas à l'occurrence d'effets toxiques directs sur la faune lorsque les herbicides sont utilisés selon les exigences légales qui les régissent. Par ailleurs, les connaissances sont beaucoup plus limitées en ce qui a trait aux effets indirects des modifications d'habitats associées à l'utilisation d'herbicides dans les systèmes de production de bois. Parmi les priorités de recherches suggérées, on retrouve la nécessité d'effectuer des études sur les réponses à long-terme des communautés de plantes et d'animaux aux herbicides utilisés dans les territoires forestiers.

Les annexes de ce rapport seront utiles aux personnes intéressées à en apprendre davantage à propos des aspects spécifiques de la littérature scientifique sur les herbicides utilisés pour la sylviculture et leurs effets écologiques dans la région du nord-ouest du Pacifique. L'annexe A contient des sommaires pour 86 études sur les réponses fauniques aux applications d'herbicides. L'annexe B contient des listes d'articles scientifiques sur les réactions des mammifères et des oiseaux aux applications d'herbicides pour la sylviculture.

Ce rapport est issu du Programme pour la faune occidentale (Western Wildlife Program ou WWP) parrainé par l'industrie forestière par l'entremise de son initiative de recherche sur la biodiversité dans les forêts aménagées de la région du nord-ouest du Pacifique. Cette initiative englobe plusieurs études sur le terrain effectuées en collaboration avec des universités, des agences et des compagnies forestières. Le WWP est géré par NCASI au nom de quatre associations industrielles qui en subventionne la majorité du budget (American Forest Resources Council, Oregon Forest Industries Council, Washington Forest Protection Association et NCASI).

Ronald A. Yeske

December 2009

FOREST HERBICIDE EFFECTS ON PACIFIC NORTHWEST ECOSYSTEMS: A LITERATURE REVIEW

TECHNICAL BULLETIN NO. 970
DECEMBER 2009

ABSTRACT

The use of silvicultural herbicides to control competing vegetation has evolved over the past 75 years and has become an integral component of today's forestry management practices. Although the direct effects of herbicides on non-target biota are generally well understood and documented, comparatively little information is available on indirect and long-term (more than five years) effects. This review summarizes extant scientific literature by providing brief synopses of the direct effects of forest herbicides on plant and animal communities, but primarily emphasizes the indirect effects to wildlife in the Pacific Northwest.

Herbicides increase survival and growth of crop trees and are effective at controlling target vegetation. Many studies have shown that herbicides have low toxicity to wildlife, tend to dissipate quickly, have limited mobility (rapidly fixed in environments), and do not bioaccumulate. Forest herbicides can enter aquatic ecosystems via accidental runoff or drift, but this riparian contact is minimized through the use of vegetation buffers, drift prediction models, application timing, and droplet size. When herbicides are applied at recommended rates in managed forests, direct toxic effects on wildlife and fish are not expected.

Based on general measures of vegetation composition and structure, plant communities found in intensively managed forests recover quickly following chemical treatment (typically within two to three years). Wildlife responses to vegetation changes induced by herbicides at a stand level tend to be species- and site-specific, with timing of wildlife community recovery linked directly to the pace of vegetation recovery. Indirect effects of herbicides on wildlife associated with habitat modification depend on a variety of factors, including composition of the wildlife and vegetation communities, herbicide characteristics, application rates, treatment, and timing. Soil microbial communities and nutrient availability can be affected by herbicide treatments, potentially influencing nutrient cycling.

Suggested future research topics include long-term indirect effects and shifts in plant community structure at both landscape scales and ecosystem levels; effects of herbicides (at field application rates) on underrepresented taxa (especially amphibians and reptiles); and effects of constantly evolving formulations and tank mixes (including adjuvants and surfactants).

KEYWORDS

2,4-D, atrazine, conifer release, ecosystem effects, glyphosate, herbicides, hexazinone, imazapyr, intensive forest management, Pacific Northwest, plant effects, site preparation, sulfometuron, triclopyr, vegetation control, wildlife effects

RELATED NCASI PUBLICATIONS

Technical Bulletin No. 886 (October 2004). *The toxicity of silvicultural herbicides to wildlife – Volume 2: Glyphosate and imazapyr*.

Technical Bulletin No. 861 (May 2003). *The toxicity of silvicultural herbicides to wildlife – Volume 1: Introduction and triclopyr*.

Special Report No. 07-01 (February 2007). *Measurement of glyphosate, hexazinone, imazapyr, and sulfometuron methyl in streamwater at the Texas Intensive Forestry Study sites*.

EFFETS DE L'UTILISATION D'HERBICIDES EN FORÊTS SUR LES ÉCOSYSTÈMES DE LA RÉGION DU NORD-OUEST DU PACIFIQUE : UNE ANALYSE DOCUMENTAIRE

BULLETIN TECHNIQUE N^{O} 970
DÉCEMBRE 2009

RÉSUMÉ

L'utilisation d'herbicides pour la sylviculture à des fins de contrôle de végétation concurrente a évolué au cours de 75 dernières années et elle est maintenant intégrée aux pratiques actuelles de gestion forestière. Quoique les effets directs des herbicides sur le biote non-visé soient généralement bien compris et documentés, il existe comparativement peu d'information disponible à propos des effets indirects et à long-terme (plus de 5 ans). La présente revue documentaire fait le bilan de la littérature scientifique par le biais de courts sommaires sur les effets directs de l'utilisation d'herbicides forestiers sur les communautés animales et végétales, tout en mettant un emphase particulier sur le sujet des effets indirects sur la faune de la région nord-ouest du Pacifique.

Les herbicides augmentent les taux de survie et de croissance des arbres cultivés et sont efficaces pour le contrôle de végétation ciblée. Plusieurs études ont démontré que les herbicides ont : une faible toxicité pour la faune, une tendance à se dissiper rapidement, une mobilité limitée (ils se fixent rapidement dans l'environnement) et finalement ils ont un taux de bioaccumulation nul. Les herbicides forestiers peuvent entrer dans les écosystèmes aquatiques par l'entremise de rejets accidentels ou par migration, mais ce type de contact riverain est minimisé par l'utilisation de végétation tampon, de modèles de prédiction de la migration, de planification des applications et par l'ajustement de la dimension des gouttelettes. Lorsque les herbicides sont appliqués aux taux recommandés dans les forêts aménagées, on prévoit l'absence d'effets toxiques directs sur la faune et les poissons.

En se fondant sur des mesures générales de la composition et de la structure de la végétation, les communautés de plantes retrouvées dans des forêts gérées de manière intensive se régénèrent rapidement suite à un traitement chimique (typiquement de deux à trois ans). Les réponses de la faune aux changements de végétation causés par l'application d'herbicides dans la forêt tendent à être spécifiques à chaque espèce et à chaque site. De plus, le temps nécessaire à la régénération de la communauté faunique est directement relié au taux de régénération de la végétation. Les effets indirects des herbicides sur la faune et associés aux modifications d'habitats sont une fonction de plusieurs facteurs tels que : composition des communautés fauniques et végétales, caractéristiques des herbicides, taux d'application, traitement et temps de l'application. Les communautés microbiennes dans le sol ainsi que la disponibilité de nutriments peuvent être perturbés par les traitements aux herbicides, ce qui peut potentiellement influencer le cycle des nutriments.

Parmi les sujets de recherches suggérés pour l'avenir, on retrouve : l'étude des effets indirects à long-terme et les changements dans la structure des communautés végétales tant au niveau du paysage qu'au niveau des écosystèmes; l'étude des effets des herbicides (au taux d'application en vigueur sur le terrain) sur les taxons sous-représentés (particulièrement les amphibiens et les reptiles); et finalement l'étude des effets reliés à l'évolution constante des formulations et mélanges dans les réservoir (incluant les adjuvants et les surfactants).

MOTS CLÉS

2,4-D, atrazine, dégagement des conifères, effets sur les écosystèmes, glyphosate, herbicides, hexazinone, imazapyr, gestion intensive des forêts, région du nord-ouest du Pacifique, effets sur la végétation, préparation de sites, sulfométuron, triclopyr, contrôle de la végétation, effets sur la faune

AUTRES PUBLICATIONS DE NCASI DANS CE DOMAINE

Bulletin technique n° 886 (octobre 2004). *The toxicity of silvicultural herbicides to wildlife – Volume 2: Glyphosate and imazapyr*.

Bulletin technique n° 861 (mai 2003). *The toxicity of silvicultural herbicides to wildlife – Volume 1: Introduction and triclopyr*.

Rapport spécial n° 07-01 (février 2007). *Measurement of glyphosate, hexazinone, imazapyr, and sulfometuron methyl in streamwater at the Texas Intensive Forestry Study sites*.

CONTENTS

TABLES

FIGURES

FOREST HERBICIDE EFFECTS ON PACIFIC NORTHWEST ECOSYSTEMS: A LITERATURE REVIEW

1.0 INTRODUCTION

Global timber harvests are projected to increase in the future, with most wood supply studies recognizing intensive forest management (e.g., plantations) as critical to meeting future demands (Nilsson and Bull 2005). Recent modeling suggests that wood fiber supply may exceed demand in the middle of the 21st century (e.g., Churkina and Running 2004), but rapidly changing global markets and environmental conditions are reasons for a less optimistic opinion (Nilsson and Bull 2005). For example, the Food and Agriculture Organization of the United Nations predicts that working forest area will decrease in the near future because forests will be more highly valued for their environmental services (e.g., water quality, biodiversity, carbon sequestration) (FAO 2007). Examples of rapidly changing wood supply conditions at global scales include increasing consumption in emerging global economies, increases in illegal logging, over-harvesting of existing forest capital in important supply countries, increasing rates of natural disturbances that reduce current forest capital, and increased competition for wood fiber between the energy industry and the traditional forest products industry (Nilsson and Bull 2005).

According to the FAO (2001), intensively managed forests constituted roughly 5% of global forest cover in 2000 but provided 35% of global roundwood. By 2020, plantation-based management is projected to constitute 45% of global roundwood supply (FAO 2001, 2007). Under current timber valuation processes (i.e., a focus on internal rate of return), forest researchers and land managers recognize that intensively managed forests must have far greater yields and operate on shorter rotations than traditional, unmanaged forests (Fenning and Gershenzon 2002). To fulfill these expectations, silvicultural regimes usually include prompt reforestation with genetically improved seedlings (Fenning and Gershenzon 2002; Thompson and Pitt 2003) and management of competing vegetation (Wagner et al. 2006).

Pacific Northwest forests are recognized worldwide for their productivity (FAO 2007) and currently help support a viable North American forest products industry. Most industrial forest landowners in this region are harvesting second (and in some cases third) rotation forests and, to remain globally competitive, have increasingly emphasized intensive forest management techniques. Thus, use of herbicides to control competing vegetation is an important management tool. However, recent news media reports and lawsuits e.g., Washington Toxics Coalition v. EPA 2005[1] have challenged the use of herbicides as part of an intensive forest management regime.

Private forest landowners recognize that understanding forest herbicide effects is essential to long-term sustainability because plant and animal community changes induced through herbicide use are closely linked to ecosystem functions such as photosynthesis, nutrient cycling, and microbial activity (Pratt et al. 1997). Much is known about potential for herbicide toxicity to wildlife (e.g., Tatum 2004) and short-term target vegetation responses to herbicide applications. Comparatively less is known about short- and long-term indirect effects on wildlife populations and ecological communities.

---

[1] The most recent court decision in this case may be found at http://agr.wa.gov/PestFert/natresources/docs/WTCVEPA/WTC%20v%20EPA%209th%20Cir%2006-29-05.pdf

Reviews of forest herbicide effects and intensive forest management have covered various topics across a variety of geographic regions (Table 1.1). Reviews through 2006 concluded that modern forest herbicides 1) do not have direct toxic effects on wildlife when applied according to label directions; 2) rapidly decompose, thereby limiting exposure to non-target species; 3) do not bioaccumulate; 4) influence species-specific responses in wildlife habitat use and forage preferences; 5) have become more efficient and environmentally benign silvicultural tools; 6) efficiently and rapidly impact target vegetation, with plant communities often exhibiting rapid recovery; 7) do not reduce stand- and landscape-level plant species richness or diversity; and 8) can be used to enhance certain wildlife habitat components. Most reviews also noted that more research on direct and indirect herbicide effects was needed, particularly with respect to different surfactants and tank mixes, and that improvements in experimental designs were warranted.

Missing from the literature is a compilation of recent (since the late 1980s) data and information focused on the Pacific Northwest. An updated compilation is important because the last Northwest-based literature reviews (Boyd et al. 1985; Balfour 1989) covered a much different herbicide and regulatory era than that experienced in the early 21st century (Figure 1.1). Forest managers currently apply more effective and efficient herbicides (e.g., imazapyr, glyphosate, triclopyr), with ever-changing chemical formulations, and use different application techniques (e.g., tank mixes).

Herbicides comprise just one tool managers use for manipulating vegetation during intensive forest management rotations. A typical Pacific Northwest intensive forest management regime includes site preparation that involves applying soil-active chemicals (and possibly a foliar-active chemical) within two years after timber harvest, planting crop trees, and following up with an application of foliar-active chemical when the plantation is two to five years old. Data on direct effects on plant and animal communities of individual chemicals used during this regime exist, but data on indirect effects of intensive forest management as a whole are sparse (Miller and Miller 2004). Managers' objectives guide decisions on what, when, how, and where vegetation is controlled and what will be grown over ensuing rotations. In this context, herbicides are one tool used for a short time period to obtain forest management objectives efficiently and effectively. Herbicides have become the preferred management tool for controlling competing vegetation because alternative techniques (e.g., mechanical, fire) have a number of disadvantages, including increased soil compaction and erosion, greater energy consumption, non-selectivity, destruction of soil habitats, and medical costs (Newton and Dost 1984).

Table 1.1 Extant Literature Reviews on Forest Herbicide Effects

Reference	Topic	Geographic Scope
Balfour 1989[a]	Herbicide trial effects on wildlife forage species	Pacific Northwest, Canada and U.S.
Boyd et al. 1985[c]	Herbicide effects on shrubs, herbs, and conifers	Inland Northwest, U.S.
Giesy, Dobson, and Solomon 2000[a]	Ecotoxicological risk assessment for glyphosate (Roundup®)	Worldwide
Grossbard and Atkinson 1985[c]	Glyphosate effects on varied topics	Varied by chapter
Guiseppe et al. 2006[a]	Glyphosate effects on non-target species (emphasis on ants)	North temperate forests
Kenaga 1975[a]	Toxicological effects of 2,4,5-T and derivatives on birds	Worldwide
Lautenschlager 1993[a]	Multiple forest herbicide effects on songbirds, small mammals, moose, and deer	Northern coniferous forests
Lautenschlager and Sullivan 2002[a]	Forest herbicide effects on fungi, plants, animals	Northern forests
Miller and Wigley 2004[c]	Relationships between herbicides and forest biodiversity	North American emphasis
Morrison and Meslow 1983a[a]	2,4-D, 2,4,5-T, and glyphosate effects on wildlife	North America
Neary and Michael 1996[a]	Forest herbicides effects on water quality	Worldwide
Newton and Dost 1984[a]	Biological and physical effects of forest vegetation management	Pacific Northwest (worldwide applicability)
Newton and Knight 1981[a]	Description of herbicides registered for forestry use	North America
Newton and Norgren 1977[a]	Relationships between water quality and forest chemical use	Worldwide
Newton and Snyder 1978[a]	Forest herbivore exposure to dioxin in areas sprayed with 2,4,5-T	U.S. (Oregon emphasis)
Norris 1981a[a]	2,4-D, 2,4,5-T (among others), and dioxin (TCDD) behavior in forest ecosystem components (air, vegetation, soils, water)	Worldwide
Ritchie and Sullivan 1989[a]	Monitoring methodologies for determining herbicide effects on small mammals	North America
Rowland, White, and Livingston 2005[a]	Intensive forestry effects on plant community structure	North America (Northeast emphasis)
Stewart, Gross, and Honkala 1984[b]	Competing vegetation effects on forest trees	North America
Sullivan 1985[a]	Glyphosate effects on select wildlife	U.S. and Canada
Sullivan and Sullivan 2003[a]	Glyphosate effects on plant and animal diversity	Temperate zone forests and agro-ecosystems

[a] review
[b] bibliography with abstracts
[c] compilation of papers

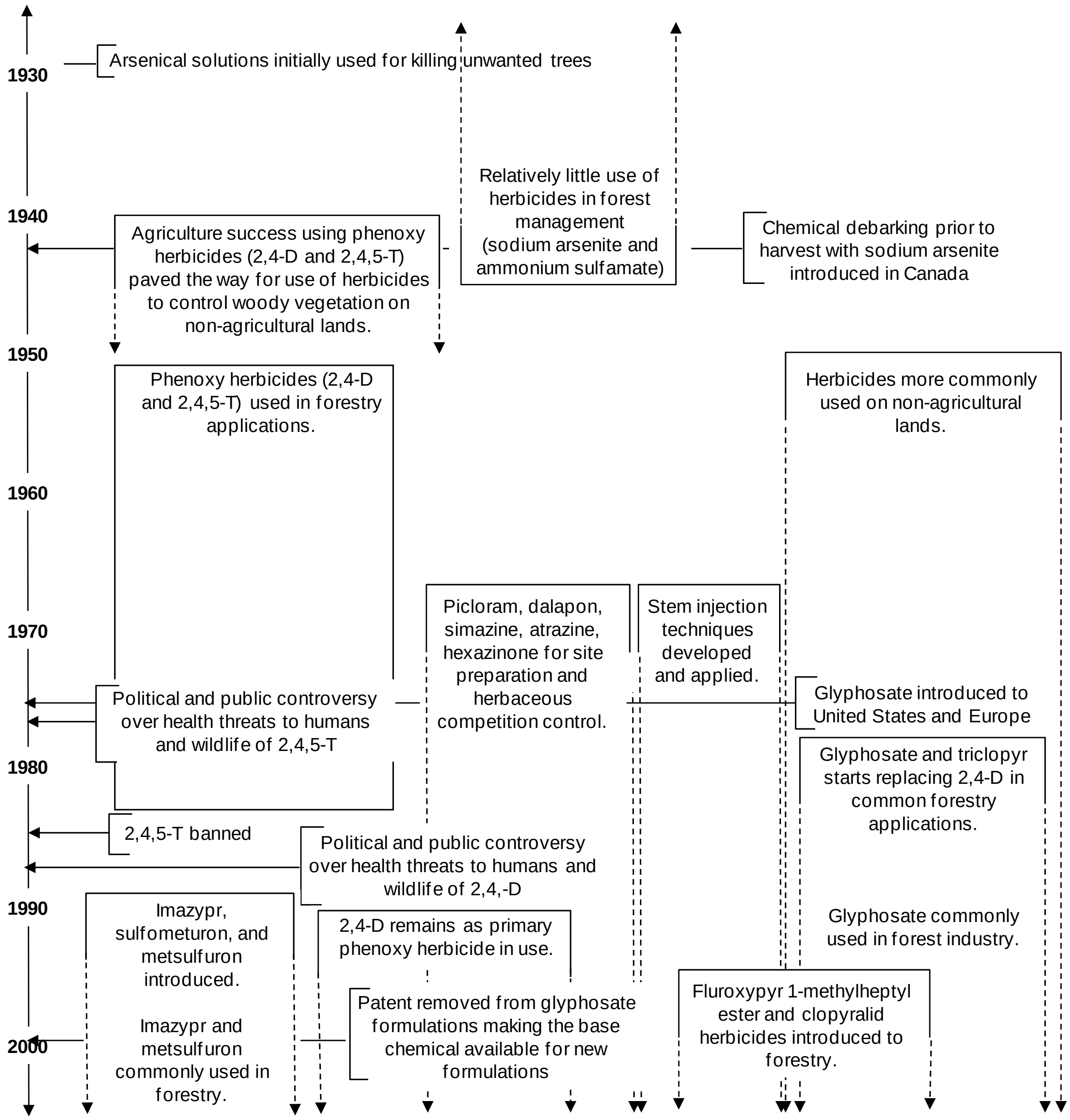

Figure 1.1 Timeline Depicting Major Events in the Evolution of Forest Herbicide Use in the United States [primarily based on House et al. 1967 and Wagner et al. 2004; glyphosate patent information based on Howe et al. 2004]

2.0 METHODS

This literature review summarizes existing information on direct and indirect effects of forest herbicide applications on plant and animal communities and ecosystems in the Pacific Northwest. For purposes herein, the Pacific Northwest includes forested areas in Washington, Oregon, Idaho, western Montana, northwestern and central California, and southern British Columbia (Figure 2.1). Direct effects are defined as those where one variable (i.e., herbicides) has an effect on another variable via a single causal path (e.g., a toxic effect on animal productivity or survival; a repellent effect on behavior). Extensive literature summaries on direct effects have been compiled elsewhere (e.g., Giesy, Dobson, and Solomon 2000; NCASI 2003, 2004). Indirect effects are those in which herbicides have intermediary effects (e.g., herbicides kill vegetation, and the loss of vegetation causes a change in animal distributions or survival; herbicide applications trigger a shift in forest succession, leading to altered vegetation composition, dominance, and structure). Although other reviews on this topic have been compiled (Table1.1 contains some examples), NCASI has not identified any reviews specifically focusing on the Pacific Northwest since the late 1980s.

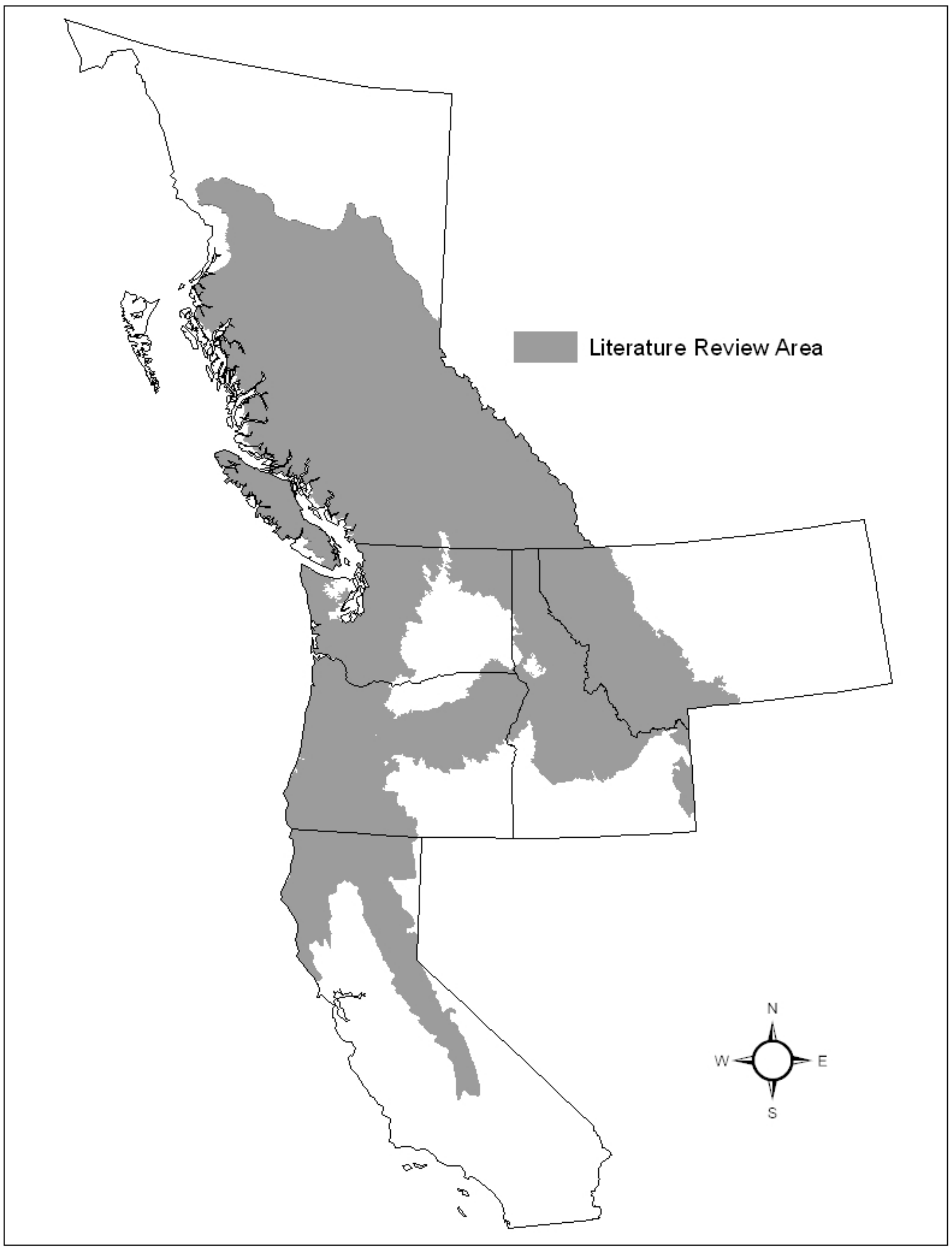

Figure 2.1 Generalized Area of Literature Review Focus in the Pacific Northwest

Articles in scientific journals, government reports, technical bulletins, symposium proceedings, and relevant book chapters were summarized to compile this review of herbicide effects. Literature searches were conducted using Internet resources (Google Scholar) and reference databases including Web of Science, AGRICOLA, Academic Search Premier, Forestry and Natural Resource Management (Forest Science), and Biological Abstracts (BIOSIS). Database search phrases used to identify pertinent articles included various combinations of intensive forest management, herbicide use, site preparation treatments, and vegetation control in forestry. Literature cited sections of acquired articles were also reviewed to cross-reference citation lists.

Articles were summarized by location, stand age, timing of herbicide application and experimental treatment, chemical type, and observed vegetation and wildlife responses (Appendix A); and by wildlife species (Appendix B). Research results from other geographic regions were included to strengthen conclusions. In reviewing articles, repeatable patterns and trends as well as contradictory results were noted. Throughout this document short-term studies of herbicide effects are defined as five years or less, while long-term studies are more than five years unless otherwise noted. The term weed denotes undesirable (from an intensive forest management perspective) plant species and weedy denotes plants that readily occupy and proliferate on disturbed sites. This review is comprehensive in that it summarizes available information to date concerning direct and indirect effects of herbicides on plants and animals in Pacific Northwest forests. It is not an exhaustive evaluation of all North American research.

3.0 BACKGROUND – HERBICIDES AND FORESTRY

Herbicides used in today's forest management are tested to ensure they meet strict safety and environmental standards before registration (Ponder 2002). Information required for registration not only includes data on product and residue chemistry, but also environmental fate, toxicology, re-entry protection for workers, toxicity to non-target biota (wildlife, aquatic, insects), and spray drift (NCASI 2003). Forest herbicide application techniques vary by region, topography, vegetation type, season, cost, and management objectives and include broadcast, individual tree injection, cut-stump sprays and wipes, basal sprays and wipes, directed foliar sprays, and soil spot or strip sprays (Walstad, Newton, and Gherstad 1987; Ponder 2002; Wigley et al. 2002; Miller 2003). Aerial application of broad-spectrum herbicides is the most common and cost-effective technique for site preparation on large areas (Walstad, Newton, and Gherstad 1987; Wigley et al. 2002).

Forest herbicides are foliar-active, soil-active, or both, referring to how the chemical enters the plant. Foliar-active herbicides are absorbed through leaf surfaces and, in some cases, can be applied directly to plant stems. Soil-active herbicides are pulled into the plants through the roots as they take up water and transpire. Unlike agricultural herbicides that are applied one to two times annually, herbicide applications in western coniferous forests typically occur three or fewer times during a 30- to 80-year rotation (Shepard, Creighton, and Duzan 2004).

Forest managers contend that herbicides are critical for intensive forest management programs in North America (Wagner et al. 2004, 2006) because they provide a cost-effective means of optimizing management outcomes (Walstad, Newton, and Gherstad 1987; Wigley et al. 2002). The goal of using herbicides is to increase reforestation success and timber yields. This is accomplished by controlling vegetation that competes with tree establishment and growth (i.e., site preparation and vegetation control regimes) (Shepard, Creighton, and Duzan 2004; Guiseppe et al. 2006), managing tree species composition, and influencing forest successional development (Gratkowski 1975; Fiddler and McDonald 1990; Wigley et al. 2002; Miller and Miller 2004; Wagner et al. 2004; Balandier et al. 2006).

Herbicides can also be an important component in wildlife habitat management and manipulation (Coulter 1958; Mullison 1970; Schroeder 1972; Newton and Norris 1976; Brandeis et al. 2002; Guynn et al. 2004; Miller and Miller 2004). Additionally, forest herbicides have been used to facilitate natural plant community restoration (Masters et al. 1996; Rice et al. 1997; Colborn and Short 1999; Olson and Whitson 2002; Rhoades, Barnes, and Washburn 2002) and reduce the spread of invasive non-native plants (Rice et al. 1997; Sigg 1999; Shepard, Creighton, and Duzan 2004). In the Pacific Northwest, most native plant restoration work with herbicides has targeted woody and invasive species in grassland and savanna ecosystems (e.g., Ewing 2002; Huddleston and Young 2005).

Forestry management objectives can be classified as site preparation, woody and herbaceous vegetation control, and conifer release (Shepard, Creighton, and Duzan 2004). Chemical site preparation involves using herbicides on recently harvested timber stands prior to replanting (Wigley et al. 2002). In some situations, subsequent chemical applications for additional vegetation control occur during the first growing season after tree planting (Wagner et al. 2004). After plantation establishment (one to four years), conifer release treatments may be used to remove or suppress competing herbaceous plants and hardwoods (Wigley et al. 2002; Shepard, Creighton, and Duzan 2004; Guiseppe et al. 2006), as hardwoods and fast-growing shrubs can overtop young conifers, resulting in smaller and slower growing seedlings (Howard and Newton 1984). These release treatments are most effective when performed before competitors gain dominance, typically within eight years after plantation establishment (Walstad, Newton, and Gherstad 1987). However, in the Washington and Oregon Coast Ranges, herbicide release treatments are typically conducted earlier (one to five years post-planting) (Harrington et al. 1995). During later stages of stand development (i.e., mid-rotation), herbicides have also been used (e.g., spot treatments, individual woody stems) in various forest types to influence stand composition, condition, and structure (Wigley et al. 2002).

3.1 History of Herbicide Use in Forestry

Foresters began applying herbicides over 75 years ago to control competing woody vegetation. Since those initial, isolated applications, herbicide chemicals and application techniques have diversified and changed (Figure 1.1). Arsenical solutions were used to kill unwanted trees as early as 1929 (Wagner et al. 2004), but forestry herbicide use was uncommon prior to 1950. In the 1930s and 1940s sodium arsenite was used to kill woody plants and ammonium sulfamate was used for non-selective weed control (House et al. 1967). At that time, there was a recognized need for better silvicides and for more selective weed control chemicals (House et al. 1967). The advent and success of phenoxy herbicides (2,4-D, 2,4,5-T, silvex) for controlling competing vegetation in agricultural fields during the 1940s led to use of these chemicals on forests. Phenoxy herbicides have the longest history of use due to their broad-spectrum efficacy on woody and herbaceous broadleaf species (Walstad, Newton, and Gherstad 1987). Forestry applications predominantly consisted of phenoxy herbicides through the 1960s (Wagner et al. 2004). These herbicides were sometimes combined into tank mixes and were often applied with oil (McCormack 1994). Large-scale forestry applications of herbicides began about 1950 with aerial spraying (House et al. 1967).

During the late 1960s and the 1970s, several other herbicides were introduced for site preparation treatments (McCormack 1994) and for controlling competing herbaceous vegetation (e.g., picloram, dalapon, simazine, atrazine, hexazinone) (Wagner et al. 2004). These chemicals were more selective than the phenoxy herbicides. Picloram, atrazine, and hexazinone are classified as residual products, meaning that the chemical resides and remains active in the environment after application (McCormack 1994; Fredrickson and Newton 1998). Stem injection techniques were also developed in the late 1960s and the 1970s and included the chemicals picloram, phenoxy herbicides, monosodium methanearsonate (MSMA), and cacodylic acid (McCormack 1994).

Political and public controversy over perceived threats to human and wildlife health from 2,4,5-T (Wagner et al. 2004) and silvex (chemical analog of 2,4,5-T) (Walstad and Dost 1986) occurred during the late 1970s (Figure 1.1). These chemicals comprised about half the components of Agent Orange used during the Vietnam War. The widely publicized presence of the toxic trace contaminant tetrachlorodibenzodioxin (TCDD) with 2,4,5-T and silvex resulted in their ban by the Environmental Protection Agency (EPA) in 1985 (Walstad and Dost 1986; Campbell 1990; McCormack 1994). Use of the related chemical 2,4-D, among the most widely used weed controllers in crop production worldwide, also came under scrutiny during the late 1970s and early 1980s (McCormack 1994); consequently, applications in forestry declined but did not disappear. This situation was deemed economically detrimental to the forest industry, because 2,4-D was so cost-effective (Campbell 1990).

After the controversy surrounding 2,4,5-T, silvex, and 2,4-D subsided, the next decade ushered in more efficient herbicides such as glyphosate (Roundup®, Accord®) and triclopyr (Garlon®). Glyphosate is a post-emergence, broad-spectrum herbicide introduced to the United States and European markets in 1974 (Grossbard and Atkinson 1985). By 1979, glyphosate had been registered for aerial forest applications in Oregon and Maine (McCormack 1994), and it has replaced 2,4-D in many of today's forestry practices (Figure 1.1) (Campbell 1990). Glyphosate is a systemic, foliar-active chemical that is actively absorbed by leaves or roots, rapidly translocates within the phloem, and ultimately inhibits new plant growth by interfering with amino acid synthesis (Fredrickson and Newton 1998; Giesy, Dobson, and Solomon 2000; NCASI 2003). It is effective for controlling shrubs, hardwoods, and many herbaceous species with little risk of crop tree damage (Campbell 1990). At about the same time, triclopyr was introduced as another forest chemical capable of removing shrubs and hardwoods from certain conifer types. It is also a systemic, foliar-active product; however, it acts as a growth regulator by interfering with protein synthesis and hormone balance, resulting in abnormal plant growth and death (Fredrickson and Newton 1998; NCASI 2003).

In the late 1980s and throughout the 1990s, imazapyr (Arsenal®, Chopper®), sulfometuron-methyl (Oust®), and metsulfuron-methyl (Escort®) were also introduced to the forestry profession (Wagner et al. 2004). These are foliar- and soil-active chemicals and are used to control broadleaf trees, shrubs, forbs, and some annual grasses by stopping cell division in the shoots and roots. Imazapyr and sulfometuron have become vital tools for modern forest management due to their efficacy, selectivity, and low active chemical application rates (McCormack 1994) (Table 3.1). The mode of chemical activity and specificity to target vegetation of today's most commonly used forestry herbicides allows land managers to choose the most appropriate herbicide application to achieve desired forest prescription objectives.

Few new active ingredients have been introduced to the forestry profession since the late 1980s (Figure 1.1). Rather, chemical manufacturers have focused on increasing effectiveness of herbicide formulations and decreasing amounts of base chemicals required. Formulations are mixtures of active ingredients, adjuvants, and inert ingredients (e.g., water). Adjuvants are included in formulations to enhance active chemical performance. Surfactants (e.g., emulsifiers and wetting agents) are a common type of adjuvant used to improve herbicide wetting and penetration of foliage (NCASI 2003).

Herbicide formulations vary according to application technique and management objectives. For liquid formulations, the solubility of the active ingredient is an important consideration (Miller and Westra 1998). In recent years, tank mixes containing two or more active ingredients have been developed to increase effectiveness of vegetation control and reduce application times and costs (Turner 1985; Shepard, Creighton and Duzan 2004; Tatum 2004). Several published studies indicate that herbicide tank mixes can be more efficient at controlling competing vegetation and that duration of vegetation control is comparable to that achieved with a single active ingredient (Newton and Overton 1973; Ketchum, Rose, and Kelpsas 2000; Keyser and Ford 2006).

Table 3.1 U.S. Environmental Protection Agency Actively Registered[a] Herbicides for Forestry Use in North America, with Specific Emphasis on the Pacific Northwest

Active Ingredient	Max. Label Rate[b] (kg/ha), mean	(range)	Trade Names	Common Forestry Uses
2,4-D	7.3	(3.4-17.9)	Savage® CA Weedar® 64	Systemic; used to control broadleaf weeds; most widely used herbicide in the world (primarily agricultural use); foliar-active
Atrazine	7.0	(4.9-9.0)	AAtrex® 4L Conifer 90®	Kills post-emergence broadleaf and grass weeds; soil and foliar-active
Glyphosate	10.5	(2.2-22.4)	Accord® Concentrate Accord® SP Razor® Pro Roundup® Vision®	Non-selective, systemic; used to kill weeds; foliar-active
Hexazinone	9.7	(3.0-22.4)	Velpar® Pronone® Oustar®	Non-selective, broad spectrum; used to control grasses and broadleaf and woody plants; soil and foliar-active
Imazapyr	2.6	(0.7-5.6)	Arsenal® Chopper® Onestep®	Non-selective, broad spectrum, systemic; used to control grasses and broadleaf herbs, woody species, and riparian and emergent aquatic species; soil and foliar-active
Metsulfuron methyl	0.2	(0.1-1.8)	Escort® Patriot®	Used to control selected broadleaf weeds, trees and brush, some annual grasses; soil and foliar-active
Sulfometuron	5.6	(5.6-5.6)	Oust® Oust® XP Oustar® Oust® Extra	Broad spectrum, urea; used to control annual and perennial grasses and broadleaf weeds; soil and foliar-active
Triclopyr	13.4	(9.0-17.9)	Garlon® 4 Forestry Garlon® 4	Selective, systemic; used to control woody and broadleaf plants; foliar-active

[SOURCES: Wigley et al. 2002; Shepard, Creighton, and Duzan 2004]
[NOTE: Table is strictly a guide and not all-inclusive. No endorsement or support of any individual product or company is given or implied.]
[a] as of 2007
[b] maximum label application rates represent the range for active ingredient concentration (NCASI 2003)

As of 2007, the most commonly used forest herbicides in the Pacific Northwest included formulations of glyphosate, triclopyr, imazapyr, 2,4-D, atrazine, hexazinone, and sulfometuron (Table 3.1) (Wagner et al. 2004). A substantial body of research shows that these chemicals have low potential to have toxic effects on wildlife and that they quickly degrade, do not persist, and do not bioaccumulate in the environment (Tatum 2004).

A recurring issue is whether herbicide formulations are more toxic than active ingredients alone. Several laboratory studies support this possibility (e.g., Turner 1985; Atkinson 1985a). However, as pointed out by Giesy, Dobson and Solomon (2000), at actual use rates, formulations still present minimal risk of direct toxicity to wildlife.

There have been few toxicity studies of herbicide tank mixes. In general, those studies found that the effects of mixtures are not significantly different from what would be expected based on the toxicity of the individual components (Abdelghani et al., 1997; Howe, Gillis and Mowbray 1998; Deneer 2000; Green and Abdelghani 2004). In some cases, the toxicity was somewhat less than expected (antagonistic) and in a few, the effects were somewhat more than expected (synergistic), but deviations from simple additive toxicity were generally small.

4.0 FOREST HERBICIDE EFFECTS ON THE VEGETATION COMMUNITY

Forest herbicides are designed to remove target vegetation species, thereby reducing resource competition and improving overall plantation survival and growth. Consequently, herbicide applications cause significant short-term changes (i.e., reduction of herbaceous and woody species) in plant community composition and structure (Sullivan and Sullivan 1982; Sullivan 1990a; Freedman 1991; MacKinnon and Freedman 1993; Miller and Miller 2004; Balandier et al. 2006). Vegetation responses to herbicide applications vary according to site conditions, phenological plant stages, application techniques and timing, chemical-specific characteristics, soil treatments, and seed bank composition (Norris 1981b; Powers and Reynolds 1999; Miller and Miller 2004; Balandier et al. 2006). This variation in both target and non-target vegetation responses stresses the importance of basing forest regeneration objectives on factors specific to the management area when using herbicides.

Direct herbicide-induced plant community effects tend to be short term, and targeted species typically recover to near pre-application levels within two to five years (e.g., Morrison and Meslow 1984a, 1984b; Sullivan and Boateng 1996; Sullivan, Lautenschlager, and Wagner 1996; Chen 2004; Balandier et al. 2006). Short-term recovery of targeted vegetation has been attributed to plant community resiliency (i.e., the ability to recover quickly) in intensively managed landscapes because herbicides only alter target vegetation composition and abundance and do not permanently kill all weedy, competitive, non-crop species (Miller and Miller 2004). However, few long-term studies have evaluated herbicide effects on non-target plants and the corresponding ramifications for plant community development. Longer-term shifts in vegetation composition (e.g., from shrub-dominated or conifer/shrub-dominated communities to persistent conifer/herb or herb-dominated communities) have been observed (Newton et al. 1992b {Maine}; Lautenschlager 1993). In addition, effects from repeated herbicide treatments can persist (Miller and Miller 2004 {15 years, southern U.S.}) and can potentially have negative effects on plant species richness for certain families (e.g., Rosaceae) and some native species (Chen 2004). In contrast, herbicide applications and other intensive forest management methods can temporarily create a more diverse species composition by suppressing dominant species (e.g., shrubs, trees) and increasing availability of resources for other species (e.g., forbs, early seral species) (Balandier et al. 2006) that may not occur under natural disturbances.

4.1 Crop Tree Survival and Growth

Studies have extensively evaluated timing of herbicide application (by season, plantation age), responses by specific crop tree and competing target species (overstory and understory), and effects of local site conditions on crop tree growth response to herbicide treatments (Campbell et al. 1981; Gratkowski 1977, 1978; Preest 1977; Sutton 1978 {Ontario}; Radosevich et al. 1980; Conard and Radosevich 1982; King and Radosevich 1985; Petersen and Newton 1985; Oliver 1990; Oester et al. 1995; Stein 1999; Rose and Ketchum 2002; Chen 2004; Roberts, Harrington, and Terry 2005; Harrington 2006; Downs 2008). Timing and duration of herbicide site preparation and release treatments are important considerations for seedling survival and plantation establishment (Sutton 1978 {Ontario}; Brodie and Walstad 1987; Newton and Preest 1988; McDonald and Fiddler 1989, 2001; Fiddler and McDonald 1990; Newton et al. 1992a, 1992b {Maine}). Tree seedling survival and growth in the first ten years (depending on site conditions) are crucial to plantation establishment and viability (Petersen and Newton 1985). For example, ten years after overstory thinning and understory herbicide treatment in 50-year old stands, Nabel (2008) found that vegetation control increased both the establishment rate of naturally regenerated Douglas fir (*Pseudotsuga menziesii*) and the survival rate of underplanted Douglas fir and western hemlock (*Tsuga heterophylla)*. In this situation, the understory was dominated by ferns, trailing blackberry (*Ribus ursinus*), hazel (*Corylus cornuta*), and ocean spray (*Holodiscus discolor*). The herbicide application resulted in a 9-10% cover reduction in these species (Nabel 2008).

