# Triclopyr Herbicide

## A Technical Bibliography of Non-target Effects

Compiled by:

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## Foreword

The following compilation into one sourcebook of an extensive collection of abstracts on the herbicide triclopyr is intended to provide users of this herbicide ready access to the breadth and evolution of scientific understanding of this herbicide. Deliberate effects – for example, efficacy were not included – as the sourcebook is intended more to assist in understanding the likelihood and type of non-target effects associated with using this herbicide. A literature search of 15 databases resulted in a total of literally hundreds of references. These were sorted into 13 generalized categories to ease access and allow users of the bibliography to target specific concerns quickly and easily. The bibliography reflects the breadth and depth of understanding triclopyr from the perspective of refereed journals and without input from the compiler.

**The bibliography is designed as an information access tool, not as a stand-alone reference. Users are urged to identify literature of interest using the abstracts in the guide then to seek out the original publication(s) to more clearly understand the results and implications of the research. Abstracts from differing sources often varied slightly in extent and content. The compiler attempted to select the abstract, which provided the most information about both outcomes and methodologies. Where abstracts were not given none was prepared and the title alone was included in the bibliography. The literature search for compiling this bibliography was completed on February 2001. The thirteen categories of references were not used as exclusive sets – where an abstract suggested the article was cogent to several categories the attempt was made to include it in all appropriate categories.**

**Acknowledgement and Thanks**

The first edition of this bibliography was compiled cooperatively with Dr. Frank Kidd the compiler of this edition acknowledges Dr. Kidd's contribution to the success of this edition.

Preparation of this bibliography would not have been possible without the hard work and valuable combination of interest and skills of Ms. Valerie Sowiak. Her efforts and contribution to this bibliography are greatly appreciated.

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Bibliography of References for Non-target Field and Laboratory Reports of Triclopyr Herbicide

## ANALYTICAL METHODOLGY

**Begley, P. and B. E. Foulger. 1988. Detection of trace levels of triclopyr using capillary gas chromatography electron capture negative ion chemical ionization mass spectrometry. J. Chromatography 438: 45-54.** Triclopyr, after esterification, is shown to be a suitable candidate for detection by gas chromatography-electron-capture negative-ion chemical ionization mass spectrometry forming a characteristic carboxylate anion which offers a high detection sensitivity. A detection limit of 70 fg reaching the ionizer is indicated. Low backgrounds and an absence of chemical interferences are shown for vegetation extracts, using a simple method of extraction and derivatization. A similar behavior is demonstrated for 2,4-D and 2,4,5-T.

**Crescenzi, C., G. D'-Ascenzo, A. di Corcia, M. Nazzari, S. Marchese, R. Samperi, and A. di-Corcia. 1999. Multiresidue herbicide analysis in soil: subcritical water extraction with an on-line sorbent trap. Analytical Chemistry Washington. 71: 2157-2163.** The feasibility was evaluated of selectively and rapidly extracting herbicide residues in soils by hot water and collecting analytes with a Carbograph 4 solid-phase extraction (SPE) cartridge set on-line with the extraction cell. Phenoxy acid herbicides and those non-acidic and acidic herbicides which are often used in combination with phenoxy acids were selected for this study. Five different soil samples were fortified with target compounds at levels of 100 and 10 ng/g (30 ng/g of clopyralid and picloram) by following a procedure able to mimic weathered soils. Herbicides were extracted with water at 90°C and collected on-line by the SPE cartridge. After the cartridge was disconnected from the extraction apparatus, analytes were recovered by stepwise elution to separate non-acidic herbicides from acidic ones. The two final extracts were analysed by liquid chromatography/mass spectrometry with an electrospray ion source. At the lowest spike level considered, analyte recoveries ranged between 81 and 93%, except those for 2,4-DB and MCPB, which were 63%. For 16 herbicides out of 18, the ANOVA test showed recoveries were not dependent on the type of soil. The method detection limit was in the 1.7-10 ng/g range. For the analytes considered, method comparison showed this extraction method was overall more efficient than Soxhlet and sonication extraction techniques.

**Deschamps, R. J. A., J. C. Hall, and M. R. McDermott. 1990. Polyclonal and monoclonal enzyme immunoassays for picloram detection in water, soil, plants and urine. J. Agric. and Food Chem. 38: 1881-1886.** Two indirect enzyme immunoassays for picloram (4-amino-3,5,6- trichloro-2-pyridinecarboxylic acid) detection were compared in terms of sensitivity, accuracy, and precision. The assay using a rabbit antiprocloram serum had a linear working range from 5 to 5000 ng/mL with a mean I-50 value of 140 ng/mL and a lower detection limit of 5 ng/mL. The assay using a monoclonal antibody obtained from a mouse hybridoma cell line yielded a linear working

range from 1 to 200 ng/mL with a mean I-50 value of 10 ng/mL and a lower detection limit of 1 ng/mL. Neither assay showed appreciable cross-reactivity with the structurally related pyridine herbicides clopyralid, fluorxypyr, and triclopyr or with the phenoxyacetic acid herbicide 2,4-D. From the analysis of fortified river water, soil extracts, plant extracts, and urine, the monoclonal antibody based assay was shown to be more sensitive, more accurate, and more precise than the polyclonal antiserum based assay. Only the monoclonal assay was suitable for quantitative determinations of picloram.

**El-Khodary, S., A. Habib, and A. Haliem. 1989. Cytological effect of the herbicide Garlon 4 on root mitosis of *Allium cepa*. Cytologia 54: 465-472.** The effect of the herbicide (Garlon 4) has been studied on root mitosis of *Allium cepa* (v. Giza-6). It contains triclopyr as an active ingredient and its chemical formula is 3,5,6-trichloro-2-pyridinyloxy-acetic acid. Root tips of *Allium cepa* were treated with a series of concentrations, ranging from 28 ppm to 38400 ppm for 3, 6, 12 and 24 hours. Examination of the roots was done in permanent root tip squash preparations stained by the Feulgen technique. Garlon affects the relative duration of each mitotic stage as compared with the control. It also caused reduction in mitotic index, indicating mitotic inhibition, and increase in the frequency of abnormal mitoses, the percentages of which are highly significant, except the lowest concentration (28 ppm) which had no significant effect after 6 hours and induced a statistically significant percentage of abnormal mitoses from the control after 12 hours of the treatment. The types of abnormalities induced included: chromosome stickiness, c-metaphase, c-anaphase, tetraploid and restitution nucleus, star metaphase, laggards, bridges, tripolar and disturbed meta- and anaphases. Micro- and binucleate cells as well as multinucleated cells at the interphase stages were also observed. The effect of Garlon 4 on root mitosis simulates that of colchicine in the type of abnormal meta- and anaphases (c-metaphase and c-anaphase) and the induction of polyploid cells as well as accumulation of metaphases.

**Fischer, J.B. and J.L. Michael. 1997. Use of ELISA immunoassay kits as a complement to HPLC analysis of imazapyr and triclopyr in water samples from forest watersheds. Bulletin of Environmental Contamination and Toxicology. 59: 611-618.**

**Fujita, I, M. Hirohata, T. Matsuzaki,Y. Ozasa, and R. Matsuoka. 1996. Determination of isoxaben and triclopyr triethylammonium used in golf courses. Kumamoto-ken Hoken Kankyo Kagaku Kenkyushoho. 25: 41-47. Japanese.**

**Garcia-Sanchez, F. A. Navas-Diaz, and J. Lovillo. 1996. Enzyme-linked immunosorbent assay by image analysis using a charge-coupled device array detector. Analytical. Biochem. 239: 2-7.** This paper describes a fluorescence enzyme-linked immunosorbent assay (ELISA) for the

quantification of (±)-2-(2,4-dichlorophenoxy)propionic methyl ester (dichlorprop methyl ester). Antibodies for dichlorprop methyl ester were produced by immunizing rabbits with a conjugate of dichlorprop methyl ester with bovine serum albumin. Data acquisition on microtiter wells is performed by a spectrofluorometer through a fiber optic and by a charge-coupled device camera. A correlation was obtained between the image analysis data on ELISA and the data acquired by the spectrofluorometer. The results demonstrate that the fluorescence image analysis performed by the charge-coupled device detector is applicable to ELISA, and the analysis time, sensitivity, and precision of the ELISA procedure are compared to conventional fluorescence ELISA performed by the spectrofluorometer. The ELISA procedure was selective for structurally similar compounds or usually found in formulation pesticides. Concentrations for 50% displacement curves were dichlorprop, 83.59 µg/ml, and 2,4,5-T, 388.23 µg/ml; triclopyr, ioxynil, bentazone, and MCPA had no response.

**Harris, A. S., M. H. Goodrow, S. J. Gee, and B. D. Hammock. 1993. Development of enzyme immunoassays for the detection of triclopyr and 3,5,6-trichloro-2-pyridinol. Abst. Papers Amer. Chem. Soc. 206: 41.**

**Hayashi, H. and T. Umetani. 1998. A study of analytical method for the determination of pesticides: acephate, dithiopyr, metalaxyl, pyributicarb and triclopyr, used in golf courses. Osaka-shi Suidokyoku Suishitsu Shikensho Chosa Kenkyu narabini Shiken Seiseki. 49: 28-31. Japanese.**

**Hogendoorn, E. A., W. F. De-Graaf, M. Tan, and P. Van-Zoonen. 1993. The residue analysis of chlorophenoxy acids and triclopyr in cereal and bean sprouts using off-line SPE and on-line column-switching RPLC. Mededelingen Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen Universiteit Gent 58(2A): 165-172.**

**Itak J.A., W.A. Day, C.D. Root, A. Montoya, J.J. Manclus, A.M. Phillips, D.A. Lindsay, and D.P. Herzog. 1996. A paramagnetic particle-based ELISA for the quantitative determination of 3,5,6-trichloro-2-pyridinol (TCP) in water. Abstracts of Papers American Chemical Society. 211: p ENVR 18. 211th American Chemical Society National Meeting New Orleans, Louisiana, USA. 1996.**

**Itak, J.A., W.A. Day, A. Montoya, J.J. Manclus, A.M. Phillips, D.A. Lindsay, D.P. Herzog. 1997. A paramagnetic particle-based enzyme-linked immunosorbent assay for the quantitative determination of 3,5,6-trichloro-2-pyridinol in water. ACS symposium series. 0097-6156 ; 657. Immunochemical technology for environmental applications /. Washington, DC : American Chemical Society. p. 261-270.** A competitive enzyme-linked immunosorbent assay (ELISA) for the quantitation of 3,5,6-trichloro-2-pyridinol (TCP), the major biological and environmental

degradation product of chlorpyrifos and triclopyr, was developed. Magnetic particles were used as the solid phase to attach monoclonal anti-TCP antibodies. The ELISA has an estimated least detectable dose of 0.25 parts per billion (ppb; ng/mL) in water. Specificity studies indicate that the assay is specific for TCP and can distinguish it from the parent compounds as well as many other related and unrelated agricultural compounds. Results compare favorably with GC/MSD measurements (r = 0.959).

**Johnson, B. D. and J. C. Hall. 1996. Fluroxypyr- and triclopyr-specific enzyme-linked immunosorbent assays development and quantitation in soil and water. J. Agric. and Food Chem. 44: 488-496.** Enzyme-linked immunosorbent assays (ELISAs) were developed to quantitate fluroxypyr (((4-amino-3,5-dichloro-6-fluoro-2-pyridinyl)xy)acetic acid) and triclopyr (((3,5,6-trichloro-2-pyridinyl)oxy)acetic acid) in soil and water. The linear working range of the fluroxypyr ELISA was from 0.1 to 10 ng/mL with a limit of detection (LOD) of 0.1 ng m/L and an $IC_{50}$ value of 1.6 ng/mL. The linear working range of the triclopyr ELISA was from 0.1 to 5 ng/mL with a LOD of 0.1 ng/mL and an $IC_{50}$ value of 1.7 ng/mL. Cross-reactivity to selected pyridine metabolites and agrochemicals was determined. Significant cross-reactivity (within the linear working range of the ELISA) using the fluroxypyr ELISA was found only to the metabolite 4-amino-3,5-dichloro-6-fluoro-2-methoxypyridine. Significant cross-reactivity using the triclopyr ELISA was found only to the auxinic herbicide 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). The ELISAs accurately estimated fluroxypyr and triclopyr in water at concentrations as low as 0.1 ng/mL. Analysis of two different soil types with different textures (clay loam and sandy clay loam) required cleanup procedures using filtration and solid phase extraction to accurately estimate fluroxypyr and triclopyr concentrations.

**Johnson, W. G., T. L. Lavy, and S. A. Senseman. 1994. Stability of selected pesticides on solid phase extraction disks. J. Environ. Qual. 23: 1027-1031.** The storage stability of 2,4-D (2,4-dichlorophenoxy acetic acid), triclopyr ([(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid), carbofuran (2,3-dihydro-2,2-dimethylbenzofuran-7-yl methylcarbamate), molinate (S-ethyl hexahydro-1 N-azepine-1 carbothioate), and thiobencarb (S-[(4-chlorophenyl) methyl] diethylcarbamothioate) on C18 solid-phase extraction (SPE) disks was determined under three temperature regimes. Water was fortified with either mixtures of the five pesticides at 20 µg/L of each pesticide or with methanol. Storage treatments included storage in water at 4°C, or the analytes were extracted onto the SPE disks and stored at 4°C, -20 C, or 4 C for 1 d followed by -20 C for the remaining storage period. Residue analyses were conducted after 0, 3, 30, 90, and 180 d of storage. All pesticides evaluated were more stable when stored on the disks vs. cold storage in water. Carbofuran was the least stable of the pesticides evaluated with losses ranging from 13 to 100% depending on storage period. The pesticides were most stable on the disks at

temperature regimes that included -20 C with losses of less than or equal to 20% for 2,4 D, triclopyr, molinate, and thiobencarb for storage periods of 180 d. Storage of the same pesticides in water at 4 C resulted in losses of 25 to 35%.

**Judy, B. M., W. R. Lower, C. D. Miles, M. W. Thomas, and G. F. Krause. 1990. Chlorophyll fluorescence of a higher plant as an assay for toxicity assessment of soil and water. In, Plants for Toxicity Assessment, W. Wang, J. W. Gorsuch, and W. R. Lower (eds.). pp. 308-318**. Inhibition of photosynthesis in leaf segments of *Tradescantia* by herbicides (25% on a w/w basis in soil of 2% glyphosate, 6% picloram + 2,4-D and 2.5% triclopyr, and 5.3 lb/acre granular hexazinone), heavy metals (Zn, Cu and Cd), a surfactant (SDS) and sodium fluoride was demonstrated using a chlorophyll fluorescence (CF) assay. The strongest changes of fluorescence induction curves were caused by hexazinone. Photosynthetic inhibition was observed as an increase in initial fluorescence (Fo)>) and a decrease in variable fluorescence (Fv) and electron pool size (EP). The CF assay predicted herbicidal injury in *Tradescantia* leaves at least 24 h before leaf necrosis appeared.

**Kiguchi, O., Y. Suzuki, K. Saitoh. 1999. Simultaneous determination of pesticides including triclopyr and triclopyr butoxyethyl in drain-water samples from golf courses by solid-phase extraction/HPLC. Bunseki Kagaku. 48: 673-680. Japanese.**

**Kreutzweiser, D. P. and S. S. Capell. 1992. A simple stream-side test system for determining acute lethal and behavioral effects of pesticides on aquatic insects. Environ. Toxicol. and Chemistry 11: 993-999.**

**Lambert, S.D., N.J.D. Graham, and B.T. Croll. 1993. Ozone degradation of selected non-agricultural herbicides. Ozone Science and Engineering. 15: 457-464.** The efficiency of ozone for the degradation of three herbicides, imazapyr, triclopyr and diuron, under controlled laboratory conditions was investigated. Experiments were conducted at pH 7.5, in a bubble contractor column, with raw lowland surface water spiked with initial active ingredient concentrations of 2 ?g/litre. The ozone doses applied and consumed were 4.79 and 2.9 mg $O_3$/litre, respectively, and resulted in removal of 53%, 48% and 90% of imazapyr, triclopyr and diuron, respectively.

**Lawruk, T. S., C. S. Hottenstein, J. R. Fleeker, J. C. Hall, D. P. Herzog, and F. M. Rubio. 1994. Quantification of 2,4-D and related chlorophenoxy herbicides by a magnetic particle-based ELISA. Bull. Environ. Contam. and Toxicol. 52: 538-545.** The development and evaluation of a competitive ELISA for the quantification of 2,4-D and its esters in environmental water samples, using magnetic particles as the solid-phase for the 2,4-D antibody, is described. The average assay recovery for 2,4-D was 103%, with a lower detection limit of 0.7 ppb. Cross-reactivity of the 2,4-D ELISA with related herbicides (including MCPA, MCPB, dichlorprop and triclopyr) was very low.

**Leveille, P., J. Legris, G. Couture, and R. Langevine. 1995. Evaluation of the effects of triclopyr used in forestry. Pub. No. RN95-3084; Ministere des Ressources Naturelles; Quebec; Canada. 18 p.**An account is given of the chemical composition, biological action, toxicology, degradation and decomposition in air, soil, water, flora and fauna (including human), and effects on vegetation, fauna and humans, of the herbicide triclopyr.

**Lewer, P. and W. J. Owen. 1987. Uptake and metabolism of triclopyr by soybean cell suspension cultures: A comparison with (2,4-D) 2,4-dichlorophenoxyacetic acid. Biochem. Soc. Transactions. 15: 1107-1108.** The metabolic fates of triclopyr and 2,4-D in cell suspensions of soybean cv. Harcor differed. Triclopyr was metabolized predominately to carboxylate derivatives analogous to those formed in rodents. The two major metabolites appeared to be aspartate and glutamate conjugates. In contrast, 2,4-D was mainly metabolised by aryl ring hydroxylation followed by O-glucosylation which represents a detoxification system for 2,4-D which is not available for triclopyr. The growth medium affected the relative proportions, but not the nature of the metabolites.

**Lewer, P. and W. J. Owen. 1989. Amino acid conjugation of triclopyr by soybean cell suspension cultures. Pesticide Biochemistry and Physiology 33: 249-256.** The uptake and metabolism of the herbicide triclopyr (3,5,6- trichloro-2-pyridinyloxyacetic acid) by cell suspension cultures of soybean, *Glycine max*. var. Harcor were investigated in comparison with those of 2,4-D. After 7 days two major metabolites of triclopyr were formed, in ca. 1.5:1 ratio. These were isolated by ion-exchange and $^{18}$C-high-performance liquid chromatography. Combined gas chromatography-mass spectrometry of their methyl esters identified the metabolites as the aspartate (major) and glutamate (minor) amide conjugates. In contrast, 2,4-D was predominantly metabolized to two more polar products having the properties of glucosyl ethers of hydroxylated 2,4-D. The effect of both incubation period and growth medium upon the behavior of soybean cells with respect to these herbicides was also studied. Cells grown in Miller's medium supplemented with naphthyl-1-acetic acid took up slightly more ($^{14}$C)triclopyr, but significantly more ($^{14}$C)2,4-D than those grown in Gamborg's B5 medium supplemented with 2,4-D. In either medium, active metabolism of absorbed herbicides continued until at least 21 days, with the qualitative nature of products being only substrate dependent.

**Machev, A., P. Kostadinova, and R. Chomova. 1984. An improved gas chromatographic method for triclopyr determination in the soil and in plant samples. Gradinarska i Lozarska Nauka. 21: 40-44.** A sensitive and selective gas-chromatographic method for determining residual triclopyr quantities in the soil and in plant samples was elaborated. Herbicide is extracted by methanol or water solution of NaOH and, after suitable purification, samples are analysed on a gas chromatograph fitted with an $Ni^{63}$ electron detector.

Satisfactory repeatability of the results and 74-92% analytical yield were achieved. The method has been successfully applied in determining residual triclopyr quantities in soil, seeds (beans, soybeans and maize) and fruit (apples, cucumbers, pepper and chilis) as well as in leaves, roots and stems (beans, soybeans, chilis).

**Manclus, J. J. and A. Montoya. 1996. Development of an enzyme-linked immunosorbent assay for 3,5,6-trichloro-2-pyridinol. 2. Assay optimization and application to environmental water samples. J. Agric. and Food Chem. 44: 3710-3716.** A monoclonal antibody-based enzyme-linked immunosorbent assay (ELISA) for 3,5,6-trichloro-2-pyridinol (TCP), the major degradation product of chlorpyrifos, chlorpyrifos-methyl, and triclopyr pesticides, was optimized for the analysis of this hydrophilic compound in water. A direct ELISA format was chosen, and the concentration of immunoreagents was first selected to provide the highest sensitivity. Next, the influence of several physical (temperature, time) and chemical (pH, salt, detergent) conditions was studied. Under optimized conditions, the TCP concentration giving 50% reduction of the maximum ELISA signal (I-50) in the competitive standard curve was 0.62 nM (0.12 µg/L), and the assay was very specific for TCP. Preliminary evaluation of assay performance in water samples showed the absence of significant matrix effects for the waters tested, whenever the ionic strength of samples was approximately adjusted to that of standards. The assay provides a limit of detection of 0.04 µg/L and a working range of 0.09-0.91 µg/L TCP and allows for a precise and accurate determination of this pesticide degradation product in water at levels as low as 0.1 µg/L without sample cleanup.

**Manclus, J. J. and A. Montoya. 1996. Development of an enzyme-linked immunosorbent assay for 3,5,6-trichloro-2-pyridinol. 1. Production and characterization of monoclonal antibodies. J. Agric. Food Chem. 44: 3703-3709.** 3,5,6-trichloro-2-pyridinol (TCP) is the major degradation product of both the widely used chlorpyrifos and chlorpyrifos-methyl insecticides and the herbicide triclopyr. In this paper we describe the development of immunoassays for the detection of this metabolite. With this aim, two types of haptens were synthesized, with spacer attachment either through the 6-position of the pyridyl ring or through the hydroxyl group. Protein conjugates of these haptens were used for the immunization of mice to produce monoclonal antibodies (MAbs). From haptens of the former type, a panel of MAbs displaying 50% inhibition (I-50) for TCP in the range 1-10 nM was obtained. Characterization of these MAbs showed their high affinity and specificity for TCP. The best MAbs were used in various assay formats in combination with homologous and heterologous assay haptens. Several immunoassays with I-50 lower than 1 nM were developed. These immunoassays are potentially very valuable analytical tools for the determination of TCP in food and in the environment, as well as for monitoring human exposure to chlorpyrifos.

**McDermott, M. R., J. C. Hall, and R. J. A. Deschamps. 1990. Polyclonal and monoclonal enzyme immunoassays for picloram detection in water, soil, plants, and urine. J. Agric. and Food Chem. 38: 1881-1886.** Two indirect enzyme immunoassays for picloram detection were compared in terms of sensitivity, accuracy and precision. The assay, using a rabbit antipicloram serum, had a linear working range from 5000 ng/mL with a mean $I_{50}$ value of 140 ng/mL and a lower detection limit of 5ng/mL. The assay, using a monoclonal antibody obtained from a mouse hybridoma cell line, yielded a linear working range from 1 to 200 ng/mL with a mean $I_{50}$ value of 10 ng/mL and a lower detection limit of 1 ng/mL. Neither assay showed appreciable cross-reactivity with the structurally related pyridine herbicides clopyralid, fluroxypyr, and triclopyr or with the phenoxyacetic acid herbicide 2,4-D. From the analysis of fortified river water, soil extracts, plant extracts, and urine, the monoclonal antibody based assay was shown to be more sensitive, more accurate and more precise than the polyclonal antiserum based assay. Only the monoclonal assay was suitable for quantitative determination of picloram.

**McMahon, C. K. 1993. A review of promising new immunoassay technology for monitoring forest herbicides. Proc. Southern Weed Sci. Soc., 46th Annual Meeting, pp. 220-222.** A review of highly sensitive, low cost immunoassays for the detection of environmental contaminants, notably herbicides in forests, is presented. The following points are discussed: antibody production and use in immunoassays, comparative cost of immunoassays vs. classical chromatographic and spectrophotometric techniques, differences between monoclonal and polyclonal antibodies, ELISA kits presently in use (for alachlor, atrazine, cyanazine, 2,4-D, imazaquin, isoproturon, metolachlor, paraquat, trifluralin and triazine herbicides in general) and being developed (for glyphosate, imazapyr, metsulfuron and triclopyr) and the future potential of immunoassays.

**Michael, J.L., M.C. Smith, W.G. Knisel, D.G. Neary, W.P. Fowler, D.J. Turton, J.A. Griffith. 1996. Using a hydrological model to determine environmentally safer windows for herbicide application. Second International Conference on Forest Vegetation Management, 1995. New Zealand Journal of Forestry Science. 26: 288-297.** A modification of the GLEAMS model (Groundwater Loading Effects of Agricultural Management Systems) was used to determine application windows which would optimize efficacy and environmental safety for herbicide application to a forest site. Herbicide/soil partition coefficients were determined using soil samples collected from a study site at Alum Creek Experimental Forest in the Ouachita Mountains in Arkansas, USA, for 2 herbicides (imazapyr, KOC (organic carbon partition coefficient) 46; triclopyr ester, KOC 1038). Published values for 2 other herbicides (hexazinone, KOC 54; triclopyr amine, KOC 20) were also used in the model. Other site-specific characteristics were taken from catchment topographic maps and soil data. Long-term climatic records for the region were

then used to provide meteorological data for use in the hydrology component of the model. The model was run with herbicide application for each day of the manufacturers' recommended growing-season application windows. Average surface run-off losses, expressed as a percentage of applied, were low for all herbicides modelled (hexazinone, 0.37%; imazapyr, 0.34%; triclopyr amine, 0.21%; triclopyr ester, 1.85%). Model predictions of herbicide loss for each application day were then summarized and the application days with the lowest predicted loss within the manufacturers' application windows were identified as the environmentally safest days (environmental window) for application. This application of the GLEAMS model predicts an environmental window for each herbicide for the site under consideration, during which the probability of adverse environmental impacts is at the lowest level achievable based upon long-term climatic records. The environmental window for pesticides other than herbicides can also be determined through modelling in a similar fashion. GLEAMS was the model chosen for this example, but other pesticide fate models may be equally applicable.

**Morre, J. T. and M. Moini. 1992. Selective detection and characterization of chlorine- and bromine-containing compounds in complex mixtures using microwave-induced plasma/chemical reaction interface mass spectrometry. Biol. Mass Spectrometry 21: 693-699.** In the environmental and pharmacological sciences, it is important to selectively detect chlorine- and bromine-containing compounds in complex mixtures. Currently, a new technique called microwave-induced plasma/chemical reaction interface mass spectrometry (MIP/CRIMS) is being used as a selective detector of elements and stable isotopes. This technique, which involves post-column reactions (a reaction interface), includes a low-pressure microwave-induced helium plasma (MIP) to which a reaction gas is added. Effluents of a chromatographic column that enter this reaction interface are converted into small stable neutrals. The mass spectra of these neutrals will identify and quantify the elements and isotopes of interest. Once the retention times of the peaks of interest are obtained, their full mass spectra can be acquired by repeating the experiment with the MIP off. This method combines the sensitivity of a halogen specific detector with the compound identification of mass spectrometry. In this study, $SO_2$ has been found highly effective as a reaction gas for selective detection of chlorine- and bromine-containing compounds using GC/MIP/CRIMS. Detection limits of 10 pg and 1 ng, and dynamic range of at least four and two orders of magnitude, were achieved for chlorine- and bromine-containing compounds, respectively. The selective detection of chlorinated compounds in complex mixtures is demonstrated by using a mixture of non-chlorinated compounds and polychlorinated biphenyls, and by selective detection of triclopyr (a chlorinated herbicide) in extracts of leaves of garden bean (*Phaseolus vulgaris* var. Topcrop).

**Sanchez, F. G., A. N. Diaz, and J. Lovillo. 1996. Enzyme-linked immunosorbent assay by image analysis using a charge-coupled device array detector. Anal Biochem. 239: 2-7.** This paper describes a fluorescence enzyme-linked immunosorbent assay (ELISA) for the quantification of (±)-2-(2, 4-dichlorophen-oxy)propionic methyl ester (dichlorprop methyl ester). Antibodies for dichlorprop methyl ester were produced by immunizing rabbits with a conjugate of dichlorprop methyl ester with bovine serum albumin. Data acquisition on microtiter wells is performed by a spectrofluorometer through a fiber optic and by a charge-coupled device camera. A correlation was obtained between the image analysis data on ELISA and the data acquired by the spectrofluorometer. The results demonstrate that the fluorescence image analysis performed by the charge-coupled device detector is applicable to ELISA, and the analysis time, sensitivity, and precision of the ELISA procedure are compared to conventional fluorescence ELISA performed by the spectrofluorometer. The ELISA procedure was selective for structurally similar compounds or usually found in formulation pesticides. Concentrations for 50% displacement curves were dichlorprop, 83.59 µg/ml, and 2,4,5-T, 388.23 µg/ml; triclopyr, ioxynil, bentazone, and MCPA had no response.

**Schlett, V. C. 1990. Determination of polar pesticides by gas chromatography in drinking and natural water. Zeitschrift fuer Wasser und Abwasser Forschung 23: 32-35.** A method is described for the determination of polar pesticides in water after extraction on carbon-18 reversed phase material and reaction with diazomethane. The analytical method and the characteristic and operational date are described for the substances Ioxynil, Bromoxynil, Bentazon, CMPA, CMPB, CMPP (Mecoprop),2,4-D, 2,4-DB, 2,4-DP (Dichlorprop), 2,4,5-T and 2,4,5-TP (Fenoprop). The determination limit is 0.025 µg/L by using a mass selective detector. The range of variation for recovery is between 80 and 130%. For six other substances (clopyralid, dicamba, triclopyr, dinoseb, picloram, and pentachlorphenol), only the chromatographic conditions are reported.

**Shackelford, D.D., D.L. Young, C.A. Mihaliak, B.A. Shurdut, and J.A. Itak. 1999. Practical immunochemical method for determination of 3,5,6-trichloro-2-pyridinol in human urine: applications and considerations for exposure assessment. Journal of Agricultural and Food Chemistry. 47: 177-182.** An analytical method is described for the quantitative determination of 3,5,6-trichloro-2-pyridinol (3,5,6-TCP), the primary analyte found in urine as a result of exposure to chlorpyrifos, chlorpyrifos-methyl and triclopyr. Conjugates of 3,5,6-TCP are released from urine by acid hydrolysis. Free 3,5,6-TCP is then purified using C18 solid-phase extraction, eluting the analyte with 1-chlorobutane. An aliquot of 1-chlorobutane is placed in a vial containing Trichloropyridinol Sample Diluent and evaporated, leaving 3,5,6-TCP in the aqueous sample diluent. The samples are assayed using the Trichloropyridinol RaPID Assay immunoassay test kit. Final results are calculated using a standard

curve constructed by linear regression after a ln/Logit data transformation is performed of the concentration and the absorbance readings, respectively. The calculated lower limit of quantitation for 3,5,6-TCP in fortified control urine samples is 2.96 ng/ml (2.96 ppb). The overall recovery level over the range of 2.00 to 200.00 ng/ml 3,5,6-TCP was 92%. A comparative study found that residues of 3,5,6-TCP determined using both immunochemical and gas chromatography with mass spectrometric detection correlated well.

**Siltanen, H. and R. Mutanen. 1985. Formation of derivatives of chlorophenoxy acids and some other herbicides. Chromatographia 20: 685-688.** A fuming sulphuric acid-ethanol esterification method has been applied to chlorophenoxy acids and some other herbicides. This method is compared with esterification by iodoethane and diazomethane. The chlorophenoxy acids studied were: 2,4-D, dichlorprop, MCPA, MCPB, mecoprop and 2,4,5-T. Other herbicides studied were: benazolin, bentazone, bromophenoxime, bromoxynil, chlorthal, dicamba, 3,6-dichloropicolinic acid, dinoseb, ethephon, fluroxypyr, glyphosate, haloxyfop, ioxynil, picloram, 2,3,6-TBA and triclopyr. Fuming sulphuric acid-ethanol esterification can be successfully applied to chlorophenoxy acids, benazolin, 3,6-dichloropicolinic acid, dinoseb, fluroxypyr, haloxyfop, picloram and triclopyr. The reproducibility of the method is ± 5%.

**Szeto, S. Y. 1993. Determination of kinetics of hydrolysis by high-pressure liquid chromatography: Application to hydrolysis of the ethylene glycol butyl ether ester of triclopyr. J. Agric. and Food Chem. 41: 1118-1121.** Using a high-pressure liquid chromatographic (HPLC) method capable of determining 3,5,6-trichloro-2-pyridinol (P), triclopyr (T), and the ethylene glycol butyl ether ester of T (G) in aqueous media without extraction or cleanup, the pseudo-first-order rate constants for the hydrolysis of G were established at 35□C in aqueous buffered solutions of pH 4.5-8.5. The reaction was base-catalyzed and the rate proportional to the pH ranging from 3.63 times 10-4 to 0.1596 $h^{-1}$. The major conversion product was T at pH 4.5-8.5, and P was an additional minor product at pH 4.5. Both products were stable in aqueous media. The hydrolysis of G was determined according to the same approach in two river waters of pH 6.6 and 7.6. Their kinetics were in agreement with those in aqueous buffers of the same pH with low ionic strength to reduce or eliminate buffer catalysis.

**Szurdoki, F, L. Jaeger, A. Harris, H. Kido, I. Wengatz, M. H. Goodrow, A. Szekacs, M. Wortberg, J. Zheng, D. W. Stoutamire, J. R. Sanborn, S. D. Gilman, A. D. Jones, S. J. Gee, P. V. Choudary, and B. D. Hammock. 1996. Rapid assays for environmental and biological monitoring. J. Environ. Sci. and Health Part B, Pesticides Food Contaminants and Agricultural Wastes 31: 451-458.** Rapid, inexpensive, sensitive, and selective enzyme-linked immunosorbent assays (ELISAs) now are utilized in environmental science. In this laboratory, many ELISAs have been developed for pesticides and other toxic substances and also for their metabolites. Compounds for which ELISAs

have recently been devised include insecticides (organophosphates, carbaryl, pyrethroids, and fenoxycarb), herbicides (s-triazines, arylureas, triclopyr, and bromacil), fungicides (myclobutanil), TCDD, and metabolites of naphthalene and toluene. New rapid assays have been developed for mercury.

**Thio, A. P., M. J. Kornet, K. Ali, and D. H. Tompkins. 1986. Preparation of amides of carboxylic acid herbicides for gas chromatographic analysis. Analytical Letters 19: 1421-1434.** Amides of 14 carboxylic acid herbicides were prepared by reacting the free acid with the amine in toluene for 1 hr at 80□C in the presence of PC1-3 or P-2I-4. The acids include phenoxyacetic acids, arylacetic acids, and benzoic acids. Aniline, o-toluidine, 3,5-bis(trifluoromethyl)aniline, piperidine, and tetrahydroquinoline were the amine components. Excess of reagents and by-products of the reaction were removed by partitioning into aqueous acid and base. Retention times relative to 2,4-D anilide on 1% OV-22 and FSOT RSL-150 columns are listed for the anilides and should be useful for confirmation purposes. The anilides of 2,4-D, Silvex and 2,4,5-T were obtained in better than 90% yield.

**Ting, K. C. and C. S. Lee. 1995. Gas chromatographic determination of triclopyr in fruits and vegetables. J. Chromatography. 690: 119-129.** Research, comprising quantitative analyses and confirmatory tests, was conducted to develop an effective and accurate analysis method for triclopyr. In the quantitative analyses, five classes of fruits and vegetables (leafy vegetables, roots, fruits, citrus and spices) comprising 10 individual commodities were fortified with triclopyr herbicide at 0.4 and 0.8 ppm. Triclopyr was extracted from the matrices and derivatized separately to 2-chloroethylene ester with 2-chloroethanol-BCl3 and methyl ester with diazomethane. The esters were then quantitated by GC-ECD [electron-capture detector] and GC-NPD [nitrogen/phosphorus detector]. The GC-ECD recoveries for 2-chloroethylene ester were 100.0% and 100.7% at 0.4 ppm and 0.8 ppm fortification levels, respectively, whereas methyl ester recovery was 103.9% at 0.4 ppm fortification level. Similarly, the GC-NPD recoveries for 2-chloroethylene ester were 99.0% and 97.9% at 0.4 ppm and 0.8 ppm fortification levels, respectively, whereas methyl ester recovery was 102.0% at 0.4 ppm fortification level. In the confirmatory test, the 2-chloroethylene ester was introduced into a GC-ion trap. The EI mass spectrum was then interpreted, based on the criteria of molecular ion, isotopes, base ion, characteristic ions and the nitrogen rule. It was concluded that, compared to existing methods, this method has reduced partition solvents to nearly one-tenth. In addition, this method proved to be simple, fast, safe and accurate.

**Tsukioka, T. and T. Murakami. 1989. Capillary gas chromatographic-mass spectrometric determination of acid herbicides in soils and sediments. J. Chromatography. 469: 351-359.** Capillary GC with selected-ion monitoring (SIM) was used to determine mecoprop, MCPB, MCPA, dicamba, 2,3,6-TBA,

2,4-D, 2,4,5-T and triclopyr. Recoveries from soil and sediment were >89% (with the exception of 77% for 2,3,6-TBA) with CV <5% (n = 7). The method is suitable for the simultaneous determination of the 8 herbicides in environmental samples with high sensitivity and accuracy.

**Tsukioka, T., R. Takeshita, and T. Murakami. 1986. Gas chromatographic determination of triclopyr in environmental waters. Analyst 11: 145-150.** The reaction of $BF_3$-trifluoroethanol with an extract of triclopyr from an acidified sample solution to form the trifluorethyl ester has been applied to the determination of triclopyr in environmental waters. The product is cleaned up by silica-gel column chromatography and determined by gas chromatography with electron-capture detection. The detection and determination limits were 0.005 ng and 0.00025 µg/ml, respectively. The recovery and coefficient of variation were found to be 90-93% and less than 4%, respectively (n = 7), for recovery experiments on river waters.

**Turner, E. G., K. D. Getsinger, and M. D. Netherland. 1994. Correlation of triclopyr and rhodamine WT dye dissipation in the Pend Oreille River. J. Aquat. Plant Manage. 32: 39-41.** The US Environmental Protection Agency (USEPA) requires extensive field residue dissipation data for the registration of all aquatic herbicides. Typically, these dissipation studies are conducted by collecting large numbers of water samples from predetermined locations for a specified length of time, without knowing the direction(s) in which the herbicide will move (especially outside of the treated area) or for how long residues will persist. Samples may be collected and analyzed from areas where the herbicide is absent, or locations where the herbicide is present may not be sampled. In addition, samples may be collected and analyzed after the herbicide has dissipated from a particular station, or sample collection may be terminated prematurely. An alternative approach to collecting aquatic herbicide dissipation data lies in the use of concurrent applications of herbicide and the fluorescent dye rhodamine WT. This dye was developed specifically for water tracing and can be monitored and quantified in situ using a fluorometer. Several studies have shown significant correlations between the dissipation patterns of this dye and those of the aquatic herbicides fluridone, bensulfuron methyl, and endothall, when applied concurrently in the field.

**Vogel, A. 1998. Methodology and determination of 2,4-D and triclopyr residues employing the GC-ITD in the analysis of lettuce plants cultivated in the Tala Valley, Republic of South Africa. Bulletin of Environmental Contamination and Toxicology. 60: 371-378.** A method for the extraction and determination (using gas chromatography) of 2,4-D and triclopyr residues in lettuces is described. In field studies conducted in the Tala Valley of Natal, South Africa, from July 1990 to February 1991, only lettuces grown during the summer (January 1991) contained detectable levels of 2,4-D, while those grown in winter and spring did not. Triclopyr was not detected.

## ARTHROPODS

**Bramble, W.C., R.H. Yahner, W.R. Byrnes. 1997. Effect of herbicides on butterfly populations of an electric transmission right-of-way. Journal of Arboriculture. 23: 196-206.** Butterfly populations were studied in 1995 and 1996 on a 500 kV transmission line of PECO Energy in the Piedmont Region of eastern Pennsylvania. The objective was to compare the long-term effect of 3 herbicide sprays (applied after mowing, or to foliage alone or with stems) with 2 mechanical methods (handcutting and mowing) of controlling trees and tall shrubs in right-of-way (ROW) maintenance on the number of butterfly species and their abundance. The wire zone/border zone technique was used on all units to maintain shrubs on border zones; there was greater control in the wire zone. Herbicides used in the treatments included Tordon K, Garlon 3A, Tordon 101, Accord, Access, Escort, Garlon 4 and Arsenal [respectively, picloram, triclopyr, picloram, glyphosate, picloram + triclopyr, sulfometuron, triclopyr, imazapyr]. Butterfly counts were made at 5 times over the growing season to coincide with flowering of common plant species. There was no discernible adverse effect of herbicide spray maintenance in comparison with mechanical methods on either the number of species, or individuals, of the ROW butterfly population. Twenty butterfly species were present on the handcutting unit and 19 to 21 on the 3 herbicide units. The number of individual butterflies present on the 3 herbicide units ranged between 122 to 154 in contrast to 116 on the handcut control unit.

**Kale, P.G., B.T. Jr. Petty, S. Walker, J.B. Ford, N. Dehkordi, S. Tarasia, B.O. Tasie, R. Kale, and Y.R. Sohni. 1995. Mutagenicity testing of nine herbicides and pesticides currently used in agriculture. Environmental and Molecular Mutagenesis. 25: 148-153.** Nine pesticides (permethrin, trifluralin, acifluorfen[-sodium], glyphosate as either Roundup or Pondmaster, 2,4-D, Crossbow [triclopyr], chlordimeform and prometon) were tested for their mutagenicity using the Drosophila sex-linked recessive lethal mutation assay. Unlike adult feeding and injection assays, the larvae were allowed to grow in medium with the test chemical, thereby providing long and chronic exposure to the sensitive and dividing diploid cells, i.e., mitotically active spermatogonia and sensitive spermatocytes. All chemicals induced significant numbers of mutations in at least one of the cell types tested. As some of these compounds gave negative results in earlier studies, an explanation for the difference in results is provided. It is probable that different germ cell stages and treatment regimes are suitable for different types of chemicals. It is concluded that larval treatment may still be valuable and can complement adult treatment in environmental mutagen testing.

**Kostyk, B., S. Greifenhagen, and F.W. Bell. 1997. Effects of alternative conifer release treatments on yellowheaded spruce sawfly defoliation. Forest Research Note –Ontario Forest Research Institute. No. 57, 4 pp.** In stands of black spruce (*Picea mariana*) and white spruce (*Picea glauca*) located in

Thunder Bay, Ontario, Canada, a randomized block design was used to investigate the effect of various conifer release treatments on defoliation rates by yellowheaded spruce sawfly (*Pikonema alaskensis*). Treatments in 1993 were motor-manual cutting with brush saws, mechanical brush cutting, aerial application of triclopyr or glyphosate. Plots were surveyed for sawfly damage in July 1995. Treatment did not have a significant effect on defoliation rate and microsite conditions (proximity of roads, lake fronts and south-facing slopes) were important factors in influencing sawfly populations.

**Leveille, P., J. Legris, G. Couture, R. Langevine. 1995. Evaluation of the effects of triclopyr used in forestry. [Evaluation des impacts du triclopyr utilise dans le milieu forestier.]. Ministere des Ressources Naturelles. Quebec, Canada. x + 98 pp.; Publication No. RN95-3084. French**. An account is given of the chemical composition, biological action, toxicology, degradation and decomposition in air, soil, water, flora and fauna (including human), and effects on vegetation, fauna and humans, of the herbicide triclopyr.

**Wood K. and C. Hollstedt (compiled by). 1995. Fallingsnow Ecosystem Workshop: program and abstracts. Workshop proceedings / Ontario. Ministry of Natural Resources. WP-001, Vegetation Management Alternatives Program, 1995. xv, 54 p.** The Fallingsnow Ecosystem Project, which is providing data on the ecological impacts of alternative vegetation management practices, is being conducted on a regenerated spruce plantation near Thunder Bay, Ontario. Four treatments have been applied at the study site in a randomized block design: manual brushing; mechanical site treatment; aerial application of glyphosate or triclopyr herbicides; and control (no treatment). Environmental variables examined include soil characteristics and biodiversity; below- and above-ground temperature and moisture; vegetation species composition and foliar nutrient content; below- and above-ground insects; terrestrial gastropods; amphibians and reptiles; small mammals; songbirds; moose and deer area use, and foods (production and quality). This report contains presentations from a workshop held to transfer to resource managers the most recent scientific information produced from this project.

## AQUATIC INVERTEBRATES

**Barron, M. G., S. C. Hansen, and T. Ball. 1991. Pharmacokinetics and metabolism of triclopyr in the crayfish (*Procambarus clarki*). Drug Metabolism and Disposition 19: 163-167.** Crayfish (*Procambarus clarki*) were exposed to ($^{14}$C)triclopyr at concentrations of 1 and 2.5 mg/liter, similar to potential field applications. Following 11 days of exposure, the elimination of accumulated residues was followed for 36 days. The majority of the residue in whole crayfish was present in the carcass (shell, hemolymph). HPLC of hepatopancreas showed the residues were primarily parent triclopyr (>80%). The principle metabolite in the hepatopancreas was confirmed by mass spectrometry as the taurine conjugate of triclopyr. Several minor metabolites also were present at very low levels (less than 0.1 ppm) and were not identified. Residues were eliminated with half-lives of 7 to 17 days, depending on the tissue and exposure concentration. Bioconcentration factors, estimated from uptake and elimination rate constants determined using a compartmental model, were about 1 in whole crayfish and hepatopancreas and about 0.2 in muscle. The results of this study indicate that there is a low potential for accumulation of triclopyr and its metabolites in the crayfish.

**Cowgill, U. M., D. P. Milazzo, and B. D. Landenberger. 1989. Toxicity of nine benchmark chemicals to *Skeletonema costatum*, a marine diatom. Environ. Toxicol. and Chem. 8: 451-455.** The sensitivity of a marine diatom to 8 common chemicals and 1 herbicide was determined. The 50% reduction in the number of cells/mm and that of total cell volume x $10^4$ $\mu m^3$/ml was estimated in relation to each of the chemicals. Nominal concentration of triclopyr triethylamine salt (Garlon 3A), $K_2Cr_2O_7$, 4-chlorophenol and phenol were slightly toxic (>10 mg/litre) according to the US Environmental Protection Agency classifactory scheme, while diethanolamine, chlorobenzene, chloroform, acetone and ethanol were classified as practically non-toxic (>100 mg/litre). No observed effect levels were found for each of the 2 cell measurements in relation to each of the chemicals tested for the 5 d period of the test. The range was 1-6,000 mg/litre for total cell count and 0.65-6,000 mg/litre to total cell volume. Data on the sensitivities of other organisms to the group of common chemicals are also included.

**Dunkel, F.V. and D.C. Richards. 1998. Effect of an azadirachtin formulation on six nontarget aquatic macroinvertebrates. Environmental-Entomology. 27: 667-674.** The effects of a botanical pesticide, azadirachtin, were evaluated on nontarget aquatic macroinvertebrates found in southwest Montana, USA. A neem product formulated for commercial use and its petroleum-based inert carrier alone were used to test the hypothesis that a commercial U.S. Environmental Protection Agency-approved formulation of the pesticide, azadirachtin-A, derived from extracts of neem tree seeds, *Azadirachta indica*, is toxic to nontarget aquatic macroinvertebrates in Montana river systems. LC50s

(24 h) for 5 insect species, *Drunella grandis, D. doddsi* (Ephemeroptera), *Skwala parallela* (Plecoptera), *Brachycentrus occidentalis* and *B. americanus* (Trichoptera) and 1 isopod species, *Caecidotea intermedia* varied from 1.8 to 9.2 ppm of the full formulation. The full formulation consisted of: azadirachtin (3% w/w); other neem-extracted material (32% w/w); petroleum solvents (65% w/w). LT50s for 4 ppm of this formulation were 9.4 to 748 h for these field-collected macroinvertebrates. Without azadirachtin, but with the petroleum-based carrier, LT50s were 13.6-46.7 h. These bioassays conducted late in winter and early spring of 1994 and 1995 and late summer and early autumn of 1994 indicated mortality from the neem formulation was similar to the herbicides 2,4-D and picloram, but mortality could be accounted for by action of petroleum solvents in the inert materials. This suggests that the registration process of new pesticides should also include documented potential toxicity of inert components in the formulation to nontarget aquatic insects.

**Gardner, S.C. and C.E. Grue. 1996. Effects of Rodeo R and Garlon R 3A on nontarget wetland species in central Washington. Environmental Toxicology and Chemistry. 15: 441-451.** Purple loosestrife, *Lythrum salicaria*, is an invasive wetland perennial that became established in northeastern North America in the early 1800s. Despite its designation as a noxious weed, its distribution has continued to expand. Treatment with herbicides is the most widely used means of controlling purple loosestrife. This study examined the nontarget effects of two herbicides, Rodeo [glyphosate] and Garlon 3A [triclopyr amine], currently used or being considered for use in controlling purple loosestrife in Washington State, resp. Growth and/or survival of duckweed [*Lemna* spp.], Daphnia, and rainbow trout were monitored for at least 24 h following an application of each herbicide. Free-living water column and benthic invertebrates were monitored 24 h and 7 d post-spray using activity traps and sediment cores. Neither chemical was associated with significant decreases in survival or growth of the bioassay organisms, with the exception that growth of duckweed was reduced 48 h after exposure to Rodeo. Nor were significant decreases in the abundance of free-living aquatic invertebrates detected following the herbicide applications. Results suggest that neither herbicide, at the application rates used, poses a hazard to aquatic invertebrates in wetlands in central Washington. However, Rodeo, because it is a broad-spectrum herbicide, may pose a greater hazard to nontarget aquatic vegetation.

**Gersich, F. M., C. G. Mendoza, D. L. Hopkins, and K. M. Bodner. 1984. Acute and chronic toxicity of triclopyr triethylamine salt to *Daphnia magna* Straus. Bull. Environ. Contam. Toxicol. 32: 497-502.** The Garlon herbicides have been shown to be effective in the control of annual and perennial broadleaf weeds and woody plants. Triclopyr (((3,5,6-trichloro-2-pyridinyl)oxy)acetic acid) is the active ingredient in Garlon herbicides. The use patterns of various herbicides and other chemical agents may result in accidental introduction into natural waters. The objective of this

study was to determine the acute and chronic toxicity of triclopyr triethylamine salt (triclopyr TEA salt) to the freshwater invertebrate, *Daphnia magna* Straus.

**Gersich, F. M., D. L. Hopkins, S. L. Applegath, C. G. Mendoza, and D. P. Milazzo. 1984. Sensitivity of chronic endpoints used in *Daphnia magna* Straus life cycle tests. Aquatic Toxicology and Hazard Assessment: 8th Symposium, ASTM Special Technical Publication 891, pp. 245-252.** The sensitivity of three endpoints used to evaluate the chronic toxicity of boric acid, un-ionized ammonia, and triclopyr triethylamine salt (TEA salt) to *Daphnia magna* was examined. The endpoints examined during these studies were reproduction, growth, and survival. A 21-day static renewal toxicity test was conducted with *Daphnia magna* for all three test materials. The maximum acceptable toxicant concentrations (MATC's) derived from these studies were boric acid 6.4 < MATC < 13.6 mg B/L, unionized ammonia 0.42 < MATC < 0.87 mg $NH_3$ N/L, and triclopyr TEA salt 80.7 < MATC , 149.0 mg/L. Reproduction was consistently the most sensitive endpoint in all three studies. An examination of the literature indicates that the utility and relative sensitivity of reproduction and survival as chronic endpoints have been questionable because of erratic adult survival and large amounts of reproductive variation. The data from this study show that use of well nourished and healthy test organisms reduces variability in both reproduction and survival and enhances the reliability of the daphnid chronic test.

**Getsinger, K.D., D.G. Petty, J.D. Madsen, J.G. Skogerboe, B.A. Houtman, W.T. Haller, and A.M. Fox. 2000. Aquatic dissipation of the herbicide triclopyr in Lake Minnetonka, Minnesota. Pest Management Science. 56: 388-400.** A study of the aquatic fate of the triethylamine salt of triclopyr was conducted in three bays of Lake Minnetonka, Minnesota (USA). The primary purpose of this study was to determine dissipation rates of the parent active ingredient, triclopyr, and its major metabolites, 3,5,6-trichloropyridinol (TCP) and 3,5,6-trichloro-2-methoxypyridine (TMP) in selected matrices including water, sediment, plants, fish and shellfish. Two 6.5-ha plots dominated by the weed species *Myriophyllum spicatum* were treated with 2.5 mg a.e. triclopyr\litre (2.5 ppm) on 21-23 June 1994. A third 6.5-ha plot was established as an untreated reference. Water and sediment samples were collected from within the plots and at selected locations up to 1600 m outside of the plots through six weeks post-treatment for chemical residue analysis. Residue samples were collected from the target and non-target plants and other non-target matrices, including game and rough fish (*Micropterus salmoides, Lepomis macrochirus, Ictalurus nebulosus and Catostomus commersoni*), clams (*Lampsilis siliquoidea*) and crayfish (*Orocnectes virilis* and *O. immunis*). All test animals were sequestered in cages located in the centre of each plot and samples were collected during four weeks post-treatment. Half-lives for dissipation of triclopyr and TCP in water ranged from 3.7 to 4.7 days and from 4.2 to 7.9 days, respectively, with trace amounts of TMP found. Peak triclopyr sediment values ranged from 257

to 335 ng g-1, with a mean half-life of 5.4 days, while peak TCP sediment levels ranged from 27 to 65 ng g-1 (mean half-life=11.0 days). Trace levels of TMP were detected at one treatment site at one sampling event. Triclopyr and TCP accumulated and cleared from animal tissues proportionately to concentrations in the water (triclopyr dissipation half-lives<11 days, TCP<14 days). TMP levels were two to three times higher than those of the other compounds, particularly in visceral tissue. In all cases, residues of these compounds were higher in the inedible portions of the animals, and were usually higher in bottom-feeding fish species. The target plant, *M. spicatum*, accumulated triclopyr steadily until its death. The nontarget plant, *Potamogeton zosteriformis*, showed a much lower accumulation of triclopyr.

**Kreutzweiser, D. P. and S. S. Capell. 1992. A simple stream-side test system for determining acute lethal and behavioral effects of pesticides on aquatic insects. Environ. Toxicol. and Chem. 11: 993-999.** A test system was developed to measure direct lethal and behavioral effects of forest pesticides on stream insects under simulated natural conditions. The system successfully quantified drift response of 10 species of stream insects to various concentrations of permethrin, triclopyr, hexazinone, and *Bacillus thuringensis*. Drift responses ranged from no effect to total displacement of species. The procedure was also successful in elucidating differential responses to pesticide exposure by determining drift profiles during treatment. The effects of pesticide concentration on survival of test organisms was clearly demonstrated. For example, the survival of *Isogenoides* sp. and *Hydropsyche* sp. was significantly lower than that of control in both collectors and substrate sections of a test unit treated at 320 mg/L triclopyr, but there were no effects on survival in the test unit treated at 3.2 mg/L. Most experiments with the system have been short-term assessments, and these data are percentages of survival in untreated test units in 24 h. Several longer-term trials indicated 80% to 100% survival of 5 genera at 7 d after treatment.

**Kreutzweiser, D. P., S. B. Holmes, and D. J. Behmer. 1992. Effects of the herbicides hexazinone and triclopyr ester on aquatic insects. Ecotoxicology and Environ. Safety 23: 364-374.** Experiments were conducted to measure acute lethal response of aquatic insects of hexazinone (Velpar L) and triclopyr ester (Garlon 4) in flow-through laboratory bioassays, and to determine lethal and behavioral effects of these herbicides on insects in outdoor stream channels. No significant mortality ($P > 0.05$) occurred in 13 test species exposed to hexazinone in laboratory flow-through bioassays (1-hr exposure, 48-hr observation) at the maximum test concentration of 80 mg/liter. The survival of insects exposed to 80 mg/liter hexazinone in outdoor stream channels was likewise unaffected. Significant drift ( $P <0.001$) of *Isonychia* sp. occurred during a hexazinone treatment of the stream channels, but only at the maximum concentration of 80 mg/liter, and survival of the displaced *Isonychia* sp. was not affected. In flow-through bioassays with triclopyr ester, 10 of 12

test species showed no significant mortality at concentrations greater than 80 mg/liter. Survival of *Isogenoides* sp. and *Dolophilodes distinctus* was significantly affected at less than 80 mg/liter. Lethal concentrations were estimated by probit analysis of concentration-response data (1-hr exposure, 48-hr observation) for *Simulium* sp., ($LC_{50}$ = 303 mg/liter), *Isogenoides* sp. ($LC_{50}$ = 61.7 mg/liter), and *D. distinctus* ($LC_{50}$ = 0.6 mg/liter). Triclopyr ester applications to the stream channels resulted in significant drift and mortality of *D. distinctus* at 3.2 mg/liter (no effects at 0.32 mg/liter), *Isogenoides* sp. at 32 mg/liter, and *Hydropsyche* sp. and *Epeorus vitrea* at 320 mg/liter. The risk to aquatic insects of these herbicides used in forest vegetation management is discussed.

**Kreutzweiser, D.P., D.G. Thompson, B. Staznik, and J.A. Shepherd. 1998. Accumulation dynamics of triclopyr ester in aquatic leaf packs and effects on detritivorous insects. Journal of Environmental Quality. 27: 1138-1147.** Previous field studies have demonstrated that residues of the herbicide, tridopyr butoxyethyl ester (3,5,6-trichloro-2-pyridinyloxyacetic add, butoxyethyl ester) (TBEE), can accumulate in submerged leaf material of aquatic systems at concentrations up to 20 times the maximum aqueous concentrations. Accumulated TBEE residues may pose a risk of adverse effects to detritivorous invertebrates inhabiting and using natural leaf packs. We examined the dynamics of TBEE accumulation and persistence in leaf materials of laboratory and outdoor aquatic systems, and determined the ecological significance of this in terms of effects on detritivorous insects and organic matter processing. Accumulations of TBEE in leaf packs of semi-static laboratory microcosms were up to 80 times aqueous concentrations, and residues persisted for 4 to 5 d. Leaf material of flow-through laboratory microcosms accumulated TBEE at much higher rates (up to 1000 times aqueous concentrations), but residues were cleared by 48 to 72 h. Accumulation and persistence in flow-through units were dependent on water depth, velocity, and exposure duration. Accumulated TBEE residues were less in outdoor stream channels than in laboratory flow-through units, probably because of losses through sorption to natural benthic material in the stream channels. Despite accumulations of TBEE in leaf packs at up to 90 mg kg-1 in systems treated at or near expected environmental concentrations, there was no significant mortality of detritivorous insects and no significant reductions in leaf consumption. Significant mortality and reduced feeding occurred only in systems treated at concentrations well above (up to 10 times) expected environmental concentrations.

**Kreutzweiser, D.P., S.B. Holmes, and D.C. Eichenberg. 1994. Influence of exposure duration on the toxicity of triclopyr ester to fish and aquatic insects. Arch. Environ. Contam. Toxicol. 26: 124-129.** Flow-through toxicity tests were conducted to determine the effects of exposure time on the toxicity of triclopyr butoxyethyl ester (Garlon 4) to fish (rainbow trout and chinook salmon) and stream insects (*Hydropsyche* sp. and *Isonychia* sp.). The toxicity of

triclopyr ester fish increased with increasing exposure duration. Median lethal concentrations for rainbow trout exposed for 1, 6, or 24 h were 22.5, 1.95, and 0.79 mg/L triclopyr ester (expressed as acid equivalent, nominal concentrations), respectively. Comparable values for chinook salmon were 34.6, 4.7, and 1.76 mg/L. The toxicity of triclopyr ester to aquatic insects also increased with increasing exposure time, but was considerably less than the toxicity to fish. There was no significant mortality of insects following 3-h exposures to the maximum test concentration of approximately 110 mg/L. Median lethal concentrations following 9- and 24-h exposures were 14.9 and 4.0 ml/L for *Hydropsyche* sp., and 37.0 and 8.8 mg/L for *Isonychia* sp., respectively. At each exposure time in the toxicity tests, there was a sharp increase in mortality over relatively small increases in concentration, resulting in extremely steep slopes of the probit lines (6.3-33.8), and indicating an apparent response threshold. The herbicide exhibited delayed lethal effects, particularly in fish, but only at short term exposures to higher concentrations. The risk of adverse effects on fish and aquatic insects from triclopyr ester contamination, based on the results of these time-toxicity tests, is discussed.

**Leveille, P., J. Legris, G. Couture, R. Langevine. 1995. Evaluation of the effects of triclopyr used in forestry. [Evaluation des impacts du triclopyr utilise dans le milieu forestier.]. Ministere des Ressources Naturelles. Quebec, Canada. x + 98 pp.; Publication No. RN95-3084. French**. An account is given of the chemical composition, biological action, toxicology, degradation and decomposition in air, soil, water, flora and fauna (including human), and effects on vegetation, fauna and humans, of the herbicide triclopyr.

