An Aquatic Plant Risk Assessment of Sixteen Herbicides Using Toxicity Tests with *Selenastrum capricornutum* and *Lemna minor*

by

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EXECUTIVE SUMMARY

The use of aquatic plant toxicity testing in environmental risk assessment has greatly increased in recent years. However, few comprehensive aquatic plant databases exist due to widespread differences in test methods and endpoints used across various studies. We conducted an aquatic plant risk assessment of sixteen herbicides (atrazine, metribuzin, simazine, cyanazine, alachlor, metolachlor, chlorsulfuron, metsulfuron, triallate, EPTC, trifluralin, diquat, paraquat, dicamba, bromoxonyl, and 2,4-D) using the algae *Selenastrum capricornutum* and the floating vascular plant *Lemna minor*. The herbicides studied represented nine chemical classes and several modes of action and were chosen to represent major current uses in the U.S. The risk assessment was conducted by comparing the 96-h EC50 (growth) to exposure predictions based on application rates and chemical sorption characteristics. Results were not always predictable in spite of obvious differences in herbicide modes of action and plant phylogeny. Major departures in sensitivity of *Selenastrum* occurred between chemicals within individual classes of the triazine, acetanilide, and thiocarbamate herbicides. Sulfonylureas were highly toxic to *Lemna*, but do not necessarily represent a large aquatic risk due to the low rates of application. Atrazine, metribuzin, cyanazine, alachlor, and metolachlor appeared to pose the greatest risk to aquatic plants. Exposure and effects data indicate that primary ecological concern occurs in areas receiving direct over-spray or excessive runoff (e.g. 1-10% of application) which may include seasonal and semipermanent wetlands that are interspersed within major farming areas of North America. However, herbicide exposures and impacts in wetlands have not been widely investigated.

Key Words: herbicides, aquatic plants, *Selenastrum*, *Lemna*, risk assessment, toxicity

INTRODUCTION

Herbicide runoff is known to be a major source of non-point source agricultural pollution in aquatic systems. In 1994 over 97% of corn and soybean acreages were treated with one or more herbicides (over 192 million pounds total application) in the Midwestern states of Illinois, Indiana, Iowa, Minnesota, Missouri, Nebraska, and Ohio (USDA 1995). Water quality monitoring programs have determined that herbicide contamination of surface waters (Goolsby and Baglin, 1995; Richards and Baker 1993), ground waters (Squillace and Thurman 1993; Mills and Thurman 1994) and rainfall (Nations and Hallberg 1992) are common and widespread. For example, the U.S. Geological Survey conducted a water quality survey of the Mississippi River Basin from 1989-1992 and measured detectable levels of herbicides in 98% of post-plant samples analyzed (Goolsby and Battaglin, 1995). Richards and Baker (1993) conducted a survey of Lake Erie tributaries from 1983 to 1991 and determined that herbicide contamination of rivers was widespread and especially common during the growing season of April to August.

The frequency and spatial extent of herbicide contamination of surface waters have led to numerous concerns about impacts on non-target aquatic organisms. Data indicates that the majority of herbicides exhibit low toxicity to fish and invertebrates (Mayer and Ellersieck 1986). However, herbicides are toxic to a variety of aquatic plants including submerged macrophytes (Jones and Winchell 1984; Kemp et al. 1985) and planktonic algae (Turbak et al. 1986; St-Laurent et al. 1992), and have been suggested as potenital causes for losses of aquatic plants in Midwestern streams (Menzel et al. 1984) and Chesapeake Bay (Forney and Davis 1981; Kemp et al. 1985). Primary production of facultative and obligate aquatic plants are the primary energy basis for aquatic ecosystems. Thus, herbicide impacts on primary producers are expected to have both direct and indirect impacts on the health of aquatic ecosystems.

To date the majority of studies on the effects of herbicides on aquatic ecosystems have been conducted with atrazine (deNoyelles et al. 1982; Larsen et al. 1986). Data on other chemicals are scant, and those that exist are based on a wide variety of test species and endpoints. Thus, comprehensive databases must be developed using similar test species and methodologies in order to allow managers to make informed decisions concerning the potential impacts of herbicides on aquatic ecosystems.

The objective of this study was to perform an aquatic plant risk assessment to determine the potential for adverse impacts of herbicides on aquatic environments. We conducted toxicity tests with sixteen herbicides on the algae *Selenastrum capricornutum* and the duckweed *Lemna minor*. A quotient method was used to compare to the toxicity data to estimated aquatic exposures based on application rates and predicted environmental behavior. Relative risks of these sixteen herbicides to non-target aquatic plants are then discussed.

MATERIALS AND METHODS

Studies were conducted at the Midwest Science Center, National Biological Service, Columbia, MO. One species of algae (*Selenastrum capricornutum*) and one species of floating vascular plant (*Lemna minor*) were tested. Basic procedures and test conditions are presented in Table 1. Water quality characteristics (dissolved oxygen, conductivity, pH, and alkalinity) were analyzed at the beginning and end of each test in control and high treatment samples according to standard methods (APHA 1992).

Herbicides were chosen to represent chemicals of current major agricultural use (Giannesi and Puffer 1991; USDA 1995) across a wide range of general classes and modes of action (Herbicide Handbook 1994) (Table 2). Physical/chemical characteristics of the herbicides are presented in Table 3. Herbicide stock solutions were prepared from technical-grade materials in either acetone or water and then diluted in a 50% dilution series (five concentrations plus solvent and negative controls) using the growth media cited in Table 1. Individual containers were tested in a completely randomized experimental design inside a lighted, temperature-controlled environmental chamber. Calculation of effect levels were based on nominal herbicide concentrations.

Data was analyzed using the Statistical Analysis System (SAS 1987). Calculation of the effective concentrations resulting in 50% growth inhibition (EC50's) were calculated using the non-linear regression program of VanEwijk and Hoekstra (1993); results of either logistic or linear logistic regression analysis was used depending on the best resulting model fit. All data were expressed as percent control response. Prior to statistical analysis the data were normalized using an arc-sin square-root transformation (Snedecor and Cochran 1967). Differences between individual treatments were analyzed using Analysis of Variance (ANOVA); no-observed effect (NOEC) and lowest observed effect (LOEC) levels were determined using Duncans Multiple Range Test ($p \leq 0.05$) (Snedecor and Cochran 1967).