Vegetation control is especially important during the first few years of plantation establishment (e.g., Newton and Preest 1988). Benefits of vegetation control to crop tree survival and establishment decline after seedlings have grown taller than the competing vegetation, and it is common to discontinue efforts to manage the non-timber plant community unless woody vegetation control is needed during early- to mid-rotation (e.g., Sullivan and Sullivan 1982; Newton et al. 1992a {Maine}; Cole et al. 1998). However, Monleon et al. (1999) advocated ten years of vegetation control to optimize growth of crop trees affected by persistent effects of competing shrubs and herbs. As a general matter, the efficacy of herbicide treatments declines within a few years because of the invasive characteristics of some competitive plant species (e.g., sprouting, abundant seeds) (Sutton 1978 {Ontario}; Petersen and Newton 1985; McDonald and Fiddler 2001; Rose and Ketchum 2003).

Once crop trees are established, chemical thinning with forest herbicides offers an alternative management technique to the more conventional (mechanical) pre-commercial thinning. In a south-central British Columbia study of unthinned, conventionally thinned, and chemically thinned lodgepole pine (*Pinus contorta*) stands, differences in stand structure attributes were reported (Sullivan et al. 2002). These authors found that chemical thinning resulted in improved horizontal stratification (clumped tree distribution) but reduced vertical stratification compared to conventional thinning. They suggested that chemical thinning could be used to create a more clumped crop tree distribution to maintain herbivore habitat.

Wildlife browsing on crop trees can significantly impact growth and survival of plantation seedlings, depending on the browser species, browser population levels, location and timing (e.g., winter range), crop tree species, and availability of alternative browse areas (Gourley, Vomocil, and Newton 1990), and size of the planted seedlings (Newton, et al. 1992a {Maine}; Moore, Hart, and Langton 1999 {Suffolk, UK}; O'Dea et al. 2000; Campbell et al. 2006 {West Virginia}). Growth of crop trees after herbicide applications can outpace herbivory effects due to improved seedling resiliency (Roth and Newton 1996; O'Dea et al. 2000), and herbicide-treated stands can grow better than those with seedling protection techniques (e.g., physical protection tubes, the chemical Deer-Away®) (Gourley, Vomocil, and Newton 1990). In some cases, forest herbicide applications, perhaps in combination with other vegetation management techniques, can shift browsing away from seedlings by stimulating growth of alternate, preferred foods (Newton and Overton 1973) or by temporarily displacing browser populations by removing their food sources (Crouch 1979). Yet in other situations, herbicide application may concentrate herbivory on the unaffected plant species (including the crop trees) because browse becomes less abundant (e.g., Ashby 1997 {southern Illinois}).

In Australia, patch characteristics (vegetation height and palatability, spatial arrangement) have also been shown to impact the degree of browsing on tree seedlings by herbivores (Pietrzykowski et al. 2003). In a field trial, browsing of pine seedlings was greatest in vegetation patches with both high quality and shorter vegetation (than seedlings), and lowest in patches of low quality and taller vegetation. These authors found that the surrounding vegetation greatly affected the discovery rate and degree of seedling damage by herbivores, as less time may have been spent in the taller patches because seedlings were less detectable. They suggested that delayed herbicide treatments could reduce the amount of browse damage in heavily browsed areas by encouraging and retaining taller, more unpalatable vegetation to help hide seedlings from potential browsers. However, they did caution that this management decision must be weighed against the negative effects of competing vegetation on crop tree survival and growth (Pietrzykowski et al. 2003).

4.2 Plant Community Composition and Structure

Numerous investigators documented significant short-term reductions in plant community species richness after herbicide application (Borrecco, Black, and Hooven 1972, 1979; Beaver 1976; Savidge 1978; Whisenant and McArthur 1989; Chen 2004). However, the time required for plant community recovery and longer-term, species-specific dynamics (e.g., successional pathways) are more relevant to biodiversity and habitat conservation. At larger scales (i.e., beyond the treated area), the temporal and spatial arrangement of herbicide treatments is a primary consideration for plant colonization, browser habitat use patterns, and plant population dynamics (Gardner and Engelhardt 2008; Jeltsch et al. 2008; Moloney and Jeltsch 2008). Plant sensitivities to herbicide type and confounding environmental conditions (e.g., precipitation, available seed bank, previous disturbance regimes) make generalizations about plant community composition and structure difficult.

4.2.1 *Plant Community Recovery*

Coarse descriptors such as total percent vegetation cover, plant species richness, or plant diversity are often used to characterize plant community recovery after herbicide application (Black and Hooven 1974; Beaver 1976; Borrecco, Black, and Hooven 1979; Crouch 1979; Sullivan and Sullivan 1981, 1982; Morrison and Meslow 1984a, 1984b; Anthony and Morrison 1985; Ritchie, Harestad, and Archibald 1987; Cole et al. 1998; Easton and Martin 2002). Studies using such coarse descriptors of plant community response tend to find rapid (less than five years) recovery to pre-herbicide levels in the Pacific Northwest (Beaver 1976; Morrison and Meslow 1984a; Anthony and Morrison 1985; Sullivan 1996; Rice et al. 1997; Cole et al. 1998). This trend was also observed in the eastern United States by Keyser and Ford (2006). However, caution should be exercised when characterizing plant community recovery using only coarse descriptors of vegetation composition and abundance, as reduction or loss of important individual species may not be detected (e.g., Stohlgren, Bull, and Otsuki 1998 {central U.S. grasslands}; Bacaro, Ricotta, and Mazzoleni 2007; Loya and Jules 2008).

Long-term research in northern and central California indicated that plant species community composition (natives and exotics) was relatively stable over the first ten years of plantation establishment (starting average of 23 species, ending average of 28) (McDonald and Fiddler 2006). However, the authors noted high variability among herbicide treated areas and found no associations between species richness and site or plantation age.

In assessing plant community recovery after herbicide applications, one must consider prior land condition, landowners' objectives, and the localized vegetation species pool. Large-scale vegetation control is almost exclusively applied on areas previously disturbed by clearcutting or afforestation techniques. Thus, plant communities in intensively managed landscapes have formed under a history of silvicultural activities, and as such do not necessarily represent vegetation communities that formed in the absence of disturbance or under historical natural disturbance regimes. Plant communities resulting from herbicide application often reflect either existing perennials (from rootstocks) or ruderal species from wind, water, or wildlife deposition (pers. comm., M. Newton, Emeritus Professor, Department of Forest Science, Oregon State University).

Data from several studies indicate that shrub recovery begins no later than two years after herbicide application and increases to approximate pre-treatment levels by the fifth year in some cases (Figure 4.1). We hypothesize that with a single herbicide treatment the shrub cover maximum occurs 4-8 years after application (Figure 4.1). Multiple herbicide treatments are known to delay this shrub recovery period and potentially reduce the magnitude of recovery (e.g., Crouch 1979). Many intensively managed forests in the Pacific Northwest, particularly those on moist, fertile sites, begin to enter a closed canopy, stem exclusion condition at approximately 12-14 years of age, at which time shrub cover starts to diminish. Studies evaluated for this report indicated that shrub cover was comparable to pre-treatment levels in year 10 of forest development (Figure 4.1).

Herbaceous vegetation cover tends to remain relatively high 1-2 years after herbicide treatment, but then declines with increasing shrub and tree competition (Figure 4.2). Research suggests that this 1-2 year increase of herbaceous vegetation is initially dominated by grasses (Figure 4.4), with forbs tending to increase later in stand development (years 2-4; Figure 4.3). All herbaceous vegetation tends to decline by year 10 to <20% coverage (Figures 4.2 to 4.4).

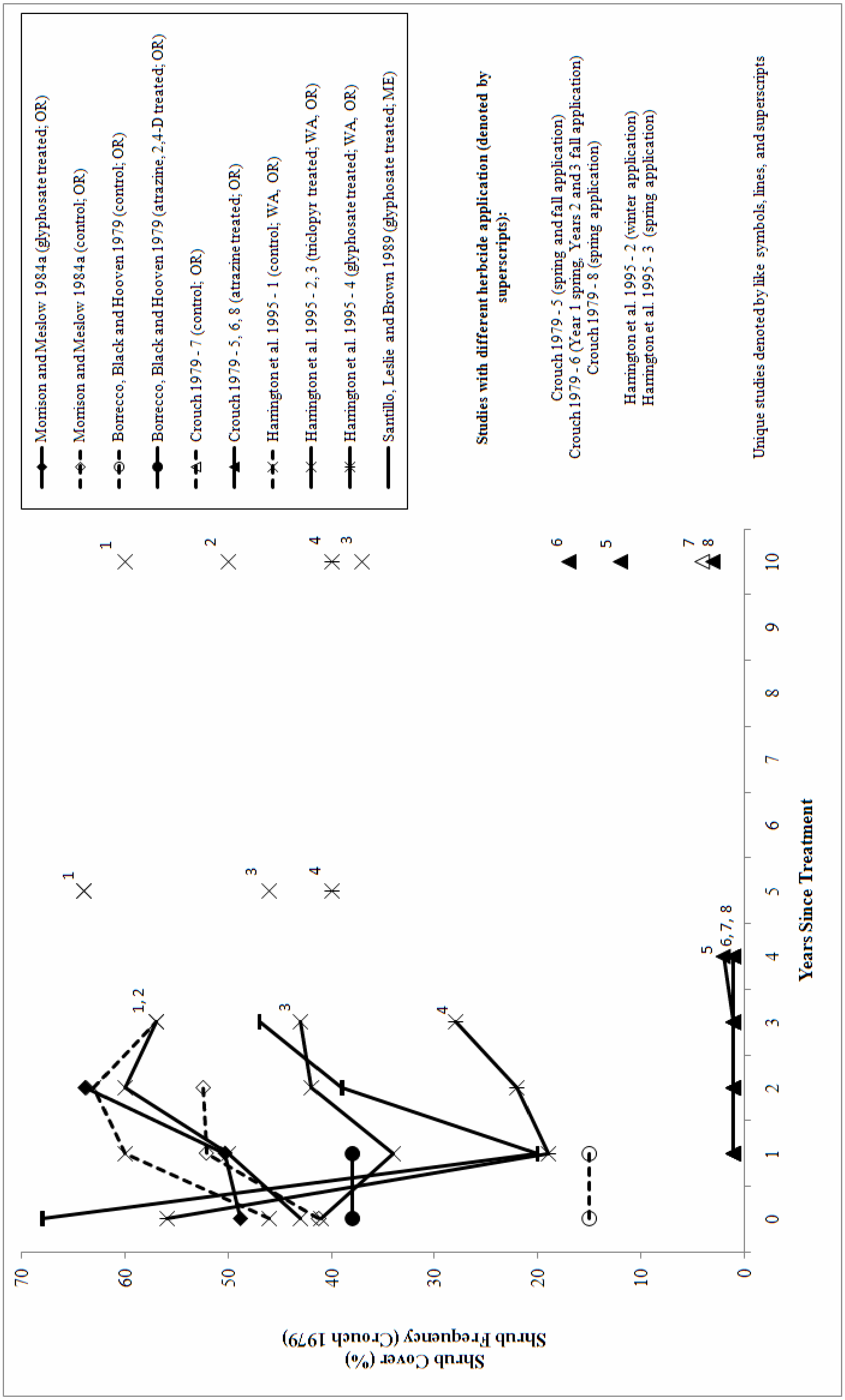

Figure 4.1 Shrub Cover or Shrub Frequency of Occurrence for Control and Herbicide Treated Areas

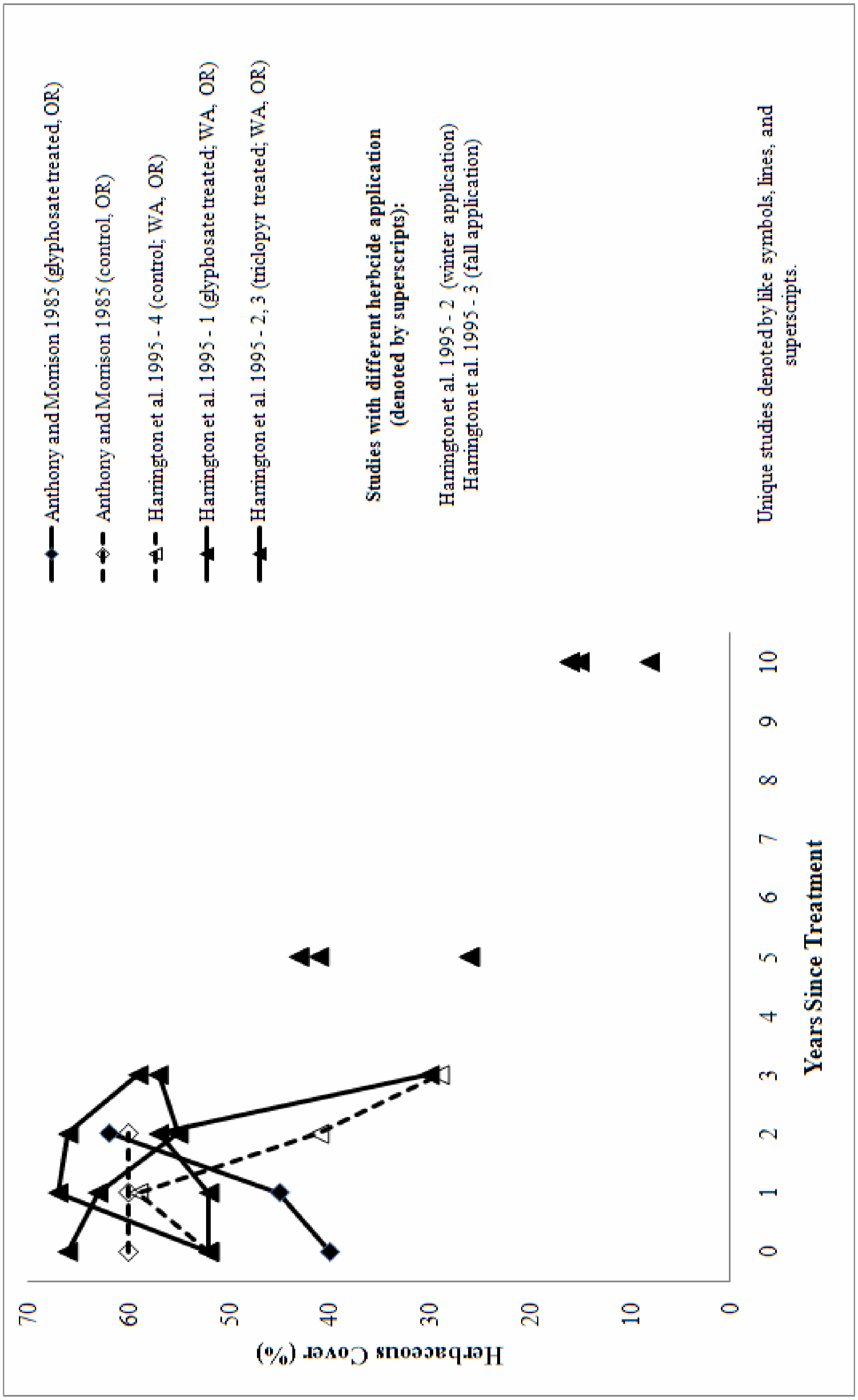

Figure 4.2 Total Herbaceous Cover for Control and Herbicide Treated Areas

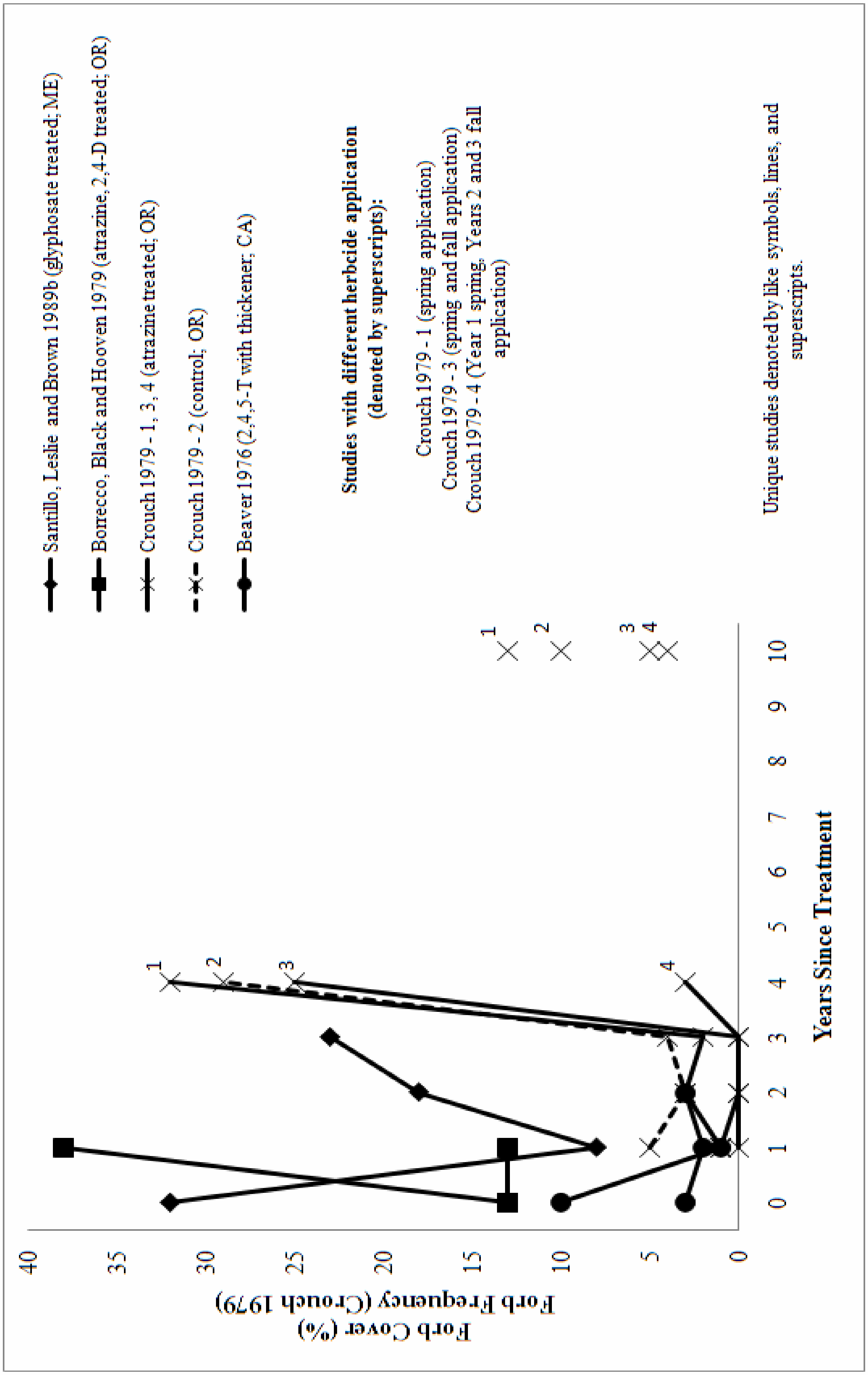

Figure 4.3 Forb Cover for Control and Herbicide Treated Areas

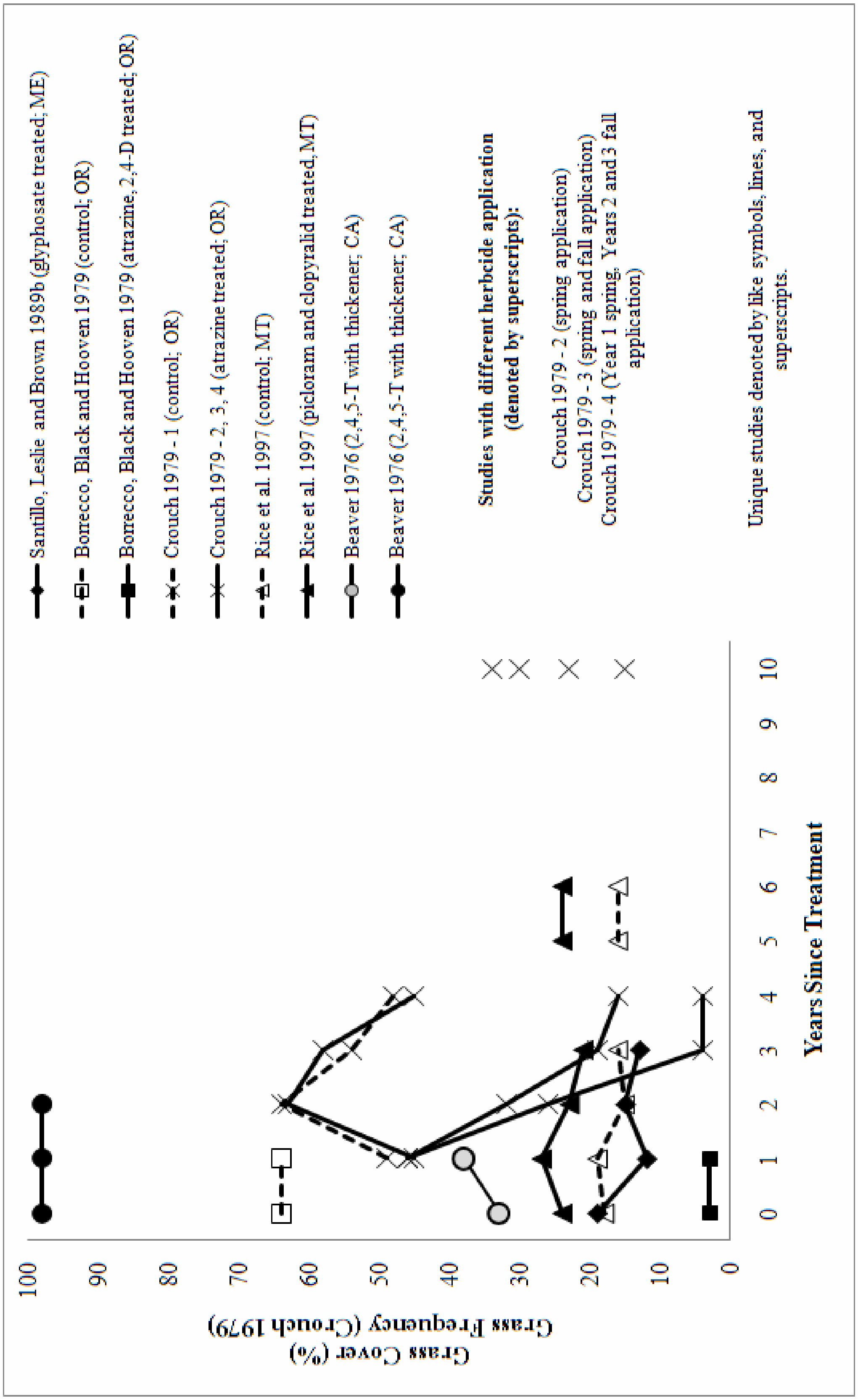

Figure 4.4 Grass Cover for Control and Herbicide Treated Areas

Our analysis of plant community recovery following herbicide application (i.e., within 10 years of plantation establishment) suggests that successional dynamics of intensively managed forests are more complex than originally thought (e.g., Figure 4.5). The prevalence of herbaceous and shrubby vegetation peaks early after plantation establishment and persists at reduced levels into the first decade of forest growth. This general temporal trend in vegetation change is similar to that hypothesized by Bunnell, Kremsater, and Wind (1999) for unmanaged forest ecosystems (Figure 4.5), though the quantity and perhaps quality (e.g., browse nutrition, nesting substrate) of understory vegetation may differ between managed and unmanaged types. The temporal dynamics of intensively managed plant communities warrant further evaluation to understand these complexities.

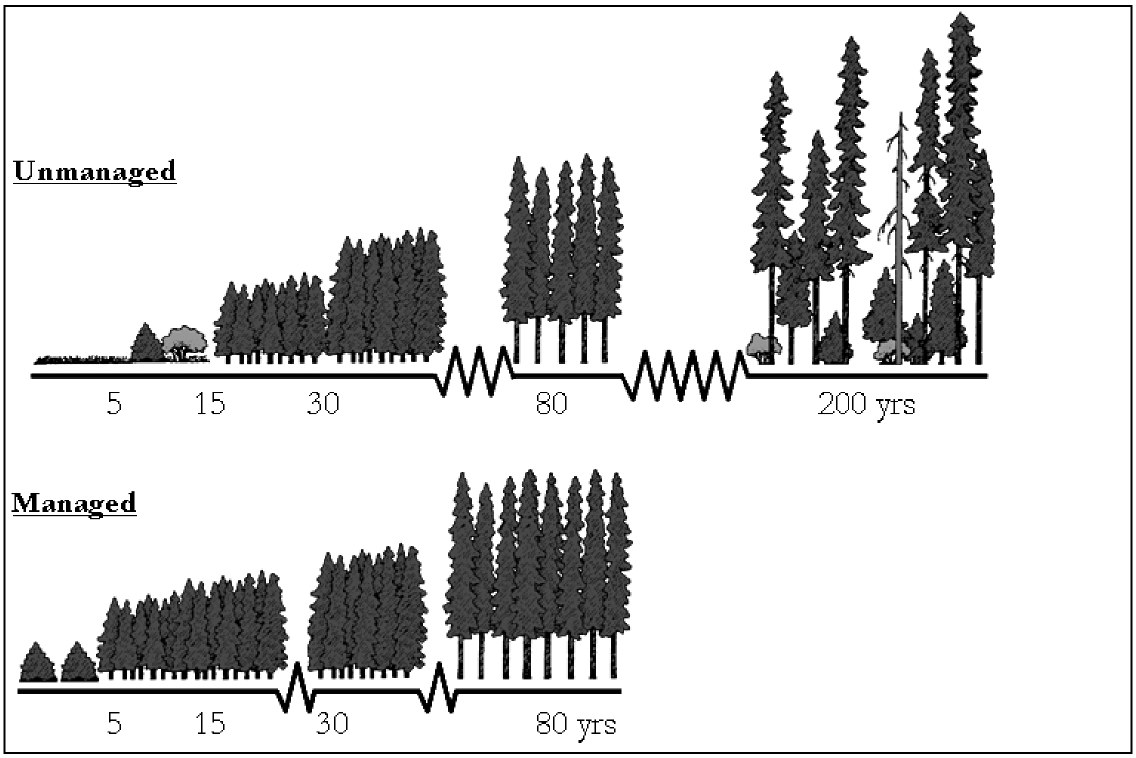

Figure 4.5 Unmanaged and Managed Forest Succession Sequences
[adapted from Bunnell, Kremsater, and Wind 1999]

4.2.2 *Changes in Plant Community Succession*

Plant community succession in forests treated with herbicide is partially dictated by herbicide specificity and species phenological state at the time of herbicide application (Beaver 1976; Savidge 1978; Newton et al. 1992a, 1992b {Maine}; Sullivan, Lautenschlager, and Wagner 1996; Miller 2001 {southeastern U.S.}). Other influential factors include crop tree rotation length, thinning programs, and in some situations, herbivory (e.g., Tremblay, Huot, and Potvin 2007 {Quebec}; Eschtruth and Battles 2008 {northeastern U.S.}).

Targeting herbaceous vegetation early in plantation establishment can result in increased shrub growth (Borrecco, Black, and Hooven 1972, 1979; Black and Hooven 1974). Shade provided by these shrubs can further restrict development of an open-grown herbaceous layer (Beaver 1976). Alternatively, targeting deciduous trees and shrubs can result in proliferation of herbaceous species (especially grasses) and certain shrubs (Keith, Hansen, and Ward 1959 {Colorado}; Johnson 1964

{Colorado}; Tietjen et al. 1967 {Colorado}; Johnson and Hansen 1969 {Colorado}; Sullivan and Sullivan 1982).

Species-specific responses to herbicide applications are important in structuring resultant plant communities (McDonald and Everest 1996). This observation is particularly relevant for quantifying herbicide effects on rare plant species, plants of importance to habitat quality for specific animals (e.g., ungulate browse or insect hosts), or invasive species monitoring. Because most published studies used coarse metrics of vegetation community composition and structure, more detailed information on specific plant responses to herbicide applications are rare.

Chen (2004) showed that native species richness consistently (>85% of comparisons) exceeded exotic species richness on herbicide-treated sites scattered throughout northwestern Oregon. Native species dominance was found to decrease with repeated treatments, depending on species tolerance to the herbicides.

Intensive forest management that includes herbicide use is known to temporally modify vegetation succession (Figure 4.5) by decreasing the stand initiation phase and thereby accelerating progression to the stem exclusion phase (*sensu* Glenn-Lewin, Peet, and Veblen 1992:269; Oliver and Larson 1996). The stem exclusion phase lacks woody and herbaceous undergrowth because competition from the growing crop trees dominates sites. Thus, although measures of plant cover and species richness indicate relatively rapid recovery of the plant community after herbicide applications in most cases (Beaver 1976; Morrison and Meslow 1984a; Anthony and Morrison 1985; Sullivan 1996; Rice et al. 1997; Cole et al. 1998; Figures 4.1 to 4.4), the time during which these shrub- or herbaceous-dominated communities occur in managed stands is reduced (Figure 4.5).

Altered temporal dynamics of successional regimes can affect plant and animal communities by favoring certain plant species, reducing the time that certain wildlife habitat elements (e.g., shrubby or herbaceous nesting substrate, browse) are available, and reducing small-scale habitat heterogeneity. These consequences have caused some to advocate for coordinated landscape-level spatial arrangement of management activities to help ensure that earlier forest successional stages are available (Oliver and Larson 1996).

Effectiveness of competing vegetation control is extremely important in determining forest succession. In the absence of competing vegetation control, gap-phase dynamics may interact with seedling and sapling shade tolerance to determine successional trajectories, with little understory effect (Royo and Carson 2006). However, dense and persistent understory canopies, like those that tend to occur after timber harvest activities in the Pacific Northwest, can significantly alter forest successional rates and directions if allowed to dominate forest regeneration (Newton 1968; Royo and Carson 2006; Tappeiner et al. 1991). Royo and Carson (2006) reviewed 125 papers on this topic and found that nearly 75% declared that herb, shrub, and hardwood competition and, potentially, allelopathy (i.e., growth or establishment suppression on one plant by another due to the release of inhibitory or toxic chemicals) were the primary mechanisms affecting planted tree survival. Thus, some form of effective vegetation control in the early stages of plantation development is crucial for increasing reforestation success and timber yields. The nearly universal application of this concept for intensive forest management reflects the consistency of its benefits.

4.2.3 *Plant Community Responses to Alternative Vegetation Management Strategies*

Successful intensive forest management often requires site preparation and initial competing vegetation control. Forest herbicides are just one tool available to land managers for accomplishing these tasks. Common alternatives to herbicides include no or minimal treatment, manual cutting, mechanical site preparation, and burning. Each of these alternatives can have positive and negative environmental consequences and can be more expensive, less effective (e.g., grazing) (McDonald, Fiddler, and Meyer 1996), and have greater physical impacts on sites.

Mechanical site preparation and burning can negatively affect soil physical properties and fertility (Bigley and Kimmins 1983) and lengthen plant community recovery times (Sullivan and Boateng 1996). In contrast, herbicides selectively reduce target vegetation without the soil disturbance caused by mechanical techniques.

Several Pacific Northwest studies that evaluated multiple tools for controlling competing vegetation have shown that herbicides are the most effective (Fiddler and McDonald 1990; McDonald and Everest 1996; Runciman and Sullivan 1996). However, Stein (1999) found that a single manual release treatment for competing shrubs improved Douglas fir volume fourfold over the control and was more cost effective than subsequent manual releases, herbicides (glyphosate or fosamine), and manual plus fosamine treatments.

In some instances, silvicultural herbicides have been used in combination with other management tools (e.g., McDonald and Fiddler 1996 {manual cut plus Garlon 3A®}). Researchers have documented expected reductions in plant species diversity and richness using these combinations (e.g., DiTomaso et al. 1997 {hexazinone plus burning}; Easton and Martin 2002 {manual thinning plus glyphosate}), but these effects seemed to be short term (DiTomaso et al. 1997). However, certain treatments (e.g., manual cutting plus cut-stump glyphosate) have been shown to increase structural diversity by removing dominant broadleaf vegetation and increasing understory layers without affecting plant species diversity and richness (Simard et al. 2005). These studies emphasize that knowledge of site and vegetation characteristics, along with vegetation treatment types and their associated interactions, is crucial for an effective and efficient vegetation control regime.

4.3 Plant Community Summary

This compilation of forest herbicide research from the Pacific Northwest indicates that short-term direct effects on the plant community are generally well understood (i.e., specific vegetation control objectives are usually achieved), predictable (i.e., targeted vegetation will experience die-back), and of short duration. Long-term effects of herbicides on plant community function are less well understood, with few results based on data collected more than five years after herbicide application. Our literature review supports the following generalizations.

- Chemical control of competing vegetation before and soon after plantation establishment is an effective means of increasing survival and early growth of crop trees. Growth rates of crop trees are often several times greater with competition control than without it (Rosner and Rose 2006).
- Forest herbicide use on conifer plantations in the Pacific Northwest tends to occur within five years (most typically one to three years) of plantation establishment. Most research has shown that coarse vegetation characteristics (e.g., cover, species richness) recover to pre-treatment levels within five years of herbicide application, but some research indicates that individual species changes can occur, resulting in short- and long-term changes in plant community composition. The direction and magnitude of change varies by location, soil types, disturbance level, silvicultural prescription, and local seed sources.
- Species targeted for herbicide control tend to recover within two to five years after an initial treatment. Some researchers attribute this short recovery period to resiliency of early seral plant communities that tend to dominate intensively managed landscapes. Rapid chemical dissipation to non-toxic levels may also contribute to this observation.

- Long-term plant community composition and corresponding ecosystem function can be influenced by forest herbicides. These long-term effects can include shifting understory dominance from shrubs to herbaceous plants (in some instances) and truncating successional trajectories (i.e., plantation canopies close sooner, thereby limiting woody and herbaceous understories). There is often a predictable relationship between increasing shrub cover and decreasing conifer or herbaceous ground cover (Sullivan and Sullivan 1982).
- Results from studies comparing herbicides and other vegetation management strategies (e.g., burning, mechanical site preparation) suggest that herbicides are often the most effective approach for site preparation and competing vegetation control because they can be targeted to specific plant species and soil disturbance is minimized. Moreover, special prescriptions can be tailored to minimize damage to desirable habitat species (e.g., Newton et al. 1989 {Maine}).
- Results from studies evaluating interactions of herbicides and other vegetation management strategies (e.g., burning, mechanical site preparation) are variable, with some studies finding more significant and longer-lasting effects from certain combinations. Variability in these results highlights the importance of understanding forest management history when attempting to explain herbicide effects, while accepting that local propagule abundance affects outcomes.

5.0 FOREST HERBICIDE EFFECTS ON THE WILDLIFE COMMUNITY

The use of forest herbicides may have direct or indirect effects on wildlife. Direct effects are the result of direct toxicity of forest herbicides to wildlife. Studies of direct toxicity are typically carried out in a laboratory setting and are an integral part of the process of pesticide registration in the United States. As described by Tatum (2004), any new herbicide active ingredient must undergo extensive testing to determine the potential for direct toxicity to aquatic and terrestrial fauna. Critical exposure levels for different organisms are identified and used to assess potential risks during the pesticide registration process. These data consistently show a large margin of safety for chemical use, in part because modern herbicides are specifically designed to affect physiological pathways unique to plants, such as photosynthesis, and in part because the exposure levels associated with toxicity in laboratory studies are much higher than actual environmental concentrations.

Relatively few field studies focus on the direct toxicity of herbicides to wildlife. Evaluating direct herbicide effects on wildlife in field settings is not only limited by the expense of investigative studies, but is also complicated by difficulties in quantifying precise exposure levels, identifying and quantifying subtle responses, and accounting for the effects of other variables (e.g., separating effects of simultaneously applied forestry activities). Critics of forest herbicide use argue that too little is known about the direct effects of herbicides following operational use and fear that laboratory studies do not adequately characterize toxicity to wildlife.

Recent work by Thompson and colleagues (Chen, Hathaway, and Folt 2004; Edginton et al. 2004; Thompson et al. 2004; Thompson 2004) was designed to address the question of how the results of laboratory studies of direct herbicide toxicity compare to the outcome of field studies. These researchers examined the effects of Vision® (glyphosate plus a polyethoxylated tallow amine surfactant) on native amphibians using a tiered approach with increasing levels of complexity and environmental relevance. They concluded that while laboratory studies are useful in the comparative sense and for understanding mechanisms, they tend to overestimate the effects actually observed in the field.

When used according to label directions (e.g., use label application rates, minimize drift, avoid water), current forest herbicides are not expected to have direct toxic effects on the wildlife community (Mullison 1970; Morrison and Meslow 1983a; Atkinson 1985a; Giesy, Dobson, and

Solomon 2000; Allran and Karasov 2001; Lautenschlager and Sullivan 2002; Tatum 2004; Wojtaszek et al. 2004, 2005; McComb et al. 2008). For example, an ecological risk assessment for aquatic organisms from over-water uses (e.g., wetland restoration) of glyphosate included a specific analysis of exposure data from forestry uses in Canada (Solomon and Thompson 2003). The authors concluded that the probabilities of exposure concentrations in natural surface waters exceeding the acute toxicity values for the formulated product (i.e., glyphosate plus surfactant) were small for aerial applications, for either direct overspray or spray drift into adjacent areas (Solomon and Thompson 2003).

Studies indicate that forest herbicides tend to dissipate quickly, do not bioaccumulate, and are rapidly excreted unchanged by animals; thus, exposures are brief (Norris 1971, 1981b; Newton et al. 1984). Brief exposure coupled with low acute, chronic, reproductive, or developmental toxicity (e.g., Tatum 2004) indicates that reproduction and survival should not be directly impacted (Kenaga 1975; Schroeder and Sturges 1975; Batt, Black, and Cowan 1980).

Indirect effects can occur when herbicides alter elements of the surrounding environment. For example, forest herbicides can be used to create specific habitat features such as downed wood or snags (Brandeis et al. 2002) or to rejuvenate shrubs that have grown too tall for use by ungulates (Mueggler 1966; Wigley et al. 2002). Herbicides have also been used to deter nuisance wildlife species (e.g., by deliberately reducing habitat quality; Crouch 1979), provide alternate or more abundant wildlife food resources (Coulter 1958; Newton and Norris 1976; Newton et al. 1989 {Maine}), influence vegetation succession to favor certain wildlife (Wiens and Rotenberry 1985; Freedman 1991; Sullivan 1994; Jones and Chamberlain 2004 {Louisiana}; Welch et al. 2004 {Florida}), and restore wetlands (Solomon and Thompson 2003).

Indirect effects are often difficult to study in laboratory settings because interactions, both between wildlife species and between wildlife and elements of the surrounding environment, can be complex. Field studies present their own difficulties, as noted by Guynn et al. (2004), who pointed out that many published reports on the indirect effects of herbicides on wildlife lack such basic elements as pre-treatment data, control plots, replications, or peer review. Indeed, this literature review found that most studies of indirect herbicide effects on wildlife were short-term and designed such that the effects of herbicides alone were confounded by other activities resulting from implementation of an intensive forest management regime.

Many researchers have concluded that the overwhelmingly dominant process by which herbicides may affect wildlife distribution and local abundance is through habitat modification (Giesy, Dobson, and Solomon 2000; Brunjes et al. 2003 {South Carolina}; Sullivan and Sullivan 2003), but scientists are just beginning to understand how wildlife responds to habitat alteration invoked by chemical treatments. Research in this area is complicated by the extent to which such effects vary due to a vast array of interacting factors that range from site- and species-specific responses to local geographic conditions (e.g., soil seed bank) and treatment types.

5.1 Invertebrates

5.1.1 *Direct Effects*

Invertebrates (e.g., *Daphnia* spp.) are tested for herbicide toxicity during the product registration process. Based on this testing, most of the commonly used forestry herbicides are classified by USEPA as either practically non-toxic or only slightly toxic to aquatic invertebrates (Tatum 2004).

Fowlkes et al. (2003) found no significant effects of imazapyr on composition, biomass, or morphology of benthic macroinvertebrates in a shallow aquatic basin adjacent to logged and chemically treated areas in Florida. Butler and Verrell (2005) found that 2,4-D was not toxic to earthworms (*Eisenia fetida*) at all tested concentration levels. In that study, the presence of 2,4-D helped ameliorate toxic effects of an insecticide.

Herbicide toxicity to invertebrates has been assessed in numerous reviews and ecological risk assessments.

- Giesy, Dobson and Solomon (2000) found that terrestrial uses of Roundup® (including forestry) pose essentially no risk to soil invertebrates, honeybees (*Apis mellifera*) and other beneficial arthropods.
- Solomon and Thompson (2003) specifically addressed over-water uses of glyphosate in forestry operations and concluded that the risk to aquatic invertebrates was small.
- The World Health Organization (1997) concluded that aquatic invertebrates, invertebrates living in water columns and sediments, honeybees, arthropods, and earthworms are all at low risk from the use of 2,4-D.
- Comprehensive reviews of the toxicity of triclopyr, glyphosate, and imazapyr concluded that exposure to environmentally relevant concentrations of those herbicides poses little risk to invertebrates (NCASI 2003, 2004).

5.1.2 *Indirect Effects*

Indirect effects of herbicides on invertebrates vary with species-specific habitat affinities, but seem to be short-term (Sullivan and Sullivan 2003). The organisms respond primarily to physical vegetation changes (Ware 1980; Brust 1990 {North Carolina}; Newton and Cole 2005; Taylor, Maxwell, and Boik 2006 {agricultural herbicides}). The most conclusive data were compiled from cultivated landscapes in the United Kingdom (Freemark and Boutin 1995; Haughton et al. 2001). In addition, resultant changes in abiotic factors (i.e., exposure to radiation, changes in wind velocity, temperature, and humidity) after herbicide and manual cutting treatments may also affect the numbers and species of invertebrates present (Slagsvold 1977 {Norway}). Beaver (1976), for example, found that green-leaf beetles (Coleoptera: Chrysomelidae) were abundant before spraying with 2,4,5-T but virtually disappeared afterward, reflecting a loss of broad-leaved habitat.

In Norway, Slagsvold (1977) found that 2,4,5-T and manual treatments had variable effects on insect fauna that were species-specific based on host plants present. In contrast, other studies have found negligible indirect effects, and in some cases beneficial effects. For example, soil and litter arthropod communities in loblolly pine (*Pinus taeda*) forests in Texas initially declined and subsequently recovered after an intensive forest management regime that included herbicide application (imazapyr and triclopyr) (Bird, Coulson, and Crossley 2000). No adverse effects on butterfly species richness or abundance were observed on power right-of-ways during the growing season after spraying with a tank mix of different triclopyr formulations (Bramble, Yahner, and Byrnes 1999). Similarly, no differences in arthropod community abundance or species richness were observed in Oklahoma tallgrass prairie treated with triclopyr, 2,4-D, and picloram (Fuhlendorf et al. 2002).

Research on arthropod community responses to other disturbance types (e.g., fire, grazing) indicates that population responses are relatively predictable (e.g., Harper et al. 2000; Kalisz and Powell 2000; Swengel 2001; Wallis De Vries et al. 2007; Dennis et al. 2008) and closely track development of the resulting vegetation community. Populations tend to decline markedly the first few months after treatment, followed by rapid (weeks to months) recovery of predominately generalist species, followed by slower and in some cases no recovery of specialist species (Swengel 2001; Panzer 2002).