**Lindgren, C.J., T.S. Gabor, and H.R. Murkin. 1998. Impact of triclopyr amine on *Galerucella calmariensis* L. (Coleoptera: Chrysomelidae) and a step toward integrated management of purple loosestrife *Lythrum salicaria* L. Biological Control. 12: 14-19.** Cage studies were conducted to determine the effects of the herbicide triclopyr amine (as Garlon 3A applied at 12 kg ha-1) on the survival and fecundity of adults of *Galerucella calmariensis*, a biological control agent of *Lythrum salicaria* in North America. To examine the effects of triclopyr on oviposition, adults of *G. calmariensis* were divided into three experimental groups: a direct contact group, an indirect contact group, and an untreated control group. Differences were not detected between the number of surviving adults in each of the three groups, the total number of eggs oviposited by adults in each group, or the total number of eggs oviposited by each group. However, adults in the indirect contact group oviposited significantly smaller mean egg-batch sizes. Eggs oviposited by each group were placed in Petri dishes and monitored until they reached the 3rd-instar. Differences were not detected between the mean number of new generation adults produced between experimental groups. To examine the effect of triclopyr amine on the ability of 3rd-instar larvae *of G. calmariensis* to pupate to teneral adults, 3rd-instar larvae were divided between a control group and a triclopyr amine group. Larvae were

sprayed to wetness with triclopyr amine at 12 kg ha-1, placed in pupation chambers and monitored for adult emergence. Differences were not detected between the number of larvae that pupated through to teneral adults in the control group compared with the triclopyr amine group. It was concluded that triclopyr amine is compatible with the biological control agent *G. calmariensis*.

**Maloney, R. F. 1995. Effect of the herbicide triclopyr on the abundance and species composition of benthic aquatic macroinvertebrates in the Ahuriri River, New Zealand. New Zealand J. Marine and Freshwater Res. 29: 505-515.** Abundance and species composition of aquatic benthic macroinvertebrates were compared between an area sprayed with the herbicide Grazon (active ingredient triclopyr), and an upstream control site (no triclopyr). Five Surber samples were collected from each of three riffles in control and treatment sites on eight occasions over a 1-month period. Aquatic invertebrate species composition was similar in treatment and control sites, and did not change over time. The five taxa that made up 91-95% of all invertebrates by abundance did not vary significantly in treatment compared to control riffles. Abundance of three of' the 15 most common taxa (> 10 individuals per riffle) differed significantly between treatment and control sites over time. However, none of these fluctuations correspond to the presence of known concentrations of triclopyr in water samples, and it is unlikely that the declines resulted from triclopyr. These results are discussed with reference to known lethal concentrations of triclopyr for some invertebrates, and to the effect of floods on invertebrate populations.

**Muirhead-Thompson, R.C. 1987. Pesticide impact on stream fauna with special reference to macroinvertebrates. Cambridge University Press, Cambridge, UK.**

**Perkins, M.J. 1997. Effects of two formulations of glyphosate and triclopyr on four non-target aquatic species: *Xenopus laevis, Myriophyllum sibiricum, Lemna gibba* and *Tubifex tubifex*. University of Guelph, 1997. 110 p.** The effects of two formulations of glyphosate (N-(phosphonomethyl)glycine): Roundup® (formulated with the surfactant, polyoxyethyleneamine) and Rodeo® (formulated without polyoxyethyleneamine) and triclopyr (((3.5.6-trichloro-2-pyridinyl)oxy)acetic acid): Garlon 4® (butoxyethyl ester) and Garlon® 3A (triethylamine salt) on four non-target aquatic species were considered in this study. There was a significant effect of formulation on the toxicity of both glyphosate and triclopyr to *X. laevis* with LC50's of 22 mg ae/L, 9870 mg ae/L, 14 mg ae/L, and 750 mg ae/L for Roundup® Rodeo® Garlon 4® and Garlon® 3A, respectively. An effect of formulation was also observed on the toxicity of glyphosate and triclopyr to *T. tubifex*. Roundup® and Garlon 4® at concentrations of 52 mg ae/L and 86 mg ae/L resulted in significant effects on reproduction and mortality, respectively. Whereas, no significant effects with either Rodeo® or Garlon® 3A were noted at

concentrations up to 106 mg ae/L and 17 mg ae/L, respectively. In contrast, there was no consistent effect of formulation on the sensitivity of *M. sibiricum* or *L. gibba* to these herbicides. *M. sibiricum* was more sensitive to both herbicides than *L. gibba.*

**Servizi, J.A., R.W. Gordon, and D.W. Martens. 1987. Acute toxicity of Garlon 4 and Roundup herbicides to salmon, daphnia, and trout. Bull. Environ. Contam. Toxicol. 39: 15-22.**

**Wood K. and C. Hollstedt (compiled by). 1995. Fallingsnow Ecosystem Workshop: program and abstracts. Workshop proceedings / Ontario. Ministry of Natural Resources. WP-001, Vegetation Management Alternatives Program, 1995. xv, 54 p.** The Fallingsnow Ecosystem Project, which is providing data on the ecological impacts of alternative vegetation management practices, is being conducted on a regenerated spruce plantation near Thunder Bay, Ontario. Four treatments have been applied at the study site in a randomized block design: manual brushing; mechanical site treatment; aerial application of glyphosate or triclopyr herbicides; and control (no treatment). Environmental variables examined include soil characteristics and biodiversity; below- and above-ground temperature and moisture; vegetation species composition and foliar nutrient content; below- and above-ground insects; terrestrial gastropods; amphibians and reptiles; small mammals; songbirds; moose and deer area use, and foods (production and quality). This report contains presentations from a workshop held to transfer to resource managers the most recent scientific information produced from this project.

## BIODIVERSITY

**Agusti, M., M. El-Otmani, and M. Aznar. 1995. Effect of 3,5,6-trichloro-2-pyridyloxyacetic acid on clementine early fruitlet development and on fruit size at maturity. J. Hort. Sci. 70: 955-62.**

**Agusti, M., V. Almela, and M. Juan. 1994. Effect of 3,5,6-trichloro-2-pyridyl-oxyacetic acid on fruit size and yield of 'Clausellina' mandarin (*Citrus unshiu* Marc.). J. Hort. Sci. 69: 219-23.**

**Anonymous. 1980. A provisional assessment of triclopyr herbicide for use in Lake States' forestry. USDA Forest Service, North Central Forest Experiment Station Res. Paper NC 180.**

**Anonymous. 1995. Rehabilitation of grassland after chemical control of silver wattle. Plant Protection News. 40: 5-8.** A 4-year study was undertaken in South Africa to compare (1) the aided recovery of degraded rangeland following silver wattle (*Acacia dealbata*) control by the sowing of suitable grasses and (2) the gradual recovery resulting from colonization by indigenous grasses after silver wattle control. Silver wattle was controlled by felling trees and treating stumps with 1% Tordon Super [picloram + triclopyr] in diesel. During the course of the study it became evident that there were several advantages to sowing grass seed after the control of silver wattle, including suppression of colonization by pioneer weeds, significantly reduced wattle regeneration, and the rapid establishment of grass cover which reduced the runoff and erosion hazard, improved soil-water relations, provided forage, and produced high fuel loads for burning. Results of the rehabilitation program revealed that Rhodes grass (*Chloris gayana*) performed well in terms of establishment, provision of good ground cover and recovery after fire; however, it has limited recovery and a mix with Smuts grass (*Digitaria eriantha*) would be preferable. *Eragrostis curvula* was successful in terms of establishment. Adding *E. teff* to *E. curvula* did not increase the grass sward but reduced costs by 27% and reduced damage by fire; however, *E. teff* is an annual and would require resowing. Kikuyu (*Pennisetum clandestinum*) was good for soil binding, particularly on slopes and recovered well after fire; however, it required regular fertilizing.

**Balfour, P. M. 1989. Effects of forest herbicides on some important wildlife forage species. FRDA Report No. 20, Victoria, B.C. 58 pp.** Data from trials in British Columbia, Alberta, Saskatchewan, Washington, Oregon and Idaho were used to consolidate information on the effect of forest herbicides on forage species important to wildlife in western North America. Tables summarize the effects of glyphosate, 2,4-D ester, 2,4-D amine, triclopyr and hexazinone on all forage species and on species of high and medium importance for various ungulates and grizzly bears. The effect of herbicide use is discussed for

important plant species in each of 4 forage groups (coniferous trees, deciduous trees, shrubs and herbaceous species).

**Balfour, P.M. 1989. Effects of forest herbicides on some important wildlife forage species. FRDA-Report Victoria, B.C. No. 020, 58 pp.** Data from trials in British Columbia, Alberta, Saskatchewan, Washington, Oregon and Idaho were used to consolidate information on the effect of forest herbicides on forage species important to wildlife in western North America. Tables summarize the effects of glyphosate, 2,4-D ester, 2,4-D amine, triclopyr and hexazinone on all forage species and on species of high and medium importance for various ungulates and grizzly bears. The effect of herbicide use is discussed for important plant species in each of 4 forage groups (coniferous trees, deciduous trees, shrubs and herbaceous species).

**Balneaves, J. M. and K. Hughey. 1990. The need for control of exotic weeds in braided river beds for conservation of wildlife. Proc. 9th Australian Weeds Conf. pp. 103-108.** A brief summary is given of studies conducted on braided river beds in New Zealand, particularly in Canterbury. The main observations made were: that bird nesting habitats were sub-standard due to rapid colonization of river beds by exotic weeds and because the amount of adjacent vegetation had made potential nesting habitats increasingly prone to predation; immediate control of *Lupinus* hybrid could be achieved with application of picloram to outlying areas and of triclopyr to main riverbed populations; herbicides could also be used for immediate control of *L. arboreus*, but biological control, possible using the fungus *Colletotrichum gloeosporioides* [*Glomerella cingulata*] was suggested. A number of requirements for exotic weed control which need further researching are given.

**Beasley, R. S., A. B. Granillo, and V. Zillmer. 1986. Sediment losses from forest management: Mechanical vs. chemical site preparation after clearcutting. J. Environ. Qual. 15: 413-416.** The comparative effects of mechanical and chemical site preparation on water yields and sediment losses following forest clearcutting were evaluated over a 4-yr period in the Athens Plateau area of southwestern Arkanses (USA). After 1 year of pretreatment measurements, three forested watersheds were clearcut and the residual vegetation and debris were sheared and windrowed but not burned. Three watersheds were clearcut in a similar manner, but received chemical site preparation. Residual trees on two watersheds were injected with 2-4,D amine; the third watershed was aerially sprayed with a mixture of Tordon (active ingredient; picloram (4-amino-3,5,6-trichloropicoline acid)) was Garlon (active ingredient; triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid)). Three additional watersheds were left undisturbed for controls. Mean annual sediment losses on the mechanically, site prepared watersheds during the first posttreatment year were significantly higher than those from either the chemically site prepared watershed or controls. Chemical site preparation did not significantly increase sediment losses. Although 2nd

year losses for the mechanical site preparation and control treatments doubled over 1st year levels, no significant treatment effect was detected for either site preparation treatment. Third-year losses decreased below 1st year losses for all treatments, but not to pretreatment year levels. The relatively sharp declines in sediment losses during the third posttreatment years were attributed to rapid regrowth of natural vegetation on the sites.

**Bernardo, D. J., D. M. Engle, R. L. Lochmiller, and F. T. McCollum. 1992. Optimal vegetation management under multiple-use objectives in the Cross Timbers. J. Range Manage. 45: 462-469.** Data from a previous study in the oak-hickory [*Quercus/Carya*] forest in Cross Timbers Region in central Oklahoma, examining forage production in response to application of tebuthiuron or triclopyr with or without annual spring burning, were used to develop a mathematical programming model to evaluate alternative vegetation management programs for livestock and white-tailed deer (*Odocoileus virginianus*) for lease hunting. The costs were discounted for net returns over a 15-year period. Results indicated that by integrating herbicides and annual burning into vegetation management programs, sufficient herbivory can be sustained to support an economically viable level of livestock production. Vegetation management programs derived under multiple-enterprise objectives differed significantly from those in conjunction with a single enterprise. Economic returns from cattle production were maximized by applying herbicides that induce large increases in grass production, and thus, allow for significant expansion of the cattle enterprise. Under multiple-enterprise objectives, 2 herbicides and annual burning may be integrated effectively to sustain sufficient production of grasses, forbs, and browse to support expanded cattle, Angora goat, and white-tailed deer populations. Economic returns from the land resource can be increased approximately 46% as a result of employing multiple-enterprise management objectives.

**Blanton, S. and M. Mihajovich. 1999. Basal bark application of Release (TM) herbicide for mixedwood management : 1999 final report. Edmonton: Alberta Environmental Protection, 11 p.** This report describes results of a mixedwood (aspen & white spruce) stand tending research project carried out on two regenerated cutover areas in Alberta. The project assessed the effectiveness & safety of low-volume basal bark application of triclopyr butoxyethyl ester herbicide for managing all tree species; compared the effectiveness & cost of motor manual tending to basal bark herbicide application for spacing & tending the post-juvenile mixedwood sites; compared the effect of motor manual tending & herbicide treatment on short-term slash loading & bird use of treated, untreated, and adjacent areas; and quantitatively measured the soil dissipation of the herbicide following treatment.

**Boggs, J. F., R. L. Lochmiller, S. T. McMurry, D. M. Leslie, Jr., and D. M. Engle. 1991. *Cuterebra* infestations in small mammal communities as influenced**

**by herbicides and fire. J. Mammalogy 72: 322-327.** The impact of habitat alterations created by five brush-management systems (herbicide applications with or without burning) on *Cuterebra* sp. infestations of a host community (n = 811) of small mammals was examined on typical cross-timbers rangeland in Payne Co., Oklahoma (USA), from summer 1986 to 1988. Prevalence of *Cuterebra* sp. infestations in host communities inhabiting pastures treated with tebuthiuron was greater than those treated with triclopyr in 1986. Prevalence on unburned pastures was greater than annually burned herbicide-treated pastures in 1986. Intensity of infestation was not influenced by habitat modification. Burning might have killed soil-dwelling larvae, and tebuthiuron treatment probably created an abundance of topographical summits for aggregation of *Cuterebra* sp.

**Boggs, J. F., S. T. McMurry, D. M. Leslie, Jr., D. M. Engle, and R. L. Lochmiller. 1990. Influence of habitat modification on the intestinal helminth community ecology of cottontail rabbit populations. J. Wildl. Dis. 26: 157-169.** The influence of five brush management treatments using the herbicides tebuthiuron and triclopyr, with or without prescribed burning, on the intestinal helminth community of cottontail rabbits (*Sylvilagus floridanus*) was studied in 1987 on the Cross Timbers Experimental Range in Payne County, Oklahoma (USA). Six helminth species were found (*Dermatoxys veligera*, *Trichostrongylus calcaratus, Passalurus nonanulatus, Wellcomia longejector, Taenia pisiformis cystercercus*, and *Mosgovoyia pectinata americana*) in 102 rabbits (88 adult and 14 juveniles) collected over two seasons (winter and summer). Prevalence of *M. pectinata americana* in cottontail rabbits was significantly greater in untreated control pastures than herbicide treated pastures in winter, while prevalence of *T. pisiformis* was significantly greater in burned than unburned pastures. Abundances of helminth species in the intestinal tract of cottontail rabbits were unaffected by brush treatments. *Mosgovoyia pectinata americana* abundance demonstrated a highly significant increase from winter to summer; conversely, abundance of all oxyurid pinworms combined (*D. veligera, P. nonanulatus, W. longejector*) was significantly higher in winter than summer. Helminth community dynamics were significantly influenced by season, but were unaffected by brush treatments. Habitat modification could have influenced cestode transmission by altering the ecology of invertebrate and vertebrate hosts.

**Boggs, J. F., S. T. McMurry, D. M. Leslie, Jr., D. M. Engle, and R. L. Lochmiller, 1990. Parasitism of cottontail rabbits (*Sylvilagus floridanus*) by *Obeliscoides cuniculi* in response to habitat modification in the Cross Timbers of Oklahoma (USA). J. Helminthological Soc. Washington 57: 146-152.**

**Boggs, J. F., S. T. McMurry, D. M. Leslie, Jr., D. M. Engle, and R. L. Lochmiller. 1991. Influence of habitat modification on the community of**

**gastrointestinal helminths of cotton rats. J. Wildl. Dis. 27: 584-593.** Dynamics of communities of gastrointestinal helminths of cotton rats (*Sigmodon hispidus*) were monitored in response to five experimental brush management treatments using herbicide applications with and without prescribed burning on the Cross Timbers Experimental Range in Payne County, Oklahoma (USA). A total of 113 adult cotton rats (68 male and 45 female) was collected from experimental pastures in winter and summer 1986 resulting in the recovery of five species of helminths: *Longistriata adunca, Syphacia sigmodontis, Strongyloides* sp., *Protospirura muris*, and *Raillietina* sp. Prevalences of *Raillietina* sp. and *S. sigmodontis* were greater on control than herbicide-treated pastures. Prevalence and abundance of *Raillietina* sp. and prevalence of *S. sigmodontis* were significantly lower on annually burned, herbicide-treated pastures compared to unburned herbicide-treated pastures. Triclopyr-treated pastures had greater abundances of *L. adunca* and lower abundances of *Raillietina* sp. than those treated with tebuthiuron. Abundances of *L. adunca* also decreased from winter to summer on annually burned, herbicide-treated pastures while increasing on other pastures. Distribution of all helminths was overdispersed, but distribution of *L. adunca* showed a significant brush treatment by season interaction as a result of greater overdispersion in summer than winter for cotton rats inhabiting brush-treated pastures. Our results indicate that man-induced habitat modifications can alter host-parasite relationships in the community.

**Boyd, R.S. and J.H. Miller. 1997. Forest herbicide site preparation treatments have little impact on plant diversity 11 years posttreatment. Bulletin of the Ecological Society of America. 78: 58.**

**Bramble, W. C., W. R. Byrnes, and R. J. Hutnik. 1985. Effects of a special technique for right-of-way maintenance on deer habitat. J. Arboriculture. 11: 278-284.** Sections of a power line right-of-way in an oak/hickory forest in central Pennsylvania were treated in 1982. The right-of-way was divided into a central 23 m-wide wire zone and 2 border zones 18 m wide. Only tall-growing trees were treated in the border zones, while all trees and tall shrubs were treated in the wire zone, by handcutting (control), summer basal spray of Garlon 4 (triclopyr), stem foliage spray of dichlorprop with picloram and 2,4-D, or selective frill and squirt application of Tordon RTU (picloram and 2,4-D). The wire zone was also treated by broadcast application of Tordon 10 K pellets (picloram). A transect across the right-of-way, including forest edge, was evaluated for suitability as habitat for white-tailed deer (*Odocoileus virginianus*). Direct factors - food plant abundance and diversity, and low plant and tall shrub cover, and indirect factors - external shrub borders, interspersion of cover types and stages of plant succession were noted. Deer use was evaluated in July 1982, 1983 and 1984 by faecal counts, and browsing was evaluated in 1984. Although there were changes in individual habitat factors,

total habitat values remained high. Deer spent more time on the right-of-way after it was treated.

**Britt, J. R., R. J. Mitchell, B. R. Zutter, D. B. South, D. H. Gjerstad, and J. F. Dickson. 1991. The influence of herbaceous weed control and seedling diameter on six years of loblolly pine growth - a classical growth analysis approach. For. Sci. 37: 655-668.** Classical growth analysis equations were applied to three loblolly pine (*Pinus taeda*) seedling ideotypes (defined by groundline diameter) that were subjected to either 2 years of complete herbaceous weed control (low weed abundance: LWA) or no herbaceous weed control (high weed abundance: HWA). The study area was located in the upper coastal plain of Alabama. The site was planted at 2.4 X 2.4 m spacing in January 1983. Sulfometuron was applied at the time of weed emergence, during the first two growing seasons. After this, new weed growth was controlled by glyphosate sprays; non-pine woody vegetation was controlled with cut stump applications of triclopyr. Seedlings of the LWA treatment had greater mean relative growth rate (RGR) and mean net assimilation rate (NAR) values for the first 2 growing seasons. However during years four through five, mean RGR and mean NAR were significantly lower in the LWA treatment than in the HWA treatment. The reduction in herbaceous weed interference appeared to reduce mean leaf area ratio (LAR) throughout the study period. Several trends in this data set suggest that growth analysis parameters may be confounded with size. The largest ideotype generally exhibited the smallest mean RGR; mean RGR declined as trees increased in biomass. To remove the potential confounding factor of size, the basis of comparison was changed from trees of equal age to trees of equal biomass (total aboveground dry weight at the beginning of each growing season). This method resulted in a different interpretation of the results. For a given biomass, trees in the LWA treatment had greater mean RGR and mean LAR than those in the HWA treatment throughout the study period. Growth of seedling ideotypes within a given weed abundance treatment all fell along a single curve, suggesting that there was no apparent interaction between initial seedling diameter and herbaceous weed control. After the trees reached a biomass of 6 kg, the direct benefits from reduced herbaceous interference had apparently ceased. Initially, large differences in NAR were observed between treatments, but these differences diminished as trees approached 5 kg. In contrast, differences in mean LAR were initially small but increased as tree biomass increased. As trees increased in biomass, the partitioning of carbon into leaf area seemed to be more responsible for the productivity gains associated with weed control.

**Brooks, J. J., A. S. Johnson., and K. V. Miller. 1993. Effects of chemical site preparation on wildlife habitat and plant species diversity in the Georgia sandhills. Gen. Tech. Rep. SO-93. Southern Forest Experiment Station, USDA For. Serv. pp. 605-612.**

**Brooks, J.J., J.L. Rodrigue, M.A. Cone, K.V. Miller, B.R. Chapman, A.S. Johnson, M.B. Edwards. 1995. Small mammal and avian communities on chemically-prepared sites in the Georgia sandhills. Proceedings of the Eighth Biennial Southern Silvicultural Research Conference, Auburn, Alabama, 1994. General Technical Report –Southern Research Station, USDA Forest Service. No. SRS-1, 21-23.** The effects of 3 forestry herbicide site preparation treatments (hexazinone, picloram + triclopyr, and imazapyr) on small mammal and avian communities were compared at pre-treatment, and 1, 2, and 3 years post-treatment in the Sandhills physiographic region of Marion County, Georgia. Few differences in small mammal capture rates occurred among treatments. Capture rates declined immediately following site preparation, but returned to pre-treatment levels by 18 months post-treatment. The greatest winter avian abundance occurred at 3 years post-treatment; however, no differences in winter avian abundance were observed among treatments. In year 3 post-treatment, summer birds favouring forest edge + scrub habitats were higher on hexazinone-treated sites. Summer avian abundance was strongly associated with residual woody vegetation.

**Campbell, M. H., I. J. McGowen, B. R. Milne, and D. T. Vere. 1990. The biology of Australian weeds 22. *Cassinia arcuata* R. Br. Plant Protection Quart. 5: 162-168.** The history and distribution of the Australian native *C. arcuata* is briefly outlined. Details of its habitat, growth, development and detrimental effects (including poisoning some grazing animals, plant competition and potential as a fire hazard) are discussed. Methods of controlling *C. arcuata* included use of herbicides (2,4,5-T, picloram, 2,4-D, glyphosate, triclopyr), bush cutting, burning, slashing, grazing and cultivation.

**Cooke, A. S. 1986. The use of herbicides on nature reserves. Focus Nature Conservation. 14: 1-80.** The first part of this report gives guidelines summarizing the Nature Conservancy Council's policy as regards the use of pesticides on nature reserves. Part 2 collates information on the impact of ammonium sulfamate, asulam, fosamine ammonium, glyphosate and triclopyr on non-target flora when used in nature reserves. In part 3, similar information is given on diquat and dalapon for use in freshwater, but with more emphasis on snags than can arise from applying herbicides. A bibliography is given in part 4.

**Cooke, A. S. 1991. The use of herbicides on national nature reserves. Proc. Brighton Crop Protection Conf., Weeds. 2: 619-626.** The principles governing the application of herbicides on national nature reserves (NNRs) in the UK, managed nationwide prior to April 1991 by the Nature Conservancy Council (NCC) and since then in England, Scotland and Wales by English Nature, the NCC for Scotland and the Countryside Council for Wales, respectively, are described. Although the total area of NNRs in the UK exceeds 150,000 ha, there are <100 herbicide applications made to them per year. Other methods of vegetation control, mainly physical, are preferred wherever

possible. Invasive tree scrub species such as *Betula* spp. and *Rhododendron ponticum* are the principal targets but non-woody species, such as *Pteridium aquilinum* on heath- and moorland, *Cirsium* spp. and blackberries (*Rubus fruticosus*) on grasslands, *Phragmites australis* in shallow freshwater and *Spartina anglica* on coastal flats, are also controlled. In 1990, 80% of recorded applications involved 1 of only 4 herbicides (glyphosate, triclopyr, asulam and ammonium sulfamate).

**Dalla-Tea, F. and E. J. Jokela. 1994. Needlefall returns and resorption rates of nutrients in young intensively managed slash and loblolly pine stands. For. Sci. 40: 650-662.** Annual needlefall (NF) returns and resorption rates of nutrients in 6-yr-old slash (*Pinus elliottii* var. *elliottii*) and loblolly (*P. taeda*) pine stands were investigated using a 2X2X2 factorial experiment (species, annual application of a complete fertilizer, sustained weed control) in north central Florida. Weed control was achieved using sulfometuron, glyphosate and triclopyr. Compared with the reference (untreated), the combination treatment (annual fertilizer plus weed control) increased NF returns of N from 2.5 to 15.8 kg/ha for slash pine, and from 1.5 to 19.9 kg/ha for loblolly pine. Similar treatment effects were found for P, with recycling rates for loblolly pine greater than for slash pine. Absolute resorption rates of N increased from 4.7 to 19.9 kg/ha for slash pine, and from 2.5 to 21.1 kg/ha for loblolly pine, as management intensity increased. Absolute resorption rates of P increased from 0.5 to 1.9 kg/ha for slash pine and from 0.2 to 2.4 kg/ha for loblolly pine. However, specific resorption rates of N and P were lowest for fertilizer treatments. When averaged over all cultural treatments, slash pine resorbed more N (62 vs. 57%) and P (62 vs. 51%) than loblolly pine; approximately 26% of the annual P requirements for slash pine were met by reabsorption compared with 13% for loblolly pine. Nutrient pool size within the plant (uptake) and annual nutrient demands for growth were dominant factors influencing the nature and extent of N and P resorption for both pine species.

**Derr, J. F. 1993. Tolerance of apple and peach trees to triclopyr. Hort. Sci. 28: 1021-1023.**

**Engle, D. M., J. F. Stritzke, and F. T. McCollum. 1991. Vegetation management in the Cross Timbers: Response of understory vegetation to herbicides and burning. Weed Tech. 5: 406-410.** Understory vegetation was studied following treatment by herbicides and fire on grazed pastures within the Cross Timbers vegetation type. Tebuthiuron and triclopyr at 2.2 kg/ha were applied in March and June of 1983, respectively. The pastures were burned in late spring of 1985, 1986 and 1987. Frequency of horseweed, rosette panicgrass, and little bluestem increased with both herbicides, but the increase was usually larger with tebuthiuron than triclopyr. Burning as a follow-up to either herbicide had little effect on frequency of rosette panicgrass and little bluestem. Horseweed increased following burning in 1985 and 1987. Standing crop of grasses and

forbs increased dramatically following herbicide treatments. Grass production was greater with tebuthiuron, whereas production of forbs and browse was generally greater with triclopyr.

**Figueroa, P. F. 1995. Reduction of weed competition below the level that impacts conifer growth: Another approach to hardwood management. New Zealand Forest Research Institute: Rotorua, New Zealand. FRI Bull. 192: 173-175.**

**Gabor, T. S., T. Haagsma, and H. R. Murkin. 1996. Wetland plant responses to varying degrees of purple loosestrife removal in southeastern Ontario, Canada. Wetlands 16: 95-98.** This study examined the response of native vegetation to varying levels of purple loosestrife (*Lythrum salicaria*) removal and determined its impact on subsequent loosestrife germination and establishment in a southern Ontario wetland during 1993 and 1994. The study site was treated in 1991 with varying dosages of triclopyr amine herbicide, the triethylamine salt formulation of triclopyr (((3,4,6-trichloro-2-pyridinyl)oxy) acetic acid); 4.0, 8.0, and 12.0 kg active ingredient (a.i.)/ha. Different levels of adult loosestrife control were achieved. The lowest density of adult loosestrife was observed in the 8.0 and 12.0 kg a.i./ha treatment plots where root kill was most effective. Most new adult loosestrife plants in the 8.0 and 12.0 kg a.i./ha treatment plots established from seed. The highest densities of loosestrife seedlings and grass (Gramineae) species were observed in the treatment plots with the lowest number of adult loosestrife plants (12.0 kg a.i./ha). Sedge species (*Carex* spp.) did not differ between treatment levels during 1993 and 1994. Loosestrife seedling densities decreased from 1993 to 1994, suggesting that increased native plant species can slow the rate of loosestrife reestablishment from the seed bank. Native vegetation seems to replace adult loosestrife for a limited time following herbicide application; however, without subsequent treatment, loosestrife will slowly reinvade a wetland.

**Gabor, T. S., T. Haagsma, H. R. Murkin, and E. Armson. 1995. Effects of triclopyr amine on purple loosestrife and non-target wetland plants in southeastern Ontario, Canada. J. Aquat. Plant Manage. 33: 48-51.** We studied the effects of triclopyr amine, the triethylamine salt formulation of triclopyr [[(3,4,6-trichloro-2-pyridinyl)oxy] acetic acid] on purple loosestrife (*Lythrum salicaria* L.) and non-target vegetation in a southern Ontario wetland during 1991 and 1992. Triclopyr was applied during bud to early bloom stage at rates of 4.0, 8.0 and 12.0 kg/ha. During 1991, all treatment levels effectively controlled the aboveground portion of purple loosestrife. Grasses (family Gramineae) were unaffected during 1991, however, sedge species (*Carex* spp.) declined in numbers at higher treatment levels. At 1 year post-treatment, adult purple loosestrife were not present in the 12.0 kg/ha treatment indicating that triclopyr effectively killed the root system. Seedlings dominated the total number of loosestrife plants in the 8.0 and 12.0 kg/ha treatment plots 1 year

post-treatment. Sedges recovered in 1992 and grasses increased above 1991 levels. Removal of adult purple loosestrife allowed more light to reach the substrate surface and created favorable conditions for seed germination and plant growth. Triclopyr amine can effectively reduce adult loosestrife stem densities, however, additional herbicide applications may be required to prevent re-establishment through regeneration from the seed bank.

**Gardner, S.C. and C.E. Grue. 1996. Effects of Rodeo R and Garlon R 3A on nontarget wetland species in central Washington. Environmental Toxicology and Chemistry. 15: 441-451.** Purple loosestrife, *Lythrum salicaria*, is an invasive wetland perennial that became established in northeastern North America in the early 1800s. Despite its designation as a noxious weed, its distribution has continued to expand. Treatment with herbicides is the most widely used means of controlling purple loosestrife. This study examined the nontarget effects of two herbicides, Rodeo [glyphosate] and Garlon 3A [triclopyr amine], currently used or being considered for use in controlling purple loosestrife in Washington State, resp. Growth and/or survival of duckweed [*Lemna* spp.], Daphnia, and rainbow trout were monitored for at least 24 h following an application of each herbicide. Free-living water column and benthic invertebrates were monitored 24 h and 7 d post-spray using activity traps and sediment cores. Neither chemical was associated with significant decreases in survival or growth of the bioassay organisms, with the exception that growth of duckweed was reduced 48 h after exposure to Rodeo. Nor were significant decreases in the abundance of free-living aquatic invertebrates detected following the herbicide applications. Results suggest that neither herbicide, at the application rates used, poses a hazard to aquatic invertebrates in wetlands in central Washington. However, Rodeo, because it is a broad-spectrum herbicide, may pose a greater hazard to nontarget aquatic vegetation.

**Getsinger, K.D., E.G. Turner, J.D. Madsen, and M.D. Netherland. 1997. Restoring native vegetation in a Eurasian water milfoil-dominated plant community using the herbicide triclopyr. Regulated Rivers Research & Management. 13: 357-375.** In an effort to evaluate the selective control of the exotic weed Eurasian water milfoil (*Myriophyllum spicatum* L.) and to assess the recovery and restoration of the native submersed plant community, a 6-ha river and 4-ha cove plot were treated with the herbicide triclopyr at application rates of 2.5 and 1.75 mg/l, respectively, in the Pend Oreille River, WA, in August 1991. Water exchange half-lives within the plots were measured using rhodamine WT dye (river, t-1/2 = 20 h; cove, t-1/2 = 52 h), and triclopyr dissipation rates were also calculated (river, r-1/2 = 19 h; cove, t-1/2 = 53 h). Triclopyr concentrations were below the proposed potable water tolerance level (0.5 mg/l) within the river treatment plot by 3 days after treatment ( lt 0.01 to 0.41 mg/l), and 675 m downstream of that plot by 1 day after treatment ( lt 0.01 to 0.47 mg/l). Following the cove treatment, triclopyr residues ranged from 0.12 to 0.29 mg/l by 7 days after treatment, and from lt 0.01 to 0.06 mg/l as close as

150 m downstream from the plot. Eurasian water milfoil biomass was reduced by 99% in the treated plots at 4 weeks post-treatment. remained low one year later (river treatment, 28% of pretreat levels; cove treatment 1% of pre-treat levels) and was still at acceptable levels of control at two years post-treatment (river treatment, 47% of pre-treat levels; cove treatment. 24% of pre-treat levels). The four-week post-treatment efficacy results verified triclopyr concentration/exposure time relationships for controlling Eurasian water milfoil developed under laboratory conditions. Non-target native plant biomass increased 500-1000% by one year post-treatment, and remained significantly higher in the cove plot at two years after treatment. Native species diversity doubled following herbicide treatment, and the restoration of this robust community delayed the re-establishment and dominance of Eurasian water milfoil for three growing seasons.

**Harrington, T. B., R. G. Wagner, S. R. Radosevich, and J. D. Walstad. 1995. Interspecific competition and herbicide injury influence 10-year responses of coastal Douglas-fir associated vegetation to release treatments. For. Ecology and Manage. 76: 55-67.** Responses of competing vegetation and planted Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) were studied for 10 years after six herbicide and manual release treatments in the Washington and Oregon Coast Ranges. Research objectives were to quantify regional, long-term responses of vegetation to various levels of competition, light and soil water availability, and intensity versus importance of factors influencing Douglas-fir growth. Three treatments reduced shrub cover relative to the untreated check: triclopyr in year 1, glyphosate in years 1-5, and repeated control (via several herbicide applications) in years 1-10. Reductions in woody cover from glyphosate stimulated increases in herb cover in years 3 and 5, while repeated control reduced herb cover in years 1, 2 and 5. Through year 10, Douglas-fir survival (86-99%) varied little among treatments. Visual symptoms of herbicide injury to Douglas-fir from triclopyr (45% of trees) and glyphosate (17% of trees) were associated with 0.1-0.2 m reductions in first-year height. After adjusting for tree size, Douglas-fir growth in stem basal area 2 years after triclopyr was less than that of the untreated check, suggesting prolonged effects of herbicide injury. Because it sustained low levels of interspecific competition, caused minimal tree injury, and prevented overtopping cover from red alder (*Alnus rubra* Bong.), repeated control was the only treatment in which Douglas-fir size (9.8 m height and 21 cm basal diameter in year 10) significantly exceeded (P˙ 0.02) that of the untreated check (7.8 m height and 12 cm diameter).

**Huffman, A. H. and P. W. Jacoby, Jr. 1984. Effects of herbicides on germination and seedling development of three native grasses. J. Range Manage. 37: 40-43.** Two experiments conducted in growth chambers examined influences of 2,4,5-T ((2,4,5-trichlorophenoxy) acetic acid), clopyralid (3,6-dichloropicolinic acid), picloram (4-amino-3,5,6-trichloropicolinic acid), and triclopyr ((3,5,6-

trichloro-2- pyridinyl)-oxy)acetic acid) on germination and early seedling development of buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.), blue grama (*Bouteloua gracilis* H.B.K.) Lag. ex Griffiths), and sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.). Germination and plumule growth were largely unaffected by clopyralid but were significantly reduced by 2,4,5-T, picloram, and triclopyr, especially at rates greater than 1.1 kg/ha. Blue grama was less affected by herbicides than either buffalograss or sideoats grama.

**Joel, D. M., Y. Kleifeld, and B. Bucsbaum. 1991. *Osyris alba* causing damage in orchards. Proc. 5th International Symposium Parasitic Weeds, Nairobi (Kenya), pp. 378-381.** *Osyris alba* (Santalaceae), a perennial parasitic plant, was found to attack orchard trees, causing considerable damage. In one orchard 73.4 (%) of the almond trees were infected. Frequently the parasite occupied the whole space underneath a tree, and occasionally it caused the death of its host. The parasite has numerous erect stems, growing densely and reaching the eight of 1 m. The underground rhizome system can be several meters long. It produces new stems that emergence from considerable depths. Large haustoria connect the parasite to host roots. Mechanical mowing kept the parasite low but did not prevent in from developing the rhizome system. Glyphosate and triclopyr, applied by the rope-whip, fairly effective in the control of the parasites.

**Katovich, E. J. S., R. L. Becker, and B. D. Kinkaid. 1996. Influence of nontarget neighbors and spray volume on retention and efficacy of triclopyr in purple loosestrife (*Lythrum salicaria*). Weed Sci. 44: 143-147.** Greenhouse studies were conducted to determine the influence of plant density and spray volume on the retention, spray deposition, efficacy, and translocation of the amine salt of triclopyr in purple loosestrife. More spray solution was retained on leaves at 935 L/ha than at 94 L/ha at populations of 0, 4, or 8 nontarget neighbors. Spray coverage decreased with decreasing height within the plant canopy when spray cards were placed in the top, middle, and soil surface adjacent to the central target plant. Within a population, spray card coverage generally increased as spray volume increased. Regrowth from the crown was affected by spray volume, and uniform spray coverage of the plant was required for adequate control of vegetative regrowth and was achieved with spray volumes of 374 and 935 L/ha spray volume. Regrowth of purple loosestrife was greater at 94 L/ha at all three plant populations indicating that less herbicide penetrated the canopy to reach the basal portion of the plant. A laboratory experiment was conducted to investigate the translocation of radiolabeled triclopyr to roots and crowns of purple loosestrife. Only 0.3 to 1.4% of absorbed $^{14}$C-labelled material was translocated to roots and crowns. Low spray volumes and dense stands of purple loosestrife would likely result in poor control because inadequate amounts of triclopyr reach the basal portion of the plant and translocate to vegetative propagules.

**Keong, W. C. 1987. Development of parthenocarpic fruits in oil palm (*Elaeis guineensis* Jacq.) due to application of herbicides. Planter 63: 90-95.** The undesirable effect of picloram, glyphosate, 2,4-D, Garlon 250 [triclopyr], Lontrel [clopyralid] and Starane [fluroxypyr] of increasing the development of parthenocarpic fruit in oil palms was studied in 3-year-old stands at Batu Tiga, Selangor, Malaysia. At 3 months after treatment only picloram had a significant effect on parthenocarpic fruit production. At 90 g a.e. picloram/ha, 50% of the total fruit bunches were parthenocarpic with ratings of 0.1-15% parthenocarpy. At 180 g a.e./ha all fruit bunches possessed parthenogenic fruit with ratings of 75-100%. Garlon, glyphosate, Lontrel and Starane applied sequentially produced normal fruit bunches and only a low number of individual fruits were parthenocarpic (<10/bunch). After a 2$^{nd}$ application of 2,4-D, only 4 out of 72 bunches exhibited parthenocarpy, but the percentage of parthenocarpic fruits/bunch was considerably higher than for the other herbicides tested.

**King, S. P. and S. R. Radosevich. 1985. Herbicide tolerance in relation to growth and stress in conifers. Weed Sci. 33: 472-478.** In an assessment of the response of *Pinus jeffreyii, P. lambertiana, Abies magnifica* and *Pseudotsuga menziesii* to 2,4-D-butoxyethanol ester, glyphosate-isopropylamine and triclopyr- triethylamine most of the spp. showed a high correlation of injury to leader or needle growth rate and xylem pressure potential; the seasonal trend in the degree of injury and the relationship of herbicide tolerance to various physiological factors were unique for each species. Optimum dates for application depended on species and herbicide.

**King, S., T. Drlik, L. Simon, and W. Quarles. 1996. Integrated weed management of gorse. IPM Practitioner. 18: 1-9.** Strategies for the integrated management of gorse (*Ulex europaeus*) are reviewed. Its worldwide spread and current distribution, and its weed status in the western USA, New Zealand, NW Spain, Tasmania and Australia are outlined, together with climatic factors affecting its distribution. The species is described and its biology outlined. Preventative land management practices and treatment thresholds are considered. Reasons for the failure of biological control programs using *Apion ulicis* in the USA and New Zealand are discussed. Preliminary control efforts with *Tetranychus lintearius* in the USA and *Sericothrips staphylinus* in Hawaii are outlined. The impact of grazing with goats and sheep is considered. The implementation and efficacy of a range of physical and cultural control options are discussed, including manual or mechanical removal and burning, annual destruction of shoot regrowth by physical or chemical (triclopyr butoxyethylester, triclopyr amine and glyphosate ± surfactants or adjuvants) means, and the use of shading to reduce or eradicate infestations. It is concluded that multiple control tactics need to be integrated into a program which should include repopulating the cleared area with appropriate native plants.

**Knowe, S. A., T. B. Harrington, and R. G. Shula. 1992. Incorporating the effects of interspecific competition and vegetation management treatments in diameter distribution models for Douglas-fir saplings. Can. J. For. Res. 22: 1255-1262.** A parameter recovery procedure for the Weibull distribution function, based on diameter percentiles, was modified to incorporate the effects of competing vegetation in young Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) plantations. The procedure was tested using data from sites in the Coast Ranges of Oregon and Washington and in the Siskiyou Mountains of SW Oregon. The Coast Ranges study was conducted in 2- to 3-yr-old plantations needing release from woody shrub (mainly *Rubus spectabilis* and *R. parviflorus*) and broadleaved tree (*Alnus rubra* and *Acer macrophyllum*) competition. Release treatments were an untreated control, manual cutting, triclopyr ester applied aerially, glyphosate applied aerially, and a total vegetation control treatment consisting of annual broadcast applications of hexazinone and spot treatments of glyphosate and triclopyr. The Siskiyou Mountains study was conducted in 1- to 2-yr-old plantations on sites covered by tanoak (*Lithocarpus densiflorus*). Tanoak sprout clumps were left unthinned or were thinned to 50, 25 and 0% of the pretreatment cover. Four percentiles (0, $25^{th}$ , $50^{th}$ , $95^{th}$ ) of the cumulative probability distribution were predicted as functions of quadratic mean diameter and age. In the Siskiyou study, cover and total vegetation control affected quadratic mean diameter and all four percentiles; intensity of the vegetation treatments affected the 0 and $25^{th}$ percentiles, and the interaction between intensity and timing of treatment affected mean diameter. In the Coast Ranges study, only quadratic mean diameter was affected by cover of woody vegetation, while quadratic mean diameter and the $25^{th}$ percentile were significantly affected by total vegetation control. The predicted distributions showed decreasing variance with increasing cover, particularly in the Siskiyou Mountains. In the Coast Ranges study, the coefficient of variation increased with increasing cover, indicating that the variance of stem diameters was affected by average size. On xeric sites in the Siskiyou Mountains, high diameter variability in plots with total vegetation control suggests that interspecific competition may inhibit the expression of microsite variation.

**Lackovic, A. and E. Glejdurova. 1989. Changes in the botanical composition and qualitative value of grass stands after the application of selective herbicides. Vedecke Prace Ustavu Luk a Pasienkov v Banskej Bystrici. 20: 71-82.** Grassland at Nova Lesna (50-60% *Taraxacum officinale*) and at Spisska Teplica (40-50% *Geranium pratense* and 8-10% *Symphytum officinale*) were treated with Aniten I [dicamba + flurenol-butyl + MCPA], Garlon [triclopyr], Starane [fluroxypyr], Lontrel [clopyralid] or SYS Nadibut [MCPB] at 4.0, 2.5, 2.0, 2.0 and 4.0 litres/ha, respectively., either in spring or after the $1^{st}$ cut. 150 kg N, 30 kg P and 80 kg K/ha were also applied. At Nova Lesna, herbicide treatment increased the percentage of grasses from 40 to 50-96% and correspondingly reduced the percentage of forbs. Legumes were not present. At

Spisska Teplica, the percentage of grasses increased from 14.0 to 55-78% and forbs decreased from 85 to 13-39% with herbicide application. Agronomically useful grasses such as *Poa pratensis, Dactylis glomerata, Alopecurus pratensis* and *Festuca pratensis* increased at the expense of low value and weedy grasses with herbicide treatment. SYS Nadibut was less effective than the other herbicides.

**Lautenschlager, R.A. 1993. Effects of conifer release with herbicides on wildlife (a review with an emphasis on Ontario's forests). Forest Research Information Paper –Ontario Forest Research Institute. No. 111, 23 pp.** This paper reviews studies that have examined the effects of forest herbicide treatments (mainly with 2,4-D, glyphosate, triclopyr and hexazinone) on wildlife in Ontario and similar northern coniferous ecosystems. Since most of the research has been short-term, valid generalizations about the effects of conifer release with herbicides on specific wildlife species and/or groups (except moose, *Alces alces*) must be limited to 1 or 2 growing seasons after treatment. Moose browse and browse use reductions following conifer release with herbicides may last up to 4 years. However, early reductions in browse availability commonly found in treated areas may be offset by later additions. Such increases have been recorded 8 growing seasons after treatment. Although the data are limited, research indicates that if herbicide treatments reduce other (non-moose) local wildlife populations, those reductions likely last for only 1 to 2 years after treatment. Conifer release is but one of several forest management tools designed to direct secondary succession and shape future forests. Managed forests, moreover, are only parts of larger ecosystems, which in turn are parts of the overall landscape. The effects of the composition of the landscape mosaic on resident wildlife should be considered when conifer release is discussed. In Ontario, where harvesting has reduced the coniferous component in forests and landscapes, conifer release could help restore this component and increase both forest and wildlife diversity.

**Lautenschlager, R.A. and J.C. Neal. 1995. Effects of manual, mechanical, and aerial herbicide conifer release on small mammal populations in the fallingsnow ecosystem (northwestern Ontario). Proceedings of the forty-ninth annual meeting of the Northeastern Weed Science Society, Boston, Massachusetts, USA, 1995. 139-140.** Field trials were conducted in a conifer [Pinopsida] forest in northwestern Ontario during 1993 to assess the effects of glyphosate and triclopyr, manual cutting, and mechanical cutting on small mammals. Counts of short tailed shrews, red backed and meadow voles, least and eastern chipmunks [*Tamias* spp.], weasels [*Mustela* spp.], *Sorex* spp. and deer mice from traps were made pre-treatment in Aug. and post-treatment in Sep. Short tail shrews, red backed voles, *Sorex* spp., deer mice, least chipmunks and eastern chipmunks increased in density from 1-2, 1-8, 1-41, 4-18, 1 and 1-3 animals/4 ha, resp., in Aug. to 18-31, 28-62, 89-116, 17-38, 1-5 and 3-17

animals, resp., in Sep. Meadow voles and weasels decreased in density from 1-3 animals in Aug. to 1-2 and 0 animals, resp., in Sep.

**Lautenschlager, R.A., F.W. Bell, and R.G. Wagner. 1997. Alternative conifer release treatments affect small mammals in northwestern Ontario. Fallingsnow Ecosystem Project. Forestry-Chronicle. 73: 99-106.** Density changes of small mammals responding to different conifer release treatments (motor-manual (brush saw) cutting; mechanical (Silvana Selective) cutting; and helicopter-applied herbicides Release (triclopyr), Vision (glyphosate) controls no treatment) were quantified in spruce (*Picea glauca* and *P. mariana*) plantations, 4-7 years old, SW of Thunder Bay, Ontario. Treatments were applied in 1993 and small mammals were monitored during 1993-95. A total of 4851 small mammals were captured and released during the three-year study. The most commonly captured (81% of total) species were: shrews (*Sorex cinereus*, *S. hoyi*, and *S. arcticus*), southern red-backed voles (*Clethrionomys gapperi*), and deer mice (*Peromyscus maniculatus*). Northern short-tailed shrews (*Blarina brevicauda*), eastern (*Tamias striatus*) and least (*T. minimus*) chipmunks, meadow voles (*Microtus pennsylvanicus*), ermine (*Mustela erminea*), and meadow jumping *mice (Zapus hudsonius*) were common. Shrew densities were statistically unaffected by these treatments. Red-backed vole densities were highest on control plots during the first post-treatment growing season, and highest on control and Vision plots during the second post-treatment growing season. During the first two growing seasons after treatment, deer mouse densities were highest on Silvana Selective plots; eastern chipmunk densities were highest on control, Vision and Silvana Selective plots, least chipmunk densities were highest on Vision and Release plots; and meadow vole densities were highest on Release plots. Small mammal responses to the alternative conifer release treatments examined were species specific one and two-growing seasons post-treatment, but similar to responses common to the standard (Vision herbicide) conifer release treatment.

**Lautenschlager, R.A., F.W. Bell, R.G. Wagner, and P.E. Reynolds. 1998. The Fallingsnow Ecosystem Project: documenting the consequences of conifer release alternatives. Journal of Forestry. 96: 20-27.** An overview is presented of the Fallingsnow Ecosystem Project, established in 1993 SW of Thunder Bay, Ontario, Canada, including the design, environmental components, and the initial results obtained. The Project was designed to document the terrestrial ecological consequences of alternative conifer release treatments. The ecosystem components studied are: soil chemistry, physics and morphology; below- and above-ground microclimates; below-ground fungi; vegetation, species composition, abundance, diversity, and foliar nutrient content; insects; terrestrial gastropods; amphibians and reptiles; small mammals; songbirds; and moose [*Alces alces*] area use and foods (production and storage). Although long-term responses are unknown, results to date indicate that cutting (with brush saws or tractor-mounted cutting heads) and

herbicide (glyphosate or triclopyr) treatments are relatively inconsequential for most environmental components found in regenerating northern forests. It is suggested that given the growing opposition to herbicide use in forestry, managers must expect that social input into natural resource management will become more common, if not required.

**Leslie, D. M. Jr., R. B. Soper, R. L. Lochmiller, and D. M. Engle. 1996. Habitat use by white-tailed deer on Cross Timbers rangeland following brush management. J. Range Manage. 49: 401-406.** Seasonal habitat use by white-tailed deer (*Odocoileus virginianus* Zimmerman) was monitored with radio telemetry in 1988-89 to determine responses to experimental brush treatments, 5-6 years post-treatment, in the cross timbers region of central Oklahoma. The study area was a mosaic of brush treatments: tebuthiuron (N-[5-(1,1-dimethylethyl)-1,3,4-thiazol-2-yl1]-N,N'-dimethylurea) herbicide, tebuthiuron with an annual spring burn, triclopyr ([(3,5,6-trichlor-2-pyridinyl)oxy]acetic acid) herbicide, triclopyr with an annual spring burn, and no herbicide with annual spring burning. Control areas with no burning or herbicide applications also were evaluated. Herbicides were applied in 1983, and fires were initiated in 1985. Annual home range (95% harmonic mean) averaged 99.9 ha, and no differences in size among seasons or between sexes were observed. Both sexes selected and avoided specific brush treatments throughout the year. Female deer selected or avoided more human-altered habitats in specific contrasts of main treatment groups (e.g., treated vs. control, herbicide vs. no herbicide, fire vs. no fire, etc.) than males. Both sexes selected fire treatments in summer and were most particular in their choice of main treatment groups in summer and fall habitat use between the sexes was most similar in winter and most disparate in fall. The mosaic of habitat types resulting from the variable herbicide and burn application pattern probably influenced deer habitat use in the cross timbers region through combined effects of increased mid-story cover and forage production as they relate to reproductive activities and nutritional needs of female deer in particular.

**Leterrier, J. L., J. Bard, and C. Delassus. 1992. Use of the association triclopyr + fluroxypyr in the release of conifers and broadleaved trees of the forest, devitalisation of the stumps. Association Nationale de Protection des Plantes, Paris, 15th International Meeting, 3: 867-874.**

**Lochmiller, R. L., J. F. Boggs, S. T. McMurry, D. M. Leslie, Jr., and D. M. Engle. 1991. Response of cottontail rabbit populations to herbicide and fire applications on Cross Timbers rangeland. J. Range Manage. 44: 150-155.** Knowledge of how resident wildlife populations respond to brush management strategies is especially limited for rangelands in the Cross Timbers vegetation type of Oklahoma. We examined how cottontail rabbit (*Sylvilagus floridanus*) density and habitat use were influenced by applications of tebuthiuron or triclopyr, with and without annual burning, on Cross Timbers rangeland. Line

transect flush-counts, mark-recapture livetrapping, and fecal pellet counts were used to evaluate seasonal differences in population density among 5 brush control treatments. Cottontail rabbits (n = 225) were flushed along 362 km of line transects during 5 census periods. Density in winter was consistently lower than summer for all treatments, except for the untreated control in winter 1987. Line transect density estimates varied from 0 to 1.975 rabbits/ha and suggested that herbicide and annual burning treatments had a positive influence on cottontail rabbit populations compared to untreated controls. Mark-recapture density estimates did not differ among treatments. Fecal pellet counts were greater on herbicide-treated pastures than an untreated control in both spring and fall. Prairie-eastern redcedar (*Juniperus virginiana* L.) and forest-prairie ecotone habitats were utilized greater than expected by cottontail rabbits. Mature hardwood overstory and mixed-brush habitats were avoided. Tebuthiuron and triclopyr effectively deceased hardwood overstory and increased preferred habitats for cottontail rabbits.

**Lochmiller, R.L., D.G. Pietz, S.T. McMurry, D.M. Jr. Leslie, and D.M. Engle. 1995. Alterations in condition of cottontail rabbits (Sylvilagus floridanus) on rangelands following brush management. Journal of Range Management. 48: 232-239.** Discriminant analysis was used to investigate responses of overall physical condition of cottontail rabbits (S. floridanus) to brush management and plant succession on replicated disturbed and undisturbed upland hardwood forest-tallgrass prairie over a 6-year period. Five different disturbed habitat types were experimentally created using herbicides (tebuthiuron or triclopyr), fire, or a combination of both. Parameters that were important discriminators of rabbit physical condition among habitat types and post-disturbance successional changes included indices of kidney fat and parasitism, and relative masses of spleen, liver, and dried stomach digesta. Brush management practices using herbicides influenced overall condition of rabbits, but the type of habitat disturbance was not important. Effects on overall body condition of cottontail rabbits from burning disturbed habitats were not apparent until later seral stages when production of herbaceous dicots declined and vegetative composition more closely resembled that of undisturbed areas.

**Luken, J.O., S.W. Beiting, R.L. Kumler. 1993. Target/non-target effects of herbicides in power-line corridor vegetation. Journal of Arboriculture. 19: 299-302.** Various herbicides and two cutting regimens (cut/spray and cut/delay spray) were tested in an Ohio power-line corridor. Herbicides were chosen to represent a range of selectivity and mode of action: Accord (glyphosate) at 18.7 litres/ha; Accord + Escort (metsulfuron) at 18.7 litres/ha + 0.14 litres/ha; Garlon (triclopyr) + Tordon (picloram) at 11.7 litres/ha + 18.7 litres/ha; and Krenite (fosamine) at 28.1 litres/ha. In all herbicide/cutting combinations, tree populations showed some recovery two years after treatment. Although Accord + Escort applied in a cut/spray treatment resulted in the lowest population of trees after two years, this treatment also had the most persistent negative effect

on non-target ground cover. Krenite had the least negative impact on ground-cover. Spraying sooner rather than later after cutting improved tree-kill by all herbicides, but it can also increase effects on non-target species (e.g. with Krenite). It is concluded that more selective herbicides and herbicide application methods are needed for management of natural vegetation.

**Marechal, J., P. Delabraze, and J. C. Valette. 1983. Juvenile sensitivity of cedar, *Cedrus atlantica manetti* and Nordmann fir, *Abies nordmanniana* Spach to doses of 2,4,5-T and triclopyr kept for firebreak maintenance in the Mediterranean region. Compte rendus de la 12e Conference du COLUMA / Comite francais de lutte contre les mauvaises herbes. 3: 281-285.**

**Marechal, J., P. Delabraze, and J. C. Valette. 1983. Maintenance of woody firebreaks in Provence: Efficacy of triclopyr ester. Compte rendus de la 12e Conference du COLUMA / Comite francais de lutte contre les mauvaises herbes. 3: 287-297.**

**Marrs, R. H. and F. M. Griffith. 1986. Terrestrial herbicides. Focus on Nature Conservation. 14: 13-64.** Information is given on the use of ammonium sulfamate, asulam, fosamine ammonium, glyphosate and triclopyr in National Nature Reserves. Application methods, environmental effects and the use of these herbicides for conservation purposes are also discussed.

**Marrs, R. H. and J. E. Lowday. 1983. The role of herbicides for nature conservation. Proc. 10$^{th}$ Intl. Congress Plant Protection. pp. 1151.** Among the herbicides evaluated for vegetation management in nature reserves/heath land, asulam, fosamine and 2,4,5-T all showed potential for use in non-target grass or Calluna heath communities. Asulam proved useful against *Pteridium aquilinum*, while fosamine, 2,4,5-T and triclopyr achieved >95% kill of *Betula* sp. The use of these and other herbicides for nature conservation is discussed.

**McCarty, L. B., D. L. Colvin, and J. M. Higgins. 1996. Highbush blackberry (*Rubus argutus*) control in bahiagrass (*Paspalum notatum*). Weed Tech. 10: 754-761.** A 3-yr study investigated highbush blackberry control in bahiagrass turf using selective herbicides. Triclopyr applied alone at 0.56 kg/ha and in combination with other herbicides provided best (75 to 95%) control for up to 52 weeks after treatment with minimal damage to bahiagrass turf. Triclopyr formulations (3A vs 4EC) provided similar highbush blackberry control and bahiagrass tolerance. The addition of either 2,4-D, dicamba, hexazinone, or sulfometuron to triclopyr provided slightly better blackberry control, but increased bahiagrass turf damage. Fluroxypyr applied at 0.14 to 0.28 kg/ha provided 60 to 80% control of highbush blackberry 12 WAT. Glyphosate and glufosinate treatments provided unacceptable highbush blackberry control and/or unacceptable bahiagrass turf injury. The addition of oxadiazon for residual control of subsequent highbush blackberry emergence was ineffective.

**McDonald, P. M. and G. O. Fiddler. 1991. Vegetation management in young conifer plantations in California. Proc. 44th Annual Meeting Southern Weed Sci. Soc. pp. 257-264.** A study was begun in 1980 on alternatives for releasing young conifer [*Pinus ponderosa* and *Pseudotsuga menziesii*] plantations in 40 study areas located on state, national forest, California, Bureau of Land Management, and private industry lands in northern and central California. Included were many variations of chemical, manual, mechanical, mulch and grazing animal treatments, and their effect on the survival and growth of conifer seedlings was studied. Plant species diversity, succession and competition in both treated and natural state sites were examined. Increased amounts of data over longer time spans permitted the establishment of trends and suggested strategies for effective release of conifer seedlings; a treatment radius of at least 1.5 m was required. Diameter, rather than height, was the best indicator of release. Several newer non-phenoxy herbicides such as Velpar [diuron + hexazinone], Garlon [triclopyr], and Roundup [glyphosate], showed promise for control of competing vegetation. Mechanical release of plantations having high shrub density required additional treatments (usually chemical) for effective control. Manual treatments provided adequate control of non-sprouting and non-rhizomatous plants, but were costly. Grazing animals, although they consumed large amounts of competing vegetation, did not result in a statistically significant increase in pine diameter or height after 9 years. Mulching was promising for weed control but problems of size and cost must be overcome.

**McDonald, P. M., G. O. Fiddler, and P. M. Dougherty. 1993. Feasibility of alternatives to herbicides in young conifer plantations in California. Can. J. For. Res. 23: 2015-2022.** A research program (involving 40 studies) was started in 1980 to compare the effectiveness and cost of various vegetation management techniques used for enhancing growth of 1- to 3-yr-old conifer (*Pseudotsuga menziesii, Pinus ponderosa, P. jeffreyi, Abies magnifica* and *A. concolor* var. *lowiana*) plantations in California. The studies were ended after 10 yr when competition became intraspecific. The techniques used included direct methods such as manual manipulation, mulching, herbicides (Garlon 3A [triclopyr], 2,4-D or Velpar [hexazinone]), and grazing for releasing conifer seedlings from undesirable vegetation, and several silvicultural practices (broadcast burning, group selection, genetically improved seedlings) that serve as indirect methods for reducing or avoiding vegetation problems. Manual release and mulching were effective but expensive. Herbicides were effective, applicable to almost all plant communities, and relatively inexpensive. Grazing was good for cattle and sheep, but did not significantly enhance conifer seedling growth. Silvicultural control of weeds was promising, but there was not enough information to evaluate feasibility. It was concluded that in most instances, forests cannot be managed economically without herbicides, if the objective is to grow seedlings at the potential of the site and the plant community includes sprouting broadleaves and shrubs or rhizomatous forbs and

ferns. If the objective is to create a forest with several age-classes and variable structure, but with slower seedling growth, longer rotations, and less species diversity in early seral stages, then it is possible to accomplish this using other vegetation management techniques.