RESULTS

Toxicity comparisons: The triazine (atrazine, cyanazine, metribuzin, and simazine), acetanilide (alachlor and metolachlor), sulfonylurea (chlorsulfuron and metsulfuron), dinitroanaline (trifluralin), and pyridine (diquat and paraquat) classes of herbicides exhibited high toxicity to one or both plant species, with toxicities ranging from 0.4 to 198 ug/L (96h EC-50) (Figure 1; Tables 4-6). One of the thiocarbamate herbicides (triallate) was toxic to *Selenastrum* at 47 ug/L (96h EC50) but was non-toxic *Lemna*. In contrast four of the herbicides (bromoxynil, benzonitrile class; dicamba, benzoic acid class; 2,4-D, phenoxy class; and EPTC, thiocarbamate class) were relatively non-toxic and exhibited toxicity values greater than 6,000 ug/L (96-h EC50) for both species.

Inter-species comparisons: Neither *Selenastrum* nor *Lemna* was uniformly more sensitive to the list of herbicides tested. *Selenastrum* was most sensitive to half (eight) of the herbicides, whereas *Lemna* was more sensitive to the remaining chemicals (Figure 1; Tables 4-6). *Lemna* was highly sensitive to the sulfonylurea herbicides chlorsulfuron (0.7 ug/L; 96h EC50) and metsulfuron (0.4 ug/L; 96h EC50), whereas *Selenastrum* was only moderately sensitive (135 and 190 ug/L, respectively; 96h EC50) (Tables 4-6). This was the greatest inter-species departure noted. *Selenastrum* was notably more sensitive than *Lemna* to triallate, cyanazine, alachlor, and metolachlor.

Results were not always predictable in spite of obvious differences in herbicide modes of action and plant phylogeny. Major departures in sensitivity of both *Selenastrum* and *Lemna* occurred between chemicals within individual classes of the triazine, acetanilide, and thiocarbamate herbicides (Tables 4-6; Figure 1). For example, intra-class variations in 96h EC50's were wide for *Selenastrum* within the triazine (e.g. cyanazine 27 ug/L; simazine 1,240 ug/L), acetanilide (e.g. 6 ug/L alachlor; 77 ug/L metolachlor), and thiocarbamate (e.g. 47 ug/L triallate; 6,451 ug/L EPTC) classes. Similar variations in 96h EC50's were noted with *Lemna* and the triazines (e.g. metribuzin 37 ug/L; cyanazine 705 ug/L); however, variation in sensitivity of *Lemna* was much less within other classes of herbicides.

Exposure evaluation: Exposure estimates were generated by assuming a standard runoff amount within a standardized, theoretical watershed. Similar approaches have been based on assumptions such as 1-10% chemical loss to a farm pond of 3-ft average depth within a 10:1 watershed:pond ratio (e.g. Urban and Cook 1986) or direct over-spray of a theoretical wetland of specific depth (e.g. 15-cm depth; Peterson et al. 1994). For our exposure estimates we merged the above approaches for inputs (1% or 10% runoff; or 100% direct over-spray) and spatiality (wetland of 15 cm depth within a 10:1 watershed:water surface ratio).

Results are presented in Table 7. Estimated exposure concentrations vary in direct proportion to the application rate due to the use of spatial constants in the calculation. It should be noted that the assumptions of direct over-spray lead to identical exposure estimates as the 10% runoff scenario due to the mathematical assumptions in input rates/spatial relationships employed.

Risk calculations: Risk was calculated by dividing potential exposure concentrations by the 96h EC50 values for *Selenastrum* and *Lemna*. Results are presented in Table 8. The results of this risk assessment indicated that alachlor (24.48), cyanazine (5.68), triallate (2.00), metolachlor (1.82), and metribuzin (0.46) present the greatest risk for *Selenastrum* under the

1% exposure. Diquat (1.85), chlorsulfuron (0.96), paraquat (0.92), and alachlor (0.74) present the highest risks for *Lemna* under the 1% runoff scenario (Table 8). The sulfonylurea herbicides (metsulfuron and chlorsulfuron) were highly toxic to *Lemna* (Table 4), but do not necessarily represent a large aquatic risk (e.g. risk <1 under 1% scenario) due to the low rates of application. Basic assumptions led to a 10-fold increase in risk for the 10% runoff or 100% direct over-spray scenarios compared to the basic 1% scenario (Table 8).

The static model used in this study can be refined by considering the K_{oc} and aqueous dissipation rates of herbicides. For example, data from Table 8 indicate that paraquat and diquat may pose some risk to aquatic plants. However, the K_{oc} values for these chemicals (Table 3) are approximately 100,000, which indicates strong soil sorption characteristics (i.e. low leachability) and likely hydrophobic behavior in water (i.e. rapid aqueous dissipation); in fact, the data of Calderbank (1972) indicates that paraquat has a dissipation rate ($T_{1/2}$) in ponds of 1-2 days (Table 3). Thus, aquatic plant exposure to paraquat or diquat would be unlikely and of short duration. In contrast, the triazines, acetanilides, and sulfonylurea herbicides (K_{oc} values less than 200; Table 3) do not sorb strongly to soils, and are therefore more leachable and likely to enter aquatic systems; exposures to these chemicals are likely.

The relative contributions of toxicity, application rate, and K_{oc} can be spatially displayed in a 3-dimensional space as in Figures 2 and 3. Chemicals of highest potential risk are clustered in the upper right rear of the graph. For example, alachlor, cyanazine, and metolachlor are the highest risk for *Selenastrum* (Figure 2), while alachlor, metolachlor, cyanazine, atrazine, and simazine are of highest risk for *Lemna* (Figure 3). EPTC groups to the right; however, the relative toxicity of the herbicide is low for both plant species (Figures 2 and 3). The aqueous half-lives of atrazine, cyanazine, simazine, alachlor, and metolachlor all exceed 20 days in aquatic systems, and therefore present potential risk to aquatic plants. Metribuzin, although relatively toxic and leachable, presents somewhat less risk due to lower application rate and the approximate aquatic dissipation half-life of 4 days (Table 3).

DISCUSSION

Risk assessments are frequently conducted using standardized test species, endpoints, test conditions (e.g. endpoints, test duration), and exposure assumptions. The limitations of each of these factors must be considered in determining the accuracy of a risk assessment.

Limitations of the Toxicity Assessment: Several researchers have found wide inter-species variation in the sensitivity of algae and aquatic plants to contaminants, and have indicated that a suite of plant species must be used to perform an accurate risk assessment (Blanck et al. 1984; Wangberg and Blanck 1988; Lewis 1990). Our research has demonstrated that both *Selenastrum* and *Lemna* appear to be reasonable surrogates for their respective classes of algae and aquatic macrophytes. In a previous study which measured the sensitivity of six species of algae and six species of macrophytes to atrazine, metribuzin, alachlor, and metolachlor Fairchild et al. (1994b) determined that *Selenastrum* was of comparable sensitivity to *Chlorella*, and considerably more sensitive on the average than *Chlamydomonas*, *Scendesmus*, *Microcystis*, or *Anabaena*. *Selenastrum* was 3-fold more sensitive to alachlor and metolachlor than any other species; and an order of magnitude more sensitive than seven of the total eleven species tested. These collective data indicate that *Selenastrum* could be considered a conservative test species in conducting algal risk assessments.

