FRDA REPORT 013

NON-TARGET IMPACTS OF THE HERBICIDE GLYPHOSATE
A compendium of references & abstracts

Thomas P. Sullivan, Ph.D.
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The original concept of a compendium of references and abstracts outlining the "non-target impacts of the herbicide glyphosate" arose from the apparent incomplete and scattered sources of information on this subject. A common complaint from both lay and professional people is: "What research has been done on non-target impacts of glyphosate and how do we access this information?" In fact, from the computerized literature search which was conducted to identify studies of non-target impacts of glyphosate, the information in this compendium was extracted from over 1800 references covering non-target impacts, toxicology, and some material on efficacy. Thus, there is a considerable literature base for glyphosate and this compendium evolved as a means of providing, in as complete a manner as possible, a collection of titles and abstracts of articles reporting on the non-target impacts of this herbicide.

As compiler of this document, I have conducted research on the non-target effects of glyphosate over the past ten years. This work has focussed primarily on small mammal populations in forestry and agriculture, as well as food preference and habitat selection by black-tailed deer. Additional work was conducted on fish, daphnids, and diatoms (algae) as part of a major field study. To date, with co-workers, there are nine publications outlining our work on the non-target impacts of glyphosate. Much of my earlier work on mammals is summarized in the chapter "Effects of Glyphosate on Selected Species of Wildlife" from the book "The Herbicide Glyphosate" published in 1985.

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ORIGIN AND USE OF COMPENDIUM

This compendium is designed as an Information Report to provide an objective assessment of the effects of glyphosate on non-target species. The majority of references (scientific journals and proceedings of symposia) have been extracted from a computerized literature search of the following sources.

AGRICOLA (Agriculture 1970-1987)
CHEMICAL ABSTRACTS (American Chemical Society 1973-1987)
AQUAREF (Canadian Water Resources References 1970-1986)
ASFA (Aquatic Sciences and Fisheries Abstracts 1978-1987)
BIOSIS (Biological Abstracts 1969-1987)
CAB (Commonwealth Agriculture Bureau Abstracts 1972-1987)

This search has been directed at a world-wide level and reflects all uses of glyphosate in agriculture, forestry, and industrial rights-of-way. The balance of the references are from manuscripts which were only recently (1987) or not yet published.

Titles and abstracts have been reproduced exactly as they appeared in the original article or as abstracted by the source system. In the case of journal articles without a formal abstract, a summary of the study has been abstracted by the compiler and this is clearly indicated by an asterisk (*).

The compendium is composed of six sections: Mammals, Birds, Fish, Aquatic Invertebrates and Algae, Terrestrial Invertebrates, and Microflora. All titles and abstracts of pertinent references with author(s) and publication outlet are listed alphabetically in each section. References without abstracts are given at the end of each section and represent those publications which could not be obtained by the compiler. References from outside North America are identified by country, wherever appropriate, to assist the reader. References which report on species representing more than one section (e.g. fish and aquatic invertebrates) will appear in each section.
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I. MAMMALS


The effect of glyphosate application on vegetation and small mammal populations in the Coast Range of western Oregon was investigated. Diversity, abundance, and biomass of small mammal populations increased one year post spray on glyphosate-treated sites as compared to control sites. These changes were ephemeral and above parameters were similar to pre-spray values two years after glyphosate application. The changes in diversity, abundance, and biomass were primarily a result of the increase in numbers of Microtus oregoni following an increase in grass and forb cover on treated grids one year post-spray. The temporary effects of glyphosate treatment on vegetation had no detrimental effects on small mammal populations.


(*)Seventy-one percent of the herbicide used in British Columbia forests in 1985 was glyphosate. This percentage is projected to be 78% in 1986. Therefore, glyphosate impacts on wildlife are of primary concern. Approximately 400 out of 1300 entries analyzed were glyphosate trials. Glyphosate is a broad spectrum, relatively non-selective herbicide. Indeed most of the species studied, with the exception of evergreen species, showed instances of severe damage. However, the degree and timing of severe results were varied. Being foliar active, the degree of damage is related to the amount of chemical absorbed and subsequently translocated in the plant. This is a function of method of application, plant characteristics and environmental conditions. The cut-surface applications were severely damaging in nearly all cases.