**McMurry, S. T., R. L. Lochmiller, J. F. Boggs, D. M. Leslie, Jr, and D. M. Engle. 1994. Demographic profiles of populations of cotton rats in a continuum of habitat types J. Mammal. 75: 50-59.** We examined temporal relationships between characteristics of populations of cotton rats (*Sigmodon hispidus*) and vegetative characteristics of habitats following secondary succession of post oak (*Quercus stellatai*)-blackjack (*Q. marilandica*) savannas in central Oklahoma. Successional changes in vegetation were induced on manipulated habitats by one of two herbicides (tebuthiuron, triclopyr) applied in 1983 and used in combination with or without annual prescribed burning during 1985 to 1988. Relative population density (animals caught per 100 trapnights) and percentage of reproductively active adult females (lactating or pregnant) were significantly greater on manipulated habitats dominated by monocots (grasses) than on habitats with monocots and dicots or undisturbed controls. Herbaceous dicots also influenced the density of cotton rats, especially in 1986; relative density peaked on all manipulated habitats following a peak in production of herbaceous dicots in 1985. Nutritional quality of herbaceous vegetation may have been enhanced by annual burning; relative densities and proportions of juveniles in the trapable population were higher in burned than in unburned habitats. This observation was most pronounced in 1986, when herbaceous dicots comprised a greater proportion of the primary production, than in 1987 or 1988.

**McMurry, S. T., R. L. Lochmiller, J. F. Boggs, D. M. Leslie, Jr., and D. M. Engle. 1993. Opportunistic foraging of eastern woodrats (*Neotoma floridana*) in manipulated habitats. Amer. Midland Naturalist. 130: 325-337.** We evaluated diets of eastern woodrats (*Neotoma floridana*) on Cross Timbers rangeland subjected to experimental brush manipulation. Treatments were tebuthiuron and triclopyr herbicides, applied with and without annual prescribed burning. Untreated reference sites also were evaluated. Microhistological techniques were used to estimate relative percent composition of plant species in diets. A total of 23 plant species were found in diets from summer and winter samples. Eastern woodrats exhibited seasonal variation in diet selection, consuming mostly forbs in summer and browse in winter. Pokeweed (*Phytolacca americana*) and eastern redcedar (*Juniperus virginiana*) comprised the greatest percentages of diets in summer and winter, respectively. Experimental brush treatment also influenced diet composition. We hypothesized that eastern woodrats would exhibit opportunistic foraging behavior and use food types in proportion to their availability. Forb and browse diet classes were used in accordance with availability except for forbs on burned tebuthiuron sites. Eastern woodrats generally followed an opportunistic

foraging strategy although occasions of selective foraging were observed, presumably in response to increased palatability and/or nutritional quality of available forage.

**McMurry, S. T., R. L. Lochmiller, J. F. Boggs, D. M. Leslie, Jr., and D. M. Engle. 1993. Woodrat population dynamics following modification of resource availability. Amer. Midland Naturalist 129: 248-256**. We examined the influence of four experimental brush treatments on relative population density, reproduction and body condition of eastern woodrat (*Neotoma floridana*) populations on Cross Timbers rangeland in Oklahoma. Experimental brush treatments were tebuthiuron and triclopyr herbicides, applied with and without annual prescribed burning. Untreated reference sites also were evaluated. A total of 333 eastern woodrats were collected from March 1986 through December 1988. Relative population density varied among seasons and experimental treatments. Maximum summer peaks in density were observed each year on triclopyr treatments. Density was similar between populations on tebuthiuron treatments and reference sites. Reproductive activity of females varied among seasons but not among experimental treatments; peaks occurred in spring and autumn 1986 and summer 1987. Percentage of reproductively active males, as evidenced by spermatogenesis, was less than expected in winter. Mean body weights and condition scores were highest in autumn and spring but were not influenced by experimental treatments. Mean stomach content weight did not differ among seasons or experimental brush treatments.

**McMurry, S. T., R. L. Lochmiller, J. F. Boggs, D. M. Leslie, Jr., and D. M. Engle. 1996. Demography and condition of populations of white-footed mice (*Peromyscus leucopus*) in late and early successional habitats. J. Mammalogy 77: 335-345.** Populations of white-footed mice (*Peromyscus leucopus*) were monitored for 3 years (1986-1988) in late and early successional habitats. Late-successional habitats consisted of mature hardwood forests with little herbaceous vegetation. Early successional habitats were induced by treatment with either triclopyr or tebuthiuron herbicides, used with and without annual prescribed burning, and consisted of varying levels of shrubs and herbaceous vegetation. Abundance of white-footed mice was highest in 1986 and declined through 1987 and 1988, which corresponded to declines in biomass of forbs. Abundance was higher on both herbicide treatments than controls and higher on triclopyr than tebuthiuron treatments. Triclopyr-altered habitats provided a mixture of dense shrubs and forbs not found in tebuthiuron-altered sites. Litter size, but not reproductive activity, was higher on triclopyr compared to tebuthiuron treatments in spring 1986. Body condition of adult mice, but not body mass, was higher on herbicide and burned treatments than on controls and unburned treatments, respectively.

**Miller, J. H., B. R. Zutter, S. M. Zedaker, M. B. Edwards, and R. A. Newbold. 1995. Early plant succession in loblolly pine plantations as affected by**

**vegetation management. South. J. Appl. For. 19: 109-126.** A common study design has been used at 13 locations across the South of the USA to examine loblolly pine (*Pinus taeda*) plantations established using four vegetation control treatments after mechanical site preparation: (a) no control, (b) woody control with triclopyear and glyphosate, (c) herbaceous control for 4 year with annual applications of sulfometuron, and (d) total control combining (b) and (c). This research, the Competition Omission Monitoring Project (COMP), is monitoring both pine growth and plant succession. During the first 8 year, the cover of herbaceous components and prevalent genera, along with pine, woody (non-pine), and total herbaceous cover were estimated annually in September. Stem numbers and heights of arborescent and nonarborescent woody species were measured during the first 5 year and year 8. There were 101 prevalent genera of herbaceous plants and 76 species/genera of woody plants present on the study sites, with a core group common to most. Herbaceous cover was rapidly reestablished on no control and woody control treatments, with greater than 80% cover in the first year. After the first year, herbaceous cover steadily declined on no control plots and was sustained when woody plants were eliminated. In general, grasses dominated the herbaceous layer (mainly *Andropogon* and *Panicum* spp.) with cover peaking in year 4. Woody control increased the actual cover of both grasses and forbs, but only the relative proportion of forbs, which peaked in year 1-2. Woody control also increased the actual cover of vines and semi-woody plants (mainly nontargeted *Rubus* spp.) by year 6-8, but only the relative cover of semi-woody plants. Development of the pine canopy cover was similar with woody and herbaceous control, but pine heights were greater with herbaceous control. Herbaceous control did not increase total woody cover until year 8, but the proportion of arborescent tree to nonarborescent shrub cover was increased. Most arborescent species and rootstocks became established in the first year.

**Miller, J.H., R.S. Boyd, M.B. Edwards, D.G. Thompson (ed.), and R.G. Wagner. 1999. Floristic diversity, stand structure, and composition 11 years after herbicide site preparation. Proceedings of the third International Conference on Forest Vegetation Management, Sault Ste. Marie, Ontario, Canada, 1998. Canadian Journal of Forest Research. 29: 1073-1083.** A study was conducted to investigate the effects of site preparation herbicides applied 11 years earlier on plant species richness, diversity and stand structure and composition. Four study sites in 3 physiographic provinces were established in central Georgia, USA, in 1984. Six herbicide treatments were included on each site (hexazinone liquid, hexazinone pellets, glyphosate, triclopyr, picloram or a mixture of dicamba and 2,4-dichlorophenoxyacetic acid (2,4-D)). Herbicide and untreated plots were prescribed-burned and *Pinus taeda* planted. Eleven years after treatment, 177 total species were identified in these dense pine plantations, 99 species being forbs and grasses. Treated and check plots did not differ in species richness or diversity. Structurally, the total basal area of the tree canopy was not significantly altered, but the proportion of pine

to hardwoods and shrub stem density were influenced by treatment. Latent effects were detected in the abundance and frequency of *Pinus taeda, Prunus serotina, Quercus stellata, Diospyros virginiana, Vaccinium stamineum, Vitis rotundifolia* and *Lespedeza bicolor*. Most were potential mast producers for wildlife. It is concluded that herbicide site preparation had little influence on total species numbers or their diversity 11 years after treatment but affected composition by altering perennial species abundance.

**Miller, K. V. and B. R. Chapman. 1995. Responses of vegetation, birds and small mammals to chemical and mechanical site preparation. FRI Bulletin, No 192; Popular Summaries from Second International Conference on Forest Vegetation Management. R.E. Gaskin and J.A. Zabkiewicz (eds.), 146-148. New Zealand Forest Research Institute, Rotorua, New Zealand.**

**Minko, G. and P. C. Fagg. 1989. Control of some mistletoe species on eucalypts by trunk injection with herbicides. Australian For. 52: 94-102.** Control of mistletoe (*Amyema* sp.) was investigated in NE Victoria following reports that mistletoe infestations had increased in recent years. The control potential of four herbicides was evaluated by injection of the boles of host eucalypts. Eleven eucalypt species (*Eucalyptus globulus* subsp. *bicostata, E. bridgesiana, E. camaldulensis, E. dives, E. goniocalyx, E. macrorhyncha, E. melliodora, E. ovata, E. polyanthemos, E. radiata* ssp. *radiata* and *E. sideroxylon*) were treated in different months in 1984 and 1985 with solutions of the translocatable herbicides Garlon 480 (triclopyr ester), Lontrel L (clopyralid), Roundup (glyphosate) and Velpar (hexazinone). Evaluation of mistletoe control in conjunction with host health 12 and 24 months after injection showed that mistletoes could be partially controlled on most species with certain herbicides. The best results were given by Roundup (diluted 1:3 in water) or Garlon (1:4) injected at the rate of 1 ml per cut, with cuts spaced at 10 cm intervals around the lower bole of the host tree. Lontrel and Velpar gave unsatisfactory results, although they received only limited testing. The particular herbicide and month of injection that gave the greatest percentage control of mistletoes with no or limited host mortality varied with eucalypt species, although the most effective months were commonly January and June. Smaller host trees (<30 cm diameter) were significantly more susceptible to death following injection than larger trees. Poor mistletoe control (<50%) was obtained in *E. sideroxylon* and *E. camaldulensis*, but both species are reasonably tolerant to glyphosate so that better results might be obtained with higher dosages. This study established that host injection with certain herbicides is a feasible and effective technique for reducing *Amyema* spp. populations on many eucalypt species.

**Morash, R. and B. Freedman. 1989. The effects of several herbicides on the germination of seeds in the forest floor. Can. J. For. Res. 19: 347-350.** In a laboratory experiment, we studied the effects of perturbation of a forest floor substrate with six concentrations (10, 50, 100, 500, 1000, and 5000 ppm) of

four herbicides: glyphosate (N- phosphonomethyl glycine), 2,4,5-T (2,4,5,-trichlorophenoxy acetic acid), triclopyr (3,5,6-trichloro-pyridinyloxyacetic acid), and two formulations of hexazinone (3-cyclohexyl-6-(dimethylamino)-1-methyl-1-1,3,5-triazine-2,4(1H,3H)dione). Although their toxic thresholds differ, the herbicides all caused significant decreases in the germination of seeds. However, large decreases in germination only occurred at concentrations that are unrealistically large in comparison with the herbicide residues that actually occur after a silvicultural treatment. In a parallel field experiment, no significant difference in seedling germination was observed for forest floor samples that were exposed to or shielded from herbicide deposition at two sites that were sprayed in an operational program.

**Neary, D. G., J. E. Smith, B. F. Swindel, and K. V. Miller. 1990. Effects of forestry herbicides on plant diversity. Proc. 43rd Annual Meeting Southern Weed Sci. Soc. pp. 266-272.** In a survey of 5-m transects within 2 newly-established stands of slash pine (*Pinus elliottii* var. *elliottii*) in the Gator National Forest, Florida, an intensive weed control program (0.56 kg sulfometuron/ha in April, followed by 0.28 kg in June, mowing with a rotary cutter in September, 2 directed spray treatments with 2% glyphosate the following year and spot spraying with the glyphosate or 2% triclopyr for a further 2 years) resulted in a reduction of species diversity from 10 to 2-3/transects and an increase in the number of transects that were bare or supported pine plants only from 0 to 18% by the end of the 5-year period. By contrast, a less intensive program (ground spraying with 0.42 kg sulfometuron in June and then with 39 litres/ha of an aqueous solution of 5% triclopyr ester + 6.6% triclopyr amine 16 months later) resulted in species diversity shifting from an average of 10 to 5-7/transect, and the number of transects that were bare or supported pine plants only remaining unchanged, 4 years after the first herbicide treatment.

**Nelson, L. S., K. D. Getsinger, and J. E. Freedman. 1996. Efficacy of triclopyr on purple loosestrife and associated wetland vegetation. J. Aquatic Plant Management 34: 72-74.**

**Newmaster, S.G., F.W. Bell, and D.H. Vitt. 1999. The effects of glyphosate and triclopyr on common bryophytes and lichens in northwestern Ontario. Canadian Journal of Forest Research. 29: 1101-1111.** The effects of two silvicultural herbicides (Vision®, Release®) on bryophytes and lichens were studied in a harvested boreal mixedwood ecosystem. A completely randomized design with 115 plots of 1 m2 allowed direct comparison between herbicides and their effects on community dynamics. Regression models were used to analyze the relationship between herbicide application rates (0.71-6.72 kg active ingredient/ha) and changes in bryophyte and lichen abundance and species richness for 2 years following herbicide application. Results showed that bryophyte and lichen abundance and species richness decreased after herbicide treatments. In general, herbicide applications reduced the diversity of

forest mesophytes and weedy colonizers to an ecosystem with only a few species of colonizers. A combination of clustering techniques and ANOVA were used to divide bryophytes and lichens into three ecologically defined response groups: herbicide-tolerant colonizers, semi tolerant long-term stayers from dry open forest, and sensitive forest mesophytes.

**Newton, M., E. C. Cole, R. A. Lautenschlager, D. E. White, and M. L. McCormack, Jr. 1989. Browse availability after conifer release in Maine's spruce-fir forests. J. Wildlife Manage. 53: 643-649.** Even-aged management in northern spruce (*Picea* spp.)-fir (*Abies* spp.) forest types may result in significant production of woody vegetation l-2.5 m tall (i.e., available to browsers) for 10 years after cutting. Rapid growth of hardwoods and associated conifers often leads to good browse conditions 7-9 years after harvest, followed by rapid reduction of available browse biomass (foliage and twigs) by the sixteenth year. August application of glyphosate or triclopyr and/or phenoxy herbicides 7 years after winter "clearcut" harvest reduced the cover of tall hardwoods and caused a 4- to 8-fold increase in available browse. Nearly all plant species present before herbicide treatment remained 9 years later, but browse available after treatment included a higher proportion of sun-grown foliage and twigs than was found in untreated control plots. Spacing in conifer stands by planting or precommercial thinning should prolong the period of browse availability to gt 20 years. Our data indicate the intensive management designed to increase forest crop production in northeastern spruce-fir ecosystems also dramatically improves conditions for resident browsers.

**Nolte, K. R. and T. E. Fulbright. 1997. Plant, small mammal, and avian diversity following control of honey mesquite. J. Range Manage. 50: 205-212.** A field trial was conducted in the Welder Wildlife Foundation Refuge, Texas, on a mesquite-mixed grass community dominated by *Prosopis glandulosa* (honey mesquite), interspersed with chaparral (e.g. *Acacia smallii, Celtis pallida* and *Zanthoxylum fagara*) and grasses *(Stipa leucotricha, Panicum obtusum* and *Setaria leucopila*), to investigate the effects of herbicide application to *P. glandulosa* on community plant and vertebrate species richness and diversity. A 1:1 mixture of triclopyr + picloram was applied to three 13 ha plots during 1992 and to 3 additional plots in 1993. Mesquite and forb canopy cover in the zone ~1 m from the soil surface were lower within treated plots than in control plots in both years. Grass canopy cover did not differ between herbicide-treated plots and control plots. Vegetation species richness and evenness, Shannon's index, beta diversity and the proportion of rare plant species did not differ between controls and sites treated during 1992 and 1993. Rodent and avian relative frequency, richness and diversity were not significantly different in 1992 on herbicide treatment plots and untreated controls. It is suggested that the application of triclopyr + picloram in mesquite-mixed grass communities in the Texas Coastal Bend does not significantly reduce plant and vertebrate species richness and diversity within the first 2 years after treatment.

**Peat, H. C. and G. G. Bowes. 1994. Management of fringed sagebrush (*Artemisia frigida*) in Saskatchewan. Weed Technol. 8: 553-558.** Fringed sagebrush is a native, drought-resistant, increaser species in Saskatchewan pastures and rangelands. Conventional control by cultivating and reseeding is neither highly effective nor sustainable. Two field experiments were conducted in 1988 and 1989 through 1991 to develop a management plan for fringed sagebrush. Comparison of fringed sagebrush control using various applications of clopyralid, dicamba, dichlorprop, fluroxypyr, picloram, triclopyr and 2,4-D, showed control was sufficient using the low-cost herbicide 2,4-D isooctyl ester at 1.5 kg a.i./ha. Total yield of crested wheatgrass plus smooth brome was compared and the plots subjected to two applications of 2,4-D yielded the greatest accumulation of grass over the length of the experiments. The economic threshold of fringed sagebrush is the density at which yield is reduced by approximately 290 kg/ha; above this density it is economically viable to use 2,4-D at 1.5 kg/ha to control fringed sagebrush. Grazing practices can aid greatly in management of fringed sagebrush by allowing the forage to out-compete fringed sagebrush.

**Perkins, M.J. 1997. Effects of two formulations of glyphosate and triclopyr on four non-target aquatic species: *Xenopus laevis, Myriophyllum sibiricum, Lemna gibba* and *Tubifex tubifex*. University of Guelph, 1997. 110 p.** The effects of two formulations of glyphosate (N-(phosphonomethyl)glycine): Roundup® (formulated with the surfactant, polyoxyethyleneamine) and Rodeo® (formulated without polyoxyethyleneamine) and triclopyr (((3.5.6-trichloro-2-pyridinyl)oxy)acetic acid): Garlon 4® (butoxyethyl ester) and Garlon® 3A (triethylamine salt) on four non-target aquatic species were considered in this study. There was a significant effect of formulation on the toxicity of both glyphosate and triclopyr to *X. laevis* with LC50's of 22 mg ae/L, 9870 mg ae/L, 14 mg ae/L, and 750 mg ae/L for Roundup® Rodeo® Garlon 4® and Garlon® 3A, respectively. An effect of formulation was also observed on the toxicity of glyphosate and triclopyr to *T. tubifex*. Roundup® and Garlon 4® at concentrations of 52 mg ae/L and 86 mg ae/L resulted in significant effects on reproduction and mortality, respectively. Whereas, no significant effects with either Rodeo® or Garlon® 3A were noted at concentrations up to 106 mg ae/L and 17 mg ae/L, respectively. In contrast, there was no consistent effect of formulation on the sensitivity of *M. sibiricum* or *L. gibba* to these herbicides. *M. sibiricum* was more sensitive to both herbicides than *L. gibba.*

**Peterson, H. G., C. Boutin, P. A. Martin, K. E. Freemark, N. J. Ruecker, and M. J. Moody. 1994. Aquatic phytotoxicity of 23 pesticides applied at expected environmental concentrations. Aquat. Toxicol. 28: 275-292.** Environment Canada uses an Expected Environmental Concentration (EEC) in evaluating the hazard of pesticides to nontarget aquatic organisms. This concentration is calculated by assuming an overspray of a 15 cm deep water body at the label

application rate. The EEC of pesticides is then related to the $EC_{50}$ (concentration causing a 50% reduction in a chosen toxicity endpoint) for a given aquatic test organism. At present, the use of an uncertainty factor is suggested in the literature if only a few species are tested because of important interspecific differences in pesticide sensitivity. The phytotoxicity of the EEC of 23 different pesticides to ten algae (24 h inhibition of $^{14}C$ uptake) and one vascular plant (7-day growth inhibition) was determined in an effort to examine the question of interspecific sensitivity and its relation to the development of pesticide registration guidelines. Chemicals included five triazine herbicides (atrazine, cyanazine, hexazinone, metribuzin, and simazine), four sulfonylurea herbicides (chlorsulfuron, metsulfuron-methyl, ethametsulfuron-methyl, triasulfuron), two phenoxy-alkane herbicides (2,4-D and MCPA), two pyridine herbicides (picloram and triclopyr), a substituted urea, an amine derivative, and an imidazolinone herbicide (tebuthiuron, glyphosate and imazethapyr, respectively), a bipyridylium (diquat), a hydroxybenxonitrile (bromoxynil), an aldehyde (acrolein) and an acetanilide (metolachlor) herbicide, as well as two carbamate insecticides (carbofuran and carbaryl) and a triazole derivative fungicide (propiconazole). Test organisms were selected based on ecological relevance and present use in test protocols.

**Pitt, D. G., D. G. Thompson, N. J. Payne, and E. G. Kettela. 1993. Response of woody eastern Canadian forest weeds to fall foliar treatments of glyphosate and triclopyr herbicides. Can. J. For. Res. 23: 2490-2498.**
Second-season post-treatment efficacy data are presented for a New Brunswick field study comparing three formulations of glyphosate (Vision®, MON 14420, and Touchdown®) and a single formulation of triclopyr (Release®). Five rates of each herbicide were broadcast applied to a 2-yr-old clearcut in early September 1989. The previous stand consisted primarily of tolerant broadleaved species, contributing to a uniform post-harvest cover of young seedlings, saplings and stump sprouts. Predominant species included sugar maple (*Acer saccharum*), striped maple (*A. pensylvanicum*), mountain maple (*A. spicatum*), yellow birch (*Betula alleghaniensis*), hazel (*Corylus cornuta*), white ash (*Fraxinus americana*), beech (*Fagus grandifolia*) and elderberry (*Sambucus pubens*). Two growing seasons after treatment, percentage control values (based on total woody crown area) ranged from 21% at glyphosate rates <0.25X label maximum to >80% at rates 0.75X label maximum. Coefficients of variation for percentage control values decreased from 104% at the lower glyphosate rates to 9% at the higher rates. Total woody control provided by triclopyr was generally equivalent to that of glyphosate at rates <0.5X label maximum. Beyond this rate, percentage control values for triclopyr averaged only 59% and coefficients of variation remained high (40%). At the individual-species level, the 3 glyphosate formulations provided greater crown volume reduction than triclopyr for white ash, beech, hazel and sugar maple. Control of mountain maple by Touchdown® was found to be slightly inferior to that of the other two glyphosate formulations. Control of elderberry by MON 14420 was

inferior to that of the other 3 herbicides. Nonlinear regression curves relating second-season control and herbicide dose are presented as a guide for silvicultural use (in conifer release and site preparation).

**Rachman, O. and J. Balfas. 1989. The effect of triclopyr poisoning and sawing pattern on the sawing properties of rasamala (*Altingia excelsa*). J. Penelitian Hasil Hutan. 6: 292-298.** Six log samples obtained from each of 3 groups of trees (poisoned with triclopyr or girdled over 1 year [dead trees], and control) were sawn in 2 patterns (live sawing and semi-quarter sawing). Data were collected (and are tabulated) for each combination on recovery, productivity, power consumption and sawn timber defects (particularly end splits and bowing). Data are also presented on moisture content (m.c.) of each log type; m.c. was 20% lower (54.00 and 52.26% respectively) in poisoned and girdled logs compared with controls (74.61%). There were no significant differences between poisoned, girdled and control logs for any sawing characteristics. Recovery and productivity tended to be greater from live sawing than from semi-quarter sawing, but sawing defects were also greater with live sawing.

**Rayachhetry, M. B. and M. L. Elliott. 1996. Compatibility of a native fungus with herbicides for *Melaleuca* control in south Florida. Phytopath. 86 (Suppl.): S22.**

**Rosley, A. 1985. Biological control of *Asystasia* by sheep grazing. Planters' Bull., Rubber Res. Inst. Malaysia, 183: 43-49.** Information of the history, impact and usage, adaptability and spread, and methods of control of *Asystasia* spp., notably *A. coromandeliana*, *A. intrusa* and *A. chelomeides* in Malaysian plantation crops is presented. Introduced in 1876, the weed has since spread throughout peninsular Malaysia, especially *A. intrusa* in central, and south and west coastal Johore. The weed has been used for medicinal purposes, as a vegetable or as animal fodder. The cost of control with 2,4-D amine + paraquat or Garlon 250 [triclopyr]/ha using knapsack, low volume or Wistone sprayers was 177.8-190.3, 25-38 and 17-39 M$/ha. Strip-grazing sheep in a weed-infested rubber plantation markedly reduced weed height (to 10 cm above the soil) after 3 grazing cycles. The sheep preferentially selected *Asystasia* spp. before passing on to other weeds such as *Ottochloa* and *Mikania* spp. *Asystasia* spp. had higher protein contents (24%) than other weeds; the benefits of sheep grazing as a means of controlling *Asystasia* spp. are discussed.

**Sexsmith, W. A. 1989. Environmental monitoring of forestry control operations: 1988 report. Annual publication. New Brunswick Dept. of the Environment, Fredericton. 48 p.** This multi-disciplinary compilation is concerned mainly with the environmental monitoring of the spruce budworm and forest herbicide aerial spray operations in New Brunswick in 1988. This report consists of 9 reports dealing with operational, research and regulatory

aspects of both spray programs. Pesticides investigated are fenitrothion and *Bacillus thuringiensis*, glyphosate, hexazinone, triclopyr, sulfometuron-methyl and metsulfuron-methyl.

**Sheley, R. L., B. H. Mullin, and P. K. Fay. 1995. Managing riparian weeds. Rangelands. 17: 154-157.** The importance and difficulty of managing riparian weeds are discussed. Prevention and containment measures considered include limiting weed seed dispersal, containing neighboring infestations, minimizing soil disturbance, managing desirable vegetation, and conducting systematic surveys and small-scale eradication programs. The significance of proper livestock grazing in maintaining competitive riparian vegetation is discussed. Application procedures and guidelines for selecting chemical control measures are considered, including those for 2,4-D, fosamine, glyphosate and triclopyr; it is argued that persistent and easily leached herbicides are inappropriate, as are those contra-indicated for water contamination. It is argued that biological control methods are not suitable because they impose stress on weeds whereas immediate kill is necessary in riparian environments. Mechanical control measures considered include hand-pulling or grubbing out for newly established weeds, but the frequency (1-2 times/month) and duration (15 years of control) in some cases are noted; mowing and cultivation are not considered suitable for these environments. A suggested revegetation program is described which uses glyphosate in early spring to control newly emerged weeds over small areas, followed by drill-planting with a seed mixture.

**Siltanen, H., C. Rosenberg, M. Raatikainen, and T. Raatikainen. 1981. Triclopyr, glyphosate and phenoxy herbicide residues in cowberries, bilberries and lichen. Bull. Environ. Contam. and Toxicol. 27: 731-737.** Investigations were carried out in Finland into herbicide residues in wild berries in forests which had been subjected to foliar spraying for brush control. Residues of triclopyr were analyzed in cowberries and bilberries after treatment with 0.25, 0.75 and 2.25 kg/ha of the herbicide. Effect of date of treatment on glyphosate (applied at the rate of 0.75 kg/ha) and triclopyr residues was investigated. Results are tabulated. These showed that the residues in the berries were of the same order of magnitude when the same amount of any of the herbicides was used. In aerial spraying the application rate was lowest for glyphosate and highest for phenoxy herbicides. As a result residues in the berries from aerially sprayed forests can be expected to the highest after phenoxy herbicide application and lowest after glyphosate application.

**Slade, N.A., S. T. McMurry, and R. L. Lochmiller. 1996. Habitat differences in mass-specific litter sizes of hispid cotton rats. J. Mammal. 77: 346-350.** Litter size and body size of *Sigmodon hispidus* are known to covary positively both among and within some populations. In captivity, litter size varies with quality of diet. In the field, however, variation in maternal size can obscure nutritional effects on litter size. We reexamine litter sizes from sites in central

Oklahoma varying in primary productivity due to application of herbicides and controlled burning. Mass-specific litter size of cotton rats showed no significant response to burning. In areas treated with tebuthiuron, litters were larger and population densities and primary productivity of monocots were higher than in areas receiving triclopyr. Slopes of the relationship between litter size, a component of fitness, and maternal mass did not significantly between habitats. Thus, percentage increase in litter size in the better habitat was greater for smaller breeding females. This implies that gains in fitness related to habitat productivity are size-specific in these populations.

**Slay, J. M., B. G. Lockagy, J. C. Adams, and C. G. Vidrine. 1987. Effects of site preparation on soil physical properties, growth of loblolly pine, and competing vegetation. Southern J. Applied For. 11: 83-86.** Bulk density was determined in soil samples collected before and 1 yr after 4 site preparation treatments ((a) chop and burn, (b) windrow, (c) fuelwood harvest and (d) fuelwood harvest followed by application of Garlon 4 [triclopyr]) were applied in July 1984 to a site in NW Louisiana. Dry weight of competing vegetation was recorded one year after site preparation. Loblolly pine seedlings (1+0) were planted in January 1985 and height and diameter at ground level were recorded 1 year later. Bulk density and total porosity were n.s.d. between treatments before site preparation. Treatment (b) increased bulk density and porosity at 0-3 inches while treatments (c) and (d) increased bulk density at 3-9 inches. Competing vegetation was significantly less with (d) and significantly more with (c) than with other treatments. Seedling growth was inversely related to weight of competing vegetation. Seedling survival was n.s.d. between treatments.

**Smith, C. T., J. W. Hornbeck, and M. L. McCormack, Jr. 1988. Changes in nutrient cycling following aerial application of triclopyr to release spruce-fir. Proc. 42nd Annual Meeting Northeastern Weed Sci. Soc. pp. 94-99.** Aerial applications of triclopyr at average rates of 1.9 kg/ha used for the release of *Picea* sp. and *Abies* sp. on watersheds in Piscataquis County, Maine, resulted in increased concentration of nitrate and Ca in the water of moderately well drained soils and in stream water during clearcut in the first 2 growing seasons after treatment. Vegetative uptake by trees on the treated plots was important in reducing changes in nitrate concentration in soil solution, and in maintaining nitrate concentration in stream water below levels unsafe for drinking water.

**Soper, R. B., R. L. Lochmiller, D. M. Leslie, Jr., and D. M. Engle. 1993. Nutritional quality of browse after brush management on Cross Timbers rangeland. J. Range Manage. 46: 399-410.** We evaluated seasonal changes in browse quality 5-6 years after experimental manipulations to control unwanted woody vegetation using combinations of herbicide and fire on Cross Timbers rangeland in central Oklahoma. The study area consisted of two 32-ha replications of untreated controls and 4 brush treatments (tebuthiuron and

triclopyr used singly or in combination with periodic prescribed burning); herbicides were applied in 1983 and fires initiated in 1985. Nutritional quality of blackberry (*Rubus* spp.), coralberry, (*Symphoricarpos orbiculatus* Moench), rough-leaf dogwood (*Cornus drummondii* Meyer), elm (*Ulmus* spp.), greenbrier (*Smilax* spp.), hackberry (*Celtis* spp.), and smooth sumac (*Rhus glabra* L.) were assessed by measuring crude protein, *in vitro* dry matter digestibility, neutral detergent fiber, acid detergent fiber, and moisture content. Crude protein concentrations of browse were 14% higher on herbicide-treated areas compared to untreated controls and 11% higher on triclopyr treatments compared to tebuthiuron treatments. *In vitro* dry matter digestibility was 9% higher on herbicide-treated areas compared to untreated controls. Fiber constituents and moisture content were not influenced by brush treatments. Prescribed burning combined with herbicide applications did not improve the quality of browse. Our results indicate that browse quality can be improved for white-tailed deer by applications of tebuthiuron or triclopyr and improvements persist for up to 6 years post treatment.

**Stamm, K., E. J., L. Becker-Roger, and D. B. Kinkaid. 1996. Influence of nontarget neighbors and spray volume on retention and efficacy of triclopyr in purple loosestrife (*Lythrum salicaria*). Weed Sci. 44: 143-147.**

**Stritzke, J. F., D. M. Engle, and F. T. McCollum. 1991. Vegetation management in the Cross Timbers: Response of woody species to herbicides and burning. Weed Tech. 5: 400-405.** Brush control and woody plant community structure in the Cross Timbers of Oklahoma (USA) resulting from treatments with herbicides and fire were compared. Tebuthiuron and triclopyr were applied alone and in combination with burning at 2.2 kg/ha a.i. in March and June of 1983, respectively. The burned pastures were burned with strip headfires in late spring of 1985, 1986, and 1987. Both herbicides were effective on the dominant overstory brush species, blackjack oak and post oak, and this resulted in good reduction of canopy of brush initially. However, effects of triclopyr were short-lived because of ineffectiveness on many of the other hardwood species (American elm, gum bumelia, hackberry, roughleaf dogwood, and buckbrush). Crown reduction and tree kill of these hardwood species was usually better with tebuthiuron than with triclopyr. Neither herbicide was effective on eastern redcedar. Better brush control, associated with tebuthiuron, resulted in better fine fuel release and by 1988, burning was having a significant effect on woody plants in the tebuthiuron-treated plots.

The influence of habitat modifications on populations of *Obeliscoides cuniculi* in cottontail rabbits (*Sylvilagus floridanus*) was examined from 1987 to 1988 in the Cross Timbers ecosystem of Oklahoma. Five experimental brush control treatments, using combinations of the herbicides tebuthiuron and triclopyr with or without prescribed burning, were replicated 4 times on 20 32.4-ha pastures. Two hundred five rabbits (25 juvenile and 180 adult) were collected with an

overall prevalence of infection of 97%. Prevalence in adult hosts apparently was not influenced by brush treatment, season, or year. Distribution of population of *O. cuniculi* within cottontail was influenced significantly by season, with a higher degree of overdispersion in winter. The influence of brush treatment on the degree of overdispersion was not clear, but seasonal variation was low on untreated control pastures. Abundance of infections of *O. cuniculi* was significantly affected by brush treatment, season, and year of collection. Mean abundances were lower on annually burned pastures treated with triclopyr than on all other experimental pastures. Abundance of *O. cuniculi* in cottontail rabbits was higher in summer (58.8 ± 7.0) than winter (23.9 ± 4.4). Variations in the intensity of the prescirbed burns and in season were probably important factors that influenced parasitism of cottontail rabbits by *O. cuniculi.*

**Weetman, G. F., R. Fournier, J. Barker, and E. Schnorbus-Panozzo. 1989. Foliar analysis and response of fertilized chlorotic western hemlock and western red cedar reproduction on salal-dominated cedar-hemlock cutovers on Vancouver Island. Can. J. For. Res. 19: 1512-1520.** Microplot and conventional plot trials (in British Columbia) were used to determine the nutritional status and required nutrient additions to bring young regeneration of western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja plicata*) out of check. The trees were growing on deep mor-humus podzols invaded by dense salal (*Gaultheria shallon*) vegetation. Salal removal by grubbing and application of Garlon [triclopyr] was also tested. Foliar vector analysis, used for hemlock, identified a response to N and P that was confirmed by subsequent 3-year height growth response. Salal removal only resulted in increased N uptake in red cedar. Red cedar also responded to N and P additions, but vector analysis was not feasible owing to indeterminate growth. Foliar analysis values were compared with published data. It is suggested that salal competition or allelopathy may be the primary cause of inadequate N and P nutrition.

**Wood K. and C. Hollstedt (compiled by). 1995. Fallingsnow Ecosystem Workshop: program and abstracts. Workshop proceedings / Ontario. Ministry of Natural Resources. WP-001, Vegetation Management Alternatives Program, 1995. xv, 54 p.** The Fallingsnow Ecosystem Project, which is providing data on the ecological impacts of alternative vegetation management practices, is being conducted on a regenerated spruce plantation near Thunder Bay, Ontario. Four treatments have been applied at the study site in a randomized block design: manual brushing; mechanical site treatment; aerial application of glyphosate or triclopyr herbicides; and control (no treatment). Environmental variables examined include soil characteristics and biodiversity; below- and above-ground temperature and moisture; vegetation species composition and foliar nutrient content; below- and above-ground insects; terrestrial gastropods; amphibians and reptiles; small mammals; songbirds; moose and deer area use, and foods (production and quality). This

report contains presentations from a workshop held to transfer to resource managers the most recent scientific information produced from this project.

**Wright, G. M. and H. A. Holt. 1983. Understory vegetation control to establish oak regeneration. Proc. North Central Weed Control Conf., pp. 139.**
Northern red oak seedling establishment with mechanical thinning and total vegetation control with mist blown tank mixtures of 2 lb glyphosate + 1.5 lb triclopyr/acre was studied in an 80-year-old stand. Woody vegetation control with herbicides was 83% with and 95% without thinning. Seedling survival was 11% less with no thinning and 7% less with thinning alone than with herbicides + thinning and was 10% higher with herbicides alone than with no treatment. Seedling survival was reduced by browsing deer but 1$^{st}$ year growth was increased by browsing with no thinning.

## ENVIRONMENTAL FATE – PLANTS

**Bentson, K.P. and L.A. Norris. 1991. Foliar penetration and dissipation of triclopyr butoxyethyl ester herbicide on leaves and glass slides in the light and dark. J. Agric. Food Chem. 39: 622-630.** The disposition of triclopyr BEE (butoxyethyl ester of ((3,5,6-trichloro-2-pyridinyl)oxy)acetic acid) from spray mix droplets on excised Pacific madrone (*Arbutus menziesii* Pursh.) and giant chinkapin (*Castanopsis chrysophylla* (Dougl.) leaves and glass microscope slides was determined in a factorial laboratory experiment. Factors were temperature (10, 25, and 40□C), illumination (light or dark), and time (from 0 to 4100 min in 820-min increments). Triclopyr BEE penetration into chinkapin leaves is greater than into madrone leaves at all temperatures. Foliar penetration into madrone leaves did not increase between 25 and 40 degree C. Losses in the dark were greatest from glass slides and least from chinkapin. Triclopyr BEE loss from chinkapin leaves at 40□C in the light was equivalent to low in the dark at 40□C. Losses of triclopyr BEE from both glass slides and madrone leaves were greater in the light treatments. Models were developed by using mass balance coefficients. Results from outdoor exposures fell within 95% confidence intervals of model predictions of triclopyr BEE fate.

**Bovey, R. W., M. L. Ketchersid, and M.G. Merkle. 1979. Distribution of triclopyr and picloram in huisache (*Acacia farnesiana*). Weed Sci. 27: 527-531.** The triethylamine salt of triclopyr [(3,5-trichloro -2- pyridinyl) oxy] acetic acid and the potassium salt of picloram (4-amino- 3,5,6- trichloropicolinic acid) were applied as soil, foliar, and soil plus foliar treatments to greenhouse-grown huisache [*Acacia farmesiana* (L.) Wildl.] At 1.12 kg/ha, picloram was more effective (97 to 100% defoliation) than triclopyr (51 to 83%) in defoliating huisache. Triclopyr was more effective at 2.24 kg/ha than at 1.12 kg/ha in defoliating huisache, except when applied to the soil. Soil or soil-plus-foliar treatments of triclopyr at 2.24 kg/ha were not significantly different from those of picloram at 1.12 kg/ha 15 weeks after treatment. Triclopyr and picloram content was determined in and on leaves, stems, and roots at 0, 3, 10, and 30 days after treatment. More picloram than triclopyr was found in the leaves 30 days after treatment with foliar sprays at equal rates. Soil, foliar, and soil-plus-foliar treatments resulted in greater accumulation of picloram than triclopyr in stem tissue. Herbicide concentrations in roots were usually low. Reasons for the greater herbicidal activity of picloram than of triclopyr in huisache are not clear; however, the greater accumulation of picloram than of triclopyr in leaf and stem tissue may partially explain the difference in herbicide activity.

**Bovey, R.W., H. Hein Jr., and R.E. Meyer. 1984. Concentration of picloram, 3,6-dichloropicolinic acid, triclopyr and 2,4,5-T in honey mesquite stems. Proc. Southern Weed Sci. Soc. 37th Annual Meeting. pp. 143.** Honey mesquite (*Prosopis juliflora* var. *glandulosa*) was treated with 1.1 kg picloram and clopyralid/ha. Concentrations of 1 to 11 μ/g picloram and 3 to 20 μ/g clopyralid

were found in the upper phloem 3 days after treatment. More herbicide was detected in the upper phloem than in the xylem or lower phloem. Although triclopyr and 2,4,5-T killed *P. juliflora*, they were less effective than picloram and clopyralid at equal rates. Concentrations in stem tissue were usually 2 µ/g and tended to be greater from early than late season applications with all compounds. All the herbicides persisted in dead stems for at least 2 years.

**Bovey, R.W., H. Hein, Jr, and R.E. Meyer. 1986. Concentration of 2,4,5-T, triclopyr, picloram, clopyralid in honey mesquite (*Prosopis glandulosa*) stems. Weed Sci. 34: 211-217.** Triclopyr (((3,5,6-trichloro-2-pyridinyl)oxy) acetic acid),2,4,5-T ((2,4,5-trichlorophenoxy)acetic acid), picloram (4-amino-3, 5,6-trichloro-2-pyridinecarboxylic acid), and clopyralid (3,6- dichloro-2-pyridinecarboxylic acid) were applied to honey mesquite (*Prosopis glandulos* Torer. PRCJG) on seven different dates about every 3 weeks from May to September in 1980 and 1981. Concentrations of 2,4,5-T or triclopyr in stem tissue were usually less than 2 µg/g fresh weight regardless of date of application. Concentrations of picloram and clopyralid were as high as 11 and 22 µg/g fresh weight, respectively, in upper stem phloem at some dates of application. Higher concentrations of all herbicides were detected in upper stem phloem than in the upper stem xylem or basal stem phloem or xylem. More herbicide tended to be detected in stems when herbicides were applied early (May and June) than late (August and September) in the season. Concentrations of triclopyr and picloram recovered from honey mesquite stems were about 25% greater at 3 than at 30 days after treatment, whereas concentrations of 2,4,5-T and clopyralid were about 50% greater at3 than at 30 days after application.

**Branham, B.E. and D.W. Lickfeldt. 1997. Effect of pesticide-treated grass clippings used as a mulch on ornamental plants. HortScience. 32: 1216-1219.** Grass clippings were collected at 2, 7 and 14 days after pesticide treatment from a turf treated with chlorpyrifos, clopyralid, 2,4-D, flurprimidol, isoxaben or triclopyr. The clippings were used as a mulch around tomatoes, *Phaseolus vulgaris*, *Petunia hybrida* and Impatiens wallerana [*I. walleriana*]. P. vulgaris as sown 4 weeks prior to mulching, whereas the other plants were grown in the greenhouse for 6 weeks and transplanted into the field 2 weeks prior to mulching. Clippings containing residues of clopyralid, 2,4-D or triclopyr killed tomatoes, *P. vulgaris* and *P. hybrida* when used 2 days after pesticide treatment (DAPT) and severely injured these plants when mulched 7 and 14 DAPT. Flurprimidol injured tomatoes, *I. wallerana* and *P. vulgaris* when present on mulch collected 2, 7 and 14 DAPT, but was not lethal. Flurprimidol slowed plant growth, caused darker green leaf colour, and reduced flowering when present on mulch used 2 DAPT. Isoxaben injured tomatoes and *P. vulgaris* when present on mulch used 2, 7 and 14 DAPT but was not lethal. Injury was not as severe in the second year of the study, suggesting that environmental stresses and climatic conditions make predicting pesticide injury

for all growing seasons difficult. However, it is suggested that grass clippings from turf treated with herbicides or plant growth regulators should not be used for mulching around sensitive plants for at least 14 DAPT.

**Braverman, M.P. 1995. Absorption, translocation, and metabolism of triclopyr in rice *(Oryza sativa*). Weed Tech. 9: 490-493.** Absorption, translocation, and metabolism of $^{14}$C-triclopyr were compared in the rice cultivars 'Lemont' and 'Tebonnet' under flooded and non-flooded conditions. Radioactivity washed from $^{14}$C- triclopyr-treated leaves was 26% at 6 h and decreased to about 11% of that applied at 96 h after treatment. Triclopyr was immobile with 98% of the recovered $^{14}$C remaining in the treated rice leaf. An average of 19% of triclopyr was metabolized at 6 h and was similar among flooded and nonflooded rice cultivars. Absorption, translocation, and metabolism of triclopyr did not differ among rice cultivars or flooding treatments.

**Byers, R.E. 1990. 'Stayman' fruit cracking as affected by surfactants, plant growth regulators, and other chemicals. Pennsylvania Fruit News 70: 28-30.** In the apple cultivar Stayman, fruit cracking usually occurs only during relatively long rainy periods after the fruits have attained a diameter of 5 cm or more. Fruits borne on the outer periphery of the tree and exposed to the sun, russeted fruits, highly-colored fruits and the sides of fruits with high sugar contents appear to be most susceptible. Some results of a series of experiments are discussed, with the following conclusions: Submerging fruits in nonionic and anionic surfactant aqueous solutions rather than water alone or standard solutions of pesticide mixtures increased water uptake and fruit cracking; the incidence of fruit cracking was sometimes reduced by sprays of GA4+7, daminozide, NAA or the antitranspirant Vapor Guard (in various combinations); scoring the tree trunk reduced cracking, increased red fruit color but also slightly reduced fruit firmness; scoring 4 times in combination with a spray of GA4+7 + oil + NAA + 20-20-20 NPK fertilizer greatly reduced the severity of cracking; dicamba at 20 mg/litre applied in early July inhibited cracking particularly in July and Aug., whereas triclopyr applied in late Apr. appeared to increase cracking; soil-applied $NH_4NO_3$ as 2 trunk drenches in May increased cracking; the incidence of cracking and the uptake of water when fruits were submerged in nonionic surfactant aqueous solution varied with strains of Stayman and with the orchard sources; fruits harvested early rather than late tended to absorb more water in submersion tests; submersion in scald-preventing solutions of ethoxyquin, diphenylamine or X-77 resulted in greater fruit cracking and water uptake; fruit cracking after test submersion in water did not occur if apples that were submerged in diphenylamine, air-dried and held for 8 days in cold storage were placed directly in plastic bags rather than passed over a commercial grader before placing in the bags for further cold storage: the grader contact may have damaged the fruit cuticle sufficiently to increase susceptibility to cracking.

**Einset, J.W., J.L. Lyon, and P. Johnson. 1981. Chemical control of abscission and degreening in stored lemons. J. Amer. Soc. Hort. Sci. 106: 531-533.** Three auxins (picloram, triclopyr and 4-CPA) and 2 inhibitors of ethylene biosynthesis (aminoethoxyvinylglycine and aminoxyaceticacid) were shown to inhibit abscission of stem parts (buttons) from lemons stored in controlled ethylene (about 5 ppm) atmospheres. Freshly picked lemons were treated by dipping them in aqueous solutions containing 500 ppm of the surfactant Triton X-100 plus-or-minus additions of the above compounds and were stored in a packing house for 13 days. When the abscission inhibitors were tested in concentrations equal to or greater than commercial concentrations of 2,4-D (210 ppm) and its isopropyl ester (250 ppm), only picloram was found to be as effective in inhibiting button abscission. As little as 50 ppm picloram gave inhibition comparable to 250 ppm isopropyl ester of 2,4-D. All the auxin inhibitors of button abscission, including the free acid and isopropyl ester of 2,4-D, delayed the degreening of fruit in the packing house. Triclopyr had the strongest effect, picloram had a moderate effect, and the free base and isopropyl ester of2,4-D had mild delaying effects on degreening. Aminoethoxyvinylglycine (200 ppm) and aminoxyacetic acid (1840 ppm) did not inhibit degreening.

**El-Khodary, S., A. Habib, and A. Haliem. 1989. Cytological effect of the herbicide Garlon 4 on root mitosis of *Allium cepa*. Cytologia. 54: 465-472.** Root tips were treated with Garlon 4 (triclopyr) at 28 to 38 400 ppm for 3, 6, 12 and 24 h. Cytological examination showed that the herbicide caused a reduction in mitotic index and an increase in abnormal mitoses at concentrations greater than 28 ppm for over 12 h. The abnormalities induced included chromosome stickiness, metaphases and anaphases like those induced bycolchicine, tetraploidy, restitution nuclei, star metaphases, laggards, bridges, tripolar anaphases, and disturbed metaphases and anaphases. Micronucleate, binucleate and multinucleate cells were also observed at interphase. It is suggested that Garlon 4 has the same cytological effects as colchicine.

**Engle, D.M. and C.D. Bonham. 1980. Nonstructural carbohydrates in roots of gambel oak sprouts following herbicide treatment. J. Range Manage. 33: 390-394.** An area in Colorado dominated by clumps of *Quercus gambelii* was treated with a roller chopper in 1975. Nine herbicide treatments (different concentrations of potassium picloram, ethylene glycol butyltriclopyr and triethylamine triclopyr) were applied to the resulting shoots in July and August 1976 and July 1977. Root samples were collected in 1977 from areas with high and low shoot densities and at 5 stages of growth: quiescence (May), full leaf (June), rapid regrowth (July), end of regrowth (September), and leaf fall (October). Total nonstructural carbohydrate (TNC) concentration was determined in the laboratory and found to vary significantly with phenological stage. In plants not treated with herbicide TNC concentration was significantly higher in roots from areas of high shoot density in June and Sept. Some

herbicide treatments caused significant increases in root TNC compared with controls, and the pattern of storage was different with respect to phenological stage. It is recommended that hormonal herbicides are applied before full leaf stage, so that maximum translocation to the roots occurs before the upward translocation of carbohydrates corresponding with leaf regrowth.

**Getsinger, K.D., D.G. Petty, J.D. Madsen, J.G. Skogerboe, B.A. Houtman, W.T. Haller, and A.M. Fox. 2000. Aquatic dissipation of the herbicide triclopyr in Lake Minnetonka, Minnesota. Pest Management Science. 56: 388-400.** A study of the aquatic fate of the triethylamine salt of triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid) was conducted in three bays of Lake Minnetonka, Minnesota. Triclopyr is under review by the US Environmental Protection Agency as a selective aquatic herbicide. The primary purpose of this study was to determine dissipation rates of the parent active ingredient, triclopyr, and its major metabolites, 3,5,6-trichloropyridinol (TCP) and 3,5,6-trichloro-2-methoxypyridine (TMP) in selected matrices including water, sediment, plants, finfish and shellfish. Two 6.5-ha plots dominated by the weedy species Eurasian watermilfoil (*Myriophyllum spicatum* L) were treated with triclopyr-triethylammonum at a rate of 2.5 mg AE liter-1 (2.5 ppm) on 21-23 June 1994. A third 6.5-ha plot was established as an untreated reference. Water and sediment samples were collected from within the plots and at selected locations up to 1600 m outside of the plots through six weeks post-treatment for chemical residue analysis. In addition, residue samples were collected from the target and non-target plants and other non-target matrices, including game and rough fish, clams and crayfish. All test animals were sequestered in cages located in the center of each plot and samples were collected through four weeks post-treatment. Half-lives for dissipation of triclopyr and TCP in water ranged from 3.7 to 4.7 days and from 4.2 to 7.9 days, respectively, with trace amounts of TMP found. Peak triclopyr sediment values ranged from 257 to 335 ng gram-1, with a mean half-life of 5.4 days, while peak TCP sediment levels ranged from 27 to 65 ng gram-1 (mean half-life=11.0 days). Trace levels of TMP were detected at one treatment site at one sampling event. Triclopyr and TCP accumulated and cleared from animal tissues proportionately to concentrations in the water (triclopyr dissipation half-lives <11 days, TCP <14 days). TMP levels were two to three times higher than those of the other compounds, particularly in visceral tissue. In all cases, residues of these compounds were higher in the inedible portions of the animals, and were usually higher in bottom-feeding fish species.

**Gorrell, R.M, S.W. Bingham; and C.L. Foy. 1988. Translocation and fate of dicamba, picloram, and triclopyr in horse nettle, *Solanum carolinense*. Weed Sci. 36: 447-452.** Greenhouse studies were conducted to determine the extent of translocation from the foliage to fleshy roots, the inherent toxicity, and the fate of radiolabeled and non-labeled dicamba, picloram, and triclopyr in horsenettle. Roots of horsenettle acted as the major sink for photosynthate

accumulation at the 0.2- to 0.5-bloom growth stages as determined by autoradiography. Dicamba, picloram, and triclopyr were translocated into the roots of horsenettle and accumulation continued for at least 16 days. $^{14}C$ associated with each herbicide found in the roots ranged from 1.3% at 4 days to 3.8% at 16 days. After 16 days, slightly more $^{14}C$ from plants treated with dicamba and triclopyr (3.8 and 3.6%) than picloram (3.0%) was translocated to roots. These compounds were metabolized slowly in the foliage and roots as determine by thin-layer chromatography (TLC) and autoradiography. In translocation studies with horsenettle shoots, picloram at 1.12 kg/ ha killed the treated and untreated shoots and roots. Dicamba and triclopyr at the highest rates killed the treated shoots and partially destroyed the root system. Symptoms were noted on the untreated shoots, but full recovery occurred at 8 weeks. Since each of the herbicides was metabolized slowly and only slight differences in their translocation were observed, the relatively higher herbicidal effectiveness of picloram must be attributed to its greater inherent potency.

**Gorrell, R.M., S.W. Bingham, and C.L. Foy. 1979. Movement and fate of dicamba, picloram and triclopyr in horse-nettle (*Solanum carolinense* L.). Annual Meeting Weed Sci. Soc. Amer. pp. 56-57.** The fate of $^{14}C$-labelled dicamba, picloram and triclopyr in *Solanum carolinense* was determined in glasshouse studies. The 3 compounds were present in the root system in small amounts after 4 days and continued to accumulate over a 16-day test period as determined by autoradiography and liquid scintillation techniques. The order of mobility was dicamba>picloram>triclopyr. TLC and autoradiography showed that the compounds existed predominantly as the parent molecule. In one study, translocated phytotoxic concentrations of unlabelled dicamba, picloram and triclopyr were measured by observing growth responses on treated and untreated paired plants arising from the same root. Only one plant of each pair was treated with the herbicides. Symptoms of leaf and stem curvature were evident after 1 week on all treated and untreated plants. Picloram appeared to be the more potent herbicide.

**Karr, B.L., W.S. Arrington, G.A. Day, D. McNeil, and G.C. Janzen. 1986. Herbicide effects on water relations during establishment of *Pinus taeda* L. Proc. Southern Weed Sci. Soc. 39th Annual Meeting. pp. 403.** A 1st year *Pinus taeda* plantation received a 0.5 lb/acre hexazinone or a 2% glyphosate solution to areas of 28 inch$^2$, in a 56-inch wide band or overall, while 2% triclopyr was applied as a basal spray on woody vegetation. Pine height and ground line diameter increased with increasing area of control. Soil water potentials, xylem pressure and stomatal resistance measured monthly in July-October, showed no evidence of water stress, perhaps because rainfall was above average.

**King, M.G. and S.R. Radosevich. 1979. Leaf surface characteristics and absorption of triclopyr by tanoak (*Lithocarpus densiflorus* (Hook. & Arn.)**

**Rehd.). Annual Meeting Weed Sci. Soc. Amer., pp. 90.** Tanoak (*Lithocarpus densiflorus*) is the most abundant hardwood tree species in the California Coast Range and often successfully competes with Douglas-fir (*Pseudotsuga menziesii*) and redwood (*Sequoia* sp.). *L. densiflorus* is generally tolerant of foliar applications of herbicides. Poor absorption could explain the tolerance. Foliage absorption of $^{14}$C-triclopyr by *L. densiflorus* was investigated using isolated leaf disks and intact leaves on whole plants. In comparison to mature leaves, immature leaves showed several characteristics which were likely to enhance absorption. These included greater stomatal density, less epicuticular wax, thinner and more permeable cuticular membrane and greater stellate trichome densities.

**Kraus,T.E., D.P. Murr, G. Hofstra, and R.A. Fletcher. 1992. Modulation of ethylene synthesis in acotyledonous soybean and wheat seedlings. J. Plant Growth Regulation 11: 47-53.** The characteristics of ethylene production and ACC conversion in 8-day-old soybean (*Glycine max*) seedlings were examined and a relationship between cytochrome P-450 activity and ethylene-forming enzyme (EFE) activity was found. An atmosphere containing 10% carbon monoxide (CO) significantly inhibited ethylene production and ACC (1-aminocyclopropane-1-carboxylic acid) conversion in control soybean seedlings, but had only a slight effect on soybean seedlings treated with uniconazole. Foliar application of triclopyr, a pyridine analogue of the phenoxy herbicides, significantly increased ethylene production and ACC conversion in control, but not in uniconazole-treated seedlings. Triclopyr treatment also resulted in a three-fold increase in extractable cytochrome P-450 of 5-day-old etiolated soybeans. At equimolar concentrations tetcyclacis was more effective than uniconazole in reducing shoot elongation and endogenous ethylene production. Although uniconazole and tetcyclacis did not inhibit ACC conversion in nonherbicide-treated soybean seedlings, they did prevent the observed increase in ACC-dependent EFE activity following triclopyr application. However, the rate of ACC conversion in etiolated soybean segments was sensitive to uniconazole, and tetcyclacis inhibited the rate of ACC conversion by 2.6-fold in etiolated soybean segments within 4 h after treatment. Microsomal membranes were isolated from 5-day-old naphthalic anhydride-treated etiolated wheat (*Triticum aestivum*) shoots as this tissue contains much higher cytochrome P-450 levels than soybean shoots. Optical difference spectroscopy demonstrated that ACC generated binding spectrum characteristic of a reverse-type-I cytochrome P-450 substrate when combined with reduced microsomes. In vitro conversion of ACC to ethylene by microsomal membranes was NADPH-dependent, inhibited by CO, and had an apparent $K_m$ and $V_{max}$ of 45 μM and 0.345 nl/mg protein/h, respectively. These results suggest that cytochrome P-450-mediated monooxygenase reactions may be intimately involved in the conversion of ACC to ethylene in young soybean and wheat seedlings.

**Kreutzweiser, D.P., D.G. Thompson, B.Staznik, and J.A.Shepherd. 1998. Accumulation dynamics of triclopyr ester in aquatic leaf packs and effects on detritivorous insects. J. Environ. Qual. 27: 1138-1147.** Previous field studies have demonstrated that residues of the herbicide triclopyr butoxyethyl ester (3,5,6 trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester) (TBEE), can accumulate in submerged leaf material of aquatic systems at concentrations up to 20 times the maximum aqueous concentrations. Accumulated TBEE residues may pose a risk of adverse effects to detritivorous invertebrates inhabiting and using natural leaf packs. We examined the dynamics of TBEE accumulation and persistence in leaf materials of laboratory and outdoor aquatic systems, and determined the ecological significance of this in terms of effects on detritivorous insects and organic matter processing. Accumulations of TBEE in leaf packs of semi-static laboratory microcosms were up to 80 times aqueous concentrations, and residues persisted for 4 to 5 d. Leaf material of flow-through laboratory microcosms accumulated TBEE at much higher rates (up to 1000 times aqueous concentrations), but residues were cleared by 48 to 72 h. Accumulation and persistence in flow-through units were dependent on water depth, velocity, and exposure duration. Accumulated TBEE residues were less in outdoor stream channels than in laboratory flow-through units, probably because of losses through sorption to natural benthic material in the stream channels. Despite accumulations of TBEE in leaf packs at up to 90 mg kg-1 in systems treated at or near expected environmental concentrations, there was no significant mortality of detritivorous insects and no significant reductions in leaf consumption. Significant mortality and reduced feeding occurred only in systems treated at concentrations well above (up to 10 times) expected environmental concentrations.

**Lautenschlager, R.A., F.W. Bell, R.G. Wagner, and P.E. Reynolds. 1998. The Fallingsnow Ecosystem Project: documenting the consequences of conifer release alternatives. Journal of Forestry. 96: 20-27.** An overview is presented of the Fallingsnow Ecosystem Project, established in 1993 SW of Thunder Bay, Ontario, Canada, including the design, environmental components, and the initial results obtained. The Project was designed to document the terrestrial ecological consequences of alternative conifer release treatments. The ecosystem components studied are: soil chemistry, physics and morphology; below- and above-ground microclimates; below-ground fungi; vegetation, species composition, abundance, diversity, and foliar nutrient content; insects; terrestrial gastropods; amphibians and reptiles; small mammals; songbirds; and moose [Alces alces] area use and foods (production and storage). Although long-term responses are unknown, results to date indicate that cutting (with brush saws or tractor-mounted cutting heads) and herbicide (glyphosate or triclopyr) treatments are relatively inconsequential for most environmental components found in regenerating northern forests. It is suggested that given the growing opposition to herbicide use in forestry,

managers must expect that social input into natural resource management will become more common, if not required.

**Leveille, P., J. Legris, G. Couture, and R. Langevine. 1995. Evaluation of the effects of triclopyr used in forestry. Pub. No. RN95-3084; Ministere des Ressources Naturelles; Quebec; Canada. 18 p.** An account is given of the chemical composition, biological action, toxicology, degradation and decomposition in air, soil, water, flora and fauna (including human), and effects on vegetation, fauna and humans, of the herbicide triclopyr.