Fairchild et al. (1994b) also determined that *Lemna* was less sensitive than *Ceratophyllum* or *Naja* to atrazine, metribuzin, alachlor, and metolachlor, but generally more sensitive than either *Egeria* or *Myriophyllum*, which indicates that *Lemna* is a vascular plant surrogate of intermediate sensitivity. Overall, the response of *Lemna* was always within 5-fold of the most sensitive of the eleven species tested (Fairchild et al. 1994b). These comparisons indicate that *Selenastrum* and *Lemna* can serve as reasonable surrogates for algae and vascular macrophytes for risk approximations. However, more refined risk assessments must rely on several representative species of several major plant groups. Alternatively, it would appear that a factor of 5 would provide the conservatism needed to protect most plants using the combination of *Selenastrum* and *Lemna*.

Numerous endpoints can be used to estimate algal biomass or standing crop, including dry weight, cell number, and chlorophyll content (APHA 1992; ASTM 1993a). Physiological activity has been measured as rates of carbon uptake (Nyholm and Damgaard 1990; Abou-Waly 1991), oxygen evolution (Turbak et al. 1986; Versteeg 1990), and nutrient uptake. However, biomass measures are generally preferred over measures of physiological activity for ecological risk assessments because they are a measure of actual production, whereas physiological measures are in many cases only comparisons of relative productive potential (Vollenweider 1979). Dry weight or organic carbon are perhaps the most direct approaches for estimations of biomass. However, dry weight measures require large sample volumes and are subject to analytical error (ASTM 1993a); organic carbon is a direct measure but is time-consuming and requires expensive instrumentation. Cell numbers can serve as indirect biomass estimates, but must be converted to biomass based on biovolume:biomass relationships (APHA 1992). In this study we chose to use in-vivo fluorescence of chlorophyll as an indirect measure of biomass for several reasons: 1) chlorophyll is highly correlated with organic carbon and dry weight of algae (Vollenweider 1974; Fairchild et al. 1994a), 2) it is a non-destructive measure, and 3) the method requires less than 10-ml volume. For these reasons, fluorometric estimation of algal biomass has been readily accepted (ASTM 1993a; APHA 1992) and should serve as a reliable indicator of effects.

Numerous endpoints have been used for toxicity testing with *Lemna*, including frond number, plant number, root number, dry or fresh biomass, root length, frond diameter, carbon uptake, chlorophyll content, etc. (see reviews by Wang 1990). Dry weight biomass is the most direct, accurate, and precise measure of growth effects (Wang 1990; Cowgill and Milazzo 1989), but is time-consuming and destructive. Frond count is the most widely used surrogate measure because it is rapid, non-destructive, and correlated with biomass (Cowgill and Milazzo 1989; Taraldsen and Norberg-King 1990; ASTM 1993b). Therefore we have confidence in this measure for the purposes of this risk assessment.

In this study plant toxicity was summarized as an EC50 or effective concentration which reduced primary production by 50%. Toxicity endpoints for algae and duckweed are inherently different than those measured in invertebrate and fish tests (Hughes et al. 1988;

Lewis 1990). Invertebrate and fish tests are usually conducted to determine the effects on an individual organism within a relevant portion of its lifetime. Regulatory studies (e.g. under the Federal Insecticide, Fungicide, and Rodenticide Act and the Toxic Substances Control Act) are usually conducted as acute tests with results expressed as the LC50, or the concentration which results in 50% mortality of organisms. However, tests with *Selenastrum* and *Lemna* are multi-generational exposures and are therefore more likely to simulate chronic effects on populations. Hughes et al. (1988) discussed the relative merits of measuring algistatic effects, algicidal effects, and the potential for plant recovery following exposure of *Lemna gibba* and three species of algae to atrazine. The results indicated that the NOEC was the most sensitive endpoint followed by the EC50, phytostatic, and phytocidal endpoints for all species (e.g. <0.10, 0.17, 1.71, and >3.2 mg/L, respectively, for *Lemna*). Thus, the NOEC and EC50's of single species tests are likely conservative, protective endpoints for use in aquatic plant risk assessments (Hughes et al. 1988). This presumption is supported by laboratory:field comparisons of atrazine (deNoyelles et al. 1982; Fairchild et al. 1994a) and metribuzin (Fairchild, unpublished data). In these cases laboratory single species data was protective of community function in outdoor experimental ponds in spite of obvious differences in exposure duration and experimental complexity. Similarity in lab:field effect levels is likely related to both population adaption (deNoyelles et al. 1982; Hersh and Crumpton 1989) and community-level redundancy (deNoyelles et al. 1982; Larson et al. 1986; Fairchild et al. 1994a) in aquatic plant communities.

Limitations of the Exposure Assessment:

Three primary approaches can be used to estimate potential exposures to herbicides: probablistic runoff models; use of static models; or monitoring of environmental concentrations.

Probablistic approaches using runoff (e.g. SWWRB) and exposure (e.g. EXAMS) models are frequently used for estimating exposures to single chemicals in ecological risk assessments (Jenkins et al. 1989). Such models, adjusted for local conditions (e.g. time to rainfall; chemical characteristics; chemical application rates; soil type; soil moisture; % soil organic carbon; slope; etc.), can incorporate the probability of various exposures to chemicals following random, extreme rainfall events. However, this approach is not practical for screening assessments of divergent groups of herbicides which are applied among a wide variety of cropping, seasonal, and regional use-patterns due to the large number of fluctuating assumptions needed for the models (Lawrence Burns, USEPA, Athens, GA; personal communication).