These observations are consistent with ecological theory that predicts increased species richness with increasingly complex environments (e.g., Shaffers, Raemakers, and Sykora 2008). This relationship may extend to herbicides, although this hypothesis remains untested.

Cobb, Langor, and Spence (2007) found that the combined effects of wildfire, salvage logging, and herbicides influenced short-term (two years post-disturbance) responses of ground beetle communities in the mixed-wood forests of Alberta. Although these disturbances resulted in positive responses (higher catch rates) by some beetle species, the authors found that these post-disturbance changes occurred to the detriment of other species. Variance partitioning across treatments indicated that fine-scale habitat features (e.g., amount of downed wood, plant species richness) were important determinants of beetle community composition. They contended that combined large-scale disturbances that simplified and homogenized landscapes (compared to wildfire or timber harvesting alone) resulted in spatially simplified beetle communities; however, temporal constraints of this study limited their ability to differentiate any persistent (longer-term) changes in habitat characteristics.

5.2 Fish

5.2.1 *Direct Effects*

Herbicide toxicity to several species of fish [e.g., rainbow trout (*Oncorhynchus mykiss*), bluegill sunfish (*Lepomis microchirus*), fathead minnow (*Pimephales promelas*)] is tested during the product registration process. Based on this testing, most of the commonly used forestry herbicides are classified by USEPA as either practically non-toxic or only slightly toxic to fish (Tatum 2004). An exception to this is the ester form of triclopyr, but the ester quickly hydrolyzes to the practically non-toxic acid form once it enters the environment (Tatum 2004; Wan, Moul and Watts 1987).

Lethal herbicide concentrations for fish are higher than even worst-case estimates of expected environmental concentrations following application (e.g., Janz et al. 1991), especially considering that larger aquatic ecosystems (e.g., rivers, ponds, marshes) do not receive direct applications and naturally dilute chemicals. Deposition of forest herbicides in these aquatic ecosystems is unintentional and, if it occurs, tends to happen via runoff or aerial drift. In general, research has shown non-toxic effects of silvicultural herbicides on fish at field-level concentrations (e.g., Norris 1967; Hildebrand, Sullivan, and Sullivan 1982 {glyphosate}; Newton et al. 1984 {glyphosate}; Janz et al. 1991 {triclopyr}; Pratt et al. 1997 {atrazine}).

Some fish species (e.g., rainbow trout, channel catfish, *Ictalurus punctatus*) have proved less sensitive to forest herbicides than other aquatic-dwelling organisms (Howe, Gillis, and Mowbray 1998). Studies have also demonstrated that direct toxicity to fish can depend on water temperature and chemistry (Macek, Hutchinson, and Cope 1969; Folmar, Sanders, and Julin 1979). Potential for adverse effects of accidental applications of herbicides is reduced during times of low water temperature and high stream flows (Sutton 1978 {Ontario}; Hildebrand, Sullivan, and Sullivan 1982).

The toxicity to fish of herbicides commonly used in forestry has been assessed in numerous reviews and ecological risk assessments. For example, Giesy, Dobson and Solomon (2000) concluded that terrestrial uses of Roundup® (including forestry) pose essentially no risk to fish. In a similar ecological risk assessment for over-water uses of glyphosate, Solomon and Thompson (2003) specifically addressed forestry applications and concluded that the risk to fish was small. Comprehensive reviews of the toxicity of triclopyr, glyphosate, and imazapyr concluded that exposure to environmentally relevant concentrations of those herbicides poses little risk to fish (NCASI 2003, 2004).

Solomon et al. (1996) conducted an ecological risk assessment for atrazine that included a consideration of fish and concluded that there was a low probability of effects on fish even in the North American bodies of water most highly impacted by agriculture. Solomon et al. (2008) recently conducted a review of the effects of atrazine on aquatic vertebrates, with an emphasis on developmental, reproductive, immune, and behavioral effects and found no evidence of such effects on fish. Ecological risk assessments conducted by the Bureau of Land Management (BLM)[2], U.S. Forest Service (USFS)[3], and the Environmental Protection Agency (USEPA)[4] for a number of herbicides all specifically considered fish and concluded that the risk associated with use of these products according to label directions is low.

Fish will avoid toxic levels of chemicals (Hildebrand, Sullivan, and Sullivan 1982). This behavior may temporarily exclude fish from preferred or favorable habitats as the chemicals disperse downstream. It is not known if such changes result in negative effects on fish survival or productivity. Alternatively, herbicide plumes in flowing water may move and dissipate so rapidly that fish exhibit no movement responses (pers. comm., M. Newton, Professor Emeritus, Department of Forest Science, Oregon State University). Herbicides bound by vegetation that potentially enter waterways through leaf-fall or over-ground transport are presumed to have a negligible effect on fish communities because chemicals rapidly deteriorate (Michael and Neary 1993).

5.2.2 *Indirect Effects*

It has been hypothesized that herbicides could have indirect effects on fish through depletion of phyto- and zooplankton communities (e.g. Anderson and Zeeman 1995). However, this review was unable to identify any documentation of such effects.

5.3 Amphibians

5.3.1 *Direct Effects*

The potential effects of herbicide use on amphibians, particularly the aquatic larval forms, have received considerable attention in recent years. Some researchers have hypothesized that amphibians may be more sensitive to pesticides in the environment because they have a permeable, exposed skin, gills, and eggs that readily absorb substances from the environment (Howe, Gillis and Mowbray 1998).

Some studies have reported that larval amphibians appear to be more sensitive than embryos, and late-stage larvae are more sensitive than those at earlier stages of development (Berrill et al. 1994; Howe, Gillis, and Mowbray 1998; Edginton et al. 2003; Howe et al. 2004). Dose-dependent larval deformities have been documented in laboratory studies (Berrill et al. 1994; Schuytema and Nebeker 1998 {diuron}; Allran and Karasov 2001), with response magnitude species- and dose-specific (Berrill et al. 1994; Allran and Karasov 2001; Howe et al. 2004; Wojtaszek et al. 2004, 2005). Consistent with studies on other aquatic organisms, the ester formulation of triclopyr is more toxic to amphibian larvae than the acid form, and glyphosate formulations containing the polyethoxylated tallowamine surfactant (POEA) have higher toxicities than glyphosate alone (Howe et al. 2004; Perkins, Boermans, and Stephenson 2000; Solomon and Thompson 2003; NCASI 2004).

---

[2] BLM's final programmatic environmental impact statement on the use of herbicides for vegetation control can be accessed at http://www.blm.gov/wo/st/en/prog/more/veg_eis.html
[3] The USFS has conducted human health and ecological risk assessments for all pesticides used on national forestland. These may be accessed at http://www.fs.fed.us/foresthealth/pesticide/risk.shtml.
[4] EPA's ecological risk assessments are carried out under the Pesticide Reregistration and Pesticide Review programs and may be accessed from the indexes at http://www.epa.gov/pesticides/reregistration/status.htm and http://www.epa.gov/oppsrrd1/registration_review/reg_review_status.htm.

Cauble and Wagner (2005) recently looked at sublethal effects of Roundup® on amphibian larval metamorphosis and development in a Pacific Northwest species of frog, *Rana cascadae*. They reported that exposure to 1 or 2 ppm Roundup® for 43 days resulted in increased mortality, earlier metamorphosis, and reduced mass after metamorphosis. It is difficult to predict whether such effects might be observed in the wild, since the researchers used exposure levels greater than those likely to be encountered in a forest environment and an exposure period (43 days) much longer than even a conservative estimate of Roundup® persistence in a forest pond or wetland.

In another recent laboratory study, Forson and Storfer (2006) studied another Pacific Northwest amphibian species, the long-toed salamander (*Ambystoma macrodactylm*). They reported that atrazine exposure for 30 days, at the highest concentration tested, 184 ppb, accelerated metamorphosis and reduced mass and snout-vent length at metamorphosis. Again, it is difficult to predict whether such effects might be observed in the wild, since the researchers used exposure levels greater than those likely to be encountered in a forest environment, and an exposure period much longer than atrazine would persist in forest ponds or wetlands.

Wojtaszek et al. (2005) placed larvae of green frogs (*Rana clamitans*) and leopard frogs (*Rana pipiens*) in *in situ* enclosures deployed in wetland sites in Ontario, Canada. Release®, a herbicide formulation containing the ester form of triclopyr, was applied to the enclosures to achieve water concentrations of 0.26 to 7.68 mg (a.e.)/L. Exposure to Release® had no effect on larval growth, but did have a dose-dependent effect on mortality and abnormal avoidance response. Estimates of the LC10 and EC10 (avoidance response) were similar to measured and estimated environmental concentrations following direct overspray of forest wetlands. The authors concluded that the ecological risk to native amphibian populations under current use scenarios in Canadian forestry was negligible.

Thompson et al. (2004) conducted chemical and biological monitoring programs in 51 different wetlands in Ontario, Canada in conjunction with operational forest herbicide spray programs using Vision®, a glyphosate formulation equivalent to Roundup®. For the biomonitoring portion of the study, leopard and green frog larvae were placed in mesh cages submerged in wetland locations where herbicide applications were planned. No significant differences were found in larval mortality among frog larvae exposed to markedly different glyphosate concentrations. Nor was there any relationship between mortality rates and measured glyphosate concentrations. The researchers concluded that aerial applications of Vision®, as typically conducted in northern Ontario, do not pose a significant risk to native amphibians in forest wetland environments.

Additional research and analyses have identified problems with extrapolating laboratory-based results to field situations. For example, Hayes and colleagues (Hayes et al. 2002, 2003; Hayes 2004) have reported that atrazine produces gonadal abnormalities in frogs. However, two recent critical reviews of all available research, including large, high-quality studies designed to specifically examine that hypothesis, have concluded that there is no evidence to support the contention that atrazine exposure at environmentally relevant concentrations has any effect on amphibian gonadal development (Solomon et al. 2008; USEPA 2007).

Similarly, Relyea and colleagues (e.g., Relyea 2005a, 2005b, 2005c; Relyea, Schoeppner, and Hoverman 2005) have asserted that the glyphosate formulation Roundup® is highly lethal to many amphibian species at environmental concentrations produced by applications at currently allowed label rates. However, as pointed out by Thompson et al. (2006), Relyea's findings bear little relevance to real-world forestry and agricultural applications. For example, the application rate used by Relyea to calculate an exposure concentration for his studies was 12.8 kg a.e./ha, 3-10 times higher than the maximum rate allowed for forestry and agricultural applications. Thompson et al. (2006) also noted that the artificial nature of the mesocosms used by Relyea seriously limited the validity of any extrapolations to natural systems. As shown by Thompson and colleagues (Chen, Hathaway and Folt 2004; Edginton et al. 2004; Thompson et al. 2004; Thompson 2004), laboratory and mesocosm studies tend to overestimate the effects actually observed in the field. The difference between laboratory, microcosm, or mesocosm studies and field results with glyphosate is particularly pronounced because glyphosate binds strongly to soil and sediments (Tatum 2004), which are typically not present in laboratory studies.

Reviews of the toxicity of triclopyr, glyphosate, and imazapyr that specifically considered amphibians concluded that when used according to label directions in forestry applications, those herbicides posed little risk to amphibians (NCASI 2003, 2004). Giesy, Dobson, and Solomon (2000), in an ecological risk assessment for Roundup®, reviewed studies of the toxicity of glyphosate and Roundup® to amphibians and concluded that Roundup® use according to label directions poses minimal acute or chronic risk. Solomon et al. (2008) conducted a critical review of the literature addressing the effects of atrazine on amphibians, with particular emphasis on developmental, reproductive, endocrine, immune, and behavioral effects. They concluded that there is no evidence of adverse effects on amphibians related to exposure to environmentally relevant concentrations of atrazine.

Howe, Gillis and Mowbray (1998) looked for synergistic effects on larval stages of northern leopard frogs (*Rana pipiens*) and American toads (*Bufo americanus*) using mixtures of two herbicides, atrazine and alachlor. They reported that, at relatively high concentrations (non-environmentally relevant), the combination of the two herbicides had greater than additive effects on mortality at the 96-hr exposure duration, although the degree of synergy was not great (less than twice additive effects).

Recent work by Thompson and colleagues (Chen, Hathaway, and Folt 2004; Edginton et al. 2003, 2004; Thompson et al. 2004; Thompson 2004; Wojtaszek et al. 2004, 2005) demonstrated that direct effects of forest herbicides on amphibian species are also a function of abiotic factors (acidity, sediment type and concentrations) that influence chemical toxicity. For example, Chen, Hathaway, and Folt (2004) and Edginton et al. (2004) found that higher water pH increased glyphosate toxicity to northern leopard frogs (*Rana pipiens*). In contrast, Edginton et al. (2003) found greater toxicity for triclopyr on four anurans in lower pH water.

Studies have documented abnormal avoidance responses in tadpoles for herbicide concentrations that are far greater than expected (4.61 mg/L of Vision®; 3.76-8.66 mg/L of Release®) environmental levels (Wojtaszek et al. 2004, 2005), but there is no evidence that such responses occur at environmentally relevant concentrations. McComb et al. (2008) found no chemically induced effect on amphibian terrestrial behavior.

5.3.2 *Indirect Effects*

Literature from field studies regarding the indirect effects of forest herbicides on amphibians is limited, especially those focusing on terrestrial forms. In one study, atrazine compromised *Ambystoma tigrinum* virus (ATV) efficacy in larval long-toed salamanders (*Ambystoma macrodactylum*), resulting in lower mortality levels and ATV infection rates (Forson and Storfer 2006). In a recent mesocosm amphibian community study, Relyea, Schoeppner, and Hoverman (2005) found that Roundup® at a concentration of 1.3 mg a.i./L, which is at the upper end of the range of estimated expected environmental concentrations, had no indirect effects on adult newt or aquatic beetle survival or algal abundance.

In the context of an intensive forest management regime it is difficult to separate herbicide effects from those of other habitat modification practices that are applied nearly simultaneously (Cole et al. 1997; Hood et al. 2002; Miller and Miller 2004). Cole et al. (1997) found variable capture rates among amphibian species after logging activities that included clearcutting, broadcast burning, then spraying with glyphosate. Capture rates among western red-backed salamanders (*Plethodon vehiculum*) increased; captures of rough-skinned newts (*Tericha granulose*), Dunn's salamanders (*Plethodon dunni*), and red-legged frogs (*Rana aurora*) remained the same; and capture rates of ensatinas (*Ensatina eschscholtzii*) and Pacific giant salamanders (*Dicamptodon tenbrosus*) decreased. However, they could not attribute these changes specifically to herbicide application. Changes in abundance of terrestrial and aquatic amphibians were more likely to be induced by broad-scale modification to habitat structure and composition resulting from the intensive forest management regime, as opposed to being solely herbicide based.

5.4 Reptiles

5.4.1 *Direct Effects*

Although toxicity testing on reptiles is not a part of the pesticide registration process, reptiles have been the subject of a few laboratory studies on herbicide toxicity. For example, Sparling et al. (2006) examined the effects of the glyphosate formulation Glypro® and the surfactant LI700 on embryos and early hatchlings of red-eared sliders (*Trachemys scripta elegans*). They observed effects only at an extremely high dose (11,209 ppm glyphosate/egg), and concluded that the use of glyphosate with LI700 poses low levels of risk to red-eared slider embryos under normal field operations. In a controlled laboratory study in Ontario, de Solla et al. (2006) monitored the effects of atrazine on gonadal tissue development in snapping turtles (*Chelydra serpentine*) by incubating eggs in soil that had been treated at a typical application rate or at ten times that rate. No significant difference in sex ratio was observed between treated and control turtle hatchlings.

Hosea, Bjurstrom, and Littrell (2004) studied the oral and dermal acute toxicity of several herbicides and a surfactant to two species of garter snake, *Thamnophis sirtalis* and *Thamnophis elegans*. Two of the herbicide active ingredients tested, 2,4-D and glyphosate, have forestry uses, as does the nonylphenol/nonylphenol polyethoxylate surfactant. The concentrations used were the same as those found in tank mixes used in California's water hyacinth control program. Herbicides and surfactant were administered alone and in combination. The researchers reported that all of the snakes survived, no alterations in behavior were observed, no skin lesions or other physical abnormalities developed, and that feeding behavior and weight remained unchanged during a 7-day post-treatment observation period.

In their critical review of the effects of atrazine on fish, amphibians, and aquatic reptiles, Solomon et al. (2008) reported that there are no data to suggest that atrazine is associated with declines in populations of reptiles. Solomon et al. (2008) also specifically addressed several studies that looked at possible associations between atrazine exposure and endocrine effects on alligators (*Alligator mississippiensis*) (e.g., Guillette et al. 1994, Vonier et al. 1996; Crain et al. 1997) and concluded that any such effects are not linked to atrazine exposure.

5.4.2 *Indirect Effects*

No studies of indirect effects of forest herbicides on reptiles in the Pacific Northwest were identified.

5.5 Mammals

5.5.1 *Direct Effects*

Research to date indicates minimal or no sub-acute, chronic, or neurotoxic effects when forest chemicals are ingested at levels representative of normal field applications (Newton et al. 1984; Atkinson 1985a). Neither do forest chemicals bioaccumulate or persist in animal tissues, with studies showing that they tend to appear in visceral and body contents of mammals at or below levels observed in treated ground cover and litter, and tend to rapidly decrease to negligible levels (decrease occurs faster in omnivores, carnivores, and herbivores, respectively) (Newton and Norris 1968; Newton et al. 1984; Santillo, Leslie, and Brown 1989 {Maine}; Lautenschlager 1992).

Studies to date indicate direct contact with forest herbicides has no adverse effect on forest mammals. Several different species of mammals are tested for acute oral and dermal herbicide toxicity during the product registration process. Mammals are also used in required tests for chronic, developmental and reproductive toxicity and carcinogenicity. Based on this testing, the most commonly used forestry herbicides are classified by USEPA as either practically non-toxic or only slightly toxic to mammals following acute exposures, and none of these commonly used herbicides shows any chronic, developmental, or reproductive toxicity or carcinogenicity at environmentally relevant exposure levels.

In addition, herbicide toxicity to mammals has been assessed in numerous reviews and ecological risk assessments. For example, in an ecological risk assessment for Roundup®, Giesy, Dobson, and Solomon (2000) concluded that for all terrestrial uses, including forestry, Roundup®, glyphosate, and POEA (surfactant) pose essentially no risk to mammals. The World Health Organization concluded that agricultural use of 2,4-D is unlikely to pose a high risk to mammals (WHO 1997). Comprehensive reviews of the toxicity of triclopyr, glyphosate, and imazapyr concluded that exposure to environmentally relevant concentrations of those herbicides poses little risk to mammals (NCASI 2003, 2004). Ecological risk assessments conducted by the BLM[5], USFS[6], and EPA[7] for a number of herbicides all specifically considered mammals and concluded that the risk associated with use of these products according to label directions is low.

5.5.2 *Indirect Effects*

Several studies from the Pacific Northwest reported on small mammal responses to habitat changes (Black and Hooven 1974; Sullivan and Sullivan 1981; Anthony and Morrison 1985; Sullivan 1990a, 1990b; Sullivan et al. 1997, 1998a, 1998b; Runciman and Sullivan 1996; Cole et al. 1998). In general, research has shown that indirect effects are site- and species-specific and temporary (Borrecco, Black, and Hooven 1979; Anthony and Morrison 1985; Ritchie, Harestad, and Archibald 1987; Lautenschlager 1993). Some of the first indirect effects studies were conducted on pocket gophers (*Thomomys* spp.). These studies documented significant reductions in local abundance on areas that were treated with forest herbicides with the intention of reducing animal numbers without using toxic baits. Population declines were attributed to forage loss and insufficient nutritional forage quality (Tietjen et al. 1967 {Colorado}; Hull 1971). However, the specific mechanism of population decline (i.e., mortality or emigration) in these studies was not identified.

---

[5] BLM's final programmatic environmental impact statement on the use of herbicides for vegetation control can be accessed at http://www.blm.gov/wo/st/en/prog/more/veg_eis.html.
[6] The USFS has conducted human health and ecological risk assessments for all pesticides used on national forestland. These may be accessed at http://www.fs.fed.us/foresthealth/pesticide/risk.shtml.
[7] EPA's ecological risk assessments are carried out under the Pesticide Reregistration and Pesticide Review programs and may be accessed from the indexes at http://www.epa.gov/pesticides/reregistration/status.htm and http://www.epa.gov/oppsrrd1/registration_review/reg_review_status.htm.

Since these initial studies, other research on small mammals has shown species-specific responses to vegetation changes resulting from forest herbicide application (Borrecco, Black, and Hooven 1972, 1979; Black and Hooven 1974; Savidge 1978; Runciman and Sullivan 1996; Sullivan et al. 1997), with responses depending on habitat affinities. For example, herbicides targeting herbaceous vegetation in young plantations tend to favor small mammal species with affinities for woody or shrubby habitats (e.g., Borrecco, Black, and Hooven 1972, 1979; Savidge 1978; Anthony and Morrison 1985). For species classified as ubiquitous habitat generalists, some studies have failed to detect an abundance response, suggesting less sensitivity to habitat alterations (Sullivan and Sullivan 1982; Runciman and Sullivan 1996). Population responses by small mammals to applications of forest herbicides may be dampened in older plantations (e.g., 20 years old) (Sullivan and Sullivan 1982) and vary by herbicide application technique (e.g., broadcast verses cut-stump) (Runciman and Sullivan 1996). Although chemical thinning in 12- to 14-year-old lodgepole pine stands reduced vegetation structural diversity compared to conventional thinning, it had little or no impact on the abundance and diversity of small mammal communities (Sullivan et al. 2002).

Small mammal responses to habitat changes caused by forest herbicide applications have been evaluated using short-term studies (Appendix B, Table B1) and generally correspond to plant community recovery (as indicated by gross metrics of vegetation structure and composition). In one of the few long-term (ten years) studies, Sullivan et al. (1997) reported no adverse effects on overall small mammal community reproduction, survival, or growth. Likewise, Sullivan (1996) found no differences in snowshoe hare (*Lepus americanus*) reproductive condition and success between herbicide treated and untreated areas (two years after treatment) in central British Columbia. In studies recording potential negative demographic responses to forest herbicides by small mammals, researchers could not differentiate between herbicide effects and natural population fluctuations (Sullivan et al. 1998a, 1998b).

Some researchers have reported effects of combined vegetation control techniques on mammals (Sullivan and Moses 1986 {nonchemical}; Sullivan and Boateng 1996; Brunjes et al. 2003 {South Carolina}; Edwards et al. 2004 {Mississippi}). Combinations of other vegetation management techniques with forest herbicides have resulted in longer lasting vegetation control that influenced species-specific small mammal responses (Sullivan and Boateng 1996; Cole et al. 1998), but the herbicide effect alone may have been negligible (Cole et al. 1998; Hood et al. 2002 {Mississippi}; Edwards et al. 2004 {Mississippi}). In some situations, researchers suggested that herbicides could complement mechanical site preparation to improve efficacy and longevity of vegetation control, thereby displacing mammals that damage crop tree seedlings (Savidge 1978; Sullivan and Moses 1986). However, as vegetation rapidly recovers, more vagile mammals (i.e., ungulates) may use treated areas more (Borrecco, Black, and Hooven 1972; Krefting, Hansen, and Stenlund 1956 {Minnesota}; Blake, Hurst, and Terry 1987 {Mississippi}; Edwards et al. 2004 {Mississippi}), at least until plantation canopy closes or palatable forage species are lost as crop trees establish dominance (Savidge 1978).

Herbicides do not generally repel herbivores from foraging on treated browse, and forage digestibility is unaltered. Controlled experiments on forest herbicide effects suggest that black-tailed deer (*Odocoileus hemionus columbianus*) are not repelled from atrazine or 2,4,5-T treated areas (Newton and Norris 1968), nor do they exhibit changes in forage preferences or adverse responses to treated vegetation (Sullivan and Sullivan 1979; Campbell et al. 1981). However, Campbell et al. (1981) found that Douglas fir seedlings treated with glyphosate were accepted at a lower rate by black-tailed deer in an enclosure, presumably because the treated seedlings were less palatable. In Wyoming, *in vitro* digestible dry matter of grasses and forbs showed no effects attributable to applications of 2,4-D, but the proportion of digestible dry matter available to herbivores increased because of greater grass biomass (Thilenius and Brown 1976).

Improving large mammal browse was a primary focus of the first decade of research on forest herbicides (pers. comm., M. Newton, Emeritus Professor, Department of Forest Science, Oregon State University) and remains an important consideration today. Forest herbicide-treated areas have received increased ungulate use, depending on forage availability (species composition, abundance, and access) and seasonal plant phenology (Borrecco, Black, and Hooven 1972; Savidge 1978; Balfour 1989; Newton et al. 1989 {Maine}). Selective herbicides such as imazapic (PLATEAU®) have also been used on exotic cheatgrass to provide a reduced competition growth window for Wyoming big sagebrush (*Artemisia tridentate*) and associated perennial grasses and forbs to enhance mule deer (*Odocoileus hemionus*) winter range habitat (Eddington 2006 {Utah}). Many forage species used by herbivores that are associated with intensively managed forests resprout as a response to top kill. In western Oregon, Chen (2004) found that plant abundance and diversity decreased after herbicide treatment, but vegetation recovered at varying rates due to a number of factors (i.e., native or exotic species, site characteristics) once treatments ceased. Vegetation cover and plant diversity slowly recovered after repeated herbicide treatments (four consecutive years), but whether pretreatment levels were attained was uncertain (Chen 2004).

The general pattern is for ungulates to respond favorably to increased vegetative growth and accessibility stimulated by herbicide application shortly (one to two years) after treatment. Heavy browsing can lengthen the available forage window by extending the coppice period (Newton et al. 1989 {Maine}). Depending on the resultant successional trajectory, ungulate use declines when the crop tree canopy or resultant plant community excludes desirable forage species (Lyon and Mueggler 1968). Under an intensive forest management regime these closed-canopy conditions develop rapidly and subsequently reduce browse species abundance earlier in the forest rotation (Figure 4.1. Thus, ungulate habitat use patterns in response to forest herbicide application in the Pacific Northwest are ephemeral depending on rate of plant community recovery, resultant successional trajectory, and treatment efficacy (Borrecco, Black, and Hooven 1972; Savidge 1978). This same general pattern in ungulate response to forest herbicides has been observed in other geographies (Krefting, Hansen, and Stenlund 1956 {Minnesota}; Krefting, Hansen, and Hunt 1961 {Minnesota}; Krefting and Hansen 1969 {Minnesota}; Kufeld 1977 {northwest Colorado}; Blake, Hurst, and Terry 1987 {Mississippi}; Thompson et al. 1991 {northeast Oklahoma}; Vreeland, Servello, and Griffith 1998 {Maine}).

One exception to this general pattern is moose (*Alces alces*). Over the short term (one to four years after herbicide application), moose tend to use treated areas less than untreated or older (seven or more years) treated habitats (Connor and McMillan 1988 {Ontario}; Cumming 1989 {Ontario}; Santillo 1994 {Maine}; Eschholz et al. 1996 {Maine}; Raymond et al. 1996 {Maine}; Raymond and Servello 1997 {Maine}; reviewed by Lautenschlager (1992), although Cole, Newton, and Youngblood (1999 {Alaska}) found contrasting results. Researchers surmised that the primary mechanism determining moose habitat use was browse and cover availability (Kelly and Cumming 1994 {Ontario}, not forage quality (Cumming et al. 1995 {Ontario}; Raymond et al. 1996 {Maine}; Raymond and Servello 1997 {Maine}; Lautenschlager et al. 1999 {Ontario}). As with the herbicide-induced patterns of habitat use observed in moose, glyphosate applications have been found to reduce woody forage (*Vaccinium* spp.) but have no impact on lichen food sources for woodland caribou (*Rangifer tarandus*) (Mihajlovich and Blake 2004 {Alberta}). In Wyoming, selective big sagebrush control treatments (2,4-D application) that reduced sagebrush cover by 96.7% did not impact elk (*Cervus canadensis*) calving behavior or elk and mule deer foraging habits (i.e., no change in grass-forb consumption ratio) (Ward 1973).

Forest herbicide use has been shown to improve short-term (less than two years; but see a six-year effect observed by Soper et al. 1993 {Oklahoma}) wildlife forage quality (e.g., increases in crude protein and digestibility), but these findings are confounded by associated silvicultural practices (e.g., application of fertilizer) (Edwards et al. 2004 {Mississippi}), natural plant response to die-back (Lautenschlager et al. 1999 {Ontario}; Stewart, Fulbright, and Drawe 2000 {Texas}), nutritional demands of the foraging species (Stewart et al. 2003 {Texas}), and geographic location (no contemporary studies identified in the Pacific Northwest). Studies on forage quality and mechanical vegetation control have repeatedly demonstrated that new sprouts contain higher forage quality than mature plants (Everitt 1983; Bozzo, Beasom, and Fulbright 1992 {Texas}; Wilmshurst, Fryzell, and Hudson 1995), and that this effect persists for less than two years (Everitt 1983; Fulbright et al. 1991). This has led to the hypothesis that herbicides have a similar effect. Timing of treatment has also been shown to affect the nutritional quality of browse. For example, Scouler's willow (*Salix scouleriana*) mechanically brushed (cut) in July was shown to have higher forage quality for moose the first two years after brushing (Rea and Gillingham 2001 {British Columbia}).

The spatial distribution of crop trees (Sullivan et al. 2002), along with the size and number of harvest entries, can affect the amount of ungulate forage (Visscher and Merrill 2009). Chemical thinning has been suggested as an alternative management strategy to develop a clumped distribution of crop trees to help maintain habitat for mule deer (Sullivan et al. 2002). Visscher and Merrill (2009) used stand-level models and simulated forage and cover availability for elk under even-flow and pulsed cutblock harvesting regimes in Alberta, Canada. Their modeling showed that herbaceous and palatable browse forage biomass peaked nine years after cutting. Although forbs increased with age of stand, browse composition shifted from palatable to unpalatable species after about 30 years. These authors demonstrated that within an elk home range (100 km^2) a simulated even-flow (variable aged) harvest regime where >10 ha were harvested per year increased overall forage availability by creating a spatial mosaic of forage patches, whereas a pulsed harvest (i.e., pine beetle control) significantly reduced forage availability over time. Herbicide applications do not usually produce a uniform reduced vegetation effect due to application techniques, weather, timing, and site characteristics, which could result in uneven spatial distributions of herbaceous and woody vegetation that may prove beneficial to wildlife by providing patch or mosaic habitat patterns.

A combination of empirical data and cumulative effects modeling has been used to help quantify longer-term changes (both temporal and spatial effects) in habitat due to herbicide treatments and potential indirect effects on mammals. Strong and Gates (2006 {Alberta}) demonstrated that hexazinone treatment of clearcut vegetation reduced forage availability for moose, deer, and elk in winter (by ≤20%) and for elk in summer (by ~6.5%) at the stand scale compared to untreated clearcut areas. They subsequently extended those field results to a larger-scale (100 km^2) cumulative effects model that used forage index values based on individual plant abundance and ungulate preference ratings as the dependent variable. Model results suggested that the potential for long-term changes in vegetation composition and resultant ungulate forage availability were most pronounced during winter.

Several short-term empirical studies have indicated positive effects of herbicide use on forage quality and/or quantity for ungulates (e.g., Borrecco, Black, and Hooven 1972; Krefting, Hansen, and Stenlund 1956 {Minnesota}; Krefting, Hansen, and Hunt 1961 {Minnesota}; Krefting and Hansen 1969 {Minnesota}; Hurst and Warren 1986 {southeastern U.S.}; Blake, Hurst, and Terry 1987 {southeastern U.S.}; Edwards et al. 2004 {Mississippi}; Thompson et al. 1991 {Oklahoma}). In contrast, Strong and Gates (2006 {Alberta}) suggested that using forest herbicides for woody vegetation control could suppress the positive ungulate habitat effects typically associated with timber harvesting. Clearly, there is a need for longer-term field research projects on the effects herbicides can have on early seral vegetation and on the implications of such effects for habitat use by ungulates at several spatial and temporal scales.

5.6 Birds

5.6.1 *Direct Effects*

Requirements for herbicide registration in the United States include testing acute and sub-acute toxicities to avian species, and some chemicals also undergo testing for potential reproductive toxicity (NCASI 2003). Direct effects of forest herbicides on birds can occur from spraying chemicals directly onto an organism, or by ingesting herbicide-coated seeds, vegetation, water, or small mammal prey (Bautista 2005). Studies to date suggest that forest herbicides are nontoxic to birds when applied at normal operational levels (i.e., according to label directions) (Kenaga 1975; Batt, Black, and Cowan 1980; Lautenschlager and Sullivan 2004), and toxic field exposure scenarios were deemed not plausible (Bautista 2005). Forest chemicals do not bioaccumulate or bioconcentrate in birds (e.g., Kenaga 1975 {2,4,5-T}; NCASI 2003 {triclopyr}, 2004 {glyphosate}).

5.6.2 *Indirect Effects*

Indirect effects of forest herbicides have been studied less for birds than for mammals (Appendix B, Table B2). Indirect effects on avian abundance, reproduction, and nesting have been detected and seem most closely tied to changes in habitat structure (Beaver 1976; Easton and Martin 1998, 2002; Schroeder and Sturges 1975 {Wyoming}; Slagsvold 1977 {Norway}; Bramble, Byrnes, and Schuler 1984 {Pennsylvania}). Bunnell, Kremsater, and Wind (1999) demonstrated that richness among shrub nesting bird species was greatest in recently clearcut areas in the Pacific Northwest. They showed weakly positive relationships between shrub cover and bird abundance, suggesting that large fluctuations in shrub cover resulted in relatively small changes in species richness. Morrison and Meslow (1983b) found that total species density varied little among twelve early-growth clearcuts (six of which were treated with herbicides) in the Oregon Coast Range, with shrub-inhabiting species dominant. They also found that total density of nesting birds increased with the amount of deciduous tree cover and decreased with increased conifer height. In southern Oregon rangeland, Wiens and Rotenberry (1985) found no immediate response from avian populations to a major habitat alteration (reduction of sagebrush from 2,4-D and manual removal). However, two years post-treatment, species-specific density fluctuations were observed that were not correlated to avian population changes elsewhere in the shrubsteppe region. These authors suggested that the lack of rapid avian responses to major habitat alterations may be due to a time-lag resulting from site tenacity of breeding residents (Wiens and Rotenberry 1985). Studies have also shown that herbicide treated habitats continue to function structurally as bird habitat until dead leaves have fallen or ground vegetation is prostrate (Savidge 1978; Morrison and Meslow 1984a; Schroeder and Sturges 1975 {Wyoming}). Thus, herbicide efficacy (i.e., the magnitude of vegetation kill and rate of structural decay) apparently plays a role in influencing avian community responses (Morrison and Meslow 1984a; Easton and Martin 1998, 2002; Taylor, Maxwell, and Boik 2006 {agricultural herbicides}), but because forest herbicides are used in early successional stages that are inherently dynamic, it is experimentally difficult to isolate herbicide effects on bird populations in field settings.

Birds appear to use vegetation structure-based cues to select potential nest locations regardless of fitness potential (Easton and Martin 2002). As a result, changes to vegetation structure resulting from herbicide application can significantly influence abundance and spatial distribution of appropriate nesting vegetation. Researchers suggest that this pronounced herbicide effect can be ameliorated by providing untreated patches or reserve areas (Santillo, Brown, and Leslie 1989 {Maine}; Easton and Martin 2002), assuming that suitable habitat conditions exist in these untreated locations. Suitable habitat for avian species dependent on dense understory vegetation may not be present in untreated areas of rotation-aged forests in managed landscapes because such landscapes generally do not support dense understories. However, even in these landscapes, areas of dense understory may be available around protected areas where herbicides are not applied. For example, a band of untreated vegetation often accompanies riparian zones in treated areas (Newton et al. 1996).

Herbicide-induced changes in avian food availability (e.g., seeds, insects) have been observed (Beaver 1976; Taylor, Maxwell, and Boik 2006 {agricultural herbicides}). In situations where avian food sources were negatively impacted by forest herbicide application, birds with non-specialized diets seemed to readily switch food sources (Beaver 1976; Savidge 1978; Morrison and Meslow 1984b). Researchers surmise that birds are adaptable to short-term changes in habitat (Beaver 1976) and may exhibit a delayed response to herbicide application (Savidge 1978). In forested areas outside the Pacific Northwest, herbicides are sometimes used to enhance food resources for some early successional bird species (e.g., northern bobwhite quail {*Colinus virginianus*} in the southeastern United States; Welch et al. 2004 {Florida}; Jones and Chamberlain 2004 {Louisiana}).

As with the patterns observed in small mammal responses, indirect effects of forest herbicide applications on birds are species-, season-, time-, and site-specific. Coarse measures of avian community response (e.g., species diversity, overall density) often show insignificant or positive responses to herbicide applications, but species-specific responses may vary substantially (Morrison and Meslow 1984a, 1984b; Slagsvold 1977 {Norway}; Santillo, Brown, and Leslie 1989 {Maine}; Brunjes et al. 2003 {South Carolina}). In a 30-year study of an electric transmission right-of-way maintained with handcutting and herbicides, Bramble, Byrnes, and Schuler (1984 {Pennsylvania}) found that those management techniques not only enhanced songbird habitat, but the resulting plant structure and species composition had a significant impact on bird species richness and abundance. These findings reinforce the importance of evaluating herbicide effects at the species level in the context of how specific herbicides change vegetation cover to meet management objectives.

5.7 Wildlife Community Summary

This synopsis of forest herbicide effects on wildlife revealed that direct effects are well documented, but often based on laboratory and mesocosm studies (usually at exposure concentrations higher than expected to occur in field situations) that may not extrapolate to field conditions. Data on indirect effects are generally sparse, but particularly so for insects, fish, and reptiles. Moreover, generalizations about effects of herbicides should be viewed cautiously because they are confounded by species-specific responses and elements of habitat change unrelated to herbicides. The most commonly studied indirect effects of herbicides in the literature evaluated how herbicide-induced vegetation changes influence wildlife habitat quality and use. Specific roles of herbicides apart from tools to promote certain vegetation types are seldom evaluated properly. This review identified several consistent themes regarding the direct and indirect effects of herbicides on wildlife.

5.7.1 *Direct Effects*

- Studies of direct herbicide toxicity to free-ranging wildlife are complicated by difficulties in quantifying exposure levels, identifying and quantifying subtle responses, and differentiating direct effects from indirect effects related to altered ecosystem functions (e.g., trophic interactions, nutrient cycling), and the methods used to achieve management objectives.
- The majority of field studies and comprehensive ecological risk assessments of forest herbicide use have concluded that when herbicides are applied per label instructions, there is little risk of direct toxicity to wildlife.

- The toxic effects of forest herbicides that have been reported in laboratory studies are typically associated with the use of exposure concentrations that are higher than those expected following operational forestry use and/or exposure durations that are much longer than those expected to occur in the environment and thus may not reflect actual risk associated with herbicide use.

5.7.2 *Indirect Effects*

- Research on indirect effects indicates that generalized statements on responses are inappropriate since responses of both vegetation and wildlife are site- and species-specific and are often also dependent on the specific herbicide formulation applied. Forest herbicides can have both positive and negative effects on wildlife habitats (Harrington et al. 2001 {southeastern U.S.}; Keyser and Ford 2006 {Virginia}), although studies specific to the Pacific Northwest are lacking.
- Forest herbicides can affect wildlife use of vegetation by altering forage species assemblages, modifying habitat structure (e.g., cover, foliage height diversity) both temporally and spatially, and decreasing the time conifer seedlings remain vulnerable to browsing.
- Timing of wildlife community recovery is directly tied to vegetation community recovery (although a lag response may exist). Thus, landscape-level timing scenarios (e.g., green-up requirements) or provisions for untreated areas play an important role in recolonization of treated areas. Whether affected organisms temporarily move off site and recolonize after vegetation recovery, or are lost with subsequent colonization occurring via immigration from proximate populations is unclear.
- Few long-term studies exist. Since short-term indirect effects (or lack of such effects) may differ from long-term effects, efforts should be made to conduct longer-term studies that collect frequent samples. For example, Wiens and Rotenberry (1985) have reported that time lags in wildlife responses to major habitat changes may exist in some environments (e.g. shrubsteppe systems). Similarly, there is a need for longer-term research on the effects of a truncated browse window on fauna associated with early seral vegetation types.
- Multiple vegetation control treatments (e.g., herbicide application plus burning) may have greater indirect effects than single treatments.
- Gross metrics of wildlife community responses, such as species richness, species evenness, and other diversity measures, may not detect potentially important species or ecosystem alterations. Studies of wildlife community responses should focus on developing mechanistic explanations for a few taxa rather than descriptive measures for all taxa, which are heavily influenced by regional species pools.

6.0 HERBICIDE EFFECTS ON ECOSYSTEMS

Forest ecosystems comprise not only collections of living organisms and their environments, but also processes (e.g., photosynthesis, predation, evapotranspiration) and functions (e.g., habitat support, regulation of water quality and flows). Effects of forest management on ecosystem processes and functions depend not only on site and stand characteristics, but also on the nature, timing, and spacing of silvicultural treatments (Waring and Running 1998; McColl and Powers 1984).

Silvicultural herbicides can influence ecosystem processes and functions through direct effects (i.e., toxicity to organisms) or indirect effects meditated by changes in the structure and composition of plant communities. However, this review has noted already that herbicide use is one of multiple events in a forest management regime that may invoke ecosystem responses. Thus, linking observed changes in ecosystems specifically to herbicides can be challenging.

In comparison to alternatives, using herbicides to control vegetation has important advantages with positive feedbacks to ecosystem sustainability and water quality (Bigley and Kimmins 1983; Neary and Michael 1996). These advantages include avoiding effects of ground-based equipment on soil physical properties; avoiding nitrogen losses associated with burning; reducing on-site soil and organic matter displacement; and minimizing soil erosion and sediment transport to streams.

Forest herbicide treatments are commonly used to restore ecosystem functionality (Masters et al. 1996; Rice et al. 1997; Colborn and Short 1999; Olson and Whitson 2002; Rhoades, Barnes, and Washburn 2002). These efforts (i.e., habitat restoration projects) affect plant community structure and function (both temporally and spatially) in a manner consistent with a desired ecological condition. Additionally, methods like selective herbicide application, chemical thinning, and retention of buffer strips that create patchwork or mosaic habitats can influence ecosystem function by providing areas for breeding or nesting wildlife in addition to cover and food resources (Santillo, Brown, and Leslie 1989; Easton and Martin 2002; Sullivan et al. 2002).

6.1 Exposure of Organisms to Herbicides in Forest Ecosystems

Potential for chemical toxicity depends on exposure of organisms to chemicals. Factors affecting exposure include chemical concentration in the environment; chemical availability (i.e., whether a chemical is in a form that can affect organisms); and duration of exposure.