**Lewer, P. and W.J. Owen. 1989. Amino acid conjugation of triclopyr by soybean cell suspension cultures. Pesticide Biochemistry and Physiology 33: 249-56.**

**Meyer, R.E., H.E. Smalley, J.F. Cooper, and F.M. Farr. 1982. Herbicide influence on foliar amino acid content in five representative southwestern range plant species. Agric. Res. Results, ARS, USDA. ARR-S-13, 71pp.** The effects of application of 80% a.i. atrazine or tebuthiuron as wettable powders, 80% a.i. bromacil in emulsion, 74% a.e. Mg-Na salt of dalapon, dimethyl-amine salt of dicamba, propylene glycolbutyl-ether esters of 2,4-D and 2,4,5-T, isopropylamine salt of glyphosate, 90% a.i. crystalline hexazinone, monoethanolamine salt of 3,6-DPA, K salt of picloram and ethylene glycol butyl ethyl esters of triclopyr all at 1.12 kg/ha except atrazine (2.2 kg/ha)and dalapon (5.6 kg/ha) on amino acid contents of rangeland weeds were studied. Amino acid contents of untreated plants were 16.88,9.87, 4.64, 7.72 and 7.5 g/100g tissue for *Prosopis juliflora* var.*glandulosa*, *Rosa bracteata, Ambrosia psilostachya, Ilex vomitoria* and *Dichanthelium sphaerocarpon*, respectively. Amino acid content was affected by plant age and by herbicide application. Different amino acids had different responses to herbicides. Phytotoxic herbicides decreased amino acid contents. Amino acid concentrations were not affected by herbicides in species resistant to the herbicide.

**Michael, J. L., K. L. Talley, and H. C. Fishburn. 1992. Forest herbicide washoff from foliar applications. Proc. 45th Annual Meeting Southern Weed Science Society, pp. 236-243.** Hexazinone, triclopyr and imazapyr at 2.24 kg/ha were applied in late summer/early autumn to excised and intact foliage by applying 5-6 drops of herbicide solution (10 µl total) to each leaf and allowing to dry. Treated excised leaves of dogwood (*Cornus florida*), sweetgum (*Liquidambar styraciflua*), black cherry (*Prunus serotina*) and water oak (*Quercus nigra*) were allowed to dry for 1-48 h before being thoroughly washed with 3 X 50 ml water to estimated maximum washoff. Treated excised sweetgum, honeysuckle (*Lonicera* spp.), blackberry (*Rubus cuneifolius*) and dogwood leaves were washed with 3-15 mm simulated rain 1 h after application. In the field, treated intact dogwood and sweetgum leaves were exposed to rain 3 h-5 d after treatment, and sweetgum leaves alone were exposed to rain within 24 h of treatment; a washoff trap collected rainwater

from each treated leaf. All herbicides were assayed by HPLC. Laboratory and field determinations of percentage washoff corresponded closely; it was found that 10 drops of rain falling on a single leaf could wash off 30% of herbicide, and 3 mm of precipitation could wash off 100% of applied herbicide. Time, species and herbicide differences were found: hexazinone and imazapyr were more easily washed off than triclopyr, and herbicide washoff decreased with time after application. Species differences varied with herbicide.

**Ralphs, M.H. and M.C. Williams. 1986. Total alkaloid, crude protein, and fiber concentrations in velvet lupine (*Lupinus leucophyllus*) following herbicide application. Weed Sci. 34: 948-952.** Total alkaloid concentration, percentage water, crude protein, and neutral detergent fiber in velvet lupine (*Lupinus leucophyllus* Dougl.) were monitored for 3 weeks following application of herbicides registered or soon to be registered for rangeland use. Picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid), dicamba (3,6-di-chloro-2-methoxybenzoic acid), and clopyralid (3,6- dichloro-2-pyridinecarboxylic acid) caused some signs of epinasty but did not kill velvet lupine. Total alkaloid concentration and nutrient quality of velvet lupine leaves treated with these herbicides was not significantly different from untreated plants. Esters of 2,4-D ((2,4-dichlorophenoxy)acetic acid) and 2,4,5-T ((2, 4,5-trichlorophenoxy)acetic acid) and triclopyr (((3,5,6-trichloro-2-pyridinyl)oxy)acetic acid) killed most velvet lupine plants and caused a subsequent decrease in total alkaloid concentration, crude protein, and water content as the plants desiccated. Herbicides that effectively killed velvet lupine decreased alkaloid levels, thus lowering the potential for increased livestock poisoning.

**Sassaman, J.F., R. Pienta, M. Jacobs, M. and J. Cioffi, 1984. Pesticide background statements. Vol. 1. Herbicides. 909 pp.** The individual Herbicide Background Statements have been compiled to provide a comprehensive review of the available information concerning the use, chemistry, toxicology, environmental fate, and comparative hazard of the herbicides in forest applications. References to the published literature at the end of each background statement are provided for those individuals who wish to independently evaluate the toxicological data and environmental fate information that is presented in summary form. In many instances, secondary sources, such as review articles, handbooks, and company technical data sheets, were used. Wherever possible in these instances, the primary source was also indicated and referenced, although it may not have been examined. Herbicides included in the document are: amitrole, atrazine, 2,4-D, 2,4-DP, dalapon, dicamba, fosamine ammonium, glyphosate, hexazinone, picloram, simazine, and triclopyr.

**Sexsmith, W.A. 1988. Environmental monitoring of forestry control operations. New Brunswick Dept. of the Environment, Fredericton. 1988 Annual Publication.**

**Siltanen, H., C. Rosenberg, M. Raatikainen, and T. Raatikainen. 1981. Triclopyr, glyphosate and phenoxy herbicide residues in cowberries, bilberries and lichen. Bull. Environ. Contam. and Toxicol. 27: 731-737.** Investigations were carried out in Finland into herbicide residues in wild berries in forests which had been subjected to foliar spraying for brush control. Residues of triclopyr were analyzed in cowberries and bilberries after treatment with 0.25, 0.75 and 2.25 kg/ha of the herbicide. Effect of date of treatment on glyphosate (applied at the rate of 0.75 kg/ha) and triclopyr residues was investigated. Results are tabulated. These showed that the residues in the berries were of the same order of magnitude when the same amount of any of the herbicides was used. In aerial spraying the application rate was lowest for glyphosate and highest for phenoxy herbicides. As a result residues in the berries from aerially sprayed forests can be expected to the highest after phenoxy herbicide application and lowest after glyphosate application.

**Sofradzija, A., R. Hadziselimovic, and D. Zovko. 1988. Mutagenic and genotoxic effects of some herbicides in meristem tissue of *Allium cepa*. Genetika 20:183-189.** Tordon 101 [2,4-D + picloram] and Arbogal [triclopyr] at 0.05 and0.1% were used to treat onion root tips for 4 and 8 h. Both herbicides under all conditions reduced the mitotic coefficient significantly. Tordon 101 inhibited mitosis at prometaphase and prevented normal separation of chromosomes, especially at anaphase, resulting in bridges. The Arbogal treatments produced polyploid cells with numerous chromosome fragments. Metaphases were rare and abnormal, and anaphase and telophase were not observed at all. The genotoxic and mutagenic effects of both herbicides increased with concentration and exposure time.

**Thompson, D.G., D.G. Pitt, T. Buscarini, B. Staznik, and D.R. Thomas. 1994. Initial deposits and persistence of forest herbicide residues in sugar maple (*Acer saccharum*) foliage. Can. J. For. Res. 24: 2251-2262.** Initial deposition and subsequent fate of herbicide residues in sugar maple (*Acer saccharum* Marsh.) foliage were quantified following applications of three different formulations of glyphosate (VISION, TOUCHDOWN, MON 14420) and one formulation of triclopyr ester (RELEASE) in a comparative field study. Maximum initial residues were 529, 773, 777, and 1630 mg of acid equivalent per kilogram dry mass, respectively. Initial foliar residues were dependent upon application rate ($r^2$ = 0.63 to 0.87) and increased by a similar factor (233 to 313 mg/kg) for each kilogram per hectare applied, irrespective of formulation type. Foliar residues dissipated following a negative exponential pattern with time, rates of which varied with initial concentration. Mean times to 50% dissipation were 2 days for all glyphosate formulations, 1.5 days for triclopyr ester, and 4 days for triclopyr acid. Mean times to 90% dissipation were < 16 days for glyphosate formulations, 9 days for triclopyr ester, and 33 days for triclopyr acid. Multivariate analyses of intercept and rate parameter estimates indicated significant (p = 0.02) differences in dissipation patterns among treatments.

Orthogonal contrasts confirmed *a priori* hypotheses that glyphosate residue dissipation was independent of the salt formulation applied, and that triclopyr ester dissipated faster than either glyphosate ($p = 0.004$) or triclopyr acid residues ($p = 0.07$). Results are considered in terms of the exposure and resultant potential toxicity to forest songbirds inhabiting or foraging in treated hardwood canopies.

**Vandervoort, C., M.J. Zabik, B. Branham, and D.W. Lickfeldt. 1997. Fate of selected pesticides applied to turfgrass: Effect of composting on residues. Bull. Environ. Contam. and Tox. 58: 38-45.** Studies were conducted to determine the persistence of chlorpyrifos, triclopyr, 2,4-D, clopyralid, isoxaben and flurprimidol applied to turfgrass foliage that was subsequently used for compost. Patterns of chemical loss in compost piles were similar for all pesticides and tended to show a biphasic degradation pattern (an initial rapid dissipation followed by a slower process). It was concluded that these initially high pesticide concentration could cause damage to plants if composts were applied immediately after composting, but within several months they would provide an excellent soil amendment.

**Whisenant, S.G. and E.D. McArthur. 1989. Triclopyr persistence in Northern Idaho forest vegetation. Bull. Environ. Contam. and Toxicol. 42: 660-665.** The persistence of triclopyr residues (measured for 12 months after application of 2.3 kg triclopyr/ha) in terminal twig and leaf segments at 2 north Idaho sites, and large herbivore toxicological data from other studies indicate that poisoning following proper use of the herbicide is unlikely.

**Williams, M.C. and M.H. Ralphs. Effect of herbicides on miserotoxin concentration in Wasatch milkvetch (*Astragalus miser* var. *oblongifolius*). Weed Sci. 35: 746-748.** The effect of herbicides on the concentration of miserotoxin, the toxic compound in Wisatch milkvetch (*Astragalus miser* var. *oblongifolius* (Rydb.) Cronq.) was investigated. Eight herbicides or herbicide combinations (using 2,4-D, butoxyethylester of triclopyr, clopyralid, picloram, dicamba) were applied to Wasatch milkvetch in June 1985 and 1986. The concentration of miserotoxin was determined weekly for 4 weeks after treatments. All treatments in both years significantly reduced the miserotoxin concentration when compared to the controls, except for the 0.6 kg ae/ha rate of clopyralid (3,6-dichloro-2-pyridine-carboxylic acid) in 1986. Wasatch milkvetch treated with triclopyr (((3,5,6- trichloro-2-pyridinyl)oxy)acetic acid) at 1.7 and 2.2 kg a.e./ha desiccated rapidly and had consistently low concentrations of miserotoxin 4 weeks after treatment.

**Wood K. and C. Hollstedt (compiled by). 1995. Fallingsnow Ecosystem Workshop: program and abstracts. Workshop proceedings / Ontario. Ministry of Natural Resources. WP-001, Vegetation Management Alternatives Program, 1995. xv, 54 p.** The Fallingsnow Ecosystem Project,

which is providing data on the ecological impacts of alternative vegetation management practices, is being conducted on a regenerated spruce plantation near Thunder Bay, Ontario. Four treatments have been applied at the study site in a randomized block design: manual brushing; mechanical site treatment; aerial application of glyphosate or triclopyr herbicides; and control (no treatment). Environmental variables examined include soil characteristics and biodiversity; below- and above-ground temperature and moisture; vegetation species composition and foliar nutrient content; below- and above-ground insects; terrestrial gastropods; amphibians and reptiles; small mammals; songbirds; moose and deer area use, and foods (production and quality). This report contains presentations from a workshop held to transfer to resource managers the most recent scientific information produced from this project.

## ENVIRONMENTAL FATE SOILS

**Blanton, S. and M. Mihajovich. 1999. Basal bark application of Release (TM) herbicide for mixedwood management : 1999 final report. Edmonton: Alberta Environmental Protection, 11 p.** This report describes results of a mixedwood (aspen & white spruce) stand tending research project carried out on two regenerated cutover areas in Alberta. The project assessed the effectiveness & safety of low-volume basal bark application of triclopyr butoxyethyl ester herbicide for managing all tree species; compared the effectiveness & cost of motor manual tending to basal bark herbicide application for spacing & tending the post-juvenile mixedwood sites; compared the effect of motor manual tending & herbicide treatment on short-term slash loading & bird use of treated, untreated, and adjacent areas; and quantitatively measured the soil dissipation of the herbicide following treatment.

**Branham, B. E. and A. J. Turgeon. Herbicide fate in turf. 1994. In, Turf Weeds and Their Control. American Society of Agronomy, Madison, Wisconsin, pp. 109-151.** The effects of soil sorption, leaching, volatilization, photolysis and persistence on the fate of the following herbicides currently used in turfgrass in the USA are discussed: benefin [benfluralin], trifluralin, pendimethalin, DCPA [chlorthal-dimethyl], bensulide, oxadiazon, siduron, linuron, ethofumesate, pronamide [propyzamide], dicamba, 2,4-D, triclopyr, clopyralid, isoxaben, fenoxaprop-ethyl and triazines.

**Bush, P. B., Y. C. Berisford, J. W. Taylor, D. G. Neary, K. V. Miller, and J. E. Street. 1995. Operational monitoring of forest site preparation herbicides in the coastal plain: Assessment of residues in perched water table. Proc. 48th Annual Meeting Southern Weed Sci. Soc. pp. 115-120.** Field trials were conducted during the spring of 1992 in Aiken, South Carolina on a fine loam in loblolly pine [*Pinus taeda*] clearcut areas to assess the potential movement of Arsenal (imazapyr) at 1 lb/acre, Velpar (hexazinone) at 3 lb and Tordon + Garlon (picloram + triclopyr, respectively) at 2 + 4 lb to shallow groundwater. Monitoring wells were installed at depths of 4 and 8 feet where clay lenses were observed. Results showed significant lateral down-slope movement of picloram and hexazinone under saturated conditions when the slopes exceeded 2%. Triclopyr and imazapyr showed limited potential for lateral movement or movement to the 8 foot perched water table. Levels of hexazinone peaked at 2 months after application and decreased to non-detectable levels at 2 years post-application. The residue magnitude and rate of dissipation were affected by plot slope and position within the plot. Triclopyr and imazapyr were not as mobile or persistent in shallow wells as picloram and hexazinone.

**De'ath, M. R. 1988. Triclopyr - a review of its forestry and industrial weed control uses. Aspects Applied Biology. 16: 183-188.** The toxicology, soil behaviour,

mode of action and use of triclopyr for forest and industrial weed control is reviewed briefly.

**Deubert, K. H. 1985. Environmental impact of spot treatment on utility rights-of-way. Proc. 39th Annual Meeting Northeastern Weed Sci. Soc. pp. 218.** Problems in studying the environmental impact of spot-applied herbicides are discussed. Field trials were conducted applying herbicides to ground cover and shrubs assuming 100% and 10% runoff during application based on 18.67 l concentrate/ha. Average retention by the plants was 50%, while >80% of picloram, 2,4-D and triclopyr remained in the top 10 inch soil layer. Contamination of ground water with herbicide residues was unlikely under these conditions.

**Deubert, K. H. and I. Corte-Real. 1986. Soil residues of picloram and triclopyr after selective foliar application on utility rights-of-way. J. Arboriculture 12: 269-72.**

**Devlin, R. M., K. H. Deubert, S. J. Karczmarczyk, and I. I. Zbiec. 1984. Vetch as an indicator of triclopyr residue in the soil. Proc. Annual Meeting Northeastern Weed Sci. Soc. 38: 94-98.**

**Ferrero, A. and P. Maini. 1993. Problems about the environmental fate and the residues of herbicides used in rice fields. Informatore Agrario. 49: 83-97.** Problems created by herbicide use on continuously waterlogged soil, as in irrigated rice, are reviewed. American findings and EC directives on water contamination thresholds are discussed and the results of monitoring trials in various countries with propanil, oxadiazon, bensulfuron methyl, molinate, dimepiperate, thiobencarb, tiocarbazil, pretilachlor, triclopyr, pyrazoxyfen and bentazone are reviewed. Residues in consumer rice are not a problem.

**Hamaker, J. W. and C. A. I. Goring. 1975. Turnover of pesticide residues in soil. <u>In</u>, Bound and Conjugated Pesticide Residues, D.D. Kaufman, G.G. Still, G.D. Paulson, S.K. Bandal (eds.). pp. 219-243.** A model is proposed for the decomposition and movement of pesticides in soil. For this model, the soil residue is partitioned into two reservoirs: a mobile and labile fraction and a fraction that is immobile and resists degradation. The degradation of chemical depends, therefore, upon the fraction of the chemical in the labile condition. The model was made quantitative by assigning first-order rate constants, k, k1 and k-1, respectively, to the rates of degradation, of entry into the bound condition and of leaving the bound condition. The resulting system of differential equations was solved and degradation curves calculated for a range of values for the three rate constants. The shapes of these calculated curves corresponded well with the experimental curves very often observed. Degradation curves for triclopyr were fitted to the model by least squares with satisfactory precision. The accumulation of soil residues from repeated annual additions was investigated mathematically for 90% degradation in a year and

different relative sizes of the mobile and immobile reservoirs. It was concluded that the accumulation would not be excessive (<2X first-year residue) and that any accumulation would be compensated for by a large degradation rate which would quickly degrade any material released from the unavailable state.

**Johnson, W. G. and T. L. Lavy. 1994. *In-situ* dissipation of benomyl, carbofuran, thiobencarb, and triclopyr at three soil depths. J. Environ. Quality 23: 556-562.** Data are lacking concerning the persistence of pesticides used in Arkansas rice production. Studies were conducted to examine the dissipation characteristics in field studies of four commonly used pesticides. Crowley silt loam soil (fine, montmorillonitic thermic Typic Albaqualfs) from 2, 20, or 60 cm was treated with benomyl (methyl-1-(butylcarbamoyl)-2-benzimidazole-2-yl carbamate), carbofuran (2,3-dihydro-2,2-dimethylbenzofuran-7-yl methylcarbamate), thiobencarb (S-[(4-chlorophenyl)methyl]diethylcarbamothioate), or triclopyr ([(3,5, 6-trichloro-2-pyridinyl)oxy]acetic acid), and buried in leaching or degradation containers for 0, 34, 104, 184, 280, 371, 736, or 1066 d at Stuttgart, AR. Degradation of carbofuran, thiobencarb, and triclopyr was more rapid than the benomyl metabolite MBC (methyl-2-benzimidazole carbamate) with the time for 50% of the initial dose to dissipate (DT50) being 94 d or less. The carbofuran metabolite 3-keto carbofuran (2,3-dihydro-2,2-dimethyl-3-keto-benzofuranyl-N-methyl carbamate) was not detected during this time period. Trace levels of 3-hydroxy carbofuran (2,3-dihydro-2,2-dimethyl-3-hydroxy-benzofuranyl-N-methyl carbamate) were detected periodically. The benomyl metabolite MBC was the most persistent pesticide in this study with DT50 values of 179 to 1020 d. The rates of dissipation decreased with increasing soil depth for all pesticides.

**Johnson, W. G., T. L. Lavy, and E. E. Gbur. 1995. Persistence of triclopyr and 2,4-D in flooded and nonflooded soils. J. Environ. Qual. 24: 493-497.** Field studies were conducted on silt loam and silty clay soils to determine the persistence of triclopyr (((3,5,6-trichloro-2-pyridinyl) oxy) acetic acid) and 2,4-D (2,4-chlorophenoxy acetic acid) in the soil and water associated with rice (*Oryza sativa* L.) production in Arkansas. Liquid formulations of these herbicides were applied postemergence to (i) paddy rice, (ii) rainfed lowland rice, and (iii) bare ground. Samples of soil and water were taken at various intervals until 49 days after application (DAA) and analyzed by gas chromatography. Dissipation of both herbicides was rapid with initial dissipation of 50% of the initial concentration, DT-50s, in paddy water, dryland-rice soil, and bareground soil being 10 d or less. Neither herbicide was detected in water later than 28 DAA. Both herbicides were slightly more persistent in soil than in water. 2,4-D was slightly more mobile in the soil of all three cultural systems.

**Johnson, W. G., T. L. Lavy, and E. E. Gbur. 1995. Sorption, mobility and degradation of triclopyr and 2,4-D on four soils. Weed Sci. 43: 678-684**. Laboratory studies were conducted to determine the relative sorption, mobility, and degradation rates of triclopyr and 2,4-D on two surface soils and two subsoils from the rice-producing areas of Arkansas. Triclopyr sorption was slightly greater than 2,4-D sorption. However, mobility of the herbicides on a given soil did not differ. Sorption of both herbicides was greatest and mobility lowest on a subsoil with the lowest pH. Triclopyr degradation rates were lower than 2,4-D degradation rates in a dark incubator. The average half life was 138 d for triclopyr and 21 d for 2,4-D. High soil moisture content (0 versus 100 kPa water tension) increased the rate of 2,4-D degradation. Triclopyr degraded more rapidly at 30°C than at 15°C. The dissipation rates of both herbicides were lowest on the soil on which sorption was greatest.

**Johnson, W. G., T. L. Lavy, J. D. Mattice, and B. W. Skulman. 1993. Dissipation of Furadan, Bolero and Grandstand at three soil depths. Arkansas Farm Research. 42: 6-7.** The extent of leaching and degradation of Furadan (carbofuran), Bolero (thiobencarb) and Grandstand (triclopyr) was assessed at three soil depths in a typical rice soil of Arkansas. Results suggest that the combination of rapid breakdown of rice pesticides and the slow permeability of rice-producing soils in Arkansas provide built-in protection against groundwater contamination.

**Jotcham, J. R., D.W. Smith, and G. R. Stephenson. 1989. Comparative persistence and mobility of pyridine and phenoxy herbicides in soil. Weed Tech. 3: 155-161.** Bioassays with soybean (*Glycine max*) and lentils (*Lens culinaris*) were used to compare the persistence of 2,4,5-T, triclopyr, and picloram in soil after applying 0.038, 0.38, and 3.8 kg a.e./ha under field conditions. Soil samples were collected from 1 to 269 days after spraying and were kept frozen until growth room bioassays were conducted. Triclopyr was slightly less persistent than 2,4,5-T, but neither herbicide was biologically active during the next season. At least 90% of picloram disappeared within 7 months, but its biological activity was more persistent than that of either triclopyr or 2,4,5-T. Nine months after treatment, neither lentils nor soybeans could be grown in soil treated with picloram at 3.8 kg/ka. Triclopyr and 2,4-D had similar soil thin layer chromatographic mobilities in four different soils. Picloram was significantly more mobile than either triclopyr or 2,4,5-T, primarily due to its lower adsorption in the soils examined.

**Kells, A. M. and K. R. Solomon. 1995. Dislodgeability of pesticides from products made with recycled pesticide container plastics. Arch. Environ. Contam. and Toxicol. 28: 134-138.** Products containing high density polyethylene plastic from recycled pesticide containers were tested for levels of dislodgeable pesticide under dry and damp conditions. Trifluralin was the pesticide released in largest quantity from plastic curbstops. Levels dislodged ranged from 0.18 to

4.18 µg/100 $cm^2$ for all plastics tested. Significantly higher dislodgeability occurred from products where low density polyethylene plastics were used to dilute pesticide container plastics, compared to products containing only pesticide container plastics. Amounts of trifluralin dislodged by wiping with dry cheesecloth for 15 min were 0.83 ± 0.50, 3.52 ± 0.40, and 2.53 ± 0.56 µg/100 $cm^2$ for products containing 100, 50 and 25% pesticide container plastics, respectively. Respective levels of trifluralin dislodged with saline-dampened cheesecloth were 2.00 ± 0.71, 3.21 ± 0.82 and 1.16 ± 0.51 µg/100 $cm^2$. Decreased amounts of trifluralin were released after product weathering, with levels dislodged under dry conditions of 0.007 ± 0.002, 0.0083 ± 0.001 and 0.0089 ± 0.001 µg/100 $cm^2$, respectively. Similar studies of asphalt products containing recycled pesticide containers found the average amounts of trifluralin and 2,4-D isooctyl ester dislodged were 0.33 and 1.35 µg/100 $cm^2$, respectively. Pesticide levels dislodged from all products tested were within acceptable daily intake levels. Calculations of margins of safety showed exposure to products made with recycled containers would not present an unacceptable risk to individuals coming in contact with them.

**Lambert, S.D., N.J.D. Graham, and B.T. Croll. 1993. Ozone degradation of selected non-agricultural herbicides. Ozone Science and Engineering. 15: 457-464.** The efficiency of ozone for the degradation of three herbicides, imazapyr, triclopyr and diuron, under controlled laboratory conditions was investigated. Experiments were conducted at pH 7.5, in a bubble contractor column, with raw lowland surface water spiked with initial active ingredient concentrations of 2 ?g/litre. The ozone doses applied and consumed were 4.79 and 2.9 mg $O_3$/litre, respectively, and resulted in removal of 53%, 48% and 90% of imazapyr, triclopyr and diuron, respectively.

**Lautenschlager, R.A., F.W. Bell, R.G. Wagner, and P.E. Reynolds. 1998. The Fallingsnow Ecosystem Project: documenting the consequences of conifer release alternatives. Journal of Forestry. 96: 20-27.** An overview is presented of the Fallingsnow Ecosystem Project, established in 1993 SW of Thunder Bay, Ontario, Canada, including the design, environmental components, and the initial results obtained. The Project was designed to document the terrestrial ecological consequences of alternative conifer release treatments. The ecosystem components studied are: soil chemistry, physics and morphology; below- and above-ground microclimates; below-ground fungi; vegetation, species composition, abundance, diversity, and foliar nutrient content; insects; terrestrial gastropods; amphibians and reptiles; small mammals; songbirds; and moose [*Alces alces*] area use and foods (production and storage). Although long-term responses are unknown, results to date indicate that cutting (with brush saws or tractor-mounted cutting heads) and herbicide (glyphosate or triclopyr) treatments are relatively inconsequential for most environmental components found in regenerating northern forests. It is suggested that given the growing opposition to herbicide use in forestry,

managers must expect that social input into natural resource management will become more common, if not required.

**Lautenschlager, R.A., F.W. Bell, R.W. Wagner, and J.C. Neal. 1995. The Fallingsnow Ecosystem Project: comparing manual, mechanical, and aerial herbicide conifer release in northwestern Ontario. Proceedings of the forty-ninth annual meeting of the Northeastern Weed Science Society, Boston, Massachusetts, USA, 1995. 144-145.** The initial findings of a field study conducted in a conifer [Pinopsida] forest in northwestern Ontario to assess the effects of glyphosate and triclopyr, manual cutting and mechanical cutting on soil factors, vegetation, below and above ground insects, amphibia, reptiles, moose [*Alces alces*] and deer are presented.

**Lee, C. H., P. C. Oloffs, and S. Y. Szeto. 1986. Persistence, degradation, and movement of triclopyr and its ethylene glycol butyl ether ester in a forest soil. J. Agric. and Food Chem. 34: 1075-1079.** Triclopyr, ((3,5,6-trichloro-2-pyridinyl)oxy)acetic acid, and its ethylene glycol butyl ether ester (EGBE), equivalent to 3.5 mg of the acid, were applied, separately, to the top layers of columns (40 cm times 8.9 cm i.d.) packed with a loam soil or with quartz sand. Water, equivalent to 2.5 cm of precipitation, was leached through each column every second day. After 54 days, residues were found only in the top 10-cm layers of the soils; they were triclopyr and the metabolites 3,5,6-trichloro-2-pyridinol (TP) and 2-methoxy-3,5,6-trichloropyridine, accounting for about 5, 85, and 10%, respectively, of the total of the resisues which, in turn, was equivalent to 65% of the amount applied initially to the top layers. No residues were detected in the lower soil layers or the eluates. Triclopyr-treated sand: Found were 10 and 65%, respectively, in the sand and the eluates after 54 days. EGBE-treated sand: All residues were in the eluates after only 34 days. All residues from sand and eluates were in the form of triclopyr, except a few eluates from the latter treatment with traces of EGBE or TP.

**Leveille, P., J. Legris, G. Couture, and R. Langevine. 1995. Evaluation of the effects of triclopyr used in forestry. Pub. No. RN95-3084; Ministere des Ressources Naturelles; Quebec; Canada. 18 p.** An account is given of the chemical composition, biological action, toxicology, degradation and decomposition in air, soil, water, flora and fauna (including human), and effects on vegetation, fauna and humans, of the herbicide triclopyr.

**Liu, W., Q. Wang, and Z.Fang. 1995. Environmental behavior of pesticide adsorption and photolysis of the herbicide triclopyr in soil-water environment. Zhongguo Huanjing Kexue. 15: 311-15. Chinese.**

**Liu, W.P., A. Pusino, Z. Fang, and C. Gessa. 1995. Adsorption of herbicide triclopyr on homoionic clays. J. Environ. Sci. 7: 385-390.** Sorption isotherms of triclopyr on montmorillonites were described by the Freundlich equation. Sorption capacity decreased in the order: $Fe^{+++}$, $Al^{+++}$, $Cu^{++}$, $Ca^{++}$, $K^{+}$ and $Na^{+}$-

clays. Infrared spectroscopy results suggest that sorption involved the formation of hydrogen bonds with water molecules in the interlayer and might have involved both the protonation of the pyridine nitrogen atom, due to a proton transfer from the acid metal-bound water, and also the formation of direct bonds between the carboxylate groups and the exchange cations. Pesticides forming complexes with interlayer cations in soil montmorillonites might be extractable by solvents and were therefore released into the environment.

**Lobaugh, S., F. Farrow, X. Feng, and A. Ogram. 1994. The effects of triclopyr on 2,4-D mineralization in two soils. Part B. Pesticides: Food Contaminants and Agricultural Wastes J. Environ. Sci. and Health 29: 459-471.** The effects of the herbicide triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid) on the mineralization of 2,4-D (2,4-dichlorophenoxyacetic acid) in two soils which differed in their histories of prior exposure to the two herbicides were investigated. The relative effects of triclopyr on 2,4-D mineralization and most probable numbers of 2,4-D degraders were dependent upon the soil. Triclopyr was shown to increase 2,4-D mineralization rates in a soil which had been exposed to both 2,4-D and triclopyr, but decreased the mineralization rate of 2,4-D and inhibited the increase of most probable numbers of 2,4-D degraders in a soil that had not been directly exposed to either herbicide.

**Malik, N. and W.H. van den Born. 1986. Use of herbicides in forest management. Information Report NOR-X-282, Northern Forestry Centre, Canadian Forestry Service. 18 pp.** A review of herbicide use in North America including an assessment of the need for herbicides in forestry, current knowledge on the environmental fate and impact of herbicides with forestry potential and the registration status of new herbicides in Canada with particular reference to fosamine-ammonium [fosamine], triclopyr and hexazinone.

**McCall, P. J., R. L. Swann, D. A. Laskowski, and T. K. Jeffries. 1979. The effects of three herbicides on nitrification, nitrogen fixation, and substrate utilization in three agricultural soils. Abstracts 178$^{th}$ National Meet. Amer. Chem. Soc. pp. 59.** Considerable attention has been focused on the effects of pesticides on microorganisms as a result of new regulations which appear in the FIFRA Guidelines for registering pesticides in the USA. Methods were developed to measure nitrification, nitrogen fixation and substrate utilization in soils treated with dinoseb, triclopyr and propachlor. Nitrification was monitored utilizing analytical techniques measuring ammonia, nitrate and nitrite. Nitrogen fixation was followed with the acetylens reduction method. Radiolabelled starch, protein, cellulose and pectin were incubated in each soil with each chemical to determine the effects on basic microbial functions. In each study conducted, no significant differences were observed between treated and control samples. The ability of these methods to reproduce conditions in the field is discussed.

**McLaughlan, M. S., F. W. Bell, and D. Myketa. 1996. Managing vegetation with herbicides: A review of glyphosate, 2,4-D, hexazinone, triclopyr and simazine. Technical Note No. TN-37. Northwest Region Science & Technology, Thunder Bay, Ontario. 13p.** Describes the five most common forestry herbicides used in Ontario. Information is included on advantages and limitations of herbicides, target species, product registration status in Ontario, permitted uses, mode of action, and mobility and persistence in the environment.

**Michael, J.L., M.C. Smith, W.G. Knisel, D.G. Neary, W.P. Fowler, D.J. Turton, J.A. Griffith. 1996. Using a hydrological model to determine environmentally safer windows for herbicide application. Second International Conference on Forest Vegetation Management, 1995. New Zealand Journal of Forestry Science. 26: 288-297.** A modification of the GLEAMS model (Groundwater Loading Effects of Agricultural Management Systems) was used to determine application windows which would optimize efficacy and environmental safety for herbicide application to a forest site. Herbicide/soil partition coefficients were determined using soil samples collected from a study site at Alum Creek Experimental Forest in the Ouachita Mountains in Arkansas, USA, for 2 herbicides (imazapyr, KOC (organic carbon partition coefficient) 46; triclopyr ester, KOC 1038). Published values for 2 other herbicides (hexazinone, KOC 54; triclopyr amine, KOC 20) were also used in the model. Other site-specific characteristics were taken from catchment topographic maps and soil data. Long-term climatic records for the region were then used to provide meteorological data for use in the hydrology component of the model. The model was run with herbicide application for each day of the manufacturers' recommended growing-season application windows. Average surface run-off losses, expressed as a percentage of applied, were low for all herbicides modelled (hexazinone, 0.37%; imazapyr, 0.34%; triclopyr amine, 0.21%; triclopyr ester, 1.85%). Model predictions of herbicide loss for each application day were then summarized and the application days with the lowest predicted loss within the manufacturers' application windows were identified as the environmentally safest days (environmental window) for application. This application of the GLEAMS model predicts an environmental window for each herbicide for the site under consideration, during which the probability of adverse environmental impacts is at the lowest level achievable based upon long-term climatic records. The environmental window for pesticides other than herbicides can also be determined through modelling in a similar fashion. GLEAMS was the model chosen for this example, but other pesticide fate models may be equally applicable.

**Molnar, J., S. Daru, A. Fulop, and S. Gedeon. 1983. Studies on washing in of triclopyr into the soil with biotest and analytical method. Novenyvedelmi Tudomanyos Napok, p. 14.** The penetration of triclopyr into the soil and possible phytotoxic effects after root absorption were investigated. Soil samples

from 0-20, 20-40 and 40-60 cm depths were sampled on the day of treatment and after 4-6 and 12-14 weeks. Oats and oilseed rape were used as indicator plants in the biotests. Analyses were made by gas chromatography. Triclopyr was detectable only in the upper 0-20 cm soil layer and was degraded within 3 months. The results are of importance both for approval of the preparation and its incorporation into the weed control technology.

**Molnar, J., S. Daru, A. Fulop, and S. Gedeon. 1983. Study of the percolation of triclopyr into the soil by bioassay and analytical methods. Novenyvedelem. 19: 267.** Soil samples were taken from the 0-20, 20-40 and 40-60 cm horizons either on the day of spraying with triclopyr or 4-6 wk or 12-14 wk after spraying and tested for the presence of the herbicide. Oats and oilseed rape were used as the test crops in the bioassays; analysis was by gas chromatography. Triclopyr was found only in the top layer of the soil and was completely broken down within 3 months of spraying.

**Moseman, T. E. and M. G. Merkle. 1977. Analysis, persistence, and activity of triclopyr. Proc. Southern Weed Sci. Soc. 30: 64.**

**Neary, D. G., P. B. Bush, and J. L. Michael. 1993. Fate, dissipation and environmental effects of pesticides in southern forests: A review of a decade of research progress. Environ. Toxicol. and Chem. 12: 411-428.** Ten years of watershed-scale research has been conducted on the fate of forestry-use pesticides in forested catchments under mainly operational conditions throughout the southern U.S. Studies have evaluated chemicals such as hexazinone, picloram, sulfometuron methyl, metsulfuron methyl, azinphosmethyl, triclopyr, carbofuran, lindane, malathion, fenvalerate, copper-chromium-arsenic, and pentachlorophenol. Model verifications of pesticide fate and dissipation and risk analyses have been conducted using simulation models such as GLEAMS, CREAMS, and PRZM. Field study data indicate that movement is controlled by the main hydrologic pathways (e.g., surface runoff, infiltration, interflow, and leaching below the root zone). Peak residue concentrations tend to be low (<500 □g/L), except where direct applications are made to perennial streams or to ephemeral channels, and where buffer strips are not used and do not persist for extended periods of time. Indirect effects noted from the use of pesticides in forested watersheds include temporarily increased nitrate nitrogen losses, reduced sediment yields, temporal changes in terrestrial invertebrate abundance, reduced plant diversity, and changes in particulate organic matter transport in streams. Analyses conducted in regional environmental impact statements indicate that the low concentrations and short persistence of forestry pesticides in surface water and groundwater do not post a significant risk to water quality, aquatic biota, or human health.

**Neary, D. G., P. B. Bush, C. K. McMahon, R. L. Cantrell, J. W. Taylor, Jr. 1988. Persistence of nine forest pesticides in the surface horizon of a typic**

**quartzipsamment soil of Ocala National Forest. Proc. Soil and Crop Sci. Soc. Florida. 47:127-134.** 2,4-D, dicamba, dichlorprop, hexazinone, picloram and triclopyr were injected into turkey oak (*Quercus laevis*) at labelled rates for site preparation, and chlorpyrifos, fenitrothion, and lindane were sprayed onto sand pine (*Pinus clausa*) for bark beetle [scolytid] control. Soil persistence of these pesticides was evaluated. Initial concentration in the A1 horizon of a Typic Quartzipsamment were related to the application rates. Except for a soil-applied granular formulation of hexazinone, application of pesticides to the soil probably occurred primarily as a result of litterfall, crown leaching, stem washoff, and spillage. Peak concentration of most herbicides in the A horizon occurred 2 months after application and ranged from 5.34 mg/kg for dichlorprop to 0.10 mg/kg for dicamba. The insecticide peak concentrations were reached between 5 and 8 months after application and ranged from 5.11 mg/kg (chlorpyrifos) to 1.54 mg/kg (fenitrothion). Secondary peaks of some pesticide residues were frequently detected in the A horizon 2 to 6 months after application. Except for chlorpyrifos and lindane, concentrations were <0.40 mg/kg after 12 months. Persistence was generally in the order of chlorpyrifos > lindane > hexazinone > fenitrothion > dichlorprop > triclopyr > picloram > dicamba > 2,4-D. The results suggested that pesticide exposure of forest workers in dusty conditions and with maximum soil pesticide concentration would not be significant (<0.2% and 0.5% of the acceptable daily intake for herbicides and insecticides, respectively).

**Neary, D.G., J.L. Michael, J.A. Griffith. 1996. Herbicides - protecting long-term sustainability and water quality in forest ecosystems. Second International Conference on Forest Vegetation Management, 1995. New Zealand Journal of Forestry Science. 26: 241-264.** World-wide, sediment is the major water quality problem. The use of herbicides for controlling competing vegetation during stand establishment can be beneficial to forest ecosystem sustainability and water quality by minimizing off-site soil loss, reducing on-site soil and organic matter displacement, and preventing deterioration of soil physical properties. Sediment losses from sites where competing vegetation is controlled by mechanical methods can be 1-2 orders of magnitude greater than natural losses from undisturbed watersheds. On a watershed basis, vegetation management techniques in general increase annual erosion by <7%. Herbicides do not increase natural erosion rates. Organic matter and nutrients that are critical to long-term site productivity can be removed off-site by mechanical vegetation-management techniques and fire, or redistributed on-site in a manner that reduces availability to the next stand. For several decades, research has been conducted on the fate of herbicides used in forestry in various watersheds throughout the southern and western USA, Canada, and Australia. This research has evaluated chemicals such as 2,4-D, glyphosate, hexazinone, imazapyr, metsulfuron methyl, picloram, sulfometuron methyl, tebuthiuron, and triclopyr. Losses in stream flow, and leaching to groundwater, have been evaluated. Field study data indicate that residue concentrations tend to be low, except where

direct applications are made to ephemeral channels or streams, and do not persist for extended periods of time. Regional environmental impact statements in the USA demonstrate that forestry herbicide presence in surface and groundwater is not a significant risk to water quality or human health. They also clearly indicate that herbicides can greatly reduce water quality deterioration that is produced by erosion and sedimentation.

**Newton, M., F. Roberts, A. Allen, B. Kelpsas, D. White, P. Boyd. 1990. Deposition and dissipation of three herbicides in foliage, litter, and soil of brushfields of southwest Oregon. J. Agric. Food. Chem. 38: 574-583.** The herbicides 2,4-D ((2,4-dichlorophenoxy)acetic acid), triclopyr ([(3,5,6-trichloro-2-pyridinyl)-oxy]acetic acid), and picloram (4- amino-3,5,6-trichloro-2-pyridinecarboxylic acid) were applied by helicopter to test grids in mountainous southwestern Oregon brushfields on shallow, rocky, clay loam soils. Herbicide concentrations were observed in crown twigs and foliage, browse twigs and foliage, litter, and soil. Initial deposits in the target area ranged from 61 to 115% (average 82%) of the nominal dosage, with coefficients of variation of 29-104%. Initial concentrations in crown foliage were 44-mg/kg for each kilogram per hectare applied; deposits on browse foliage and litter were 38% and 74%, respectively, of crown concentrations. Early after application, decreases were more rapid for salt formulations than for esters. After 79 days, decrease of all herbicides was slight in foliage, but continued in soil. Picloram disappeared most rapidly and was least mobile, followed by triclopyr and 2,4-D. Triclopyr and 2,4-D remained nearly constant in foliage through winter. Disappearance was rapid in litter.

**Nilsson, H. 1983. Persistence and mobility of herbicides in arable soil. Investigations in 1980-81. In, Weeds and Weed Control. 24th Swedish Weed Conference, Uppsala, Vol.1. pp. 302-310.** In field trials in Sweden in 1980-1, herbicide residues in different soils under barley and *Brassica* crops were studied. Barley was given 10 or 40 g chlorsulfuron or 960 g triclopyr/ha at the 2- to 3-leaf stage and the *Brassica* spp. were given 1.5 kg alloxydim-sodium, 1.0 kg pyridate or 0.6 kg flamprop-isopropyl/ha. Persistence of triclopyr was short and it remained mainly in the 5-15 cm soil layer. Chlorsulfuron was very persistent and very mobile, leaching downwards and moving laterally in the soil. Herbicides in the *Brassica* spp. had short persistence, the most persistent being alloxydim-sodium.

**Norris, L. A., M. L. Montgomery, and L. E. Warren. 1987. Triclopyr persistence in western Oregon hill pastures. Bull. Environ. Contam. and Toxicol. 39:134-141.** Studies were conducted on hill-pastures near Coquille (site 1) and near Corvallis (site 2), W. Oregon. At site 1, 3.4 kg triclopyr/ha was aerially applied on 24 May to 2.5 ha which included a 1.74-ha watershed. Soil was sampled 0-365 days after herbicide application at depths of 0-90 cm at 6 randomly chosen locations. At site 2, 10.1 kg triclopyr/ha was applied with a

hand-held sprayer to three 6.1 X 30.5 m plots on June 24. Grass and soil samples were taken 0-365 days after herbicide application. Residues on grasses from site 2 were highest immediately after application (527 mg/kg) but decreased rapidly with time to 1.3 mg/kg 365 days after treatment. There was some conversion of triclopyr to 3,5,6-trichloro-2-pyridinol, but very little to 2-methoxy-3,5,6-trichloropyridine, and neither metabolite accumulated. The half-life of triclopyr in soil was estimated as 75 days and 81 days at sites 1 and 2, respectively. Only trace amounts of triclopyr metabolites were detected. Residues of triclopyr and its metabolites were essentially confined to the top 30 cm of soil. Maximum triclopyr concentration in steam water (195 µg/litre) occurred in the 1st 20 h after application. The results suggested that neither long distance overland flow nor leaching introduced significant amounts of triclopyr into the stream.

**Obenshain, K.R., M.C. Metcalf, A.A. Abdelghani, J.L. Regens, D.G. Hodges, and C.M. Swalm. 1997. Spatial analysis of herbicide decay rates in Louisiana. Environmental Monitoring and Assessment. 48: 307-316.** The results of a five-year study, in which the acute toxicity, fate and effect of herbicide mixtures on human health and the environment were assessed, are presented. Three sites in Louisiana (Baton Rouge, Bridge City and Hammond) were routinely sprayed by the Louisiana Department of Transportation and Development to kill weeds along roadsides. Two herbicide mixtures were used, 2,4-D + Roundup (glyphosate), and Garlon 3A (triclopyr) + Roundup. Water, vegetation, soil and sediment samples were collected quarterly for three years and were analysed for herbicide content to study the fate and impact of herbicides in the environment. The results indicated a correlation between soil type, herbicide type, and persistence of the herbicide in the environment. Using the correlations found in these data, spatial analysis identified areas where herbicide use may potentially cause surface water and sediment contamination, based on soil composition/properties, type of herbicide applied, and proximity of water bodies to sprayed areas.

**Perala, D. A. 1980. A provisional assessment of triclopyr herbicide for use in Lake States forestry. USDA Forest Service Res. Paper No. FSRP-NC-180, 7 pp.** Triclopyr-triethylamine at 1.5-4.5 lb a.e./acre was applied alone or in combination with 2,4-D or Tordon 101 Mixture (tri-isopropanolamine salts of 2,4-D 2 lb + picloram 0.54 lb a.e./gal) at 2 lb + 0.5 lb a.e./acre in July 1975; white spruce (*Picea glauca*) was planted on 6 site preparation treatments in April 1976. Soil analyses in May 1976 showed that triclopyr and picloram residues were unlikely to be leached out of the topsoil high in OM content and that their rates of degradation were similar. The white spruce planted in the spring following treatment was not damaged. *Betula papyrifera* and *Acer rubrum* were readily top-killed by triclopyr at 4.5 lb/acre and 6 lb/acre would probably kill *Quercus rubra* and *Tilia americana*. Tordon 101 was more effective against *Acer saccharum* and *Populus tremuloides*. Triclopyr mixtures

with 2,4-D or Tordon 101 were not as effective as the individual herbicides applied alone at the same total rate. Tordon 101 reduced sprouting better than triclopyr. Triclopyr at rates of 1-2 lb a.e./acre proved highly effective and safe for the release of white spruce when sprayed 2-3 weeks after the completion of shoot growth.

**Pusino, A., W. Liu, and C. Gessa. 1994. Adsorption of triclopyr on soil and some of its components. J. Agric. and Food Chem. 42: 1026-1029.** The adsorption of triclopyr (((3,5,6-trichloro-2-pyridynyl)oxyl) acetic acid) by homoionic clays, soil organic matter (H- and Ca-saturated), and seven soils was studied. The extent of adsorption on clays decreased in the order of decreasing acidity of the saturating cations. The H-organic matter was more active in triclopyr adsorption than Ca-organic matter and Ca-clay, whereas studies on mixtures of clay and organic matter indicated that the interaction between these two soil components reduced the surfaces available for triclopyr adsorption. Adsorption isotherms conformed to the Freundlich equation. It was found that in soil the Freundlich adsorption constant decreased linearly with organic matter (r = 0.930) and adsorption decreased with increasing pH. Multiple-regression analysis indicated that k-f values were better correlated if cation-exchange capacity and pH (r = 0.989) were simultaneously taken into account.

**Racke, K. D. and S. T. Robbins. 1991. Factors affecting the degradation of 3,5,6-trichloro-2-pyridinol in soil. In: Pesticide Transformation Products: Fate and Significance in the Environment. ACS Symposium Series 459. American Chemical Society, Washington, DC. pp 93-107.** The degradation and sorption of 3,5,6-trichloro-2-pyridinol (TCP), a primary metabolite of the insecticide chlorpyrifos and the herbicide triclopyr, was examined in 25 different soils in order to better predict its environmental fate and significance. TCP exhibited sorption ($K_d$) coefficients of between 0.3 and 20.3 mL/g, with a mean $K_d$ of 3.1 ml/g. Calculated mean $K_{oc}$ coefficients were 3344 mL/G for the neutral form of TCP, and 54 mL/g for the anionic forms of TCP, respectively. Mineralization was used as an indicator of the degradation in soil of TCP and similar organic compounds chosen for comparative study (3-chloro-5-trifluoromethyl-2-pyridinol, 2-hydroxypyridine, 2,4-dichlorophenol). Although rates of TCP degradation varied between soils, multiple regression analyses revealed a poor correlation of degradation with commonly measured soil properties. However, inclusion of soil degradation rates of related organic compounds or glucose, and sorption information in the regression model resulted in a significant improvement in the ability to predict TCP degradation. The mineralization of TCP is microbially mediated, yet it is unclear whether catabolic or cometabolic processes are predominant. Only two soils contained microbial populations that could utilize TCP as a sole carbon source in mixed culture.

**Reeves, G. L. 1995. The mobility of triclopyr under laboratory and field conditions. In Pesticide Movement to Water, Walker, A., Allen, R., Bailey, S.W., Blair, A.M., Brown, C.D., Gunther, P., Leake, C.R., and Nicholls, P.H. (eds.) British Crop Protection Council Symposium, Coventry (UK) Monograph No. 62. pp. 223-228.** Laboratory studies are used to provide data to support the registration of pesticides. While these experiments give some indication as to the environmental fate of a molecule, they do not always predict the results seen under field conditions. For example, the herbicide triclopyr was shown from sorption and column leaching studies to have high leaching potential, which triggered the need for a lysimeter study under field conditions. However, the results from the lysimeter study were contrary to the laboratory work indicating little or no leaching potential. The likely reason for this is that triclopyr degrades more rapidly in the field than in the laboratory, significantly reducing the availability of any residues for leaching. One factor contributing to the increased degradation of triclopyr is sunlight, which promotes ring-cleavage and mineralization to carbon dioxide.

**Sassaman, J. F., R. Pienta, M. Jacobs, and J. Cioffi. 1984. Pesticide Background Statements. Vol. 1. Herbicides. 909 pp.** The individual Herbicide Background Statements have been compiled to provide a comprehensive review of the available information concerning the use, chemistry, toxicology, environmental fate, and comparative hazard of the herbicides in forest applications. References to the published literature at the end of each background statement are provided for those individuals who wish to independently evaluate the toxicological data and environmental fate information that is presented in summary form. In many instances, secondary sources, such as review articles, handbooks, and company technical data sheets, were used. Wherever possible in these instances, the primary source was also indicated and referenced, although it may not have been examined. Herbicides included in the document are: amitrole, atrazine, 2,4-D, 2,4-DP, dalapon, dicamba, fosamine ammonium, glyphosate, hexazinone, picloram, simazine, and triclopyr.

**Sexsmith, W.A. 1988. Environmental monitoring of forestry control operations: Annual Report, New Brunswick Dept. of the Environment, Fredericton.**

**Siltanen, H., C. Rosenberg, M. Raatikainen, and T. Raatikainen. 1981. Triclopyr, glyphosate and phenoxy herbicide residues in cowberries, bilberries and lichen. Bull. Environ. Contam. and Toxicol. 27: 731-737.** Investigations were carried out in Finland into herbicide residues in wild berries in forests which had been subjected to foliar spraying for brush control. Residues of triclopyr were analysed in cowberries and bilberries after treatment with 0.25, 0.75 and 2.25 kg/ha of the herbicide. Effect of date of treatment on glyphosate (applied at the rate of 0.75 kg/ha) and triclopyr residues was investigated. Results are tabulated. These showed that the residues in the berries were of the same order of magnitude when the same amount of any of the herbicides was used. In

aerial spraying the application rate was lowest for glyphosate and highest for phenoxy herbicides. As a result residues in the berries from aerially sprayed forests can be expected to the highest after phenoxy herbicide application and lowest after glyphosate application.

**Stark, J. 1982. Persistence of herbicides in forest soils. Rapport, Institutionen Mikrobiologi, Sveriges Lantbruksuniversitet. 15. 143 pp.** Degradation was studied of phenoxyacetic acids, glyphosate and triclopyr, applied in both a pure form and commercial formulations, on various types of soil and in different climatic conditions (lat. 59 deg 32'-66 deg 36'N, alt. 10-650 m). The herbicides were applied with a knapsack sprayer at 2, 4 (2 sites) and 20 (one site) kg/ha a.i. in July-August 1976-80. Samples taken at 0-5 cm indicated that degradation of the phenoxyacetic acids 2,4-D, MCPA and 2,4,5-T occurred mainly within a few months after the application. Only small amounts were detectable after one year. Glyphosate and triclopyr were more persistent; in soil with high biological activity glyphosate was decomposed within 6 months and triclopyr acid and ester within one year, in soil with low biological activity glyphosate could persist longer than one year and triclopyr longer than two years. Factors such as organic matter content, pH, temperature and water content of the soil clearly influenced the decomposition rate, but since these factors are interrelated, their individual importance was difficult to evaluate.

**Stark, J. 1983. Persistence of herbicides in forest soils. <u>In</u>, Weeds and Weed Control, 24$^{th}$ Swedish Weed Conf., Uppsala. Vol. 1. pp. 275-286.** Degradation of phenoxyacetic acids, glyphosate and triclopyr at sites with varying soil and climatic conditions was studied in field and laboratory trials in Sweden. Hydrolysis of 2,4-D buthoxyethyl ester in the laboratory occurred very rapidly, whereas it took several weeks or months in the field. Degradation of 2,4-D and MCPA was similar at different sites. The main part of each herbicide was degraded within 1-2 months and the residues within 2-15 months. 2,4,5-T was degraded within 2 months at most sites and within a year at other sites, although residues remained longer than those of 2,4-D or MCPA. Degradation of glyphosate was rapid but residues remained in the soil for >2 yr at some sites. Triclopyr persisted for 1-2 yr in the soil. Degradation of herbicides was related to soil OM, pH, temperature, and moisture content.

**Stephenson, G. R., K. R. Solomon, C. S. Bowhey, and K. Liber. 1990. Persistence, leachability, and lateral movement of triclopyr (Garlon) in selected Canadian forestry soils. J. Agric. and Food Chem. 38:584-588.** Triclopyr, a pyridine herbicide, is highly active for the control of broad-leaved weeds and brush but has little activity on grasses. Although triclopyr has been used for several years to control brush in rangelands of the U.S., it is just now being considered for use on rights-of-way and for conifer release in Canada. A number of possible sites were investigated in the Matheson area of Northern Ontario. Triclopyr, ((3,5,6-trichloro-2-pyridyl)oxy)acetic acid, Garlon 4,) was

moderately persistent in sandy and clay soils at the Northern Ontario site. Time to 50% disappearance was 2 weeks and 90% for 4 weeks, regardless of soil type. Evidence of triclopyr leaching in response to heavy rainfall was observed 7 days after application in both soils, but residues of triclopyr at a depth of 25-30 cm never exceeded 6 microgram/kg, when present. In a study of lateral movement of triclopyr with runoff water, residues (in the range 0.01-0.96 microgram/L) were recovered in a collection ditch 12-13 m downslope; however, there was no evidence of mass movement of triclopyr at quantifiable levels (0.54 microgram/kg) downslope in the soil. Field studies of persistence and mobility confirmed earlier laboratory results and indicate that environmental problems are unlikely to occur as a result of excessive triclopyr persistence and/or mobility in soils typical of Northern Ontario forestry areas.

**Thomas, M. W., B. M. Judy, W. R. Lower, G. F. Krause, and W. W. Sutton. 1989. Time-dependent toxicity assessment of herbicide contaminated soil using the green alga *Selenastrum capricornutum*. In, Plants for Toxicity Assessment, pp. 235-254.** Bioassays with *S. capricornutum* were performed on filtered eluates from a clay loam soil treated 1 h-10 d beforehand with 6 herbicides (glyphosate, imazapyr, triclopyr, picloram, 2,4-D and hexazinone) at recommended rates. The 96-h $EC_{50}$ (effective concentration) values indicated growth inhibition (relative to control sample) for all treatments when assayed 1 h after herbicide application. Algal $EC_{50}$ values of +100 (control), +27.3 (glyphosate), -20.4 (imazapyr), -22.4 (triclopyr), -49.4 (picloram + 2,4-D) and -100 (hexazinone) were obtained. Assays conducted 10 d after herbicide application to soil revealed substantially reduced toxicity. A slight reduction in toxicity was noted for triclopyr and picloram + 2,4-D, and no change was observed with hexazinone. When the herbicides were applied to water, the following 96-h $EC_{50}$ (in µg/ ml) were obtained: 5300-5500 (imazapyr), 5000 (picloram + 2,4-D), 5000 (triclopyr), 2600 (glyphosate) and 1.2-2.5 (hexazinone).

**Torstensson, L. and J. Stark. 1982. Persistence of triclopyr in forest soils. In, Weeds and Weed Control, 23rd Swedish Weed Conf., Uppsala, Vol. 2. pp. 393-399.** In eight field experiments in different parts of Sweden, triclopyr amine as Garlon 3A (360 g/litre) at 2.2 kg a.i./ha, triclopyr ester as Garlon 4E (480 g/litre) at 1.9 kg a.i./ha and 2,4-D ester as Hormoslyr (500 g/litre) at 2 kg a.i./ha were applied to forest soils. Analyses of samples taken at different times showed that triclopyr persisted for at least 1-2 years and sometimes more, very much longer than 2,4-D. Analyses of early spring samplings often showed higher values than the previous autumn's samples, because triclopyr accumulated in the uppermost soil layers during winter when the decomposition rate was low. This suggests that persistence may be long under field conditions where soil temperature is low.

**Whisenant, S. G. and E. D. McArthur. 1989. Triclopyr persistence in northern Idaho forest vegetation. Bull. Environ. Contam. Toxicol. 42: 660-665.**

**Wood K. and C. Hollstedt (compiled by). 1995. Fallingsnow Ecosystem Workshop: program and abstracts. Workshop proceedings / Ontario. Ministry of Natural Resources. WP-001, Vegetation Management Alternatives Program, 1995. xv, 54 p.** The Fallingsnow Ecosystem Project, which is providing data on the ecological impacts of alternative vegetation management practices, is being conducted on a regenerated spruce plantation near Thunder Bay, Ontario. Four treatments have been applied at the study site in a randomized block design: manual brushing; mechanical site treatment; aerial application of glyphosate or triclopyr herbicides; and control (no treatment). Environmental variables examined include soil characteristics and biodiversity; below- and above-ground temperature and moisture; vegetation species composition and foliar nutrient content; below- and above-ground insects; terrestrial gastropods; amphibians and reptiles; small mammals; songbirds; moose and deer area use, and foods (production and quality). This report contains presentations from a workshop held to transfer to resource managers the most recent scientific information produced from this project.

**Worrall, F., D.A. Wooff, A.H. Seheult, and F.P.A.Coolen. 1998. A Bayesian approach to the analysis of environmental fate and behavior data for pesticide registration. Pestic. Sci. 54: 99-112.** With the harmonisation of data requirements for pesticide registration under EC Directive 91/414 there is need for progress on the techniques used to analyse such data and so help make consistent the judgements applied by national regulatory authorities. This paper proposes a Bayesian technique for combining data from environmental fate and behaviour studies of pesticides in soil. The method uses expert knowledge, based on degradation and adsorption data, and logistic regression methods to form a prior probability distribution for the probability that a given compound leaches. Results from lysimeter experiments are used update the prior knowledge. Data for the compounds bentazone and triclopyr are used to illustrate the techniques. The advantages of the methodology and its implications for the pesticide registration procedure are discussed in the light of possible advances using modern Bayesian statistical techniques and mathematical models.

## ENVIRONMENTAL FATE WATER

**Agriculture Canada. 1991. Triclopyr herbicide: Discussion document, Ottawa, Food Production and Inspection Branch, Pesticide Directorate.**

**Bush, P. B., D. G. Neary, and J. W. Taylor. 1988. Effect of triclopyr amine and ester formulations on groundwater and surface water runoff water quality in the coastal plain. Proc. 41st Annual Meeting Southern Weed Sci. Soc., pp. 226-232.** Triclopyr ester and amine (as Garlon 4 and Garlon 3A, respectively) applied at 4 and 3 lb a.e./gal, respectively, controlled *Panicum* spp., *Dichanthelium* sp., *Arietida stricta, Ilex glabra* and most herbaceous species on coastal plain flatwood watersheds near Gainesville. Triclopyr resulted in a shift towards an understory dominated by *Andropogon* spp., particularly *A. capillipes*. Triclopyr residues were detected at trace levels (1-2 ppb.) in storm runoff, but no residues were detected in subsequent runoff events or in any groundwater monitor wells 6 months after application.

**Bush, P. B., D. G. Neary, J. F. Dowd, D. G. Allison, and W. L. Nutter. 1986. Role of models in environmental impact assessment. Proc. Southern Weed Science Society, 39th Annual Meeting, pp. 502-516.** The agricultural field scale models CREAMS (Chemical Runoff and Erosion from Agricultural Management Systems) and PRZM (Pesticide Root Zone Model) were used to simulate pesticide movement from forested watersheds. Comparison with measured hexazinone loss showed than CREAMS accurately predicted hexazinone concentration for storms occurring up to 75 days after application. For storms 75 and 270 days after application, CREAMS under predicted herbicide concentration. The model predicted the following potential residues in stormflow: bromacil>triclopyr>hexazinone>picloram>dicamba. PRZM accurately predicted sub-surface picloram movement using site modified runoff curve number, partition coefficient ($K_d$) and half-life ($K_s$). $K_d$, $K_s$ and water infiltration terms affected pesticide leachability most strongly. Regarding $K_d$, PRZM predicts leaching from a forested mountain watershed as follows: high leaching for $K_d<0.1$, potential leaching, given favourable hydrological conditions for $0.1>K_d>10$, and no leaching for $K_d>10$. A half-life >0.05 years is needed for a compound to leach.