Static models have largely been developed based on extensive studies conducted in small-scale experimental plots. Static models are primarily used to estimate worst-case conditions in situations where an extreme rainfall event occurs within a few hours or days following chemical application. Experimental plot data has demonstrated that herbicide losses in runoff usually average less than 1.0% of total chemical applied; however, extreme rainfall events immediately following chemical application can result in losses of up to 10% (Hall 1974; Wauchope 1978; Weber et al. 1980; Hall et al. 1991). For example, Wauchope (1978) reviewed the literature on edge-of-field concentrations of pesticides in runoff adjacent to small agricultural plots and found that atrazine concentrations ranged from 37 to 4,700 μg/L across eleven small-plot studies; highest exposures occurred at the edges of 40 m^2 plots (14% slope) following a storm event. Baker et al. (1976) measured high concentrations of alachlor (75 to 198 μg/L) adjacent to 33 m^2 plots following a severe storm. Extremely high concentrations have also been observed in irrigation-return ponds. For example, Kadoum and Mock (1978) observed high average concentrations of alachlor (38-188 ug/L) and atrazine (average 13 to 82 μg/L; maximum of 1074 ug/L) in irrigation tail-water pits adjacent to 65 ha grain fields. Although these concentrations represent extremes in herbicide exposures, they indicate that herbicide concentrations in wetlands and aquatic habitats adjacent to agricultural fields can likely exceed levels known to cause impacts on aquatic plants, and support the use of the 1 and 10% runoff estimates used in this risk assessment.

The third approach for exposure assessment is the measurement and collation of environmental data. Richards and Baker (1993) measured environmental concentrations of herbicides in 7 rivers of the Lake Erie-Ohio Region over an 8-yr period (Table 9). Maximum measured concentrations of herbicides occasionally exceeded levels which can adversely impact more sensitive plant species (e.g. *Ceratophyllum* and *Selenastrum*; Fairchild 1994b) (Table 9). However, comparisons of the 95th percentile, 50th percentile, and time-weighted means (TWM's) indicates that these extremes occured only as pulses over a few days and are therefore not likely to occur in large streams as chronic exposures (Richards and Baker 1993) (Table 9). Thurman (1991) evaluated herbicide levels in rivers and streams in the Midwest in 1989 and 1990 and determined that highest levels of herbicides occurred immediately post-planting during spring flushes. Maximum values of atrazine, metribuzin, alachlor, and metolachlor were 108, 8, 51, and 40 ug/L, respectively, while median values were less than 4 ug/L for all chemicals. Midwestern studies comparing herbicide concentrations in reservoirs to those in large streams have indicated that reservoirs exhibit lower peak concentrations, but higher average concentrations and exposure durations than streams due to differences in spatial and hydrological patterns (Goolsby et al. 1993; Spalding et al. 1994) However, median and maximum concentrations of commonly-used herbicides such as atrazine rarely exceed 10 ug/L. Thus, the collective data indicate that the use of the 1% value within the static model is a conservative approach for estimating exposures in large streams and reservoirs.

Relatively little environmental data exists for herbicides in small streams or wetlands. However, Richards and Baker (1993) determined that concentrations of herbicides increase inversely with size of the watershed, which indicates that maximum herbicide levels would probably occur in edge-of-field habitats and relatively small (<500 km^2) watersheds. In the absence of data, use of static models derived from small plot studies (i.e. assumptions of 1-10% chemical loss) is justified. Actual losses can vary considerably depending on time to rainfall, chemical, and soil characteristics. However, these figures can provide useful approaches for estimating worst-case exposures of wetlands and small intermittent streams.

CONCLUSIONS

Comparisons of the toxicity, application rate, K_{oc}, and aqueous half-life indicate that alachlor, metolachlor, cyanazine, simazine, and atrazine pose the greatest potential risk to aquatic plants. Metribuzin, triallate, chlorsulfuron, and metsulfuron are highly toxic. However, the relative risk of these herbicides is reduced due to either lower application rates (e.g. metribuzin; chlorsufuron; metsulfuron), rapid dissipation rates (e.g. metribuzin and triallate), or partitioning potential (e.g. triallate).

Existing environmental data indicates that primary concerns for these herbicides would occur in areas receiving direct over-spray or excessive runoff (e.g. 1-10% of application) which may include ephemeral wetlands and farmed wetlands that exist in or near agricultural fields as temporary, seasonally-flooded habitats. Such exposures can be expected in natural and managed wetlands interspersed with farmed land in California, the Dakotas, Florida, Iowa, Illinois, Minnesota, Nebraska, Ohio, Oregon, and other states. However, herbicide exposures and impacts in wetlands have not been widely studied and therefore represent a primary data gap in environmental protection.

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Table 1. Experimental conditions for plant studies.

	Test Conditions	
Test Parameter	*Selenastrum*[1]	*Lemna*[2]
Temperature (°C)	25	25
Light source	cool-white	cool-white
Light intensity (fc)	400	400
Photoperiod	16:8	16:8
Test chamber	10-ml tube	50-ml beaker
Test volume (ml)	5	30
Organisms stocked (#)	20,000 cells/ml	12 fronds
Replicates	3	3
Media	ASTM[1]	NEW[2]
Test duration (h)	96	96
Aeration	no; shake once daily	no; shake once daily
Water renewal	no	no
Endpoint	fluorescence	frond count

[1] Modified from ASTM (1993a).

[2] Modified from Taraldsen and Norberg-King (1990)

Table 2. Classification, mode of action, production, and use levels of herbicides tested with *Selenastrum* and *Lemna*.

Chemical	**Class**	**Mode of Action[1]**	**Production (#/yr X 10^3)[2]**	**Range of Use Rates (kg/ha)[1]**	**Actual Use Rate (kg/ha)[3]**
alachlor	acetanilide	inhibits protein synthesis	55187	1.7 - 6.7	2.2
atrazine	triazine	inhibits photosynthesis	64236	1.1 - 2.2	1.1
bromoxynil	benzonitrile	inhibits photosynthesis	2627	0.2- 0.6	0.3
chlorsulfuron	sulfonylurea	inhibits amino acid synthesis	77	.009 - .018	0.010
cyanazine	triazine	inhibits photosynthesis	22894	0.9 - 5.3	2.3
dicamba	benzoic acid	auxin simulator	11240	0.3 - 0.6	0.4
diquat	pyridine	free radical formation	166	0.4 - 0.6[4]	0.5
EPTC	thiocarbamate	unknown	37191	2.2 - 6.7	4.6
metolachlor	chloracetanilide	inhibits protein synthesis	49713	1.4 - 4.5	2.1
metribuzin	triazinone	inhibits photosynthesis	4822	0.3 - 0.8	0.3
metsulfuron	sulfonylurea	inhibits amino acid synthesis	41	.004 - .012	0.003
paraquat (salt)	pyridine	free-radical formation	3025	0.3 - 1.1	0.7
simazine	triazine	inhibits photosynthesis	3964	2.2 - 4.5	1.3
triallate	thiocarbamate	inhibits cell elongation/division	3509	1.1 - 1.7	1.4
trifluralin	dinitroaniline	inhibits germination processes	27119	0.6 - 2.2	0.9
2,4,-d (salt)	phenoxy	auxin simulator	33096	0.3 - 1.1	0.4

[1] from Herbicide Handbook (1994).