In managed forests, exposure of organisms to herbicides and potential for toxic effects depend on many factors, including

- characteristics of the herbicide formulation (e.g., toxicity, mobility, persistence);
- application rate and method;
- site conditions (e.g., soil type, proximity to surface waters, presence of sensitive organisms); and
- weather conditions.

There have been many studies of the transport and fate of herbicides following application. Relevant processes include uptake by plants; adsorption to soil and plant surfaces; volatilization; degradation by photochemical and microbial mechanisms; and leaching (Norris 1967, 1981a; Mullison 1970; Radosevich, Holt, and Ghersa 1997; Monaco, Weller and Ashton 2002). Because a small portion of available chemical remains on leaf surfaces after treatment, precipitation often washes chemical residue to the forest floor (Norris 1967, 1981b). Actual chemical amounts reaching the forest floor vary by vegetation density and by precipitation amounts and frequency (Norris 1981b). For example, shrub canopy (Wyoming big sagebrush) has been shown to interfere with the penetration of herbicides to targeted herbaceous (cheatgrass) understory (Eddington 2006 {Utah}). This author suggested using a smaller droplet size with increased pressure to force more chemical through the canopy to reach the cheatgrass. The amount of litter cover was also suggested as a possible means of tying up the herbicide and preventing it from reaching the understory (Eddington 2006). Absorption and adsorption are usually rapid processes, depending on soil and chemical properties (Mullison 1970).

As part of the pesticide registration process, extensive data are collected on the environmental fate and transport of herbicides. For many herbicides with forestry applications, the registrants are requested to conduct field dissipation studies under operational forestry conditions. Multiple studies, reviews, and BLM[8], USFS[9], and EPA[10] risk assessments have concluded that herbicide concentrations in forest ecosystems generally decrease rapidly after application (Norris, Montgomery, and Johnson 1977; Plumb, Norris, and Montgomery 1977; Radosevich and Winterlin 1977; Briggs et al. 2000; Giesy, Dobson, and Solomon 2000; NCASI 2003, 2004; Tatum 2004).

Documented soil half-lives for herbicides are variable and range from days to months (Norris 1981b; Newton and Norris 1976; Ware 1980; Torstensson 1985; NCASI 2003, 2004; Tatum 2004). Soil persistence depends on chemical properties of the herbicide, application rates, soil type, the presence and activity of soil microorganisms, and climatological factors (e.g., rainfall, temperature) (Radosevich, Holt, and Ghersa 1997; Monaco, Weller, and Ashton 2002). Herbicide dissipation (degradation) in soils is mostly by microbial decomposition, but also occurs via hydrolysis and photodegradation (Radosevich, Holt, and Ghersa 1997; Monaco, Weller, and Ashton 2002). Certain soil conditions (i.e., warm, moist, nutrient rich) expedite herbicide dissipation (Mullison 1970; Briggs et al. 2000). A variety of organisms can decompose herbicides, including at least ten genera of bacteria, three actinomycetes, and ten fungi (Mullison 1970). Detectable herbicide residues are often shallow (<15 cm) in the soil horizon and at low concentrations (0.1 to 0.2% of application rates) (Radosevich and Winterlin 1977 {2,4-D}).

Longer soil half-lives are typically a function of the degree of herbicide adsorption to soil, although in field studies, they may also be a result of climate factors (e.g., lack of precipitation). Herbicides are bound in soil via adsorption to clay minerals, organic material, metallic oxides, or humic substances, with potential for mobility impacted by soil chemistry (e.g., pH, inorganic phosphate levels) and soil type (Monaco, Weller, and Ashton 2002). Strong adsorption to soil may increase soil half-life, but at the same time, such binding renders the herbicide biologically inactive and provides a safe route of decontamination while allowing slow degradation that poses no short- or long-term problems (Gevao, Semple, and Jones 2000).

Feng and Thompson (1990) monitored glyphosate (Roundup®) and its metabolite aminomethyl phosphonic acid (AMPA, a primary glyphosate degradation product) and found residues in foliage, leaf litter, and soil up to one year after aerial application (nominal rate 2.0 kg/ha a.i.) to a Vancouver Island (British Columbia) watershed. Glyphosate residues varied immediately after application within the watershed from 1.85 to 2.2 kg(a.i.)/ha. The target foliage of red alder (*Alnus rubra*) and salmonberry (*Rubus spectabilis*) received foliar deposits of 261.0 and 447.6 µg/g, respectively, similar to results observed by Newton et al. (1984). Initial average leaf litter residues for red alder (12.5 µg/g) and salmonberry (19.2 µg/g) rapidly declined to less than 1 µg/g within 45 days after treatment (DT_{50} {50% dissipation} <14 days). Soil upper organic layers retained >90% of the total glyphosate deposits within the 0 to 15 cm depth. Soil glyphosate residues were non-persistent and dissipated over time (estimated DT_{50} 45 to 60 days), with total glyphosate soil residues 6 to 18% of initial levels after 360 days. Despite the moisture contents (varying from well drained to seasonally flooded) of soils, little evidence of leaching was observed. These results are consistent with findings of other laboratory and small-scale field studies that glyphosate is generally non-mobile and non-persistent in soils (Giesy, Dobson, and Solomon 2000; Newton et al. 1984).

---

[8] BLM's final programmatic environmental impact statement on the use of herbicides for vegetation control can be accessed at http://www.blm.gov/wo/st/en/prog/more/veg_eis.html.
[9] The USFS has conducted human health and ecological risk assessments for all pesticides used on national forestland. These may be accessed at http://www.fs.fed.us/foresthealth/pesticide/risk.shtml.
[10] EPA's ecological risk assessments are carried out under the Pesticide Reregistration and Pesticide Review programs and may be accessed from the indexes at http://www.epa.gov/pesticides/reregistration/status.htm and http://www.epa.gov/oppsrrd1/registration_review/reg_review_status.htm.

A study conducted in a 11.5 ha watershed in northwestern Arkansas measured environmental concentrations of hexazinone (2.0 kg a.i./ha) in soil, water, and vegetation after application (Bouchard, Lavy, and Lawson 1985). Soil concentrations (top 10 cm) decreased to about 10% of application concentration after 42 days. Maximum instream concentrations were 14 µg/L, with residues <3 µg/L found in stream discharge one year after treatment. Forest floor components (oak foliage and leaf litter) contained <0.10% of the initial hexazinone concentration. Hexazinone in soil (incubated at 10 and 30°C) had a half-life of 77 days. The authors concluded that hexazinone was moderately persistent and mobile in soil and water and could persist at low concentrations in watershed discharge for more than one year after application, but occurred at concentrations well below levels toxic to aquatic fauna or soil microbes.

Exposures to non-target organisms during forestry herbicide applications are minimized through a variety of techniques. For example, some automated application techniques rely on geographic information systems, global positioning systems, and variable application rates, where application rates are pre-programmed into a computer based on *a priori* knowledge of soils and target vegetation composition at small spatial scales within the treated area (e.g., Al-Gaadi and Ayers 1999; Tian 2002). Additionally, many land management organizations have adopted best management practices (BMPs) designed to minimize unintentional negative effects from herbicides (Ice et al. 2004).

6.2 Herbicide Effects on Terrestrial Ecosystem Processes

Herbicide treatments reduce aboveground vegetation biomass for some period of time and change the structure and composition of plant communities. It follows that herbicide effects on plants will alter many terrestrial ecosystem processes such as photosynthesis, carbon allocation, evapotranspiration, nutrient uptake, and litter fall. Moreover, herbicide effects on plants may alter complex interactions among organisms such as host-pathogen relationships (Ware 1980). However, studies have generally reported negligible herbicide impacts on soil, its components, or ecosystem productivity, especially in field settings (Newton and Norris 1976; Bollen and Norris 1979; Norris 1981a; Eijsackers 1985; Grossbard 1985; Poff 1996).

Changes in ecosystem processes may be reflected in changes in soil conditions (Ponder 2002). For example, field observations following glyphosate application in southwest British Columbia documented increases in soil nitrate concentrations (within and below the rooting zone) that were attributed to reduced nitrogen uptake by vegetation and increases in nitrification (Bigley and Kimmins 1983). Similarly, Ohtonen, Munson and Brand (1992), in Ontario, Canada, examined responses of the microbial community to clearcutting followed by five annual applications of Vision® (glyphosate). They reported that this extended vegetation control program resulted in reduced soil moisture, increased soil temperature, increased availability of light and increased nitrogen supply, concluding that clearcutting promoted nitrification and vegetation control intensified that effect. However, ten years after the initial clearcut, the nitrate-dominated cycle reported by Ohtonen, Munson and Brand (1992) had been replaced by an ammonium-dominated N cycle (Perie and Munson 2000). Both Munson, Margolis, and Brand (1993) and Haney et al. (2000) reported increased carbon and nitrogen mineralization in soil following long-term use of glyphosate.

The results of studies of the effects of herbicides on microbial activity and biomass are inconsistent. Some researchers have suggested that microbial responses to herbicides are species-specific (Eijsackers 1985; Grossbard 1985; Guiseppe et al. 2006). In a review of chemical effects on bacterial biodiversity in soil, Trevors (1998) concluded that changes in microbial activity in soils treated with herbicides were typically associated with concentrations higher than those recommended for use. Trevors (1998) also noted that field studies were less likely to show negative impacts than laboratory studies.

In a literature review of herbicide effects on biotic components of northern forests, Lautenschlager and Sullivan (2002) found that fungal components were relatively unaffected. Busse et al. (2001) found that although direct exposure to glyphosate was toxic to soil bacteria and fungi, this toxicity disappeared when glyphosate was applied to a soil substrate. Haney et al. (2000) reported that glyphosate significantly stimulated soil microbial activity, but had no effect on microbial biomass. Studies of agricultural ecosystems typically show that normal application rates of alachlor, atrazine, metolachlor, and trifluralin have no significant effects on bacterial or fungal populations (Dzantor and Felsot 1991).

At a California study site of ponderosa pine (*Pinus ponderosa*) plantations established after clearcutting existing vegetation, Busse et al. (2001, 2006) reported small, inconsistent variations in microbial biomass and respiration in field plots treated repeatedly over a period of nine years with glyphosate, with no effect on carbon use. However, in North Carolina and Louisiana, Busse et al. (2006) reported that weed control treatments (repeated applications of glyphosate, imazapyr, triclopyr, or sulfometuron with manual cutting) reduced microbial biomass and plant respiration between 15 and 30% and affected soil community structure. They concluded that differences among the North Carolina, Louisiana, and California sites were related to dominant understory vegetation types. The California site was dominated by slow-growing shrub species, while the North Carolina and Louisiana sites were dominated by faster growing herbaceous cover.

In central Ontario, Canada, repeated applications (over five years) of Vision® for vegetation control were associated with decreases in microorganisms of 36% and 20% in the soil F/H horizon and surface mineral horizon, respectively. In addition, average reductions of 41% in bacteria and 67% in fungi were observed on slides incubated for five months in bags with litter collected from the study sites (Ohtonen, Munson and Brand 1992). The researchers hypothesized that vegetation control increased soil nitrogen availability and reduced carbon inputs (via litter and root turnover), resulting in carbon limitations to the microbial community.

Some authors have also drawn attention to soil acidification caused by exporting biomass and applying fertilizers, and depletion of mineral reserves caused by increasing land productivity (Flueck and Smith-Flueck 2006). Given that herbicides enable increases in productivity, it is reasonable to consider connections between herbicide use and the need to manage soil fertility and tree nutrition in managed forests.

6.3 Herbicide Effects on Aquatic Ecosystem Processes

Ecological risks to aquatic systems associated with herbicide use have been studied extensively. Concerns about herbicide effects on aquatic ecosystems are often focused on photosynthetic pathways of aquatic microorganisms. Pratt et al. (1997) showed that atrazine concentrations of 3 to 100 µg/L disrupted photosynthetic pathways and stopped energy flow in an aquatic mesocosm experiment. Peterson et al. (1997) reported that in laboratory studies, hexazinone and diquat inhibited the growth of green algae, diatoms, cyanobacteria, and duckweed. Roshon et al. (1999) evaluated the toxicity of seven forestry herbicides (2,4-D, glyphosate, hexazinone, imazapyr, metsulfuron methyl, sulfometuron methyl, triclopyr) to the submersed macrophyte *Myriophyllum sibiricum* in laboratory studies. They reported that all of the herbicides tested produced 25-50% inhibition of shoot and/or root growth at exposure concentrations lower than the calculated expected environmental concentration.

Pérez et al. (2007) reported that glyphosate can affect freshwater phytoplankton and periphyton communities in mesocosm experiments; however, the test concentrations used (6 and 12 mg a.i./L) were significantly higher than those likely to be found in the environment. For example, Thompson et al. (2004) reported 0.33 mg a.i./L in oversprayed wetlands following forestry application of Vision®. Rohr and Crumrine (2005) used mesocosms stocked with periphyton, wood frog tadpoles, adult snails, caged dragonfly larvae, chironomid larvae, and *Daphnia* to study the effects of atrazine on pond community structure and processes. They reported that atrazine at 25 µg/L directly reduced periphyton, which resulted in indirect reductions in chironomid abundance, snail reproduction and growth, and tadpole development and growth.

Interpretation of laboratory studies of the toxicity of herbicides to non-target aquatic organisms is complicated by difficulties in determining realistic exposure concentrations and durations. In general, the default approach to calculating expected environmental concentrations, which is frequently used in laboratory studies, yields concentrations much higher than those observed in actual practice. In addition, exposure durations in laboratory studies are typically at least 24 hours and often longer, while the duration of peak concentrations in bodies of water following forestry applications of herbicides is typically a matter of a few hours.

A small fraction of herbicide applied to forests may be transported to surface waters via accidental direct application, drift, overland flow, leaching, or mobilization in ephemeral streams (Norris 1981b). Herbicide concentrations in surface waters seldom reach levels that are biologically significant; are often highest immediately after application; and decline quickly due to rapid dilution (Norris 1981b; Neary and Michael 1996). Factors affecting herbicide concentrations in water include area treated, stream surface area, amount of intercepting vegetation, and time since application (Norris 1967; Michael and Neary 1993; Thistle, Ice, and Karsky 2007).

Transport of herbicides to surface waters is greatly reduced when drift is intercepted by vegetation above and adjacent to the water (Solomon and Thompson 2003). It is now standard forestry practice to leave a buffer strip of unsprayed vegetation adjacent to surface waters to intercept drift and thus minimize herbicide transport and deposition to water (Neary and Michael 1996; Teske and Ice 2002; Thompson et al. 2004; Thistle, Ice, and Karsky 2007; Ice, Thistle and Karsky 2008; Michael and Neary 1993 {southeastern United States}; Adams, Smith, and Miller 2007 {New Brunswick}).

Other effective measures for reducing herbicide movement to surface waters include using the minimum application rate consistent with silvicultural objectives; minimizing drift from aerial applications by controlling parameters such as droplet size and flight speed; and applying herbicides during low-risk weather conditions (e.g., low wind speeds) (Atkinson 1985b). Computer models of drift control measures can be useful in designing and documenting the effectiveness of integrated control strategies (Teske and Ice 2002; Teske, Thistle, and Ice 2003).

Potential for drift is generally low with ground-based application methods conducted during appropriate weather conditions. For example, Marrs and Frost (1997) found that effects of chemical drift on natural plant communities extended only 8 m from the sprayer (tractor mounted boom). However, ground-based methods are often not feasible on sites in steep terrain.

Contamination of groundwater in areas where there is heavy agricultural use of herbicides is a concern that prompted Neary and Michael (1996) to consider the potential for groundwater contamination following forestry applications of herbicides. They concluded that, in general, forestry use of herbicides poses little risk to groundwater quality because of the use pattern. For example, herbicide use in forestry is only 10% of agricultural usage, applications rates are low, herbicides are applied infrequently, and only a small portion (<5%) of any large watershed in which groundwater recharge occurs is likely to be treated in any one year. They noted that surface, unconfined aquifers in the immediate vicinity of herbicide applications zones have the most potential for contamination, but even in those aquifers, detection of herbicides following forest applications is sporadic and at low concentrations.

Environmental assessments in the U.S. have shown that forestry herbicides in surface and ground water pose minimal risk to human health, water quality, watersheds, or ecosystem productivity (Newton and Norris 1976; Neary and Michael 1996). Factors that contribute to low risk findings for forestry herbicides include low rates and frequencies of application (e.g. applied one or two times during a 25 to 75 year rotation).

6.4 Ecosystem Effects Summary

Changes to the temporal dynamics of vegetation succession induced by intensive forest management (see Figure 4.1) can influence microclimates, nutrient availability, and competitive relationships among flora and fauna (Waring and Running 1998), thereby shifting longer-term ecosystem composition and structure. However, this review has noted that flora and fauna changes are typically of short duration, and the multitude of interactions of ecosystem components and varying degree of responses from flora and fauna make it difficult to identify specific effects from herbicide treatment, versus altered vegetation composition due to other forest management practices.

Research on ecosystem-level responses to forest herbicide applications tends to focus on specific ecosystem components such as chemical persistence and mobility in soil, water, and vegetation and on how chemical presence may influence processes. Most of the research on ecosystem effects has been undertaken at small scales (tens of hectares), with few studies conducted at landscape levels (Guynn et al. 2004; Miller and Miller 2004). This review of ecosystem herbicide effects indicated:

- Herbicide efficacy at altering plant community composition and structure over short temporal and large spatial scales can result in ecosystem-level responses (i.e., soil nutrient cycling, microbial activity, amount of organic matter, water contamination), as with other methods of vegetation control.
- Forest herbicide residues decline rapidly (typically within days to months) after application and fall below minimal detectable levels. Forest herbicides persist at detectable levels longest (up to years depending on the herbicide, microbial activity, and soil properties) in soils and sediments.
- Interactions of herbicides with plants and soils (e.g., uptake and adsorption) can reduce herbicide mobility and bioavailability substantially.
- By changing aboveground vegetation (e.g., abundance and species composition), forest herbicides affect the soil microbial community and nutrient availability, resulting in potential ramifications for nutrient cycling processes. Forest herbicide use reduces soil erosion and compaction compared to other intensive forest management site preparation and vegetation control techniques.
- In general, forest herbicide use poses low risk to groundwater (Neary and Michael 1996). Application rates are low, use is typically infrequent, and within large watersheds where extensive groundwater recharge occurs, even intensive use of silvicultural herbicides would affect less than 5% of the area in any one year (Neary and Michael 1996).
- Herbicide contact with riparian areas can be minimized by utilizing drift prediction computer models, applying vegetation buffer zones, using short spray booms with appropriate droplet size, and following recommended timing and application rates.
- Vegetation buffer strips have proven beneficial in reducing water exposure to forest herbicides (e.g., Rashin and Graber 1993). The amount of intercepting vegetation and the ability of herbicide applicators to avoid buffers appear to be the primary attributes that influence functionality.

7.0 CONCLUSIONS AND RESEARCH NEEDS

Historic land use trends and future wood demand projections indicate that intensively managed forests will remain a significant component of Pacific Northwest ecosystems. There is clearly a strong interest among individuals and organizations affiliated with large private forest landowners to understand how resource stewardship can sustain their livelihoods (Charnley, Fischer, and Jones 2007). Part of this understanding involves balancing wood production and ecological objectives using techniques that optimize cost-effective crop tree production, predict changes in plant and wildlife communities, protect environmental quality, and maintain favorable public perceptions.

Maintaining a social license to operate and effectively competing in a global market are necessities that are affected by forest herbicide use. Public and industry interest in potential environmental effects of forest herbicides prompted this literature review.

Forest herbicides have become valuable silvicultural tools for achieving economic and ecological objectives. Herbicides provide effective vegetation control and tend to have fewer negative environmental consequences than alternative management techniques (e.g., mechanical, fire). When herbicides are applied at recommended rates in managed forests, direct toxic effects on wildlife and fish are not expected.

Herbicide effects on plant communities are most extensively studied for crop tree and target vegetation responses. The literature on how to minimize crop tree damage while maximizing target vegetation control is relatively complete. From a broader, community-level perspective, the literature indicates that coarse metrics of plant community structure and species richness rapidly recover to pretreatment levels, but that occurrence rates of individual species fluctuate. Long-term implications of these fluctuations on ecosystem functions are poorly understood.

Plant community responses to forest herbicides vary spatially and temporally because they depend on factors such site conditions, management history, chemical properties of specific herbicides, and the timing and method of herbicide application. Such complexity stresses the importance of understanding not only the ecosystem, but also the historical management regime.

Field studies of wildlife after applications of forest herbicides have failed to identify negative responses consistently, and some responses have been positive. These varied results may be artifacts of study design (Lautenschlager 1993). Direct toxic effects of herbicide exposure have been documented in studies in laboratories and artificial environments, but are typically associated with exposure levels far in excess of those occurring in standard field operations.

Short-term negative effects on wildlife correspond to plant community changes induced by herbicide activity. It is unclear if wildlife remain on-site (Lautenschlager, Bell, and Wagner 1997), temporarily move off-site and then recolonize, or perish and later recolonize via immigration from surrounding populations.

Because wildlife and plant communities are so closely associated, wildlife community recovery (expressed by coarse metrics such as species richness, evenness, and diversity) is often rapid following herbicide treatment. However, general statements on wildlife community responses are inappropriate because herbicide effects vary by species. In fact, researchers caution against using community-level metrics to measure herbicide effects because they may not detect potentially important species or ecosystem alterations (Barlow et al. 2007; Jennings et al. 2008). Only three long-term studies have occurred to date; each failed to detect lasting negative effects of forest herbicides on wildlife population dynamics.

It is generally accepted that forest herbicides alter ecosystems over short temporal and large spatial scales. Studies have shown that herbicide treatments can influence soil microbial communities, with potential ramifications for nutrient cycling and how rapidly chemicals are dissipated. Herbicide decomposition rates vary depending on the level of microbial activity or the strength of adsorption in the soil environment (Torstensson 1985). The potential for groundwater contamination is minimal and forestry best management practices (e.g., riparian buffer strips) are successful in minimizing surface water exposure. Magnitude and direction of forest ecosystem responses to herbicide applications depend on a complex integration of chemical and system factors, making tightly controlled experiments difficult.

The scientific literature includes discussions of information gaps and research needs related to ecological effects of forest herbicides (e.g., Balfour 1989; Ritchie and Sullivan 1989; Lautenschlager 1993; Neary and Michael 1996; Chen 2004; Lautenschlager and Sullivan 2004). It is generally recognized that research priorities evolve over time because herbicide formulations and application techniques are continually changing. Several authors have noted a need for standardized vegetation response data and the importance of accurate data collection and reporting (Boyd et al. 1985; Kline, Fears, and Zedaker 1985).

Following are some tasks and topics that merit consideration in research planning.

- Compare forest herbicides and other vegetation control methods with respect to their effects on human safety, soil properties and processes, water quality, and long-term site productivity.
- Identify and fill gaps in information about herbicide transport and fate in air, water, soils, vegetation, and wildlife to support comprehensive assessments of ecological risk. Assessments should focus on current and emerging practices (e.g., common formulations and tank mixes; best management practices; etc.)
- Conduct long-term (>5 years) studies of indirect effects of herbicides that are focused on the ecology of landscapes (i.e., multiple stands) and include frequent measurements of plant and animal communities; potentially sensitive taxa (e.g., stream associated amphibians and reptiles); microbial communities; and ecosystem processes such as carbon and nutrient cycling.
- Assess the ecological consequences of 1) temporal truncation of early seral vegetation in intensively managed stands and 2) mosaics of plant community types in intensively managed landscapes. Ecological consequences of interest include temporal and spatial patterns of food availability for ungulates, birds, and other taxa.
- Conduct studies of wildlife responses to herbicides that 1) include measurements of demographic parameters (e.g., fecundity, survival, emigration, immigration); 2) consider ecosystem interactions (e.g., by collecting data across trophic levels); and 3) test specific hypotheses about mechanisms of indirect effects.
- Determine how herbicide use in wood production forests and ecosystem restoration projects affects the spread of exotic, invasive plant species and populations of rare native species of plants and animals.
- There is a lack of research on the environmental impacts of tank mixes, adjuvants, and surfactants and potential synergistic effects. Various chemical formulations are also an area needing further attention.

REFERENCES

Abdelghani, A.A., Tchounwou, P.B., Anderson, A.C., Sujono, H., Heyer, L.R., and Monkiedje, A. 1997. Toxicity evaluation of single and chemical mixtures of Roundup®, Garlon-3A, 2,4-D, and Syndets surfactant to channel catfish (*Ictalurus punctatus*), bluegill sunfish (*Lepomis microchirus*), and crawfish (*Procambarus* spp.). *Environmental Toxicology and Water Quality* 12:237-243.

Adams, G.W., Smith, T., and Miller, J.D. 2007. The absence of glyphosate residues in wet soil and the adjacent watercourse after a forestry application in New Brunswick. *Northern Journal of Applied Forestry* 24(3):230-232.

Al-Gaadi, K.A., and Ayers, P.D. 1999. Integrating GIS and GPS into a spatially variable rate herbicide application system. *Applied Engineering in Agriculture* 15(4):255-262.

Allran, J.W., and Karasov, W.H. 2001. Effects of atrazine on embryos, larvae, and adults of anuran amphibians. *Environmental Toxicology and Chemistry* 20(4):769-775.

Anderson, D.P. and Zeeman, M.G. 1995. Immunotoxicology in fish. In *Fundamentals of aquatic toxicology*, ed. Gary M. Rand, 371-404. Washington, D.C.: Taylor & Francis.

Anthony, R.G., and Morrison, M.L. 1985. Influence of glyphosate herbicide on small-mammal populations in western Oregon. *Northwest Science* 59(3):159-168.

Ashby, W.C. 1997. Soil ripping and herbicides enhance tree and shrub restoration on stripmines. *Restoration Ecology* 5(2):169-177.

Atkinson, D. 1985a. Toxicological properties of glyphosate – A summary. In *The herbicide glyphosate*, ed. E. Grossbard and D. Atkinson, 127-133. Boston, MA: Butterworths.

———. 1985b. Glyphosate damage symptoms and the effects of drift. In *The herbicide glyphosate*, ed. E. Grossbard and D. Atkinson, 455-465. *The herbicide glyphosate*. Boston, MA: Butterworths.

Bacaro, G., Ricotta, C., and Mazzoleni, S. 2007. Measuring beta-diversity from taxonomic similarity. *Journal of Vegetation Science* 18:793-798.

Balandier, P., Collet, C., Miller, J.H., Reynolds, P.E., and Zedaker, S.M. 2006. Designing forest vegetation management strategies based on the mechanisms and dynamics of crop tree competition by neighboring vegetation. *Forestry* 79(1):3-27.

Balfour, P.M. 1989. *Effects of forest herbicides on some important wildlife forage species*. British Columbia Forest Resource Development Agreement (FRDA) Report 0835-0752;(020). Victoria, BC: British Columbia Ministry of Forests, Research Branch.

Barlow, J., Gardner, T.A., Araujo, I.S., Ávila-Pires, T.C., Bonaldo, A.B., Costa, J.E., Esposito, M.C., Ferreira, L.V., Hawes, J., Hernandez, M.I.M., Hoogmoed, M.S., Leite, R.N., Lo-Man-Hung, N.F., Malcolm, J.R., Martins, M.B., Mestre, L.A.M., Miranda-Santos, R., Nunes-Gutjahl, A.L., Overal, W.L., Parry, L., Peters, S.L., Ribeiro-Junior, M.A., da Silva, M.N.F., da Silva Motta, C., and Peres, C.A. 2007. Quantifying the biodiversity value of tropical primary, secondary, and plantation forests. *Proceedings of the National Academy of Sciences* 104(47):18555-18560.

Batt, B.D.J., Black, J.A., and Cowan, W.F. 1980. The effects of glyphosate herbicide on chicken egg hatchability. *Canadian Journal of Zoology* 58:1940-1942.

Bautista, S.L. 2005. Summary of herbicide effects to wildlife – Draft. Appendix B, *Pacific Northwest Region Invasive Plant Program, preventing and managing invasive plants*. Draft Environmental Impact Statement. Portland, OR: USDA Forest Service, Pacific Northwest Region.

Beaver, D.L. 1976. Avian populations in herbicide treated brush fields. *The Auk* 93:543-553.

Berrill, M., Bertram, S., McGillivray, L., Kolohon, M., and Pauli, B. 1994. Effects of low concentrations of forest-use pesticides on frog embryos and tadpoles. *Environmental Toxicology and Chemistry* 13(4):657-664.

Bigley, R.E., and Kimmins, J.P. 1983. Herbicide effects on ecosystem nitrogen loss. In *New forests for a changing world*, 199-203. Proceedings of the 1983 Convention of the Society of American Foresters (SAF), Portland, Oregon. SAF Publication 84-03. Washington, DC: Society of American Foresters.

Bird, S., Coulson, R.N., and Crossley, D.A., Jr. 2000. Impacts of silvicultural practices on soil and litter arthropod diversity in a Texas pine plantation. *Forest Ecology and Management* 131:65-80.

Black, H.C., and Hooven, E.H. 1974. Response of small-mammal communities to habitat changes in western Oregon. In *Wildlife and forest management in the Pacific Northwest*, ed. H.C. Black, 177-186. Corvallis, OR: Oregon State University, School of Forestry.

Blake, P.M., Hurst, G.A., and Terry, T.A. 1987. Responses of vegetation and deer forage following application of hexazinone. *Southern Journal of Applied Forestry* 11:176-180.

Bollen, W.B., and Norris, L.A. 1979. Influence of 2,3,7,8-tetrachlorodibenzo-*P*-dioxin on respiration in a forest floor and soil. *Bulletin of Environmental Contamination and Toxicology* 22:648-652.

Borrecco, J.E., Black, H.C., and Hooven, E.F. 1972. Response of black-tailed deer to herbicide-induced habitat change. In *Proceedings of the 52d annual conference of the Western Association of State Game and Fish Commissioners*, 437-451. Portland, OR.

———. 1979. Response of small mammals to herbicide-induced habitat changes. *Northwest Science* 53(2):97-106.

Bouchard, D.C., Lavy, T.L., and Lawson, E.R. 1985. Mobility and persistence of hexazinone in a forest watershed. *Journal of Environmental Quality* 14(2):229-233.

Boyd, R.J., Miller, D.L., Kidd, F.A., and Ritter, C.P. 1985. *Herbicides for forest weed control in the Inland Northwest: A summary of effects on weeds and conifers*. General Technical Report INT-195. Ogden, UT: United States Department of Agriculture Forest Service, Intermountain Research Station.

Bozzo, J.A., Beasom, S.L., and Fulbright, T.E. 1992. White-tailed deer use of rangeland following browse rejuvenation. *Journal of Range Management* 45:496-499.

Bramble, W.C., Byrnes, W.R., and Schuler, M.D. 1984. The bird population of a transmission right-of-way maintained by herbicides. *Journal of Arboriculture* 10(1):13-20.

Bramble, W.C., Yahner, R.H., and Byrnes, W.R. 1999. Effect of herbicide maintenance of an electric transmission line right-of-way on butterfly populations. *Journal of Arboriculture* 25(6):302-310.

Brandeis, T.J., Newton, M., Filip, G.M., and Cole, E.C. 2002. Cavity-nester habitat development in artificially made Douglas-fir snags. *Journal of Wildlife Management* 66(3):625-633.

Briggs, R.D., Hornbeck, J.W., Smith, C.T., Lemin, R.C., Jr., and McCormack, M.L., Jr. 2000. Long-term effects of forest management on nutrient cycling in spruce-fir forests. *Forest Ecology and Management* 138:285-299.

Brodie, J.D., and Walstad, J.D. 1987. Douglas-fir growth and yield response to vegetation management. In *Vegetation management for conifer production*, ed. J.D. Walstad and P.J. Kuch, 273-294. New York: John Wiley & Sons.

Brunjes, K.J., Miller, K.V., Ford, W.M., Harrington, T.B., and Edwards, M.B. 2003. Effects of thinning and herbicide application on vertebrate communities in longleaf pine plantations. *Proceedings of the Annual Conference of Southeastern Association Fish and Wildlife Agencies* 57:252-267.

Brust, G.E. 1990. Direct and indirect effects of four herbicides on the activity of carabid beetles (coleopteran: Carabidae). *Pesticide Science* 30(3):309-320.

Bunnell, F.L., Kremsater, L.L., and Wind, E. 1999. Managing to sustain vertebrate richness in forests of the Pacific Northwest: Relationships within stands. *Environmental Review* 7:97-146.

Busse, M.D., Beattie, S.E., Powers, R.F., Sanchez, F.G., and Tiarks, A.E. 2006. Microbial community responses in forest mineral soil to compaction, organic matter removal, and vegetation control. *Canadian Journal of Forest Research* 36:577-588.

Busse, M.D., Ratcliff, A.W., Shestak, C.J., and Powers, R.F. 2001. Glyphosate toxicity and the effects of long-term vegetation control on soil microbial communities. *Soil Biology and Biochemistry* 33:1777-1789.

Butler, D.W., and Verrell, P.A. 2005. Inhibitory effect of a herbicide formulation on toxicity of malathion to the worm *Eisenia fetida*. *Bulletin of Environmental Contamination and Toxicology* 75:421-428.

Campbell, D.L., Evans, J., Lindsey, G.D., and Dusenberry, W.E. 1981. *Acceptance by black-tailed deer of foliage treated with herbicides*. Research Paper PNW-290. Portland, OR: United States Department of Agriculture Forest Service, Pacific Northwest Forest and Range Experiment Station; Olympia, WA: United States Department of the Interior Fish and Wildlife Service, Forest-Animal Damage Control Research Project.

Campbell, R.A. 1990. Herbicide use for forest management in Canada: Where we are and where we are going. *Forestry Chronicle* 64:355-360.

Campbell, T.A., Laseter, B.R., Ford, W.M., Odom, R.H., and Miller, K.V. 2006. Abiotic factors influencing deer browsing in West Virginia. *Northern Journal of Applied Forestry* 23(1):20-26.

Cauble, K., and Wagner, R.S. 2005. Sublethal effects of the herbicide glyphosate on amphibian metamorphosis and development. *Bulletin of Environmental Contamination and Toxicology* 75:429-435.

Charnley, S., Fischer, A.P., and Jones, E.T. 2007. Integrating traditional and local ecological knowledge into forest biodiversity conservation in the Pacific Northwest. *Forest Ecology and Management* 246:14-28.

Chen, C.Y., Hathaway, K.M., and Folt, C.L. 2004. Multiple stress effects of Vision® herbicide, pH, and food on zooplankton and larval amphibian species from forest wetlands. *Environmental Toxicology and Chemistry* 23(4):823-831.

Chen, F.-H. 2004. *Effects of weed control on vegetation dynamics in Pacific Northwest conifer plantations*. Vegetation Management Research Cooperative Special Report 05-1. Doctor of Philosophy in Forest Science dissertation. Corvallis, OR: Oregon State University.

Churkina, G., and Running, S. 2004. Investigating the balance between timber harvest and productivity of global coniferous forests under global change. *Climatic Change* 47:167-191.

Cobb, T.P., Langor, D.W., and Spence, J.R. 2007. Biodiversity and multiple disturbances: Boreal forest ground beetle (Coleoptera: Carabidae) responses to wildfire, harvesting, and herbicide. *Canadian Journal of Forest Research* 37:1310-1323.

Colborn, T., and Short, P. 1999. Pesticide use in the U.S. and policy implications: A focus on herbicides. *Toxicology and Industrial Health* 15:241-276.

Cole, E.C., McComb, W.C., Newton, M., Chambers, C.L., and Leeming, J.P. 1997. Response of amphibians to clearcutting, burning, and glyphosate application in the Oregon Coast Range. *Journal of Wildlife Management* 61(3):656-664.

Cole, E.C., McComb, W.C., Newton, M., Leeming, J.P., and Chambers, C.L. 1998. Response of small mammals to clearcutting, burning, and glyphosate application in the Oregon Coast Range. *Journal of Wildlife Management* 62(4):1207-1216.

Cole, E.C., Newton, M., and Youngblood, A. 1999. Regenerating white spruce, paper birch, and willow in south-central Alaska. *Canadian Journal of Forest Research* 29(7):993-1001.

Conard, S.G., and Radosevich, S.R. 1982. Growth responses of white fir to decreased shading and root competition by montane chaparral shrubs. *Forest Science* 28:309-320.

Connor, J., and McMillan, L. 1988. Winter utilization by moose of glyphosate treated cutovers – An interim report. *Alces* 24:133-142.

Coulter, L.L. 1958. The role of herbicides in wildlife production through creation and stabilization of habitats. *Down to Earth* 13:4-6.

Crain, D.A., Guillette, L.J., Jr., Rooney, A.A., and Pickford, D.B. 1997. Alterations in steroidogenesis in alligators (*Alligator mississippiensis*) exposed naturally and experimentally to environmental contaminants. *Environmental Health Perspective* 105:528-533.

Crouch, G.L. 1979. Atrazine improves survival and growth of ponderosa pine threatened by vegetative competition and pocket gophers. *Forest Science* 25(1):99-111.

Cumming, H.G. 1989. First year effects on moose browse from two silvicultural applications of glyphosate in Ontario. *Alces* 25:118-132.

Cumming, H.G., Kelly, C.P., Lautenschlager, R.A., and Thapa, S. 1995. Effects of conifer release with Vision® (glyphosate) on moose forage quality. *Alces* 31:221-232.

de Solla, S.R., Martin, P.A., Fernie, K.J., Park, B.J., and Mayne, G. 2006. Effects of environmentally relevant concentrations of atrazine on gonadal development of snapping turtles (*Chelydra serpentine*). *Environmental Toxicology and Chemistry* 25(2):520-526.

Deneer, J.W. 2000. Toxicity of mixtures of pesticides in aquatic systems. *Pest Management Science* 56:516-520.

Dennis, P., Skartveit, J., McCracken, D.I., Pakeman, R.J., Beaton, K., Kunaver, A., and Evans, D.M. 2008. The effects of livestock grazing on foliar arthropods associated with bird diet in upland grasslands of Scotland. *Journal of Applied Ecology* 45(1):279-287.

DiTomaso, J.M., Marcum, D.B., Rasmussen, M.S., Healy, E.A., and Kyser, G.B. 1997. Post-fire herbicide sprays enhance native plant diversity. *California Agriculture* 51(1):6-11.

Downs, T. 2008. The phytotoxic effects of herbicide and adjuvant applications by physiological timing on the woody shrub salal (*Gaultheria shallon*). Master of Science in Forest Science thesis. Corvallis, OR: Oregon State University.

Dzantor, E.K., and Felsot, A.S. 1991. Microbial responses to large concentrations of herbicides in soil. *Environmental Toxicology and Chemistry* 10:649-655.

Easton, W.E., and Martin, K. 1998. The effect of vegetation management on breeding bird communities in British Columbia. *Ecological Applications* 8(4):1092-1103.

———. 2002. Effects of thinning and herbicide treatments on nest-site selection by songbirds in young managed forests. *The Auk* 119(3):685-694.

Eddington, D.B. 2006. Effects of cheatgrass control on Wyoming big sagebrush in southeastern Utah. Master of Science in Plant and Animal Science thesis. Provo, UT: Brigham Young University.

Edginton, A.N., Sheridan, P.M., Stephenson, G.R., Thompson, D.G., and Boermans, H.J. 2004. Comparative effects of pH and Vision herbicide on two life stages of four anuran amphibian species. *Environmental Toxicology and Chemistry* 23(4):815-822.

Edginton, A.N., Stephenson, G.R., Sheridan, P.M., Thompson, D.G., and Boermans, H.J. 2003. Effect of pH and Release® on two life stages of four anuran amphibians. *Environmental Toxicology and Chemistry* 22(11):2673-2678.

Edwards, S.L., Demarais, S., Watkins, B., and Strickland, B.K. 2004. White-tailed deer forage production in managed and unmanaged pine stands and summer food plots in Mississippi. *Wildlife Society Bulletin* 32(3):739-745.

Eijsackers, H. 1985. Effects of glyphosate on the soil fauna. In *The herbicide glyphosate*, ed. E. Grossbard and D. Atkinson, 151-158. Boston, MA: Butterworths.

Eschholz, W.E., Servello, F.A., Griffith, B., and Raymond, K.S. 1996. Winter use of glyphosate-treated clearcuts by moose in Maine. *Journal of Wildlife Management* 60(4):764-769.

Eschtruth, A.K., and Battles, J.J. 2008. Deer herbivory alters forest response to canopy decline caused by exotic insect pest. *Ecological Applications* 18(2):360-376.

Everitt, J.H. 1983. Effects of plant shredding on nutrient content of four south Texas deer browse species. *Journal of Range Management* 36:779-781.

Ewing, K. 2002. Effects of initial site treatments on early growth and three-year survival of Idaho fescue. *Restoration Ecology* 10(2):282-288.

Feng, J.C., and Thompson, D.G. 1990. Fate of glyphosate in a Canadian forest watershed. 2. Persistence in foliage and soils. *Journal of Agriculture and Food Chemistry* 38:1118-1125.

Fenning, T.M., and Gershenzon, J. 2002. Where will the wood come from? Plantation forests and the role of biotechnology. *Trends in Biotechnology* 20(7):291-296.

Fiddler, G.O., and McDonald, P.M. 1990. *Vegetation response to five methods of plantation release in northern California*. Forest Resource Development Agreement (FRDA) Report (109):59. Victoria, BC: British Columbia Ministry of Forests.

Flueck, W.T., and Smith-Flueck, J.M. 2006. Herbicides and forest biodiversity: An alternative perspective. *Wildlife Society Bulletin* 34(5):1472-1478.

Folmar, L.C., Sanders, H.O., and Julin, A.M. 1979. Toxicity of the herbicide glyphosate and several of its formulations to fish and aquatic invertebrates. *Archives of Environmental Contamination and Toxicology* 8:269-278.

Food and Agriculture Organization of the United Nations (FAO). 2001. *State of the world's forests*. Rome, Italy: Food and Agriculture Organization of the United Nations.

———. 2007. *State of the world's forests*. Rome, Italy: Food and Agriculture Organization of the United Nations.

Forson, D., and Storfer, A. 2006. Effects of atrazine and iridovirus infection on survival and life-history traits of the long-toed salamander (*Ambystoma macrodactylum*). *Environmental Toxicology and Chemistry* 25(1):168-173.

Fowlkes, M.D., Michael, J.L., Crisman, T.L., and Prenger, J.P. 2003. Effects of the herbicide imazapyr on benthic macroinvertebrates in a logged pond cypress dome. *Environmental Toxicology and Chemistry* 22(4):900-907.

Fredrickson, E., and Newton, M. 1998. *Maximizing efficiency of forest herbicides in the Sierra Nevada and Oregon: Research background and user guide*. Corvallis, OR: Oregon State University, College of Forestry, Forest Research Laboratory.

Freedman, B. 1991. Controversy over the use of herbicides in forestry, with particular reference to glyphosate usage. *Journal of Environmental Science and Health* C8:277-286.

Freemark, K., and Boutin, C. 1995. Impacts of agricultural herbicide use on terrestrial wildlife in temperate landscapes: A review with special reference to North America. *Agriculture, Ecosystems, and the Environment* 52:67-91.