**Bush, P. B., Y. C. Berisford, J. W. Taylor, D. G. Neary, K. V. Miller, and J. E. Street. 1995. Operational monitoring of forest site preparation herbicides in the coastal plain: Assessment of residues in perched water table. Proc. 48th Annual Meeting Southern Weed Sci. Soc. pp. 115-120.** Field trials were conducted during the spring of 1992 in Aiken, South Carolina on a fine loam in loblolly pine [*Pinus taeda*] clearcut areas to assess the potential movement of Arsenal (imazapyr) at 1 lb/acre, Velpar (hexazinone) at 3 lb and Tordon + Garlon (picloram + triclopyr, respectively) at 2 + 4 lb to shallow groundwater. Monitoring wells were installed at depths of 4 and 8 feet where clay lenses

were observed. Results showed significant lateral down-slope movement of picloram and hexazinone under saturated conditions when the slopes exceeded 2%. Triclopyr and imazapyr showed limited potential for lateral movement or movement to the 8 foot perched water table. Levels of hexazinone peaked at 2 months after application and decreased to non-detectable levels at 2 years post-application. The residue magnitude and rate of dissipation were affected by plot slope and position within the plot. Triclopyr and imazapyr were not as mobile or persistent in shallow wells as picloram and hexazinone.

**Dilling, W.L., L.C. Lickly, T.D. Lickly, P.G. Murphy, and R.L. McKellar. 1984. Organic photochemistry: 19 — Quantum yields of O,O-diethyl-O-(3,5,6-trichloro-2-pyridinyl) phosphorothioate (clorpyrifos) and 3,5,6-trichloro-2-pyridinol in dilute aqueous solutions and their environmental phototransformation rates. Environ. Sci. Technol. 18: 540-543.**

**Funk, W. H. 1990. Fiscal Year 1989 Program Report (Washington Water Research Center). PB91-136259/AS, Program Report G1597-01 National Technical Information Service, Springfield, VA. 23p.** Water is a key resource in the development of the Pacific Northwest and Washington State. Nineteen dams and hydropower systems provide 80% of the power needs of the region. Water from the Columbia-Snake River watersheds irrigate over 4.9 million acres of farmland. The 50,000 miles of streams and 8,000 freshwater lakes play a major role in the social, recreational, and economic structure of the state. A major commitment of the state water agencies and the public is to preserve the migration of anadromous fishes in Pacific Northwest rivers as well as enhance the recreation value and save usage of the surface water and groundwater. Recent droughts have shown that under low-water conditions allocations are not sufficient for all users. Funding from the State Water Research Institute Program allowed researchers working through the State of Washington Water Research Center to evaluate the criteria proposed by the Timber/Fish/Wildlife group to classify streams. TFW is a program to minimize losses of fisheries and wildlife while utilizing resources. Other concerns studied included the movement of pesticides through various soils under different soil, environmental, and cultural conditions in order to develop better predictive models. Investigations were carried out on the toxicity of a herbicide, triclopyr, on a non-target aquatic organism. Studies were made on increasing the germination of a plant species, *Agropyron spicatum*, to enhance vegetation over the loess soils of semi-arid erosive lands. The State of Washington Water Research Center program is directed toward informing, educating, and attempting to solve or mitigate these complex water contamination, allocation, use and reuse issues. These goals are carried out through publication of research results, conferences, workshops, and presentations. The Water Research Center publishes an annual “plain text” report summarizing all research carried out through the Center during that year. In addition, newsletter and brochures are produced for distribution to agencies and the public.

**Gardner, S.C. and C.E. Grue. 1996. Effects of Rodeo and Garlon 3A on nontarget wetland species in central Washington. Environ. toxicol. chem. 15: 441-451.** Purple loosestrife (*Lythrum salicaria*) is an invasive wetland perennial that became established in northeastern North America in the early 1800s. Despite its designation as a noxious weed, its distribution has continued to expand. Treatment with herbicides is the most widely used means of controlling purple loosestrife. This study examined the nontarget effects of two herbicides, Rodeo and Garlon 3A, currently used or being considered for use in controlling purple loosestrife in Washington State, respectively. Growth and/or survival of duckweed, Daphnia, and rainbow trout were monitored for at least 24 h following an application of each herbicide. Free-living water column and benthic invertebrates were monitored 24 h and 7 d post-spray using activity traps and sediment cores. Neither chemical was associated with significant decreases in survival or growth of the bioassay organisms, with the exception that growth of duckweed was reduced 48 h after exposure to Rodeo. Nor were significant decreases in the abundance of free-living aquatic invertebrates detected following the herbicide applications. Results suggest that neither herbicide, at the application rates used, poses a hazard to aquatic invertebrates in wetlands in central Washington. However, Rodeo, because it is a broad-spectrum herbicide, may pose a greater hazard to nontarget aquatic vegetation.

**Gardner, S.C., C.E. Grue, J.M. Grassley, L.A. Lenz, J.M. Lindenauer, and M.E. Seeley. 1997. Single species algal (Ankistrodesmus) toxicity tests with Rodeo R and Garlon R 3A. Bulletin of Environmental Contamination and Toxicology. 59: 492-499.** Experiments were conducted to compare the toxicity of 0-5120 µg/ml Rodeo (glyphosate) and Garlon 3A (triclopyr) to the green alga Ankistrodesmus. In a further experiment the direct effects of Rodeo and indirect effects of associated changes in pH were differentiated by adjusting the pH to 7.0. Results indicated that, when herbicide-induced changes in pH were not adjusted for, the toxicity of Rodeo to the alga was 4.5 times more than that of Garlon. However, it is noted that these results may not be consistent in the field where pH may vary, and water quality may affect the stability and solubility of the herbicides and, thus, their toxicity.

**Getsinger, K. D. and H. E. Westerdahl. 1984. Field evaluation of Garlon 3A (triclopyr) and 14-ACE-B (2,4-D BEE) for the control of Eurasian watermilfoil. Army Engineer Waterways Experiment Station, Vicksburg, MS. Environmental Lab. 29p.** The efficacy and residue persistence in water and sediment of triclopyr (Garlon 3A) and the controlled-release (CR) formulation of 2,4-D BEE (14-ACE-B) on 0.4-ha plots of Eurasian watermilfoil (*Myriophyllum spicatum* L.) in Lake Seminole, GA., were evaluated through field application. Results showed that rapid dissipation of triclopyr occurred in water and sediment in both the 1.0-mg/l active ingredient (a.i.) and 2.5-mg/l a.i. treatment plots. Triclopyr applied at these rates did not control watermilfoil as well as 2,4-D BEE applied at conventional rates. The CR elastomer formulation

14-ACE-B did not provide desired long-term 2,4-D concentrations in the water column, although watermilfoil was controlled for a short period of time. Triclopyr shows promise as an aquatic herbicide, but 14-ACE-B is unacceptable as a CR 2,4-D formulation.

**Getsinger, K. D., J. D. Madsen, M. D. Netherland, and E. G. Turner. 1996. Field evaluation of triclopyr (Garlon 3A) for controlling Eurasian watermilfoil in the Pend Oreille River, Washington. Govt. Reports Announcements and Index (GRA&I), Issue 16.** In an effort to evaluate the selective control of the exotic weed Eurasian watermilfoil (*Myriophyllum spicatum* L.) and to assess the recovery of the native submersed plant community, a 6-ha river and 4-ha cove plot were treated with the herbicide triclopyr at application rates of 2.5 and 1.75 mg/f, respectively, in the Pend Oreille River, Washington, in August 1991. Water-exchange half-lives within the plots were measured using rhodamine WT dye (river, $t_{1/2}$ =20 hr; cove, $t_{1/2}$ =52 hr), and triclopyr dissipation rates were also calculated (river, $t_{1/2}$ = 19 hr; cover, $t_{1/2}$ =53 hr). Triclopyr concentrations were below proposed potable water tolerance levels (0.5 mg/f) within the river treatment plot by 3 days after treatment (DAT) (<0.01 to OAl mg/f), and 675 m downstream of that plot by 1 days after treatment (DAT) <0.01 to 0A7 mg/f. Following the cove treatment, triclopyr residues ranged from 0.12 to 0.29 mg/f by 7 DAT, and from <0.01 to 0.06 mg/f as close as 150 m downstream from the plot. Eurasian watermilfoil biomass was reduced by 99 percent in the treated plots at 4 weeks posttreatment, remained low 1 year later (river treatment, 28 percent of pretreat levels; cove treatment, 1 percent of pretreat levels), and was still at acceptable levels of control at 2 years posttreatment (river treatment, 47 percent of pretreat levels; cove treatment 24 percent of pretreat levels). The 4-week posttreatment efficacy results verified triclopyr concentration/exposure time relationships for controlling Eurasian watermilfoil developed under laboratory conditions. Nontarget native plant biomass increased 500 to 1,000 percent by 1 year posttreatment, and remained significantly higher in the cove plot at 2 years after treatment.

**Getsinger, K.D. and H. E. Westerdahl. 1985. Aquatic Plant Control Research Program. Field Evaluation of Garlon 3A (Triclopyr) and 14-ACE-B (2,4-D BEE) for the Control of Eurasian Watermilfoil. Govt Reports Announcements & Index (GRA&I), Issue 04.** The efficacy and residue persistence in water and sediment of triclopyr (Garlon 3A) and the controlled-release (CR) formulation of 2,4-D BEE (14-ACE-B) on 0.4-ha plots of Eurasian watermilfoil (*Myriophyllum spicatum* L.) in Lake Seminole, GA., were evaluated through field application. Results showed that rapid dissipation of triclopyr occurred in water and sediment in both the 1.0-mg/l active ingredient (a.i.) and 2.5-mg/l a.i. treatment plots. Triclopyr applied at these rates did not control watermilfoil as well as 2,4-D BEE applied at conventional rates. The CR elastomer formulation 14-ACE-B did not provide desired long-term 2,4-D concentrations in the water column, although watermilfoil was controlled for a

short period of time. Triclopyr shows promise as an aquatic herbicide, but 14-ACE-B is unacceptable as a CR 2,4-D formulation.

**Getsinger, K.D., D.G. Petty, J.D. Madsen, J.G. Skogerboe, B.A. Houtman, W.T. Haller, and A.M. Fox. 2000. Aquatic dissipation of the herbicide triclopyr in Lake Minnetonka, Minnesota. Pest Management Science. 56: 388-400.** A study of the aquatic fate of the triethylamine salt of triclopyr was conducted in three bays of Lake Minnetonka, Minnesota (USA). The primary purpose of this study was to determine dissipation rates of the parent active ingredient, triclopyr, and its major metabolites, 3,5,6-trichloropyridinol (TCP) and 3,5,6-trichloro-2-methoxypyridine (TMP) in selected matrices including water, sediment, plants, fish and shellfish. Two 6.5-ha plots dominated by the weed species Myriophyllum spicatum were treated with 2.5 mg a.e. triclopyr\litre (2.5 ppm) on 21-23 June 1994. A third 6.5-ha plot was established as an untreated reference. Water and sediment samples were collected from within the plots and at selected locations up to 1600 m outside of the plots through six weeks post-treatment for chemical residue analysis. Residue samples were collected from the target and non-target plants and other non-target matrices, including game and rough fish (Micropterus salmoides, Lepomis macrochirus, Ictalurus nebulosus and Catostomus commersoni), clams (Lampsilis siliquoidea) and crayfish (Orocnectes virilis and O. immunis). All test animals were sequestered in cages located in the centre of each plot and samples were collected during four weeks post-treatment. Half-lives for dissipation of triclopyr and TCP in water ranged from 3.7 to 4.7 days and from 4.2 to 7.9 days, respectively, with trace amounts of TMP found. Peak triclopyr sediment values ranged from 257 to 335 ng g-1, with a mean half-life of 5.4 days, while peak TCP sediment levels ranged from 27 to 65 ng g-1 (mean half-life=11.0 days). Trace levels of TMP were detected at one treatment site at one sampling event. Triclopyr and TCP accumulated and cleared from animal tissues proportionately to concentrations in the water (triclopyr dissipation half-lives<11 days, TCP<14 days). TMP levels were two to three times higher than those of the other compounds, particularly in visceral tissue. In all cases, residues of these compounds were higher in the inedible portions of the animals, and were usually higher in bottom-feeding fish species. The target plant, M. spicatum, accumulated triclopyr steadily until its death. The nontarget plant, Potamogeton zosteriformis, showed a much lower accumulation of triclopyr.

**Getsinger, K.D., E.G. Turner, J.D. Madsen, and M.D. Netherland. 1997. Restoring native vegetation in a Eurasian water milfoil-dominated plant community using the herbicide triclopyr. Regulated Rivers Research & Management. 13: 357-375.** In an effort to evaluate the selective control of the exotic weed Eurasian water milfoil (*Myriophyllum spicatum* L.) and to assess the recovery and restoration of the native submersed plant community, a 6-ha river and 4-ha cove plot were treated with the herbicide triclopyr at application

rates of 2.5 and 1.75 mg/l, respectively, in the Pend Oreille River, WA, in August 1991. Water exchange half-lives within the plots were measured using rhodamine WT dye (river, t-1/2 = 20 h; cove, t-1/2 = 52 h), and triclopyr dissipation rates were also calculated (river, r-1/2 = 19 h; cove, t-1/2 = 53 h). Triclopyr concentrations were below the proposed potable water tolerance level (0.5 mg/l) within the river treatment plot by 3 days after treatment ( lt 0.01 to 0.41 mg/l), and 675 m downstream of that plot by 1 day after treatment ( lt 0.01 to 0.47 mg/l). Following the cove treatment, triclopyr residues ranged from 0.12 to 0.29 mg/l by 7 days after treatment, and from lt 0.01 to 0.06 mg/l as close as 150 m downstream from the plot. Eurasian water milfoil biomass was reduced by 99% in the treated plots at 4 weeks post-treatment. remained low one year later (river treatment, 28% of pretreat levels; cove treatment 1% of pre-treat levels) and was still at acceptable levels of control at two years post-treatment (river treatment, 47% of pre-treat levels; cove treatment. 24% of pre-treat levels). The four-week post-treatment efficacy results verified triclopyr concentration/exposure time relationships for controlling Eurasian water milfoil developed under laboratory conditions. Non-target native plant biomass increased 500-1000% by one year post-treatment, and remained significantly higher in the cove plot at two years after treatment. Native species diversity doubled following herbicide treatment, and the restoration of this robust community delayed the re-establishment and dominance of Eurasian water milfoil for three growing seasons.

**Green, W. and Reed. 1989. Triclopyr (Garlon 3A) dissipation in Lake Seminole, Georgia. U.S. Army Engineer Waterways Experiment Station ; Springfield, Va., National Technical Information Service. 34 p.**

**Itak, J.A., W.A. Day, A. Montoya, J.J. Manclus, A.M. Phillips, D.A. Lindsay, D.P. Herzog. 1997. A paramagnetic particle-based enzyme-linked immunosorbent assay for the quantitative determination of 3,5,6-trichloro-2-pyridinol in water. ACS symposium series. 0097-6156 ; 657. Immunochemical technology for environmental applications /. Washington, DC : American Chemical Society. p. 261-270.** A competitive enzyme-linked immunosorbent assay (ELISA) for the quantitation of 3,5,6-trichloro-2-pyridinol (TCP), the major biological and environmental degradation product of chlorpyrifos and triclopyr, was developed. Magnetic particles were used as the solid phase to attach monoclonal anti-TCP antibodies. The ELISA has an estimated least detectable dose of 0.25 parts per billion (ppb; ng/mL) in water. Specificity studies indicate that the assay is specific for TCP and can distinguish it from the parent compounds as well as many other related and unrelated agricultural compounds. Results compare favorably with GC/MSD measurements (r = 0.959).

**Johnson, W. G., T. L. Lavy, J. D. Mattice, B. W. Skulman, R. J. Smith Jr., and R. E. Talbert . 1992. Environmental implications of pesticides [propanil,**

**thiobencarb, molinate, triclopyr, 2,4-D, quinclorac and benomyl] in rice production. Research Series Arkansas Agric. Exp. Sta. No. 422: 59-64.**

**Joyce, J. C. and W. T. Haller. 1989. Aquatic Plant Control Research Program: Triclopyr (Garlon 3A) dissipation in Lake Seminole, Georgia. Govt. Reports Announcements and Index (GRA&I), Issue 19. 36 pp.** A liquid formulation of triclopyr (Garlon 3A) was applied under Experimental Use Permit at proposed maximum rates to areas of Lake Seminole, GA, in order to examine herbicide dissipation and environmental fate. Residue persistence varied between the two treated plots. Triclopyr residues persisted in water above detectable levels through posttreatment day 3 in one plot and through posttreatment day 21 in the other. The residue half-life for the two plots was 0.5 and 3.4 days, respectively. Triclopyr (<0.3 mg/kg) was found in the sediment only on treatment day and posttreatment day 1. Triclopyr residues in plant tissue (>1.0 mg/kg) existed through posttreatment day 8. Triclopyr residues were not detected in fish but were detected in caged crayfish through posttreatment day 21. Indigenous clam tissue contained triclopyr residues only through posttreatment day 1. Based on the results of this study, applications of the Garlon 3A formulation of triclopyr for submersed aquatic plant control should not produce adverse effects on the environment. However, further evaluation of the accumulation and effects of triclopyr on clams and crayfish should be considered before establishing tolerance limits.

**Karov, I., G. Hrlec, and E. Tomeva. 1987. Weed control and herbicide residues in rice production. Fragmenta Herbologica Jugoslavica. 16: 129-138.** This is the summary of a paper given at the Third Congress on Weeds held at Ohrid, Yugoslavia, on 8-10 June 1988. Post-emergent applications of 4 litres Sofit Combi 600 EC (pretilachlor 20% + molinate 40%) or 5 litres Sofit plus 500 EC (pretilachlor 17% + propanil 33%)/ha, both in mixtures with 4.5 litres Basagran (bentazone) gave good control of emerged weeds in rice. Optimum application time for Sorfit application was at the 1- to 2-leaf stage of rice. Residues in rice were below the maximum permitted level, but the water should not be released into rivers until at least 42 days after treatment because of risks to fish. Triclopyr residues persisted longer in soil and water but were not harmful to fish. A possible build-up of triclopyr residues in water might damage other crops.

**Kreutzweiser, D.P., D.G. Thompson, B. Staznik, and J.A. Shepherd. 1998. Accumulation dynamics of triclopyr ester in aquatic leaf packs and effects on detritivorous insects. Journal of Environmental Quality. 27: 1138-1147.** Previous field studies have demonstrated that residues of the herbicide triclopyr butoxyethyl ester (TBEE) can accumulate in submerged leaf material of aquatic systems at concentrations up to 20 times the maximum aqueous concentrations. Accumulated TBEE residues may pose a risk of adverse effects to detritivorous invertebrates inhabiting and using natural leaf packs. The dynamics of TBEE

accumulation and persistence in leaf materials of laboratory and outdoor aquatic systems were studied, and the ecological significance determined in terms of effects on detritivorous insects and organic matter processing. Accumulations of TBEE in leaf packs of semi-static laboratory microcosms were up to 80 times aqueous concentrations, and residues persisted for 4 to 5 days. Leaf material of flow-through laboratory microcosms accumulated TBEE at much higher rates (up to 1000 times aqueous concentrations), but residues were cleared by 48 to 72 h. Accumulation and persistence in flow-through units were dependent on water depth, velocity and exposure duration. Accumulated TBEE residues were lower in outdoor stream channels than in laboratory flow-through units, probably because of losses through sorption to natural benthic material in the stream channels. Despite accumulations of TBEE in leaf packs at up to 90 mg kg-1 in systems treated at or near expected environmental concentrations, there was no significant mortality of detritivorous insects and no significant reductions in leaf consumption. Significant mortality and reduced feeding occurred only in systems treated at concentrations well above (up to 10 times) expected environmental concentrations.

**Kwong, K.F.N.K., G. Umrit, M. Nowbotsing, and A.K. Gopaul. 1999. Ground and surface water contamination by herbicide residues used in sugar cane fields in Mauritius. Sugar Cane. No. 3, 14-18.** Residues of nine herbicides, namely atrazine, diuron, hexazinone, 2,4-D, linuron, ioxynil, paraquat, oxyfluorfen and picloram, which are all used in weed control in sugarcane, were monitored at fortnightly intervals during 1995 and 1996 in ground and surface waters in Mauritius. The groundwater came from 20 boreholes representing the 10 main groundwater basins of Mauritius while the surface water was sampled at 25 locations along rivers forming part of the Grand River North West catchment area. Only the residues of atrazine, hexazinone and diuron could be detected in the freshwater sources in Mauritius. More than 60% of the groundwater samples analysed (> 50% for river water) did not contain any detectable level of herbicide residue. Even when present, the levels of the residues were mostly within the range 0.05 to 0.5 ppb with their highest recorded concentrations rarely exceeding the maximum limits of 3 ppb atrazine, 14 ppb diuron and 210 ppb hexazinone recommended for drinking water sources in the 1991 Environment Protection Act of Mauritius or by the United States Environment Protection Agency. The frequency of appearance of the herbicide residues varied from site to site and was not related to the piezometric depth of the groundwater basin. High rainfall events had a greater impact than time of herbicide application on the appearance of herbicide residues in the ground and surface waters. It is suggested that no freshwater source in Mauritius is sheltered from possible contamination by these herbicides, but that the public fear and mistrust of herbicides are not justified as the level of herbicide residues in the water does not in general pose a risk to human health.

**Lambert, S. D, N. J. D. Graham, and B. T. Croll. 1996. Degradation of selected herbicides in a lowland surface water by ozone and ozone-hydrogen peroxide. Ozone Science & Engineering 18: 251-269.**

**Lambert, S. D., N. J. D. Graham, and B. T. Croll. 1993. Ozone degradation of selected non-agricultural herbicides. Ozone Sci. and Engineering. 15: 457-464.** The efficiency of ozone for the degradation of three herbicides, imazapyr, triclopyr and diuron, under controlled laboratory conditions was investigated. Experiments were conducted at pH 7.5, in a bubble contractor column, with raw lowland surface water spiked with initial active ingredient concentrations of 2 μg/litre. The ozone doses applied and consumed were 4.79 and 2.9 mg/litre, respectively, and resulted in removal of 53%, 48% and 90% of imazapyr, triclopyr and diuron, respectively.

**Lavy, T.L., JD. Mattice, and R.J. Norman. 1998. Environmental implications of pesticides in rice production - 1997. Research Series –Arkansas Agricultural Experiment Station. No. 460, 63-71.** Six independent locations in Arkansas, USA, were monitored for 17 rice pesticides in 1997. The rivers selected for monitoring included the White, Arkansas, L'Anguille and St. Francis and two sites on the Mississippi River. Water samples were transported to the laboratory and extracted using solid phase extraction (SPE) techniques. Quantification and confirmation of pesticide residues were obtained by HPLC and GC/MS analysis. Pesticides selected for monitoring were determined after assessing state recommendations and laboratories' analytical capabilities. Pesticides included were: benomyl (Benlate R), thiobencarb (Bolero R), quinclorac (Facet R), carbofuran (Furadan R), triclopyr (Grandstand R), bensulfuron (Londax R), malathion, methyl parathion [parathion-methyl], molinate (Ordram R), pendimethalin (Prowl R), iprodione (Rovral R), carbaryl (Sevin R), propanil (Stam R), propiconazole (Tilt R), fenoxaprop (Whip R), 2,4-D and MCPA. A complementary field study was also conducted to evaluate the dissipation of 2,4-D and quinclorac under 12 different water treatments. Pesticides were detected in surface waters flowing from rice-producing areas in Arkansas. Most of these detections were at very low levels and often were not detected in the next sampling period. This suggests that water contamination was sporadic and not present throughout the rice production season. The field study showed that light is an important factor in the degradation of both 2,4-D and quinclorac. 2,4-D dissipated more rapidly and under more conditions than did quinclorac. Detectable amounts of quinclorac remained throughout the 36-day study.

**Lembi, C. A. 1978. Results of 1978 aquatic herbicide trials in Indiana. Proc. North Central Weed Control Conf. 33: 102-103.** Terbutryne gave excellent (80 to 100%) control of *Chara* sp. and submersed vascular plants such as *Myriophyllum spicatum* at rates as low as 0.025 mg/litre. Although the compound gave excellent control of *Lemna* sp. no control was observed on

*Wolffia* sp. Simazine at 1 mg/litre was also weak on *Wolffia* sp. Triclopyr was effective only on submersed vascular plants such as *Wolffia* sp. and *Potamogeton pectinatus*. Hexazinone was evaluated in the field in both 1977 and 1978. In 1977, a rate of 1 mg/litre effectively controlled *Ceratophyllum demersum*, *Najas guadalupensis* and *Chara* sp. However, considerable shoreline injury to grasses, trees and broadleaved shrubs was also observed. In 1978, the rate was reduced to 0.5 mg/litre. Good control was obtained of *Potamogeton foliosus* and *Lemna* sp. but only 50% control was observed on *Pithophora*, a difficult-to-control filamentous alga. No shoreline injury was observed on this pond. Control of marginal and rooted floating vascular plants with glyphosate was also tested. Rates as low as 1.5 kg/ha gave 100% control of a number of species.

**Liu, W., Q. Wang, and Z.Fang. 1995. Environmental behavior of pesticide adsorption and photolysis of the herbicide triclopyr in soil-water environment. Zhongguo Huanjing Kexue. 15: 311-15. Chinese.**

**Mackenzie, D.L. 1996. Persistence of triclopyr and glyphosate in a southern Ontario aquatic environment. University of Guelph. 88 p.** In situ enclosures were employed to investigate the dissipation of glyphosate and triclopyr in a southern Ontario aquatic environment. Enclosures were treated with Rodeo® & Roundup® and with Garlon® 4 & Garlon® 3A in two experiments. Estimated aqueous $DT_{50}$ for Roundup® and Rodeo® treated enclosures ranged from 3.2-13.2 d. No significant difference in dissipation was detected between the two formulations. In all enclosures, glyphosate concentrations in sediments peaked by day 30 and remained detectable throughout the 212 d monitoring period. In all enclosures, less than 0.1% of the total glyphosate was associated with the liner biofilm on any given sampling date. For enclosures treated with Garlon® 3A and Garlon® 4, estimated aqueous $DT_{50}$ ranged from 16.4-21.2 d. No significant difference in dissipation was detected between the two triclopyr formulations. Triclopyr residues in sediments reached maxima by day 7 and were non-detectable by day 89 post-application. Triclopyr residues associated with the plastic liners contributed less than 0.1% of the total triclopyr mass on any given sampling date. Results suggest that under similar conditions of use, glyphosate may dissipate more quickly than triclopyr in southern Ontario aquatic environments.

**McCall, P. J. and P.D. Gavit. 1986. Aqueous photolysis of triclopyr and its butoxyethyl ester and calculated environmental photodecomposition rates. Environ. Tox. and Chem. 5: 879-886.** Studies determining the photochemical quantum yields of ((3,5,6- trichloro-2-pyridinyl) oxy)acetic acid (triclopyr) and its butoxyethyl ester are reported. Values of 0.040 ± 0.003 and 0.0084 ± 0.0008, respectively, were obtained using 313-nm light at pH 5 in a dilute aqueous solution at 35□C. Quantum yields were used to compute half-lives for direct photolysis under seasonal and locational sunlight conditions with the computer

program SOLAR. Triclopyr was observed to photodegrade approximately six times faster than the ester, with typical calculated midday, midsummer half-lives of 2.1 and 12.5 h, respectively, at the water's surface at 40□C latitude. The relative importance of photolysis to other environmental transport and transformation mechanisms of the chemicals is discussed.

**McCall, P.J., D. A. Laskowski, and H. D. Bidlack. 1988. Simulation of the aquatic fate of triclopyr butoxyethyl ester and its predicted effects on Coho salmon. Environ. Toxicol. Chem. 7: 517-527.** Mathematical simulations of the dissipation of triclopyrbutoxyethyl ester in a model aquatic system representing a shallow, static pond were conducted. Aqueous hydrolysis, sorption to bottom sediment, hydrolysis in sediment and photolysis were considered in predicting aqueous concentration time profiles. Potential concentrations in Coho salmon were evaluated as part of the model based on rate constants for uptake, hydrolysis and elimination as determined in laboratory investigations. Predicted chemical concentrations in the fish were related to toxicity data to estimate aqueous concentrations in the model environment required to give a toxic response. The simulations showed that the ester concentration in the pond water would decline, with an approximate half-life of 6 to 24 h. Initial ester concentrations of 1.0 to 1.5 mg/L in this simulated pond environment would be required to result in chemical concentrations in fish above toxic threshold levels.

**McLaughlan, M.S., F. W. Bell, and D. O. Myketa. Managing vegetation with herbicides: A review of glyphosate, 2,4-D, hexazinone, triclopyr and simazine. Technical Note No. TN-37. VMAP, Vegetation Management Alternatives Program: A guide to opportunities.** Describes the five most common forestry herbicides used in Ontario. Information is included on advantages and limitations of herbicides, target species, product registration status in Ontario, permitted uses, mode of action, and mobility and persistence in the environment.

**Menconi, M. and S. Siepman. 1994. Preliminary hazard assessment of the herbicide triclopyr to fish and wildlife. California Department of Fish and Game, Sacramento, CA.**

**Michael, J. L., W. P. Fowler., H. L. Gibbs, and J. B. Fischer. 1994. Water chemistry of ephemeral streams. Gen. Tech. Rep 112. pp. 186-190.**

**Michael, J.L., M.C. Smith, W.G. Knisel, D.G. Neary, W.P. Fowler, D.J. Turton, and J.A. Griffith. 1996. Using a hydrological model to determine environmentally safer windows for herbicide application. Second International Conference on Forest Vegetation Management, 1995. New Zealand Journal of Forestry Science. 26: 288-297.** A modification of the GLEAMS model (Groundwater Loading Effects of Agricultural Management Systems) was used to determine application windows which would optimize

efficacy and environmental safety for herbicide application to a forest site. Herbicide/soil partition coefficients were determined using soil samples collected from a study site at Alum Creek Experimental Forest in the Ouachita Mountains in Arkansas, USA, for 2 herbicides (imazapyr, KOC (organic carbon partition coefficient) 46; triclopyr ester, KOC 1038). Published values for 2 other herbicides (hexazinone, KOC 54; triclopyr amine, KOC 20) were also used in the model. Other site-specific characteristics were taken from catchment topographic maps and soil data. Long-term climatic records for the region were then used to provide meteorological data for use in the hydrology component of the model. The model was run with herbicide application for each day of the manufacturers' recommended growing-season application windows. Average surface run-off losses, expressed as a percentage of applied, were low for all herbicides modelled (hexazinone, 0.37%; imazapyr, 0.34%; triclopyr amine, 0.21%; triclopyr ester, 1.85%). Model predictions of herbicide loss for each application day were then summarized and the application days with the lowest predicted loss within the manufacturers' application windows were identified as the environmentally safest days (environmental window) for application. This application of the GLEAMS model predicts an environmental window for each herbicide for the site under consideration, during which the probability of adverse environmental impacts is at the lowest level achievable based upon long-term climatic records. The environmental window for pesticides other than herbicides can also be determined through modelling in a similar fashion. GLEAMS was the model chosen for this example, but other pesticide fate models may be equally applicable.

**Moore, D.W., M.D. Schluchter, and G.I. Scott. 1990. Use of hazard models in evaluating the effect of exposure duration on the acute toxicity of three pesticides. In, Aquatic Toxicology and Risk Assessment; Volume 13, W.G. Landis and W.H. van der Schalie (eds.). American Society for Testing Materials, ATM STP 1096. Philadelphia, PA. pp. 247-263.**

**Morgan, J.D., G.A. Vigers, A.P. Farrell, D.M. Janz, and J.F. Manville. 1991. Acute avoidance reactions and behavioral responses of juvenile rainbow trout (*Oncorhynchus mykiss*) to Garlon 4, Garlon 3A, and Vision herbicides. Environ. Toxicol. Chem. 10: 73-79.**

**Neary, D. G., P. B. Bush., and J. L. Michael. 1993. Fate, dissipation and environmental effects of pesticides in southern forests: A review of a decade of research progress. Environ. Toxicol. Chem. 12: 411-428.** Ten years of watershed-scale research has been conducted on the fate of forestry-use pesticides in forested catchments under mainly operational conditions throughout the southern United States. Studies have evaluated chemicals such as hexazinone, picloram, sulfometuron methyl, metsulfuron methyl, azinphosmethyl, triclopyr, carbofuran, lindane, malathion, fenvalerate, copper-chromium-arsenic, and pentachlorophenol. Off-site movement in stream flow,

leaching to ground water, and thermal combustion have been examined. Model verifications of pesticide fate and dissipation and risk analyses have been conducted using simulation models such as GLEAMS, CREAMS, and PRZM. Field study data indicate that movement is controlled by the main hydrologic pathways (e.g., surface runoff, infiltration, interflow, and leaching below the root zone). Peak residue concentrations tend to be low (< 500 µg/L), except where direct applications are made to perennial streams or to ephemeral channels, and where buffer strips are not used and do not persist for extended periods of time.

**Neary, D.G., J.L. Michael, J.A. Griffith. 1996. Herbicides - protecting long-term sustainability and water quality in forest ecosystems. Second International Conference on Forest Vegetation Management, 1995. New Zealand Journal of Forestry Science. 26: 241-264.** World-wide, sediment is the major water quality problem. The use of herbicides for controlling competing vegetation during stand establishment can be beneficial to forest ecosystem sustainability and water quality by minimizing off-site soil loss, reducing on-site soil and organic matter displacement, and preventing deterioration of soil physical properties. Sediment losses from sites where competing vegetation is controlled by mechanical methods can be 1-2 orders of magnitude greater than natural losses from undisturbed watersheds. On a watershed basis, vegetation management techniques in general increase annual erosion by <7%. Herbicides do not increase natural erosion rates. Organic matter and nutrients that are critical to long-term site productivity can be removed off-site by mechanical vegetation-management techniques and fire, or redistributed on-site in a manner that reduces availability to the next stand. For several decades, research has been conducted on the fate of herbicides used in forestry in various watersheds throughout the southern and western USA, Canada, and Australia. This research has evaluated chemicals such as 2,4-D, glyphosate, hexazinone, imazapyr, metsulfuron methyl, picloram, sulfometuron methyl, tebuthiuron, and triclopyr. Losses in stream flow, and leaching to groundwater, have been evaluated. Field study data indicate that residue concentrations tend to be low, except where direct applications are made to ephemeral channels or streams, and do not persist for extended periods of time. Regional environmental impact statements in the USA demonstrate that forestry herbicide presence in surface and groundwater is not a significant risk to water quality or human health. They also clearly indicate that herbicides can greatly reduce water quality deterioration that is produced by erosion and sedimentation.

**Netherland, M. D. and K. D. Getsinger. 1992. Efficacy of triclopyr on Eurasian watermilfoil: concentration and exposure time effects. J. Aquatic Plant Manage. 30: 1-5.** Herbicide concentration and exposure time relationships were determined for the triethylamine salt formulation of triclopyr and control of Eurasian watermilfoil (*Myriophyllum spicatum*) under controlled-environment conditions. Thirty-four combinations of triclopyr concentration

and exposure times were tested. Concentrations ranged from 0.25 to 2.5 mg/litre, and exposure times ranged from 2 to 84 h. Plant control was based on shoot and root biomass harvested at 5 weeks post-treatment. Weekly visual injury ratings were used to characterize initial injury response and recuperative ability of plants following treatment. Plant response was rapid and most treatments resulted in severe injury to existing tissue with the majority of regrowth coming from root crowns and lower stems. Plant control increased (biomass decreased) as concentration and/or exposure times were increased until a threshold level was reached which provided complete plant control. Excellent control (>85% biomass reduction) was achieved at concentration/exposure time combinations of 0.25 mg for 72 h, 0.5 mg for 48 h,1.0 mg for 36 h, 1.5 mg for 24 h, and 2.0 and 2.5 mg for 18 h. Treatments of 2.5 mg for 2 h, 1.0 mg for 6 h, and 0.25 and 0.5 mg for 12 h were ineffective and produced only minor initial injury symptoms followed by rapid plant growth. Results indicated that increased *M. spicatum* control is likely in systems where plants remain in contact with triclopyr concentration greater than developed threshold levels.

**Netherland, M. D., D. Sisneros, E. G. Turner, and R. M. Stewart. 1994. Laboratory and mesocosm evaluations of controlled-release matrices as potential herbicide delivery systems. Army Engineer Waterways Experiment Station, Vicksburg, MS. Environmental Lab. 61 p.** Formulations for the controlled release of aquatic herbicides were tested in the laboratory and in flowing water hydraulic flumes. Protein- and gypsum-based matrices were formulated with bensulfuron methyl (2% active ingredient (a.i.)), fluridone (2 % a.i.), 2,4-D (2 and 15 % acid equivalent (a.e.)), and triclopyr (2 and 15 % a.e.). These formulations were tested in the laboratory for release properties over a 7-day period. In addition, conventional granular formulations of fluridone SRP 5 % a.i.) and 2,4-D 19 % a.e.) were tested to provide a basis for comparison of release rates. Results showed the protein matrices produced inconsistent release profiles; whereas, the gypsum matrices resulted in consistent release rates during the course of the study. Triclopyr and 2,4-D were identified as excellent candidates for hydraulic flume testing. Triclopyr was chosen due to its experimental status and the lack of field efficacy and dissipation information for this compound. Three formulations of endothall were also tested for controlled release properties and included the conventional granule 10.1 % a.i.), a 27% a.i. clay granule, and a 45% a.i. supersorbent polymer. Results showed all matrices released >90 % of the active ingredient within 2 hr posttreatment. Although no controlled-release properties were demonstrated, the 45% a.i. polymer is a good candidate for field testing due to the high percent a.i. load and the lack of dusting.

**Nutter, W. L., T. Tkacs, T. B. Bush, and D. G. Neary. 1984. Simulation of herbicide concentrations in stormflow from forested watersheds. Water Resources Bull. 20: 851-857.** The breakpoint rainfall hydrology and pesticide

options of the field scale model CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) were used to predict average concentrations of hexazinone (3 cyclohexyl-6-(dimethyl-amino)-1- methyl-1,3,5-triazine-2,4(1H ,3H)-dione) in stormflow from four forested watersheds in the upper Piedmont region of Georgia. Predicted concentrations were compared with measured concentrations recorded over a 13-month period. CREAMS accurately predicted hexazinone concentrations in the initial stormflow events which also contained the highest concentrations. The model underestimated the hexazinone concentrations in stormflow two months and greater following pesticide application. In a companion study, the daily rainfall option of the CREAMS model was used to evaluate the relative risk associated with the maximum expected concentration of hexazinone, bromacil (5-bromo-3 sec-butyl-6 methyuracil), picloram (4-amino-3,5,6 trichloropicolinic acid), dicamba (3 ,6-dichloro-0-anisic acid), and triclopyr (((3,5 ,6-trichloro-2-pyridinyl)oxy)acetic acid) in stormflow from small forested watersheds. The model predicted the following order of potential residue appearance in stormflow: bromacil > triclopyr > hexazinone > picloram > dicamba. Subsurface movement of residues via interflow and deep leaching losses are not simulated by the version of CREAMS used in these studies.

**Obenshain, K.R., M.C. Metcalf, A.A. Abdelghani, J.L. Regens, D.G. Hodges, and C.M. Swalm. 1997. Spatial analysis of herbicide decay rates in Louisiana. Environmental Monitoring and Assessment. 48: 307-316.** The results of a five-year study, in which the acute toxicity, fate and effect of herbicide mixtures on human health and the environment were assessed, are presented. Three sites in Louisiana (Baton Rouge, Bridge City and Hammond) were routinely sprayed by the Louisiana Department of Transportation and Development to kill weeds along roadsides. Two herbicide mixtures were used, 2,4-D + Roundup (glyphosate), and Garlon 3A (triclopyr) + Roundup. Water, vegetation, soil and sediment samples were collected quarterly for three years and were analysed for herbicide content to study the fate and impact of herbicides in the environment. The results indicated a correlation between soil type, herbicide type, and persistence of the herbicide in the environment. Using the correlations found in these data, spatial analysis identified areas where herbicide use may potentially cause surface water and sediment contamination, based on soil composition/properties, type of herbicide applied, and proximity of water bodies to sprayed areas.

**Perala, D. A. 1980. A provisional assessment of triclopyr herbicide for use in Lake States' forestry. Research Paper NC-180. North Central Forest Experiment Station, USDA Forest Service. 7 pp.** Various application rates of (a) triclopyr were used for white spruce release and of (a) alone and in combination with (b) 2,4-D or (c) 2,4-D + picloram for site preparation during the conversion of mixed broadleaf stands in Minnesota in which *Populus tremuloides* suckers comprised 86% of the competition to planted spruce.

Results showed that (a) top-killed several species at 4.5-6 lb/acre a.e., but not *P. tremuloides* or sugar maple which were better controlled with (c). Mixtures of (a) with (b) or (c) were less effective than (a) or (c) alone. Bare root spruce stock can be safely planted during the spring following summer applications, provided the forest floor is undisturbed. Application of (a) at 1-2 lb/acre a.e. is highly effective and safe for releasing spruce when sprayed 2-3 weeks after shoot growth is completed. Both leaching resistance and degradation rates of triclopyr are similar to those for picloram.

**Peterson, H. G., C. Boutin, P. A. Martin, K. E. Freemark, N. J. Ruecker, and M. J. Moody. 1994. Aquatic phytotoxicity of 23 pesticides applied at expected environmental concentrations. Aquatic Toxicol. 28: 275-292.** The phytotoxicity of the Expected Environmental Concentration (EEC, used to evaluate the hazard of pesticides to nontarget organisms) of 23 pesticides to 9 species of algae and cyanobacteria (24-h inhibition of $^{14}$C-labelled pesticide uptake), and 1 aquatic plant (7-d growth inhibition) was determined in order to examine the question of interspecific sensitivity and its relation to the development of Canadian pesticide registration guidelines. Chemicals included 5 triazine herbicides (atrazine, cyanazine, hexazinone, metribuzin and simazine), 4 sulfonylurea herbicides (chlorsulfuron, metsulfuron-methyl, ethametsulfuron-methyl and triasulfuron), 2 phenoxyalkane herbicides (2,4-D and MCPA), 2 pyridine herbicides (picloram and triclopyr), a substituted urea (tebuthiuron), an amine derivative (glyphosate), an imidazolinone herbicide (imazethapyr), a bipyridylium (diquat), a hydroxybenzonitrile (bromoxynil), an aldehyde (acrolein), an acetanilide herbicide (metolachlor), 2 carbamate insecticides (carbofuran and carbaryl) and a triazole derivative fungicide (propiconazole). The following test organisms were selected: green algae (*Scenedesmus quadricauda* and *Selenastrum capricornutum*); diatoms (*Nitzschia* sp. and *Cyclotella meneghiana* [*C. meneghiniana*]); cyanobacteria (2 strains of *Microcystis aeruginosa*, *Oscillatoria* sp., *Pseudoanabaena* sp., *Anabaena inaequalis* and *Aphanizomenon flos-aquae*); and duckweed (*Lemna minor*). The 5 triazine herbicides, acrolein and diquat inhibited the C uptake of all algae and cyanobacteria by >50%. Carbaryl and tebuthiuron caused > 50% inhibition in 90% of the algae tested. The triazine herbicides, sulfonylurea herbicides, acrolein, diquat, metolachlor and tebuthiuron inhibited the growth of duckweed by >50%. Duckweed was the most sensitive organism tested, being equally affected by all pesticides (with the exception of carbaryl), as well as being acutely affected by sulfonylurea herbicides. Green algae were least sensitive to diquat; diatoms and 1 cyanobacterium were the only organisms that showed sensitivity to glyphosate. It is concluded that there are considerable differences in sensitivity among species and that an uncertainty factor is necessary to provide an acceptable margin of safety in evaluating the hazard presented by these chemicals to the aquatic environment.

**Roshon, R.D., J.H. McCann, D.G. Thompson, G.R. Stephenson, D.G. Thompson (ed.), and R.G. Wagner. 1999. Effects of seven forestry management herbicides on *Myriophyllum sibiricum*, as compared with other nontarget aquatic organisms. Proceedings of the third International Conference on Forest Vegetation Management, Sault Ste. Marie, Ontario, Canada, 1998. Canadian Journal of Forest Research., 29: 1158-1169.** Based on a review of the scientific literature and results from laboratory testing with the submersed macrophyte *Myriophyllum sibiricum*, the effects of 2,4 dichlorophenoxyacetic acid (2,4-D), glyphosate, hexazinone, imazapyr, metsulfuron methyl, sulfometuron methyl and triclopyr on non-target aquatic organisms were compared. Laboratory results indicated that *M. sibiricum* was sensitive to herbicide effects, especially those that impact on root growth. For most herbicides, the inhibitory concentrations IC25 and IC50 (concentrations that inhibit an endpoint parameter by 25 and 50%, respectively) for shoot and root growth were below the expected environmental concentrations (EEC). For example, the IC50 values for root dry mass were 0.00012 and 0.00022 mg active ingredient/litre for sulfometuron methyl and metsulfuron methyl, respectively, concentrations that were approximately 3100 and 1700 times below the EEC for these compounds. Interspecies comparisons, conducted during this study, demonstrated that *M. sibiricum* was equally or more sensitive to these herbicides than other aquatic plant species (i.e. floating macrophytes and algae) and, in some cases, more sensitive than fish, zooplankton and other invertebrates. Available data demonstrated that 2,4-D, imazapyr and the sulfonylureas investigated were more toxic to rooted and floating macrophytes than to other aquatic organisms, including algae. It is suggested that because of the high sensitivity and ecological significance of aquatic macrophytes, a greater emphasis should be placed on evaluating aquatic phytotoxicity in future ecotoxicological research.

**Sassman, J., R. Pienta, M. Jacobs, and J. Cioffi. 1984. Pesticide background statements. Vol. 1. Herbicides. Agriculture Handbook, USDA Forest-Service, No.633, 909 pp.** This handbook begins with general information including sections on the USDA Forest Service, physical and chemical properties, toxicity, toxicity testing, relative toxicities, the fate and transport of pesticides in organisms, soil and water, assessment of hazards and the assumptions made in the preparation of the data presented. This preliminary section is followed by the background statements on amitrole, atrazine, 2,4-D, 2,4-DP [dichlorprop], dalapon, dicamba, fosamine ammonium, glyphosate, hexazinone, picloram, simazine and triclopyr. Each background statement includes sections on general information such as physical and chemical properties and the normal use patterns, toxicity to various organisms, mutagenicity, fate in the environment and in organisms, use by the USDA Forest Service, exposure and hazard assessment.

**Servizi, J.A., R.W. Gordon, and D.W. Martens. 1987. Acute toxicity of Garlon 4 and Roundup herbicides to salmon, daphnia, and trout. Bull. Environ. Contam. Toxicol. 39: 15-22.**

**Smith, C. T., and M. L. McCormack, Jr. 1988. Watershed losses of triclopyr after aerial application to release spruce-fir. Proc. 42nd Annual Meeting Northeastern Weed Sci. Soc., pp. 104-108.** Triclopyr was aerially applied to release conifers on regenerating, whole-tree clearcut *Picea rubens/Abies balsamea* watershed in northern Maine at an average rate of 1.8 kg/ha. Stream water draining the 49 ha of the treated area and an adjacent 73 ha control watershed were sampled periodically for 298 days after spray application to monitor triclopyr concentration. Peak concentration of 56 ppb triclopyr was observed immediately after direct application to the stream channel. Another pulse of 48 ppb triclopyr occurred after 11-mm rain 6-days after application. The highest concentration observed below a 450 m buffer strip along the treatment stream was 11 ppb. Total losses of triclopyr from the watershed for a 113-day period after application were estimated from triclopyr concentration and stream volume predicted by the hydrologic simulation model BROOK. Watershed losses were estimated to be 0.02% of the total of 90.9 kg triclopyr applied. The buffer strip was effective at reducing the losses of triclopyr from the watershed.

**Solomon, K. R., C. S. Bowhey, K. Liber, and G. R. Stephenson. 1988. Persistence of hexazinone (Velpar), triclopyr (Garlon), and 2,4-D in a northern Ontario (Canada) aquatic environment. J. Agric. and Food Chem. 36: 1314-1318.** A field study was conducted in enclosures located in a typical bog lake in a sandy soil area near Matheson in northeastern Ontario. Three groups of six polyethylene enclosures each were constructed and installed in the lake. Three enclosures each were treated with triclopyr (butoxyethanol ester), with 2,4-D (isooctyl ester), and with hexazinone (solution) at rates equivalent to 0.3 and 3.0; 1.0 and 2.5; and 0.4 and 4.0 kg/ha, respectively. Water, sediment, and enclosure wall samples were analyzed for residues, and temperature and oxygen levels were measured. A significant dose-dependent change in oxygen concentration was only seen in the hexazinone-treated enclosures. Rates of dissipation of 2,4-D were similar at both concentrations, and within 15 days less than 5% remained in the water. Up to 25% of the 2,4-D adsorbed to the sides of the corrals. Triclopyr concentration in water was below 5% from day 15 and could not be detected from day 42 onward. The amount of pesticide adsorbed to the sides of the enclosures was lower and appeared to dissipate more rapidly than was the case with 2,4-D. At the lower application rate, hexazinone was undetectable 21 days and at the higher rate 42 days after application. Hexazinone dissipated more rapidly than 2,4-D and was not adsorbed to sediments.

**Sprecher, S.L. and A.B. Stewart. 1995. Triclopyr effects on peroxidase activity in target and non-target aquatic plants. Journal of Aquatic Plant Management. 33: 43-48.** Rapid and characteristic physiological responses to herbicidal activity in aquatic plants have potential for monitoring treatment effect in laboratory evaluations and operational applications, or indicating contaminant runoff in aquatic ecosystems. Change in peroxidase enzyme (PRX) has been considered for use as such a parameter, and was investigated following application of the auxin-like herbicide triclopyr to four species at 1 mg ae/l for 12 hr, and 2.5 mg ae/l for 24 hr. Guaiacol-specific PRX increased rapidly within 1.5 days after triclopyr application in the dicot Eurasian watermilfoil (*Myriophyllum spicatum* L.). The non-target monocots elodea (*Elodea canadensis* Rich.), sago pondweed (*Potamogeton pectinatus* L.), and vallisneria (*Vallisneria americana* Michx.) showed no visual effects of triclopyr treatment through 8 DAT, and PRX levels were unchanged in treated and untreated plants during this time. However, by 35 DAT the 2.5 mg/l triclopyr rate (the maximum label rate) had reduced biomass of sago pondweed by 60%. The early PRX response to triclopyr effect which differentiated Eurasian watermilfoil from non-target species suggests that this parameter may be predictive of rapid susceptibility to this herbicide.

**Szeto, S. Y. 1993. Determination of kinetics of hydrolysis butyl ether ester of triclopyr. J. Agric. and Food Chem. 41: 1118-1121.** To predict the fate and transport processes of pesticides in the aquatic environment requires information on the hydrolytic pathways and kinetic data over the normal pH range of the aquatic environment. To this end a high-pressure liquid chromatograph (HPLC) was used to determine 3,5,6-trichloro-2-pyridinol, triclopyr, and the ethylene glycol butyl ether ester of triclopyr (Garlon) in aqueous media without extraction or cleanup. The pseudo-first-order rate constants for the hydrolysis of Garlon were established at 35□C in aqueous buffered solutions of pH 4.5-8.5. The reaction was base-catalyzed and the rate proportional to the pH ranging from 0.77 per second to 0.1596 per hour. The major conversion product was triclopyr at pH 4.5-8.5, and 3,5,6-trichloro-2-pyridinol was an additional minor product at pH 4.5. Both products were stable in aqueous media. The hydrolysis of Garlon was determined according to the same approach in two river waters of pH 6.6 and 7.6. Their kinetics were in agreement with those in aqueous buffers of the same pH with low ionic strength to reduce or eliminate buffer catalysts.

**Thompson, D. G, D. P. Kreutzweiser, S. S. Capell, D. R. Thomas, B. Staznik, and T. Viinikka. 1995. Fate and effects of triclopyr ester in a first-order forest stream. Environ. Toxicol. and Chem. 14: 1307-1317.** The fate and the effects of triclopyr butoxyethyl ester (TBEE) were investigated in a first-order forest stream. Quantification of TBEE in stream-water samples showed maximal concentration of 0.848 and 0.949 µg/ml at sampling stations nearest two discrete injection points. Average TBEE concentrations ranged from 0.32 µg/ml

at stations nearest injection points to 0.02 µg/ml approximately 225 m downstream. Periods of exposure to aqueous TBEE concentrations in excess of 0.001 µg/ml ranged from 55 min in fast-flowing upstream locations to 120 min at slower, downstream sampling locations. Simultaneous quantitation of triclopyr acid (TRI) residues in stream-water samples indicated that natural degradative mechanisms rapidly converted TBEE to TRI, and that sorption to natural allochthonous materials occurred as chemical pulses moved downstream. Chemical behaviour resulted in short-term, pulse-type exposures to TBEE, with decreasing magnitude and slightly increasing duration in relation to downstream distance. Short-term, low-level exposures generated in this stream treatment resulted in slightly elevated drift (approximately 3- to 4-fold increase) for up to 36 h, but no measurable reductions in abundance of benthic invertebrates. Increases in chlorophyll a concentrations in epilithic periphyton from treated sections indicated short-term eutrophication or growth-regulation effects of the herbicide applications.

**Thompson, D. G., B. Staznik, D. D. Fontaine, T. Mackay, G. R. Oliver, and J. Troth. 1991. Fate of triclopyr ester (Release) in a boreal forest stream. Environ. Toxicol. and Chem. 10: 619-632.** The fate of triclopyr butoxyethyl ester was investigated following direct aerial application to a boreal forest stream. The average deposit monitored at the stream surface was 3.67 kg acid equivalent (a.e.)/ha (range = 3.35-3.99 kg a.e./ha). Residues of triclopyr as the butoxyethyl ester (TBEE), triclopyr acid (TRI) and pyridinol metabolite (PYR) were determined in various aquatic substrates. Stream water residues of TBEE resulting from direct overspray were characterized by instantaneous maxima (0.23-0.35 mg/L). A series of diminishing pulses of chemical associated with inputs upstream of the sampling site were observed. Average concentrations of TBEE in stream water ranged from 0.05 to 0.11 mg/L during the first 12 to 14 h post-application and declined to levels below the limits of quantification (0.001 mg/L) within 72 h post-application. Transient residues of TRI were observed in stream water, with a maximum concentration (0.14 mg/L) 6 h post-application. The PYR residues did not exceed limits of quantification (0.05 mg/L) in any sample. Results indicate that natural dissipation mechanisms reduce both the period and the concentrations to which aquatic organisms would be exposed.

**Turner, E. G., K. D. Getsinger, and M. D. Netherland. 1994. Correlation of triclopyr and rhodamine WT dye dissipation in the Pend Oreille River. J. Aquat. Plant Manage. 32: 39-41.** The US Environmental Protection Agency (USEPA) requires extensive field residue dissipation data for the registration of all aquatic herbicides. Typically, these dissipation studies are conducted by collecting large numbers of water samples from predetermined locations for a specified length of time, without knowing the direction(s) in which the herbicide will move (especially outside of the treated area) or for how long residues will persist. Samples may be collected and analyzed from areas where the herbicide is absent, or locations where the herbicide is present may not be

sampled. In addition, samples may be collected and analyzed after the herbicide has dissipated from a particular station, or sample collection may be terminated prematurely. An alternative approach to collecting aquatic herbicide dissipation data lies in the use of concurrent applications of herbicide and the fluorescent dye rhodamine WT. This dye was developed specifically for water tracing and can be monitored and quantified *in situ* using a fluorometer. Several studies have shown significant correlations between the dissipation patterns of this dye and those of the aquatic herbicides fluridone, bensulfuron methyl, and endothall, when applied concurrently in the field.

**Vighi, M., D. Sandroni, C. S. Fioretti, and M. Trevisan. 1996. Modeling herbicide fate in paddy fields. The Environmental Fate of Xenobiotics. Proc. 10th Symposium Pesticide Chem., Castelnuovo Fogliani, Piacenza, Italy, pp 449-456.** Fugacity-based models were used to predict the environmental fate of herbicides (bensulfuron-methyl, benthiocarb [thiobencarb], dalapon sodium, flurenol, MCPA, molinate, propanil, oxadiazon, TCA sodium and triclopyr) applied to a rice crop in 1991 for weed control. A "paddy field scenario" was developed to describe the agricultural practices typical of the Vercelli rice district (northwestern Po Valley, Italy). Different models were used in relation to the different use patterns of herbicides. The SoilFug model was used for compounds applied on dry soil. A level III fugacity model was used for compounds applied on flooded fields. On the basis of data on herbicide use, load to the surface and groundwater systems was evaluate and an approximate mass balance was calculated to estimate the risk for the Po river. Promising results were obtained through a comparison with some available experimental data.

**Wilcock, R. J., K. J. Costley, R. J. Cowles, B. Wilson, and P. Southgate. 1991. Stream runoff losses and soil and grass residues of triclopyr applied to hillside gorse. New Zealand J. Agric. Res. 34: 351-358.** Gorse and pasture grass on a hillside area of 0.9 ha was sprayed with 3.57 kg acid equivalent of the butoxyethyl ester of triclopyr. Water from an adjacent stream was sampled continuously for 6 months, and soil and grass samples were collected 7 times over 8 months. Triclopyr residues were detected in three water samples and the largest mass was lost in the first significant rainfall of the study. A total of 103 ± 40g (2.9 ± 1.1%) of the amount applied, was lost in stream flow. No triclopyr residues were observed in samples taken at the catchment outlet. Soil half-life was about 100 days and was comparable with other values in the literature. The grass concentrations declined exponentially to yield half-lives of 30 days for the period 2-249 days after spraying. Concentrations of triclopyr in grass and soil samples taken from sites below large gorse bushes increased over the first 32 days but declined similarly to samples from exposed sites, after the first significant rainfall of the study.

**Woodburn, K. B., F. B. Batzer, F. H. White, and M. R. Schultz. 1993. The aqueous photolysis of triclopyr. Environ. Toxicol. and Chem. 12: 43-55.** The aqueous photolysis of triclopyr, a frequently used herbicide, was examined in both pH 7 buffered water and natural river water under artificial light and midsummer sunlight (40 °N latitude). The pseudo-first order half-lives in pH 7 buffered water and natural river water averaged 0.5 and 1.3 days, respectively, at 25°C. Diffuse mercury lamps and midsummer sunlight produced similar rates of triclopyr decay and photoproduct distribution for a given solution. The photolysis of untreated water produced a significantly different distribution of photoproducts compared to sterile, pH 7 buffered water. The photolysis of triclopyr in river water generated oxamic acid as the major photoproduct and a pH 7 buffered water produced 5-chloro-3,6-dihydroxy-2-pyridinyloxyacetic acid as the major photoproduct, with minor amounts of oxamic acid and other low-molecular-weight acids. These results indicate that photolysis of triclopyr is the principal degradation pathway in the aquatic environment, and low molecular weight, generally nonhalogenated carboxylic acids are produced in significant quantities in natural water.

**Woodburn, K. B., W. R. Green, and H. E. Westerdahl. 1993. Aquatic dissipation of triclopyr in Lake Seminole, Georgia. J. Agric. and Food Chem. 41: 2172-2177.** A field study was conducted to evaluate the environmental dissipation of triclopyr herbicide under aquatic-use conditions. Three 4 ha plots in Lake Seminole, Georgia, were selected for use: one control, one aerial plot, and one subsurface plot; both applications were at the maximum aquatic-use rate of 2.5 mg/L. Water, sediment, plants, fish, clams, and crayfish were all analyzed for residues, and water temperature, oxygen levels, pH, and conductivity were monitored. The half-life for aqueous-phase triclopyr ranged from 0.5 to 3.6 days, and the dissipation in surface and bottom waters was equivalent. The intermediate decay product of triclopyr, 3,5,6-trichloro-2-pyridinol (TCP), had an observed aquatic half-life of less than 1 day. No accumulation of triclopyr or TCP on sediment was observed. The half-life of triclopyr metabolized by aquatic plants averaged 4 days. Fish species did not exhibit any bioconcentration of triclopyr or TCP, with only trace amounts of either compound found in fish tissue. Both clams and crayfish contained detectable residues of triclopyr. The elimination of triclopyr from clam tissue was more rapid, with an observed half-life of 1.5 days, vs. 12 days for crayfish; retention of triclopyr in the crayfish carcass (carapace, chelopeds, and gills) may have been an important mechanism. There was no detectable decline in water quality in either treatment plot.