During the data analysis, conflicting results with regard to season of application were found. It is often assumed that early foliar glyphosate applications will be most damaging as this is the period of most active translocation. Alternatively, when the leaves are at maximum growth there is more surface and increased absorption capabilities. The data analyzed in this study range over every possible permutation of these two theories. However, there is suggestion of some forage species showing particular trends, for instance mallow ninebark was undamaged by early treatments but severely damaged by fall treatments. Further research directed at particular seasonal/phenological sensitivities is warranted for glyphosate. Plant species may also respond on an individual basis to their general health or other

Although the introduction of even-aged forestry, with consequent large regeneration areas, is probably not the only cause of the population explosion of elks (Alces alces) in recent years, such areas do provide rich browse for elks which are also the only browsers of young pine (Pinus sylvestris). In trials in which insufficient regeneration of Picea abies was supplemented by pine, elk damage was so severe that this method had to be abandoned. Pine is also heavily attacked in natural mixed stands (pine and spruce) and in pure stands. In mixed broadleaf and conifer regeneration elk browse particularly heavily on aspen (Populus tremula) and maple (Acer spp.). It is suggested that by judicious cleaning of regeneration areas with glyphosate, the food supply for elk might be greatly reduced thereby reducing the present intolerably high population density.


To test their acceptance of foliage treated with herbicides, captive black-tailed deer were exposed to Douglas-fir seedlings and salal treated with standard formulations of 2,4,5-T, 2,4-D, atrazine, dalapon, fosamine, and glyphosate herbicides. Carriers were diesel oil and water. Tests were made from November 1977 through February 1978. Deer readily browsed 2,4,5-T treatments and most formulations of 2,4-D in oil compared with oil alone, but showed rejection of some phytotoxic glyphosate treatments. Consumption of herbicide-treated foliage did not cause noticeable health problems in test animals.


Small mammals were trapped in a 1-year-old glyphosate release treatment, a current glyphosate treatment and an unsprayed control in 4-to 5-year-old spruce/fir clearcut in Maine
in 1984. Glyphosate did not affect the total number of small mammals trapped, but decreased the abundance of Cletirionomyss gapperi. This was thought due to the creation of a more open habitat by glyphosate. The other main spp. trapped were Peromyscus maniculatus, Sorex cinereus and Microsorex hoyi.


Refer to Birds section (page 11).


Results of helicopter spraying in August on plots laid out in weed-infested 7-year-old spruce plantations on various site types in Nord Trondelag, Norway are discussed. Most of the species particularly harmful to spruce were highly susceptible; a few could be classed as tolerant, including Vaccinium vitis-idaea. Grass was controlled up to 100% and herbs, including V. myrtillus, up to 70%, suggesting that treatment might deprive field mice of much of their food and (in snow-free periods) cover. Such control of vegetation developing after fellings, might reduce infestation of clear fellings by small rodents. However, it was also found that spraying increased the sugar content of spruce bark wood and needles (in the case of bark up to 41%), which might make trees more palatable to rodents.


Sheep were used in a Latin-square experiment to investigate the effect of preharvest treatment of pasture with glyphosate (Roundup), a translocated herbicide, on the palatability of hay. Four hays were used: control (C), Roundup (R), quinine (Q) (100 mg/kg), and Roundup with quinine (QR). During each week one of the following choices was given to each animal: (a) C/C; (b) C/R; (c) R/R; (d) Q/C; (e) Q/R; and (f) C/QR. There were no significant effects of treatment on the proportion chosen or on total daily intake, mean meal size, or rate of eating. Thus, neither preharvest treatment with Roundup nor postharvest treatment with quinine affected the palatability of hay.

Conifer plantations in northeastern Minnesota are important browse areas for moose. The U.S. Forest Service has recently shifted to glyphosate (Roundup) as the predominant herbicide for controlling hardwood shrub competition in plantations. Glyphosate is a systemic toxin that kills the entire plant so little resprouting occurs. Previously, the preferred herbicide was 2,4-D, which allows vigorous sprouting. We sampled available browse in glyphosate and 2,4-D treated stands. Three years after spraying, the glyphosate stands averaged only half the available browse as the 2,4-D stands. While sensitivity to 2,4-D differs markedly among woody plant species, glyphosate kills woody species more uniformly. Grass and raspberries are not controlled one year after spraying because glyphosate has no residual effects. We could not measure longterm effects in this study because glyphosate was not used in this region before 1981. This report covers only the first half of a 2-year study.


Plant species composition and abundance were measured in regenerating (4-5 years) clearcut strips in Maine spruce-fir forests prior to, one year after, and three years after application of varying rates of glyphosate, glyphosate in combination with 2,4-D, and triclopyr. Changes in plant species indices were used to categorize plant response to the herbicides used. The implications of these changes to wildlife use of herbicide-modified clearcut strips are discussed.