Fuhlendorf, S.D., Engle, D.M., Arnold, D.C., and Bidwell, T.G. 2002. Influence of herbicide application on forb and arthropod communities of North American tallgrass prairies. *Agriculture, Ecosystems and Environment* 92:251-259.

Fulbright, T.E., Reynolds, J.P., Beasom, S.L., and Demaris, S. 1991. Mineral content of guajillo regrowth following roller chopping. *Journal of Range Management* 44:520-522.

Gardner, R.H., and Engelhardt, K.A.M. 2008. Spatial processes that maintain biodiversity in plant communities. *Perspectives in Plant Ecology, Evolution and Systematics* 9:211-228.

Gevao, B., Semple, K.T., and Jones, K.C. 2000. Bound pesticide residues in soils: A review. *Environmental Pollution* 108:3-14.

Giesy, J.P., Dobson, S., and Solomon, K.R. 2000. Ecotoxicological risk assessment for Roundup® herbicide. *Review of Environmental Contamination and Toxicology* 167:35-120.

Glenn-Lewin, D.C., Peet, R.K. and Veblen, T.T. 1992. *Plant succession: Theory and prediction*. New York: Springer.

Gourley, M., Vomocil, M., and Newton, M. 1990. Forest weeding reduces the effect of deer-browsing on Douglas fir. *Forest Ecology and Management* 36:177-185.

Gratkowski, H. 1975. *Silvicultural use of herbicides in Pacific Northwest forests*. General Technical Report PNW-37. Portland, OR: United States Department of Agriculture Forest Service, Pacific Northwest Forest and Range Experiment Station.

———. 1977. Seasonal effects of phenoxy herbicides on ponderosa pine and associated brush species. *Forest Science* 23(1):2-12.

———. 1978. Annual variation in effect of 2,4-D and 2,4,5-T on ponderosa pine. *Forest Science* 24(2):281-287.

Green, R.M. and Abdelghani, A.A. 2004. Toxicity of a mixture of 2,4-dichlorophenoxyacetic acid and monosodium methanearsonate to the red swamp crawfish, *Procambarus clarkii*. *International Journal of Environmental Research and Public Health* 1:35-38.

Grossbard, E. 1985. Effects of glyphosate on the microflora: With reference to the decomposition of treated vegetation and interaction with some plant pathogens. In *The herbicide glyphosate*, ed. E. Grossbard and D. Atkinson, 159-185. Boston, MA: Butterworths.

Grossbard, E., and Atkinson, D. (eds.). 1985. *The herbicide glyphosate*. Boston, MA: Butterworths.

Guillette, L.J., Jr., Gross, T.S., Masson, G.R., Matter, J.M., and Woodward, A.R. 1994. Developmental abnormalities of the gonad of juvenile alligators from contaminated and control lakes in Florida. *Environmental Health Perspectives* 102:680-688.

Guiseppe, K.F.L., Drummond, F.A., Stubbs, D., and Woods, S. 2006. *The use of glyphosate herbicides in managed forest ecosystems and their effects on non-target organisms with particular reference to ants as bioindicators*. Technical Bulletin 192. Orono, ME: University of Maine, Maine Agricultural and Forest Experiment Station.

Guynn, D.C., Jr., Guynn, S.T., Wigley, T.B., and Miller, D.A. 2004. Herbicides and forest biodiversity – What do we know and where do we go from here? *Wildlife Society Bulletin* 32(4):1085-1092.

Haney, R.L., Senseman, S.A., Hons, F.M., and Zuberer, D.A. 2000. Effect of glyphosate on soil microbial activity and biomass. *Weed Science* 48:89-93.

Harper, M.G., Dietrich, C.H., Larimore R.L., and Tessene, P.A. 2000. Effects of prescribed fire on prairie arthropods: An enclosure study. *Natural Areas Journal* 20(4):325-335.

Harrington, T.B. 2006. Five-year growth responses of Douglas-fir, western hemlock, and western redcedar seedlings to manipulated levels of overstory and understory competition. *Canadian Journal of Forest Research* 36:2439-2453.

Harrington, T.B., Minogue, P.J., Lauer, D.K., and Ezell, A.W. 2001. Separate effects of broadcast burning and imazapyr tank mixtures on vegetation development after clearcutting. In *Proceedings of the 8th biennial southern silvicultural research conference*, ed. M.B. Edwards, 108-110. General Technical Report SRS-1. United States Department of Agriculture Forest Service.

Harrington, T.B., Wagner, R.G., Radosevich, S.R., and Walstad, J.D. 1995. Interspecific competition and herbicide injury influence 10-year responses of coastal Douglas-fir and associated vegetation to release treatments. *Forest Ecology and Management* 76:55-67.

Haughton, A.J., Bell, J.R., Boatman, N.D., and Wilcox, A. 2001. The effect of the herbicide glyphosate on non-target spiders: Part III. Indirect effects on *Lepthyphantes tenuis* in field margins. *Pest Management Science* 57(11):1037-1042.

Hayes, T.B. 2004. There is no denying this: Defusing the confusion about atrazine. *Bioscience* 54:1138-1149.

Hayes, T.B., Collins, A., Mendoza, M., Noriega, N. Stuart, A.A. and Vonk, A. 2002. Hermaphroditic, demasculinized frogs exposure to the herbicide atrazine at low ecologically relevant doses. *Proceedings of the National Academy of Science* USA 99:5476-5480.

Hayes, T.B., Haston, K., Tsui, M., Hoang, A., Haeffele, C., and Vonk, A. 2003. Atrazine-induced hermaphroditism at 0.1 ppb in American leopard frogs (Rana pipiens): Laboratory and field evidence. *Environmental Health Perspectives* 111:568-575.

Hildebrand, L.D., Sullivan, D.S., and Sullivan, T.P. 1982. Experimental studies of rainbow trout populations exposed to field applications of Roundup® herbicide. *Archives of Environmental Contamination and Toxicology* 11:93-98.

Hood, S.A., Miller, D.A., Leopold, B.D., and Burger, L.W. 2002. Small mammal and herpetile response to mid-rotation pine management in Mississippi. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 56:171-186.

Hosea, R.C., Bjurstrom, K.Z., and Littrell, E.E. 2004. *Acute oral and dermal toxicity of aquatic herbicides and a surfactant to garter snakes*. California Department of Fish and Game Office of Spill Prevention and Response Administrative Report 2004-01.

House, W.B., Goodson, L.H., Gadberry, H.M., and Dockter, K.W. 1967. *Assessment of ecological effects of extensive or repeated use of herbicides*. Kansas City, MO: Midwest Research Institute.

Howard, K.M., and Newton, M. 1984. Overtopping by successional Coast-Range vegetation slows Douglas-fir seedlings. *Journal of Forestry* 82:178-180.

Howe, C.M., Berrill, M., Pauli, B.D., Helbing, C.C., Werry, K., and Veldhoen, N. 2004. Toxicity of glyphosate-based pesticides to four North American frog species. *Environmental Toxicology and Chemistry* 23(8):1928-1938.

Howe, G.E., Gillis, R., and Mowbray, R.C. 1998. Effect of chemical synergy and larval stage on the toxicity of atrazine and alachlor to amphibian larvae. *Environmental Toxicology and Chemistry* 17(3):519-525.

Huddleston, R.T., and Young, T.P. 2005. Weed control and soil amendment effects on restoration plantings in an Oregon grassland. *Western North American Naturalist* 65(4):507-515.

Hull, A.C., Jr. 1971. Effect of spraying with 2,4-D upon abundance in pocket gophers in Franklin Basin, Idaho. *Journal of Range Management* 24:230-232.

Hurst, G.A., and Warren, R.C. 1986. Deer forage on pine plantations after a herbicide application for pine release. *Proceedings of the Southern Weed Science Society* 39:238.

Ice, G., Dent, L., Robben, J., Cafferata, P., Light, J., Sugden, B., and Cundy, T. 2004. Programs assessing implementation and effectiveness of state forest practices rules and BMPs in the West. *Water, Air and Soil Pollution: Focus* 4(1):143-169.

Ice, G., Thistle, H., and Karsky, R. 2008. Reduction in chemical drift by a vegetative buffer. In *Proceedings of the American Water Resources Association 2008 summer specialty conference – Riparian ecosystems and buffers: Working at the water's edge* (on CD), ed. J. Okay and A. Todd. Middleburg, VA: American Water Resources Association.

Janz, D.M., Farrell, A.P., Morgan, J.D., and Vigers, G.A. 1991. Acute physiological stress responses of juvenile coho salmon (*Ohcorhynchus kistutch*) to sublethal concentrations of Garlon 4®, Garlon 3A®, and Vision® herbicides. *Environmental Toxicology and Chemistry* 10:81-91.

Jeltsch, F., Moloney, K.A., Schurr, F.M., Köchy, M., and Schwager, M. 2008. The state of plant population modelling in light of environmental change. *Perspectives in Plant Ecology, Evolution and Systematics* 9:171-189.

Jennings, M.D., Hoekstra, J., Higgins, J., and Boucher, T. 2008. A comparative measure of biodiversity based on species composition. *Biodiversity and Conservation* 17:833-840.

Johnson, D.R. 1964. Effects of range treatment with 2,4-D on food habits of rodents. *Ecology* 45(2):241-249.

Johnson, D.R., and Hansen, R.M. 1969. Effects of range treatment with 2,4-D on rodent populations. *Journal of Wildlife Management* 33(1):125-132.

Jones, J.D.J., and Chamberlain, M.J. 2004. Efficacy of herbicides and fire to improve vegetative conditions for northern bobwhites in mature pine forests. *Wildlife Society Bulletin* 32(4):1077-1084.

Kalisz, P.J., and Powell, J.E. 2000. Effects of prescribed fire on soil invertebrates in upland forests on the Cumberland Plateau of Kentucky, USA. *Natural Areas Journal* 20(4):336-341.

Keith, J.O., Hansen, R.M., and Ward, A.L. 1959. Effect of 2,4-D on abundance and foods of pocket gophers. *Journal of Wildlife Management* 23(2):137-145.

Kelly, C.P., and Cumming, H.G. 1994. Effects of Vision® application on moose winter browsing and hardwood vegetation. *Alces* 30:173-188.

Kenaga, E.E. 1975. The evaluation of the safety of 2,4,5-T to birds in areas treated for vegetation control. *Residue Reviews* 59:1-19.

Ketchum, J.S., Rose, R., and Kelpsas, B. 2000. Comparison of adjuvants used in fall-release herbicide mixtures for forest site preparation. *Tree Planters' Notes* 49(3):66-71.

Keyser, P.D., and Ford, V.L. 2006. Wildlife habitat and herbicides: An evaluation of a widely applied tank mix. *Southern Journal of Applied Forestry* 30(1):46-51.

King, S.P., and Radosevich, S.R. 1985. Herbicide tolerance in relation to growth and stress in conifers. *Weed Science* 33:472-478.

Kline, W.N., Fears, R.D., and Zedaker, S.M. 1985. Procedures for evaluating woody plant control in forest management systems. *Down to Earth* 41(2):9-15.

Krefting, L.W., and Hansen, H.L. 1969. Increasing browse for deer by aerial applications of 2,4-D. *Journal of Wildlife Management* 33(4):784-790.

Krefting, L.W., Hansen, H.L., and Hunt, R.W. 1961. Aerial applications of 2,4-D to improve the browse supply for deer. In *Proceedings of the Society of American Foresters Meeting*, 103-106. Washington, DC: Society of American Foresters.

Krefting, L.W., Hansen, H.L., and Stenlund, M.H. 1956. Stimulating regrowth of mountain maple for deer browse by herbicides, cutting and fire. *Journal of Wildlife Management* 20(4):434-441.

Kufeld, R.C. 1977. Improving gambel oak ranges for elk and mule deer by spraying with 2,4,5-TP. *Journal of Range Management* 30(1):53-57.

Lautenschlager, R.A. 1992. Effects of conifer release with herbicides on moose: Browse production, habitat use, and residues in meat. *Alces* 28:215-222.

———. 1993. Response of wildlife to forest herbicide applications in northern coniferous ecosystems. *Canadian Journal of Forest Research* 23:2286-2299.

Lautenschlager, R.A., Bell, F.W., and Wagner, R.G. 1997. Alternative conifer release treatments affect small mammals in northwestern Ontario. *Forestry Chronicle* 73(1):99-106.

Lautenschlager, R.A., Dalton, W.J., Cherry, M.L., and Graham, J.L. 1999. Conifer release alternatives to increase aspen forage quality in northwestern Ontario. *Journal of Wildlife Management* 63(4):1320-1326.

Lautenschlager, R.A., and Sullivan, T.P. 2002. Effects of herbicide treatments on biotic components in regenerating northern forests. *Forestry Chronicle* 78(5):695-731.

———. 2004. Improving research into effects of forest herbicide use on biota in northern ecosystems. *Wildlife Society Bulletin* 32(4):1061-1070.

Loya, D.T., and Jules, E.S. 2008. Use of species richness estimators improves evaluation of understory plant response to logging: A study of redwood forests. *Plant Ecology* 194:179-194.

Lyon, L.J., and Mueggler, W.F. 1968. Herbicide treatment of north Idaho browse evaluated six years later. *Journal of Wildlife Management* 32(2):538-541.

Macek, K.J., Hutchinson, C., and Cope, O.B. 1969. The effects of temperature on the susceptibility of bluegills and rainbow trout to selected pesticides. *Bulletin of Environmental Contamination and Toxicology* 4(3):174-183.

MacKinnon, D.S., and Freedman, B. 1993. Effects of silvicultural use of the herbicide glyphosate on breeding birds of regenerating clearcuts in Nova Scotia, Canada. *Journal of Applied Ecology* 30:395-406.

Marrs, R.H., and Frost, A.J. 1997. A microcosm approach to the detection of the effects of herbicide spray drift in plant communities. *Journal of Environmental Management* 50(4):369-388.

Masters, R.A., Nissen, S.J., Gaussoin, R.E., Beran, D.D., and Stougaard, R.N. 1996. Imidazolinone herbicides improve restoration of Great Plains grasslands. *Weed Technology* 10(2):392-403.

McColl, J.G., and Powers, R.F. 1984. Consequences of forest management on soil-tree relationships. In *Nutrition of plantation forests*, ed. G.D. Bowen and E.K.S. Nambiar, 379-412. New York: Academic Press.

McComb, B.C., Curtis, L., Chambers, C.L., Newton, M., and Bentson, K. 2008. Acute toxic hazard evaluations of glyphosate herbicide on terrestrial vertebrates of the Oregon Coast Range. *Environmental Science and Pollution Research* 15(3):266-272.

McCormack, M., Jr. 1994. Reductions in herbicide use for forest vegetation management. *Weed Technology* 8:344-349.

McDonald, P.M., and Everest, G.A. 1996. *Response of young ponderosa pines, shrubs, and grasses to two release treatments*. Research Note PSW-RN-419. Albany, CA: United States Department of Agriculture Forest Service, Pacific Southwest Research Station.

McDonald, P.M., and Fiddler, G.O. 1989. *Competing vegetation in ponderosa pine plantations: Ecology and control*. General Technical Report PSW-113. Berkeley, CA: United States Department of Agriculture Forest Service, Pacific Southwest Forest and Range Experiment Station.

———. 1996. *Development of a mixed shrub-tanoak-Douglas-fir community in a treated and untreated condition*. Research Paper PSW-RP-225-Web. Albany, CA: United States Department of Agriculture Forest Service, Pacific Southwest Research Station.

———. 2001. *Timing and duration of release treatments affect vegetation development in a young California white fir plantation*. Research Paper PSW-RP-246. Washington DC: United States Department of Agriculture Forest Service, Pacific Southwest Research Station.

———. 2006. Plant species diversity in young conifer plantations in northern and central California. *Western Journal of Applied Forestry* 21(1):49-54.

McDonald, P.M., Fiddler, G.O., and Meyer, P.W. 1996. *Vegetation trends in a young conifer plantation after grazing, grubbing, and chemical release*. Research Paper PSW-RP-228-Web. Albany, CA: United States Department of Agriculture Forest Service, Pacific Southwest Research Station.

Michael, J.L., and Neary, D.G. 1993. Herbicide dissipation studies in southern forest ecosystems. *Environmental Toxicology and Chemistry* 12:405-410.

Mihajlovich, M., and Blake, P. 2004. An evaluation of the potential of glyphosate herbicide for woodland caribou habitat management. *Alces* 40:7-11.

Miller, D.A., and Wigley, T.B. 2004. Introduction: Herbicides and forest biodiversity. *Wildlife Society Bulletin* 32(4):1016-1019.

Miller, J.H. 2001. Long-term effects of forest herbicides on plant diversity in pine plantations in the southeast. In *Proceedings of the 2000 NCASI Southern Regional Meeting*, 208-213. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

———. 2003. *Nonnative invasive plants in southern forests: A field guide for identification and control*. Revised General Technical Report SRS-62. Washington, DC: United States Department of Agriculture Forest Service, Southern Research Station.

Miller, K.V., and Miller, J.H. 2004. Forestry herbicide influences on biodiversity and wildlife habitat in southern forests. *Wildlife Society Bulletin* 32(4):1049-1060.

Miller, P., and Westra, P. 1998. *Herbicide formulations*. Number 0.558. Fort Collins, CO: Colorado State University Extension.

Moloney, K.A., and Jeltsch, F. 2008. Space matters – Novel developments in plant ecology through spatial modeling. *Perspectives in Plant Ecology, Evolution and Systematics* 9:119-120.

Monaco, T.J., Weller, S.C., and Ashton, F.M. 2002. *Weed science: Principles and practices,* 4th ed. New York: John Wiley & Sons, Inc.

Monleon, V.J., Newton, M., Hooper, C., and Tappeiner, J.C. II. 1999. Ten-year growth response of young Douglas-fir to variable density varnishleaf ceanothus and herb competition. *Western Journal of Applied Forestry* 14(4):208-213.

Moore, N.P., Hart, J.D., and Langton, S.D. 1999. Factors influencing browsing by fallow deer *Dama dama* in young broad-leaved plantations. *Biological Conservation* 87(2):255-260.

Morrison, M.L., and Meslow, E.C. 1983a. Impacts of forest herbicides on wildlife: Toxicity and habitat alteration. *Transactions of the North American Wildlife and Natural Resources Conference* 48:175-185.

———. 1983b. Bird community structure on early-growth clearcuts in western Oregon. *American Midland Naturalist* 110(1):129-137.

———. 1984a. Effects of the herbicide glyphosate on bird community structure, western Oregon. *Forest Science* 30(1):95-106.

———. 1984b. Response of avian communities to herbicide-induced vegetation changes. *Journal of Wildlife Management* 48(1):14-22.

Mueggler, W.F. 1966. Herbicide treatment of browse on a big-game winter range in northern Idaho. *Journal of Wildlife Management* 30(1):141-151.

Mullison, W.R. 1970. The significance of herbicides to non-target organisms. *Northeast Weed Control Conference Proceedings* 24:111-147.

Munson, A.D., Margolis, H.A., and Brand, D.G. 1993. Intensive silvicultural treatment: Impacts on soil fertility and planted conifer response. *Soil Science Society of America Journal* 57:246-255.

Nabel, M.R. 2008. Establishment and growth of natural and planted conifers ten years after overstory thinning and vegetation control in 50-year-old Douglas-fir stands. Master of Science in Forest Science thesis. Corvallis, OR: Oregon State University.

National Council for Air and Stream Improvement, Inc. (NCASI). 2003. *The toxicity of silvicultural herbicides to wildlife. Volume I: Introduction and triclopyr*. Technical Bulletin No. 861. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

———. 2004. *The toxicity of silvicultural herbicides to wildlife. Volume II: Glyphosate and imazapyr*. Technical Bulletin No. 886. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

Neary, D.G., and Michael, J.L. 1996. Herbicides – Protecting long-term sustainability and water quality in forest ecosystems. *New Zealand Journal of Forestry Science* 26(1/2):241-264.

Newton, M. 1968. Defoliation effects on forest ecology. *Science* 161:109.

Newton, M., and Cole, E.C. 2005. Linkage between riparian buffer features and regeneration, benthic communities, and water temperature in headwater streams, western Oregon. In *Productivity of western forests: A forest products focus*, C.A. Harrington and Schoenholtz, S.H. (tech. eds.), 81-101. General Technical Report PNW-GTR-642. United States Department of Agriculture Forest Service.

Newton, M., Cole, E.C., Lautenschlager, R.A., White, D.E., and McCormack, M.L. 1989. Browse availability after conifer release in Maine's spruce-fir forests. *Journal of Wildlife Management* 53(3):643-649.

Newton, M., Cole, E.C., McCormack, M.L., Jr., and White, D.E. 1992a. Young spruce-fir forests released by herbicides. II. Conifer response to residual hardwoods and overstocking. *Northern Journal of Applied Forestry* 9:130-135.

Newton, M., Cole, E.C., White, D.E., and McCormack, M.L., Jr. 1992b. Young spruce-fir forests released by herbicides. I. Response of hardwoods and shrubs. *Northern Journal of Applied Forestry* 9:126-129.

Newton, M., and Dost, F.N. 1984. *Biological and physical effects of forest vegetation management. Final report*. Olympia, WA: Washington Department of Natural Resources.

Newton, M., and Holt, H.A. 1971. Scolytid and Buprestid mortality in ponderosa pines injected with organic arsenicals. *Journal of Economic Entomology* 64(4):952-958.

Newton, M., Howard, K.M., Kelpsas, B.R., Danhaus, R., Lottman, C.M., and Dubelman, S. 1984. Fate of glyphosate in an Oregon forest ecosystem. *Journal of Agriculture and Food Chemistry* 32:1144-1151.

Newton, M., and Knight, F.B. 1981. *Handbook of weed and insect control chemicals for forest resource managers*. Beaverton, OR: Timber Press.

Newton, M., and Norgren, J.A. 1977. *Silvicultural chemicals and protection of water quality*. Report EPA 77. Seattle, WA: United States Environmental Protection Agency.

Newton, M., and Norris, L.A. 1968. Herbicide residues in blacktail deer from forests treated with 2,4,5-T and atrazine. *Proceedings of the Western Society of Weed Science* 22:32-34.

———. 1976. Evaluating short- and long-term effects of herbicides on nontarget forest and range biota. *Down to Earth* 32(3):18-26.

Newton, M., and Overton, W.S. 1973. Direct and indirect effects of atrazine, 2,4-D, and dalapon mixtures on conifers. *Weed Science* 21(4):269-275.

Newton, M., and Preest, D.S. 1988. Growth and water relations of Douglas-fir (*Pseudotsuga menziesii*) seedlings under different weed control regimes. *Weed Science* 36:653-662.

Newton, M., and Snyder, S.P. 1978. Exposure of forest herbivores to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) in areas sprayed with 2,4,5-T. *Bulletin of Environmental Contamination and Toxicology* 20:743-750.

Newton, M., Willis, R., Walsh, J., Cole, E., and Chan, S. 1996. Enhancing riparian habitat for fish, wildlife, and timber in managed forests. *Weed Technology* 10:429-438.

Nilsson, S., and Bull, G. 2005. Global wood supply analysis. Presentation at the 46th Session of the Food and Agriculture Organization of the United Nations (FAO) Advisory Committee, Vancouver, Canada.

Norris, L.A. 1967. Chemical brush control and herbicide residues in the forest environment. In *Symposium proceedings: Herbicides and vegetation management in forests, ranges, and noncrop lands*, 103-123. Corvallis, OR: Oregon State University.

———. 1971. Chemical brush control: Assessing the hazard. *Journal of Forestry* 69:715-720.

———. 1981a. The movement, persistence, and fate of the phenoxy herbicides and TCDD in the forest. *Residue Reviews* 80:65-135.

———. 1981b. The behavior of herbicides in the forest environment and risk assessment. In *Proceedings of the John S. Wright Forestry Conference, Weed control in forest management*, 192-215. West Lafayette, IN: Purdue University.

Norris, L.A., Montgomery, M.L., and Johnson, E.R. 1977. The persistence of 2,4,5-T in a Pacific Northwest forest. *Weed Science* 25(1):417-422.

O’Dea, M.E., Newton, M., Cole, E.C., and Gourley, M. 2000. The influence of weeding on growth of browsed seedlings in Douglas-fir plantations. *Western Journal of Applied Forestry* 15(3):163-168.

Oester, P.T., Emmingham, W., Larson, P., and Clements, S. 1995. Performance of ponderosa pine seedlings under four herbicide regimes in northeast Oregon. *New Forests* 10:123-131.

Ohtonen, R., Munson, A., and Brand, D. 1992. Soil microbial community response to silvicultural intervention in coniferous plantation ecosystems. *Ecological Applications* 2(4):363-375.

Oliver, C.D., and Larson, B.C. 1996. *Forest stand dynamics*, updated ed. Hoboken, NJ: John Wiley & Sons, Inc.

Oliver, W.W. 1990. Spacing and shrub competition influence 20-year development of planted ponderosa pine. *Western Journal of Applied Forestry* 5(3):79-82.

Olson, R.A., and Whitson, T.D. 2002. Restoring structure in late-successional sagebrush communities by thinning with Tebuthiuron. *Restoration Ecology* 10(1):146-155.

Panzer, R. 2002. Compatibility of prescribed burning with the conservation of insects in small, isolated prairie reserves. *Conservation Biology* 16(5):1296-1307.

Pérez, G.L., Torremorell, A., Mugni, H., Rodríguez, P., Vera, M.S., Do Nascimento, M., Allende, L., Bustingorry, J., Escaray, R., Ferrara, M., Izaguirre, I., Pizarro, H., Bonetto, C., Morris, D.P., and Zagarese, H. 2007. Effects of the herbicide Roundup® on freshwater microbial communities: A mesocosm study. *Ecological Applications* 17(8):2310-2322.

Perie, C. and Munson, A.D. 2000. Ten-year responses of soil quality and conifer growth to silvicultural treatments. *Soil Science Society of America Journal* 64:1815-1826.

Perkins, P.J., Boermans, H.J., and Stephenson, G.R. 2000. Toxicity of glyphosate and triclopyr using the frog embryo teratogenesis assay-Xenopus. *Environmental Toxicology and Chemistry* 19(4):940-945.

Petersen, T.D., and Newton, M. 1985. Growth of Douglas-fir following control of snowbrush and herbaceous vegetation in Oregon. *Down to Earth* 41(1):21-25.

Peterson, H.G., Boutin, C., Freemark, K.E., and Martin, P.A. 1997. Toxicity of hexazinone and diquat to green algae, diatoms, cyanobacteria and duckweed. *Aquatic Toxicology* 39:111-134.

Pietrzykowski, E., McArthur, C., Fitzgerald, H., and Goodwin, A.N. 2003. Influence of patch characteristics on browsing of tree seedlings by mammalian herbivores. *Journal of Applied Ecology* 40:458-469.

Plumb, T.R., Norris, L.A., and Montgomery, M.L. 1977. Persistence of 2,4-D and 2,4,5-T in chaparral soil and vegetation. *Bulletin of Environmental Contamination and Toxicology* 17(1):1-8.

Poff, R.J. 1996. Effects of silvicultural practices and wildfire on productivity of forest soils. Chapter 16 in *Sierra Nevada Ecosystem Project: Final report to Congress, Vol. II, Assessments and scientific basis for management options*, 477-494. Davis, CA: University of California, Centers for Water and Wildland Resources.

Ponder, F., Jr. 2002. Implications of silvicultural pesticides on forest soil, animals, insects, fungi, and other organisms and ramifications of soil fertility and health. *Community Soil Science. Plant Analysis* 33(11&12):1927-1940.

Powers, R.F., and Reynolds, P.E. 1999. Ten-year responses to repeated vegetation and nutrient control along an environmental gradient. *Canadian Journal of Forest Research* 29:1027-1038.

Pratt, J.R., Melendez, A.E., Barreiro, R., and Bowers, N.J. 1997. Predicting the ecological effects of herbicides. *Ecological Applications* 7(4):1117-1124.

Preest, D.S. 1977. Long-term growth response of Douglas-fir to weed control. *New Zealand Journal of Forestry Science* 7(3):329-332.

Radosevich, S.R., Holt, J.S. and Ghersa, C. 1997. *Weed ecology: Implications for management,* 2nd ed. New York: John Wiley & Sons, Inc.

Radosevich, S.R., Roncoroni, E.J., Conard, S.G., and McHenry, W.B. 1980. Seasonal tolerance of six coniferous species to eight foliage-active herbicides. *Forest Science* 26(1):3-9.

Radosevich, S.R., and Winterlin, W.I. 1977. Persistence of 2,4-D and 2,4,5-T in chaparral vegetation and soil. *Weed Science* 25(5):423-425.

Rashin, E., and Graber, C. 1993. *Effectiveness of best management practices for aerial application of forest pesticides*. TFW-WQ1-93-001. Olympia, WA: Washington Department of Ecology.

Raymond, K.S., and Servello, F.A. 1997. Nutritional quality of glyphosate-injured browse for moose in Maine. *Alces* 33:181-185.

Raymond, K.S., Servello, F.A., Griffith, B., and Eschholz, W.E. 1996. Winter foraging ecology of moose on glyphosate treated clearcuts in Maine. *Journal of Wildlife Management* 60(4):753-763.

Rea, R.V., and Gillingham, M.P. 2001. The impact of the timing of brush management on the nutritional value of woody browse for moose *Alces alces*. *Journal of Applied Ecology* 38:710-719.

Relyea, R.A. 2005a. The impact of insecticides and herbicides on the biodiversity and productivity of aquatic communities. *Ecological Applications* 15:618-627.

———. 2005b. The lethal impacts of Roundup® and predatory stress on six species of North American tadpoles. *Archives of Environmental Contamination and Toxicology* 48:351-357.

———. 2005c. The lethal impact of Roundup® on aquatic and terrestrial amphibians. *Ecological Applications* 15:1118-1124.

Relyea, R.A., Schoeppner, N.M., and Hoverman, J.T. 2005. Pesticides and amphibians: The importance of community context. *Ecological Applications* 15:1125-1134.

Rhoades, C., Barnes, T., and Washburn, B. 2002. Prescribed fire and herbicide effects on soil processes during barrens restoration. *Restoration Ecology* 10(4):656-664.

Rice, P.M., Toney, J.C., Bedunah, D.J., and Carlson, C.E. 1997. Plant community diversity and growth form responses to herbicide applications for control of *Centaurea maculosa*. *Journal of Applied Ecology* 34:1397-1412.

Ritchie, C., and Sullivan, T.P. 1989. *Monitoring methodology for assessing the impact of forest herbicide use on small mammal populations in British Columbia*. British Columbia Forest Resource Development Agreement (FRDA) Report 081. Victoria, BC: British Columbia Ministry of Forests.

Ritchie, D.C., Harestad, A.S., and Archibald, R. 1987. Glyphosate treatment and deer mice in clearcut and forest. *Northwest Science* 61(3):199-202.

Roberts, S.D., Harrington, C.A., and Terry, T.A. 2005. Harvest residue and competing vegetation affect soil moisture, soil temperature, N availability, and Douglas-fir seedling growth. *Forest Ecology and Management* 205:333-350.

Rohr, J.R. and Crumrine, P.W. 2005. Effects of an herbicide and an insecticide on pond community structure and processes. *Ecological Applications* 15:1135-1147.

Rose, R., and Ketchum, J.S. 2002. Interaction of vegetation control and fertilization on conifer species across the Pacific Northwest. *Canadian Journal of Forest Research* 32:136-152.

———. 2003. Interaction of initial seedling diameter, fertilization and weed control on Douglas-fir growth over the first four years after planting. *Annals of Forest Science* 60:625-635.

Roshon, R.D., McCann, J.H., Thompson, D.G., and Stephenson, G.R. 1999. Effects of seven forestry management herbicides on *Myriophyllum sibiricum*, as compared with other nontarget aquatic organisms. *Canadian Journal of Forest Research* 29:1158-1169.

Rosner, L.S., and Rose, R. 2006. Synergistic stem volume response to combinations of vegetation control and seedling size in conifer plantations in Oregon. *Canadian Journal of Forest Research* 36:930-944.

Roth, B.E., and Newton, M. 1996. Role of lammas growth in recovery of Douglas-fir seedlings from deer browsing, as influenced by weed control, fertilization, and seed source. *Canadian Journal of Forest Research* 26:936-944.

Rowland, E.L., White, A.S., and Livingston, W.H. 2005. *A literature review of the effects of intensive forestry on forest structure and plant community composition at the stand and landscape levels*. Miscellaneous Publication 754. University of Maine, Maine Agricultural and Forest Experiment Station.

Royo, A.A., and Carson, W.P. 2006. On the formation of dense understory layers in forests worldwide: Consequences and implications for forest dynamics, biodiversity, and succession. *Canadian Journal of Forest Research* 36:1345-1362.

Runciman, J.B., and Sullivan, T.P. 1996. Influence of alternative conifer release treatments on habitat structure and small mammal populations in south central British Columbia. *Canadian Journal of Forest Research* 26:2023-2034.

Santillo, D.J. 1994. Observations on moose, *Alces alces*, habitat and use on herbicide-treated clearcuts in Maine. *Canadian Field-Naturalist* 108(1):22-25.

Santillo, D.J., Brown, P.W., and Leslie, D.M., Jr. 1989. Response of songbirds to glyphosate-induced habitat changes on clearcuts. *Journal of Wildlife Management* 53(1):64-71.

Santillo, D.J., Leslie, D.M., Jr., and Brown, P.W. 1989. Responses of small mammals and habitat to glyphosate application on clearcuts. *Journal of Wildlife Management* 53(1):164-172.

Savidge, J.A. 1978. Wildlife in a herbicide-treated Jeffrey pine plantation in eastern California. *Journal of Forestry* 76:476-478.

Schroeder, M.H. 1972. Relationships of range and forest management with herbicides on wildlife. *Proceedings of the Western Society of Weed Science* 25:11-15.

Schroeder, M.H., and Sturges, D.L. 1975. The effect on the Brewer's sparrow of spraying big sagebrush. *Journal of Range Management* 28(4):294-297.

Schuytema, G.S., and Nebeker, A.V. 1998. Comparative toxicity of diuron on survival and growth of Pacific treefrog, bullfrog, red-legged frog, and African clawed frog embryos and tadpoles. *Archives of Environmental Contamination and Toxicology* 34:370-376.

Shaffers, A.P., Raemakers, I.P., and Sykora, K.V. 2008. Arthropod assemblages are best predicted by plant species composition. *Ecology* 89(3):782-794.

Shepard, J.P., Creighton, J., and Duzan, H. 2004. Forestry herbicides in the United States: An overview. *Wildlife Society Bulletin* 32(4):1020-1027.

Sigg, J. 1999. The role of herbicides in preserving biodiversity. *California Exotic Plant Pest Council News* 10-13.

Simard, S.W., Hagerman, S.M., Sachs, D.L., Heineman, J.L., and Mather, W.J. 2005. Conifer growth, *Armillaria ostoyae* root disease, and plant diversity responses to broadleaf competition reduction in mixed forests of southern interior British Columbia. *Canadian Journal of Forest Research* 35:843-859.

Slagsvold, T. 1977. Bird population changes after clearance of deciduous shrub. *Biological Conservation* 12:229-244.

Society of American Foresters (SAF). 1978. *Herbicide use in forest management. A position statement*. Bethesda, MD: Society of American Foresters. www.safnet.org.

Solomon, K.R., and Thompson, D.G. 2003. Ecological risk assessment for aquatic organisms from over-water uses of glyphosate. *Journal of Toxicology and Environmental Health*, Part B 6:289-324.

Solomon, K.R., Baker, D.B., Richards, R.P., Dixon, K.R., Klaine, S.J., La Point, T.W., Kendall, R.J., Weisskopf, C.P., Giddings, J.M., Giesy, J.P., Hall, Jr., L.W., and Williams, W.M. 1996. Ecological risk assessment of atrazine in North American surface waters. *Environmental Toxicology and Chemistry* 15:31-76.

Solomon, K.R., Carr, J.A., Du Preez, L.H., Giesy, J.P., Kendall, R.J., Smith, E.E., and Van Der Kraak, G.J. 2008. Effects of atrazine on fish, amphibians, and aquatic reptiles: A critical review. *Critical Reviews in Toxicology* 38:721-772.

Soper, R.B., Lochmiller, R.L., Leslie, D.M., and Engle, D.M. 1993. Nutritional quality of browse after brush management on Cross Timbers rangeland. *Journal of Range Management* 46(5):399-410.

Sparling, D.W., Matson, C., Bickham, J., and Doelling-Brown, P. 2006. Toxicity of glyphosate as Glypro® and LI700 to Red-Eared Slider (*Trachemys scripta elegans*) embryos and early hatchlings. *Environmental Toxicology and Chemistry* 25:2768-2774.

Stein, W.I. 1999. *Six-year growth of Douglas-fir saplings after manual or herbicide release from coastal shrub competition*. Research Paper PNW-RP-500. Portland, OR: United States Department of Agriculture Forest Service, Pacific Northwest Research Station.

Stewart, K.M., Fulbright, T.E., and Drawe, D.L. 2000. White-tailed deer use of clearings relative to forage availability. *Journal of Wildlife Management* 64(3):733-741.

Stewart, K.M., Fulbright, T.E., Drawe, D.L., and Bowyer, R.T. 2003. Sexual segregation in white-tailed deer: Responses to habitat manipulations. *Wildlife Society Bulletin* 31(4):1210-1217.

Stewart, R.E., Gross, L.L., and Honkala, B.H. 1984. *Effects of competing vegetation on forest trees: A bibliography with abstracts*. General Technical Report WO-43. United States Department of Agriculture Forest Service.

Stohlgren, T.J., Bull, K.A., and Otsuki, Y. 1998. Comparison of rangeland vegetation sampling techniques in the central grasslands. *Journal of Range Management* 51(2):164-172.

Strong, W.L., and Gates, C.C. 2006. Herbicide-induced changes to ungulate forage habitat in western Alberta, Canada. *Forest Ecology and Management* 222:469-475.

Sullivan, T.P. 1985. Effects of glyphosate on selected species of wildlife. In *The herbicide glyphosate*, ed. E. Grossbard and D. Atkinson, 186-199. Boston, MA: Butterworths.

———. 1990a. Demographic responses of small mammal populations to a herbicide application in coastal coniferous forest: Population density and resiliency. *Canadian Journal of Zoology* 68:874-883.

———. 1990b. Influence of forest herbicide on deer mouse and Oregon vole population dynamics. *Journal of Wildlife Management* 54(4):566-576.

———. 1994. Influence of herbicide-induced habitat alteration on vegetation and snowshoe hare populations in sub-boreal spruce forest. *Journal of Applied Ecology* 31(4):717-730.

———. 1996. Influence of forest herbicide on snowshoe hare population dynamics: Reproduction, growth, and survival. *Canadian Journal of Forest Research* 26:112-119.

Sullivan, T.P., and Boateng, J.O. 1996. Comparison of small-mammal community responses to broadcast burning and herbicide application in cutover forest habitats. *Canadian Journal of Forest Research* 26:462-473.

Sullivan, T.P., Lautenschlager, R.A., and Wagner, R.G. 1996. Influence of glyphosate on vegetation dynamics in different successional stages of sub-boreal spruce forest. *Weed Technology* 10:439-446.

Sullivan, T.P., and Moses, R.A. 1986. Demographic and feeding responses of a snowshoe hare population to habitat alteration. *Journal of Applied Ecology* 23:53-63.

Sullivan, T.P., Nowotny, C., Lautenschlager, R.A., and Wagner, R.G. 1998a. Silvicultural use of herbicide in sub-boreal spruce forest: Implications for small mammal population dynamics. *Journal of Wildlife Management* 62(4):1196-1206.

Sullivan, T.P., and Sullivan, D.S. 1979. The effects of glyphosate herbicide on food preference and consumption in black-tailed deer. *Canadian Journal of Zoology* 57:1406-1412.

———. 1981. Responses of a deer mouse population to a forest herbicide application: Reproduction, growth, and survival. *Canadian Journal of Zoology* 59:1148-1154.

———. 1982. Responses of small-mammal populations to a forest herbicide application in a 20-year-old conifer plantation. *Journal of Applied Ecology* 19:95-106.

———. 2003. Vegetation management and ecosystem disturbance: Impact of glyphosate herbicide on plant and animal diversity in terrestrial systems. *Environmental Reviews* 11:37-59.

Sullivan, T.P., Sullivan, D.S., Lautenschlager, R.A., and Wagner, R.G. 1997. Long-term influence of glyphosate herbicide on demography and diversity of small mammal communities in coastal coniferous forest. *Northwest Science* 71(1):6-17.

Sullivan, T.P., Sullivan, D.S., Lindgren, P.M.F., and Boateng, J.O. 2002. Influence of conventional and chemical thinning on stand structure and diversity of plant and mammal communities in young lodgepole pine forest. *Forest Ecology and Management* 170:173-187.

Sullivan, T.P., Wagner, R.G., Pitt, D.G., Lautenschlager, R.A., and Chen, D.G. 1998b. Changes in diversity of plant and small mammal communities after herbicide application in sub-boreal spruce forest. *Canadian Journal of Forest Research* 28:168-177.

Sutton, R.F. 1978. Glyphosate herbicide: An assessment of forestry potential. *Forestry Chronicle* 54:24-28.

Swengel, A.B. 2001. A literature review of insect responses to fire, compared to other conservation managements of open habitat. *Biodiversity and Conservation* 10: 1141-1169.

Tappeiner, J., Zasada, J., Ryan, P., and Newton, M. 1991. Salmonberry clonal and population structure: The basis for a persistent cover. *Ecology* 72(2):609-618.

Tatum, V.L. 2004. Toxicity, transport, and fate of forest herbicides. *Wildlife Society Bulletin* 32(4):1042-1048.

Taylor, R.L., Maxwell, B.D., and Boik, R.J. 2006. Indirect effects of herbicides on bird food resources and beneficial arthropods. *Agriculture, Ecosystems and Environment* 116:157-164.

Teske, M.E., and Ice, G.G. 2002. A one-dimensional model for aerial spray assessment in forest streams. *Journal of Forestry* 100(3):40-45.

Teske, M.E., Thistle, H.W., and Ice, G.G. 2003. Technical advances in modeling aerially applied sprays. *Transactions of the American Society of Agricultural Engineers* 46(4):985-996.

Thilenius, J.F., and Brown, G.R. 1976. Effects of 2,4-D on digestibility and production of subalpine herbage. *Journal of Range Management* 29(1):63-65.

Thistle, H.W., Ice, G., and Karsky, R. 2007. Spray capture by riparian barrier. Paper No. 071148 presented at the 2007 American Society of Agricultural and Biological Engineers Annual International Meeting, Minneapolis, MN.

Thompson, D.G. 2004. Potential effects of herbicides on native amphibians: A hierarchical approach to ecotoxicology research and risk assessment. *Environmental Toxicology and Chemistry* 23:813-814.

Thompson, D.G., and Pitt, D.G. 2003. A review of Canadian forest vegetation management research and practice. *Annals of Forest Science* 60:559-572.