## FISH & AMPHIBIANS

**Abdelghani, A.A., P.B. Tchounwou, A.C. Anderson, H. Sujono, L.R. Heyer, and A. Monkiedje. 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 Toxicity and Water Quality. 12: 237-243.** The acute toxicity of individual and mixtures of three herbicides (2,4-D, Garlon-3A (a.i. triclopyr) and Roundup (a.i. glyphosate)) and a chemical additive (Syndets surfactant) was evaluated using three species of freshwater organisms (channel catfish, bluegill sunfish and crawfish). Among the three herbicides, Roundup was more toxic to catfish and bluegill than Garlon-3A and 2,4-D. The order of toxicity in fish (Roundup > Garlon-3A > 2,4-D) was reversed in bioassays with crawfish, indicating a significant difference in interspecies (vertebrate vs. invertebrate) biological variability. Adjusted 96-h LC50s were 14.5, 13.0 and 21,632.8 mg/litre for Roundup, 109.5, 91.0 and 6,397.5 mg/litre for Garlon-3A, and 181.2, 226.3 and 750.1 mg/litre for 2,4-D, for catfish, bluegill and crawfish, respectively. For Syndets surfactant, LC50 values of 1.9 mg/litre (bluegill), 2.3 mg/litre (catfish) and 15.2 mg/litre (crawfish) were recorded, indicating that this chemical additive was much more toxic than the three herbicides. Bioassays with herbicide mixtures resulted in combined toxic effects that were slightly antagonistic and/or additive. Lethal concentrations of herbicide mixtures were found to be lower than recommended field formulations, but it was anticipated that such hazardous amounts would be rarely reached in roadside ditches where the presence of large volumes of water is likely to provide dilutions to levels that may not pose a threat to aquatic life.

**Barron, M. G., M. A. Mayes, P. G. Murphy, and R. J. Nolan. 1990. Pharmacokinetics and metabolism of triclopyr butoxyethyl ester in Coho salmon. Aquatic Toxicol. 16:19-32.** The pharmacokinetics and metabolism of triclopyr butoxyethyl ester (BEE), a toxic element of the herbicide Garlon, were studied in yolk-sac fry of the Coho salmon (*Oncorhynchus kisutch*). Triclopyr BEE was rapidly absorbed from water, then rapidly de-esterified by the fish, which limited triclopyr BEE accumulation. Triclopyr acid was the principal metabolite observed in fish and exposure water, and was the principal residue in fish. A compartmental model describing the dynamics of triclopyr BEE and acid in fish and water allowed prediction of ester accumulation under various exposure regimes. The model indicated that a small fraction of ester escaping metabolism was transferred to a peripheral storage compartment. The slower terminal elimination of triclopyr BEE was due to transfer of ester back into the metabolic compartment, rather than slow metabolism. Exposure to triclopyr BEE in the presence of a carboxylesterase inhibitor had no effect on toxicity or total residue levels in the fish, but ester concentrations in the fish increased by seven times. The observed lack of change in triclopyr acid levels during esterase inhibition was predicted by the pharmacokinetic model, and indicated

that mortality resulted from lethal tissue concentrations of triclopyr acid or total residues.

**Berrill, M., S. Bertram, L. McGillivray, M. Kolohon, and B. Pauli. 1994. Effects of low concentrations of forest-use pesticides on frog embryos and tadpoles. Environ. Toxicol. Chem. 13: 657-664.** Management of coniferous forests of eastern Canada may involve spraying with the insecticide fenitrothion and the herbicides triclopyr and hexazinone. Because ranid frogs breed in ponds that are unavoidably contaminated by spraying, we measured the toxicity of these chemicals to embryos and tadpoles of *Rana pipiens* (leopard frog), *Rana clamitans* (green frog), and *Rana catesbeiana* (bullfrog) under lab conditions. Embryos were exposed during late neurula and tadpoles with 48 h after hatching to fenitrothion (24 h; 0.5-8.0 ppm), triclopyr (48 h; 0.6-4.8 ppm), and hexazinone (8 d; 100 ppm). We measured hatching success of embryos, and for tadpoles, mortality, ability to swim away when prodded, and total body length one week after exposure. Hexazinone had no effects on embryos or tadpoles, even at the unreasonably high levels to which they were exposed. Hatching success of embryos and subsequent avoidance behavior were unaffected in all species by exposures to triclopyr and fenitrothion. Newly hatched tadpoles of all species were very sensitive to 2.4 and 4.8 ppm triclopyr and to 4.0 and 8.0 ppm fenitrothion, either dying or remaining paralyzed following exposure. Tadpoles initially affected by exposure to lower concentrations of fenitrothion or triclopyr usually recovered within 1 to 3 d. Bullfrog and green frog tadpoles appear to be more sensitive than leopard frog tadpoles, and bullfrog tadpoles were consistently more sensitive than green frog tadpoles.

**Czerwinski. C. and R.L. Laughlin. 2000. Bioaccumulation of triclopyr in *Xenopus laevis*. Journal of the Pennsylvania Academy of Science. 73 ( Suppl. ): 153-154.**

**Getsinger, K.D., D.G. Petty, J.D. Madsen, J.G. Skogerboe, B.A. Houtman, W.T. Haller, and A.M. Fox. 2000. Aquatic dissipation of the herbicide triclopyr in Lake Minnetonka, Minnesota. Pest Management Science. 56: 388-400.** A study of the aquatic fate of the triethylamine salt of triclopyr was conducted in three bays of Lake Minnetonka, Minnesota (USA). The primary purpose of this study was to determine dissipation rates of the parent active ingredient, triclopyr, and its major metabolites, 3,5,6-trichloropyridinol (TCP) and 3,5,6-trichloro-2-methoxypyridine (TMP) in selected matrices including water, sediment, plants, fish and shellfish. Two 6.5-ha plots dominated by the weed species *Myriophyllum spicatum* were treated with 2.5 mg a.e. triclopyr\litre (2.5 ppm) on 21-23 June 1994. A third 6.5-ha plot was established as an untreated reference. Water and sediment samples were collected from within the plots and at selected locations up to 1600 m outside of the plots through six weeks post-treatment for chemical residue analysis. Residue samples were collected from the target and non-target plants and other non-target matrices, including game

and rough fish (*Micropterus salmoides, Lepomis macrochirus, Ictalurus nebulosus and Catostomus commersoni*), clams (*Lampsilis siliquoidea*) and crayfish (*Orocnectes virilis* and *O. immunis*). All test animals were sequestered in cages located in the centre of each plot and samples were collected during four weeks post-treatment. Half-lives for dissipation of triclopyr and TCP in water ranged from 3.7 to 4.7 days and from 4.2 to 7.9 days, respectively, with trace amounts of TMP found. Peak triclopyr sediment values ranged from 257 to 335 ng g-1, with a mean half-life of 5.4 days, while peak TCP sediment levels ranged from 27 to 65 ng g-1 (mean half-life=11.0 days). Trace levels of TMP were detected at one treatment site at one sampling event. Triclopyr and TCP accumulated and cleared from animal tissues proportionately to concentrations in the water (triclopyr dissipation half-lives<11 days, TCP<14 days). TMP levels were two to three times higher than those of the other compounds, particularly in visceral tissue. In all cases, residues of these compounds were higher in the inedible portions of the animals, and were usually higher in bottom-feeding fish species. The target plant, *M. spicatum*, accumulated triclopyr steadily until its death. The nontarget plant, *Potamogeton zosteriformis*, showed a much lower accumulation of triclopyr.

**Harpole, D.N. and C.A. Haas. 1999. Effects of seven silvicultural treatments on terrestrial salamanders. For. Ecol. Manage. 114: 349-356.**

**Janz, D. M., A. P. Farrell, J. D. Morgan, and G. A. Vigers. 1991. Acute physiological stress responses of juvenile Coho salmon (*Oncorhynchus kisutch*) to sublethal concentrations of Garlon 4, Garlon 3A, and Vision herbicides. Environ. Toxicol. and Chem. 10: 81-90.** Juvenile Coho salmon (*Oncorhynchus kisutch*) were exposed for 4 hr to sublethal concentrations of the herbicides Garlon 4 (butoxyethyl ester of triclopyr), Garlon 3A (triethylamine salt of triclopyr), and Vision (isopropylamine salt of glyphosate). Trials were performed in a closed-system respirometer that measured oxygen consumption of fish prior to and during a 4-hr exposure. At the end of the exposure period, plasma glucose and lactate concentrations, hematocrit, and leucocrit were measured as indicators of acute physiological stress. There were no biologically significant indications of acute physiological stress in fish exposed to Garlon 4, Garlon 3A, or Vision at 5-80% of the 96-hr $LC_{50}$ concentrations. The results suggest that threshold herbicide concentrations causing physiological stress in short-term exposure (4 hr) in juvenile Coho salmon may be higher than the 96-hr $LC_{50}$ value for those herbicides. It was concluded that sublethal concentrations of Garlon and Vision herbicides do not induce significant physiological stress responses in juvenile coho salmon during a 4-hr exposure period.

**Johansen, J. A. and G. H. Geen. 1990. Sublethal and acute toxicity of the ethylene glycol butyl ether ester formulation of triclopyr to juvenile Coho salmon (*Oncorhynchus kisutch*). Arch. Environ. Contam. Toxicol. 19: 610-6.** The

toxicity of Garlon 4, the ethylene glycol butyl ether ester formulation of the herbicide tryclopyr, to juvenile Coho salmon (*Oncorhynchus kisutch*) was investigated at several lethal and sublethal concentrations. Fish behavior, random activity and oxygen uptake were monitored. Coho salmon exhibited three distinct responses related to concentration and duration of exposure: (1) at concentrations greater than 0.56 mg/L fish were initially lethargic, then regressed to a highly distressed condition characterized by elevated oxygen uptake and finally death, (2) at 0.32-0.43 mg/L fish were lethargic throughout the exposure period with reduced oxygen uptake, and (3) at concentrations less than or equal to 0.10 mg/L fish were hypersensitive to stimuli, exhibiting elevated activity and oxygen uptake levels during photoperiod transitions. Whole body residue analysis showed that uptake of the ester and subsequent hydrolysis to the acid form in the fish was rapid, with significant accumulation of the acid in the tissues. This suggests that some threshold tissue concentrations were associated with the observed results. For juvenile Coho salmon the 96-hr $LC_{50}$ of Garlon 4 was 0.84 mg/L.

**Kreutzweiser, D. P. and S. S. Capell. 1992. A simple stream-side test system for determining acute lethal and behavioral effects of pesticides on aquatic insects. Environ. Toxicol. and Chem. 11: 993-999.** A test system was developed to measure direct lethal and behavioral effects of forest pesticides on stream insects under simulated natural conditions. The system successfully quantified drift response of 10 species of stream insects to various concentrations of permethrin, triclopyr, hexazinone, and *Bacillus thuringensis*. Drift responses ranged from no effect to total displacement of species. The procedure was also successful in elucidating differential responses to pesticide exposure by determining drift profiles during treatment. The effects of pesticide concentration on survival of test organisms was clearly demonstrated. For example, the survival of *Isogenoides* sp. and *Hydropsyche* sp. was significantly lower than that of control in both collectors and substrate sections of a test unit treated at 320 mg/L triclopyr, but there were no effects on survival in the test unit treated at 3.2 mg/L. Most experiments with the system have been short-term assessments, and these data are percentages of survival in untreated test units in 24 h. Several longer-term trials indicated 80% to 100% survival of 5 genera at 7 d after treatment.

**Kreutzweiser, D. P., D. G. Thompson, S. S. Capell, D. R. Thomas, and B. Staznik. 1995. Field evaluation of triclopyr ester toxicity to fish. Arch. Environ. Contam. Toxicol. 28: 18-26.** Two field experiments were conducted to assess the predictions of laboratory time-toxicity tests regarding lethal effects of triclopyr butoxyethyl ester (TBEE) on fish in standing and flowing water bodies. Large lake enclosures were treated with TBEE by backpack sprayer at concentrations of 0.25-7.6 mg/L, expressed as acid equivalents. Median dissipation times for TBEE in lake water ranged from 4-8 d. Effects of the treatments on survival and growth of caged rainbow trout were measured. All

trout died by 3 d at initial concentrations of 0.69-7.6 mg/L. There was 43% mortality of rainbow trout in the enclosure treated at 0.45 mg/L, and no mortality in the 0.25 mg/L enclosure or the controls. The treatments at the two lower concentrations had significant adverse effects on the growth rates of surviving trout. TBEE was applied to sections of a forest headwater stream at nominal concentrations of 0.8 mg/L and 2.7 mg/L. These concentrations represent maximum-expected environmental concentrations in 50- and 15-cm deep bodies of water, respectively, when directly oversprayed at an application rate of 3.84 kg/ha. Concentrations of TBEE were rapidly dissipated (as much as 70% decline within 55 m) and exposure periods at concentrations above 0.1 mg/L varied from 25 min in the low-concentration area to 55 min in the high-concentration area. The applications of TBEE at both initial test concentrations did not result in any mortality of resident brook trout. There were no significant effects of the herbicide treatments on the growth of 1+ and 2+ brook trout, but there were indications that the growth of 0+ trout was reduced as a result of exposure to TBEE in the stream. These results were in general agreement with the predictions of laboratory time-toxicity tests.

**Kreutzweiser, D. P., S. B. Holmes, and D. C. Eichenberg. 1994. Influence of exposure duration on the toxicity of triclopyr ester to fish and aquatic insects. Arch. Environ. Contam. Toxicol. 26: 124-129.** Flow-through toxicity tests were conducted to determine the effects of exposure time on the toxicity of triclopyr butoxyethyl ester (Garlon 4) to fish (rainbow trout and chinook salmon) and stream insects (*Hydropsyche* sp. and *Isonychia* sp.). The toxicity of triclopyr ester fish increased with increasing exposure duration. Median lethal concentrations for rainbow trout exposed for 1, 6, or 24h were 22.5, 1.95, and 0.79 mg/L triclopyr ester (expressed as acid equivalent, nominal concentrations), respectively. Comparable values for chinook salmon were 34.6, 4.7, and 1.76 mg/ L. The toxicity of triclopyr ester to aquatic insects also increased with increasing exposure time, but was considerably less than the toxicity to fish. There was no significant mortality of insects following 3-h exposures to the maximum test concentration of approximately 110 mg/L. Median lethal concentrations following 9- and 24-h exposures were 14.9 and 4.0 ml/L for *Hydropsyche* sp., and 37.0 and 8.8 mg/L for *Isonychia* sp., respectively. At each exposure time in the toxicity tests, there was a sharp increase in mortality over relatively small increases in concentration, resulting in extremely steep slopes of the probit lines (6.3-33.8), and indicating an apparent response threshold. The herbicide exhibited delayed lethal effects, particularly in fish, but only at short term exposures to higher concentrations. The risk of adverse effects on fish and aquatic insects from triclopyr ester contamination, based on the results of these time-toxicity tests, is discussed.

**Lautenschlager, R.A., F.W. Bell, R.G. Wagner, and P.E. Reynolds. 1998. The Fallingsnow Ecosystem Project: documenting the consequences of conifer release alternatives. Journal of Forestry. 96: 20-27.** An overview is

presented of the Fallingsnow Ecosystem Project, established in 1993 SW of Thunder Bay, Ontario, Canada, including the design, environmental components, and the initial results obtained. The Project was designed to document the terrestrial ecological consequences of alternative conifer release treatments. The ecosystem components studied are: soil chemistry, physics and morphology; below- and above-ground microclimates; below-ground fungi; vegetation, species composition, abundance, diversity, and foliar nutrient content; insects; terrestrial gastropods; amphibians and reptiles; small mammals; songbirds; and moose [Alces alces] area use and foods (production and storage). Although long-term responses are unknown, results to date indicate that cutting (with brush saws or tractor-mounted cutting heads) and herbicide (glyphosate or triclopyr) treatments are relatively inconsequential for most environmental components found in regenerating northern forests. It is suggested that given the growing opposition to herbicide use in forestry, managers must expect that social input into natural resource management will become more common, if not required.

**Lautenschlager, R.A., F.W. Bell, R.W. Wagner, and J.C. Neal. 1995. The Fallingsnow Ecosystem Project: comparing manual, mechanical, and aerial herbicide conifer release in northwestern Ontario. Proceedings of the forty-ninth annual meeting of the Northeastern Weed Science Society, Boston, Massachusetts, USA, 1995. 144-145.** The initial findings of a field study conducted in a conifer [Pinopsida] forest in northwestern Ontario to assess the effects of glyphosate and triclopyr, manual cutting and mechanical cutting on soil factors, vegetation, below and above ground insects, amphibia, reptiles, moose [*Alces alces*] and deer are presented.

**Leveille, P., J. Legris, G. Couture, R. Langevine. 1995. Evaluation of the effects of triclopyr used in forestry. [Evaluation des impacts du triclopyr utilise dans le milieu forestier.]. Ministere des Ressources Naturelles. Quebec, Canada. x + 98 pp.; Publication No. RN95-3084. French**. An account is given of the chemical composition, biological action, toxicology, degradation and decomposition in air, soil, water, flora and fauna (including human), and effects on vegetation, fauna and humans, of the herbicide triclopyr.

**Lickly, T. D. and P. G. Murphy. 1987. The amount and identity of carbon-14 residues in bluegills (*Lepomis macrochirus*) exposed to carbon-14 triclopyr. Environ. International 13: 213-218.** The level and identity of ($^{14}$C) residues in bluegills (*Lepomis macrochirus*) exposed to 2.5 mg/L ($^{14}$C) triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid) have been determined. The highest level of radioactivity observed in the flesh of a fish at any time point (0.13 mg/kg, calculated as equivalent mg triclopyr/kg fish) was less than 5% of the fish exposure level of 2.5 mg/L, while the maximum level in the remainder (head, skin, and viscera) was about 95% (2.33 mg/kg) of the fish exposure level, indicating no concentrating effect. The principal components observed in the

fish tissues were triclopyr, 3,5,6-trichloro-2-pyridinol, 2-methoxy-3,5,6-trichloropyridine and a conjugate. These components accounted for greater than 75% of all the residues observed.

**Mayes, M. A., D. C. Dill, K. M. Bodner, and C. G. Mendoza. 1984. Triclopyr triethylamine salt toxicity to life stages of the fathead minnow (*Pimephales promelas* Rafinesque). Bull. Environ. Contam. and Toxicol. 33: 339-347.** The study included a 96 hr static acute test, a 192 hr flow-through acute test and a 31 day embryo-larval test. The static acute $LC_{50}$ and 95% confidence interval (CI) was determined to be 245 (224-269) mg/L; the flow through 96 and 192 hr $LC_{50}$ values with 95% CI were 120 (104-140) mg/L and 101 (88.5-116) mg/L, respectively. Larval survival varied in the embryo larval tests nonsystematically except at the 114 mg/L level where survival dropped precipitously and was significantly different from the controls. Triclopyr TEA salt appears to be relatively non-toxic to fathead minnows. The concentration of the compound which is toxic to the fathead minnow is well above expected environmental concentrations. Comparison of the acute and embryo-larval toxicity data indicate triclopyr TEA salt has little cummulative or chronic effect on the fathead minnow.

**McCall, P. J., D. A. Laskowski, H. D. Bidlack, and M. J. Mac. 1988. Simulation of the aquatic fate of triclopyr butoxyethyl ester and its predicted effects on Coho salmon. Environ. Toxicol. and Chem. 7: 517-527.** Mathematical simulations of the dissipation of triclopyr butoxyethyl ester in a model aquatic system representing a shallow, static pond were conducted. Aqueous hydrolysis, sorption to bottom sediment, hydrolysis in sediment and photolysis were considered in predicting aqueous concentration-time profiles. Potential concentrations in Coho salmon were evaluated as part of the model based on rate constants for uptake, hydrolysis and elimination as determined in laboratory investigations conducted in other studies. Predicted chemical concentrations in the fish were then related to toxicity data to estimate aqueous concentrations in the model environment required to give a toxic response. In general, the simulations showed that the ester concentration in the pond water would decline, with an approximate half-life of 6 to 24 hours. Initial ester concentrations of 1.0 to 1.5 mg/L in this simulated pond environment would be required to result in chemical concentrations in fish above toxic threshold levels.

**Morgan, J. D., G. A. Vigers, A. P. Farrell, D. M. Janz, and J. F. Manville. 1991. Acute avoidance reactions and behavioral responses of juvenile rainbow trout *(Oncorhynchus mykiss*) to Garlon 4, Garlon 3A and Vision herbicides. Environ. Toxicol. and Chem. 10: 73-79.** Laboratory bioassay experiments were conducted with juvenile rainbow trout *(Oncorhynchus mykiss*) to determine the acute lethal (96-hr $LC_{50}$) values of the forest-use herbicides Garlon 3A (triethylamine salt of triclopyr), Garlon 4 (butoxyethyl

ester of triclopyr), and Vision (isopropylamine salt of glyphosate) with 15% and 10% surfactant formulations, and the threshold concentrations of these herbicides that would cause behavioral effects. A Y-maze apparatus was used to determine the threshold concentration of each herbicide that elicited either an avoidance or a preference reaction from rainbow trout fry after a 1-hr exposure period. Rainbow trout fry were observed for qualitative behavioral changes (e.g., increased coughing and ventilatory rates, loss of equilibrium, etc.) over a four-day period of exposure to a wide range of chemical strengths. Nominal concentrations of the herbicides eliciting threshold avoidance reactions in test fish were 150 ppm Vision-10% surfactant, 54 ppm Vision-15% surfactant, 19.2 ppm Garlon 4, and 800 ppm Garlon 3A, which were, respectively, 2, 2, 8, and 2 times the 96-hr $LC_{50}$ values determined for each herbicide. Preferential reactions to the herbicide solutions were not observed. Qualitative behavioral changes were observed in rainbow trout fry at levels from 25% (Garlon 4) to 50% (Garlon 3A, Vision-10% and-15% surfactants) of the 96-hr $LC_{50}$ values. Nominal concentrations of the herbicides causing threshold changes in fish behavior were 37.5 ppm Vision-10% surfactant, 13.5 ppm Vision-15% surfactant, 0.60 ppm Garlon 4, and 200 ppm Garlon 3A.

**Perkins, M.J. 1997. Effects of two formulations of glyphosate and triclopyr on four non-target aquatic species: *Xenopus laevis, Myriophyllum sibiricum, Lemna gibba* and *Tubifex tubifex*. University of Guelph, 1997. 110 p.** The effects of two formulations of glyphosate (N-(phosphonomethyl)glycine): Roundup® (formulated with the surfactant, polyoxyethyleneamine) and Rodeo® (formulated without polyoxyethyleneamine) and triclopyr (((3.5.6-trichloro-2-pyridinyl)oxy)acetic acid): Garlon 4® (butoxyethyl ester) and Garlon® 3A (triethylamine salt) on four non-target aquatic species were considered in this study. There was a significant effect of formulation on the toxicity of both glyphosate and triclopyr to *X. laevis* with LC50's of 22 mg ae/L, 9870 mg ae/L, 14 mg ae/L, and 750 mg ae/L for Roundup® Rodeo® Garlon 4® and Garlon® 3A, respectively. An effect of formulation was also observed on the toxicity of glyphosate and triclopyr to *T. tubifex*. Roundup® and Garlon 4® at concentrations of 52 mg ae/L and 86 mg ae/L resulted in significant effects on reproduction and mortality, respectively. Whereas, no significant effects with either Rodeo® or Garlon® 3A were noted at concentrations up to 106 mg ae/L and 17 mg ae/L, respectively. In contrast, there was no consistent effect of formulation on the sensitivity of *M. sibiricum* or *L. gibba* to these herbicides. *M. sibiricum* was more sensitive to both herbicides than *L. gibba.*

**Perkins, P.J., H.J. Boermans, and G.R. Stephenson. 2000. Toxicity of glyphosate and triclopyr using the frog embryo teratogenesis assay - Xenopus. Environmental Toxicology and Chemistry. 19: 940-945; 21.** The effects of glyphosate and triclopyr on the embryonic development of *Xenopus laevis* were evaluated using the frog embryo teratogenesis assay - Xenopus (FETAX).

Rodeo R, the isopropylamine (ipa) salt of glyphosate formulated without a surfactant was found to be the least toxic, with a LC5 and LC50 of 3,779 and 5,407 mg acid equivalent (AE)/L, respectively. The LC5 and LC50 of Roundup R, the ipa salt of glyphosate formulated with a surfactant, was 6.4 and 9.4 mg AE/L, respectively. The surfactant component of Roundup, polyoxyethyleneamine (POEA), had a LC5 and LC50 of 2.2 and 2.7 mg/L, respectively. Garlon R 3A, the triethylamine salt of triclopyr, had a LC5 and LC50 of 119 and 162.5 mg AE/L, respectively. The LC5 and LC50 of Garlon 4 R, the butoxyethyl ester of triclopyr, was 6.7 and 9.3 mg AE/L, respectively. Considering a theoretical worst case scenario when the highest rates recommended for glyphosate (12 L of Roundup/ha) or triclopyr (8 L of Garlon/ha) are applied to water 15 cm in depth, the expected environmental concentrations calculated on the basis of AE would be 2.8 and 2.6 mg AE/L, respectively. The margins of safety (LC5/expected environmental concentrations) for frog embryos exposed to these concentrations would be approximately 2, 2, 47, and 1,312 for Roundup, Garlon 4, Garlon 3A, and Rodeo, respectively.

**Sassaman, J. F., R. Pienta, M. Jacobs, J. Cioffi. 1984. Pesticide background statements. Vol. 1. Herbicides. 909 pp.** The individual Herbicide Background Statements have been compiled to provide a comprehensive review of the available information concerning the use, chemistry, toxicology, environmental fate, and comparative hazard of the herbicides in forest applications. References to the published literature at the end of each background statement are provided for those individuals who wish to independently evaluate the toxicological data and environmental fate information that is presented in summary form. In many instances, secondary sources, such as review articles, handbooks, and company technical data sheets, were used. Wherever possible in these instances, the primary source was also indicated and referenced, although it may not have been examined. Herbicides included in the document are: amitrole, atrazine, 2,4-D, 2,4-DP,dalapon, dicamba, fosamine ammonium, glyphosate, hexazinone, picloram, simazine, and triclopyr.

**Sawit, V. 1986. Toxicities of triclopyr to fish *Tilapia nilotica* Linn. and warm blooded animals. Research Report 1984: Rubber, Sericulture, Farming System Department of Agriculture, Bangkok (Thailand). pp. 420.**

**Sawit, W. 1985. Toxicities of triclopyr to fish *Tilapia nilotica* Linn. and warm blooded animals. Department of Agriculture, Bangkok (Thailand). pp. 75.**

**Servizi, J. A., R. W. Gordon, and D. W. Martens. 1987. Bull. Environ. Contam. and Toxicol. 39:15-22.** In laboratory studies with Garlon 4 (triclopyr), the mean 96 h $LC_{50}$ for *Oncorhynchus nerka* was 1.3 mg/litre at 4.5□C and pH 7.9 and for both *O. kisutch* and *Salmo gairdneri* it was 2.2 mg/litre at 15□C and pH 6.2, while the 96 h $EC_{50}$ for *Daphnia pulex* was 1.2 mg/litre at 21□C and pH

7.5. *O. nerka* fingerlings and fry were equally susceptible to Roundup (glyphosate), the 96 h $LC_{50}$ averaged 27.7 mg/litre at 4.2-4.5□C and pH 7.7-8.0. For *D. pulex* the 96 h $EC_{50}$ for Roundup was 25.5 mg/litre at 21□C and pH 7.3. Based on tests using Roundup in weakly buffered water (pH 4.8-6.2 after addition of the herbicide), the average 96 h $LC_{50}$ for *S. gairdneri* was 26.8 mg/litre at 14.5-15.0□C and for *O. kisutch* it was 42.0 mg/litre at 15.0□C. Since Roundup contains glyphosate and the wetter MON 0818, the acute toxicities and interaction of these compounds were studied. For glyphosate the 96 h $LC_{50}$'s were 106 and 962 mg/litre for *Salmo* and *Daphnia*, respectively (species, temperature and pH not specified). For MON O818 the 96 h $LC_{50}$ was 2.0-3.5 mg/litre for *Daphnia, O. nerka, O. kisutch* and *S. gairdneri* at 5.2-21.0□C and pH 6.2-7.9. Glyphosate appeared to antagonize MON 0818 toxicity in certain experiments, but using *S. gairdneri* fry in reconstituted water the combined effect of glyphosate and MON 0818 was more than additive.

**Thompson, D. G., B. Staznik, D. D. Fontaine, T. Mackay, G. R. Oliver, and J. Troth. 1991. Fate of triclopyr ester (Release) in a boreal forest stream. Environ. Toxicol. and Chem. 10: 619-623.** The fate of triclopyr was investigated in 1987 in Ontario following direct aerial application to a boreal forest stream. The average deposit monitored at the stream surface was 3.67 kg/ha (range = 3.35-3.99 kg/ha). Residues of triclopyr as the butoxyethyl ester (TBEE), triclopyr acid (TRI) and pyridinol metabolite (PYR) were determined in various aquatic substrates. Stream water residues of TBEE resulting from direct overspray were characterized by instantaneous maxima (0.23-0.35 mg/litre). A series of diminishing pulses of chemical associated with inputs upstream of the sampling site were observed. Average concentration of TBEE in stream water ranged from 0.05 to 0.11 mg/litre during the first 12-14 hours post-application and declined to levels below the limits of quantification (0.001 mg/litre) within 72 hour post-application. Transient residues of TRI were observed in stream water, with a maximum concentration (0.14 mg/litre) 6 hour post-application. The PYR residues did not exceed limits of quantification (0.05 mg/litre) in any sample.

**VandenKooy, A.P. and J.S. Smith. 2000. The induction of glutathione-S-transferase (GST) in the liver of *Notemigonus chrysoleucas* in response to the herbicides glyphosate and triclopyr. Journal of the Pennsylvania Academy of Science. 73 ( Suppl. ): p 182.**

**Wan, M. T., D. J. Moul, and R. G. Watts. 1987. Acute toxicity to juvenile Pacific salmonids of Garlon 3A, Garlon, triclopyr, triclopyr ester, and their transformation products: 3,5,6-trichloro-2-pyridinol and 2-methoxy-3,5,6-trichloropyridine. Bull. Environ. Contam. and Toxicol. 39: 721-728.** Herbicide toxicity tests were conducted with the following juvenile salmonids in 35-litre aquaria: *Oncorhynchus kisutch, O. tshawytscha, O. keta, O. gorbuscha, O. nerka* and *Salmo gairdneri*. Garlon 4 (triclopyr butoxyethyl ester

48% a.e.) was highly toxic (average <96-h $LC_{50}$ 347 ± 44 mg/litre), but Garlon 3A (triclopyr triethylamine 36% a.e.) was considerably less toxic to the salmonids (average 96-h $LC_{50}$ 2.0 ± 0.2). Of the 2 triclopyr degradation products, 3,5,6-trichloro-2-pyridinol was as toxic as Garlon 4, while 2-methoxy-3,5,6-trichloropyridine seemed more toxic to young *O. gorbuscha* than to the other salmon species tested. The emulsifiers used in the formation of Garlon 3A and Garlon 4 appeared unlikely to increase fish toxicity.

**Wan, M. T., R. G. Watts, and D. J. Moul. 1988. Evaluation of the acute toxicity of juvenile Pacific salmonids of hexazinone and its formulated products, Pronone 10G, Velpar L and their carriers. Bull. Environ. Contam. and Toxicol. 41: 609-616.** Acute 96-h $LC_{50}$ of technical hexazinone to juvenile Pacific salmonids (*Oncorhynchus* spp.) averaged 276 mg/litre, compared with 1686 and 904 mg for granular and liquid formulations of hexazinone, Pronone 10G and Velpar L, respectively. Average 24-h $LC_{50}$'s were 17, 21 and 14% higher, respectively. The results indicate that the carriers in the 2 formulated products decrease the toxicity of hexazinone to fish. Though hexazinone is not as toxic as triclopyr to juvenile Pacific salmonids, it has the potential to affect the riparian vegetation of salmon habitat.

**Wan, M. T., R. G. Watts, and D. J. Moul. 1991. Acute toxicity to juvenile Pacific Northwest salmonids of Basacid Blue NB755 and its mixture with formulated products of 2,4-D, glyphosate, and triclopyr. Bull. Environ. Contam. and Toxicol. 47: 471-478.** Basacid Blue NB755 (BB) is a triphenylmethane dye used as a marker during aerial and ground herbicide spraying operations in forestry. Concern about its possible toxicity to salmonids led to an attempt to determine the acute toxicity to juvenile Pacific Northwest salmonids of BB and its mixture with formulated products of 2,4-D, glyphosate, and triclopyr in different sources of dilution water. A series of 96-hr static acute toxicity tests was conducted in fresh water using *Onchorhynchus kisutch, O. tshawytsha, O. keta, O. gorbuscha*, and *O. mykiss* obtained from British Columbia hatcheries. Dilution waters were soft, with acid pH, hard, with alkaline pH, and intermediate. The bioassay indicated that BB dye is quite toxic to salmonids, particularly in soft water. The dye (without herbicides) is not likely to have an acute impact on salmonids at the rates commonly used by foresters. However, the use of this dye as an indicator at the rate of 100 mg/L in spray mixtures increases the toxicity to young salmon of formulated products of 2,4-D amine, 2,4-D ester, Garlon 4 (triclopyr, except in intermediate water), but not Roundup (glyphosate) irrespective of water type. It is suggested that the use of BB dye indicator for Roundup ground and aerial operations should not exceed 100 mg/L (equivalent to 8 mL BB NB755 per 100 L spray mixture) per spray mixture load of 100 L.

**Wan, M.T. 1987. The persistence of triclopyr and its pyridinol metabolite in a coastal British Columbia stream. Regional Program Report #86-24.**

**Department of the Environment, Pacific and Yukon Region, West Vancouver, British Columbia, Canada.**

**Wood K. and C. Hollstedt (compiled by). 1995. Fallingsnow Ecosystem Workshop: program and abstracts. Workshop proceedings / Ontario. Ministry of Natural Resources. WP-001, Vegetation Management Alternatives Program, 1995. xv, 54 p.** The Fallingsnow Ecosystem Project, which is providing data on the ecological impacts of alternative vegetation management practices, is being conducted on a regenerated spruce plantation near Thunder Bay, Ontario. Four treatments have been applied at the study site in a randomized block design: manual brushing; mechanical site treatment; aerial application of glyphosate or triclopyr herbicides; and control (no treatment). Environmental variables examined include soil characteristics and biodiversity; below- and above-ground temperature and moisture; vegetation species composition and foliar nutrient content; below- and above-ground insects; terrestrial gastropods; amphibians and reptiles; small mammals; songbirds; moose and deer area use, and foods (production and quality). This report contains presentations from a workshop held to transfer to resource managers the most recent scientific information produced from this project.

**Zucker, E. 1985. Acute toxicity test for freshwater fish. U.S. Environmental Protection Agency, EPA-540/9-85-006.**

## HUMAN TOXICOLOGY

**Baker, L., R. Tomin, and D. Fitzell. 1993. Air monitoring of herbicide applications. Proc. For., Veg. Manage. Conf., Redding. Calif. pp. 41-43.**

**Bush, P. B., D. G. Neary, C. K. McMahon, and J. W. Taylor, Jr. 1987. Suitability of hardwoods treated with phenoxy and pyridine herbicides for use as firewood. Arch. Environ. Contam. and Toxicol. 16: 333-342.** Potential exposure to pesticide residues resulting from burning wood treated with phenoxy and pyridine herbicides was assessed. Wood samples from trees treated with 2,4-D (2,4-dichlorophenoxy acetic acid), dicamba (3,6-dichloro-o-anisic acid), dichlorprop (2- (2,4-dichlorphenoxy) propionic acid), picloram (4-amino-3,5,6-trichloropicolinic acid), and triclopyr (3,5,6-trichloro-2-pyri-dinyl)oxy acetic acid contained variable amounts of parent compound residues at 4, 8, and 12 months after application. At the time of the latter sampling, residues of 2,4-D, dicamba, and picloram were 2.1 mg/kg on a fresh weight basis. Mean residue concentrations of triclopyr and dichlorprop were somewhat higher at 3.5 and 13.0 mg/kg, respectively. In a laboratory experiment, samples with known amounts of herbicide residue were subjected to either slow or rapidly burning conditions in a tube furnace. During slow combustion, relatively stable compounds such as 2,4-D, dicamba, and dichlorprop were released in significant amounts. Rapid combustion greatly enhanced decomposition of 2,4-D, dicamba, dichlorprop, picloram, and triclopyr. A well-developed fire in a wood stove or fireplace, with active flaming combustion, where temperatures commonly reach 800-1,000°C, should result in greater than 95% thermal decomposition of the herbicides examined in this study. Burning of herbicide-treated wood under smoldering conditions could result in very low levels of herbicide residue in ambient indoor air. However, the exposure levels are less than 0.3% of the threshold limit value for 2,4-D and triclopyr. The exposure is also more than 3 orders of magnitude lower than the established acceptable daily intakes for these products.

**Carmichael, N. G. 1989. Assessment of hazards to workers applying pesticides. Food Addit. Contam. 6 Suppl 1, PS21-7.** Exposure to pesticides as a result of their use in agriculture will vary according to the type of formulation, the method of application and the protective measures used. Quantitation of external exposure does not on its own predict the amount absorbed nor does it allow the toxic hazard to be assessed; information on skin penetration is also required. With the use of a suitable generic database for exposure, the assessment of many compounds would only require the measurement of skin penetration. With the knowledge of human dermal pharmacokinetics a field study can be performed which measures the absorbed dose directly and avoids the need for exposure measurement.

**Carmichael, N. G., R. J. Nolan, J. M. Perkins, R. Davies, and S. J. Warrington. 1989. Oral and dermal pharmacokinetics of triclopyr in human volunteers. Human Toxicol. 8: 431-438.** Blood levels and urinary excretion of triclopyr, the active ingredient in Garlon herbicides, were followed in six volunteers given single doses of 0.1 and 0.5 mg/kg body weight. Five of these volunteers later received dermal applications of Garlon 4 herbicide formulation equivalent to 3.7 mg triclopyr/kg body weight applied to the forearm. Following oral administration blood levels peaked at 2-3 h and declined to undetectable levels within 48 h; more than 80% of the dose was found as unchanged triclopyr in the urine. A two-compartment pharmacokinetic model was used to describe the time-course of triclopyr clearance; half-lives for the rapid initial and slower terminal phases were 1.3 h and 5.1 h respectively, and were independent of dose. Due to the slow half-life for determal absorption ($t_{1/2}$ = 16.8 h) the rapid initial elimination phase was obscured and the pharmacokinetics could be simplified by a one-compartment model. An average of 1.37% of the applied dose was recovered in the urine; when corrected for recovery after oral administration this was equivalent to an absorption of 1.65%. Triclopyr is slowly absorbed through skin and is rapidly eliminated. It has very low potential to accumulate in man or to be absorbed through the skin in acutely toxic amounts.

**De'ath, M. R. 1988. Triclopyr - a review of its forestry and industrial weed control uses. Aspects Applied Biology. 16: 183-188.** The toxicology, soil behaviour, mode of action and use of triclopyr for forest and industrial weed control is reviewed briefly.

**Hotchkiss, S. A. M., P. Hewitt, J. Caldwell, W. L. Chen, and R. R. Rowe. 1992. Percutaneous absorption of nicotinic acid, phenol, benzoic acid and triclopyr butoxyethyl ester through rat and human skin *in vitro*: Further validation of an *in vitro* model by comparison with in vivo data. Food and Chem. Toxicol. 30: 891-899.** The *in vivo* percutaneous absorption of three model compounds, nicotinic acid, phenol and benzoic acid, and the herbicide triclopyr butoxyethyl ester (triclopyr BEE) has been investigated in flow-through diffusion cells using skin from male Fischer 344 rats and humans. After the application of four chemicals to the epidermal surface of unoccluded full-thickness rat skin, the absorption of each compound across the skin and into the receptor fluid at 72 hr reached 3.7 ± 0.3, 5.7 ± 0.6, 26.7 ± 3.7 and 48.3 ± 1.2% (mean ± SD, n = 2-7) of the applied dose for triclopyr BEE, nicotinic acid, phenol and benzoic acid, respectively. After the application of the four chemicals to the epidermal surface of unoccluded full-thickness human skin, the absorption of each compound across the skin and into the receptor fluid at 72 hr was significantly ($P < 0.05$) less than through rat skin, reaching 0.7 ± 0.1, 0.7 ± 0.2, 18.8 ± 1.3 and 37.8 ± 6.9% (mean ± SD, n = 2-7) of the applied dose for triclopyr BEE, nicotinic acid, phenol and benzoic acid, respectively. Occlusion of the skin surface with teflon caps often significantly ($P < 0.05$)

enhanced the percutaneous absorption of the model compounds, although this effect was not uniform, varying with the compound under study and the skin (rat or human) used. When rat skin was occluded with teflon caps, the extent of absorption at 72 hr reached 8.6 ± 0.8, 36.2 ± 1.7 and 51.8 ± 3.3% (mean ± SD, n = 3-4) for nicotinic acid, phenol and benzoic acid, respectively. Corresponding values for human skin occluded with teflon caps were 3.3 ± 1.6, 47.1 ± 0.5 and 65.5 ± 7.1% (mean ± SD, n = 3-4). The experiments on the absorption of each model compound through rat and human skin were repeated and there was generally good agreement between the results from the two sets of experiments. The *in vitro* data reported compare favorably with data obtained by other workers using both *in vitro* and *in vivo* methodologies. The *in vitro:in vivo* correlation supports the use of the flow-through diffusion cell system as a model for the prediction of percutaneous absorption *in vivo* in the rat and in humans.

**Johnson, E. M. 1987. A tier system for developmental toxicity evaluations based on considerations of exposure and effect relationships. Teratology 35:405-427.**

**Kale, P. G., B. T. Petty, Jr., W. Walker, J. B. Ford, N. Dehkordi, S. Tarasia, B. O. Tasie, R. Kale, and Y. R. Sohni. 1995. Mutagenicity testing of nine herbicides and pesticides currently used in agriculture. Environ. and Molecular Mutagenesis. 25: 148-153.** Nine pesticides (permethrin, trifluralin, acifluorfen[-sodium], glyphosate as either Roundup or Pondmaster, 2,4-D, Crossbow [triclopyr], chlordimeform and prometon) were tested for their mutagenicity using the *Drosophila* sex-linked recessive lethal mutation assay. Unlike adult feeding and injection assays, the larvae were allowed to grow in medium with the test chemical, thereby providing long and chronic exposure to the sensitive and dividing diploid cells, i.e., mitotically active spermatogonia and sensitive spermatocytes. All chemicals induced significant numbers of mutations in at least one of the cell types tested. As some of these compounds gave negative results in earlier studies, an explanation for the difference in results is provided. It is probable that different germ cell stages and treatment regimes are suitable for different types of chemicals. It is concluded that larval treatment may still be valuable and can complement adult treatment in environmental mutagen testing.

**Leveille, P., J. Legris, G. Couture, and R. Langevine. 1995. Evaluation of the effects of triclopyr used in forestry. Pub. No. RN95-3084; Ministere des Ressources Naturelles; Quebec; Canada. 18 p.** An account is given of the chemical composition, biological action, toxicology, degradation and decomposition in air, soil, water, flora and fauna (including human), and effects on vegetation, fauna and humans, of the herbicide triclopyr.

**McMahon, C. K. and P. B. Bush. 1992. Forest worker exposure to airborne herbicide residues in smoke from prescribed fires in the southern United States. Amer. Indus. Hygiene Assoc. J. 53: 265-272.** Occupational safety and health concerns have been raised in a number of southern states by workers conducting prescribed burns on forest lands treated with herbicides. Modeling assessments coupled with laboratory experiments have shown that the risk of airborne herbicide residues to workers is insignificant, even if the fire occurs immediately after herbicide application. However, no field studies had been conducted to confirm these findings. To bridge that gap, a field validation study was conducted in Georgia to measure breathing zone concentrations of smoke suspended particulate matter (SPM), herbicide residues, and carbon monoxide (CO) on 14 operational prescribed fires. Smoke was monitored on sites treated with labeled rates of forestry herbicides containing the active ingredients imazapyr, triclopyr, hexazinone, and picloram. The sites were burned within 30-169 days after herbicide application. Tract size ranged from 2.4 to 154 hectares. Personal monitors and area monitors employing glass fiber filters and polyurethane foam collection media were used. No herbicide residues were detected in the 140 smoke samples from the 14 fires conducted in this study. The sensitivity of the monitoring methods was in the 0.1 to 4.0 $\mu g/m^3$ range, which is several hundred to several thousand times less than any established occupational exposure limit for herbicides. The SPM and CO monitored on these fires is the first time breathing zone concentrations of these smoke constituents have been measured in the South. As expected, concentrations were highly variable depending on fire conditions and the location of personnel. Worker respirable (2.3 $\mu$ particle cut point) SPM concentrations ranged between 0.2 and 3.7 $mg/m^3$.

**McMahon, C. K., P. B. Bush, and T. G. Rials. 1994. Evaluation of worker respiratory exposure to herbicide residues in prescribed fire smoke: A preliminary report. Symposium on current research in the chemical sciences. Third Annual Southern Station Chemical Sciences Meeting, Alexandria, Louisiana, 7-8 February 1990. General Technical Report, Southern Forest Experiment Station, USDA Forest Service, No. SO-101. pp. 37-41.** Concentrations of smoke particles, herbicide residues and carbon monoxide were measured during 14 operational site-preparation prescribed fires on forest sites in Georgia which had been treated with labelled rates of imazapyr, triclopyr, hexazinone or picloram 30-169 days before burning.

**Middendorf, P., C. Timchalk, B. Kropscott, and D. Rick. 1992. Forest worker exposures to triclopyr butoxyethyl ester during directed foliar applications of Garlon 4 herbicide. Proc. 45$^{th}$ Annual Meeting Southern Weed Sci. Soc. pp. 177-185.** Exposure of forest workers to triclopyr over 1 working day while mixing and applying a directed 3% foliar spray by backpack sprayer was assessed for teams of workers at 4 sites by monitoring inhalation and dermal exposures over 1 test day and urine triclopyr levels over 5 days. The overall

geometric mean of the biomonitored dose of triclopyr was 1106 µg, with the dermal route giving 86.2% of the total estimated dose; 6 of 21 workers had doses >1% of the no-observed-effect level. An analysis of factors contributing to higher doses included consideration of weather, site conditions, gloves, training and experience, equipment, mixing, adjuvant and tobacco use; it was concluded that vegetation density and height, training and experience, gloves, mixing procedures and equipment maintenance influence exposure to triclopyr.

**Moriya, M. T. Ohta, K. Watanabe, T. Miyazawa, K. Kato, and Y. Shirasu. 1983. Further mutagenicity studies on pesticides in bacterial reversion assay systems. Mutat. Res. 116:185-216.**

**Samuel, O., L. Houde, and D. Phaneuf. 1994. Evaluation of risks to human health attributable to the use of triclopyr in a forest environment.** An assessment was made of the potential risks to human health associated with the use of the phytocide Release® in forest regeneration maintenance operations (basal bark application). In general, worker exposure to triclopyr is low if the recommended safety measures are complied with. However, further information is required before firm conclusions can be drawn as to health risks associated with the use of triclopyr. The amounts of triclopyr used should not constitute a risk to public health.

**Sassaman, J. F., R. Pienta, M. Jacobs, and J. Cioffi. 1984. Pesticide background statements. Vol. 1. Herbicides. 909 pp.** The individual Herbicide Background Statements have been compiled to provide a comprehensive review of the available information concerning the use, chemistry, toxicology, environmental fate, and comparative hazard of the herbicides in forest applications. References to the published literature at the end of each background statement are provided for those individuals who wish to independently evaluate the toxicological data and environmental fate information that is presented in summary form. In many instances, secondary sources, such as review articles, handbooks, and company technical data sheets, were used. Wherever possible in these instances, the primary source was also indicated and referenced, although it may not have been examined. Herbicides included in the document are: amitrole, atrazine, 2,4-D, 2,4-DP, dalapon, dicamba, fosamine ammonium, glyphosate, hexazinone, picloram, simazine, and triclopyr.

**Segawa, R., A. Bradley, P. Lee, D. Tran, J. Hsu, J. White, and K.S. Goh. 1997. Residues of forestry herbicides in plants of importance to California native Americans. Bulletin of Environmental Contamination and Toxicology. 59: 556-563.** The monitoring results are reported for herbicide residues in 13 plant species collected from inside and outside treatment areas in 4 National Forests in California following ground applications of 1.0-1.5 lbs/acre glyphosate and 3.0-3.5 lbs triclopyr and aerial or ground applications of 1.0-1.5 lbs hexazinone. From within the treatment area, 45 out of 92 samples contained detectable

residues while the figure for outside this area was 4 out of 119. Glyphosate, hexazinone and triclopyr residues were found in 52, 47 and 50%, and 5, 2 and 3% of samples inside and outside the treatment areas, respectively. However, residues were found in 94 and 15% of samples taken from plots subjected to aerial (broadcast over the entire plot) and ground (direct on individual trees) treatment with hexazinone, respectively.

**Shackelford, D.D., D.L. Young, C.A. Mihaliak, B.A. Shurdut, and J.A. Itak. 1999. Practical immunochemical method for determination of 3,5,6-trichloro-2-pyridinol in human urine: applications and considerations for exposure assessment. Journal of Agricultural and Food Chemistry. 47: 177-182.** An analytical method is described for the quantitative determination of 3,5,6-trichloro-2-pyridinol (3,5,6-TCP), the primary analyte found in urine as a result of exposure to chlorpyrifos, chlorpyrifos-methyl and triclopyr. Conjugates of 3,5,6-TCP are released from urine by acid hydrolysis. Free 3,5,6-TCP is then purified using C18 solid-phase extraction, eluting the analyte with 1-chlorobutane. An aliquot of 1-chlorobutane is placed in a vial containing Trichloropyridinol Sample Diluent and evaporated, leaving 3,5,6-TCP in the aqueous sample diluent. The samples are assayed using the Trichloropyridinol RaPID Assay immunoassay test kit. Final results are calculated using a standard curve constructed by linear regression after a ln/Logit data transformation is performed of the concentration and the absorbance readings, respectively. The calculated lower limit of quantitation for 3,5,6-TCP in fortified control urine samples is 2.96 ng/ml (2.96 ppb). The overall recovery level over the range of 2.00 to 200.00 ng/ml 3,5,6-TCP was 92%. A comparative study found that residues of 3,5,6-TCP determined using both immunochemical and gas chromatography with mass spectrometric detection correlated well.

**Shirasu, Y., M. Moriya, H. Tezuka, S. Teramoto, T. Ohta, and T. Inoue. 1982. Knowledge gained from the testing of large numbers of chemicals in a multi-laboratory, multi-system mutagenicity testing program. Environ. Mutagen. Carcinog., Proc. 3rd International Conf., pp. 331-335.**

**Siltanen, H., C. Rosenberg, M. Raatikainen, and T. Raatikainen. 1981. Triclopyr, glyphosate and phenoxy herbicide residues in cowberries, bilberries and lichen. Bull. Environ. Contam. and Toxicol. 27: 731-737.** Investigations were carried out in Finland into herbicide residues in wild berries in forests which had been subjected to foliar spraying for brush control. Residues of triclopyr were analyzed in cowberries and bilberries after treatment with 0.25, 0.75 and 2.25 kg/ha of the herbicide. Effect of date of treatment on glyphosate (applied at the rate of 0.75 kg/ha) and triclopyr residues was investigated. Results are tabulated. These showed that the residues in the berries were of the same order of magnitude when the same amount of any of the herbicides was used. In aerial spraying the application rate was lowest for glyphosate and highest for phenoxy herbicides. As a result residues in the berries from aerially sprayed

forests can be expected to the highest after phenoxy herbicide application and lowest after glyphosate application.

**Timchalk, C. and R.J. Nolan. 1997. Pharmacokinetics of triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid) in the beagle dog and rhesus monkey: perspective on the reduced capacity of dogs to excrete this organic acid relative to the rat, monkey, and human. Toxicology and Applied Pharmacology. 144: 268-278.** The pharmacokinetics of triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid) were measured in the beagle dog and rhesus monkey and compared with the kinetics observed in rats and humans. In addition, studies were conducted in anesthetized dogs to better understand the mechanism by which ($^{14}$C)triclopyr is eliminated in this species. Triclopyr was dissolved in distilled water, and administered as a single oral dose of 0.5, 5, or 20 mg/kg to three male dogs. A single male rhesus monkey was given an intravenous dose of 30 mg ($^{14}$C)triclopyr/kg body wt on two occasions separated by 10 days. Anesthetized male dogs, were implanted with venous, arterial, and urethral catheters and given increasing amounts of triclopyr to produce plasma triclopyr levels ranging from 0.3 to 27 mu-g eq/mL. In the monkey, triclopyr was rapidly eliminated from the plasma (t-1/2 = 6.3 hr) with gt 95% of the urinary $^{14}$C activity excreted within 24 hr postdosing. In the dog, orally administered triclopyr was rapidly and effectively absorbed at every dose level with virtually all of it excreted in the urine by 72 hr postdosing. However, the kinetics were slightly nonlinear, and the fraction of the dose excreted in the urine decreased with increasing dose. Several nonlinear processes may collectively contribute to the modest nonlinear pharmacokinetics in the dog. Plasma protein binding of triclopyr in the dog ranged from 94 to 99%, was nonlinear, and was an important determinant in the renal clearance of triclopyr. The nonlinear plasma protein binding indicates that glomerular filtration became disproportionately more important as plasma triclopyr concentration increased. There was good evidence for a high-affinity low-capacity active-secretory process that was saturated by low plasma triclopyr concentrations. As plasma triclopyr concentrations increased, tubular reabsorption begins to exceed secretion, resulting in decreased renal clearance. The volume of distribution, normalized for body weight, was constant across all species. While clearance and half-life could be allometrically scaled to body weight for the rat, monkey, and human, the dog had a much slower clearance and longer half-life for triclopyr elimination than predicted allometrically. These data demonstrate that the pharmacokinetics of triclopyr in the dog are markedly different than in rat, monkey, and human.

**Timchalk, C., D. R. Finco, and J. F. Quast. 1997. Evaluation of renal function in rhesus monkeys and comparison to beagle dogs following oral administration of the organic acid triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid). Fundamental and Applied Toxicol. 36: 47-53.** The current study evaluated the effects of triclopyr (3,5,6- trichloro-2-

pyridinyloxyacetic acid) on renal function following oral administration in the beagle dog and Rhesus monkey. Male rhesus monkeys were orally administered triclopyr by gavage at a dose of 5 mg/kg/day, 7 days/week for 28 days, after which the dosage was increased to 20 mg/kg/day for 102 consecutive days. Groups of male dogs were administered either a single oral dose of 5 mg/ kg triclopyr or were fed a diet spiked with triclopyr at a dose of 5 mg/kg/day for 47 consecutive days. The following functional and clinical chemistry parameters were evaluated: exogenous phenolsulfonphthalein (PSP) excretion, inulin and para-aminohippurate (PAH) clearance (monkeys only), endogenous serum creatinine, and blood urea nitrogen (BUN) at multiple time points during the study. Creatinine, BUN, and inulin clearance were within the normal range from both species following triclopyr administration which indicates that repeated administration of triclopyr in the dog and monkey had no effect on glomerular filtration rate (GFR). In monkeys, the percentage excretion of PSP and PAH appeared to increase following triclopyr administration (20 mg/kg/day), suggesting that these weak organic acids may be competing for the same plasma protein-binding site enhancing their clearance. More importantly, these data strongly suggest that triclopyr is not competing with PSP or PAH for the active secretory site within the monkey kidney proximal tubules. In contrast, PSP clearance studies in dogs clearly demonstrated that triclopyr administration (5 mg/kg) can significantly decrease the percentage PSP excretion even following a single dose administration. The decrease in percentage PSP was reversible and inversely related to the plasma triclopyr concentration. Overall, these data clearly indicate that triclopyr effectively competes with PSP for the active secretory site within the dog kidney proximal tubules. In contrast, the monkey was insensitive to the effects of triclopyr on the active secretory process even at doses fourfold higher (20 mg/kg/day) than the effective dose in the dog (5 mg/kg/day). These findings suggest that the effect observed on PSP and PAH excretion in the dog represent a physiological competition for excretion and not toxicity.

**World Health Organization Geneva, Switzerland 1996. Maximum residue limit of triclopyr - Canada. International Digest Health Legislation 47 (2) 199. Food and Drug Regulations, Schedule No. 990, SOR/96-87.** Amends the Canada Food and Drugs Act by establishing a maximum residue limit of 0.5 ppm for triclopyr, including its metabolite, in animals intended for human consumption.

## MAMMALIAN TOXICOLOGY

**Boggs, J. F., S. T. McMurry, D. M. Leslie, Jr., D. M. Engle, and R. L. Lochmiller. 1990. Influence of habitat modification on the intestinal helminth community ecology of cottontail rabbit populations. J. Wildlife Diseases. 26: 157-69.** The influence of five brush management treatments using the herbicides tebuthiuron and triclopyr, with or without prescribed burning, on the intestinal helminth community of cottontail rabbits (*Sylvilagus floridanus*) was studied in 1987 on the Cross Timbers Experimental Range in Payne County, Oklahoma (USA). Six helminth species were found (*Dermatoxys veligera*, *Trichostrongylus calcaratus, Passalurus nonanulatus, Wellcomia longejector, Taenia pisiformis cystercercus*, and *Mosgovoyia pectinata americana*) in 102 rabbits (88 adult and 14 juveniles) collected over two seasons (winter and summer). Prevalence of *M. pectinata americana* in cottontail rabbits was significantly greater in untreated control pastures than herbicide treated pastures in winter, while prevalence of *T. pisiformis* was significantly greater in burned than unburned pastures. Abundances of helminth species in the intestinal tract of cottontail rabbits were unaffected by brush treatments. *Mosgovoyia pectinata americana* abundance demonstrated a highly significant increase from winter to summer; conversely, abundance of all oxyurid pinworms combined (*D. veligera, P. nonanulatus, W. longejector*) was significantly higher in winter than summer. Helminth community dynamics were significantly influenced by season, but were unaffected by brush treatments. Habitat modification could have influenced cestode transmission by altering the ecology of invertebrate and vertebrate hosts.

**Breslin, W. J. and R. Billington. 1995. Evaluation of the developmental toxicity of triclopyr triethylamine salt (TEA) and triclopyr butoxyethyl ester (BEE) in rabbits. International Toxicologist 7:74-75.** Pregnant New Zealand white rabbits were given triclopyr TEA or triclopyr BEE, by gavage, on days 6 through 18 of gestation, at dose levels of 0, 10, 30 or 100 mg/kg/day. Severe maternal toxicity was observed at 100 mg/kg/day for both triclopyr TEA and BEE, with considerable individual animal variability apparent. The maternal effects included mortality, body weight loss and decreased feed consumption. Dams given 100 mg/kg/day of triclopyr TEA also had increased abortions and increased liver and kidney weights. The increased abortions at 100 mg/kg/day were attributed to maternal toxicity. Equivocal effects on abortions and early deliveries, associated with weight loss and/or anorexia in affected dams, were also noted at 30 mg/kg/day triclopyr TEA. Developmental effects were limited to 100 mg/kg/day of triclopyr BEE and included increased resorptions, decreased litter size and litter weight, and increases in minor skeletal alterations (additional sterebral centers, reduced ossification of digital bones and extra (13) ribs). No developmental effects were observed with triclopyr TEA and neither triclopyr TEA or BEE were teratogenic even at maternally toxic dose levels. The maternal no-observed-effect levels (NOEL) for triclopyr TEA and BEE

were 10 and 30 mg/kg/day, respectively; the developmental NOEL's were 100 and 30 mg/kg/day, respectively. These results indicate that triclopyr TEA was less toxic and triclopyr BEE equally toxic to the rabbit embryo/fetus relative to the dam.

**Breslin, W. J., R. Billington, and K. Jones. 1996. Evaluation of the developmental toxicity of triclopyr triethylamine salt (TTEA) and triclopyr butoxyethyl ester (TBEE) in rats. Teratology 53: 106.**

**Brooks, J.J., J.L. Rodrigue, M.A. Cone, K.V. Miller, B.R. Chapman, A.S. Johnson, M.B. Edwards. 1995. Small mammal and avian communities on chemically-prepared sites in the Georgia sandhills. Proceedings of the Eighth Biennial Southern Silvicultural Research Conference, Auburn, Alabama, 1994. General Technical Report –Southern Research Station, USDA Forest Service. No. SRS-1, 21-23.** The effects of 3 forestry herbicide site preparation treatments (hexazinone, picloram + triclopyr, and imazapyr) on small mammal and avian communities were compared at pre-treatment, and 1, 2, and 3 years post-treatment in the Sandhills physiographic region of Marion County, Georgia. Few differences in small mammal capture rates occurred among treatments. Capture rates declined immediately following site preparation, but returned to pre-treatment levels by 18 months post-treatment. The greatest winter avian abundance occurred at 3 years post-treatment; however, no differences in winter avian abundance were observed among treatments. In year 3 post-treatment, summer birds favouring forest edge + scrub habitats were higher on hexazinone-treated sites. Summer avian abundance was strongly associated with residual woody vegetation.

**Eckerlin, R. H., J. G. Ebel, Jr., G. A. Maylin, T. V. Muscato, W. H. Gutenmann, C. A. Bache, and D. J. Lisk. 1987. Excretion of triclopyr herbicide in the bovine. Bull. Environ. Contam. and Toxicol. 39: 443-447.** A lactating cow (630 kg) was fed a diet (22.7 kg/day) containing triclopyr (5 mg/kg) for 4 days. Triclopyr was measured in solvent extracts of milk, feces and urine, collected daily, for 6 days, by gas chromatography, using an electron capture detector, and confirmed by mass spectrometry. No residues were detected in milk or feces. 86.4% of the total dose (454.4 mg) was excreted unchanged in urine. Excretion increased up to day 3 (110.2 mg) and was almost complete by day 5 (4.0 mg).