[2] from Gianessi and Puffer (1991).

[3] from USDA (1995) for major use crops (corn, soybeans, or wheat). Values averaged across approximately 12 states of major use.

[4] from Herbicide Handbook (1989) as pre-harvest dessicant. Not listed in Herbicide Handbook (1994) for row-crops; however, registered aquatic application rate is 2.2 to 4.5 kg/ha water surface.

Table 3. Physical/chemical data for herbicides tested with *Selenastrum* and *Lemna*.

Chemical	**H_2O solubility (mg/L)[1]**	**Koc[1]**	**$t_{1/2}$ soil (d)[1]**	**$t_{1/2}$ water (d), system type, and reference**
alachlor	242	190	14	21 (550 ha reservoir; Spalding et al. 1994)
atrazine	33	160	60	47 (0.2 ha ponds; Fairchild et al. 1994) 193 (550 ha reservoir; Spalding et al. 1994)
bromoxynil	50	100	14	1 (0.01 ha pond; Muir et al. 1991) 2 (100 ml bacterial culture; Golovleva et al. 1988)
chlorsulfuron	2000	1	30	no available data
cyanazine	171	168	20	103 (550 ha reservoir; Spalding et al. 1994)
dicamba	800,000	2	14	30 (0.1 ha ponds; Scifres et al. 1973)
diquat	700,000	100,000	3600	1-2 d (variety of ecosystems; Reinert and Rodgers 1987)
EPTC	375	280	30	no available data
metolachlor	530	200	20	75 (550 ha reservoir; Spalding et al. 1994)
metribuzin	1220	41	30	4 (0.1 ha pond; Fairchild, unpublished)
metsulfuron	2000	61	120	29 (in-situ enclosures; Thompson et al. 1992)
paraquat (salt)	100,000	100,000	3600	1-2 (variety of habitats; Calderbank 1972) 1 (2 ha pond; Way et al. 1970)
simazine	3.5	138	75	30 (none given; Reinert and Rodgers 1987)
triallate	4	3600	60	1 estimated based on K_{oc}
trifluralin	0.3	1400	60	2 (30 L microcosm; Isensee et al. 1979) 1 (1 L microcosm; Huckins et al. 1986)
2,4,-d (salt)	890	20	10	1-7 (various reservoirs; Reinert and Rodgers 1987)

[1] From Wauchope, D.L.(1988), Interim Properties Database.

Table 4. Sensitivity of *Selenastrum* and *Lemna* to sixteen herbicides.

Herbicide	**Chemical Class**	***Selenastrum***	***Lemna***
		EC50[1]	**EC50**[1]
alachlor	acetanilide	6 (4-9)	198 (80-316)
atrazine	triazine	235 (189-281)	153 (89-217)
bromoxynil	benzonitrile	7,762 (6,863-8,662)	8,065 (3,783-12,348)
chlorsulfuron	sulfonylurea	135 (109-161)	0.7 (0.5-0.9)
cyanazine	triazine	27 (25-30)	705 (577-834)
dicamba	benzoic acid	36,375 (31,309-41,440)	>100,000
diquat	pyridine	80 (64-95)	18 (7-28)
EPTC	thiocarbamate	6,451 (5,455-7,446)	7,512 (1,736-13,288)
metolachlor	chloracetanilide	77 (70-84)	343 (-187-872)
metribuzin	triazinone	43 (40-46)	37 (22-47)
metsulfuron	sulfonylurea	190 (137-243)	0.4 (0.3-0.5)
paraquat	pyridine	559 (471-646)	51 (25-77)
simazine	triazine	1,240 (1,088-1,393)	166 (102-230)
triallate	thiocarbamate	47 (41-49)	>10,000
trifluralin	dinitroaniline	673 (594-751)	170 (10-330)
2,4-D salt	phenoxy	41,772 (37,352-46,192)	>100,000

[1] Numbers represent 96h EC50 (ug/L) with 95% confidence intervals in parentheses.

Table 5. Statistical data for *Selenastrum* response to sixteen herbicides.

Herbicide	**Chemical Class**	**Model**				
			Slope	**EC50**[1]	**NOEC**[2]	**LOEC**[2]
alachlor	acetanilide	linear logistic	1.71	6 (4-9)	4	8
atrazine	triazine	linear logistic	1.74	235 (189-281)	75	150
bromoxynil	benzonitrile	linear logistic	2.61	7,762 (6,863-8,662)	3,125	6,250
chlorsulfuron	sulfonylurea	linear logistic	1.02	135 (109-161)	<19	19
cyanazine	triazine	linear logistic	2.09	27 (25-30)	9	19
dicamba	benzoic acid	linear logistic	3.02	36,375 (31,309-41,440)	12,500	25,000
diquat	pyridine	linear logistic	2.61	80 (64-95)	44	88
EPTC	thiocarbamate	logistic	3.22	6,451 (5,455-7,446)	<6,250	6,250
metolachlor	chloracetanilide	linear logistic	2.70	77 (70-84)	38	75
metribuzin	triazinone	linear logistic	1.96	43 (40-46)	19	38
metsulfuron	sulfonylurea	linear logistic	0.93	190 (137-243)	<19	19
paraquat	pyridine	linear logistic	2.60	559 (471-646)	114	227
simazine	triazine	linear logistic	1.95	1,240 (1,088-1,393)	600	1,200
triallate	thiocarbamate	logistic	2.57	47 (41-49)	12.5	25
trifluralin	dinitroaniline	linear logistic	1.93	673 (594-751)	150	300
2,4-D salt	phenoxy	linear logistic	3.95	41,772 (37,352-46,192)	25,000	50,000

[1] Numbers represent 96h EC50 (ug/L) with 95% confidence intervals in parentheses.

[2] Determined using Duncans Test ($P \leq 0.05$ significance).

Table 6. Statistical data for *Lemna* response to sixteen herbicides.