Thompson, D.G., Wojtaszek, B.F., Staznik, B., Chartrand, D.T., and Stephenson, G.R. 2004. Chemical and biomonitoring to assess potential acute effects of Vision® herbicide on native amphibian larvae in forest wetlands. *Environmental Toxicology and Chemistry* 23(4):843-849.

Thompson, D.G., Solomon, K.R., Wojtaszek, B.F., Edginton, A.N., and Stephenson, G.R. 2006. The impact of insecticides and herbicides on the biodiversity and productivity of aquatic communities. *Ecological Applications* 16:2022-2027.

Thompson, M.W., Shaw, M.G., Umber, R.W., Skeen, J.E., and Thackston, R.E. 1991. Effects of herbicides and burning on overstory defoliation and deer forage production. *Wildlife Society Bulletin* 19:163-170.

Tian, L. 2002. Development of a sensor-based precision herbicide application system. *Computers and Electronics in Agriculture* 36(2-3):133-149.

Tietjen, H.P., Halvorson, C.H., Hegdal, P.L., and Johnson, A.M. 1967. 2,4-D herbicide, vegetation, and pocket gopher relationships Black Mesa, Colorado. *Ecology* 48(4):634-643.

Torstensson, L. 1985. Behaviour of glyphosate in soils and its degradation. In *The herbicide glyphosate*, ed. E. Grossbard and D. Atkinson, 137-150. Boston, MA: Butterworths.

Tremblay, J.P., Huot, J., and Potvin, F. 2007. Density-related effects of deer browsing on the regeneration dynamics of boreal forests. *Journal of Applied Ecology* 44(3):552-562.

Trevors, J.T. 1998. Bacterial biodiversity in soil with an emphasis on chemically-contaminated soils. *Water, Air, and Soil Pollution* 101:45-67.

Turner, D.J. 1985. Effects of glyphosate performance of formulation, additives and mixing with other herbicides. In *The herbicide glyphosate*, ed. E. Grossbard and D. Atkinson, 221-240. Boston, MA: Butterworths.

United States Environmental Protection Agency (USEPA). 2007. *White paper on the potential for atrazine to affect amphibian gonadal development*. Washington, DC: United States Environmental Protection Agency, Office of Prevention, Pesticides, and Toxic Substances, Office of Pesticide Programs, Environmental Fate and Effects Division,

Visscher, D.R., and Merrill, E.H. 2009. Temporal dynamics of forage succession for elk at two scales: Implications of forest management. *Forest Ecology and Management* 257:96-106.

Vonier, P.M., Crain, D.A., McLachlan, J.A., Guillette, L.J., Jr., and Arnold, S.F. 1996. Interaction of environmental chemicals with estrogen and progesterone receptors from the oviduct of the American alligator. *Environmental Health Perspective* 104:1318-1322.

Vreeland, J.K., Servello, F.A., and Griffith, B. 1998. Effects of conifer release with glyphosate on summer forage abundance for deer in Maine. *Canadian Journal of Forest Research* 28:1574-1578.

Wagner, R.G., Little, K.M., Richardson, B., and McNabb, K. 2006. The role of vegetation management for enhancing productivity of the world's forest. *Forestry* 79(1):57-79.

Wagner, R.G., Newton, M., Cole, E.C., Miller, J.H., and Shiver, B.D. 2004. The role of herbicides for enhancing forest productivity and conserving land for biodiversity in North America. *Wildlife Society Bulletin* 32(4):1028-1041.

Wallis De Vries, M.F., Parkinson, A.E., Dulphy, J.P., Sayer, M., and Diana, E. 2007. Effects of livestock breed and grazing intensity on biodiversity and production grazing systems. 4. Effects on animal diversity. *Grass and Forage Science* 62(2):185-197.

Walstad, J.D., and Dost, F.N. 1986. All the king's horses and all the king's men: The lessons of 2,4,5-T. *Journal of Forestry* 84(9):28-33.

Walstad, J.D., Newton, M., and Gherstad, D.H. 1987. Overview of vegetation management alternatives. In *Forest vegetation management for conifer production*, ed. J.D. Walstad and P.J. Kuch, 157-200. New York: John Wiley & Sons.

Wan, M.T., Moul, D.J., and Watts, R.G. 1987. Acute toxicity to juvenile Pacific salmonids of Garlon 3A™, Garlon 4™, triclopyr, triclopyr ester, and their transformation products: 3,5,6-trichloro-2-pyridinol and 2-methoxy-3,5,6-trichloropyridine. *Bulletin of Environmental Contamination and Toxicology* 39:721-728.

Ward, A.L. 1973. *Sagebrush control with herbicide has little effect on elk calving behavior*. Research Note RM-240. United States Department of Agriculture Forest Service, Rocky Mountain Forest and Range Experiment Station.

Ware, G.W. 1980. Effects of pesticides on nontarget organisms. *Residue Reviews* 76:173-201.

Waring, R.H., and Running, S.W. 1998. *Forest ecosystems: Analysis at multiple scales*. San Diego, CA: Academic Press.

Welch, J.R., Miller, K.V., Palmer, W.E., and Harrington, T.B. 2004. Response of understory vegetation important to the northern bobwhite following imazapyr and mechanical treatments. *Wildlife Society Bulletin* 32(4):1071-1076.

Whisenant, S.G., and McArthur, E.D. 1989. Triclopyr persistence in northern Idaho forest vegetation. *Bulletin of Environmental Contamination and Toxicology* 42:660-665.

World Health Organization (WHO). 1997. 2,4-D and its salts and esters, evaluation of effects on the environment. *Pesticide Residues in Food – 1997*. International Programme on Chemical Safety.

Wiens, J.A., and Rotenberry, J.T. 1985. Response of breeding passerine birds to rangeland alteration in a North American shrubsteppe locality. *Journal of Applied Ecology* 22(3):655-668.

Wigley, T.B., Miller, K.V., deCalesta, D.S., and Thomas, M.W. 2002. Herbicides as an alternative to prescribed burning for achieving wildlife management objectives. In *The role of fire in nongame wildlife management and community restoration: Traditional uses and new directions, proceedings of a special symposium*, ed. W.M. Ford, K.R. Russell, and C.E. Moorman, 124-138. General Technical Report NE-288. Washington, DC: United States Department of Agriculture Forest Service.

Wilmshurst, J.F., Fryzell, J.M., and Hudson, R.J. 1995. Forage quality and patch choice by wapiti (*Cervus elaphus*). *Behavioral Ecology* 6:209-217.

Wojtaszek, B.F., Buscarini, T.M., Chartrand, D.T., Stephenson, G.R., and Thompson, D.G. 2005. Effect of Release® herbicide on mortality, avoidance response, and growth of amphibian larvae in two forest wetlands. *Environmental Toxicology and Chemistry* 24(10):2533-2544.

Wojtaszek, B.F., Staznik, B., Chartrand, D.T., Stephenson, G.R., and Thompson, D.G. 2004. Effects of Vision® herbicide on mortality, avoidance response, and growth of amphibian larvae in two forest wetlands. *Environmental Toxicology and Chemistry* 23(4):832-842.

APPENDIX A

SYNOPSES OF HERBICIDE EFFECTS RESEARCH IN PACIFIC NORTHWEST FORESTS

LISTED BY YEAR OF PUBLICATION, THEN ALPHABETICALLY BY AUTHOR

Year: 1966

Author(s): Mueggler, W.F.

Running Head: Herbicides Tested to Increase Browse

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: north-central Idaho

Treated Plant Community: shrub-dominated winter elk range

Stand Age at Treatment Time: not specified

Pretreatment Data: Y **Duration**: treatment date

Post-treatment Data: Y **Duration**: 15 months

Chemical(s) Studied: 2,4-D, 2,4,5-T, and a 50:50 mixture of 2,4-D:2,4,5-T

Treatments Evaluated: rejuvenation of big-game winter range via herbicides

Vegetation Response: Rocky Mountain maple[11] was most resistant to spraying and had a moderate increase in basal sprouting. Saskatoon serviceberry, Scouler willow, creambush rockspirea, and bitter cherry were moderately affected by herbicides. Redstem ceanothus and Lewis mockorange were severely damaged by spraying. Willow sprouting increased tenfold with treatment. Creambush rockspirea sprouted moderately, while redstem ceanothus and Lewis mockorange sprouted poorly. Reaction to season of treatment was species specific, with early and late summer spraying showing greater effectiveness than midsummer. Herbicide use can potentially improve big-game forage by killing the aerial crowns and stimulating basal growth of preferred browse species.

Wildlife Response: N/A

[11] Tables of genus and species names included at end of appendix

Year: 1968

Author(s): Lyon, L.J., and Mueggler, W.F.

Running Head: Herbicide Treatment of Browse

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: northern Idaho

Treated Plant Community: 5 common shrub species

Stand Age at Treatment Time: not specified

Pretreatment Data: Y **Duration**: at time of spraying (see Mueggler 1966)

Post-treatment Data: Y **Duration**: 6 years

Chemical(s) Studied: 2,4-D, 2,4,5-T, and a 50:50 mixture of 2,4-D:2,4,5-T

Treatments Evaluated: long-term shrub response to herbicides

Vegetation Response: The shrub species studied included Rocky Mountain maple, Scouler willow, creambush rockspirea, mallow ninebark, and redstem ceanothus. Observed vegetation responses to herbicide spray were species specific and varied by season of treatment. Overall, undesirable species experienced some delayed mortality and poor sprouting persistence, while the more desirable species had quick recovery from crown dieback. Redstem ceanothus (most desirable) was killed by all treatments.

Wildlife Response: N/A

Year: 1968

Author(s): Newton, M., and Norris, L.A.

Running Head: Herbicide Residues in Blacktail Deer

Study Type: ☒ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range

Treated Plant Community: open grassy areas to heavy brush areas

Stand Age at Treatment Time: not specified

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 10 to 44 days

Chemical(s) Studied: 2,4,5-T (with 2,4-D) and atrazine

Treatments Evaluated: not specified

Vegetation Response: N/A

Wildlife Response: Results were not conclusive. Blacktail deer did not avoid herbicide treated areas. Large amounts of atrazine and 2,4,5-T did not accumulate in deer exposed to maximum dosages within their habitats. Intestinal contents did show past or present evidence of herbicide exposure. However, chemical concentrations in deer flesh were minimal, and herbicides degraded soon after ingestion.

Year: 1971

Author(s): Hull, A.C., Jr.

Running Head: Gophers and 2,4-D

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Franklin Basin, southeastern Idaho

Treated Plant Community: herbaceous vegetation in spruce-fir type

Stand Age at Treatment Time: not specified

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 10 years

Chemical(s) Studied: 2,4-D

Treatments Evaluated: herbaceous vegetation control

Vegetation Response: Herbicide spraying resulted in the loss of annuals and fleshy rooted plants.

Wildlife Response: No direct 2,4-D toxicity to gophers was reported, but indirect effects from the lack of fleshy rooted food plants were observed. The number of gopher mounds and casts varied yearly. However, compared to unsprayed areas over the ten year period, spraying reduced summer mounds and winter casts by 93% and 94%, respectively.

Year: 1971

Author(s): Newton, M., and Holt, H.A.

Running Head: Beetle Mortality in Injected Pines

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: central Oregon

Treated Plant Community: ponderosa pine

Stand Age at Treatment Time: 60 years

Pretreatment Data: Y **Duration**: initial observations, measurements (time not specified)

Post-treatment Data: Y **Duration**: 2 years

Chemical(s) Studied: cacodylic acid, monosodium methanearsonate (MSMA) and a 50:50 mixture of cacodylic acid:MSMA

Treatments Evaluated: herbicide injections for precommercial thinning

Vegetation Response: Greater than 93% ponderosa pine mortality was observed within four months of final treatment and the living trees were severely damaged.

Wildlife Response: Even though bark beetle responses were species-specific, beetle attack levels were lower on all treated trees than felled trees for all treatments. The evidence for beetle larva mortality and hatch failure was high, and scolytid entry varied by season and chemicals used.

Year: 1972

Author(s): Borrecco, J.E., Black, H.C., and Hooven, E.F.

Running Head: Indirect Herbicide Effects on Black-tailed Deer

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: western Oregon

Treated Plant Community: Douglas fir, shrub dominant

Stand Age at Treatment Time: clearcuts 8 to 12 years, with recently planted and established Douglas-fir seedlings

Pretreatment Data: Y **Duration**: prior to both spring treatments (see Borrecco, Black, and Hooven 1979)

Post-treatment Data: Y **Duration**: 18 months

Chemical(s) Studied: atrazine, dalapon, 2,4-D, and silvex mixtures

Treatments Evaluated: woody and herbaceous vegetation control

Vegetation Response: Herbicide treated plots had a reduction in the number of grass, forb, and ground cover species. Treated plots also had an increase in shrub growth and Douglas fir growth and survival.

Wildlife Response: Pre- and post-treatment small mammal trapping suggested no direct toxic effects. On treated plots, small mammal responses were species specific, varying by habitat preferences. Treated plots had a reduction in small mammals that prefer open areas, and an increase in small mammals that prefer brushy habitats. Deer pellet counts varied seasonally and among study areas, but there was no significant difference due to herbicide effects alone. Herbicidal vegetation changes appeared to improve black-tailed deer habitat during the growing season, as deer usage on treated plots increased. Habitat changes did not result in a significant difference in Douglas fir browsing.

Year: 1973

Author(s): Newton, M., and Overton, W.S.

Running Head: Atrazine, 2,4-D, and Dalapon Mixtures

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: western Oregon

Treated Plant Community: Douglas fir, grand fir

Stand Age at Treatment Time: newly planted seedlings (2 to 3 years)

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 2 growing seasons

Chemical(s) Studied: atrazine, dalapon, and 2,4-D combinations

Treatments Evaluated: herbaceous vegetation control

Vegetation Response: When used by itself for vegetation control, dalapon injured both tree species. When combined with atrazine and 2,4-D, the negative effects of dalapon were masked and it became safe and beneficial. Both dalapon and atrazine adequately controlled grasses. Atrazine worked better on annual grasses, while dalapon worked better on perennial grasses. Meadow fescue was controlled better with combinations of atrazine and dalapon.

Wildlife Response: N/A

Year: 1974

Author(s): Black, H.C., and Hooven, E.H.

Running Head: Small-Mammal Response to Habitat Changes

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: western and southwestern Oregon

Treated Plant Community: Douglas fir, mixed conifer

Stand Age at Treatment Time: 1 to 10 years (burned clearcuts), 12 years (clearcuts)

Pretreatment Data: Y **Duration**: prior to both spring treatments (see Borrecco, Black, and Hooven 1979)

Post-treatment Data: Y **Duration**: 2 to 7 years (treatment-based)

Chemical(s) Studied: atrazine, simazine, 2,4-D combinations

Treatments Evaluated: fire, clearcut, woody and herbaceous vegetation control (herbicides)

Vegetation Response: Herbicides reduced ground cover, grasses, and forbs, while increasing growth of Douglas fir and most shrubs. Plant species recovered within two years of treatment and vegetation cover was comparable on treated and untreated areas.

Wildlife Response: Small mammal responses to habitat changes were species specific. On post-fire Douglas fir clearcuts shrews, voles, and Townsend's chipmunks were rare or absent, while shrews and voles were abundant in early seral unburned Douglas fir clearcuts. Red-backed voles were rare on clearcuts. Mixed conifer clearcuts had abundant numbers of golden-mantled ground squirrels and Great Basin pocket mice. Herbicide treated areas had reduced numbers of vagrant shrews, Pacific jumping mice, and Oregon voles, but increased numbers of Trowbridge's shrews and deer mice. One year post-treatment, complete vegetation control significantly reduced the abundance of pocket gophers.

Year: 1976

Author(s): Beaver, D.L.

Running Head: Birds in Treated Fields

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Sierra Nevada Mountains, north-central California

Treated Plant Community: brush field with Jeffrey pine

Stand Age at Treatment Time: 5 years

Pretreatment Data: Y **Duration**: 2 years (plot I), 3 years (plot II)

Post-treatment Data: Y **Duration**: 2 years (plot I), 1 years (plot II)

Chemical(s) Studied: 2,4,5-T

Treatments Evaluated: vegetation (brush) control

Vegetation Response: Although herbicide treatment caused retardation and mortality of tobacco bush and greenleaf manzanita, there was little change in shrub cover due to dead leaf retention. One year post-spray, shrubs started to recover. Currant was not affected by the herbicide treatment. Tobacco bush and manzanita did not produce seeds after herbicide treatment. Post-spray, coverage of forbs and grasses increased slightly in plot I, but coverage of forbs decreased in plot II (lighter spray application).

Wildlife Response: Herbicide treatment did not significantly change population size, relative abundance, or avian species composition on Plot I or Plot II. Breeding and nest placement for all species appeared normal post-spray. An abundant (pre-spray) green-leaf beetle population was almost absent post-spray due to tobacco bush damage and mortality. Some shifts in bird foraging behavior were observed (e.g., fox sparrow used an alternate food source due to lack of tobacco bush seeds).

Year: 1977

Author(s): Gratkowski, H.J.

Running Head: Seasonal Phenoxy Herbicide Effects on Pine and Brush

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Cascade and Coast Ranges, southwestern Oregon

Treated Plant Community: ponderosa pine plantations and associated brush; aerial spray trials were a mixture of ponderosa pine and Douglas fir

Stand Age at Treatment Time: not specified; plantation trees were 1 to 3 m tall

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 2 years

Chemical(s) Studied: 2,4-D and 2,4,5-T

Treatments Evaluated: changes in susceptibility to herbicides and shrub control

Vegetation Response: Ponderosa pine was damaged less by 2,4,5-T. Late summer (late August through September) 2,4,5-T (in water) herbicide treatment works well to release ponderosa pine from shrub competition in western Oregon. In late summer, snowbrush ceanothus was highly susceptible, while varnishleaf ceanothus and Pacific madrone were moderately susceptible to herbicide treatment.

Wildlife Response: N/A

Year: 1977

Author(s): Norris, L.A., Montgomery, M.L., and Johnson, E.R.

Running Head: Persistence of 2,4,5-T in a Forest

Study Type: ☒ Laboratory ☒ Field

Geographic Scope: northwest Oregon Coast Range

Treated Plant Community: Douglas fir, vine maple, blackberry, grass composites

Stand Age at Treatment Time: not specified

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 2 years

Chemical(s) Studied: 2,4,5-T

Treatments Evaluated: persistence of 2,4,5-T

Vegetation Response: Initial post-application concentrations of 2,4,5-T ranged from 11 to 115 ppmw (parts per million by weight) in all four vegetation types, and declined to less than 0.5 ppmw within one year. Forest floor herbicide levels declined 90% in the first six months post-treatment, and were even lower after one year. Soil leaching was minimal, with residues no deeper than 15 cm.

Wildlife Response: N/A

Year: 1977

Author(s): Preest, D.S.

Running Head: Response of Douglas-fir to Weed Control

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range

Treated Plant Community: Douglas fir

Stand Age at Treatment Time: newly planted

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 4 years

Chemical(s) Studied: not specified

Treatments Evaluated: herbaceous vegetation (weed) control

Vegetation Response: The weed control treatments increased (ephemeral) soil moisture availability, thereby increasing Douglas fir growth. This positive effect on fir growth rate became highly significant and continued for several years following treatment.

Wildlife Response: N/A

Year: 1978

Author(s): Gratkowski, H.J.

Running Head: Annual Variation in Herbicide Effects on Ponderosa Pine

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range

Treated Plant Community: ponderosa pine, greenleaf manzanita

Stand Age at Treatment Time: not specified; trees 1 to 2 m tall, shrubs 1 to 1.5 m tall

Pretreatment Data: Y **Duration**: on spray dates

Post-treatment Data: Y **Duration**: 2 years

Chemical(s) Studied: 2,4-D and 2,4,5-T

Treatments Evaluated: susceptibility to herbicides and shrub control

Vegetation Response: In the Cascade Range, early spring (February through June) treatments of 2,4-D and 2,4,5-T to release ponderosa pines are unsafe due to pine susceptibility. Pines are most susceptible to damage during active growth periods (May and June), with full resistance in late summer through late winter. Therefore, in the Pacific Northwest, late summer release treatments using 2,4-D and 2,4,5-T result in minimal tree damage. Greenleaf manzanita susceptibility to 2,4-D was highest from late November through May.

Wildlife Response: N/A

Year: 1978

Author(s): Savidge, J.A.

Running Head: Wildlife in an Herbicide-Treated Jeffrey Pine Plantation

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Sierra Nevada Mountains, north-central California

Treated Plant Community: Jeffrey pine plantation

Stand Age at Treatment Time: 6 years

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: spring and summer (6 years post-treatment)

Chemical(s) Studied: 2,4,5-T

Treatments Evaluated: woody and herbaceous vegetation control

Vegetation Response: A species-specific shrub response to the herbicide treatment was observed. Most of the snowbrush was eliminated on the sprayed plot, with only 1% surviving treatment. Live snowbrush cover was 30% and 2% on the unsprayed and sprayed plot, respectively. Currant increased on the sprayed plot compared to the unsprayed plot. Pines were similar between the two plots.

Wildlife Response: The altered vegetation composition on the sprayed plot reduced the number and species of resident bird populations. The unsprayed plot had almost twice the number and species of birds as the sprayed plot. Mule deer numbers were lower on the sprayed plot, presumably due to altered food and ground cover availability. Some small mammals increased in numbers on the sprayed plot due to increased food availability (currant, grasses).

Year: 1979

Author(s): Bollen, W.B., and Norris, L.A.

Running Head: Herbicide Effects on the Forest Floor and Soil

Study Type: ☒ Laboratory ☒ Field

Geographic Scope: Oregon Cascade Range

Treated Plant Community: forest floor components from mixed stand of Douglas-fir and red alder

Stand Age at Treatment Time: not specified

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 4 weeks

Chemical(s) Studied: dioxin, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD from 2,4,5-T application)

Treatments Evaluated: effects of TCDD on carbon dioxide evolution in the soil and forest floor

Vegetation Response: TCDD, even at varying levels, did not affect carbon dioxide evolution from the forest floor. Carbon metabolism rate was constant throughout the four week study. TCDD did have a stimulating effect on the soil.

Wildlife Response: Applied at normal rates, herbicides with TCDD should not directly affect soil microbial populations, nutrient recycling, or carbon metabolism.

Year: 1979

Author(s): Borrecco, J.E., Black, H.C., and Hooven, E.F.

Running Head: Small Mammals and Herbicide-Induced Habitat Changes

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: western Oregon

Treated Plant Community: Douglas fir, shrub dominant

Stand Age at Treatment Time: 8 to 12 years

Pretreatment Data: Y **Duration**: prior to both spring herbicide treatments

Post-treatment Data: Y **Duration**: 2 years

Chemical(s) Studied: atrazine, dalapon, 2,4-D, and silvex mixtures

Treatments Evaluated: woody and herbaceous vegetation control

Vegetation Response: Herbicide treatments altered the vegetation composition of the area. On treated plots, there was a reduction in grass, forbs, and ground cover, increased growth in most shrubs, and an increased growth and survival of Douglas fir.

Wildlife Response: Herbaceous vegetation control altered small mammal species composition. Small mammal responses were species-specific. On treated plots, small mammals that preferred grassy habitats decreased in numbers, while those that preferred brushy habitats increased in abundance.

Year: 1979

Author(s): Crouch, G.L.

Running Head: Atrazine Effects on Ponderosa Pine and Pocket Gophers

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: south-central Oregon

Treated Plant Community: ponderosa pine, dense brushfields

Stand Age at Treatment Time: newly planted seedlings (following day)

Pretreatment Data: Y **Duration**: immediately after planting

Post-treatment Data: Y **Duration**: 10 growing seasons

Chemical(s) Studied: atrazine

Treatments Evaluated: herbaceous vegetation control

Vegetation Response: Spring treatments were ineffective on vegetation. Fall treatments doubled survival and increased pine growth after ten growing seasons. Atrazine treatments significantly decreased grasses and forbs within the first year, and the effects lasted through the tenth year. Bitterbrush and currant increased over the study period. Shrubs had significantly improved growth with fall atrazine applications.

Wildlife Response: Fall treatment had an indirect effect on pocket gophers by altering vegetation composition. There was an eightfold reduction in gopher mounds with fall treatment over no treatment or spring treatment. Gophers caused most of the pine mortality, and the pine damage varied among years and treatment plots. However, pine losses were much lower on fall treated plots.

Year: 1979

Author(s): Sullivan, T.P., and Sullivan, D.S.

Running Head: Glyphosate Effects on Deer Browsing

Study Type: ☐ Laboratory ☒ Field (captive deer in enclosures)

Geographic Scope: University of British Columbia Research Forest, south-coastal British Columbia

Treated Plant Community: red alder browse, alfalfa hay

Stand Age at Treatment Time: N/A

Pretreatment Data: Y **Duration**: 21 days acclimate; 19 days feed/control

Post-treatment Data: Y **Duration**: 28 days (alder), 11 days (alfalfa)

Chemical(s) Studied: glyphosate

Treatments Evaluated: deciduous shrub control (herbicide treated red alder and alfalfa hay consumption

Vegetation Response: N/A

Wildlife Response: Black-tailed deer showed no preference between the control and the glyphosate treated browse (alder or alfalfa), and even ate more of the treated foliage (especially the dead alder leaves). Consumption of treated browse had no effect on the amount of laboratory chow eaten by deer. These findings suggest that deer should not avoid foraging in glyphosate treated areas.

Year: 1980

Author(s): Radosevich, S.R., Roncoroni, E.J., Conard, S.G., and McHenry, W.B.

Running Head: Seasonal Tolerances of Conifers to Herbicides

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: northern California

Treated Plant Community: ponderosa pine, Jeffrey pine, sugar pine, Douglas fir, white fir, red fir

Stand Age at Treatment Time: 1 year post-planting

Pretreatment Data: Y **Duration**: at each herbicide application

Post-treatment Data: Y **Duration**: 1 year

Chemical(s) Studied: 2,4-D, 2,4,5-T, silvex, dichlorprop, glyphosate, and tank mixes (asulam, triclopyr, fosamine)

Treatments Evaluated: seasonal herbicide selectivity

Vegetation Response: All six conifer species were most tolerant to fall herbicide treatment, and were more susceptible to the July treatment. Spring or summer treatments (low moisture stress and high photosynthesis times) caused significant conifer injury and/or mortality. Pines had higher fall glyphosate tolerance.

Wildlife Response: N/A

Year: 1981

Author(s): Campbell, D.L., Evans, J., Lindsey, G.D., and Dusenberry, W.E.

Running Head: Deer Acceptance of Herbicide-Treated Browse

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Olympia, Washington

Treated Plant Community: Douglas fir, salal

Stand Age at Treatment Time: N/A

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 4 months

Chemical(s) Studied: 2,4,5-T, 2,4-D, dalapon, atrazine, fosamine, and glyphosate

Treatments Evaluated: acceptance of treated Douglas fir and salal

Vegetation Response: Formulations of atrazine treated Douglas fir showed significant growth over controls. Proper application timing of glyphosate can minimize phytotoxic effects on Douglas fir.

Wildlife Response: All treated browse was accepted by black-tailed deer, with lower acceptance of glyphosate treated browse. A lower acceptance of glyphosate treated seedlings (phytotoxic) showed possible deer sensitivity to the herbicide or a physiological change in fir. No adverse health or behavioral effects were observed in the deer tested. Long-term effects are unknown.

Year: 1981

Author(s): Sullivan, T.P., and Sullivan, D.S.

Running Head: Herbicide Effects on a Deer Mouse Population

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: University of British Columbia Research Forest, south-coastal British Columbia

Treated Plant Community: Douglas fir plantation

Stand Age at Treatment Time: 20 years

Pretreatment Data: Y **Duration**: ~1.5 years

Post-treatment Data: Y **Duration**: ~1.5 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: conifer release and woody vegetation control

Vegetation Response: Roundup® treatment killed most of the overstory deciduous trees and understory shrubs. This deciduous removal promoted herbaceous vegetation growth and the release of Douglas fir.

Wildlife Response: Deer mouse population changes on the control vs. the treated areas were minimal. No adverse Roundup® effects on deer mouse populations (reproduction, growth, and survival) were observed one year post-treatment.

Year: 1982

Author(s): Conard, S.G., and Radosevich, S.R.

Running Head: White Fir Response to Reduced Competition

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: northern Sierra Nevada Mountains, California

Treated Plant Community: shrub dominated, white fir saplings understory

Stand Age at Treatment Time: shrubs 35 to 50 years; saplings up to 1.5 m tall

Pretreatment Data: Y **Duration**: not specified

Post-treatment Data: Y **Duration**: 4 years

Chemical(s) Studied: 2,4-D, glyphosate

Treatments Evaluated: woody vegetation control (manual canopy removal, manual shrub topping and 2,4-D, glyphosate, and sprout suppression with glyphosate)

Vegetation Response: Shrub control was site- and treatment-dependent, and ranged from 0 to 95%. White fir survival ranged from 56 to 100%. At two sites, the creation of artificial shade and shrub removal doubled white fir growth after four years. Shrub cover reductions ≥80% without shade provisions resulted in smaller growth increases. Overall, increased soil moisture and shade greatly increased fir growth after four years. Treatments inhibited shrub sprouting, thereby increasing fir survival. Greenleaf manzanita and bush chinquapin were more tolerant to glyphosate than ceanothus.

Wildlife Response: N/A

Year: 1982

Author(s): Hildebrand, L.D., Sullivan, D.S., and Sullivan, T.P.

Running Head: Exposure of Rainbow Trout to Roundup®

Study Type: ☒ Laboratory ☒ Field

Geographic Scope: University of British Columbia Research Forest, south-coastal British Columbia

Treated Plant Community: conifer plantation

Stand Age at Treatment Time: 20 years (experiment D)

Pretreatment Data: Y **Duration**: 28 to 36 days (holding/acclimation)

Post-treatment Data: Y **Duration**: immediately to 17 days

Chemical(s) Studied: glyphosate

Treatments Evaluated: Roundup® toxicity via lab/field bioassays, manual and aerial applications

Vegetation Response: N/A

Wildlife Response: The rainbow trout laboratory and field 96 hr LC_{50} for Roundup® were very similar. Rainbow trout survival rates were 100% in the manual Roundup® treatments (1 time, 10 times, and 100 times the recommended field dose) and operational aerial application. Behaviorally, trout showed no signs of stress, but they would avoid lethal Roundup® levels. Operational application of Roundup® at field rates will not lead to avoidance concentrations due to the chemical dilution in streams.

Year: 1982

Author(s): Sullivan, T.P., and Sullivan, D.S.

Running Head: Forest Herbicide and Small Mammals

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: University of British Columbia Research Forest, south-coastal British Columbia

Treated Plant Community: Douglas fir plantation

Stand Age at Treatment Time: 20 years

Pretreatment Data: Y **Duration**: ~1.5 years

Post-treatment Data: Y **Duration**: ~1.5 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: conifer release and woody vegetation control

Vegetation Response: Roundup® application killed most of the overstory deciduous trees and understory shrubs. A few hardwoods that were herbicide-resistant or missed by the spraying survived the treatment. The reduction in overstory cover released Douglas fir and spurred significant herbaceous vegetation growth.

Wildlife Response: One year post-treatment, no adverse effects on distribution and abundance of small mammal communities (deer mice, Oregon vole, Townsend chipmunk, and shrews) were recorded. No significant movements of deer mice in or out of the treated area were observed.

Year: 1983b

Author(s): Morrison, M.L., and Meslow, E.C.

Running Head: Bird Community Structure

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range

Treated Plant Community: Douglas fir

Stand Age at Treatment Time: 3 to 5 years

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 3 years

Chemical(s) Studied: 2,4-D, 2,4,5-T

Treatments Evaluated: conifer release and woody vegetation control

Vegetation Response: Six of the twelve study sites received aerial herbicide treatment one to four years pre-study. The vegetation cover of the low shrub-herb layer (<1 m) was continuous on all study sites, predominantly consisting of shrubs 1.0 m high. Conifer cover was <9.0% on ten sites, but >20% on the other two. Deciduous tree cover was highly variable among sites (0.8 to 22.4%), while foliage height diversity was not.

Wildlife Response: The estimated total density of all nesting bird species was 326 to 552 birds/40.5 ha, and the number of species varied little among sites. The four most common species on all sites included the white-crowned sparrow, song sparrow, rufous hummingbird, and Swainson’s thrush. Another six species were found at moderate and low densities at all sites. Total density of nesting birds increased with the amount of deciduous tree cover and decreased with increased conifer height. Birds that dominated these early-growth clearcuts were shrub-inhabiting species.

Year: 1984a

Author(s): Morrison, M.L., and Meslow, E.C.

Running Head: Glyphosate Effects on Bird Communities

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range

Treated Plant Community: Douglas fir

Stand Age at Treatment Time: about 4.5 years

Pretreatment Data: Y **Duration**: "pre-spray" measurements (time frame not specified)

Post-treatment Data: Y **Duration**: 1 and 2 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: conifer release treatment

Vegetation Response: Post-spray total plant cover damage was 23%. Although salmonberry and thimbleberry were most damaged by glyphosate treatment, only 5% of each species was killed. There was a reduction of shrub cover one year post-spray, with vegetation regrowth to near pre-spray levels occurring within two years.

Wildlife Response: Overall density of the bird community did not differ between treated and untreated sites throughout the study, but there were changes in densities of individual species. One year post-treatment, some species altered their behavior (habitat use) due to changes in vegetation (e.g., decreased shrub use and increased deciduous tree use). By two years post-treatment many species had returned to pre-treatment habitat behavior.

Year: 1984b

Author(s): Morrison, M.L., and Meslow, E.C.

Running Head: Response of Birds to Herbicides

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range

Treated Plant Community: Douglas fir

Stand Age at Treatment Time: 3 to 4 years and 2 to 4 years

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 1 and 4 years

Chemical(s) Studied: 2,4-D and a mixture of 2,4-D and/or 2,4,5-T

Treatments Evaluated: conifer release treatment

Vegetation Response: Vegetation diversity was greatest on the control sites. One year post-spray, herbicide treatment resulted in a reduction of vegetation complexity, primarily through the loss of deciduous trees (red alder). Rapid shrub recovery was observed post-treatment. Suppression of deciduous trees was still evident the fourth year post-spray. Conifer growth was greater on the sprayed sites than on the control sites.

Wildlife Response: Overall, there was no variation in diversity and total density of birds between treated and untreated sites. Some bird species (e.g., Wilson's warbler) altered habitat use and foraging behavior on treated sites (loss of deciduous trees resulted in increased use of shrubs). Other species (e.g., white-crowned sparrow) increased in density on treated sites due to habitat enhancement (reduced deciduous tree cover).

Year: 1984

Author(s): Newton, M., Howard, K.M., Kelpsas, B.R., Danhaus, R., Lottman, C.M., and Dubelman, S.

Running Head: Fate of Glyphosate in an Oregon Forest Ecosystem

Study Type: ☒ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range

Treated Plant Community: deciduous stand dominated by red alder, bitter cherry, shrubs

Stand Age at Treatment Time: 20 to 100+ years

Pretreatment Data: Y **Duration**: not specified

Post-treatment Data: Y **Duration**: 55 days

Chemical(s) Studied: glyphosate

Treatments Evaluated: glyphosate residues in the ecosystem

Vegetation Response: Forest vegetation intercepted nearly all the glyphosate (low ground-level deposits), with most being in the tree layers. Glyphosate half-life in soil was twice as long as the half-life in foliage and litter (10.4 to 26.6 days). Glyphosate concentrations in the treated stream decreased rapidly, but were more concentrated and persistent in sediment.

Wildlife Response: Non-target species exposure to glyphosate was low. Coho salmon fingerlings had no detectable accumulations of glyphosate. Exposed mammals (herbivores, carnivores, and omnivores) had variable body accumulations of glyphosate due to food habits, but all visceral concentrations were at or below levels in ground cover and litter. These results indicate that glyphosate is not a toxicological threat to wildlife or humans.

Year: 1985

Author(s): Anthony, R.G., and Morrison, M.L.

Running Head: Influence of Glyphosate Herbicide

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range

Treated Plant Community: clearcuts, shrub dominated

Stand Age at Treatment Time: less than 7 years post-harvest

Pretreatment Data: Y **Duration**: 1 year

Post-treatment Data: Y **Duration**: 2 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: woody vegetation (brush) control

Vegetation Response: One year post-spray, >50% of the salmonberry and thimbleberry were damaged, with only 5% mortality. Damaged shrubs recovered from glyphosate treatment within two years. The treated site had increased forbs and grasses, whereas herbaceous cover on the control site was relatively constant throughout the study.

Wildlife Response: One year after glyphosate application, the primary community change was an increase in abundance, diversity, and biomass of small mammals (mainly *Microtus*) on treated vs. control sites. This increase was attributed to increased levels of herbaceous cover after the shrub layer was damaged by spraying. However, these changes were temporary, with the small mammal community returning to pre-spray levels (along with the vegetation) by the second year post-spray. Small mammal responses to herbicide-induced vegetation changes were species-specific. Glyphosate application had no significant negative effects on small mammal communities.

Year: 1985

Author(s): King, S.P., and Radosevich, S.R.

Running Head: Herbicide Tolerance in Conifers

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Sierra Nevada Mountains, California

Treated Plant Community: Jeffrey pine, sugar pine, red fir, white fir, Douglas fir

Stand Age at Treatment Time: approximately 6 years

Pretreatment Data: Y **Duration**: date of herbicide applications

Post-treatment Data: Y **Duration**: 12 to 18 months

Chemical(s) Studied: 2,4-D, glyphosate, and triclopyr

Treatments Evaluated: conifer herbicide tolerance

Vegetation Response: Most conifers demonstrated a high correlation between injury and growth rate (leader or needle) and xylem pressure potential. However, conifer injury was dependent on species, season, and herbicide treatment. In general, the greatest conifer injury occurred after June through August herbicide applications, while the least conifer injury was from April, May, and September applications.

Wildlife Response: N/A

Year: 1985

Author(s): Petersen, T.D., and Newton, M.

Running Head: Effects of Woody and Herbaceous Control on Douglas fir

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Cascade Range

Treated Plant Community: Douglas fir plantations

Stand Age at Treatment Time: 5 and 10 years

Pretreatment Data: Y **Duration**: at time of treatment

Post-treatment Data: Y **Duration**: 5 growing seasons

Chemical(s) Studied: ESTERON® 99 Concentrate (shrubs), glyphosate (herbs)

Treatments Evaluated: woody and herbaceous release treatment (herbicides, manual)

Vegetation Response: Herbicides controlled competing vegetation throughout the first year post-spray. Herbicide treatments for both woody and herbaceous cover also resulted in the best Douglas fir growth responses. Increased growth in released Douglas fir depended on the degree of competing vegetation control, tree age at release, and the method of release. Control of both herbaceous vegetation and snowbrush produced the greatest Douglas fir growth after five years in both age classes. In the five-year-old stands, snowbrush control without herbaceous control did improve fir growth, but total vegetation control was needed in ten year old stands for significantly improved growth. Therefore, timing of release was important, as trees that grew with snowbrush competition for ten or more years showed little growth response from release. In summary, shrub and herbaceous release treatments should be done at an early age.

Wildlife Response: N/A

Year: 1968

Author(s): Newton, M.

Running Head: Organic Arsenical Residues in Chemically Thinned Forests

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Washington and Oregon

Treated Plant Community: Douglas fir, mixed conifer, lodgepole pine, ponderosa pine stands

Stand Age at Treatment Time: 30 to 65 years

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: June to July, and September to October

Chemical(s) Studied: cacodylic acid and monosodium methanearsonate (MSMA)

Treatments Evaluated: forest thinning via stem injection

Vegetation Response: Arsenic (As) residue concentrations from MSMA and cacodylic acid were determined in tree stems, twigs, foliage, soil, and litter. Spring treatments resulted in slightly higher crown As concentrations than fall applications for all forest types. Residual concentrations ranged from 20 to 60 mg As/kg (dry weight). Trees five years post-mortality had As concentrations of 122 to 670 mg /kg in phloem above injection sites, 10.9 to 25.0 mg/kg in xylem, and 34.7 to 77.8 mg/kg in upper lateral twigs and terminal leader shoots. Douglas fir stands had the lowest litter residues (5 to 9 mg/kg), while lodgepole pine stands had the highest (27 to 46 mg/kg). Differences in soil As concentrations between treated and untreated soils were low.

Wildlife Response: Arsenical residues in the phloem resulted in reproductive failure of some beetles (scolytid and burprestid) that feed on the inner bark of diseased, dying, and dead trees.

Year: 1987

Author(s): Ritchie, D.C., Harestad, A.S., and Archibald, R.

Running Head: Glyphosate Treatment and Deer Mice

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: northern Vancouver Island, south-coastal British Columbia

Treated Plant Community: early seral stage clearcut

Stand Age at Treatment Time: clearcut (2 years post-harvest)

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 1 year post-treatment for 13 days

Chemical(s) Studied: glyphosate

Treatments Evaluated: site preparation, vegetation control

Vegetation Response: Glyphosate reduced percent understory cover and plant species composition, thereby changing seasonal food and cover availability.

Wildlife Response: Deer mice from treated and untreated clearcuts had similar body size and reproductive rates. Surrounding old growth forest had the highest density of deer mice, followed by the untreated clearcut, then the treated clearcut. Glyphosate-induced vegetation changes reduced deer mice densities in a young seral stage stand.

Year: 1987

Author(s): Wan, M.T., Moul, D.J., and Watts, R.G.

Running Head: Direct Herbicide Toxicity to Juvenile Salmonids

Study Type: ☒ Laboratory ☐ Field

Geographic Scope: British Columbia

Treated Plant Community: N/A

Stand Age at Treatment Time: N/A

Pretreatment Data: Y **Duration**: minimum 2 weeks (acclimation)

Post-treatment Data: Y **Duration**: 24 to 96 hour tests for 2 study periods

Chemical(s) Studied: Garlon 3A®, Garlon 4®, triclopyr, triclopyr ester, pyridinol, and pyridine

Treatments Evaluated: Acute toxicity

Vegetation Response: N/A

Wildlife Response: The LC_{50} values varied little after 96 hours of herbicide exposure. Of the herbicides tested in this study, Garlon 3A® was the least toxic to salmonids, while triclopyr ester was the most toxic. Garlon 4® and pyridinol were equally toxic, while Garlon 3A® was 170 times less toxic than Garlon 4® to salmonids. Under field applications and applied at recommended rates, the potential for Garlon 3A® salmonid toxicity is small. However, if residues are not rapidly diluted and flushed from an aquatic system, Garlon 4® could potentially pose a toxic hazard to salmonids.

Year: 1988

Author(s): Newton, M., and Preest, D.S.

Running Head: Growth and Water Relations of Douglas-fir Under Weed Control

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: central Oregon Coast Range

Treated Plant Community: Douglas-fir in a bottomland meadow with colonial bentgrass

Stand Age at Treatment Time: newly planted 2-year-old Douglas fir seedlings

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 5 years

Chemical(s) Studied: atrazine, atrazine plus 2,4,5-T, atrazine plus 2,4-D

Treatments Evaluated: herbaceous vegetation (weed) control

Vegetation Response: Herbicide control of herbaceous vegetation during the first three years post-planting increased Douglas fir growth. Weed control at the time of Douglas fir planting produced the most growth in seedlings, with early weed control benefits continuing through the fifth year. Plots with reduced or no herbaceous vegetation had greater soil water availability for tree seedlings. Third-year post-planting irrigation did increase stem diameters of seedlings that year, but had no effect in subsequent years. The positive effects of weed control on Douglas fir growth were more pronounced and longer lasting than those from irrigation.