Our review indicates that the response of wildlife to herbicide-induced habitat change is extremely varied. Variations in response by wildlife are understandable given that plants respond in a species-specific manner to the chemical applied, the rate and time of application, and various environmental constraints. What generalizations can be drawn then? First, we have seen that certain animals respond to habitat alteration by increasing their use of undamaged vegetation. Other species, however, are seemingly unable to compensate for habitat loss and thus decline in density. Other species respond to habitat change
by increasing in density. This shift in concentration of density is due, quite simply, to changes in the amount of preferred habitat available to each species following treatment. An increase in density by certain species following treatment is not necessarily desired, for this change has been artificially induced by a management practice. Increasing deer browse through herbicide application, for example, would also cause a decreased habitat availability for other species. The general response of wildlife to herbicide application can thus be predicted if data are available on the range of habitats occupied by a species and their density in these habitats. Changes anticipated in animal communities can be alleviated, in part, by careful planning of treatment. What is generally deemed desirable is retention of the natural variety of vegetation types so that managed lands can supply a diversity of vegetation and wildlife through time.


Glyphosate herbicide residues and metabolites were evaluated in forest brush field ecosystems in the Oregon coast range aerially treated with 3.3 kg/ha glyphosate. Deposits were recorded at various canopy depths to determine interception and residues in foliage, litter, soil, streamwater, sediments and wildlife for the following 55 days. The half-life of glyphosate ranged from 10.4 to 26.6 days in foliage and litter and twice as long in soil. The treated stream peaked at 0.27 mg/l and decreased rapidly; concentrations were higher in sediment than in water and persisted longer. Coho salmon fingerlings did not accumulate detectable amounts. Exposure of mammalian herbivores, carnivores and omnivores and retention of herbicide seemed to vary with food preference; however, all species had visceral and body contents at or below observed levels in ground cover and litter, indicating that glyphosate will not accumulate in higher trophic levels. (Aminomethyl)phosphonic acid was found at low concentrations but degraded rapidly. N-Nitrosoglyphosate was nondetectable.


Even-aged forest management in northern spruce-fir types may lead to high production of high-quality browse species from year 3 to years 9 or more after clearcutting. Rapid growth of hardwoods and dense growth of conifers reduce foliage and twig volumes below 2.5 m to a low level by year 16. Application of
glyphosate, triclopyr or phenoxy herbicides in August of year 7 reduced tall hardwood cover and increased available browse below 2.5 m by factors of 4-8. Nearly all species present before treatment remained present for at least 9 years after treatment. Available browse after treatment includes a higher ratio of sun-grown foliage and twigs, than controls. Spacing of conifers by planting or pre-commercial thinning should prolong the period of high quality browse conditions to well beyond the 20th year. Treatments causing the greatest control of the tallest hardwood species provided the most accessible browse and also the highest proportion of sun-grown material. When using glyphosate, the short period of reduced forage availability after treatment suggests splitting large units and treating in phases separated by about two years.


Prior to planting conifers, herbicides are commonly used to reduce competition from deciduous trees and shrubs. Herbicides are usually not toxic to wildlife but do affect their habitats. We examined deer mice (Peromyscus maniculatus) to assess the impact of herbicides on small mammals. Deer mice from adjacent untreated and glyphosate-treated clearcuts had similar body sizes and numbers of placentals scars and foeti. In untreated clearcut, deer mice were more abundant than in treated clearcut, but were less abundant than in surrounding old growth forest. Glyphosate altered vegetation and reduced density of deer mice in young seral stages. Habitat changes induced by glyphosate likely modified abundance and quality of food and cover for small mammals.


This study was designed to assess the responses of small mammal populations to herbicide-induced habitat alteration in a 7-year-old Douglas fir (Pseudotsuga menziesii) plantation near Maple Ridge, British Columbia, Canada. These populations included the deer mouse (Peromyscus maniculatus), Oregon vole (Microtus oregoni), Townsend chipmunk (Eutamias townsendii), shrews (Sorex spp.), and several less common species. Population density and colonization rate or resiliency were measured on 1-ha non-removal and pulse-removal live-trap grids in control and treatment plantation habitats from April 1981 to September 1983; non-removal grids only were sampled from April to October 1985. Glyphosate herbicide was aerially applied to the treatment area in June 1982. There was little difference in abundance of deer
mice, Oregon voles, and shrews between control and treatment study areas. Chipmunk populations appeared to decline temporarily on the treatment grids relative to controls. The resiliency or colonization rate of voles was not affected by habitat change. However, resiliency of the deer mouse population on the treatment area was lower than that recorded on the control. Deer mouse and Oregon vole populations were each at comparable densities on control and treatment areas in the second and fourth years after herbicide treatment. These small mammal species should be able to persist in areas of coastal coniferous forest which are treated with glyphosate herbicide for conifer release.