**Hanley, T. R. Jr., D. J. Thompson, A. K. Palmer, R. P. Beliles, and B. A. Schwetz. 1984. Teratology and reproduction studies with triclopyr in the rat and rabbit. Fundam. Appl. Toxicol. 4: 872-882.** Triclopyr (3,5,6-trichloro-2-pyridyloxyacetic acid), being developed as a new herbicide for use on brush and weeds, was evaluated for its potential effects on reproduction, and embryonal and fetal development. Pregnant Sprague-Dawley rats were given doses of 0, 50, 100, or 200 mg/kg/day by gavage on Days 6 through 15 of

gestation. Dose-related signs of maternal toxicity were observed during the treatment period. No teratogenic effects were observed at any dose level, though slight fetotoxicity, possibly secondary to maternal toxicity, occurred at the high dose level (200 mg/kg/day). Pregnant New Zealand White rabbits were given doses of 0, 10, or 25 mg/kg/day by gavage on Days 6 through 18 of gestation which produced transient, dose-related decreases in maternal body weight gain. However, there were no indications of any treatment-related effects on fetal growth and development among rabbits. Male and female Sprague-Dawley rats maintained on diets supplying 0, 3, 10, or 30 mg/kg/day over three generations exhibited no consistent treatment-related effects on reproductive performance, pregnancy, parturition, or neonatal survival. These data indicated that triclopyr had little or no potential for teratogenic or reproductive toxicity even when the level of exposure approached that which elicited maternal toxicity.

**Lautenschlager, R. A. and J. C. Neal. 1995. Effects of manual, mechanical, and aerial herbicide conifer release on small mammal populations in the Fallingsnow Ecosystem (northwestern Ontario). Proc. 49th Annual Meeting Northeastern Weed Sci. Soc., pp. 139-140.** Field trials were conducted in a conifer [Pinopsida] forest in northwestern Ontario during 1993 to assess the effects of glyphosate and triclopyr, manual cutting, and mechanical cutting on small mammals. Counts of short tailed shrews, red backed and meadow voles, least and eastern chipmunks [*Tamias* spp.], weasels [*Mustela* spp.], *Sorex* spp. and deer mice from traps were made pre-treatment in Aug. and post-treatment in September. Short tail shrews, red backed voles, *Sorex* spp., deer mice, least chipmunks and eastern chipmunks increased in density from 1-2, 1-8, 1-41, 4-18, 1 and 1-3 animals/4 ha, resp., in Aug. to 18-31, 28-62, 89-116, 17-38, 1-5 and 3-17 animals, respectively, in September. Meadow voles and weasels decreased in density from 1-3 animals in Aug. to 1-2 and 0 animals, respectively, in September.

**Leslie, D. M. Jr., R. B. Soper, R. L. Lochmiller, and D. M. Engle. 1996. Habitat use by white-tailed deer on Cross Timbers rangeland following brush management. J. Range Manag. 49: 401-406.** Seasonal habitat use by white-tailed deer (*Odocoileus virginianus* Zimmerman) was monitored with radio telemetry in 1988-89 to determine responses to experimental brush treatments, 5-6 years post-treatment, in the cross timbers region of central Oklahoma. The study area was a mosaic of brush treatments: tebuthiuron (N-[5-(1,1-dimethylethyl)-1,3,4-thiazol-2-yl1]-N,N'-dimethylurea) herbicide, tebuthiuron with an annual spring burn, triclopyr ([(3,5,6-trichlor-2-pyridinyl)oxy]acetic acid) herbicide, triclopyr with an annual spring burn, and no herbicide with annual spring burning. Control areas with no burning or herbicide applications also were evaluated. Herbicides were applied in 1983, and fires were initiated in 1985. Annual home range (95% harmonic mean) averaged 99.9 ha, and no differences in size among seasons or between sexes were observed. Both sexes

selected and avoided specific brush treatments throughout the year. Female deer selected or avoided more human-altered habitats in specific contrasts of main treatment groups (e.g., treated vs. control, herbicide vs. no herbicide, fire vs. no fire, etc.) than males. Both sexes selected fire treatments in summer and were most particular in their choice of main treatment groups in summer and fall habitat use between the sexes was most similar in winter and most disparate in fall. The mosaic of habitat types resulting from the variable herbicide and burn application pattern probably influenced deer habitat use in the cross timbers region through combined effects of increased mid-story cover and forage production as they relate to reproductive activities and nutritional needs of female deer in particular.

**Lochmiller, R. L., D. G. Pietz, S. T. McMurry, D. M. Leslie, Jr., and D. M. Engle. 1995. Alterations in condition of cottontail rabbits (*Sylvilagus floridanus*) on rangelands following brush management. J. Range Manage. 48: 232-239.** Although the use of herbicides and prescribed fire have been shown to increase density of cottontail rabbit (*Sylvilagus floridanus*) populations, the impact of such brush management practices on their condition has not been explored. We used discriminant analysis to investigate responses of overall physical condition of cottontail rabbits (n = 422 adults) to brush management and succession on replicated disturbed and undisturbed upland hardwood forest-tallgrass prairie over a 6-year period. Five different disturbed habitat types were experimentally created using herbicides (tebuthiuron or triclopyr), fire, or a combination of both. Parameters that were important discriminators of rabbit physical condition among habitat types and post-disturbance successional changes included indices of kidney fat and parasitism, and relative masses of spleen, liver, and dried stomach digesta. Brush management practices using herbicides influenced overall condition of rabbits, but the type of habitat disturbance was not important. Effects on overall body condition of cottontail rabbits from burning disturbed habitats were not apparent until later seral stages when production of herbaceous dicots declined and vegetative composition more closely resembled that of undisturbed areas.

**Lochmiller, R. L., J. F. Boggs, S. T. McMurry, D. M. Leslie, Jr., and D. M. Engle. 1991. Response of cottontail rabbit populations to herbicide and fire applications on Cross Timbers rangeland. J. Range Manag. 44: 150-155.** Knowledge of how resident wildlife populations respond to brush management strategies is especially limited for rangelands in the cross timbers vegetation type of Oklahoma. We examined how cottontail rabbit (*Sylvilagus floridanus*) density and habitat use were influenced by applications of tebuthiuron or triclopyr, with and without annual burning, on Cross Timbers rangeland. Line transect flush-counts, mark-recapture livetrapping, and fecal pellet counts were used to evaluate seasonal differences in population density among 5 brush control treatments. Cottontail rabbits (n = 225) were flushed along 362 km of line transects during 5 census periods. Density in winter was consistently lower

than summer for all treatments, except for the untreated control in winter 1987. Line transect density estimates varied from 0 to 1.975 rabbits/ha and suggested that herbicide and annual burning treatments had a positive influence on cottontail rabbit populations compared to untreated controls. Mark-recapture density estimates did not differ among treatments. Fecal pellet counts were greater on herbicide-treated pastures than an untreated control in both spring and fall. Prairie-eastern redcedar (*Juniperus virginiana* L.) and forest-prairie ecotone habitats were utilized greater than expected by cottontail rabbits. Mature hardwood overstory and mixed-brush habitats were avoided. Tebuthiuron and triclopyr effectively deceased hardwood overstory and increased preferred habitats for cottontail rabbits.

**McMurry, S. T., R. L. Lochmiller, J. F. Boggs, D. M. Leslie, Jr., and D. M. Engle. 1993. Opportunistic foraging of eastern woodrats (*Neotoma floridana*) in manipulated habitats. Amer. Midland Naturalist. 130: 325-337.** We evaluated diets of eastern woodrats (*Neotoma floridana*) on Cross Timbers rangeland subjected to experimental brush manipulation. Treatments were tebuthiuron and triclopyr herbicides, applied with and without annual prescribed burning. Untreated reference sites also were evaluated. Microhistological techniques were used to estimate relative percent composition of plant species in diets. A total of 23 plant species were found in diets from summer and winter samples. Eastern woodrats exhibited seasonal variation in diet selection, consuming mostly forbs in summer and browse in winter. Pokeweed (*Phytolacca americana*) and eastern redcedar (*Juniperus virginiana*) comprised the greatest percentages of diets in summer and winter, respectively. Experimental brush treatment also influenced diet composition. We hypothesized that eastern woodrats would exhibit opportunistic foraging behavior and use food types in proportion to their availability. Forb and browse diet classes were used in accordance with availability except for forbs on burned tebuthiuron sites. Eastern woodrats generally followed an opportunistic foraging strategy although occasions of selective foraging were observed, presumably in response to increased palatability and/or nutritional quality of available forage.

**McMurry, S. T., R. L. Lochmiller, J. F. Boggs, D. M. Leslie, Jr., and D. M. Engle. 1993. Woodrat population dynamics following modification of resource availability. Amer. Midland Naturalist 129: 248-256.** We examined the influence of four experimental brush treatments on relative population density, reproduction and body condition of eastern woodrat (*Neotoma floridana*) populations on Cross Timbers rangeland in Oklahoma (USA). Experimental brush treatments were tebuthiuron and triclopyr herbicides, applied with and without annual prescribed burning. Untreated reference sites also were evaluated. A total of 333 eastern woodrats were collected from March 1986 through December 1988. Relative population density varied among seasons and experimental treatments. Maximum summer peaks in density were observed

each year on triclopyr treatments. Density was similar between populations on tebuthiuron treatments and reference sites. Reproductive activity of females varied among seasons but not among experimental treatments; peaks occurred in spring and autumn 1986 and summer 1987. Percentage of reproductively active males, as evidenced by spermatogenesis, was less than expected in winter. mean body weights and condition scores were highest in autumn and spring but were not influenced by experimental treatments. Mean stomach content weight did not differ among seasons or experimental brush treatments.

**McMurry, S. T., R. L. Lochmiller, J. F. Boggs, D. M. Leslie, Jr., and D. M. Engle. 1994. Demographic profiles of populations of cotton rats in a continuum of habitat types. J. Mammalogy 75: 50-59.** We examined temporal relationships between characteristics of populations of cotton rats (*Sigmodon hispidus*) and vegetative characteristics of habitats following secondary succession of post oak (*Quercus stellata*)-blackjack (*Q. marilandica*) savannas in central Oklahoma. Successional changes in vegetation were induced on manipulated habitats by one of two herbicides (tebuthiuron, triclopyr) applied in 1983 and used in combination with or without annual prescribed burning during 1985 to 1988. Relative population density (animals caught per 100 trapnights) and percentage of reproductively active adult females (lactating or pregnant) were significantly greater on manipulated habitats dominated by monocots (grasses) than on habitats with monocots and dicots or undisturbed controls. Herbaceous dicots also influenced the density of cotton rats, especially in 1986; relative density peaked on all manipulated habitats following a peak in production of herbaceous dicots in 1985. Nutritional quality of herbaceous vegetation may have been enhanced by annual burning; relative densities and proportions of juveniles in the trapable population were higher in burned than in unburned habitats. This observation was most pronounced in 1986, when herbaceous dicots comprised a greater proportion of the primary production, than in 1987 or 1988.

**McMurry, S. T., R. L. Lochmiller, J. F. Boggs, D. M. Leslie, Jr., and D. M. Engle. 1996. Demography and condition of populations of white-footed mice (*Peromyscus leucopus*) in late and early successional habitats. J. Mammalogy 77: 335-345.** Populations of white-footed mice (*Peromyscus leucopus*) were monitored for 3 years (1986-1988) in late and early successional habitats. Late-successional habitats consisted of mature hardwood forests with little herbaceous vegetation. Early successional habitats were induced by treatment with either triclopyr or tebuthiuron herbicides, used with and without annual prescribed burning, and consisted of varying levels of shrubs and herbaceous vegetation. Abundance of white-footed mice was highest in 1986 and declined through 1987 and 1988, which corresponded to declines in biomass of forbs. Abundance was higher on both herbicide treatments than controls and higher on triclopyr than tebuthiuron treatments. Triclopyr-altered habitats provided a mixture of dense shrubs and forbs not

found in tebuthiuron-altered sites. Litter size, but not reproductive activity, was higher on triclopyr compared to tebuthiuron treatments in spring 1986. Body condition of adult mice, but not body mass, was higher on herbicide and burned treatments than on controls and unburned treatments, respectively.

**Osweiler, G. D. 1983. Toxicology of triclopyr herbicide in the equine [Horses]. Proc. Annual Meeting Amer. Assn. Veterinary Lab. Diagnosticians 26: 193-201.**

**Sassaman, J. F., R. Pienta, M. Jacobs, and J. Cioffi. 1984. Pesticide background statements. Vol. 1. Herbicides. 909 pp.** The individual Herbicide Background Statements have been compiled to provide a comprehensive review of the available information concerning the use, chemistry, toxicology, environmental fate, and comparative hazard of the herbicides in forest applications. References to the published literature at the end of each background statement are provided for those individuals who wish to independently evaluate the toxicological data and environmental fate information that is presented in summary form. In many instances, secondary sources, such as review articles, handbooks, and company technical data sheets, were used. Wherever possible in these instances, the primary source was also indicated and referenced, although it may not have been examined. Herbicides included in the document are: amitrole, atrazine, 2,4-D, 2,4-DP, dalapon, dicamba, fosamine ammonium, glyphosate, hexazinone, picloram, simazine, and triclopyr.

**Slade, N. A., S. T. McMurray, and R. L. Lochmiller. 1996. Habitat differences in mass-specific litter sizes of hispid cotton rats. J. Mammalogy 77: 346-350.** Litter size and body size of *Sigmodon hispidus* are known to covary positively both among and within some populations. In captivity, litter size varies with quality of diet. In the field, however, variation in maternal size can obscure nutritional effects on litter size. We reexamine litter sizes from sites in central Oklahoma varying in primary productivity due to application of herbicides and controlled burning. Mass-specific litter size of cotton rats showed no significant response to burning. In areas treated with tebuthiuron, litters were larger and population densities and primary productivity of monocots were higher than in areas receiving triclopyr. Slopes of the relationship between litter size, a component of fitness, and maternal mass did not differ significantly between habitats. Thus, percentage increase in litter size in the better habitat was greater for smaller breeding females. This implies that gains in fitness related to habitat productivity are size-specific in these populations.

**Timchalk, C. and R. J. Nolan. 1997. Pharmacokinetics of triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid) in the beagle dog and rhesus monkey: perspective on the reduced capacity of dogs to excrete this organic acid relative to the rat, monkey, and human. Toxicol. Appl. Pharmacol. 144: 268-78.** The pharmacokinetics of triclopyr (3,5,6-trichloro-2-

pyridinyloxyacetic acid) were measured in the beagle dog and rhesus monkey and compared with the kinetics observed in rats and humans. In addition, studies were conducted in anesthetized dogs to better understand the mechanism by which [$^{14}$C]triclopyr is eliminated in this species. Triclopyr was dissolved in distilled water, and administered as a single oral dose of 0.5, 5, or 20 mg/kg to three male dogs. A single male rhesus monkey was given an intravenous dose of 30 mg [$^{14}$C]triclopyr/kg body wt on two occasions separated by 10 days. Anesthetized male dogs, were implanted with venous, arterial, and urethral catheters and given increasing amounts of triclopyr to produce plasma triclopyr levels ranging from 0.3 to 27 microg eq/mL. In the monkey, triclopyr was rapidly eliminated from the plasma ($t_{1/2}$ = 6.3 hr) with >95% of the urinary $^{14}$C activity excreted within 24 hr postdosing. In the dog, orally administered triclopyr was rapidly and effectively absorbed at every dose level with virtually all of it excreted in the urine by 72 hr postdosing. However, the kinetics were slightly nonlinear, and the fraction of the dose excreted in the urine decreased with increasing dose. Several nonlinear processes may collectively contribute to the modest nonlinear pharmacokinetics in the dog. Plasma protein binding of triclopyr in the dog ranged from 94 to 99%, was nonlinear, and was an important determinant in the renal clearance of triclopyr. The nonlinear plasma protein binding indicates that glomerular filtration became disproportionately more important as plasma triclopyr concentration increased. There was good evidence for a high-affinity low-capacity active-secretory process that was saturated by low plasma triclopyr concentrations. As plasma triclopyr concentrations increased, tubular reabsorption begins to exceed secretion, resulting in decreased renal clearance. The volume of distribution, normalized for body weight, was constant across all species. While clearance and half-life could be allometrically scaled to body weight for the rat, monkey, and human, the dog had a much slower clearance and longer half-life for triclopyr elimination than predicted allometrically. These data demonstrate that the pharmacokinetics of triclopyr in the dog are markedly different than in rat, monkey, and human.

**Timchalk, C., D. R. Finco, and J. F. Quast. 1997. Evaluation of renal function in rhesus monkeys and comparison to beagle dogs following oral administration of the organic acid triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid). Fundam. Appl. Toxicol. 36: 47-53.** The current study evaluated the effects of triclopyr (3,5, 6-trichloro-2-pyridinyloxyacetic acid) on renal function following oral administration in the beagle dog and rhesus monkey. Male rhesus monkeys were orally administered triclopyr by gavage at a dose of 5 mg/kg/day, 7 days/week for 28 days, after which the dosage was increased to 20 mg/kg/day for 102 consecutive days. Groups of male dogs were administered either a single oral dose of 5 mg/kg triclopyr or were fed a diet spiked with triclopyr at a dose of 5 mg/kg/day for 47 consecutive days. The following functional and clinical chemistry parameters were evaluated: exogenous phenolsulfonphthalein (PSP) excretion, inulin and

para-aminohippurate (PAH) clearance (monkeys only), endogenous serum creatinine, and blood urea nitrogen (BUN) at multiple time points during the study. Creatinine, BUN, and inulin clearance were within the normal range from both species following triclopyr administration which indicates that repeated administration of triclopyr in the dog and monkey had no effect on glomerular filtration rate (GFR). In monkeys, the percentage excretion of PSP and PAH appeared to increase following triclopyr administration (20 mg/kg/day), suggesting that these weak organic acids may be competing for the same plasma protein-binding site enhancing their clearance. More importantly, these data strongly suggest that triclopyr is not competing with PSP or PAH for the active secretory site within the monkey kidney proximal tubules. In contrast, PSP clearance tudies in dogs clearly demonstrated that triclopyr administration (5 mg/kg) can significantly decrease the percentage PSP excretion even following a single dose administration. The decrease in percentage PSP was reversible and inversely related to the plasma triclopyr concentration. Overall, these data clearly indicate that triclopyr effectively competes with PSP for the active secretory site within the dog kidney proximal tubules. In contrast, the monkey was insensitive to the effects of triclopyr on the active secretory process even at doses fourfold higher (20 mg/kg/day) than the effective dose in the dog (5 mg/kg/day). These findings suggest that the effect observed on PSP and PAH excretion in the dog represent a physiological competition for excretion and not toxicity.

**Timchalk, C., M. D. Dryzga, and P. E. Kastl. 1990. Pharmacokinetics and metabolism of triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid) in Fischer 344 rats. Toxicology. 62: 71-87.** Triclopyr, (3,5,6-trichloro-2-pyridinyloxyacetic acid) is the active component of Garlon brand herbicide. [$^{14}$C]Triclopyr was administered orally to groups of 5 rats/sex as a single 3 and 60 mg/kg body weight dose and as a multiple 3 mg/kg nonradiolabeled dose for 14 days followed by a single 3 mg [$^{14}$C]triclopyr/kg dose on day 15. A fourth group (5 rats/sex) was administered a single 3 mg/kg intravenous dose of [$^{14}$C]triclopyr. In addition, two groups of male rats (3/dose) were used to obtain $^{14}$C plasma time-course data and were orally administered [$^{14}$C]triclopyr at doses of 3 and 60 mg/kg. Between 94 and 97% of the administered radioactivity was recovered, and the principal route of excretion was the urine (89-95%). The feces contained less than 3% of the dose and the expired $^{14}CO_2$ and cage wash accounted for less than 0.2 and 1% of the dose, respectively. The tissues and carcass accounted for less than 2% of the radioactivity at 72 h post-dosing. [$^{14}$C]Triclopyr was rapidly and completely absorbed after oral administration of 3 and 60 mg/kg. The radioactivity was cleared from the plasma of male rats at 3 mg/kg in a mono-exponential manner, with an apparent first-order elimination half-life of 3.6 h. The primary difference between the 3 and 60 mg/kg dose kinetics was the saturation of renal elimination of triclopyr through 9 h post-dosing for the 60 mg/ kg group. [$^{14}$C]Triclopyr was primarily excreted unchanged in the urine (81-96% of the urinary radioactivity), although

4 minor urinary metabolites were noted. Aside from the initial saturation of renal elimination of triclopyr at 60 mg/kg, there were no appreciable differences in the absorption, disposition, or metabolism of [$^{14}$C]triclopyr, based on sex, or prior exposure.

**World Health Organization Geneva, Switzerland 1996. Maximum residue limit of triclopyr - Canada. International Digest Health Legislation 47 (2) 199. Food and Drug Regulations, Schedule No. 990, SOR/96-87.** Amends the Canada Food and Drugs Act by establishing a maximum residue limit of 0.5 ppm for triclopyr, including its metabolite, in animals intended for human consumption.[ See Canada Gazette (1996) Part II, 130 (3) 625-627.]

## NON-TARGET AVIAN

**Blanton, S. and M. Mihajovich. 1999. Basal bark application of Release (TM) herbicide for mixedwood management : 1999 final report. Edmonton: Alberta Environmental Protection, 11 p.** This report describes results of a mixedwood (aspen & white spruce) stand tending research project carried out on two regenerated cutover areas in Alberta. The project assessed the effectiveness & safety of low-volume basal bark application of triclopyr butoxyethyl ester herbicide for managing all tree species; compared the effectiveness & cost of motor manual tending to basal bark herbicide application for spacing & tending the post-juvenile mixedwood sites; compared the effect of motor manual tending & herbicide treatment on short-term slash loading & bird use of treated, untreated, and adjacent areas; and quantitatively measured the soil dissipation of the herbicide following treatment.

**Boren, J.C., R.L. Lochmiller, D.M. Leslie Jr., and D.M. Engle. 1993. Long-term effects of woody vegetation management on seasonal body condition of northern bobwhites. J. Range Manage. 46: 520-523.** In a field study at Cross Timbers Experimental Range, Payne County, Oklahoma, brush management by herbicide (tebuthiuron or triclopyr) application, herbicide + burning or mechanical removal had minimal long-term effects on *Colinus virginianus* body condition.

**Brooks, J.J., J.L. Rodrigue, M.A. Cone, K.V. Miller, B.R. Chapman, A.S. Johnson, M.B. Edwards. 1995. Small mammal and avian communities on chemically-prepared sites in the Georgia sandhills. Proceedings of the Eighth Biennial Southern Silvicultural Research Conference, Auburn, Alabama, 1994. General Technical Report –Southern Research Station, USDA Forest Service. No. SRS-1, 21-23.** The effects of 3 forestry herbicide site preparation treatments (hexazinone, picloram + triclopyr, and imazapyr) on small mammal and avian communities were compared at pre-treatment, and 1, 2, and 3 years post-treatment in the Sandhills physiographic region of Marion County, Georgia. Few differences in small mammal capture rates occurred among treatments. Capture rates declined immediately following site preparation, but returned to pre-treatment levels by 18 months post-treatment. The greatest winter avian abundance occurred at 3 years post-treatment; however, no differences in winter avian abundance were observed among treatments. In year 3 post-treatment, summer birds favouring forest edge + scrub habitats were higher on hexazinone-treated sites. Summer avian abundance was strongly associated with residual woody vegetation.

**Brown, J.G., and G. Bos. 1977. Triclopyr a new herbicide for control of woody plants, *In* Symposium on the Different Methods of Weed Control and Their Integration, Vol. 1: 121-128.** Includes toxicity to mammals, birds and fish.

**Holmes, S.B., D.G. Thompson, K.L. Wainio-Keizer, S.S. Capell, and B. Staznik. 1994. Effects of lethal and sublethal concentrations of the herbicide, triclopyr butoxyethyl ester, in the diet of zebra finches. J. Wildlife Diseases, 30: 319-327.** Lethal and sublethal effects of dietary triclopyr butoxyethyl ester (TBEE) on zebra finches (*Poephila guttata*) were determined in laboratory experiments conducted between 8 January and 1 May 1991. The 8-day median lethal dietary concentration, $LC_{50}$ (95% confidence interval), of TBEE to zebra finches was 1923 (1627 to 2277) mg/kg. In the sublethal effects experiment when birds were exposed to 500 mg/kg TBEE in the diet for 29 days, food consumption and body weight were significantly depressed. Similar prolonged exposures to 50 and 150 mg/kg TBEE in the diet had no significant effect on food consumption or body weight. Perch hopping activity was depressed relative to controls in the 500 mg/kg group, and elevated in the 150 mg kg group, but neither of these differences was significant. Disappearance of TBEE residues from treated seeds over the 29 day experimental period followed an exponential decay model, with half-lives in the order of 15 to 18 days. On the basis of the observation that TBEE had no significant adverse effects at a concentration greater than the maximum expected environmental concentration, it is proposed that forestry applications of triclopyr at registered dosage rates pose little risk to wild songbirds.

**Lautenschlager, R.A., F.W. Bell, R.G. Wagner, and P.E. Reynolds. 1998. The Fallingsnow Ecosystem Project: documenting the consequences of conifer release alternatives. Journal of Forestry. 96: 20-27.** An overview is presented of the Fallingsnow Ecosystem Project, established in 1993 SW of Thunder Bay, Ontario, Canada, including the design, environmental components, and the initial results obtained. The Project was designed to document the terrestrial ecological consequences of alternative conifer release treatments. The ecosystem components studied are: soil chemistry, physics and morphology; below- and above-ground microclimates; below-ground fungi; vegetation, species composition, abundance, diversity, and foliar nutrient content; insects; terrestrial gastropods; amphibians and reptiles; small mammals; songbirds; and moose [*Alces alces*] area use and foods (production and storage). Although long-term responses are unknown, results to date indicate that cutting (with brush saws or tractor-mounted cutting heads) and herbicide (glyphosate or triclopyr) treatments are relatively inconsequential for most environmental components found in regenerating northern forests. It is suggested that given the growing opposition to herbicide use in forestry, managers must expect that social input into natural resource management will become more common, if not required.

**Miller, K. V. and B. R. Chapman. 1995. Responses of vegetation, birds and small mammals to chemical and mechanical site preparation. FRI Bulletin, No 192; Popular Summaries from Second International Conference on Forest**

**Vegetation Management. R.E. Gaskin and J.A. Zabkiewicz (eds.), 146-148. New Zealand Forest Research Institute, Rotorua, New Zealand.**

**Nolte, K.R. and T.E. Fulbright. 1997. Plant, small mammal, and avian diversity following control of honey mesquite. J. Range. Manage. 50: 205-212.** The effects of herbicide applications to kill honey mesquite (*Prosopis glandulosa* Torr.) on community diversity are poorly documented. Our objective was to test the hypothesis that herbicide application to kill honey mesquite would reduce plant and vertebrate species richness and diversity. A 1:1 mixture of triclopyr ([(3,5,6-trichloro-2-pyridinyl) oxy]acetic acid) + picloram (4-amino-3,5,6-tricholopicolinic acid) was applied to three 13-ha plots during 1992 and to 3 additional plots in 1993. Mesquite and forb canopy cover in the zone less than or equal to 1 m from the soil surface were lower within treated plots than in control plots (n = 3) following the 1992 and 1993 treatments. Grass canopy cover did not differ between herbicide-treated plots and control plots. Vegetation species richness and evenness, Shannon's index, beta diversity, and proportion of rare plant species did not differ between controls and sites treated during 1992 and 1993. Rodent and avian relative frequency, richness, and diversity were not different on 1992 herbicide treatment plots and controls. Based on these results, application of triclopyr + picloram in mesquite-mixed grass communities in the Texas Coastal Bend does not appear to reduce plant and vertebrate species richness and diversity within the first 2 years after treatment. However, our results should be interpreted cautiously because (1) annual rainfall was 16% above the annual average during the study and (2) limited replication possibly reduced statistical power to detect differences.

**Schulz, C.A., D.M. Leslie Jr., R.L. Lochmiller, and D.M. Engle. 1992. Herbicide effects on Cross Timbers breeding birds. J. Range Manage. 45: 407-411.** Effects of tebuthiuron and triclopyr, used to improve grazing in the hardwood forests (especially *Quercus stellata* and *Q. marilandica*) in the Cross Timbers region of central Oklahoma, were investigated 5-6 years after application had ceased (1988-89). Twenty species of breeding birds were observed. No treatment effects were detected for total bird density, species diversity or richness; however, species composition varied considerably among treatments. Control sites supported species associated with closed canopy woodlands and treated sites supported species associated with bushy and prairie habitat. Generally, control sites had greater foliar cover, fewer snags and less slash and herbaceous cover than treated sites. Tebuthiuron treated sites tended to have less woody vegetation than triclopyr treated sites. Densities of 6 of the 7 most abundant bird species were correlated variously with habitat characteristics. It is concluded that changes in habitat structure arising from herbicide usage resulted in differences in bird species composition.

**Schulz, C.A., D.M. Leslie Jr., R.L. Lochmiller, and D.M. Engle. 1992. Autumn and winter bird populations in herbicide-treated Cross Timbers in**

**Oklahoma. Amer. Midland Naturalist 127: 215-223.** Birds were counted during autumn and winter from October 1987 through February 1989 on sites in Cross Timbers in central Oklahoma 5 and 6 yr after herbicide treatments. We censused two replications of tebuthiuron-treated, triclopyr-treated, and untreated reference sites with a modification of the point-count method. Thirty-five species were documented during the entire census period; 16 species were observed only on herbicide-treated sites and two species only on reference sites. During autumn and winter, more birds and more species were found on sites treated with herbicides than on reference sites. Tebuthiuron- and triclopyr-treated sites supported similar numbers of species during both seasons. Herbicide-treated sites had the highest species richness, but untreated areas were needed to maintain interior woodland species.

**Wood K. and C. Hollstedt (compiled by). 1995. Fallingsnow Ecosystem Workshop: program and abstracts. Workshop proceedings / Ontario. Ministry of Natural Resources. WP-001, Vegetation Management Alternatives Program, 1995. xv, 54 p.** The Fallingsnow Ecosystem Project, which is providing data on the ecological impacts of alternative vegetation management practices, is being conducted on a regenerated spruce plantation near Thunder Bay, Ontario. Four treatments have been applied at the study site in a randomized block design: manual brushing; mechanical site treatment; aerial application of glyphosate or triclopyr herbicides; and control (no treatment). Environmental variables examined include soil characteristics and biodiversity; below- and above-ground temperature and moisture; vegetation species composition and foliar nutrient content; below- and above-ground insects; terrestrial gastropods; amphibians and reptiles; small mammals; songbirds; moose and deer area use, and foods (production and quality). This report contains presentations from a workshop held to transfer to resource managers the most recent scientific information produced from this project.

**Woodcock, J., R.A. Lautenschlager, F.W. Bell, and J.P. Ryder. 1997. Indirect effects of conifer release alternatives on songbird populations in northwestern Ontario. Fallingsnow Ecosystem Project. Forestry-Chronicle. 73: 107-112.** The effects of conifer-release alternatives on songbird densities (determined by territory mapping, mist netting, and banding) were examined in four young (four to seven years old) spruce (*Picea mariana* and *P. glauca*) plantations SW of Thunder Bay, Ontario. Treatments, applied in 1993, were: motor-manual release with brush saws; mechanical release with the Silvana Selective/Ford Versatile; helicopter-applied Release (triclopyr); and helicopter-applied Vision (glyphosate); the control was untreated. Twenty to 38 (block dependent) species bred on each treatment block. Post-treatment data, collected in summer 1994, revealed no major treatment-related changes in breeding bird species composition. The mean density of all birds decreased from 6.9 pairs/ha pre-treatment, to 6.3 pairs/ha in the first post-treatment growing season ($P>0.05$). Mean densities of the 11 most common species

increased by 0.35/ha on the control plots during the first post-treatment growing season, but decreased on treated plots by 1.1/ha (brush saw), 1.6/ha (Silvana Selective), 0.14/ha (Release) and 0.72/ha (Vision). Following the conifer-release treatments, chestnut-sided warbler (*Dendroica pensylvanica*) had lower ($P<0.05$) mean densities on the brush saw- and Silvana Selective-treated plots than on the control plots and fewer ($P<0.05$) female birds were captured in the first post-treatment year.

**Woodcock, J., R.A. Lautenschlager, J.P. Ryder, F.W. Bell, and J.C. Neal. 1995. Effects of manual, mechanical, and aerial herbicide conifer release on songbird populations in the Fallingsnow Ecosystem (northwestern Ontario). Proc. 49th Annual Meeting Northeastern Weed Sci. Soc., pp. 141-142.** Field trials were conducted in northwestern Ontario to assess the effects of glyphosate and triclopyr applications, manual cutting, and mechanical cutting on songbirds breeding in a conifer [ Pinopsida] forest. Songbird populations were assessed pre-treatment during June-Sep. 1993 and post-treatment during June-Sep. 1994. A table of the results is presented.

## NON-TARGET PLANTS

**Agusti, M., V. Almela, M. Juan, E. Primo-Millo, I. Trenor, and S. Zaragoza. 1994. Effect of 3,5,6-trichloro-2-pyridyl-oxyacetic acid on fruit size and yield of 'Clausellina' mandarin (*Citrus unshiu* Marc.). J. Hort. Sci. 69: 219-223.** The application of 3,5,6-trichloro-2-pyridyl-oxyacetic acid [triclopyr] increased fruit size of *Clausellina mandarin* [satsuma]. The response was related to the size of fruit at the time of treatment. Two concentrations, 10 and 20 mg/litre, were tested with the same result on fruit size and fruit abscission. Because the increment in fruit size occurred irrespective of the number of fruits that remained on the tree, it is suggested that the auxin had a direct effect on fruit growth. This was confirmed by applying the auxin locally to a small number of fruits per tree. Fruit characteristics, with the exception of those related to fruit maturity, were not altered by the treatments.

**Anderson, T. M. D. and F. D. Panetta. 1995. Fireweed response to boomspray applications of different herbicides and adjuvants. Plant Protection Quarterly. 10: 152-153.** Applications of bromoxynil in early May 1993 to pastures in southeastern Queensland have given inadequate control of fireweed (*Senecio madagascariensis*) under some conditions. Alternative chemicals registered for use in pastures, as well as a range of additives were compared in demonstration plots in the Biddadaba district, Beaudesert Shire about 60 km south of Brisbane, Queensland. The treatments were 3.2 kg/ha 2,4-D dimethylamine salt, 2.0-4.0 kg 2,4-D sodium salt, 5.0 L dichlorprop potassium salt, 1.25 L dicamba dimethylamine salt, 40-80 g metsulfuron-methyl, 2.5-5.0 L clopyralid monoethanolamine, 1.0 L triclopyr butoxyethanol ester, 1 L triclopyr butoxyethanol ester + picloram triisopropanol amine and 6 L atrazine + 2,4-D sodium salt. 2,4-D amine (dimethylamine salt) and 2,4-D sodium salt gave the best control and did not damage beneficial species. Atrazine + 2,4-D caused severe damage to both the grass and clover. Clover was badly injured by metsulfuron-methyl, clopyralid, triclopyr and triclopyr + picloram. Results indicated that the use of adjuvants was not justified.

**Bovey, R. W., H. Hein, Jr., and R. E. Meyer. 1984. Effect of herbicides on the production of common buffelgrass (*Cenchrus ciliaris*). Weed Sci. 32: 8-12.** Dicamba (3,6-dichloro-o-anisic acid), 2,4-D 2,4,5-T, 3,6-dichloropicolinic acid, picloram (4-amino-3,5,6-trichloropicolinic acid), triclopyr (((3,5,6-trichloro-2-pyridinyl)oxy)acetic acid), tebuthiuron (N-(5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl)-N,N'-dimethylurea) and hexazinone (3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione) were applied at rates of 0.3, 0.6, 1.1, and 2.2 kg/ha pre- and postemergence to greenhouse-grown common buffelgrass. Buffelgrass tolerated preemergence sprays of 3,6-dichloropicolinic acid up to and including 1.1 kg/ha. All other treatments except picloram and 2,4,5-T at 0.3 kg/ha were phytotoxic to emerging buffelgrass. Buffelgrass tolerated early postemergence applications of 2,4-D, picloram, and

tebuthiuron at 0.3 kg/ha; dicamba and 2,4,5-T at 0.6 kg/ha; and 3,6-dichloropicolinic acid at 2.2 kg/ha based on oven-dry shoot production 1 month after treatment. Regrowth of buffelgrass from stubble 1 month after original harvest of the early postemergence treatment occurred only with all rates of 3,6-dichloropicolinic acid and 2,4,5-T at 0.3 kg/ha. When treated at 45 days after planting, buffelgrass tolerated dicamba, 2,4-D, 2,4,5-T, 3,6-dichloropicolinic acid, and picloram at 2.2 kg/ha, but top growth production was significantly reduced by most rates of hexazinone and tebuthiuron. Relative differences in regrowth of buffelgrass 1 month after the original harvest were similar to those of the original harvest. Mature buffelgrass (90 or 150 days old) responded similarly to herbicides as the 45-day-old buffelgrass.

**Branham, B.E. and D.W. Lickfeldt. 1997. Effect of pesticide-treated grass clippings used as a mulch on ornamental plants. HortScience. 32: 1216-1219.** Grass clippings were collected at 2, 7 and 14 days after pesticide treatment from a turf treated with chlorpyrifos, clopyralid, 2,4-D, flurprimidol, isoxaben or triclopyr. The clippings were used as a mulch around tomatoes, *Phaseolus vulgaris*, *Petunia hybrida* and *Impatiens wallerana* [*I. walleriana*]. *P. vulgaris* as sown 4 weeks prior to mulching, whereas the other plants were grown in the greenhouse for 6 weeks and transplanted into the field 2 weeks prior to mulching. Clippings containing residues of clopyralid, 2,4-D or triclopyr killed tomatoes, *P. vulgaris* and *P. hybrida* when used 2 days after pesticide treatment (DAPT) and severely injured these plants when mulched 7 and 14 DAPT. Flurprimidol injured tomatoes, *I. wallerana* and *P. vulgaris* when present on mulch collected 2, 7 and 14 DAPT, but was not lethal. Flurprimidol slowed plant growth, caused darker green leaf colour, and reduced flowering when present on mulch used 2 DAPT. Isoxaben injured tomatoes and *P. vulgaris* when present on mulch used 2, 7 and 14 DAPT but was not lethal. Injury was not as severe in the second year of the study, suggesting that environmental stresses and climatic conditions make predicting pesticide injury for all growing seasons difficult. However, it is suggested that grass clippings from turf treated with herbicides or plant growth regulators should not be used for mulching around sensitive plants for at least 14 DAPT.

**Braverman, M. P. 1995. Absorption, translocation, and metabolism of triclopyr in rice *(Oryza sativa*). Weed Tech. 9: 490-493.**

**Buendia, J., R. Molina, and J. L. P. Gil. 1997. Method of using triclopyr to increase fruit size or quality or maturation rate. Official Gazette of the United States Patent and Trademark Office Patents 1197(4 April 22): 2575.**

**Cowgill, U. M., D. P. Milazzo, and B. D. Landenberger. 1989. A comparison of the effect of triclopyr triethylamine salt on two species of duckweed (*Lemna*) examined for a 7-and 14-day test period. Water Res. 23: 617-623.** The objective of this study was to estimate the level of phytotoxicity (50% reduction

in the number of plants or fronds as compared to controls) to five clones of *Lemna* over a 7 and 14-day period. The end-points examined were the number of fronds, the number of plants, biomass, chlorophyll a and chlorophyll b. All data gathered during this investigation confirm the fact that this herbicide is only slightly toxic to duckweed clones using the U.S. EPA classificatory scheme. There is no statistically significant difference among the five end-points for the 7-day test for any of the plant clones with the exception of chlorophyll b. The 14-day results are not nearly as consistent. *L. gibba* G-3 is more sensitive than the four clones of *L. minor*. The $EC_{50}$ for biomass is more tolerant in *L. minor* 6591, *L. minor* 7102 and *L. minor* 7101 than for *L. gibba* G-3. The difference of greatest interest is that of chlorophyll production between the two test periods. In all cases chlorophyll a is significantly reduced in the 14-day test over that of the 7-day test, while chlorophyll b is only significantly reduced in the 14-day test for *L. minor* 6591, *L. minor* 7102 and *L. minor* 7136. It is hypothesized that the reason for this is that the system runs out of nutrients. This alone militates against the use of the 14-day test and favors the use of the 7-day one (DBO).

**Dahl, B.E., J. C. Mosley, P. F. Cotter, and R. L. Dickerson Jr. 1989. Winter forb control for increased grass yield on sandy rangeland. J. Range Manage. 42: 400-403.** Herbicides were evaluated for control of overwintering weeds on sandy rangeland in west Texas. Triclopyr and dicamba + 2,4-D were ineffective, but picloram ± 2,4-D and dicamba gave adequate control of the main weed present, *Ambrosia psilostachya*. In another trial, picloram at 0.07 kg/ha and triclopyr at 0.28 kg reduced *A. psilostachya*. Picloram controlled forbs while triclopyr suppressed *Quercus havardii*. In another study picloram 0.28 kg applied to *Q. havardii* resulted in good increases in grass yield. Picloram + 2,4-D did not suppress *Q. havardii*.

**D'Anjou, B. 1991. Growth response of several vegetation species to herbicides and manual cutting treatments in the Vancouver Forest Region. Govt. Reports Announcements and Index (GRA&I), Issue 14.** Non-crop vegetation can compete with young conifers, potentially reducing conifer survival and growth rates. Since 1985, several research trials have been conducted to document the effect of herbicides (both registered and unregistered) and manual cutting on vegetation growth. This interim report summarizes the growth response of various vegetation species 1-5 growing seasons after treatment with glyphosate, hexazinone, triclopyr ester, sulfometuron methyl, and metsulfuron methyl. Background information on each herbicide is also presented, including registration status, trade name, manufacturer, formulation tested, and route of plant uptake. The potential importance of each herbicide in a vegetation management program is briefly discussed, focusing on its effectiveness in controlling the growth of those species sampled in these trials.

**Derr, J. F. 1993. Tolerance of apple and peach trees to triclopyr. Hort. Sci. 28: 1021-1023.** The tolerance of newly planted apple (*Malus domestica* Borkh.) and peach [*Prunuspersica* (L.) Batsch] trees to the postemergence herbicide triclopyr was evaluated in field trials. Apple and peach trees were not injured by triclopyr applied at rates ranging from 0.28 to 1.12 kg acid equivalent (a.e.)/ha as a directed spray to soil. No injury was observed following direct application of 10 ml of a triclopyr solution at 2 g a.e/liter to the lower bark of either tree species. Applications of that solution to an individual branch injured or killed the treated apple or peach branch but did not affect the rest of the tree. No reduction in tree growth or injury was noted 1 year after triclopyr application. Applications of 10 ml of a glyphosate solution at 15 g a.i./liter to an apple branch caused severe injury and a growth reduction by 1 year after application, and killed all treated peach trees when applied to one branch. No triclopyr or 2,4-D treatment had affected apple or peach trunk diameter, number of branches, or tree size 1 year after application.

**Einset, J. W., L. Lyon, and P. Johnson. 1981. Chemical control of abscission and degreening in stored lemons (*Citrus limon*). J. Amer. Soc. Hort. Sci. 106: 531-533.** Three auxins (4-amino-3,5,6-trichloropyridine-2-carboxylic acid; 3,5,6-trichloropyridine-2-oxyacetic acid; and 4-chlorophenoxyacetic acid) and 2 inhibitors of ethylene biosynthesis (i.e., aminoethoxyvinylglycine and aminoxyacetic acid) inhibit abscission of stem parts (buttons) from fruit of lemon (*C. limon* Burm.) stored in controlled ethylene (about 5 ppm) atmospheres. Freshly picked lemons were treated by dipping them in aqueous solutions containing 500 ppm Triton X-100 plus-or-minus additions and then were stored at a packing house for 13 days; the fruit then were color-stored and analyzed for evidence of button abscission. When the abscission inhibitors were tested in concentrations equal to or greater than commercial concentrations of 2,4-D (250 ppm) and its isopropyl ester (250 ppm), only 4-amino-3,5,6-trichloropyridine-2-carboxylic acid (picloram) was found to be as effective in inhibiting button abscission. As little as 50 ppm picloram gave inhibition of abscission comparable to 250 ppm isopropyl ester of 2,4-D. All of the auxin inhibitors of button abscission including the free acid and isopropyl ester of 2,4-D delayed the degreening of fruit in the packing house. Triclopyr (3,5,6-trichloropyridine-2-oxyacetic acid) had the severest effect, picloram had a moderate effect and the free base and isopropyl ester of 2,4-D had mild delaying effects on degreening. Aminoethoxyvinylglycine (200 ppm) and aminoxyacetic acid (1840 ppm) did not inhibit degreening.

**El-Khodary, S., A. Habib, and A. Haliem. 1989. Cytological effect of the herbicide Garlon 4 on root mitosis of *Allium cepa*. Cytologia 54: 465-472.** Many cytological studies have been carried out to detect the harmful effect of different pesticides on different plants. The herbicide 3,5,6 trichloro-2-pyridinyloxy-acetic acid, is also known as Garlon 4. The active chemical ingredient in Garlon herbicide is triclopyr. In both the laboratory and the field,

triclopyr has demonstrated highly effective control of many woody plants and broad leaf weeds. The present investigation was carried out to study the cytological effect of the herbicide Garlon 4 on the process of mitosis in root tips of *Allium cepa*.

**Engle, D. M., J. F. Stritzke, and F. T. McCollum. 1992. Response of understory vegetation to herbicides and burning on the Cross Timbers Experimental Range. Circular E, Oklahoma State University, Cooperative Extension Service (No. 905) pp. 6-7.**

**Fry, J. D. and W. S. Upham. 1994. Buffalograss seedling tolerance to postemergence herbicides. Hort. Sci. 29: 1156-1157.** In 1992 and 1993, 12 postemergence herbicide treatments were applied to field-grown buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.] seedlings having 1 to 3 leaves and 2 to 4 tillers, respectively. The only herbicide treatments that did not cause plant injury at 1 or 2 weeks after treatment (WAT) or reduce turf coverage 4 or 6 WAT compared to nontreated plots (in 1992 or 1993) were (in kg/ha) 0.6 dithiopyr, 0.8 quinclorac, 2.2 MSMA, and 0.8 clopyralid. Evaluated only in 1993, metsulfuron methyl (0.04 kg/ha) also caused no plant injury or reduction in coverage. Fenoxaprop-ethyl (0.2 kg/ha) caused severe plant injury and reduced coverage by > 95 % at 6 WAT. Dicamba reduced coverage by 11% at 6 WAT in 1992 but not 1993. The chemicals (in kg/ha) triclopyr (0.6), 2,4-D (0.8), triclopyr (1.1) + 2,4-D (2.8), 2,4-D (3.1) + triclopyr (0.3) + clopyralid (0.2), and 2,4-D (2.0) + mecoprop (1.1) + dicamba (0.2) caused plant injury at 1 or 2 WAT in 1992 or 1993, but coverage was similar to that of nontreated turf by 6 WAT.

**Gabor, T.S., T. Haagsma, and H. R. Murkin. 1996. Wetland plant responses to varying degrees of purple loosestrife removal in southeastern Ontario, Canada. Wetlands 16: 95-98.** This study examined the response of native vegetation to varying levels of purple loosestrife (*Lythrum salicaria*) removal and determined its impact on subsequent loosestrife germination and establishment in a southern Ontario wetland during 1993 and 1994. The study site was treated in 1991 with varying dosages of triclopyr amine herbicide, the triethylamine salt formulation of triclopyr [[(3,4,6-trichloro-2-pyridinyl)oxy] acetic acid]; 4.0, 8.0, and 12.0 kg active ingredient (a.i.)/ha. Different levels of adult loosestrife control were achieved. The lowest density of adult loosestrife was observed in the 8.0 and 12.0 kg a.i./ha treatment plots where root kill was most effective. Most new adult loosestrife plants in the 8.0 and 12.0 kg a.i./ha treatment plots established from seed. The highest densities of loosestrife seedlings and grass (Gramineae) species were observed in the treatment plots with the lowest number of adult loosestrife plants (12.0 kg a.i./ha). Sedge species (*Carex* spp.) did not differ between treatment levels during 1993 and 1994. Loosestrife seedling densities decreased from 1993 to 1994, suggesting that increased native plant species can slow the rate of loosestrife

reestablishment from the seed bank. Native vegetation seems to replace adult loosestrife for a limited time following herbicide application; however, without subsequent treatment, loosestrife will slowly reinvade a wetland.

**Gabor, T.S., T. Haagsma, H. R. Murkin, and E. Armson. 1995. Effects of triclopyr amine on purple loosestrife and non-target wetland plants in southeastern Ontario, Canada. J. Aquat. Plant Manage. 33: 48-51.** We studied the effects of triclopyr amine, the triethylamine salt formulation of triclopyr [[(3,4,6-trichloro-2-pyridinyl)oxy] acetic acid] on purple loosestrife (*Lythrum salicaria* L.) and non-target vegetation in a southern Ontario wetland during 1991 and 1992. Triclopyr was applied during bud to early bloom stage at rates of 4.0, 8.0 and 12.0 kg/ha. During 1991, all treatment levels effectively controlled the aboveground portion of purple loosestrife. Grasses (family Gramineae) were unaffected during 1991, however, sedge species (*Carex spp*.) declined in numbers at higher treatment levels. At 1 year post-treatment, adult purple loosestrife were not present in the 12.0 kg/ha treatment indicating that triclopyr effectively killed the root system. Seedlings dominated the total number of loosestrife plants in the 8.0 and 12.0 kg/ha treatment plots 1 year post-treatment. Sedges recovered in 1992 and grasses increased above 1991 levels. Removal of adult purple loosestrife allowed more light to reach the substrate surface and created favorable conditions for seed germination and plant growth. Triclopyr amine can effectively reduce adult loosestrife stem densities, however, additional herbicide applications may be required to prevent re-establishment through regeneration from the seed bank.

**Gardner, S. C. and C. E. Grue. 1996. Effects of Rodeo and Garlon 3A on nontarget wetland species in central Washington. Environ. Tox. Chem. 15: 441-451.** Purple loosestrife (*Lythrum salicaria*) is an invasive wetland perennial that became established in northeastern North America in the early 1800s. Despite its designation as a noxious weed, its distribution has continued to expand. Treatment with herbicides is the most widely used means of controlling purple loosestrife. This study examined the nontarget effects of two herbicides, Rodeo and Garlon 3A, currently used or being considered for use in controlling purple loosestrife in Washington State, respectively. Growth and/or survival of duckweed, *Daphnia*, and rainbow trout were monitored for at least 24 h following an application of each herbicide. Free-living water column and benthic invertebrates were monitored 24 h and 7 d post-spray using activity traps and sediment cores. Neither chemical was associated with significant decreases in survival or growth of the bioassay organisms, with the exception that growth of duckweed was reduced 48 h after exposure to Rodeo. Nor were significant decreases in the abundance of free-living aquatic invertebrates detected following the herbicide applications. Results suggest that neither herbicide, at the application rates used, poses a hazard to aquatic invertebrates in wetlands in central Washington. However, Rodeo, because it is a broad-spectrum herbicide, may pose a greater hazard to nontarget aquatic vegetation.

**Gardner, S.C., C.E. Grue, J.M. Grassley, L.A. Lenz, J.M. Lindenauer, and M.E. Seeley. 1997. Single species algal (Ankistrodesmus) toxicity tests with Rodeo R and Garlon R 3A. Bulletin of Environmental Contamination and Toxicology. 59: 492-499.** Experiments were conducted to compare the toxicity of 0-5120 g/ml Rodeo (glyphosate) and Garlon 3A (triclopyr) to the green alga Ankistrodesmus. In a further experiment the direct effects of Rodeo and indirect effects of associated changes in pH were differentiated by adjusting the pH to 7.0. Results indicated that, when herbicide-induced changes in pH were not adjusted for, the toxicity of Rodeo to the alga was 4.5 times more than that of Garlon. However, it is noted that these results may not be consistent in the field where pH may vary, and water quality may affect the stability and solubility of the herbicides and, thus, their toxicity.

**Getsinger, K.D., D.G. Petty, J.D. Madsen, J.G. Skogerboe, B.A. Houtman, W.T. Haller, and A.M. Fox. 2000. Aquatic dissipation of the herbicide triclopyr in Lake Minnetonka, Minnesota. Pest Management Science. 56: 388-400.** A study of the aquatic fate of the triethylamine salt of triclopyr was conducted in three bays of Lake Minnetonka, Minnesota (USA). The primary purpose of this study was to determine dissipation rates of the parent active ingredient, triclopyr, and its major metabolites, 3,5,6-trichloropyridinol (TCP) and 3,5,6-trichloro-2-methoxypyridine (TMP) in selected matrices including water, sediment, plants, fish and shellfish. Two 6.5-ha plots dominated by the weed species Myriophyllum spicatum were treated with 2.5 mg a.e. triclopyr\litre (2.5 ppm) on 21-23 June 1994. A third 6.5-ha plot was established as an untreated reference. Water and sediment samples were collected from within the plots and at selected locations up to 1600 m outside of the plots through six weeks post-treatment for chemical residue analysis. Residue samples were collected from the target and non-target plants and other non-target matrices, including game and rough fish (*Micropterus salmoides, Lepomis macrochirus, Ictalurus nebulosus and Catostomus commersoni*), clams (*Lampsilis siliquoidea*) and crayfish (*Orocnectes virilis* and *O. immunis*). All test animals were sequestered in cages located in the centre of each plot and samples were collected during four weeks post-treatment. Half-lives for dissipation of triclopyr and TCP in water ranged from 3.7 to 4.7 days and from 4.2 to 7.9 days, respectively, with trace amounts of TMP found. Peak triclopyr sediment values ranged from 257 to 335 ng g-1, with a mean half-life of 5.4 days, while peak TCP sediment levels ranged from 27 to 65 ng g-1 (mean half-life=11.0 days). Trace levels of TMP were detected at one treatment site at one sampling event. Triclopyr and TCP accumulated and cleared from animal tissues proportionately to concentrations in the water (triclopyr dissipation half-lives<11 days, TCP<14 days). TMP levels were two to three times higher than those of the other compounds, particularly in visceral tissue. In all cases, residues of these compounds were higher in the inedible portions of the animals, and were usually higher in bottom-feeding fish species. The target plant, *M. spicatum,* accumulated triclopyr steadily until its death. The nontarget

plant, *Potamogeton zosteriformis*, showed a much lower accumulation of triclopyr.

**Haellbom, L. and B. Bergman. 1979. Influence of certain herbicides and a forest fertilizer on the nitrogen fixation by the lichen *Peltigera praetextata*. Oecologia 40: 19-27**. The effects of Garlon 3A (triclopyr), MCPA, 2,4-D, and Krenite (fosamine ammonium), and the nitrogen fertilizer, $NH_4NO_3$ on the nitrogen fixation of *Peltigera praetextata* (Sommerf.) Zopf. in field and laboratory tests, and the nitrogen fixation and chlorophyll content of its symbiotic alga, *Nostoc* sp. in laboratory tests was examined. Measurement of nitrogenase activity was by the acetylene reduction technique. Krenite, 2,4-D, and the nitrogen fertilizer caused a decrease in algal nitrogenase activity. A depression of nitrogenase activity and disturbance of the symbiotic relationship were caused by the application of the nitrogen fertilizer in both field and laboratory tests to *Peltigera praetextata* lichens. Electron micrographic studies show that the disturbances of the symbiosis were due largely to the lethal effects of the $NH_4NO_3$ fertilizer which caused a significant decrease in the chlorophyll content of the algae.

**Harrington, T.B., R. G. Wagner, S. R. Radosevich, and J. D. Walstad. 1995. Interspecific competition and herbicide injury influence 10-year responses of coastal Douglas-fir and associated vegetation to release treatments. For. Ecol. and Manage. 76: 55-67.** Responses of competing vegetation and planted Douglas-fir ( *Pseudotsuga menziesii* var. *menziesii*) were studied for 10 years after six herbicide and manual release treatments in the Washington and Oregon Coast Ranges. Studies were installed in six 2- or 3-yr-old plantations, with Douglas-fir densities of 988 to 1482 plants/ha at time of planting and 721 to 1282/ha 2 to 3 years later. Research objectives were to quantify regional, long-term responses of vegetation (Douglas-fir and non-coniferous species) to various levels of competition, light and soil water availability, and intensity versus importance of factors influencing Douglas-fir growth. Three treatments reduced shrub cover relative to the untreated check: triclopyr in year 1, glyphosate in years 1-5, and repeated control (via several herbicide applications) in years 1-10. Reductions in woody cover from glyphosate stimulated increases in herb cover in years 3 and 5, while repeated control reduced herb cover in years 1, 2 and 5. Through year 10, Douglas-fir survival (86-99%) varied little among treatments. Visual symptoms of herbicide injury to Douglas-fir from triclopyr (45% of trees) and glyphosate (17% of trees) were associated with 0.1-0.2 m reductions in first-year height. After adjusting for tree size, Douglas-fir growth in stem basal area 2 years after triclopyr was less than that of the untreated check, suggesting prolonged effects of herbicide injury. Because it sustained low levels of interspecific competition, caused minimal tree injury, and prevented overtopping cover from red alder (*Alnus rubra*), repeated control was the only treatment in which Douglas-fir size (9.8 m height

and 21 cm basal diameter in year 10) significantly exceeded (Ṗ0.02) that of the untreated check (7.8 m height and 12 cm diameter).

**Hatterman, V. H., N. E. Christians, and M. D. K. Owen. 1995. Effect of 2,4-D and triclopyr on annual bedding plants. J. Environ. Hort. 13: 122-125.** Greenhouse trials were conducted to evaluate annual flower response to simulated drift of Weedar 64 (dimethylamine salt of 2,4-D) and Turflon amine (triethylamine salt of triclopyr). Mature annual flowers responded differently to low concentrations of Weedar 64 and Turflon; the order for species from most sensitive to least sensitive was *Petunia* X *hybrida* (cv. Daddy Mixture, Supercascade Lilac, Simply Madness and Red Madness) > *Begonia* X *semperflorens-cultorum* (cv. Espresso Rose and Party White) = *Tagetes erecta* (cv. Perfection Gold, Bonanza Mixture and Legend Yellow) and *T. patula* (cv. Boy O'Boy) = *Viola* X *wittrockiana* (cv. Majestic Mixture) = *Limonium sinuatum* (cv. Regal Mixed Colors) > *Pelargonium* X *hortorum* (cv. Cardinal and Pink Orbit) = *Impatiens walleriana* (cv. Bright Eye, Accent Coral, Accent Apricot and Accent White) = *Catharanthus roseus* (cv. Pretty in Pink and Bright Eye) = *Salvia farinacea* (cv. Empire Lilac). Rates less than 128 a.e./ ha (0.11 lb a.e./A) caused only slight injury. Injury was expressed in reduced flower production and callus. Turflon suppressed flowering 19% more than Weedar 64. Both herbicides reduced flowering at rates greater than 100 g/ha (0.088 lb/A).

**Hix, D. M., C. A. McNeel, and E. C. Townsend. 1994. Treatments for enhancing early survival and growth of northern red oak seedlings. Tree Planters' Notes. 45: 137-141.** Early survival and height growth of underplanted 2+0 northern red oak (*Quercus rubra*) nursery stock and of naturally established seedlings in northern West Virginia were evaluated one field growing season after treatments in a replicated multi-split-plot experiment. The experiment evaluated site quality (excellent and good sites), shelterwood felling, understory herbicide treatment and use of tree shelters. Tubex tree shelters 1.5 m tall promoted planted northern red oak height growth and general vigor (form and number of leaves) but did not affect survival. No other factor affected survival or height growth of planted stock, although there were significant interactions between site quality and both understory treatment and tree shelters. Understory treatment (application of triclopyr or picloram and 2,4-D to stumps) reduced the average height of woody vegetation competing with natural oak seedlings, and survival rates of major competing species, black cherry (*Prunus serotina*) and red maple (*Acer rubrum*) were less, but there was not a significant difference in the mean height of oaks. Results suggest that height growth of underplanted northern red oak seedlings may be enhanced by using tree shelters and by understory treatment on excellent sites.

**Holt, J. S., S. R. Radosevich, and W. L. Graves. 1985. Long-term effects on vegetation of herbicide treatments in chaparral. Weed Sci. 33: 353-357.**

Field studies were established in 1974 and 1975 at various locations in San Diego Country, CA (California, USA) to evaluate several herbicide for the control of chamise (*Adenostoma fasiculatum* H. & A.) and redshank chamise (*A. sparsifolium* Torr.). Herbicide effects on vegetation were reevaluated in 1982. Plots originally treated with 2.2 or 4.5 kg a.e./ha of glyphosate (N-(phosphonomethyl)glycine) had virtually no chamise regrowth 8 yr after treatment. The herbicides 2,4-D, combinations of 2,4-D with 2,4,5-T or dichlorprop (2-(2,4-dichlorophenoxy)propionic acid), fosamine (ethyl hydrogen (aminocarbonyl)phosphonate), triclopyr (((3,5,6-trichloro-2-pyridinyl)oxy)acetic acid), tebuthiuron (N-(5-(1, 1-dimethylethyl)-1,3,4-thiadiazol-2-yl)-N,N'-dimethylurea) and picloram (4-amino-3,5,6-trichloropicolinic acid) had no long-term effects on chamise. Soil collected in 1982 from glyphosate-treated plots contained similar numbers of chamise seeds but fewer seeds of other species compared to untreated plots. Canopy cover of redshank chamise was similar in treated and untreated plots after 8 yr. These results document the effectiveness of glyphosate in killing the underground root crown of chamise, which prevented sprouting, but not redshank chamise.