Wildlife Response: N/A

Year: 1989

Author(s): Whisenant, S.G., and McArthur, E.D.

Running Head: Triclopyr Persistence in Forest Vegetation

Study Type: ☒ Laboratory ☒ Field

Geographic Scope: northern Idaho

Treated Plant Community: primarily Douglas fir, shinyleaf ceanothus

Stand Age at Treatment Time: not specified; Douglas fir averaged 0.48 m tall

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 1 year

Chemical(s) Studied: triclopyr

Treatments Evaluated: triclopyr persistence in forage

Vegetation Response: At both sites, foliage triclopyr concentrations were variable among all species and sampling times. Shinyleaf ceanothus had the highest herbicide concentrations, and retained dead leaves one year post-treatment. In addition, one year after herbicide application there was a >98% reduction in triclopyr residues for all species.

Wildlife Response: Residue data suggested that if properly applied, triclopyr toxicity to non-target species is unlikely.

Year: 1990

Author(s): Gourley, M., Vomocil, M., and Newton, M.

Running Head: Weeding Reduces Deer Browsing on Douglas-fir

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range

Treated Plant Community: Douglas fir

Stand Age at Treatment Time: newly planted

Pretreatment Data: Y **Duration**: at planting

Post-treatment Data: Y **Duration**: 5 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: herbaceous vegetation (weed) control (herbicide) and protective (Deer Away®, physical barriers)

Vegetation Response: Survival of Douglas fir was not significantly affected by any of the protective treatments. After five years, protective treatments did not prove advantageous for conifer growth, and some had negative impacts. However, weed control treatments (with or without protection) positively impacted conifer growth. After five years, weeded trees had double the biomass of unweeded trees. The weeded treatment with no browse protection averaged the largest tree size. Weed control and large transplants appeared to offset damage from deer browsing.

Wildlife Response: Deer browsing was difficult to predict. Browsing was severe at two sites during the study period. Protective products reduced browsing frequency in the first two years.

Year: 1990

Author(s): Oliver, W.W.

Running Head: Shrub Competition Effects on Ponderosa Pine

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: west-side Sierra Nevada Mountains, northern California

Treated Plant Community: ponderosa pine

Stand Age at Treatment Time: 2 and 4 years post-planting

Pretreatment Data: Y **Duration**: 2 years

Post-treatment Data: Y **Duration**: 18 years

Chemical(s) Studied: 2,4,5-T

Treatments Evaluated: woody vegetation control (herbicide and grubbing)

Vegetation Response: Tree mortality throughout the 20-year study was low. Mean tree size was positively correlated with spacing and removal of competing shrubs. Stand values were negatively correlated with spacing and shrub removal. Trees grown with shrub competition were significantly smaller than those grown without competition. Shrubs not only limited crown size, but also reduced crown widths and live crown percents, regardless of spacing. These results suggested that shrub competition in ponderosa pine stands could lead to increased rotation lengths.

Wildlife Response: N/A

Year: 1990a

Author(s): Sullivan, T.P.

Running Head: Responses of Small Mammals to Herbicide Applications

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: University of British Columbia Research Forest, south-coastal British Columbia

Treated Plant Community: Douglas fir plantation

Stand Age at Treatment Time: 7 years

Pretreatment Data: Y **Duration**: 1 year

Post-treatment Data: Y **Duration**: 3 years (1^{st}, 2^{nd}, 4^{th} years post-treatment)

Chemical(s) Studied: glyphosate

Treatments Evaluated: conifer release and weed control

Vegetation Response: Herbicide treatment had a 90% efficacy, with only the conifers and salal surviving. Three years post-spray, some aboveground live biomass recovery was evident. Species dominance in the plant community varied between the herbicide treated and control areas.

Wildlife Response: Abundance of deer mice, Oregon voles, and shrews was similar between treatment and control sites. Chipmunk populations temporarily declined on the treated sites. Vole recolonization did not change with habitat, but deer mice recolonization was lower on the treated area than the control. The life span and proportion of reproductive deer mice and voles were similar for the control and treatment populations.

Year: 1990b

Author(s): Sullivan, T.P.

Running Head: Herbicide and Small Mammals

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: University of British Columbia Research Forest, south-coastal British Columbia

Treated Plant Community: Douglas fir plantation

Stand Age at Treatment Time: 7 years

Pretreatment Data: Y **Duration**: 1 year

Post-treatment Data: Y **Duration**: 3 years (1st, 2nd, 4th years post-treatment)

Chemical(s) Studied: glyphosate

Treatments Evaluated: direct glyphosate effects on small mammals

Vegetation Response: Herbicide treatment had a 90% efficacy, and only the conifers and salal survived.

Wildlife Response: Deer mice recruitment declined within the first year post-spray, but in later years increased on the treated area. Survival and recruitment of Oregon voles was similar between control and treated areas. However, within the first year post-spray, female voles had a significantly higher survival rate on treated areas over control. Differences in body mass and growth rates of voles and mice were inconsistent between control and treated areas. No direct effects from glyphosate exposure or ingestion were observed in individual animals. Overall, the demography parameters of deer mice and Oregon vole populations should not be adversely affected by glyphosate treatments.

Year: 1991

Author(s): Janz, D.M., Farrell, A.P., Morgan, J.D., and Vigers, G.A.

Running Head: Acute Physiological Responses of Coho Salmon to Herbicides

Study Type: ☒ Laboratory ☐ Field

Geographic Scope: British Columbia

Treated Plant Community: N/A

Stand Age at Treatment Time: N/A

Pretreatment Data: Y **Duration**: 24 to 48 hours (acclimation), and trials

Post-treatment Data: Y **Duration**: 4 hours exposure period for 3 months

Chemical(s) Studied: Garlon 3A® (triethylamine salt of triclopyr), Garlon 4® (butoxyethyl ester of triclopyr), and Vision® (isopropylamine salt of glyphosate)

Treatments Evaluated: salmon stress responses to herbicides

Vegetation Response: N/A

Wildlife Response: No significant signs of acute physiological stress responses in juvenile coho salmon were observed when exposed to all three herbicides at 5 to 80% of the 96 hour LC_{50} concentrations. During a four hour exposure period, sublethal concentrations of Garlon® and Vision® did not promote significant stress responses in juvenile coho. This study used hatchery reared salmon, which might differ from wild salmon in stress responses.

Year: 1994

Author(s): Sullivan, T.P.

Running Head: Habitat Alteration and Snowshoe Hares

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: central British Columbia

Treated Plant Community: white spruce plantations

Stand Age at Treatment Time: 8 to 13 years

Pretreatment Data: Y **Duration**: 1 year

Post-treatment Data: Y **Duration**: 3 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: conifer release

Vegetation Response: Herbicide-induced habitat changes were temporary, with herbaceous cover and biomass recovering to control levels within two to three years post-spray. In conifer dominated areas, shrubs and trees were minimally affected by a conifer release treatment. Dominant deciduous trees and shrubs recovered slowly in the backlog conversion treatment.

Wildlife Response: In optimum habitat conditions, the resultant habitat changes from herbicide treatment had no effect on hare abundance in summer and fall. Post-harvest forests (10 to 20 years) that provide critical habitat components (food, cover) may support hare populations regardless of herbicide treatment.

Year: 1995

Author(s): Harrington, T.B., Wagner, R.G., Radosevich, S.R., and Walstad, J.D.

Running Head: Effects of Release Treatments on Douglas-fir Communities

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Washington and Oregon Coast Ranges

Treated Plant Community: Douglas fir plantations

Stand Age at Treatment Time: 2 to 3 years

Pretreatment Data: Y **Duration**: not specified

Post-treatment Data: Y **Duration**: 10 years

Chemical(s) Studied: triclopyr, glyphosate, hexazinone

Treatments Evaluated: competition release (manual cutting, herbicides)

Vegetation Response: Douglas fir survival ranged from 86 to 99% among treatments. Pre-treatment overtopping averaged 25%, and ten years later it did not exceed 35% for any treatments. Shrub cover was reduced with triclopyr (year 1), glyphosate (years 1 to 5), and repeated herbicide treatments (years 1 to 10) relative to the untreated check. Herb cover increased in the third and fifth years due to the shrub cover reduction from glyphosate treatment. However, repeated control reduced herbaceous cover in years 1, 2, and 5. Triclopyr caused more fir injury than glyphosate, and both resulted in fir height reductions the first year. Since repeated control reduced competing vegetation, caused minimal conifer injury, and prevented overtopping, it was the only treatment in which Douglas fir size was greater than that of the untreated check.

Wildlife Response: N/A

Year: 1995

Author(s): Oester, P.T., Emmingham, W., Larson, P., and Clements, S.

Running Head: Effects of Herbicide Regimes on Ponderosa Pine

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: northeast Oregon

Treated Plant Community: ponderosa pine plantation

Stand Age at Treatment Time: newly planted

Pretreatment Data: Y **Duration**: at planting

Post-treatment Data: Y **Duration**: 5 growing seasons

Chemical(s) Studied: hexazinone

Treatments Evaluated: herbaceous vegetation control (herbicides via broadcast, small spot, and large spot applications)

Vegetation Response: Herbicide treatments significantly enhance ponderosa pine establishment, survival, and growth by reducing competing vegetation. Pine survival doubled with large or small spot applications over the control, whereas broadcast applications increased survival another 30% over spot treatments. Two broadcast applications produced significantly more stem volume than single broadcast or spot applications.

Wildlife Response: N/A

Year: 1996

Author(s): McDonald, P.M., and Everest, G.A.

Running Head: Effects of Release Treatments on Pines, Shrubs, and Grasses

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Sierra Nevada Mountains, central California

Treated Plant Community: ponderosa pine plantation

Stand Age at Treatment Time: newly planted

Pretreatment Data: Y **Duration**: not specified

Post-treatment Data: Y **Duration**: 4 years

Chemical(s) Studied: glyphosate, triclopyr, bivert adjuvant, and surfactant tank mix and Pronone® 10G

Treatments Evaluated: release treatments (herbicides, mulches)

Vegetation Response: Ponderosa pine survival was 100%, 73%, and 77% in the herbicide, control, and mulch treatment, respectively. Herbicides reduced bearclover, grasses, and forbs, delayed cheatgrass invasion, and increased growth and survival of ponderosa pine over mulching and control. Mulches did not effectively control bearclover. A cheatgrass invasion occurred in the second year and within two more years was more abundant on the herbicide plots than the control.

Wildlife Response: N/A

Year: 1996

Author(s): McDonald, P.M., and Fiddler, G.O.

Running Head: Development of a Mixed Shrub-Tanoak-Douglas-fir Community

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: northern California

Treated Plant Community: Douglas fir, tanoak, mixed shrub

Stand Age at Treatment Time: newly planted

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 11 years

Chemical(s) Studied: 2,4-D, Garlon 3A®, Garlon 4®, and combinations

Treatments Evaluated: chemical and manual release

Vegetation Response: All treatments studied produced a Douglas fir-dominated plant community or a mixture of fir, tanoak, and snowbrush. However, the manual cut and spray with Garlon 3A® treatment was the most effective for controlling trees and shrubs and promoted the best Douglas fir growth. The untreated control developed into a predominantly hardwoods and shrubs stand.

Wildlife Response: N/A

Year: 1996

Author(s): McDonald, P.M., Fiddler, G.O., and Meyer, P.W.

Running Head: Effects of Various Release Treatments on a Conifer Plantation

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: northern California

Treated Plant Community: Jeffrey pine plantation

Stand Age at Treatment Time: 3 years

Pretreatment Data: Y **Duration**: not specified

Post-treatment Data: Y **Duration**: 9 years

Chemical(s) Studied: hexazinone

Treatments Evaluated: release treatments (herbicides, grazing, grubbing)

Vegetation Response: Vegetation composition varied by treatment. Herbicide treatment reduced competing vegetation (shrubs, cheatgrass), and Jeffrey pine seedlings had significant growth over other treatments. Grubbing around pine seedlings resulted in slightly higher densities of greenleaf manzanita and forbs, and did not significantly improve seedling growth over the control. Sheep grazing significantly stimulated snowbrush growth and reduced greenleaf manzanita cover over other treatments. Grazed plots had slightly more cheatgrass than other treatments, and pine seedling growth did not differ from the control.

Wildlife Response: N/A

Year: 1996

Author(s): Roth, B.E., and Newton, M.

Running Head: Shoot Growth and Douglas-fir Recovery from Browsing

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range

Treated Plant Community: Douglas fir

Stand Age at Treatment Time: seedlings

Pretreatment Data: Y **Duration**: measurements after planting

Post-treatment Data: Y **Duration**: 2 years

Chemical(s) Studied: hexazinone, glyphosate (weed control under electric fence)

Treatments Evaluated: weed control (herbicides), nitrogen fertilization, and seed source

Vegetation Response: Weed control resulted in significant increase in shoot growth (partially due to increased soil moisture and nutrients), whereas nitrogen fertilization significantly decreased growth (partially due to favored weed growth). Seed source had no influence on shoot growth. Increased shoot growth with weeding helped offset the negative effects of browsing. Even though weeded seedlings were more prone to repeated browsing, they grew twice as large as nonbrowsed, unweeded seedlings.

Wildlife Response: Deer browsing was variable, but mostly occurred within three weeks of bud break.

Year: 1996

Author(s): Runciman, J.B., and Sullivan, T.P.

Running Head: Effects of Release Treatments on Habitat and Small Mammals

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: south-central British Columbia

Treated Plant Community: predominantly Douglas fir, lodgepole pine

Stand Age at Treatment Time: 2 to 7 years

Pretreatment Data: Y **Duration**: 1 to 2 years

Post-treatment Data: Y **Duration**: 2 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: conifer release (manual, cut-stump with herbicide)

Vegetation Response: One year post-treatment, manual and cut-stump treatments decreased total deciduous tree volumes, thereby effectively releasing conifers. Deciduous tree volumes recovered on the manual treatment sites by the second year post-treatment. Both treatments reduced competition, but the cut-stump/glyphosate treatment maintained reduced competition levels for another year over manual treatment.

Wildlife Response: No significant effects on the population size of small mammals (deer mice, yellow-pine chipmunks, southern red-backed voles, or long-tailed voles) were observed from either treatment. Meadow vole responses were variable, while deer mice populations were unaffected by manual or cut-stump treatments.

Year: 1996

Author(s): Sullivan, T.P.

Running Head: Herbicide Effects on Snowshoe Hare Population Dynamics

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: central British Columbia

Treated Plant Community: white spruce, deciduous shrubs/trees

Stand Age at Treatment Time: 10 to 12 years

Pretreatment Data: Y **Duration**: 1 to 2 years

Post-treatment Data: Y **Duration**: 2 to 3 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: conifer release (reduce angiosperms), and "rehabilitation" treatment via herbicides to control undesirable vegetation prior to conifer replanting

Vegetation Response: Recovery of the herb layers to control levels was achieved within two to three years post-treatment. Where conifers dominated, shrubs and trees were minimally affected by the conifer release treatment. Dominant deciduous trees and shrubs recovered slowly after the backlog conversion treatment.

Wildlife Response: Snowshoe hare reproductive condition and success was similar between control and treatment populations. One study area had significantly more juvenile female recruitments entering the control over the treatment population. For two years post-treatment, the second area had significantly higher total recruitment in treatment than control in 1990 (both sexes) and 1991(adult females). Little or no differences in hare survival, mean body mass, and growth rates between control and treatments were observed. Glyphosate had no significant effect on the demographics of snowshoe hare populations.

Year: 1996

Author(s): Sullivan, T.P., and Boateng, J.O.

Running Head: Small Mammal Responses to Burning and Herbicides

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: south-coastal and west-central British Columbia

Treated Plant Community: Douglas fir, lodgepole pine, interior spruce

Stand Age at Treatment Time: newly planted to 7 years (regenerated)

Pretreatment Data: Y **Duration**: 1 to 2 years

Post-treatment Data: Y **Duration**: 2 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: site preparation (broadcast burning) and woody and herbaceous vegetation control (herbicide)

Vegetation Response: Herbicide treatment had a 90% efficacy, and only the conifers and salal survived. Plant community dominance varied by treatment. Three years post-spray, shrubs recovered and dominated herbaceous vegetation. Broadcast burning resulted in more extreme habitat changes and slower vegetation recovery time than herbicide treatment.

Wildlife Response: In the coastal area, deer mice had a temporary (one to two months) decline in population post-spray, but were unaffected by habitat changes at the interior site. *Microtus* were not found on the interior burned areas, but Oregon voles remained on the coastal burned area (except for the red-backed vole). Treatments did not affect chipmunks. Species diversity was not affected by either treatment. In both study areas, herbicide treatments had minimal effect on small mammal abundance.

Year: 1996

Author(s): Sullivan, T.P., Lautenschlager, R.A., and Wagner, R.G.

Running Head: Influence of Glyphosate on Vegetation Dynamics in Spruce Forests

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: central British Columbia

Treated Plant Community: interior spruce

Stand Age at Treatment Time: 2 to 12 years

Pretreatment Data: Y **Duration**: 2 months

Post-treatment Data: Y **Duration**: 3 to 4 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: successional stages: herb, shrub, and shrub-tree (conifer release from angiosperms, weed control)

Vegetation Response: One year post-treatment, herb layer volume temporarily declined. The herb-shrub stage had reduced shrubs, and the shrub-tree stage had a temporary reduction in shrubs and trees. In the herb stage, species richness of herbs and shrubs was similar in treatments and controls. Post-spray, shrub richness declined in the shrub stage. Glyphosate did not affect herbaceous species diversity in any stage. However, shrub diversity was lower in the herb and shrub stages of the treatment than the control. Post-treatment, tree diversity was reduced in the shrub-tree stage. Overall, vegetation community effects (reductions in biomass and diversity) were minimal and plant changes were temporary.

Wildlife Response: N/A

Year: 1997

Author(s): Cole, E.C., McComb, W.C., Newton, M., Chambers, C.L., and Leeming, J.P.

Running Head: Amphibian Response to Forest Management

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range

Treated Plant Community: Douglas fir

Stand Age at Treatment Time: newly planted

Pretreatment Data: Y **Duration**: 1 year

Post-treatment Data: Y **Duration**: 2 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: woody and herbaceous vegetation control (clearcut-burn, clearcut-burn-herbicide)

Vegetation Response: not specified

Wildlife Response: Post-logging, amphibian capture rates varied by species, with half of the species showing no difference. Rough-skinned newts, Dunn's salamander, and red-legged frogs had no change in capture rates post-logging. Ensatinas and Pacific giant salamander capture rates decreased post-logging, while those of the western redbacked salamander increased one year post-logging. One year post-spray, glyphosate had no significant effect on capture rates of amphibians for any treatment.

Year: 1997

Author(s): DiTomaso, J.M., Marcum, D.B., Rasmussen, M.S., Healy, E.A., and Kyser, G.B.

Running Head: Effects of Post-Fire Herbicides on Native Plant Diversity

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: northern California

Treated Plant Community: native conifer species, primarily ponderosa pine

Stand Age at Treatment Time: recently burned to 2 years

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 2 to 12 years

Chemical(s) Studied: hexazinone

Treatments Evaluated: site preparation

Vegetation Response: Herbicide site preparation (post-burn) had a significantly positive effect on conifer growth and survival, mainly due to the reduction in competing vegetation. Herbicide treatment initially reduced plant diversity and species richness, but within eight years post-treatment, native species rapidly recovered and diversity was not significantly different from unburned sites. Untreated burned areas had an extended reduction in plant diversity and species richness compared with the unburned area. Early herbicide control of dominant shrubs improved the success of native plant species.

Wildlife Response: N/A

Year: 1997

Author(s): Rice, P.M., Toney, J.C., Bedunah, D.J., and Carlson, C.E.

Running Head: Plant Community Responses to Herbicide Treatment

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: west-central Montana

Treated Plant Community: grassland, early seral forest with Douglas fir

Stand Age at Treatment Time: not specified

Pretreatment Data: Y **Duration**: 2 seasons

Post-treatment Data: Y **Duration**: 3 to 6 years

Chemical(s) Studied: picloram, clopyralid, and a clopyralis-2,4-D mixture

Treatments Evaluated: exotic forb control

Vegetation Response: Herbicide treatments were highly effective on the target weed, and plant communities returned to a grass dominated stage. However, reductions in plant diversity were minor and temporary, with plant recovery even surpassing untreated plots by three years post-treatment. Re-treatment (three to four years) after initial herbicides did not reduce plant diversity compared to untreated. Late season herbicide applications reduced impacts on plant diversity.

Wildlife Response: N/A

Year: 1997

Author(s): Sullivan, T.P., Sullivan, D.S., Lautenschlager, R.A., and Wagner, R.G.

Running Head: Long-Term Herbicide and Small Mammals

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: University of British Columbia Malcolm Knapp Research Forest, south-coastal British Columbia

Treated Plant Community: Douglas fir

Stand Age at Treatment Time: 7 years and 20 years

Pretreatment Data: Y **Duration**: 2 years per area (original trapping)

Post-treatment Data: Y **Duration**: 9 and 11 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: conifer release

Vegetation Response: Successional vegetation changes occurred throughout the study. The seven-year-old stand transitioned from a shrub-seedling to pole-sapling stage. The 20-year-old stand transitioned from a pole-sapling to a young stand stage.

Wildlife Response: Initial post-treatment densities of deer mice were lower in the treated areas than the control, but rebounded in subsequent years. At eleven years post-treatment, deer mice numbers were similar between treatment and control. Oregon vole densities were higher on treatment areas for both nine and eleven year post-treatment. Fewer chipmunks were present on the treatment than control at the nine year post-treatment and absent from the eleven year post-treatment. Shrew densities did not differ between treatments or among sites. Glyphosate had no adverse effects on deer mice and voles ten years post-treatment. Little change in species richness and diversity of the small mammal community was observed throughout this study.

Year: 1998

Author(s): Cole, E.C., McComb, W.C., Newton, M., Leeming, J.P., and Chambers, C.L.

Running Head: Small Mammals and Forest Management

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range

Treated Plant Community: Douglas fir

Stand Age at Treatment Time: newly planted

Pretreatment Data: Y **Duration**: 1 year

Post-treatment Data: Y **Duration**: 2 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: woody and herbaceous vegetation control (clearcut-burn, clearcut-burn-herbicide)

Vegetation Response: Minimal vegetative changes were observed. There was no significant variation in the total ground vegetation cover between the sprayed and unsprayed logged units.

Wildlife Response: Post-logging, small mammal responses were species-specific; however, deer mice capture rates did not change among treatments. Creeping vole and vagrant shrew capture rates in upslope areas increased post-logging, while capture rates of Pacific shrews and Trowbridge's shrews decreased. Capture rates of Townsend's chipmunks were higher in the buffer strips post-harvest. One year post-spray, there was no difference in capture rates of all six small mammal species studied between the logged-burned-sprayed and the logged-burned-unsprayed areas. Glyphosate did not appear to alter small mammal capture rates.

Year: 1998

Author(s): Easton, W.E., and Martin, K.

Running Head: Bird Community and Vegetation Management

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: south-central British Columbia

Treated Plant Community: young conifer plantations

Stand Age at Treatment Time: not specified

Pretreatment Data: Y **Duration**: 1 season (3 months)

Post-treatment Data: Y **Duration**: 3 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: conifer release by deciduous vegetation control (manual thinning, manual thinning plus herbicide – hand sprayed)

Vegetation Response: Efficacy of treatments was high, reducing deciduous tree volume by 90 to 96%. Three years post-treatment, the recovery and regrowth of deciduous trees was greater on the manual treated than the herbicide treated sites.

Wildlife Response: Post-herbicide treatment, avian species numbers declined, total individual numbers increased, and common species were dominant. Post-manual treatment, species number, total individual numbers, and evenness increased. Herbicide treated areas had the highest turnover of avian species, and controls had the lowest. Avian responses to the herbicide-induced habitat changes were species-specific. For example, post-herbicide treatment, ground gleaners, conifer nesters, residents, and short-distance migrants significantly increased, while warbling vireos (deciduous specialists) declined. Nesting success was significantly reduced for certain species post-herbicide treatment compared to manual treatment. Generally, post-herbicide treatment resulted in more homogenous bird communities, while post-manual treatment showed minimal change.

Year: 1998

Author(s): Frederickson, E., and Newton, M.

Running Head: Maximizing Forest Herbicide Efficiency

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Sierra Nevada Mountains, northern California, Oregon Coast and Cascade Ranges

Treated Plant Community: ponderosa pine, Douglas fir

Stand Age at Treatment Time: 2 years (CA), 7 to 9 years (OR)

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 3 to 13 months

Chemical(s) Studied: glyphosate, imazapyr, dichlorprop emulsifiable ester, fluroxypr, triclopyr ester, 2,4-D emulsifiable ester, atrazine, hexazinone (liquid and granular) with Activator®, Mor-Act®, and Silwet L-77® surfactants

Treatments Evaluated: herbaceous and woody vegetation control

Vegetation Response: Dose is the most important factor in determining herbicide efficacy. Release treatments should avoid surfactants due to the disproportionately increased seedling damage. Chemical type and application season are critical considerations for long-term control. The relationship of drop size to efficacy varies with chemical, timing, surfactant, and vegetation.

Wildlife Response: N/A

Year: 1998

Author(s): Schuytema, G.S., and Nebeker, A.V.

Running Head: Effects of Diuron on Frogs

Study Type: ☒ Laboratory ☐ Field

Geographic Scope: western Oregon (egg mass collection)

Treated Plant Community: N/A

Stand Age at Treatment Time: N/A

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: up to 60 days

Chemical(s) Studied: diuron

Treatments Evaluated: acute toxicity

Vegetation Response: N/A

Wildlife Response: In this study diuron was applied at higher concentrations than normally observed in the field and survival, growth, and development of amphibian embryos and tadpoles was affected. Concentrations >20 mg/L reduced growth and increased deformities in Pacific treefrogs and African clawed frogs. ed-legged frog limb development was retarded after 14 days exposure at concentrations >7.6 mg/L.

Year: 1998

Author(s): Sullivan, T.P., Nowotny, C., Lautenschlager, R.A., and Wagner, R.G.

Running Head: Herbicide and Small Mammals

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: central British Columbia

Treated Plant Community: interior spruce

Stand Age at Treatment Time: 2 to 7 years

Pretreatment Data: Y **Duration**: 1 year

Post-treatment Data: Y **Duration**: 4 years (1^{st}, 2^{nd}, 4^{th}, 5^{th} years post-treatment)

Chemical(s) Studied: glyphosate

Treatments Evaluated: conifer release

Vegetation Response: Post-herbicide treatment, shrub and herb volumes were reduced. Herbaceous vegetation recovered to control levels within two years, while shrubs recovered to only 16% of control crown volumes by five years post-treatment.

Wildlife Response: In early post-treatment years, red-backed voles and shrews were more prevalent on the control than the treated areas. Abundance of meadow voles and deer mice was similar on treated and control sites for all years. Weasels were frequently captured on control and treated sites during the study. In post-treatment years, red-backed voles had a higher successful pregnancy rate on the control than the treated areas, whereas deer mice did not. Survival estimates for red-backed voles were higher in treated areas than control, whereas deer mice were not. Although herbicide-induced changes were observed, the demographic effects on small mammal communities were within the scope of natural fluctuations.

Year: 1998

Author(s): Sullivan, T.P., Wagner, R.G., Pitt, D.G., Lautenschlager, R.A., and Chen, D.G.

Running Head: Herbicide Effects on Plants and Small Mammals

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: central British Columbia

Treated Plant Community: interior spruce

Stand Age at Treatment Time: 2 to 7 years

Pretreatment Data: Y **Duration**: 1 year

Post-treatment Data: Y **Duration**: 4 years (1st, 2nd, 4th, 5th years post-treatment)

Chemical(s) Studied: glyphosate

Treatments Evaluated: conifer release

Vegetation Response: One year post-treatment, herbaceous vegetation crown volume was reduced, but it recovered to control levels within two years. Herbicide treatment did not affect species richness of herbs. Post-herbicide treatment, shrub crown volume and species richness was reduced. Shrub species richness remained lower on the herbicide treated sites throughout the study.

Wildlife Response: Small mammal diversity was not affected by herbicide-induced habitat changes in this study.

Year: 1999

Author(s): Monleon, V.J., Newton, M., Hooper, C., and Tappeiner, J.C. II

Running Head: Vegetation Competition Effects on Douglas-fir Growth

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: western Oregon Cascade Range

Treated Plant Community: Douglas fir

Stand Age at Treatment Time: newly planted

Pretreatment Data: Y **Duration**: not specified

Post-treatment Data: Y **Duration**: 10 years

Chemical(s) Studied: triclopyr, and glyphosate plus simazine

Treatments Evaluated: chemical thinning and herbaceous vegetation control

Vegetation Response: Ceanothus density had a significant effect on Douglas fir growth rates. A ceanothus density <6,750 plant/ha did not affect Douglas fir growth at ten years post-treatment. However, Douglas fir growth significantly decreased with a ceanothus density >15,000 plants/ha. The amount of herbaceous vegetation had a significant impact on the long-term growth and size of Douglas fir. Herbaceous vegetation removal significantly improved fir growth rates over untreated trees, regardless of ceanothus density.

Wildlife Response: N/A

Year: 1999

Author(s): Powers, R.F., and Reynolds, P.E.

Running Head: Responses of Ponderosa Pine to Vegetation and Nutrient Control

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Klamath, Cascade, and Sierra Nevada regions, northern California

Treated Plant Community: ponderosa pine

Stand Age at Treatment Time: newly planted

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 10 years

Chemical(s) Studied: glyphosate or hexazinone, insecticide (acephate or dimethoate), and combinations

Treatments Evaluated: vegetation, nutrient, and insect control

Vegetation Response: Vegetation control treatments had a greater positive effect on ponderosa pine growth on xeric sites with a lesser effect on the most mesic sites. On xeric and infertile soil sites, pine growth was linked primarily to soil moisture availability and secondarily to improved nutrition. On the more mesic, most productive site fertilizers and herbicides produced similar significant growth increases. Benefits from vegetation control (increased water availability) will diminish with tree crown closure and increased transpiration.

Wildlife Response: N/A

Year: 1999

Author(s): Stein, W.I.

Running Head: Effects of Manual and Herbicide Shrub Release on Douglas-fir Growth

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range

Treated Plant Community: Douglas fir

Stand Age at Treatment Time: 2 to 5 years

Pretreatment Data: Y **Duration**: initial measurements, cover plots

Post-treatment Data: Y **Duration**: 6 years

Chemical(s) Studied: glyphosate, fosamine

Treatments Evaluated: release treatments (herbicides, manual, combinations)

Vegetation Response: Douglas fir survival averaged 95.9% throughout the study. All release treatments were effective at increasing Douglas fir growth and development. Firs on treated areas had greater total height, stem diameter, and crown radius than on untreated areas six years post-treatment. One manual shrub removal created four times the Douglas fir volume of the control. Subsequent manual releases, herbicides, and manual plus fosamine treatments were less effective than a single manual release treatment at improving fir growth. Shrub cover was significantly greater on untreated areas than treated areas. Herbicide treatments were most effective on red alder, salmonberry, and red elder. Post-release, diversity of competing vegetation temporarily increased.

Wildlife Response: N/A

Year: 2000

Author(s): O'Dea, M.E., Newton, M., Cole, E.C., and Gourley, M.

Running Head: Influence of Weeding on Growth of Browsed Douglas-fir Seedlings

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Coast and Cascade Ranges

Treated Plant Community: Douglas fir

Stand Age at Treatment Time: seedlings

Pretreatment Data: Y **Duration**: initial measurements

Post-treatment Data: Y **Duration**: 4 and 5 years

Chemical(s) Studied: atrazine, hexazinone, sulfometuron, and glyphosate

Treatments Evaluated: competing vegetation release treatments (weed control via herbicides)

Vegetation Response: Control seedlings (unweeded) had modest growth, with little effect from browsing. Herbicide treatments facilitated seedling growth and escapement from browsing. Weeded seedlings also had increased post-herbivory recovery rates, resulting in significantly increased net growth. Sizes of repeatedly browsed seedlings were similar to those weeded within the first two years. Weeded seedlings were larger than unweeded seedlings. Browsed Douglas fir seedling growth was greater on weeded than on nonweeded sites, regardless of site quality.

Wildlife Response: Browsing of Douglas fir seedlings by deer and elk was moderately heavy to severe on both study areas. The amount of cover appeared to have some influence on the degree of deer browsing, whereas level, more open areas were indiscriminately browsed by elk.

Year: 2001

Author(s): Busse, M.D., Ratcliff, A.W., Shestak, C.J., and Powers, R.F.

Running Head: Effects of Glyphosate on Soil Microbial Communities

Study Type: ☒ Laboratory ☒ Field

Geographic Scope: Klamath Mountains, southern Cascade Range, and northern Sierra Nevada Mountains, northern California

Treated Plant Community: ponderosa pine

Stand Age at Treatment Time: newly planted

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: collected after 9 to 13 years of control

Chemical(s) Studied: glyphosate

Treatments Evaluated: competing vegetation control

Vegetation Response: Two to three years after the final herbicide application, little or no understory vegetation remained on treated plots. After ten years the control plots had shrub cover ranging from 25 to 110% (see Powers and Reynolds 1999).

Wildlife Response: Glyphosate was toxic to cultured (soil-free media) bacteria and fungi from the plantations. The growth rate, metabolic diversity, and culturable populations of bacteria were reduced with increased doses of glyphosate. However, glyphosate toxicity was not observed when added directly to the soil. Microbial respiration was not affected by glyphosate at field concentrations. However, glyphosate concentrations at 100 times field rates stimulated microbial respiration. Repeated treatments of glyphosate over long periods of time had no significant effect on seasonal microbial characteristics. Applied at recommended field rates, glyphosate should have minimal or no affect on soil microbial communities in ponderosa pine plantations.

Year: 2001

Author(s): McDonald, P.M., and Fiddler, G.O.

Running Head: Effects of Timing and Duration Release Treatments on White Fir

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: southern Cascade Mountains, northern California

Treated Plant Community: California white fir

Stand Age at Treatment Time: newly planted

Pretreatment Data: Y **Duration**: not specified

Post-treatment Data: Y **Duration**: 10 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: site preparation and release (herbicide, grubbing)

Vegetation Response: Survival rates of white fir were 92% and 86% after the first and tenth year, respectively. Site preparation removed competing vegetation, and timing of release was critical. Treatments had variable results, as shrub and forb responses were species-specific. For example, treatment significantly reduced the density and foliar cover of snowbrush. Both timing and duration of treatment were important factors affecting treatment results. Early release treatment significantly increased survival and growth of white fir seedlings over the control. Delayed release treatments produced fir seedlings with similar growth values as those in the control.

Wildlife Response: N/A

Year: 2002

Author(s): Brandeis, T.J., Newton, M., Filip, G.M., and Cole, E.C.

Running Head: Artificially Made Snags

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: western Oregon

Treated Plant Community: Douglas fir

Stand Age at Treatment Time: 50 to 55 years

Pretreatment Data: Y **Duration**: initial measurements

Post-treatment Data: Y **Duration**: 4 years

Chemical(s) Studied: triclopyr and monosodium methanearsonate (MSMA)

Treatments Evaluated: Five snag creation methods: axe girdling; cut and frill with triclopyr; cut and frill with MSMA; topping at base of live crown; and topping at middle of live crown. Artificial inoculation with fungi was done one year post snag treatment to select trees.

Vegetation Response: Herbicide treated trees and fully topped trees died sooner than girdled or mid-topped trees, at just over a year. Girdled trees died in about two years, while mid-topped trees that died took almost three years.

Wildlife Response: Four years post-treatment, snag creation methods and artificial inoculation had no direct effect on bark beetle activity, presence of fungal fruiting bodies, or woodpecker activity. Bird usage was most influenced by the length of time the snag was dead. Pileated and hairy woodpeckers and other species did use the created snags for foraging and possible nesting activity.

Year: 2002

Author(s): Easton, W.E., and Martin, K.

Running Head: Songbird Nesting Habitat in Young Forest

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: south-central British Columbia

Treated Plant Community: mixed conifer plantations with deciduous components

Stand Age at Treatment Time: 11 to 22 years

Pretreatment Data: Y **Duration**: see Easton and Martin 1998

Post-treatment Data: Y **Duration**: 3 years

Chemical(s) Studied: glyphosate

Treatments Evaluated: conifer release by deciduous vegetation control (manual thinning, manual thinning plus herbicide)

Vegetation Response: Conifer release treatments removed 90 to 96% of deciduous stems. Three years post-treatment, the thinning plus herbicide treatment areas still had scarce deciduous vegetation, while the deciduous vegetation in the thinned areas recovered to control levels.

Wildlife Response: Songbird nest patch selection was positively correlated with the remaining amount of deciduous vegetation. All five species studied showed a preference for deciduous vegetation, even though nesting and foraging requirements varied. A decline in the number of song birds after herbicide and thinning treatment was probably due to the reduction in deciduous vegetation for nesting. Birds altered their behavior (type of nesting tree) in response to habitat change, creating a reproductive cost for certain species.

Year: 2002

Author(s): Ewing, K.

Running Head: Early Growth and 3-Year Survival of Idaho Fescue

Study Type: ☒ Laboratory ☒ Field

Geographic Scope: University of Washington

Treated Plant Community: transplanted Idaho fescue in non-native pasture grassland

Stand Age at Treatment Time: pre-planting

Pretreatment Data: Y **Duration**: 6 months (seed to transplant)

Post-treatment Data: Y **Duration**: 3 growing seasons

Chemical(s) Studied: glyphosate

Treatments Evaluated: woody and herbaceous vegetation control (herbicide-till, burn, soil impoverishment, compost mulch application, fertilizer application)

Vegetation Response: Initial Idaho fescue growth was highest with fertilizer and compost treatments. However, after the first year, the fescue on fertilized and composted plots had the lowest survival. Glyphosate-till and impoverishment plots had the greatest three year Idaho fescue survival, while compost mulch plots had the greatest three-year weed growth. Treatments to enhance Idaho fescue growth also encourage the growth of competitive weedy species, subsequently reducing growth and survival of fescue. Creating a stressful environment by decreasing resource availability gave Idaho fescue a competitive edge and increased fescue survival.

Wildlife Response: N/A

Year: 2002

Author(s): Rose, R., and Ketchum, J.S.

Running Head: Vegetation Control and Fertilizer Effects on Conifers

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range, coastal Oregon, eastern Washington, northern California

Treated Plant Community: Douglas fir, ponderosa pine, coastal redwood, western hemlock

Stand Age at Treatment Time: newly planted

Pretreatment Data: Y **Duration**: 1 month post-planting

Post-treatment Data: Y **Duration**: 4 years

Chemical(s) Studied: sulfometuron, hexazinone, atrazine

Treatments Evaluated: woody and herbaceous vegetation control (herbicides, fertilizer)

Vegetation Response: At most sites (four out of five) seedling mean stem volume, basal diameter, and height increased significantly with increased coverage of weed control. Fertilization significantly increased seedling growth at two sites that had adequate soil moisture content. Conifer responses to weed control were greater and lasted longer (four years) than those from fertilizer (one year).

Wildlife Response: N/A

Year: 2002

Author(s): Sullivan, T.P., Sullivan D.S., Lindgren, P.M.F., and Boateng, J.O.

Running Head: Effects of Conventional and Chemical Thinning on a Lodgepole Pine Community

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: south-central British Columbia

Treated Plant Community: Lodgepole pine

Stand Age at Treatment Time: 12 to 14 years

Pretreatment Data: Y **Duration**: prior to thinning

Post-treatment Data: Y **Duration**: 5 years

Chemical(s) Studied: Ezject® selective injection capsules with Vision® glyphosate

Treatments Evaluated: conventional (chainsaw) and chemical thinning

Vegetation Response: Conventional thinning resulted in a more uniform distribution of lodgepole pine, whereas chemical thinning produced a more aggregated pattern of crop trees. Lodgepole diameter growth was similar for chemical, conventional, and unthinned stands. Chemical thinning enhanced horizontal stratification, but reduced vertical stratification compared to conventional thinning. Generally, understory vegetation abundance and diversity were not affected by stand thinning (up to five years post-treatment).

Wildlife Response: Small mammal communities were unaffected by stand thinning, except for deer mice and heather voles that were more abundant in chemically thinned and conventionally thinned stands, respectively. Mule deer habitat use was greatest in conventionally thinned stands and lowest in unthinned stands, while snowshoe hare habitat use was the opposite. Moose habitat use did not differ among stands. Chemical thinning could be a beneficial treatment to create a clumped pattern of plantation trees to help maintain habitat for herbivores such as snowshoe hares and mule deer.

Year: 2003

Author(s): Rose, R., and Ketchum, J.S.

Running Head: Douglas-fir Seedling Treatments and Growth

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: western Washington

Treated Plant Community: Douglas fir

Stand Age at Treatment Time: newly planted to 3 years

Pretreatment Data: Y **Duration**: initial measurements

Post-treatment Data: Y **Duration**: 4 years

Chemical(s) Studied: Oust®, Transline®, Accord®, Garlon® in Web Oil®, Velpar®

Treatments Evaluated: hardwoods and herbaceous vegetation control, fertilization, seedling diameter

Vegetation Response: Fertilizer treatments produced early but temporary seedling growth gains. Herbicide weed control in the third year did not affect stem volume (fourth year) or volume growth (third and fourth years). Using larger seedling stock (2+ mm basal diameter) produced the greatest stem volume gains (35 to 43%) in the fourth year.

Wildlife Response: N/A

Year: 2004

Author(s): Chen, F.-H.

Running Head: Herbicide Effects on Vegetation in Conifer Plantations

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: western Oregon

Treated Plant Community: mixed conifer plantations

Stand Age at Treatment Time: newly planted to 5 years

Pretreatment Data: Y **Duration**: initial measurements (a few weeks post-planting), vegetation assessments (late July)

Post-treatment Data: Y **Duration**: 4 years

Chemical(s) Studied: sulfometuron, metsulfuron, glyphosate, imazapyr, triclopyr, atrazine clopyralid

Treatments Evaluated: site preparation and release treatments for herbaceous and woody vegetation (weed) control

Vegetation Response: Increased years of vegetation control had a positive effect on conifer growth. However, by the third or fourth year, seedling survival was not affected by herbicides. The timing of herbicide application post-planting (initial years vs. later treatments) did not produce a significant difference in conifer growth. Although weed control treatments reduced total vegetation cover up to 90%, only a small decrease in plant diversity was observed. Both total cover and plant diversity recovered, but at different rates (varied by site), after the cessation of herbicide treatments. Generally, shrub species richness did not vary by treatment. Site preparation treatments returned vegetation to an early successional stage, after which vegetation recovery was rapid. Repeated herbicide treatments showed possible negative effects on some plant families (e.g., Rosaceae) and native species.