This study investigated the direct effects of a forest application of herbicide on reproduction, growth and survival in deer mouse (*Peromyscus maniculatus*), Oregon vole (*Microtus oregoni*), and to a limited degree, Townsend chipmunk (*Eutamias townsendii*) populations. Non-removal and pulse-removal live-trap grids (1-ha) in control and treatment plantation habitats near Maple Ridge, British Columbia, Canada, sampled populations from April 1981 to September 1983; non-removal grids only were monitored from April to October 1985. Glyphosate herbicide was aerially applied to the treatment area in June 1982. Reproductive performance of deer mice and Oregon voles, in terms of length of breeding periods, proportion of breeding animals, and number of successful pregnancies, was unaffected by glyphosate. In fact, there were significantly more breeding deer mice in the treatment than control population in 1983, and this may have contributed to poor early juvenile survival of mice by limiting recruitment on the treatment area. Survival of animals, in general, was similar in control and treatment populations of all three species. However, female voles did survive significantly better in the treatment than control population in the post-spray summer of 1982 and winter of 1982-83. Lack of consistent differences in body weights, and somewhat better growth rates of deer mice and voles in treatment than control populations, during post-spray periods, indicated that glyphosate had no effect on metabolic or general physiological processes in the development of young animals. Physiological changes in individual animals, from exposure to or ingestion of glyphosate, and manifestation of these effects in demographic attributes at the population level were not apparent in this study.

Removal of all vegetation with herbicides over the total orchard floor or only in tree rows significantly reduced montane vole (Microtus montanus Peale), meadow vole (M. pennsylvanicus Ord), and northern pocket gopher (Thomomys talpoides Richardson) populations and damage. Herbicide treatments in four test orchards were carried out during May, July, and Sept. 1983 to 1985. Average overwinter abundance of voles was reduced 53% to 99% on treatment areas. Several vole populations went to extinction in the third year of herbicide treatment. Incidence of tree damage was 40.6% and 9.6% with feeding intensities of 17.2 cm² and 0.4 cm² of bark and tissues removed per tree on control and treatment blocks, respectively, during a peak year in abundance of voles. Pocket gopher populations and damage were significantly lower in treatment than control blocks. Deer mouse (Peromyscus maniculatus Wagner) and yellow pine chipmunk (Eutamias amoens J.A. Allen) populations generally increased on treated areas. Use of herbicides to control orchard floor vegetation is an effective means of rodent damage control.


The use of herbicides is an important part of forestry management practices in the Pacific Northwest because the regeneration of coastal forests is hampered by many species of deciduous shrubs and weeds. The herbicide glyphosate is used to control these undesirable species. Some effects of glyphosate on black-tailed deer have been investigated by analyzing food preference and consumption under simulated field conditions. Deer given a choice of control or glyphosate-treated alder and alfalfa browse showed no preference or ate more of the treated foliage. The ingestion of treated browse did not affect the consumption of laboratory chow by the deer. These results indicate that spraying with the herbicide glyphosate should not prevent deer from feeding on foliage in the affected area.


This study was designed to monitor some of the demographic responses of a deer mouse population to a forest application of
Roundup® herbicide. Populations of Peromyscus maniculatus were livetrapped from July 1978 to November 1980 on a control area and in a herbicide-treated 20-year-old Douglas-fir plantation at Maple Ridge, British Columbia. The herbicide had no apparent adverse effects on reproduction, growth, or survival of deer mice 1 year after treatment. Inconsistencies in growth rates and juvenile survival between control and experimental deer mice in 1980 could be due to the herbicide or demographic factors. Field dose applications of this herbicide should not have a direct effect on the dynamics of deer mouse populations.


The responses of small-mammal populations in a forest application of Roundup® herbicide have been investigated at the University of British Columbia Research Forest, Maple Ridge, B.C., Canada. These populations included the deer mouse, Oregon vole, Townsend chipmunk, and shrews. Treatment of a 20-year-old Douglas fir plantation did not have any negative effects on the distribution and abundance of small-mammal populations during the first year after this habitat alteration. Movements of deer mice were monitored by drift lines. There was not an influx of new animals from the surrounding regions onto the treated area nor was there a significant movement of marked animals away from the sprayed area. Future changes in composition of the small-mammal community may occur in association with successional stages advancing from the herbicide-induced habitat alteration.