**Huffman, A. H. and P. W. Jacoby, Jr. 1984. Effects of herbicides on germination and seedling development of 3 native grasses. J. Range Manage. 37: 40-43.** Two experiments conducted in growth chambers examined influences of 2,4,5-T, clopyralid (3,6-dichloropicolinic acid), picloram (4- amino-3,5,6-trichloropicolinic acid) and triclopyr (((3,5,6- trichloro-2-pyridinyl)-oxy)acetic acid) on germination and early seedling development of buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.), blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Griffiths) and sideoats grama (*B. curtipendula* (Michx.) Torr.). Germination and plumule growth were largely unaffected by clopyralid but were significantly reduced by 2,4,5-T, picloram and triclopyr, especially at rates greater than 1.1 kg/ha. Blue grama was less affected by herbicides than either buffalograss or sideoats grama.

**Katovich, E. J. S., R. L. Becker, and B. D. Kinkaid. 1996. Influence of nontarget neighbors and spray volume on retention and efficacy of triclopyr in purple loosestrife (*Lythrum salicaria*). Weed Sci. 44: 143-147.** Greenhouse studies were conducted to determine the influence of plant density and spray volume on the retention, spray deposition, efficacy and translocation of the amine salt of triclopyr in purple loosestrife. More spray solution was retained on leaves at 935 L $ha^{-1}$ than at 94 L $ha^{-1}$ at populations of 0, 4 or 8 nontarget neighbors. Spray coverage decreased with decreasing height within the plant canopy when spray cards were placed in the top, middle and soil surface adjacent to the central target plant. Within a population, spray card coverage generally increased as spray volume increased. Regrowth from the crown was affected by spray volume, and uniform spray coverage of the plant was required for adequate control of vegetative regrowth and was achieved with spray volumes of 374 and 935 L $ha^{-1}$. Regrowth of purple loosestrife was greater at 94

L $ha^{-1}$ at all three plant populations, indicating that less herbicide penetrated the canopy to reach the basal portion of the plant. A laboratory experiment was conducted to investigate the translocation of radiolabelled triclopyr to roots and crowns of purple loosestrife. Only 0.3 to 1.4% of absorbed $^{14}C$-labelled material was translocated to roots and crowns. It was concluded that low spray volumes and dense stands of purple loosestrife are likely to result in poor control because inadequate amounts of triclopyr reach the basal portion of the plant and translocate to vegetative propagules.

**Kraus, T. E., D. P. Murr, G. Hofstra, and R. A. Fletcher. 1992. Modulation of ethylene synthesis in acotyledonous soybean and wheat seedlings. J. Plant Growth Reg. 11: 47-53.** The characteristics of ethylene production and ACC conversion in 8-day-old soybean seedlings were examined and a relationship between cytochrome P-450 activity and ethylene-forming enzyme (EFE) activity was found. An atmosphere containing 10% carbon monoxide inhibited ethylene production and ACC conversion in control soyabean seedlings, but only slightly affected seedlings treated with uniconazole. Foliar application of triclopyr, a pyridine analogue of the phenoxy herbicides, increased ethylene production and ACC conversion in control, but not in uniconazole-treated seedlings. Triclopyr treatment also resulted in a 3-fold increase in extractable cytochrome P-450 of 5-day-old etiolated soybeans. At equimolar concentrations tetcyclacis was more effective than uniconazole in reducing shoot elongation and endogenous ethylene production. Although uniconazole and tetcyclacis did not inhibit ACC conversion in nonherbicide-treated soybean seedlings, they prevented the increase in ACC-dependent EFE activity following triclopyr application. However, the rate of ACC conversion in etiolated soyabean segments was sensitive to uniconazole, and tetcyclacis inhibited the rate of ACC conversion by 2.6-fold in etiolated soybean segments within 4 h after treatment. Microsomal membranes were isolated from 5-day-old naphthalic anhydride-treated etiolated wheat shoots (containing higher cytochrome P-450 levels than soybean shoots). Optical difference spectroscopy demonstrated that ACC generated binding spectrum characteristic of a reverse-type-I cytochrome P-450 substrate when combined with reduced microsomes. In vitro conversion of ACC to ethylene by microsomal membranes was NADPH-dependent, inhibited by carbon monoxide and had an apparent $K_m$ and $V_{max}$ of 45 µM and 0.345 nl/mg protein/h, respectively.

**Kreutzweiser, D.P., D.G. Thompson, B. Staznik, and J.A. Shepherd. 1998. Accumulation dynamics of triclopyr ester in aquatic leaf packs and effects on detritivorous insects. Journal of Environmental Quality. 27: 1138-1147.** Previous field studies have demonstrated that residues of the herbicide triclopyr butoxyethyl ester (TBEE) can accumulate in submerged leaf material of aquatic systems at concentrations up to 20 times the maximum aqueous concentrations. Accumulated TBEE residues may pose a risk of adverse effects to detritivorous invertebrates inhabiting and using natural leaf packs. The dynamics of TBEE

accumulation and persistence in leaf materials of laboratory and outdoor aquatic systems were studied, and the ecological significance determined in terms of effects on detritivorous insects and organic matter processing. Accumulations of TBEE in leaf packs of semi-static laboratory microcosms were up to 80 times aqueous concentrations, and residues persisted for 4 to 5 days. Leaf material of flow-through laboratory microcosms accumulated TBEE at much higher rates (up to 1000 times aqueous concentrations), but residues were cleared by 48 to 72 h. Accumulation and persistence in flow-through units were dependent on water depth, velocity and exposure duration. Accumulated TBEE residues were lower in outdoor stream channels than in laboratory flow-through units, probably because of losses through sorption to natural benthic material in the stream channels. Despite accumulations of TBEE in leaf packs at up to 90 mg kg-1 in systems treated at or near expected environmental concentrations, there was no significant mortality of detritivorous insects and no significant reductions in leaf consumption. Significant mortality and reduced feeding occurred only in systems treated at concentrations well above (up to 10 times) expected environmental concentrations.

**Lautenschlager, R. A., F. W. Bell, R. W. Wagner, and J. C. Neal. 1995. The Fallingsnow Ecosystem project: comparing manual, mechanical, and aerial herbicide conifer release in northwestern Ontario. Proc. 49th Annual Meeting Northeastern Weed Science Society, pp. 144-145.** The initial findings of a field study conducted in a conifer [Pinopsida] forest in northwestern Ontario to assess the effects of glyphosate and triclopyr, manual cutting and mechanical cutting on soil factors, vegetation, below and above ground insects, amphibia, reptiles, moose [*Alces alces*] and deer are presented.

**Lautenschlager, R.A., F.W. Bell, R.G. Wagner, and P.E. Reynolds. 1998. The Fallingsnow Ecosystem Project: documenting the consequences of conifer release alternatives. Journal of Forestry. 96: 20-27.** An overview is presented of the Fallingsnow Ecosystem Project, established in 1993 SW of Thunder Bay, Ontario, Canada, including the design, environmental components, and the initial results obtained. The Project was designed to document the terrestrial ecological consequences of alternative conifer release treatments. The ecosystem components studied are: soil chemistry, physics and morphology; below- and above-ground microclimates; below-ground fungi; vegetation, species composition, abundance, diversity, and foliar nutrient content; insects; terrestrial gastropods; amphibians and reptiles; small mammals; songbirds; and moose [*Alces alces*] area use and foods (production and storage). Although long-term responses are unknown, results to date indicate that cutting (with brush saws or tractor-mounted cutting heads) and herbicide (glyphosate or triclopyr) treatments are relatively inconsequential for most environmental components found in regenerating northern forests. It is suggested that given the growing opposition to herbicide use in forestry,

managers must expect that social input into natural resource management will become more common, if not required.

**Leveille, P., J. Legris, G. Couture, and R. Langevine. 1995. Evaluation of the effects of triclopyr used in forestry. Pub. No. RN95-3084; Ministere des Ressources Naturelles; Quebec; Canada. 18 p.** An account is given of the chemical composition, biological action, toxicology, degradation and decomposition in air, soil, water, flora and fauna (including human), and effects on vegetation, fauna and humans, of the herbicide triclopyr.

**Lewer, P. and W. J. Owen. 1987. Triclopyr: An investigation of the basis for its species selectivity. Proc. 1987 British Crop Protection Conference, Weeds. Vol. 1, 353-360.** In radiotracer studies, triclopyr ethylene glycol butyl ether (EB) ester was taken up more readily than the corresponding solketal ester or acid form by wheat (triclopyr tolerant), barley (moderately tolerant), *Stellaria media* (susceptible) and *Chenopodium album* (very susceptible). Translocation of $^{14}C$ following leaf application of the EB ester was apparently not correlated with tolerance to the ester. Each species hydrolysed triclopyr EB ester equally efficiently. Extensive metabolism of the acid occurred in each species, but with different metabolite profiles. Triclopyr aspartate was tentatively identified as the major metabolite in *S. media* and *C. album* plants and soybean cell cultures, whereas wheat and barley metabolized triclopyr predominantly to compounds having the properties of saccharide esters.

**Lewer, P. and W.J. Owen. 1990. Selective action of the herbicide triclopyr. Pesticide Biochemistry and Physiology 36: 187-200.**

**Lobb, P. G. 1989. Response of potatoes, onions and tomatoes to herbicides used for brushweed control. Proc. 42nd New Zealand Weed and Pest Control Conf. 251-253.** Three herbicides recommended for brushweed control, triclopyr (1-1000 g/ha), glyphosate (1-1000 g) and metsulfuron-methyl (0.1-100 g), were each applied during field trials in 1988-89 to potatoes cv. Ilam hardy, onions cv. Pukekohne long keeper and tomatoes cv. Scoresby dwarf. Triclopyr did not reduce yields of onions at the 100 g rate but reduced potato and tomato yields at 500 and 50 g, respectively. Glyphosate at 500 g caused severe foliar damage and yield reductions in all 3 crops. Metsulfuron-methyl severely damaged potatoes at 5 g and onions at 1 g and decreased the yields of tomatoes at 0.1 g.

**Lobb, P. G. and G. W. Woon. 1983. Response of potatoes, grapes and kiwifruit to low rates of six commercially available pasture and brushweed herbicides. Proc. 36th New Zealand Weed and Pest Control Conf. 148-150.** Pasture herbicides 2,4-D and clopyralid + MCPB and brushweed herbicides 2,4,5-T, picloram + 2,4,5-T, picloram + triclopyr and amitrole-T (amitrole + ammonium thiocyanate) were applied to potatoes, grapes and kiwifruit at 10, 1.0 and 0.1% of standard commercial rates. Neither of the pasture herbicides affected potatoes but clopyralid + MCPB was better tolerated by both grapes and

kiwifruit than 2,4-D. All auxin-type brushweed herbicides reduced potato yield at the 10% rate but picloram + triclopyr was better tolerated by both grapes and kiwifruit than 2,4,5-T or picloram + 2,4,5-T. Amitrole-T was well tolerated by grapes and kiwifruit but severely affected potatoes.

**Luken J. O., S. W. Beiting, S. K. Kareth, R. L. Kumler, J. H. Liu, and C. A. Seither. 1994. Target and nontarget discrimination of herbicides applied to vegetation in a power-line corridor. Environ. Manage. 18: 251-255.** In field trials conducted in Clermont County, Ohio, during 1990-91, 2 cutting regimens (cut/spray and cut/delay spray) and 4 radiarc-applied herbicides (11.7 litres/ha Garlon (triclopyr) + 18.71 litres Tordon (picloram), 18.71 litres Accord (glyphosate), 18.71 litres Accord + 0.141 litres Escort (metsulfuron), and 28.11 litres Krenite (fosamine)) were tested in a power-line corridor to determine which management combination best eliminated target species (trees) and preserved non-target species (low shrubs, vines, perennial herbs and grasses). When spraying was delayed after cutting, the herbicide with the least impact on non-target species (Krenite) was also least efficient at killing target trees. Spraying soon after cutting improved the tree-killing efficiency of several herbicides, but it also increased the negative impact on non-target species. The herbicide with the most consistent tree-killing ability (Accord + Escort) had the most impact on non-target species. It was concluded that, because none of the herbicide/cutting treatments performed ideally, resource managers must decide the acceptable impact on non-target species when considering herbicide use.

**Luken, J.O., S.W. Beiting, R.L. Kumler. 1993. Target/non-target effects of herbicides in power-line corridor vegetation. Journal of Arboriculture. 19: 299-302.** Various herbicides and two cutting regimens (cut/spray and cut/delay spray) were tested in an Ohio power-line corridor. Herbicides were chosen to represent a range of selectivity and mode of action: Accord (glyphosate) at 18.7 litres/ha; Accord + Escort (metsulfuron) at 18.7 litres/ha + 0.14 litres/ha; Garlon (triclopyr) + Tordon (picloram) at 11.7 litres/ha + 18.7 litres/ha; and Krenite (fosamine) at 28.1 litres/ha. In all herbicide/cutting combinations, tree populations showed some recovery two years after treatment. Although Accord + Escort applied in a cut/spray treatment resulted in the lowest population of trees after two years, this treatment also had the most persistent negative effect on non-target ground cover. Krenite had the least negative impact on ground-cover. Spraying sooner rather than later after cutting improved tree-kill by all herbicides, but it can also increase effects on non-target species (e.g. with Krenite). It is concluded that more selective herbicides and herbicide application methods are needed for management of natural vegetation.

**Marini, R. and R. Byers. 1988. Methods for evaluating chemical inhibitors of apple abscission. Hort. Sci. 23: 849-851.** Several methods were evaluated for inducing apple (*Malus domestica* Borkh.) fruit abscission before the harvest season. Pedicels abscised within 7 days after being defruited, but drop

inhibitors retarded abscission minimally. Injecting ethephon into the seed cavity induced only 70% to 80% fruit drop within 13 days after treatment. Removing the calyx half of a fruit (half-fruit) induced abscission within 13 days of treatment, and half-fruit responded to drop inhibitors. Scoring branches before treatment did not influence abscission of half-fruit, but increased the severity of phytotoxic symptoms caused by triclopyr and dicamba. The half-fruit method facilitates the screening of many potential drop inhibitors because treatments can be applied to single-limb units at any time during the growing season.

**Marini, R. P., R. E. Byers, and D. L. Sowers. 1989. Growth regulators and herbicides for delaying apple fruit abscission. Hort. Sci. 24: 957-959.** Various chemicals were applied to whole-tree, quarter-tree, or single-limb units to determine their efficacy for delaying apple (*Malus domestica* Borkh.) fruit abscission. NAA and the herbicides fenoprop, dicamba, triclopyr, lontrel, fluroxypyr, and chloroxuron delayed fruit abscission. Benzoic acid, calcium acetate; the growth regulators lactidichlor ethyl, mefluidide, BA, GA-4+7, and chlormequat; and the herbicides pronamide, pendimethalin, chloramben, and DCPA did not delay fruit abscission.

**Marrs, R. H. 1985. The effects of potential bracken and scrub control herbicides on lowland *Calluna* and grass heath communities in East Anglia, UK. Biological Conservation 32: 13-32.** To assess the effects of 9 herbicides, which have a potential use for bracken and/or scrub control, on non-target lowland heath vegetation, 2 screening experiments were carried out at a *Calluna vulgaris* heath, and a grass heath dominated by *Festuca ovina.* The aims of the experiments were to select herbicides which caused minimal damage to the heath plant communities, and to monitor recovery from damage should any occur. No significant damage to *Calluna* was found where asulam, fosamine ammonium or 2,4,5-T were applied; on the grass heath these 3 herbicides and triclopyr caused no damage. Thus, these herbicides are suitable for use of the control of bracken and/or scrub on lowland heaths. Damage caused by other herbicides may be beneficial in some situations, for example in promoting new pioneer *Calluna*, by increasing numbers of dicotyledons on the grass heath. This is almost certainly caused by gap creation and suppression of competition, but the role of increased rabbit activity in damaged plots on the grass heath may also be important. Some of the difficulties inherent in assessing risks of herbicide use on nature reserves are noted, and briefly discussed.

**Marrs, R. H. and J. E. Lowday. 1984. Herbicidal control of weeds on nature reserves with special reference to lowland heaths. Annual Report 1983, Institute of Terrestrial Ecology. 30-35.** In herbicide screening trials on *Calluna vulgaris* and grass heaths, 11.2 L asulam, 10 L fosamine-ammonium and 3 L 2,4,5-T/ha did not damage the non-target vegetation, while 6 L triclopyr/ha damaged *C. vulgaris* and 150 kg asulam, 3 kg hexazinone, 5 L glyphosate, 9 L picloram and 45 kg tebuthiuron/ha caused unacceptable damage

to both heaths. In a mixed *Betula/Calluna* stand, fosamine-ammonium, 2,4,5-T and triclopyr reduced survival of saplings, but the first 2 herbicides also increased *Betula* seedling emergence. Triclopyr reduced the density of established *Calluna*, numbers of *Calluna* seedlings and *Betula* seedling emergence. All herbicides tested reduced the regrowth of *Betula* after cutting and initially reduced the density of *Calluna*. In studies on *Pteridium aquilinum* control, asulam initially gave 99% control with no damage to heath vegetation, but reinvasion occurred.

**McCarty, L. B. and D. L. Colvin. 1992. Buffalograss tolerance to postemergence herbicides. Hort. Sci. 27: 898-899.** A field trial was performed on fine sand at a site near Bradenton in 1991 to evaluate the tolerance of 2 new buffalograss [*Buchloe dactyloides*] cultivars Oasis and Prairie to the following post-emergence herbicides: bentazone, asulam, MSMA and atrazine at 2.24 kg/ha; mecoprop, diclofop and 2,4-D at 1.12 kg; quinclorac, triclopyr, dicamba and sethoxydim at 0.56 kg; imazaquin at 0.42 kg; metsulfuron and sulfometuron at 0.017 kg and a combination of 2,4-D + dicamba + mecoprop at 1.2 + 0.54 + 0.13 kg. Twenty to 40 d were required for each cultivar to recover from treatment with asulam, MSMA, and sethoxydim, but the other herbicides did not cause unacceptable buffalograss injury. Triclopyr, 2,4-D, sulfometuron, dicamba, and a combination of 2,4-D + dicamba + mecoprop caused 20-30 d of unacceptable or marginally acceptable turfgrass quality, while 20 d were required for buffalograss cv. Prairie to recover from atrazine treatments. Buffalograss cv. Oasis had not fully recovered from 2,4-D or 2,4-D + dicamba + mecoprop by 40 d after treatment. Bentazone and imazaquin caused slightly reduced, but acceptable, levels of turf quality in both cultivars throughout the experiment.

**McCarty, M. K. 1979. Yield and quality of 2 cool-season grasses as affected by selected herbicides. Weed Sci. 27: 415-421.** Several herbicides applied either in the fall or spring at rates used for musk thistle (*Carduus nutans* L.) control had no deleterious effects on 2 cool-season grasses, smooth brome (*Bromus inermis* Leyss.) and intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.). Herbicides used were 2,4-D, 2,4,5-T dicamba (3,6-dichloro-o-anisic acid), picloram (4-amino-3,5,6-trichloropicolinic acid), triclopyr (((3,5,6-trichloro-2-pyridinyl)oxy)acetic acid), and Dowco 290 (3,6-dichloropicolinic acid). Atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine) was included for comparative purposes because it is known to affect the protein content of some forage grasses. Effects on the quality of the forages were measured by in vitro dry matter disappearance (IVDMD), protein and $KNO_3$ determinations. Intermediate wheatgrass was less susceptible to damage from the highest rates of picloram and atrazine than smooth brome.

**Meredith, P. 1996. Effects of picloram (Tordon), clopyralid, triclopyr and chlorpyrifos on growth vigor, leaf form, pigmentation, yield specific**

**gravity, tuber shape, and light sensitivity of potatoes. American Potato J. 73: 373.**

**Meyer, R. E. and R. W. Bovey. 1991. Response of Yankeeweed (*Eupatorium compositifolium*) and associated pasture plants to herbicides. Weed Tech. 5: 214-217.**

**Meyer, R. E., R. W. Bovey, L. F. Bouse, and J. B. Carlton. 1983. Response of live oak (*Quercus virginiana*) and understory vegetation to herbicides. Weed Sci. 31: 639-647.** Live oak (*Q. virginiana* Mill, QUEVM) (a rangeland weed) on the Texas Coastal Prairie (USA) was treated with herbicides using ground and aerial application methods. Tebuthiuron (N-(5-(1,1- dimethylethyl)-1,3,4-thiadiazol-2-yl)-N,N'dimethylurea) and pellets of buthidazole (3-(5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl)-4-hydroxy-1-methyl-2-imidazolidinone) at 2.2 kg ai(active ingredient)/ha were the most effective herbicides, killing 60-95% of the live oak. Tebuthiuron pellets 3.2 mm in diameter were more effective than the wettable powder at 1.1 kg/ha. Bay Met 1486 (N-(5-(ethylsulfonyl)-1,3,4-thiadiazole-2-yl)-N,N'-dimethylurea), Dowco 290 (3,6-dichloropicolinic acid), hexazinone (3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione) and picloram (4-amino-3,5,6-trichloropicolinic acid) reduced the live oak canopy at 2.2 kg/ha; 2,4,5-T and triclopyr (((3,5,6-trichloro-2-pyridinyl)oxy) acetic acid) were ineffective. Foliage-active herbicides generally were most effective in reducing the live oak canopy during the year of application. The soil-active herbicides generally were most active 1 or 2 yr after herbicide application. All herbicides reduced the live oak cover sufficiently to allow an increase in grass cover 2-4 mo. after treatment. Tebuthiuron at 2.2 kg/ha maintained a high degree of grass cover at least 2 or 3 yr after treatment.

**Molnar, J. and I. Nemeth. 1983. Weed control experiments against *Rubus caesius* with Garlon 3A herbicide in fruit tree plantations. Novenyvedelmi Tudomanyos Napok, 3.** 5.0 to 7.5 l Garlon 3A [triclopyr]/ha provided good initial control of *Rubus caesius* in pear orchards or plantations of apple, cherry, peach, apricot or acacia but resprouting occurred within 2-3 months. Late summer spraying minimized resprouting. Garlon 3A was less effective applied alone than applied in combination with Glialka 20 EC. Phytotoxicity to pear was minimal. In grapevine the herbicide caused phytotoxic effects on shoot tips and young fruit bunches.

**Newmaster, S.G., F.W. Bell, and D.H. Vitt. 1999. The effects of glyphosate and triclopyr on common bryophytes and lichens in northwestern Ontario. Canadian Journal of Forest Research. 29: 1101-1111.** The effects of two silvicultural herbicides (Vision®, Release®) on bryophytes and lichens were studied in a harvested boreal mixedwood ecosystem. A completely randomized design with 115 plots of 1 m2 allowed direct comparison between herbicides

and their effects on community dynamics. Regression models were used to analyze the relationship between herbicide application rates (0.71-6.72 kg active ingredient/ha) and changes in bryophyte and lichen abundance and species richness for 2 years following herbicide application. Results showed that bryophyte and lichen abundance and species richness decreased after herbicide treatments. In general, herbicide applications reduced the diversity of forest mesophytes and weedy colonizers to an ecosystem with only a few species of colonizers. A combination of clustering techniques and ANOVA were used to divide bryophytes and lichens into three ecologically defined response groups: herbicide-tolerant colonizers, semi tolerant long-term stayers from dry open forest, and sensitive forest mesophytes.

**Newton, M., F. Roberts, A. Allen, B. Kelpsas, D. White, P. Boyd. 1990. Deposition and dissipation of three herbicides in foliage, litter, and soil of brushfields of southwest Oregon. J. Agric. Food. Chem. 38: 574-583.** The herbicides 2,4-D ((2,4-dichlorophenoxy)acetic acid), triclopyr ([(3,5,6-trichloro-2-pyridinyl)-oxy]acetic acid), and picloram (4- amino-3,5,6-trichloro-2-pyridinecarboxylic acid) were applied by helicopter to test grids in mountainous southwestern Oregon brushfields on shallow, rocky, clay loam soils. Herbicide concentrations were observed in crown twigs and foliage, browse twigs and foliage, litter, and soil. Initial deposits in the target area ranged from 61 to 115% (average 82%) of the nominal dosage, with coefficients of variation of 29-104%. Initial concentrations in crown foliage were 44-mg/kg for each kilogram per hectare applied; deposits on browse foliage and litter were 38% and 74%, respectively, of crown concentrations. Early after application, decreases were more rapid for salt formulations than for esters. After 79 days, decrease of all herbicides was slight in foliage, but continued in soil. Picloram disappeared most rapidly and was least mobile, followed by triclopyr and 2,4-D. Triclopyr and 2,4-D remained nearly constant in foliage through winter. Disappearance was rapid in litter.

**Novak, J. 1995. Use of Garlon 4 in the control of bracken in pasture. Agrochemia Bratislava. 35: 59-60.** Garlon 4 [triclopyr] was tested at 1.5 and 3 litre/ha for the control of bracken (*Pteridium aquilinum*) in pasture containing submontane herbage species of the *Festuca-Cynosurus cristatus* type. The treatment was 100% effective at both doses, but at the higher dose its phytotoxicity towards the herbage species was more marked and ranged from 2.5% to 10% for white clover [*Trifolium repens*].

**Perkins, M.J. 1997. Effects of two formulations of glyphosate and triclopyr on four non-target aquatic species: *Xenopus laevis*, *Myriophyllum sibiricum*, *Lemna gibba* and *Tubifex tubifex*. University of Guelph, 1997. 110 p.** The effects of two formulations of glyphosate (N-(phosphonomethyl)glycine): Roundup® (formulated with the surfactant, polyoxyethyleneamine) and Rodeo® (formulated without polyoxyethyleneamine) and triclopyr (((3.5.6-

trichloro-2-pyridinyl)oxy)acetic acid): Garlon 4® (butoxyethyl ester) and Garlon® 3A (triethylamine salt) on four non-target aquatic species were considered in this study. There was a significant effect of formulation on the toxicity of both glyphosate and triclopyr to *X. laevis* with LC50's of 22 mg ae/L, 9870 mg ae/L, 14 mg ae/L, and 750 mg ae/L for Roundup® Rodeo® Garlon 4® and Garlon® 3A, respectively. An effect of formulation was also observed on the toxicity of glyphosate and triclopyr to *T. tubifex*. Roundup® and Garlon 4® at concentrations of 52 mg ae/L and 86 mg ae/L resulted in significant effects on reproduction and mortality, respectively. Whereas, no significant effects with either Rodeo® or Garlon® 3A were noted at concentrations up to 106 mg ae/L and 17 mg ae/L, respectively. In contrast, there was no consistent effect of formulation on the sensitivity of *M. sibiricum* or *L. gibba* to these herbicides. *M. sibiricum* was more sensitive to both herbicides than *L. gibba.*

**Peterson, H.G., C. Boutin, P. A. Martin, K. E. Freemark., N. J. Ruecker, and M. J. Moody. 1994. Aquatic phytotoxicity of 23 pesticides applied at expected environmental concentrations. Aquat. Toxicol. 28: 275-292.** Environment Canada uses an Expected Environmental Concentration (EEC) in evaluating the hazard of pesticides to nontarget aquatic organisms. This concentration is calculated by assuming an overspray of a 15 cm deep water body at the label application rate. The EEC of pesticides is then related to the $EC_{50}$ (concentration causing a 50% reduction in a chosen toxicity endpoint) for a given aquatic test organism. At present, the use of an uncertainty factor is suggested in the literature if only a few species are tested because of important interspecific differences in pesticide sensitivity. The phytotoxicity of the EEC of 23 different pesticides to ten algae (24 h inhibition of $^{14}C$ uptake) and one vascular plant (7-day growth inhibition) was determined in an effort to examine the question of interspecific sensitivity and its relation to the development of pesticide registration guidelines. Chemicals included five triazine herbicides (atrazine, cyanazine, hexazinone, metribuzin, and simazine), four sulfonylurea herbicides (chlorsulfuron, metsulfuron-methyl, ethametsulfuron-methyl, triasulfuron), two phenoxy-alkane herbicides (2,4-D and MCPA), two pyridine herbicides (picloram and triclopyr), a substituted urea, an amine derivative, and an imidazolinone herbicide (tebuthiuron, glyphosate and imazethapyr, respectively), a bipyridylium (diquat), a hydroxybenxonitrile (bromoxynil), an aldehyde (acrolein) and an acetanilide (metolachlor) herbicide, as well as two carbamate insecticides (carbofuran and carbaryl) and a triazole derivative fungicide (propiconazole). Test organisms were selected based on ecological relevance and present use in test protocols.

**Prasad, R. and H. O. Yates III. 1984. Some physiological and phytotoxic effects of herbicides on forest seeds and seedlings: I. Evaluation of herbicidal properties by a seed germination technique. Proc. Cone and Seed Insects Working Party Conf.: Working Party S2.07.01. pp. 168-177.** The effects on

seed germination, radicle elongation and seedling growth of triclopyr, tebuthiuron and hexazinone were evaluated (using 2,4-D as a standard) in *Pinus banksiana, P. strobus, P. contorta, Picea glauca, P. mariana, P. sitchensis, Pseudotsuga menziesii, Tsuga canadensis, Alnus rugosa, Fraxinus subintegerrima [F. pennsylvanica], Betula papyrifera, B. alleghaniensis* and *Acer rubrum*.

**Roshon, R.D., J.H. McCann, D.G. Thompson, G.R. Stephenson, D.G. Thompson (ed.), and R.G. Wagner. 1999. Effects of seven forestry management herbicides on *Myriophyllum sibiricum*, as compared with other nontarget aquatic organisms. Proceedings of the third International Conference on Forest Vegetation Management, Sault Ste. Marie, Ontario, Canada, 1998. Canadian Journal of Forest Research., 29: 1158-1169.** Based on a review of the scientific literature and results from laboratory testing with the submersed macrophyte *Myriophyllum sibiricum*, the effects of 2,4 dichlorophenoxyacetic acid (2,4-D), glyphosate, hexazinone, imazapyr, metsulfuron methyl, sulfometuron methyl and triclopyr on non-target aquatic organisms were compared. Laboratory results indicated that *M. sibiricum* was sensitive to herbicide effects, especially those that impact on root growth. For most herbicides, the inhibitory concentrations IC25 and IC50 (concentrations that inhibit an endpoint parameter by 25 and 50%, respectively) for shoot and root growth were below the expected environmental concentrations (EEC). For example, the IC50 values for root dry mass were 0.00012 and 0.00022 mg active ingredient/litre for sulfometuron methyl and metsulfuron methyl, respectively, concentrations that were approximately 3100 and 1700 times below the EEC for these compounds. Interspecies comparisons, conducted during this study, demonstrated that *M. sibiricum* was equally or more sensitive to these herbicides than other aquatic plant species (i.e. floating macrophytes and algae) and, in some cases, more sensitive than fish, zooplankton and other invertebrates. Available data demonstrated that 2,4-D, imazapyr and the sulfonylureas investigated were more toxic to rooted and floating macrophytes than to other aquatic organisms, including algae. It is suggested that because of the high sensitivity and ecological significance of aquatic macrophytes, a greater emphasis should be placed on evaluating aquatic phytotoxicity in future ecotoxicological research.

**Segawa, R., A. Bradley, P. Lee, D. Tran, J. Hsu, J. White, and K.S. Goh. 1997. Residues of forestry herbicides in plants of importance to California native Americans. Bulletin of Environmental Contamination and Toxicology. 59: 556-563.** The monitoring results are reported for herbicide residues in 13 plant species collected from inside and outside treatment areas in 4 National Forests in California following ground applications of 1.0-1.5 lbs/acre glyphosate and 3.0-3.5 lbs triclopyr and aerial or ground applications of 1.0-1.5 lbs hexazinone. From within the treatment area, 45 out of 92 samples contained detectable residues while the figure for outside this area was 4 out of 119. Glyphosate,

hexazinone and triclopyr residues were found in 52, 47 and 50%, and 5, 2 and 3% of samples inside and outside the treatment areas, respectively. However, residues were found in 94 and 15% of samples taken from plots subjected to aerial (broadcast over the entire plot) and ground (direct on individual trees) treatment with hexazinone, respectively.

**Shipman, R. D. and T. J. Prunty. 1988. Effects of herbicide residues on germination and early survival of red oak acorns. Proc. 42nd Annual Meeting Northeastern Weed Sci. Soc. pp. 86-91.** The response of greenhouse-grown *Quercus rubra* to several herbicides at 1, 2 and 4 times the manufacturer's recommended rate was studied under greenhouse conditions. Dicamba, 2,4-D, picloram, sulfometuron-methyl and triclopyr ± picloram significantly reduced the percentage of germinating acorns. Picloram, sulfometuron-methyl and triclopyr significantly reduced seedling height. Glyphosate ± non-ionic wetter, hexazinone and simazine had little or no effect on percentage germination or seedling height. However, hexazinone inhibited photosynthesis and eventually killed the seedlings. Soil type significantly affected herbicide availability and subsequent phytotoxicity.

**Siltanen, H., C. Rosenberg, M. Raatikainen, and T. Raatikainen. 1981. Triclopyr, glyphosate and phenoxyherbicide residues in cowberries, bilberries and lichen. Bull. Environ. Contam. Tox. 27: 731-737.** Investigations were carried out in Finland into herbicide residues in wild berries in forests which had been subjected to foliar spraying for brush control. Residues of triclopyr were analyzed in cowberries and bilberries after treatment with 0.25, 0.75 and 2.25 kg/ha of the herbicide. Effect of date of treatment on glyphosate (applied at the rate of 0.75 kg/ha) and triclopyr residues was investigated. Results are tabulated. These showed that the residues in the berries were of the same order of magnitude when the same amount of any of the herbicides was used. In aerial spraying the application rate was lowest for glyphosate and highest for phenoxyherbicides. As a result residues in the berries from aerially sprayed forests can be expected to the highest after phenoxyherbicide application and lowest after glyphosate application.

**Skender, A. and I. Stevic. 1991. Effect of triclopyr and amino salts of 2,4-D on the changes of weed flora in the ditches of the confluence region of Vuka-Drava-Dunav Rivers. Znanost u Proizvodnji. 18-19: 48-53.** Field trials were conducted in 1988-90 to study the effects of triclopyr and amino salts of 2,4-D on changes in the weed flora in ditches in the confluence region of the Vuka, Drava and Dunav rivers. Garlozor 4-E (48% triclopyr) at 5 litres/ha and Monosan herbi [2,4-D] at 3 litres showed excellent efficacy against all *Salix* spp. and prevented their regrowth in the dry bottoms of drainage channels in the confluence region. In 1988, application of the herbicides resulted in a 10-fold reduction in infestation by *Urtica dioica* and *Galium aparine* and a 6-fold reduction in herbaceous dicotyledons in relation to controls. These changes in

the weed flora favor a more hygienic appearance of the channel, better water flow and a reduction in erosion of the channel slope due to the rapid development of spring grasses [Gramineae].

**Smith, L. J. and W. A. Skroch. 1995. Turf herbicide injury to landscape trees as influenced by mulch. J. Environ. Hort. 13: 60-63.** A two year field study was conducted in 1991 and 1992 to evaluate the sensitivity of landscape trees to certain turf herbicides as affected by mulch. The study included four tree species ('Bradford' callery pear, crape myrtle, Eastern redbud, red maple), four mulch treatments (shredded hardwood bark, pine bark, pine needles, no mulch), and six herbicide treatments (Banvel (dicamba), BAS 514 OOH (quinclorac), Image (imazaquin), Redeem (triclopyr), Stinger (clopyralid)). Herbicides were applied as directed sprays at the labeled rates for use on turf. Visual injury (%) ratings were measured at 30, 60, 90, 120, and 150 days after treatment. Trunk diameters and total plant fresh weights were measured at the conclusion of the study. In most cases, applying the herbicide over mulch decreased tree injury compared to applications to bare soil (Fig. 3). Red maples were most severely injured by Stinger (clopyralid) (27%) (60 DAT) and BAS 514 OOH (quinclorac) (33%) (60 DAT). Redbuds were most severely injured by the same two herbicides, but at 89% (120 DAT) and 73% (120 DAT), respectively. 'Bradford' pears were injured by Banvel (dicamba) (32%) (120 DAT), and crape myrtles by Image (imazaquin) (10%) (120 DAT).

**Smith, R. J., Jr. 1988. Tolerance of rice (*Oryza sativa*) to acifluorfen and triclopyr applied alone or in mixtures with propanil. Weed Sci. 36: 379-83.**

**Sprecher, S. L. and A. B. Stewart. 1995. Triclopyr effects on peroxidase activity in target and non-target aquatic plants. J. Aquat. Plant Manage. 33: 43-48.** Rapid and characteristic physiological responses to herbicidal activity in aquatic plants have potential for monitoring treatment effect in laboratory evaluations and operational applications, or indicating contaminant runoff in aquatic ecosystems. Change in peroxidase enzyme (PRX) has been considered for use as such a parameter, and was investigated following application of the auxin-like herbicide triclopyr to four species at 1 mg a.e./l for 12 hr, and 2.5 mg a.e./l for 24 hr. Guaiacol-specific PRX increased rapidly within 1.5 days after triclopyr application in the dicot Eurasian watermilfoil (*Myriophyllum spicatum* L.). The non-target monocots elodea (*Elodea canadensis* Rich.), sago pondweed (*Potamogeton pectinatus* L.), and vallisneria (*Vallisneria americana* Michx.) showed no visual effects of triclopyr treatment through 8 DAT, and PRX levels were unchanged in treated and untreated plants during this time. However, by 35 DAT the 2.5 mg/l triclopyr rate (the maximum label rate) had reduced biomass of sago pondweed by 60%. The early PRX response to triclopyr effect which differentiated. Eurasian watermilfoil from non-target species suggests that this parameter may be predictive of rapid susceptibility to this herbicide.

**Stjernquist, I. 1983. Photosynthesis, growth and competitive ability of some coniferous forest mosses and the influence of herbicides and heavy metals (Cu, Zn). Govt. Reports Announcements and Index (GRA&I), Issue 11.** The importance of morphological characteristics and environmental variables as controlling factors for photosynthesis and growth of *Dicranum polysetum*, *Pleurozium schreberi* and *Ptilium crista-castrensis* were studied. The three mosses had maximum assimilation capacity in different segments of the shoot and the growth form determined to what degree the capacity could be utilized. $CO_2$ fixation was limited by nutrient supply and selectivity affected by the environmental variables. *In situ* growth in a certain habitat or during a certain season closely corresponded to the oscillation of the variables important for $CO_2$ fixation. Application of 2,4-D, MCPA, triclopyr and glyphosate to populations of *Dicranum*, *Pleurozium* and five co-existing species gave selective effects on assimilation and respiration depending on bryophyte and herbicide. Generally, glyphosate had negative long-term effects on photosynthesis of coniferous mosses with the exception of *Sphagnum squarrosum*. MCPA, 2,4-D and triclopyr immediately decreased $CO_2$ fixation to maximally 30% of the control (*Pleurozium* and *Hylocomium* splendens). After one month $CO_2$ assimilation increased. Effects of varying concentrations of 2,4-D, and glyphosate were studied and the influence on growth discussed. Assimilation and respiration of *Dicranum* was negatively related to increasing content of Cu+Zn in the shoot.

**Talbert, R., M. J. Tierney, T. A. Strebe, M. J. Kitt, and N. R. Burgos. 1994. Field evaluations of herbicides on small fruit, vegetable and ornamental crops. Research Series Arkansas Agric. Exp. Stat. No. 447, 58 pp.** The results are reported of field trials conducted in Arkansas in 1994 to assess weed control and crop damage in the following: broccoli cv. Super Dome F1 hybrid treated with paraquat, green onion [*Allium cepa*] cv. Ishikura treated with DCPA [chlorthal-dimethyl] ± pendimethalin, southern pea [cowpeas] cv. Encore treated with metolachlor, dimethenamid, flumetsulam and RH-1658, autumn and over-wintering spinach cv. Fall Green with treated with metolachlor, Betamix [desmedipham or phenmedipham] and the fungicide zinc dimethyldithiocarbamate, summer and winter squash cv. Black Zucchini and Butternut, resp., treated with ethalfluralin ± clomazone, metolachlor and dimethenamid, tomato cv. Mountain Pride treated with quinclorac, 2,4-D and triclopyr, turnip cv. White Lady treated with DCPA, metalaxyl ± copper, snap bean [*Phaseolus vulgaris*] cv. True Blue treated with trifluralin, metolachlor, and sethoxydim or clethodim + bentazone + fomesafen, grapes cv. Concord treated with glufosinate + oryzalin, diuron or thiazopyr, and paraquat + metribuzin or oryzalin, and the ornamentals *Lobularia maritima* treated with oryzalin, metolachlor and napropamide, Gaillardia cv. Red Plumme treated with metolachlor, fluazifop-P and napropamide, *Impatiens walleriana* treated with napropamide and bentazone, *Tagetes erecta* treated with bentazone, *Viola tricolor* and *Petunia* spp. treated with pendimethalin, and *Limonium* spp. treated

with EPTC and napropamide. Trials were also conducted to assess desiccation of cover crops (wheat or rye + hairy vetch [*Vicia villosa*]) with glufosinate, glyphosate and/or paraquat.

**Tesar, O. 1995. Use of herbicides for the chemical protection of non-traditional forage crop seed stands. Scientific Studies Research Institute for Fodder Plants. No. 13, pp. 91-104.** One pre-sowing and 14 post-emergence herbicides were compared in seed crops of the annual forage legumes *Melilotus alba*, *Trigonella coerulea*, *Tetragonolobus purpureus*, *Lotus ornithopodioides* and *Malva verticillata* in 1993 and 1994. The most effective combinations were imazethapyr-ammonium + pyridate + rapeseed oil in *T. coerulea* and *M.. alba* with yield increases, no phytotoxicity and 95.7-100% control of *Amaranthus sp.* and 67.8-71.5% control of *Chenopodium sp.* In *M. verticillata*, metamitron + triclopyr, metamitron + phenmedipham or desmedipham, and metamitron + fluazifop-P-butyl or haloxyfop gave 72.1-90.7% weed control without phytotoxicity but crop yields were unaffected. *T. purpureus* and *L. ornithopodioides* trials were unsatisfactory.

**Whisenant, S. G. and E. D. McArthur. 1989. Triclopyr persistence in northern Idaho forest vegetation. Bull. Environ. Contam. Toxicol. 42: 660-665.**

## SOIL INVERTEBRATES

**Afun, J. V. K., E. A. Heinrichs, D. E. Johnson, and A. Russell-Smith. 1995. The influence of weeds in the natural control of upland rice insect pests in Cote d'Ivoire. Proc. Brighton Crop Protection Conference: Weeds. 1:181-186.** There is considerable evidence that weeds, in addition to competing directly with crops, provide shelter and other resources for both insect pests and their natural enemies. Since natural enemies are crucial to control of insect pests in rice, it is important that weed management strategies should conserve their populations. Results of research on the effects of weed and weed residue management strategies on predatory arthropods in the forest and derived savanna zones in January-October 1994 in Cote d'Ivoire are described. Weeding regimes included treatment with oxadiazon (1 kg/ha a.i. at planting) and Garil (triclopyr at 0.3 kg/ha a i. + propanil at 1.44 kg/ha a.i. at 25 days after emergence (DAE)). On-farm surveys of weed, insect pest and natural enemy populations of fields demonstrated that length of prior fallow and proportions of grass and broadleaved weeds influenced insect pests and some groups of natural enemies, such as spiders [Araneae] and ants [Formicidae]. Experiments at Bouake demonstrated that weeding upland rice between 28 and 63 DAE increased spider populations and gave rice yields equivalent to those following a standard herbicide treatment, although there was no apparent effect of weeding regimes on insect pests. Different weed trash management regimes also affected predatory arthropod populations.

**Asteraki, E. J., C. B. Hanks, and R. O. Clements. 1992. The impact of the chemical removal of the hedge-base flora on the community structure of carabid beetles (*Coleoptera, Carabidae*) and spiders (*Araneae*) of the field and hedge bottom. J. Applied Entomol. 113: 398-406.** In commercial farming practice, herbicides may be used to eradicate or manipulate the flora in the base of hedgerows. The effect of this on the carabid and spider communities was assessed. The carabid and spider communities of a hawthorn hedge alongside a semipermanent sward and of the adjacent part of the field were sampled in Berkshire, UK, using pitfall traps. The hedge was divided into 3 replicates of 2 herbicide treatments (glyphosate and 2,4-D + dicamba + triclopyr) and a control. The carabid data were ordinated (DECORANA) and showed that both herbicide treatments affected the communities; the spider data showed similar but less marked responses. Both herbicides had important effects on the carabid communities, but the spider communities were most affected when only the broadleaved forbs were removed.

**Baarschers, W. H., J. G. Donnelly, and H. S. Heitland. 1988. Microbial toxicity of triclopyr and related herbicides. Toxicity Assessment. 3: 127-136.** Microbial toxicity of triclopyr was measured with several microorganisms in comparison with 2,4-D and picloram. Growth inhibition of three fungi (*Trichoderma viride, Mortierella isabellina*, and *Saprolegnia parasitica*) was measured in terms of

colony size on agar plates and in terms of cell counts for two algae (*Chlorella vulgaris* and *C. pyrenoidosa*). Dehydrogenase measurement by a direct 2-(4-lodophenyl)-3-(4- nitrophenyl)-5-phenyl tetrazolium chloride method was used for the bacteria *Pseudomonas pictorum* and *Arthrobacter globiformis*. Dose-response curves were determined to obtain $EC_{50}$ values for triclopyr, 2,4-D, picloram, their commonly used amine salts, and the degradation products, 3,5,6-trichloro-2-pyridinol, 2,4-dichlorophenol and decarboxy picloram. Toxicities of triclopyr and 2,4-D were similar in most cases, and both compounds were more toxic than picloram. The 3 degradation products were substantially more toxic than the respective parent compounds. The algae were most sensitive and gave much lower $EC_{50}$ values than the fungi and bacteria.

**Chakravarty, P. and S. S. Sidhu. 1987. Effect of glyphosate, hexazinone and triclopyr on *in vitro* growth of five species of ectomycorrhizal fungi. European J. For. Pathology 17: 204-210.** *In vitro* growth tests with glyphosate (Roundup), hexazinone (liquid Velpar L and granule Pronone 5G) and triclopyr (Garlon) on five species of ectomycorrhizal fungi (*Hebeloma crustuliniforme, Laccaria laccata, Thelophora americana, T. terrestris* and *Suillus tomentosus*) showed varied species sensitivity to different concentrations of herbicides. Fungal growth was significantly ($P = 0.05$) reduced particularly at concentrations above 10 ppm. Garlon with tricolopyr as a.i. (active ingredient) was the most toxic of the four herbicide formulations.

**Estok, D., B. Freedman, and D. Boyle. 1989. Effects of the herbicides 2,4-D, glyphosate, hexazinone, and triclopyr on the growth of three species of ectomycorrhizal fungi. Bull. Environ. Contam. Toxicol. 42: 835-839.**

**Feng, Y. and J. M. Bollag. 1994. Transformation of 3,5,6-trichloro-2-pyridinol by *Pseudomonas corrugata*. Proc. General Meeting Amer. Soc. Microbiol. 94: 401.**

**Haellbom, L. and B. Bergman. 1979. Influence of certain herbicides and a forest fertilizer on the nitrogen fixation by the lichen *Peltigera praetextata*. Oecologia 40: 19-27.** The effects of Garlon 3A (triclopyr), MCPA, 2,4-D, and Krenite (fosamine ammonium), and the nitrogen fertilizer, $NH_4NO_3$ on the nitrogen fixation of *Peltigera praetextata* (Sommerf.) Zopf. in field and laboratory tests, and the nitrogen fixation and chlorophyll content of its symbiotic alga, *Nostoc* sp. in laboratory tests was examined. Measurement of nitrogenase activity was by the acetylene reduction technique. Krenite, 2,4-D, and the nitrogen fertilizer caused a decrease in algal nitrogenase activity. A depression of nitrogenase activity and disturbance of the symbiotic relationship were caused by the application of the nitrogen fertilizer in both field and laboratory tests to *Peltigera praetextata* lichens. Electron micrographic studies show that the disturbances of the symbiosis were due largely to the lethal

effects of the $NH_4NO_3$ fertilizer which caused a significant decrease in the chlorophyll content of the algae.

**Hawkins, J. W., M. W. Lankester, R. A. Lautenschlager, F. W. Bell, and J. C. Neal. 1995. Effects of manual, mechanical, and aerial herbicide conifer release on terrestrial gastropods in the Fallingsnow Ecosystem (northwestern Ontario). Proc. 49th Annual Meeting Northeastern Weed Sci. Soc., pp. 137-138.** Forest sampling was conducted in northwestern Ontario to assess the effects of glyphosate and triclopyr applications to conifer [Pinopsida] forests and their effects on terrestrial gastropods. The densities of the 11 most common gastropod species were monitored before and after weed control (using herbicides, mechanical methods and manual weed control) during the spring and summer of 1993 and 1994. Herbicidal applications resulted in the increased density of 4 gastropod species, the decrease of 3 other species and had no effect on another 4 species. Mechanical and manual weed control resulted in the reduction in densities of 5 gastropod species, but had no effect on 5 other species.

**Hawkins, J.W., M.W. Lankester, R.A. Lautenschlager, F.W. Bell. 1997. Effects of alternative conifer release treatments on terrestrial gastropods in northwestern Ontario. Fallingsnow Ecosystem Project. Forestry-Chronicle. 73: 91-98.** Changes in terrestrial gastropod species richness and density were monitored in regenerating spruce [*Picea mariana* and *P. glauca*] plantations following application of four conifer release treatments including two chemical herbicides, Vision (glyphosate) and Release (triclopyr), cutting by mechanical means (Silvana Selective/Ford Versatile), and motor-manual cutting with brush saws. The site is SW of Thunder Bay, Ontario. Mean gastropod density increased to a maximum of 21/m2 over the summer of 1993 (pre-treatment) when a total of 27 396 gastropods were collected, but remained fairly stable at about 10/m2 throughout the summer of 1994 (post-treatment) when only 20 199 were collected. This difference between years was not related to the conifer release treatments, since gastropod densities on both treated and control areas were lower in 1994. The decline in 1994 was probably due to decreased population size and detectability because of less rainfall. The lack of difference following treatments was attributed to rapid re-establishment of the herbaceous layer which probably continued to provide favourable conditions for snails and slugs. Gastropod density was higher in a 9-year-old regenerating spruce plantation (15.5/m2) than in a 70-year-old mixed-wood forest (9.4/m2) and species richness was also slightly greater (20 vs. 18 species) in the plantation. These differences were attributed to the more abundant near-ground vegetation and the greater amount of broadleaved litter characterizing the regenerating plantation.

**Lautenschlager, R. A., F. W. Bell, R. W. Wagner, and J. C. Neal. 1995. The Fallingsnow Ecosystem project: comparing manual, mechanical, and aerial**

**herbicide conifer release in northwestern Ontario. Proc. 49th Annual Meeting Northeastern Weed Science Society, pp. 144-145.** The initial findings of a field study conducted in a conifer [Pinopsida] forest in northwestern Ontario to assess the effects of glyphosate and triclopyr, manual cutting and mechanical cutting on soil factors, vegetation, below and above ground insects, amphibia, reptiles, moose [*Alces alces*] and deer are presented.

**Lautenschlager, R.A., F.W. Bell, R.G. Wagner, and P.E. Reynolds. 1998. The Fallingsnow Ecosystem Project: documenting the consequences of conifer release alternatives. Journal of Forestry. 96: 20-27.** An overview is presented of the Fallingsnow Ecosystem Project, established in 1993 SW of Thunder Bay, Ontario, Canada, including the design, environmental components, and the initial results obtained. The Project was designed to document the terrestrial ecological consequences of alternative conifer release treatments. The ecosystem components studied are: soil chemistry, physics and morphology; below- and above-ground microclimates; below-ground fungi; vegetation, species composition, abundance, diversity, and foliar nutrient content; insects; terrestrial gastropods; amphibians and reptiles; small mammals; songbirds; and moose [*Alces alces*] area use and foods (production and storage). Although long-term responses are unknown, results to date indicate that cutting (with brush saws or tractor-mounted cutting heads) and herbicide (glyphosate or triclopyr) treatments are relatively inconsequential for most environmental components found in regenerating northern forests. It is suggested that given the growing opposition to herbicide use in forestry, managers must expect that social input into natural resource management will become more common, if not required.

**Lobaugh, S., F. Farrow, X. Feng, and A. Ogram. 1994. The effects of triclopyr on 2,4-D mineralization in two soils. J. Environ. Sci. Health, Part B. 29: 459-471.** The effects of the herbicide triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid) on the mineralization of 2,4-D (2,4-dichlorophenoxyacetic acid) in two soils which differed in their histories of prior exposure to the two herbicides were investigated. The relative effects of triclopyr on 2,4-D mineralization and most probable numbers of 2,4-D degraders were dependent upon the soil. Triclopyr was shown to increase 2,4-D mineralization rates in a soil which had been exposed to both 2,4-D and triclopyr, but decreased the mineralization rate of 2,4-D and inhibited the increase of most probable numbers of 2,4-D degraders in a soil that had not been directly exposed to either herbicide.

**Prezio, J.R., M.W. Lankester, R.A. Lautenschlager, F.W. Bell, D.G. Thompson (ed.). R.G. Wagner. 1999. Effects of alternative conifer release treatments on terrestrial gastropods in regenerating spruce plantations. Proceedings of the third International Conference on Forest Vegetation Management, Sault Ste. Marie, Ontario, Canada, 1998. Canadian Journal of Forest**

**Research. 29: 1141-1148.** Changes in terrestrial gastropod density and species composition were studied in the second and third years (1995-96) after the application of conifer release treatments in regenerating *Picea* spp. plantations in Fraleigh Township, Ontario. The conifer release treatments included one of two herbicides (glyphosate (Vision) or triclopyr (Release)) aerially applied or vegetation removal by motor-manual cutting with brushsaws or mechanical cutting. Data were collected monthly from June to September during 1995-96, and a total of 15thin083 terrestrial gastropods, comprising 18 genera and 21 species, was collected using cardboard sheets over this period. Gastropod densities in untreated control areas were 50 and 60% greater than those in treated areas, in 1995 and 1996, respectively. The greatest differences in densities among individual treatments were evident in the third summer following treatments. It is suggested that declines may be attributable to decreased litter deposition and changed near-ground microclimate on the treated sites. Gastropod densities in non-chemical, cutting treatments started to recover more quickly than those in herbicide-treated sites.

**Sapoundjieva, K. 1987. Effect of Garlon 3A on soil microbial activity. Pochvoznanie Agrokhimiya i Rastitelna Zashchita. 22: 48-55.** The effect of Garlon 3A (triclopyr) at rates of 2000 and 4000 ml/ha on microbial activity in a meadow boggy soil was studied. Samples for analysis were taken from the 0-15 cm layer on days 5, 25, 75 and 135 after the application of the herbicide. To study its aftereffect, samples were taken on days 365 and 800. Determinations were made of the number of bacteria, actinomycetes, microscopic fungi and *Azotobacter* and also of $CO_2$ evolution. Garlon 3A was shown to be slightly toxic to the microorganisms studied. The biological balance in the soil was not redressed even after two years of detoxication.

**Searle, G. G., D. R. Penman, and R. B. Chapman. 1990. The toxicity of herbicides to the gorse spider mite *Tetranychus lintearius*. Proc. 43rd New Zealand Weed and Pest Control Conf. pp. 178-181.** The toxicity of 4 herbicides (metsulfuron at 0.75 g/litre, triclopyr at 1.8 g, triclopyr/picloram at 1.2 g and glyphosate at 3.6 g) and 4 surfactants (Silwet L-77 at 1 ml/litre, Agral LN at 1 ml, Citowett at 0.2 ml and Triton X-45 at 2.5 ml), commonly used on gorse (*Ulex europaeus*), to adult female gorse spider mites (*T. lintearius*) was investigated in the laboratory. All herbicide and surfactant combinations except metsulfuron with either Triton X-45, Agral LN or Citowett were toxic to the mites.

**Sidhu, S. S. and P. Chakravarty. 1990. Effect of selected forestry herbicides on ectomycorrhizal development and seedling growth of lodgepole pine and white spruce under controlled and field environment. European J. For. Pathology 20: 77-94.** In tests under aseptic conditions, the herbicides hexazinone (Pronone 5G and Velpar L), glyphosate, and triclopyr reduced seedling growth and mycorrhizal development of *Pinus contorta* var. *latifolia*

and *Picea glauca*. Triclopyr was most toxic of the four herbicide formulations. Under greenhouse condition, only 2 formulations of hexazinone (Pronone 5G and Velpar L) were tested. At high concentrations (2 and 4 kg/ha) it reduced growth and mycorrhizal infections significantly but showed recovery with time. No adverse effects were observed at low concentration (1 kg/ha). In general, seedlings inoculated with mycorrhizal fungus (*Suillus tomentosus*), were more sensitive to herbicide than the ones without mycorrhizal inoculation. Under field conditions overall effects of herbicide application were less intense. Only 4 kg/ha rates of hexazinone resulted in reductions in seedling growth and mycorrhizal infections. The nonmycorrhizal seedlings planted in the field developed mycorrhizae in over 40% of short roots within 2 months after planting in all herbicide treatments.

**Wardle, D.A. 1989. : The influence of environmental variables and herbicide application on the soil microbial biomass (microbial biomass, moisture level). University of Calgary, 243 p.** Equations for predicting the total soil microbial biomass were evaluated from a statistical viewpoint, and, where necessary, re-determined after correcting for dependency and non-normality of the data used. The fumigation-incubation method of microbial biomass determination depends on values of the $\underline{k}_c$-factor which is the fraction of microbial biomass carbon released within 10 days of fumigation. The three $\underline{k}_c$-values currently in use, i.e. 0.41, 0.45, and 0.50, all have a high degree of associated variability, which is influenced by variability between microbial species and estimates of bacterial:fungal ratios in soil samples. Four methods have been directly or indirectly calibrated against the fumigation-incubation technique, i.e. substrate-induced respiration (S.I.R.), ATP analysis, ninhydrin-extractable nitrogen, and fumigation-extraction. However, when problems associated with dependency and non-normality are corrected for it is uncertain as to whether or not these methods provide a realistic estimate of soil microbial biomass carbon. Evaluation of methods used for predicting total microbial biomass carbon were performed on soil samples maintained at five different moisture levels for 4 incubation periods. These were amended with $^{14}C$-labelled microbial tissue, and fumigation $\underline{k}_c$ values determined. Values of $\underline{k}_c$ were significantly affected by soil moisture content, time of preincubation, and sampling strategy (blocking effects). Microbial biomass for these samples was predicted using fumigation-incubation ($\underline{k}_c = 0.41$), fumigation-incubation (different $\underline{k}_c$ value for each sample and treatment), S.I.R. with and without remoistening, and oxygen uptake curves (with fumigation). Little agreement was found between any of the five approaches used, with $r^2$ values between pairs of methods always being below 0.50. The different approaches also often predicted different responses of the microbial biomass to the soil moisture gradient. The S.I.R. method agreed reasonably well with techniques used to measure only the active microbial biomass, and it is concluded that S.I.R. and related techniques (including selective inhibition) can be used for assessing the dynamics of the active biomass. In a field study examining the effects of

temperature and moisture on S.I.R. and basal respiration determinations, soil moisture was the principal factor involved, especially in conditions of rapid soil moisture fluctuation. Soil temperature was important only when soil moisture content was relatively constant, or when variations of soil moisture were removed using partial correlation analysis. The response of S.I.R., basal respiration, and inhibition by selective inhibitors in soil to various herbicide applications were determined in laboratory studies and in field plots. In the laboratory study response of biotic variables occurred only at concentrations of 200 ppm glyphosate, 2,4-D, or picloram, which is probably two orders of magnitude higher than what probably occurs in field situations. In field experiments, glyphosate and 2,4-D had little effect on the biotic variables tested compared with the natural dynamics of these variables.

**Wood K. and C. Hollstedt (compiled by). 1995. Fallingsnow Ecosystem Workshop: program and abstracts. Workshop proceedings / Ontario. Ministry of Natural Resources. WP-001, Vegetation Management Alternatives Program, 1995. xv, 54 p.** The Fallingsnow Ecosystem Project, which is providing data on the ecological impacts of alternative vegetation management practices, is being conducted on a regenerated spruce plantation near Thunder Bay, Ontario. Four treatments have been applied at the study site in a randomized block design: manual brushing; mechanical site treatment; aerial application of glyphosate or triclopyr herbicides; and control (no treatment). Environmental variables examined include soil characteristics and biodiversity; below- and above-ground temperature and moisture; vegetation species composition and foliar nutrient content; below- and above-ground insects; terrestrial gastropods; amphibians and reptiles; small mammals; songbirds; moose and deer area use, and foods (production and quality). This report contains presentations from a workshop held to transfer to resource managers the most recent scientific information produced from this project.