Herbicide	**Chemical Class**	**Model**				
			Slope	**EC50[1]**	**NOEC[2]**	**LOEC[2]**
alachlor	acetanilide	linear logistic	0.75	198 (80-316)	32	62
atrazine	triazine	linear logistic	1.59	153 (89-217)	75	150
bromoxynil	benzonitrile	linear logistic	0.96	8,065 (3,783-12,348)	<3,125	3,125
chlorsulfuron	sulfonylurea	linear logistic	1.90	0.7 (0.5-0.9)	0.4	0.7
cyanazine	triazine	logistic	3.82	705 (577-834)	300	600
dicamba	benzoic acid	linear logistic	n/a	>100,000	n/a	n/a
diquat	pyridine	linear logistic	0.43	18 (7-28)	<11	11
EPTC	thiocarbamate	logistic	9.38	7,512 (1,736-13,288)	5,000	10,000
metolachlor	chloracetanilide	logistic	1.08	343 (-187-872)	187	375
metribuzin	triazinone	linear logistic	1.88	37 (22-47)	19	38
metsulfuron	sulfonylurea	linear logistic	1.94	0.4 (0.3-0.5)	<0.2	0.2
paraquat	pyridine	linear logistic	1.61	51 (25-77)	14	28
simazine	triazine	logistic	2.23	166 (102-230)	75	150
triallate	thiocarbamate	linear logistic	n/a	>10,000	n/a	n/a
trifluralin	dinitroaniline	logistic	0.85	170 (10-330)	75	150
2,4-D salt	phenoxy	linear logistic	n/a	>100,000	n/a	n/a

[1] Numbers represent 96h EC50 (ug/L) with 95% confidence intervals in parentheses.

[2] Determined using Duncans Test ($p \leq 0.05$ significance).

Table 7. Calculated exposure concentrations of sixteen herbicides based on 1%, 10%, and 100% direct over-spray scenarios.

Herbicide	Application Rate[1] (kg/ha)	*Selenastrum* 96h EC50 (ug/L)	*Lemna* 96h EC50 (ug/L)	calculated exposure concentrations (ug/L)		
				1%[2] runoff scenario	10%[2] runoff scenario	100%[3] over-spray or inundation scenario
alachlor	2.2	6	195	147	1,469	1,469
atrazine	1.1	235	153	73	734	734
bromoxynil	0.3	7,762	8,065	20	200	200
chlorsulfuron	0.010	135	0.7	0.7	7	7
cyanazine	2.3	27	705	154	1537	1537
dicamba	0.4	36,375	>100,000	27	267	267
diquat	0.5	80	18	33	334	334
EPTC	4.6	6,451	7,512	307	3074	3074
metolachlor	2.1	77	343	140	1403	1403
metribuzin	0.3	43	37	20	200	200
metsulfuron	0.003	190	0.4	0.2	2	2
paraquat	0.7	559	51	47	468	468
simazine	1.3	1,240	166	87	869	869
triallate	1.4	47	>10,000	94	935	935
trifluralin	0.9	673	170	60	601	601
2,4-D salt	0.4	41,772	>100,000	27	267	267

[1] From USDA (1995) for major use crops (corn, soybeans, or wheat). Values averaged across approximately 12 states of major use.

[2] Final concentration in wetland, assuming 10:1 watershed:wetland ratio (from Urban and Cook 1986) and average of 15 cm depth (from Petersen et al. 1994).

[3] Final concentration assuming direct over-spray of wetland resulting in 100% deposition (from Petersen et al. 1994) assuming wetland depth of 15 cm.

Table 8. Relative risk calculation of *Selenastrum* and *Lemna* to sixteen herbicides using 1%, 10%, and 100% direct over-spray scenarios. Risk value is calculated as a multiple of the EC50 (i.e. a value> 1 indicates that the EC50 is anticipated to be exceeded).

	Selenastrum				*Lemna*		
	relative risk value by exposure scenario				relative risk calculation by exposure scenario		
Herbicide	1%[1]	10%[1]	100%[2]		1%[1]	10%[1]	100%[2]
alachlor	24.48	244.76	244.76		0.74	7.41	7.41
atrazine	0.31	3.12	3.12		0.48	4.79	4.79
bromoxynil	<0.01	0.03	0.03		<0.01	0.04	0.04
chlorsulfuron	<0.01	0.05	0.05		0.96	9.63	9.63
cyanazine	5.68	56.82	56.82		0.22	2.18	2.18
dicamba	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01
diquat	0.42	4.17	4.17		1.85	18.53	18.53
EPTC	0.05	0.48	0.48		0.04	0.41	0.41
metolachlor	1.82	18.19	18.19		0.41	4.08	4.08
metribuzin	0.46	4.65	4.65		0.55	5.46	5.46
metsulfuron	<0.01	0.01	0.01		0.50	5.00	5.00
paraquat	0.08	0.83	0.83		0.92	9.15	9.15
simazine	0.07	0.70	0.70		0.52	5.22	5.22
triallate	2.00	20.00	20.00		<0.01	<0.07	<0.07
trifluralin	0.09	0.89	0.89		0.35	3.53	3.53
2,4-D salt	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01

[1] Final concentration in wetland, assuming 10:1 watershed:wetland ratio (from Urban and Cook 1986) and average of 15 cm depth (from Petersen et al. 1994).

[2] Final concentration assuming direct over-spray of wetland resulting in 100% deposition assuming wetland depth of 15 cm (from Petersen et al. 1994).

Table 9. Comparison of plant response range to 1% scenario and maximum, 95th percentile, 50th percentile, and time-weighted mean (TWM) for four herbicides in 7 Lake Erie tributaries over 8-yr period from 1983-1991[1]. All concentrations expressed as ug/L.

Chemical	**Plant response median and range[1]**	**1% exposure scenario**	**Maximum**	**95th percentile**	**50th percentile**	**TWM**
atrazine	92 (22-3000)	73	7-69	1-11	≤ 0.7	≤ 2.0
metribuzin	36 (14-3000)	20	1-25	≤ 2.0	≤ 0.1	≤ 0.3
alachlor	584 (10-3000)	147	1-65	0-4	≤ 0.1	≤ 0.9
metolachlor	1138 (70-3000)	140	5-97	1-9	≤ 0.4	≤ 2.0

[1] from Richards and Baker (1993).

[2] from Fairchild et al. (1994b).