This study was designed to establish the impact of aerial application of glyphosate for conifer release (in the boreal forest of northern Ontario) by studying the changes in vegetative composition and density, and its effect on the winter utilization by moose and snowshoe hare and fall utilization by small mammals, over a three year study period. Treated and adjacent untreated areas are being studied and compared to determine differences, if any, due to herbicide treatment. The study methodology is designed to assess changes over a three year period in the vegetative community on areas treated with glyphosate through comparison with similar untreated areas. Changes in the vegetative community may affect the utilization of treated sites by herbivores (moose and small mammals) and thus carnivores (terrestrial furbearers). Periodic assessment would be beneficial
after the initial three-year study to observe long term changes, i.e. 5, 10 and 15 years.


The herbicide Roundup® has the potential for increased use in the control of competitive shrub and tree species in forest plantations. This report examines the effect of Roundup® on reproductive performance in mammals which may inhabit these forest ecotypes. Laboratory mice are used as test animals. For the variable chosen to represent the physiological processes of reproduction, no differences were found using F-tests and Chi-squared analyses at the five per cent probability level. The experiment was run over a period of two litters from the same parents.
II. BIRDS


Hatchability and time to hatch of chicken eggs were found to be unaffected by application of glyphosate herbicide at three different concentrations and at four different embryo ages. We concluded that the use of the chemical as a weed control agent in zero tillage farming should not negatively affect the hatchability of the eggs of upland nesting birds.


Five zebra finches, Phoebihila guttata, allowed unrestricted access to seed containing 5000 .mu.g glyphosate/g all died in 3-7 days, but they may well have died from starvation since their food consumption was drastically reduced. Six finches survived after ingesting seed containing 2500 .mu.g glyphosate/g for 5 days. The marsupial Sminthopsis macroura, and 2 species of hopping mouse, Notomys alexis and N. mitchelli survived on a diet in which the concentration of glyphosate was increased from 625 .mu.g/g to 5000 .mu.g/g by doubling the concentration of glyphosate in the food every few days during a 23-day period. The only toxic effect observed in the mammals was a marked body weight loss in the treated N. alexis. Thus, glyphosate for the 4 species is probably nontoxic to slightly toxic.


The embryotoxicity of 42 environmental contaminants applied externally to mallard (Anas platyrhynchos) eggs including crude and refined petroleum, and complete formulations of herbicides and insecticides, are reported. Many of the petroleum pollutants were embryotoxic and moderately teratogenic and had LD50s of 0.3-5 .mu.L/egg (approximately 6–90 .mu.g/g egg). The most toxic was a commercial oil used for control of road dust followed by South Louisiana crude oil, Kuwait crude, no. 2 fuel oil, bunker C fuel oil, and industrial and automotive waste oil. Prudhoe Bay crude, unused crankcase oil, aviation kerosene, and aliphatic hydrocarbon mixtures were less toxic (LD50s of 18 to > 75 .mu.L)
and less teratogenic. The median lethal concentrations (LC50s) of herbicides and insecticides in aqueous emulsion were measured by egg immersion: the most toxic were paraquat (1) and trifluralin (LC50s of approximately 1.5 lbs/acre; 1.7 kg/ha). Propanil, bromoxynil with MCPA, Methyl dicoltop, Prometon, endrin, sulprofos, and parathion were toxic (LC50s of 7-40 lbs/acre; 7.8-44.8 kg/ha), whereas 2,4-D, glyphosate, atrazine, carbaryl, dalapon, dicamba, methomyl, and phosmet were only slightly toxic or not toxic (LC50s of 178 to > 500 lbs/acre; 199-560 kg/ha). Pesticides in nontoxic oil vehicle applied by microliter pipet were up to 18 times more toxic than when applied in water vehicle, which was probably due to better penetration of the pesticide past the eggshell and its membranes. Teratogenic effects and impaired embryonic growth are reported and results discussed in terms of potential hazard at field levels of application. A discussion is provided on the effects of pollutants on the eggs of other species of birds under laboratory and field conditions.


Vegetative changes induced by the herbicide glyphosate and the resultant habitat use of birds nesting on 2 clearcuts in western Oregon were studied. About 23% of total plant cover was initially damaged by aerial application of glyphosate. Most measures of vegetation on the treated site decreased relative to the untreated site 1 year after glyphosate application. By 2 years post spray, vegetation on the treated site had recovered to near prespray status. No difference in density of the bird community was evident between treated and untreated sites during all years of study, although individual species densities were modified. Several bird species decreased their use of shrub cover and increased their use of deciduous trees 1 year after treatment. By 2 years postspray, many species returned to prespray use of most measured habitat components. Results indicated that application of glyphosate can modify the density and habitat use of birds.

TITLES