Wildlife Response: N/A

Year: 2005

Author(s): Cauble, K., and Wagner, R.S.

Running Head: Sublethal Effects of Glyphosate on Amphibian Development

Study Type: ☒ Laboratory ☐ Field

Geographic Scope: central Washington (egg collection)

Treated Plant Community: N/A

Stand Age at Treatment Time: N/A

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 43 days

Chemical(s) Studied: glyphosate formulations

Treatments Evaluated: chronic glyphosate exposure (non-acute levels) effects on Cascade frog metamorphosis

Vegetation Response: N/A

Wildlife Response: Low Roundup® concentrations significantly affected Cascade frog larvae survivability, metamorphosis rate (earlier), and post-metamorphosis mass (lower). Exposure to the highest Roundup® concentrations resulted in no larval survival to metamorphosis. Testing suggested mortality was primarily due to chronic herbicide exposure. A possible indirect effect of chronic exposure to glyphosate could include an increased risk of predation due to smaller metamorphosis size.

Year: 2005

Author(s): Huddleston, R.T., and Young, T.P.

Running Head: Oregon Grassland Restoration

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: southwestern Oregon

Treated Plant Community: native perennial grasslands

Stand Age at Treatment Time: not specified

Pretreatment Data: Y **Duration**: time of initial seeding

Post-treatment Data: Y **Duration**: 3 to 6 months

Chemical(s) Studied: glyphosate

Treatments Evaluated: weed control and native grass support (herbicide, sawdust, herbicide plus alfalfa mulch

Vegetation Response: On the unburned site, total available soil nitrogen was temporarily reduced with the sawdust treatment. Alfalfa treatments significantly increased soil nitrogen availability at all sites. However, these differences in soil nitrogen availability did not affect development of weeds or perennial grasses. Neither nitrogen impoverishment nor nitrogen enrichment was a useful restoration technique. Glyphosate treatment not only reduced exotic annuals and forbs, but also promoted establishment and development of native forbs and planted perennial grasses, making it a good management technique to restore native perennial grasses.

Wildlife Response: N/A

Year: 2005

Author(s): Roberts, S.D., Harrington, C.A., and Terry, T.A.

Running Head: Harvest Residue and Competing Vegetation Effects on Douglas-fir

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Coast Range, southwest Washington

Treated Plant Community: Douglas fir plantation

Stand Age at Treatment Time: 1 year

Pretreatment Data: Y **Duration**: initial measurements

Post-treatment Data: Y **Duration**: 3 years

Chemical(s) Studied: Oust®, Accord concentrate®, Atrazine 4L®, and Transline® combinations

Treatments Evaluated: vegetation control and residual biomass retention

Vegetation Response: Volumetric soil moisture, seedling diameter, and volume growth were lowest on bole-only harvest without vegetation control plots (second and third growing seasons). In the second year, volume growth was slightly higher on total tree harvest with vegetation control plots (lower soil moisture, warmer soil temperatures) than bole-only harvest with vegetation control plots. In the third year, bole-only harvest with vegetation control plots (higher soil moisture) had the greatest growth. Nitrogen availability varied with vegetation control in the third year, and higher nitrogen availability was positively correlated with seedling growth. After the third growing season, tree size differed by treatment. Vegetation control treatments increased the availability of soil moisture and nitrogen, thereby improving seedling growth. Soil moisture had the largest effect on seedling growth, especially late in the season. Soil moisture and temperature and available nitrogen can be affected by residue retention and vegetation control, which can significantly influence Douglas fir growth.

Wildlife Response: N/A

Year: 2005

Author(s): Simard, S.W., Hagerman, S.M., Sachs, D.L., Heineman, J.L., and Mather, W.J.

Running Head: Conifer and Plant Responses to Reduced Broadleaf Competition

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: southern interior British Columbia

Treated Plant Community: Douglas fir, lodgepole pine in mixed broadleaf shrub, aspen complexes

Stand Age at Treatment Time: 5 to 10 years

Pretreatment Data: Y **Duration**: initial measurements

Post-treatment Data: Y **Duration**: 3 years (1st, 3rd, and 5th years post treatment)

Chemical(s) Studied: glyphosate

Treatments Evaluated: manual cutting, girdling, cut-stump with herbicide

Vegetation Response: Five year conifer survival was >85% for all treatments. Conifer growth increased with intensity of broadleaf vegetation control and site productivity. Cut-stump glyphosate treatment resulted in the greatest reduction in broadleaf vegetation, and Douglas fir diameter increased by 37%. Girdling increased fir diameter by 17%, while manual cutting had no effect on fir diameter. Manual cutting or girdling of birch reduced conifer survival (for three to five years) due to an increase in mortality from *Armillaria ostoyae* root disease. The cut-stump glyphosate treatment of birch or manual aspen cutting did not result in higher mortality from *Armillaria ostoyae.* Manual cutting and cut-stump glyphosate treatments increased structural diversity due to the removal of dominant broadleaf vegetation and increase in understory components.

Wildlife Response: N/A

Year: 2006

Author(s): Forson, D., and Storfer, A.

Running Head: Effects of Atrazine and ATV on Survival and Life History

Study Type: ☒ Laboratory ☐ Field

Geographic Scope: northwest Montana (salamander egg collection)

Treated Plant Community: N/A

Stand Age at Treatment Time: N/A

Pretreatment Data: Y **Duration**: 1 week (initial measurements)

Post-treatment Data: Y **Duration**: 30 days

Chemical(s) Studied: atrazine

Treatments Evaluated: atrazine effects, *Ambystoma tigrinum* virus (ATV) susceptibility, and possible synergistic effects

Vegetation Response: N/A

Wildlife Response: Infection rates of ATV were lower than expected. Exposure to atrazine and ATV lowered larvae mortality rates compared to ATV exposure alone. Highest atrazine levels accelerated metamorphosis, thereby reducing size and snout-vent length (SVL) at metamorphosis. ATV exposure also reduced SVL at metamorphosis. Atrazine may compromise the efficacy of ATV on long-toed salamanders. Higher levels of atrazine can result in smaller metamorphosis size and can potentially reduce fitness.

Year: 2006

Author(s): Harrington, T.B.

Running Head: Conifer Growth Responses to Altered Vegetation Competition

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: western Washington

Treated Plant Community: Douglas fir, western hemlock, western redcedar

Stand Age at Treatment Time: 1 year old (seedlings in clearcut), 40 or 70 year old (shelterwood or thinned stands)

Pretreatment Data: Y **Duration**: 1 month

Post-treatment Data: Y **Duration**: 4 years

Chemical(s) Studied: glyphosate, triclopyr, Havahart® Deeraway® powder

Treatments Evaluated: various densities of overstory and understory vegetation competition, evergreen shrub control (thinning, herbicides)

Vegetation Response: In general, the effects of overstory level and vegetation control on conifer seedling growth and resource availability were additive and did not significantly interact. Overtopping of seedlings was greater in the absence of competing vegetation control. Herb cover was greater with overstory trees and in thinned stands than in shelterwoods or clearcuts. Photosynthetically active radiation increased with vegetation control, but only in thinned stands. Increased areas of vegetation control around seedlings resulted in higher soil water content in clearcuts and lower soil water content in shelterwood or thinned stands. Increases in Douglas fir foliar nitrogen content from vegetation control were greater in clearcuts than in shelterwoods or thinned stands. Increased area of vegetation control also increased the midday water potential of Douglas fir in thinned stands but not in shelterwoods.

Wildlife Response: N/A

Year: 2006

Author(s): McDonald, P.M., and Fiddler, G.O.

Running Head: Plant Species Diversity in Managed Conifer Stands

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: northern and central California

Treated Plant Community: ponderosa pine, Douglas fir, Jeffrey pine, white fir, red fir

Stand Age at Treatment Time: 1 to 3 years (when sampling began)

Pretreatment Data: N **Duration**:

Post-treatment Data: Y **Duration**: 10 to 11 years

Chemical(s) Studied: not specified

Treatments Evaluated: variety of site preparation and release

Vegetation Response: Results from 21 study areas were reported. The total number of conifer, hardwood, shrub, forb, graminoid, and fern species was 237. After ten years, the average number of species per plantation increased from 23 to 28. The number of species per study area was highly variable, ranging from 13 to 61. Trends of species richness to site productivity or vegetation age were not apparent. Four species present at the beginning of the studies were found to be absent at the end, and 12 species at the end of the studies were not found at the start. Three species and ten genera commonly occupied the majority of plantations.

Wildlife Response: N/A

Year: 2006

Author(s): Rosner, L.S., and Rose, R.

Running Head: Synergistic Stem Volume Response to Vegetation Control and Seedling Size

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Coast and Cascade Ranges, Oregon

Treated Plant Community: Douglas fir, western redcedar, western hemlock, grand fir

Stand Age at Treatment Time: newly planted up to 3 years post-planting

Pretreatment Data: Y **Duration**: initial measurement 1 month post-planting

Post-treatment Data: Y **Duration**: 3 to 5 years

Chemical(s) Studied: imazapyr, sulfometuron, metsulfuron, glyphosate, atrazine, clopyralid

Treatments Evaluated: site preparation and conifer release (consecutive herbicide, herbaceous-only, and woody-only control treatments)

Vegetation Response: Even though herbicide treatments reduced total vegetation cover, treatment effectiveness varied across the years. Conifer responses were species- and site-specific. Seedling size and weed control significantly increased growth of all conifer species (year 4, 5, or 12). Conifer diameter and height responses to herbicides and seedling size were additive. Herbicide treatment effects on stem volume were synergistic (volume increased with increasing seedling size). Conifer growth can be optimized by increased weed control and planting larger seedlings.

Wildlife Response: N/A

Year: 2008

Author(s): Downs, T.

Running Head: Phytotoxic Effects of Herbicides and Adjuvants on Salal

Study Type: ☒ Laboratory ☒ Field

Geographic Scope: coastal Oregon

Treated Plant Community: primarily salal

Stand Age at Treatment Time: early active foliar growth state and after bud-set (dormant state, field); 1 year old potted salal plants (lab)

Pretreatment Data: Y **Duration**: immediately pre-treatment

Post-treatment Data: Y **Duration**: 1 year (1.5, 6, and 12 months) in field; 2 weeks in lab

Chemical(s) Studied: glyphosate, triclopyr, imazapyr, picloram, adjuvants

Treatments Evaluated: herbicides, surfactants, application rates, and seasons of treatment (field); leaf sorption and translocation (lab)

Vegetation Response: Effectiveness of all herbicides and adjuvants was not significantly different. However, the consistently least and most efficacious were glyphosate and triclopyr, respectively. High application rates and spring treatments were significantly more effective than low application rates and fall treatments. Imazapyr was the only herbicide to exhibit a significant interaction with treatment factors (adjuvant by season, adjuvant by herbicide rate). Imazapyr and triclopyr delivered the highest concentrations of herbicide into leaves, stems, and rhizomes. Timing of treatment significantly affected the delivery of chemical. Spring treatments improved leaf absorption, while fall treatments produced greater amounts of labeled material in below-ground rhizomes. Methylated seed oil (MSO) was the most efficacious surfactant.

Wildlife Response: N/A

Year: 2008

Author(s): McComb, B.C., Curtis, L., Chambers, C.L., Newton, M., and Bentson, K.

Running Head: Glyphosate Herbicide

Study Type: ☒ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range and western Oregon

Treated Plant Community: Douglas fir stand (treated animals released)

Stand Age at Treatment Time: N/A

Pretreatment Data: Y **Duration**: measurements, acclimation 7 to 14 days

Post-treatment Data: Y **Duration**: 96+ hours (lab); 7 to 10 days (field)

Chemical(s) Studied: glyphosate

Treatments Evaluated: acute herbicide toxicity and behavioral effects

Vegetation Response: N/A

Wildlife Response: Median mammalian lethal doses of glyphosate ranged from 800 to 1340 mg/kg (laboratory mice were in the middle of the mammal range) and amphibian doses were 1170 to >2000 mg/kg. Oregon voles had a higher glyphosate sensitivity than deer mice, while the tailed frog was the least sensitive. Oral and intraperitoneal toxicity was low. Glyphosate (at sublethal doses) did not affect the mobility and behavior of chipmunks or rough-skinned newts. With the large safety margin of glyphosate dosages, any direct toxic effects on these nine non-target species from aerial application should be negligible.

Year: 2008

Author(s): Nabel, M.R.

Running Head: Establishment and Growth of Conifers 10 Years Post-Treatment

Study Type: ☐ Laboratory ☒ Field

Geographic Scope: Oregon Coast Range

Treated Plant Community: Douglas fir dominated; Douglas fir/western hemlock dominated

Stand Age at Treatment Time: 50 to 55 years (pre- and post-thinning), and recently underplanted conifer seedlings

Pretreatment Data: Y **Duration**: not specified

Post-treatment Data: Y **Duration**: 10 years (cover = 1st, 3rd, 5th, 7th, 10th) and 13 years

Chemical(s) Studied: glyphosate, triclopyr ester, imazapyr, sulfometuron, 2,4-D

Treatments Evaluated: overstory thinning, vegetation control (perennial shrubs/forbs), release

Vegetation Response: On the more xeric site, establishment of natural regeneration and survival of underplanted conifers was greater under lower overstory densities; however, no differences were found on the more mesic site that had prolific western hemlock understory regeneration. Conifers growing under lower overstory retention levels grew taller and had larger diameters ten years post-treatment. Vegetation control increased both the establishment rate of naturally-regenerated Douglas fir and the survival rate of underplanted Douglas fir and western hemlock. Although vegetation control increased the size of underplanted conifer seedlings ten years post-treatment, the size of naturally-regenerated conifers was unaffected.

Wildlife Response: N/A

Table A1 Common Names and Genus Species Names of Plants in Appendix A

Common Name	Genus Species
Alfalfa	*Medicago sativa*
Bear clover	*Chamaebatia foliolosa*
Bitter cherry	*Prunus emarginata*
Bitterbrush	*Purshia tridentata*
Blackberry	*Rubus* spp.
Bush chinquapin	*Chrysolepis sempervirens*
California white fir	*Abies concolor*
Cheatgrass	*Bromus tectorum*
Coastal redwood	*Sequoia sempervirens*
Colonial bentgrass	*Agrostis tenuis*
Creambush rockspirea	*Holodiscus discolor*
Currant	*Ribes aureum, Ribes cereum*
Douglas fir	*Pseudotsuga menziesii*
Grand fir	*Abies grandis*
Greenleaf manzanita	*Arctostaphylos patula*
Idaho fescue	*Festuca idahoensis*
Interior spruce	*Picea glauca*
Jeffrey pine	*Pinus jeffreyi*
Lewis mockorange	*Philadelphus lewisii*
Lodgepole pine	*Pinus contorta*
Mallow ninebark	*Physocarpus malvaceus*
Meadow fescue	*Festuca elatior*
Pacific madrone	*Arbutus menziesii*
Ponderosa pine	*Pinus ponderosa*
Red alder	*Alnus rubra*
Red elder (elderberry)	*Sambucus callicarpa*
Red fir	*Abies magnifica*
Redstem ceanothus	*Ceanothus sanguineus*
Rocky Mountain maple	*Acer glabrum*
Saskatoon serviceberry	*Amelanchier alnifolia*
Salal	*Gaultheria shallon*
Salmonberry	*Rubus spectabilis*
Scouler willow	*Salix scouleriana*
Shinyleaf ceanothus	*Ceanothus velutinus*
Snowbrush ceanothus	*Ceanothus velutinus*
Spotted knapweed	*Centaurea maculosa*
Sugar pine	*Pinus lambertiana*
Tanoak	*Lithocarpus densiflorus*
Thimbleberry	*Rubus parviflorus*
Tobacco bush	*Ceanothus velutinus*
Varnishleaf ceanothus	*Ceanothus velutinus laevigatus*
Vine maple	*Acer circinatum*
Western hemlock	*Tsuga heterophylla*
Western redcedar	*Thuja plicata*
White fir	*Abies concolor*
White spruce	*Picea glauca*

Table A2 Common Names and Genus Species Names of Mammals in Appendix A

Common Name	Genus Species
Black-tailed deer	*Odocoileus hemionus columbianus*
Creeping vole	*Microtus oregoni*
Deer mouse	*Peromyscus maniculatus*
Elk	*Cervus canadensis*
Golden-mantled ground squirrel	*Spermophilus lateralis*
Great Basin pocket mouse	*Perognathus parvus*
Heather vole	*Phenacomys intermidius*
Long-tailed vole	*Microtus longicaudus*
Meadow vole	*Microtus pennsylvanicus*
Moose	*Alces alces*
Mule deer	*Odocoileus hemionus*
Oregon vole	*Microtus oregoni*
Pacific jumping mouse	*Zapus trinotatus*
Pacific shrew	*Sorex pacificus*
Pocket gopher	*Thomomys* spp.
Red-backed vole	*Myodes gapperi*
Snowshoe hare	*Lepus americanus*
Southern red-backed vole	*Clethrionomys gapperi*
Townsend’s chipmunk	*Tamias townsendii*
Trowbridge’s shrew	*Sorex trowbridgii*
Vagrant shrew	*Sorex vagrans*
Yellow-pine chipmunk	*Tamias amoenus*

Table A3 Common Names and Genus Species Names of Birds in Appendix A

Common Name	Genus Species
Fox sparrow	*Passerella iliaca*
Hairy woodpecker	*Picoides villosus*
Pileated woodpecker	*Dryocopus pileatus*
Rufous hummingbird	*Selasphorus rufus*
Song sparrow	*Melospiza melodia*
Swainson’s thrush	*Catharus ustulatus*
Warbling vireo	*Vireo gilvus*
White-crowned sparrow	*Zonotrichia leucophrys*
Wilson’s warbler	*Wilsonia pusilla*

Table A4. Common Names and Genus Species Names of Other Species in Appendix A

Common Name	Genus Species
African clawed frog	*Xenopus laevis*
ATV	*Ambystoma tigrinum* virus
Bark beetle	Scolytinae
Beetles	Scolytid, Burprestid
Cascade frog	*Rana cascadae*
Coho salmon	*Oncorhynchus kisutch*
Dunn’s salamander	*Plethodon dunni*
Ensatina	*Ensatina eschscholtzii*
Fomes annosus	*Fomes annosus*
Green-leaf beetle	Coleoptera: Chrysomelidae
Long-toed salamander	*Ambystoma macrodactylum*
Pacific giant salamander	*Dicamptodon tenebrosus*
Pacific treefrog	*Pseudacris regilla*
Rainbow trout	*Salmo gairdner, Onchorhyncus mykissi*
Red-legged frog	*Rana aurora*
Rough-skinned newt	*Taricha granulose*
Shoestring rot, honey mushroom	*Armillaria ostoyae*
Tailed frog	*Ascaphus truei*
Western redbacked salamander	*Plethodon vehiculum*

APPENDIX B

PACIFIC NORTHWEST STUDIES OF FOREST HERBICIDE EFFECTS: TABULAR LISTS

B2

Table B1 Pacific Northwest Studies of Forest Herbicide Effects on Mammals

Species and (Common Name)	Location and [Reference][a]	Chemical(s)[b]	Application Rate[c]	Duration (years)[d]
Carnivores				
Mustela erminea (Ermine)	OR (coastal) [1]	glyphosate (W)	2.25 L/ha*	3
	OR (western) [2]	atrazine+2,4-D		3
	OR (coastal) [10]	glyphosate	3.3 kg/ha	55 days
	BC (south-coastal) [19]	glyphosate	2.14 or 3.0 kg/ha	4
	BC (west-central) [19]	glyphosate	2.14 or 3.0 kg/ha	4
	BC (central) [20,26]	glyphosate	2.14 kg/ha	5
	BC (south-central) [25]	glyphosate	chemical thinning	5
Mustela frenata (Long-tailed weasel)	BC (central) [20,25]	glyphosate	2.14 kg/ha	5
Insectivores				
Neurotrichus gibbsii (American shrew mole)	OR (southwestern) [2]	untreated		2
	OR (western) [2]	atrazine+2,4-D		3
	BC (south-coastal) [15]	glyphosate	3.0 kg/ha	4
	BC (south-coastal) [19]	glyphosate	2.14 or 3.0 kg/ha	4
	BC (south-coastal) [24]	glyphosate	2.2 or 3.0 kg/ha	11, 13
Sorex spp. (Shrew)	OR (coastal) [10]	glyphosate	3.3 kg/ha	55 days
	BC (south-coastal) [15]	glyphosate	3.0 kg/ha	4
	BC (south-coastal) [19]	glyphosate	2.14 or 3.0 kg/ha	4
	BC (west-central) [19]	glyphosate	2.14 or 3.0 kg/ha	4
	BC (central) [20]	glyphosate	2.14 kg/ha	5
	BC (south-coastal) [23]	glyphosate	2.2 kg/ha	3
	BC (south-coastal) [24]	glyphosate	2.2 or 3.0 kg/ha	11, 13
Sorex cinereus (Common shrew)	BC (south-central) [25]	glyphosate	chemical thinning	5
	BC (central) [26]	glyphosate	2.14 kg/ha	5
Sorex monticolus (Montane shrew)	BC (south-central) [25]	glyphosate	chemical thinning	5
Sorex monticolus (Dusky shrew)	BC (central) [26]	glyphosate	2.14 kg/ha	5

(Continued on next page. See notes at end of table.)

Table B1 Continued

Species and (Common Name)	Location and [Reference][a]	Chemical(s)[b]	Application Rate[c]	Duration (years)[d]
Insectivores (continued)				
Sorex pacificus (Pacific shrew)	OR (coastal) [1]	glyphosate (W)	2.25 L/ha*	3
	OR (coastal) [6]	glyphosate (W)	1.3 kg/ha	3
Sorex palustris (Water shrew)	OR (southwestern) [2]	atrazine, simazine, 2,4-D		2
Sorex trowbridgii (Trowbridge shrew)	OR (coastal) [1]	glyphosate (W)	2.25 L/ha*	3
	OR (western) [2]	atrazine+2,4-D		3
	OR (western) [4]	atrazine, dalapon, 2,4-D, silvex (W,D)	8.96 or 11.20 kg/ha*	2
	OR (coastal) [6]	glyphosate (W)	1.3 kg/ha	3
	OR (coastal) [9]	glyphosate	oral, injection	10 days
Sorex vagrans (Vagrant shrew)	OR (coastal) [1]	glyphosate (W)	2.25 L/ha*	3
	OR (western) [2]	atrazine+2,4-D		3
	OR (southwestern) [2]	atrazine, simazine, 2,4-D		2
	OR (western) [4]	atrazine, dalapon, 2,4-D, silvex (W,D)	8.96 or 11.20 kg/ha*	2
	OR (coastal) [6]	glyphosate (W)	1.3 kg/ha	3
Lagomorphs				
Lepus americanus (Snowshoe hare)	BC (central) [17]	glyphosate	4.0 or 6.0 L/ha*	4
	BC (central) [18]	glyphosate	1.5 or 2.2 kg/ha	4
	BC (south-central) [25]	glyphosate	chemical thinning	5
Rodents				
Arborimus longicaudus (Red tree vole)	OR (southwestern) [2]	untreated		2
Cleithrionomys gapperi (Southern red-backed vole)	BC (south-central) [13]	glyphosate (W)	cut-stump	4
	BC (southwestern) [15]	glyphosate	3.0 kg/ha	4
	BC (south-coastal) [19]	glyphosate	2.14 or 3.0 kg/ha	4
	BC (central) [20,26]	glyphosate	2.14 kg/ha	5
	BC (south-coastal) [24]	glyphosate	2.2 or 3.0 kg/ha	11, 13
	BC (south-central) [25]	glyphosate	chemical thinning	5

(Continued on next page. See notes at end of table.)

Table B1 Continued

Species and (Common Name)	Location and [Reference][a]	Chemical(s)[b]	Application Rate[c]	Duration (years)[d]
Rodents (continued)				
Cleithrionomys occidentalis (Western red-backed vole)	OR (southwestern) [2]	atrazine, simazine, 2,4-D		2
Microtus spp. (Vole)	OR (coastal) [10]	glyphosate	3.3 kg/ha	55 days
Microtus longicaudus (Long-tailed vole)	OR (coastal) [1]	glyphosate (W)	2.25 L/ha*	3
	OR (southwestern) [2]	atrazine, simazine, 2,4-D		2
	BC (south-central) [13]	glyphosate (W)	cut-stump	4
	BC (south-coastal) [15]	glyphosate	3.0 kg/ha	4
	BC (south-coastal) [19]	glyphosate	2.14 or 3.0 kg/ha	4
	BC (west-central) [19]	glyphosate	2.1 or 3.0 kg/ha	4
	BC (central) [20,26]	glyphosate	2.14 kg/ha	5
	BC (south-coastal) [24]	glyphosate	2.2 or 3.0 kg/ha	11, 13
	BC (south-central) [25]	glyphosate	Chemical thinning	5
Microtus oregoni (Oregon vole)	OR (coastal) [1]	glyphosate (W)	2.25 L/ha*	3
	OR (western) [2]	atrazine+2,4-D		3
	OR (western) [4]	atrazine, dalapon, 2,4-D, silvex (W,D)	8.96 or 11.20 kg/ha*	2
	OR (coastal) [6]	glyphosate (W)	1.3 kg/ha	3
	OR (coastal) [9]	glyphosate	oral, injection	10 days
	BC (south-coast) [15,16]	glyphosate	3.0 kg/ha	4
	BC (south-coastal) [19]	glyphosate	2.14 or 3.0 kg/ha	4
	BC (south-coastal) [23]	glyphosate	2.2 kg/ha	3
	BC (south-coastal) [24]	glyphosate	2.2 or 3.0 kg/ha	11, 13
Microtus pennsylvanicus (Meadow vole)	BC (south-central) [13]	glyphosate (W)	cut-stump	4
	BC (west-central) [19]	glyphosate	2.14 or 3.0 kg/ha	4
	BC (central) [20,26]	glyphosate	2.14 kg/ha	5
	BC (south-central) [25]	glyphosate	chemical thinning	5

(Continued on next page. See notes at end of table.)

Table B1 Continued

Species and (Common Name)	Location and [Reference][a]	Chemical(s)[b]	Application Rate[c]	Duration (years)[d]
Rodents (continued)				
Mus musculus (House mouse)	OR (western) [2]	atrazine+2,4-D		3
Neotoma cinerea (Bushy-tailed woodrat)	OR (coastal) [1]	glyphosate (W)	2.25 L/ha*	3
	OR (coastal) [10]	glyphosate	3.3 kg/ha	55 days
Perognathus parvus (Great Basin pocket mouse)	OR (southwestern) [2]	atrazine, simazine, 2,4-D		2
Peromyscus maniculatus (White-footed deer mouse)	OR (coastal) [1]	glyphosate (W)	2.25 L/ha*	3
	OR (southwestern) [2]	atrazine, simazine, 2,4-D		2
	OR (western) [2]	atrazine+2,4-D		3
	OR (western) [4]	atrazine, dalapon, 2,4-D, silvex (W,D)	8.96 or 11.20 kg/ha*	2
	OR (coastal) [6]	glyphosate (W)	1.3 kg/ha	3
	OR (coastal) [9]	glyphosate	oral, injection	10 days
	OR (coastal) [10]	glyphosate	3.3 kg/ha	55 days
	BC (south-coastal) [12]	glyphosate	1.1 or 1.2 kg/ha	1
	BC (south-central) [13]	glyphosate (W)	cut-stump	4
	BC (south-coast) [15,16]	glyphosate	3.0 kg/ha	4
	BC (west-central) [19]	glyphosate	2.14 or 3.0 kg/ha	4
	BC (south-coastal) [19]	glyphosate	2.14 or 3.0 kg/ha	4
	BC (central) [20,26]	glyphosate	2.14 kg/ha	5
	BC (south-coast) [22,23]	glyphosate	2.2 kg/ha	3
	BC (south-coastal) [24]	glyphosate	2.2 or 3.0 kg/ha	11, 13
	BC (south-central) [25]	glyphosate	chemical thinning	5
Phenacomys intermedius (Heather vole)	BC (south-central) [25]	glyphosate	chemical thinning	5
Spermophilus (Callospermophilus) lateralis (Golden-mantled ground squirrel)	OR (southwestern) [2]	atrazine, simazine, 2,4-D		2
	CA (north-central) [14]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]

(Continued on next page. See notes at end of table.)

Table B1 Continued

Species and (Common Name)	Location and [Reference][a]	Chemical(s)[b]	Application Rate[c]	Duration (years)[d]
Rodents (continued)				
Synaptomys borealis (Northern bog lemming)	BC (central) [20,26]	glyphosate	2.14 kg/ha	5
Tamias amoenus (Yellow pine chipmunk)	OR (southwestern) [2]	atrazine, simazine, 2,4-D		2
	BC (south-central) [13]	glyphosate (W)	cut-stump	4
	CA (north-central) [14]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
	BC (west-central) [19]	glyphosate	2.14 or 3.0 kg/ha	4
	BC (central) [20,26]	glyphosate	2.14 kg/ha	5
	BC (south-central) [25]	glyphosate	chemical thinning	5
Tamias townsendii (Townsend's chipmunk)	OR (coastal) [1]	glyphosate (W)	2.25 L/ha*	3
	OR (southwestern) [2]	atrazine, simazine, 2,4-D		2
	OR (western) [2]	atrazine+2,4-D		3
	OR (coastal) [6]	glyphosate (W)	1.3 kg/ha	3
	OR (coastal) [9]	glyphosate	oral, injection	10 days
	OR (coastal) [10]	glyphosate	3.3 kg/ha	55 days
	BC (south-coastal) [15]	glyphosate	3.0 kg/ha	4
	BC (south-coastal) [19]	glyphosate	2.14 or 3.0 kg/ha	4
	BC (south-coastal) [23]	glyphosate	2.2 kg/ha	3
	BC (south-coastal) [24]	glyphosate	2.2 or 3.0 kg/ha	11, 13
Tamiasciurus douglasii (Douglas squirrel)	OR (coastal) [10]	glyphosate	3.3 kg/ha	55 days
Thomomys mazama (Western pocket gopher)	OR (southwestern) [2]	atrazine, simazine, 2,4-D		2
	OR (south-central) [7]	atrazine (W)	4.5 kg/ha	10
Thomomys talpoides (Northern pocket gopher)	ID (southeastern) [8]	2,4-D (low volatile)	2.24 kg/ha*	10

(Continued on next page. See notes at end of table.)

Table B1 Continued

Species and (Common Name)	Location and [Reference][a]	Chemical(s)[b]	Application Rate[c]	Duration (years)[d]
Rodents (continued)				
Zapus spp. (Jumping mouse)	BC (west-central) [19]	glyphosate	2.14 or 3.0 kg/ha	4
	BC (central) [26]	glyphosate	2.14 kg/ha	5
Zapus princeps (Western jumping mouse)	BC (central) [20]	glyphosate	2.14 kg/ha	5
Zapus trinotatus (Pacific jumping mouse)	OR (coastal) [1]	glyphosate (W)	2.25 L/ha*	3
	OR (western) [2]	atrazine+2,4-D		3
	OR (western) [4]	atrazine, dalapon, 2,4-D, silvex (W,D)	8.96 or 11.20 kg/ha*	2
	BC (south-coastal) [15]	glyphosate	3.0 kg/ha	4
	BC (south-coastal) [19]	glyphosate	2.14 or 3.0 kg/ha	4
	BC (south-coastal) [24]	glyphosate	2.2 or 3..0 kg/ha	11, 13
Ungulates				
Alces alces (Moose)	BC (south-central) [25]	glyphosate	chemical thinning	5
Odocoileus hemionus (Mule deer)	CA (north-central) [14]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
	BC (south-central) [25]	glyphosate	chemical thinning	5
Odocoileus hemionus columbianus (Black-tailed deer)	OR (western) [3]	atrazine, dalapon, 2,4-D, silvex (W,D)	8.96 or 11.20 kg/ha*	1.5
	WA (western) [5]	glyphosate, atrazine, 2,4-D (W,D), 2,4,5-T, dalapon, fosamine	1.12 to 8.96 kg/ha	4 mon
	OR (coastal) [11]	atrazine (W), 2,4,5-T (D)	2.24 or 4.48* kg/ha	44 days
	BC (south-coastal) [21]	glyphosate	2.2 kg/ha*	28 days

(End of table. See notes on next page.)

[a] study references:
[1] = Anthony and Morrison 1985
[2] = Black and Hooven 1974
[3] = Borrecco, Black, and Hooven 1972
[4] = Borrecco, Black, and Hooven 1979
[5] = Campbell, Evans, Lindsey, and Dusenberry 1981
[6] = Cole, McComb, Newton, Leeming, and Chambers 1998; includes 6 most common of 28 noted (those with sufficient data to analyze)
[7] = Crouch 1979
[8] = Hull 1971
[9] = McComb, Curtis, Chambers, Newton, and Bentson 2008
[10] = Newton, Howard, Kelpsas, Danhaus, Lottman, and Dubelman 1984
[11] = Newton and Norris 1968
[12] = Ritchie, Harestad, and Archibald 1987
[13] = Runciman and Sullivan 1996
[14] = Savidge 1978
[15] = Sullivan 1990a
[16] = Sullivan 1990b
[17] = Sullivan 1994
[18] = Sullivan 1996
[19] = Sullivan and Boateng 1996
[20] = Sullivan, Nowotny, Lautenschlager, and Wagner 1998
[21] = Sullivan and Sullivan 1979
[22] = Sullivan and Sullivan 1981
[23] = Sullivan and Sullivan 1982
[24] = Sullivan, Sullivan, Lautenschlager, and Wagner 1997
[25] = Sullivan, Sullivan, Lindgren, and Boateng 2002
[26] = Sullivan, Wagner, Pitt, Lautenschlager, and Chen 1998

[b] carrier, surfactant, or adjuvant included as part of chemical application:
(W) = water (D) = diesel oil

[c] application rates expressed as active ingredients (a.i.) per unit area; blank indicates information not provided in literature, * indicates study did not express chemical units [a.i. or acid equivalents (a.e.)], "or" indicates chemical(s) applied at different rates at different sites or times

[d] duration of study or years during which data were collected (in years unless otherwise noted)

[e] data collected two seasons (spring and summer) six years post-treatment

Table B2 Pacific Northwest Studies of Forest Herbicide Effects on Birds

Species and (Common Name)	Location and [Reference][a]	Chemical(s)[b]	Application Rate[c]	Duration (years)[d]
Carduelis tristis (American goldfinch)	OR (Coast Range [5]	2,4-D, 2,4,5-T		3
	OR (Coast Range) [6]	glyphosate (W)	2.25 L/ha*	3
	OR (Coast Range) [7]	2,4-D, 2,4,5-T		1, 4
Carpodacus cassinii (Cassin's finch)	CA (north-central) [8]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
Catharus ustulatus (Swainson's thrush)	BC (south-central) [3]	glyphosate	cut-stump	4
	BC (south-central) [4]	glyphosate	cut-stump	3
	OR (Coast Range [5]	2,4-D, 2,4,5-T		3
	OR (Coast Range) [6]	glyphosate (W)	2.25 L/ha*	3
	OR (Coast Range) [7]	2,4-D, 2,4,5-T		1, 4
Chamaea fasciata (Wrentit)	OR (Coast Range [5]	2,4-D, 2,4,5-T		3
Chlorua chlorua (Green-tailed towhee)	CA (north-central) [1]	2,4,5-T (low volatile, T)	0.54 or 0.72 kg/ha	4
	CA (north-central) [8]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
Colaptes cafer (Common flicker)	CA (north-central) [8]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
Dendroica coronate (Yellow-rumped warbler)	BC (south-central) [3]	glyphosate	cut-stump	4
Dendroica petechia (Yellow warbler)	CA (north-central) [1]	2,4,5-T (low volatile, T)	0.54 or 0.72 kg/ha	4
	CA (north-central) [8]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
Dryocopus pileatus (Pileated woodpecker)	OR (western) [2]	triclopyr, MSMA	cut and frill	4
Empidonax oberholseri (Dusky flycatcher)	CA (north-central) [1]	2,4,5-T (low volatile, T)	0.54 or 0.72 kg/ha	4
	BC (south-central) [3]	glyphosate	cut-stump	4
	BC (south-central) [4]	glyphosate	cut-stump	3
	CA (north-central) [8]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
Empidonax trallii (Willow flycatcher)	OR (Coast Range [5]	2,4-D, 2,4,5-T		3
	OR (Coast Range) [6]	glyphosate (W)	2.25 L/ha*	3
	OR (Coast Range) [7]	2,4-D, 2,4,5-T		1, 4

(Continued on next page. See notes at end of table.)

Table B2 Continued

Species and (Common Name)	Location and [Reference][a]	Chemical(s)[b]	Application Rate[c]	Duration (years)[d]
Junco hyemalis (Dark-eyed junco)	BC (south-central) [3]	glyphosate	cut-stump	4
	OR (Coast Range [5]	2,4-D, 2,4,5-T		3
	OR (Coast Range) [6]	glyphosate (W)	2.25 L/ha*	3
	OR (Coast Range) [7]	2,4-D, 2,4,5-T		1, 4
	CA (north-central) [8]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
Junco hyemalis oregoni (Oregon junco)	CA (north-central) [1]	2,4,5-T (low volatile, T)	0.54 or 0.72 kg/ha	4
Melospiza melodia (Song sparrow)	OR (Coast Range [5]	2,4-D, 2,4,5-T		3
	OR (Coast Range) [6]	glyphosate (W)	2.25 L/ha*	3
	OR (Coast Range) [7]	2,4-D, 2,4,5-T		1, 4
Oporomis tolmiei (MacGillivray's warbler)	BC (south-central) [3]	glyphosate	cut-stump	4
	OR (Coast Range [5]	2,4-D, 2,4,5-T		3
	OR (Coast Range) [6]	glyphosate (W)	2.25 L/ha*	3
	OR (Coast Range) [7]	2,4-D, 2,4,5-T		1, 4
Oreotyx pictus (Mountain quail)	CA (north-central) [1]	2,4,5-T (low volatile, T)	0.54 or 0.72 kg/ha	4
	CA (north-central) [8]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
Passerella iliaca (Fox sparrow)	CA (north-central) [1]	2,4,5-T (low volatile, T)	0.54 or 0.72 kg/ha	4
	CA (north-central) [8]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
Passerina amoena (Lazuli bunting)	CA (north-central) [1]	2,4,5-T (low volatile, T)	0.54 or 0.72 kg/ha	4
	CA (north-central) [8]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
Pheucticus melanocephalus (Black-headed grosbeak)	OR (Coast Range [5]	2,4-D, 2,4,5-T		3
	OR (Coast Range) [6]	glyphosate (W)	2.25 L/ha*	3
	CA (north-central) [8]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
Picoides villosus (Hairy woodpecker)	OR (western) [2]	triclopyr, MSMA	cut and frill	4

(Continued on next page. See notes at end of table.)

Table B2 Continued

Species and (Common Name)	Location and [Reference][a]	Chemical(s)[b]	Application Rate[c]	Duration (years)[d]
Pipilo erythrophthalmus (Rufous-sided towhee)	OR (Coast Range [5]	2,4-D, 2,4,5-T		3
	OR (Coast Range) [6]	glyphosate (W)	2.25 L/ha*	3
	OR (Coast Range) [7]	2,4-D, 2,4,5-T		1, 4
Selaphorus rufus (Rufous hummingbird)	OR (Coast Range [5]	2,4-D, 2,4,5-T		3
	OR (Coast Range) [6]	glyphosate (W)	2.25 L/ha*	3
	OR (Coast Range) [7]	2,4-D, 2,4,5-T		1, 4
Sialia currucoides (Mountain bluebird)	CA (north-central) [8]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
Spizella breweri (Brewer's sparrow)	CA (north-central) [1]	2,4,5-T (low volatile, T)	0.54 or 0.72 kg/ha	4
	CA (north-central) [8]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
Spizzella passerine (Chipping sparrow)	BC (south-central) [3]	glyphosate	cut-stump	4
	BC (south-central) [4]	glyphosate	cut-stump	3
	CA (north-central) [8]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
Thryomanes bewickii (Bewick's wren)	OR (Coast Range [5]	2,4-D, 2,4,5-T		3
	OR (Coast Range) [6]	glyphosate (W)	2.25 L/ha*	3
Turdus migratorius (American robin)	BC (south-central) [3]	glyphosate	cut-stump	4
	BC (south-central) [4]	glyphosate	cut-stump	3
	OR (Coast Range [5]	2,4-D, 2,4,5-T		3
	OR (Coast Range) [6]	glyphosate (W)	2.25 L/ha*	3
	CA (north-central) [8]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
Vermivora celata (Orange-crowned warbler)	BC (south-central) [3]	glyphosate	cut-stump	4
	OR (Coast Range [5]	2,4-D, 2,4,5-T		3
	OR (Coast Range) [6]	glyphosate (W)	2.25 L/ha*	3
	OR (Coast Range) [7]	2,4-D, 2,4,5-T		1, 4
Vermivora ruficapilla (Nashville warbler)	BC (south-central) [3]	glyphosate	cut-stump	4

(Continued on next page. See notes at end of table.)

Table B2 Continued

Species and (Common Name)	Location and [Reference][a]	Chemical(s)[b]	Application Rate[c]	Duration (years)[d]
Vireo gilvus (Warbling warbler)	BC (south-central) [3]	glyphosate	cut-stump	4
	BC (south-central) [4]	glyphosate	cut-stump	3
Wilsonia pusilla (Wilson's warbler)	OR (Coast Range [5]	2,4-D, 2,4,5-T		3
	OR (Coast Range) [6]	glyphosate (W)	2.25 L/ha*	3
	OR (Coast Range) [7]	2,4-D, 2,4,5-T		1, 4
Zenaida macroura (Morning dove)	CA (north-central) [1]	2,4,5-T (low volatile, T)	0.54 or 0.72 kg/ha	4
	CA (north-central) [8]	2,4,5-T (low volatile)	4.45 kg/ha	6[e]
Zonotrichia leucophrys (White-crowned sparrow)	OR (Coast Range [5]	2,4-D, 2,4,5-T		3
	OR (Coast Range) [6]	glyphosate (W)	2.25 L/ha*	3
	OR (Coast Range) [7]	2,4-D, 2,4,5-T		1, 4

[a] study references:
[1] = Beaver 1976
[2] = Brandeis, Newton, Filip, and Cole 2002
[3] = Easton and Martin 1998; includes 10 most common of 31 noted (92% of detections)
[4] = Easton and Martin 2002
[5] = Morrison and Meslow 1983b
[6] = Morrison and Meslow 1984a
[7] = Morrison and Meslow 1984b
[8] = Savidge 1978

[b] carrier, surfactant, or adjuvant included as part of chemical application:
(W) = water (T) = thickener

[c] application rates expressed as active ingredients (a.i.) per unit area; blank indicates information not provided in literature, * indicates study did not express chemical units [a.i. or acid equivalents (a.e.)], "or" indicates chemical(s) applied at different rates at different sites or times

[d] duration of study or years during which data were collected

[e] data collected two seasons (spring and summer) six years post-treatment