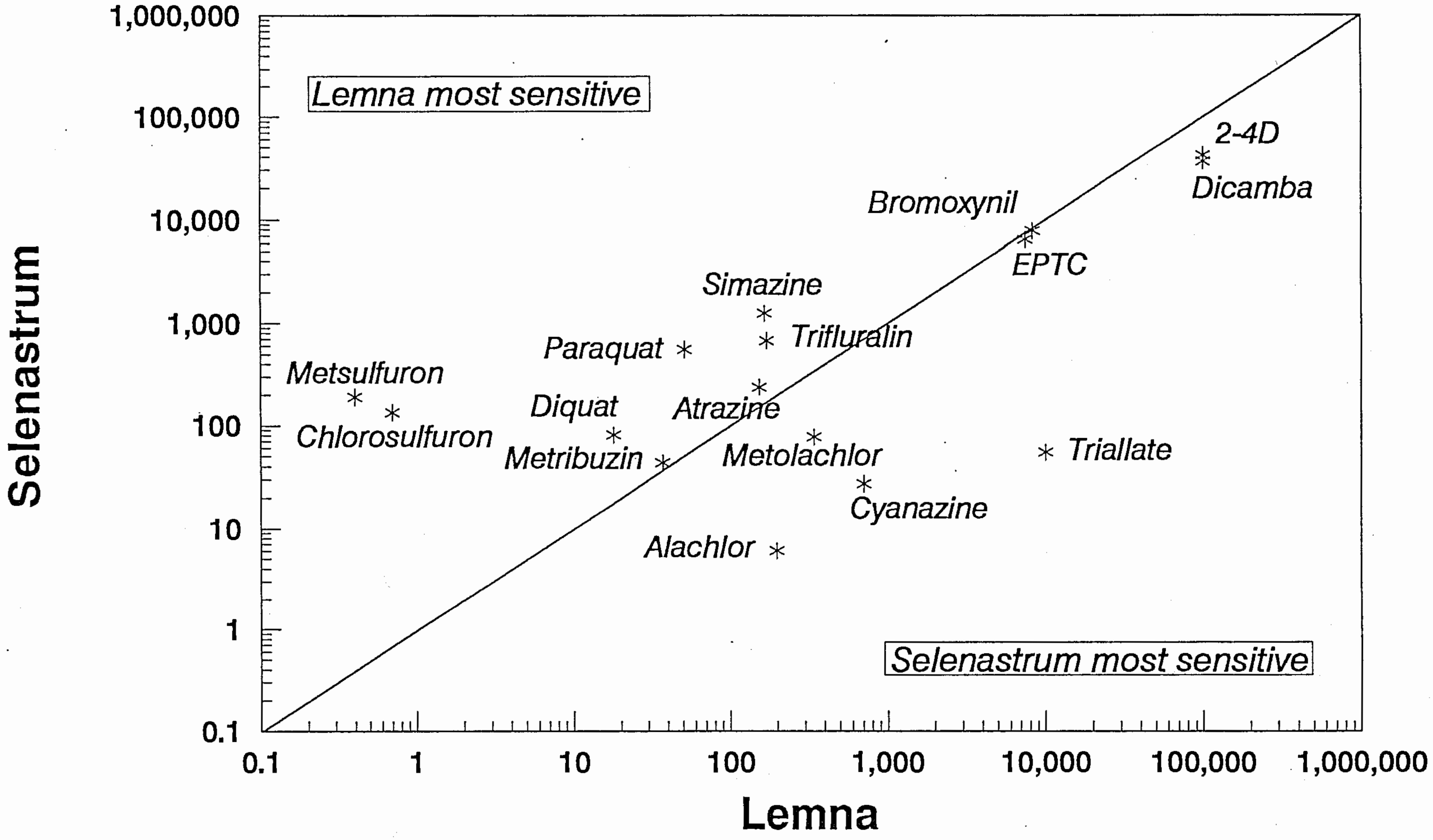

Figure 1. Comparison of relative sensitivity of *Selenastrum* and *Lemna* to sixteen herbicides.

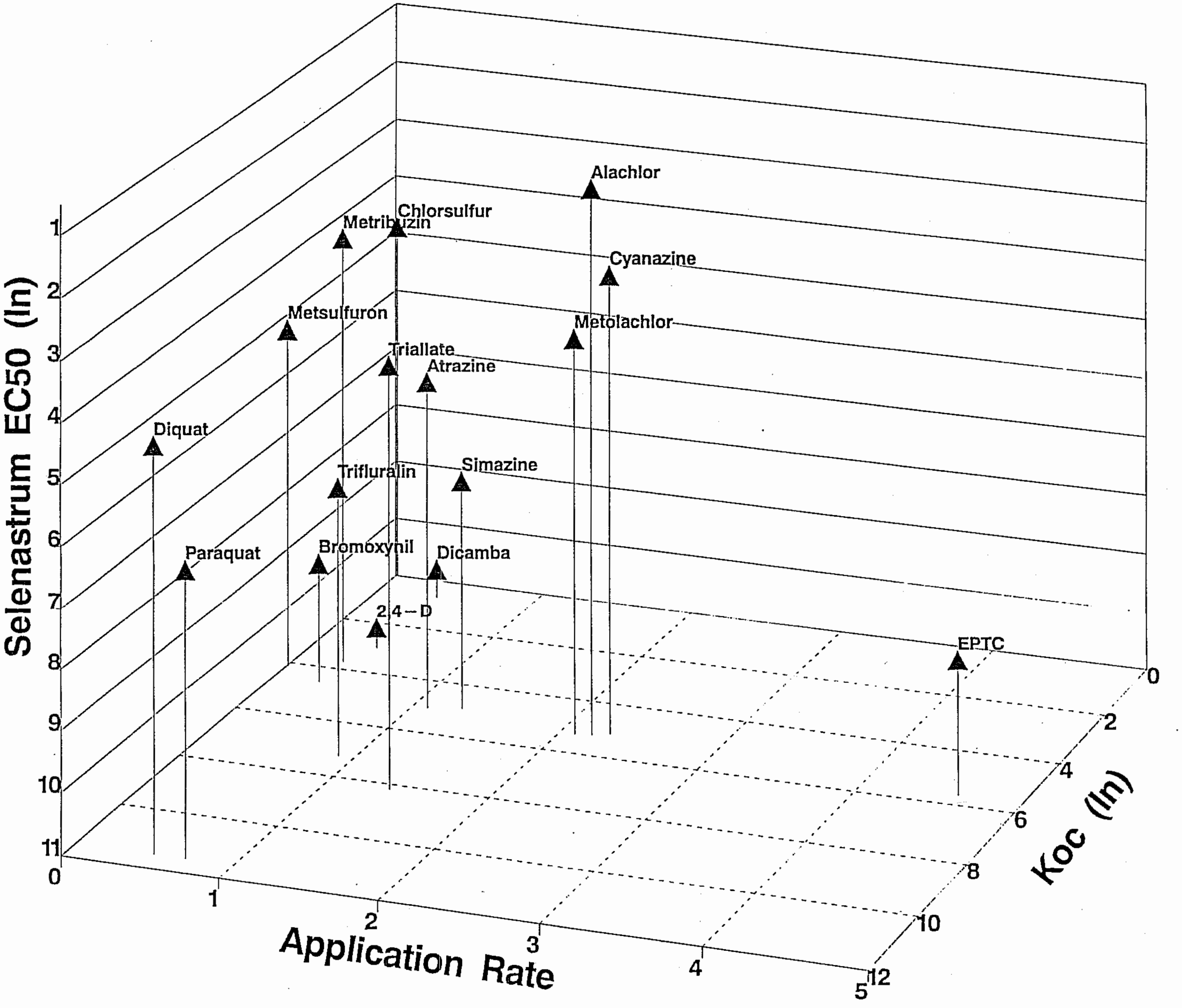

Figure 2. Comparative risk of sixteen herbicides to *Selenastrum*. Chemicals with lowest K_{oc} (higher leachablity), lowest EC50 (high toxicity), and highest application rate are considered to be highest risk. These chemicals cluster in upper, right rear of figure.

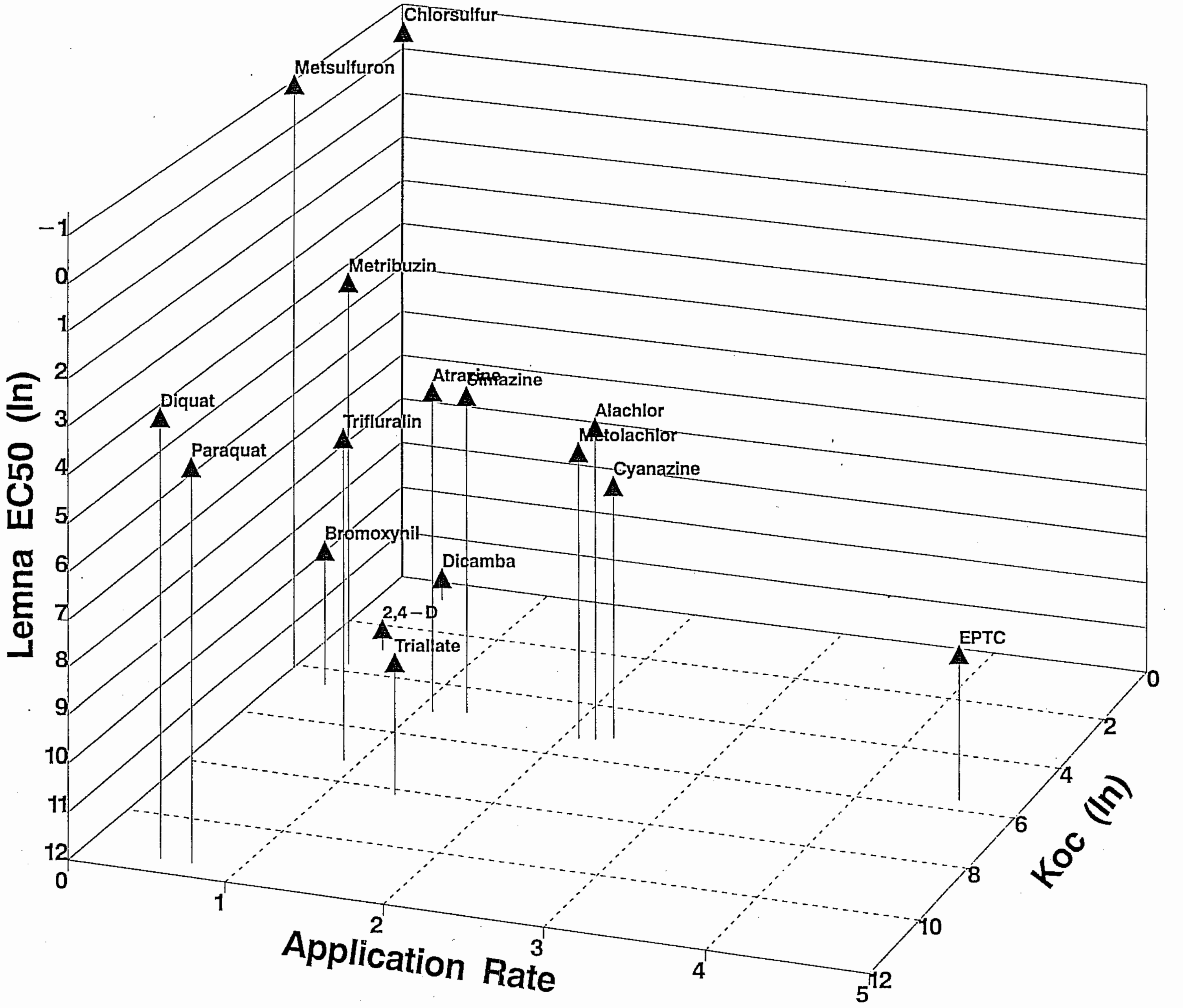

Figure 3. Comparative risk of sixteen herbicides to *Lemna*. Chemicals with lowest K_{oc} (higher leachablity), lowest EC50 (high toxicity), and highest application rate are considered to be highest risk. These chemicals cluster in upper, right rear of figure.

Appendix I. Raw data from Selenastrum studies.

Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
02/03/95	77	Control	0	1	100	29.34	4.8	14083.2	13496.4	104.3478	100
02/03/95	3	Control	0	2	100	29.34	4.2	12322.8		91.30435	
02/03/95	63	Control	0	3	100	29.34	4.8	14083.2		104.3478	
02/03/95	4	Metribuzin	9	1	100	29.34	5.8	17017.2	17701.8	126.087	131.1594
02/03/95	78	Metribuzin	9	2	100	29.34	6.2	18190.8		134.7826	
02/03/95	21	Metribuzin	9	3	100	29.34	6.1	17897.4		132.6087	
02/03/95	47	Metribuzin	19	1	100	29.34	4.4	12909.6	13398.6	95.65217	99.27536
02/03/95	27	Metribuzin	19	2	100	29.34	4.7	13789.8		102.1739	
02/03/95	56	Metribuzin	19	3	100	29.34	4.6	13496.4		100	
02/03/95	64	Metribuzin	38	1	100	29.34	2.6	7628.4	7530.6	56.52174	55.7971
02/03/95	31	Metribuzin	38	2	100	29.34	2.5	7335		54.34783	
02/03/95	80	Metribuzin	38	3	100	29.34	2.6	7628.4		56.52174	
02/03/95	55	Metribuzin	75	1	100	9.25	4.2	3885	3885	28.78545	28.78545
02/03/95	18	Metribuzin	75	2	100	9.25	4.3	3977.5		29.47082	
02/03/95	53	Metribuzin	75	3	100	9.25	4.1	3792.5		28.10009	
02/03/95	17	Metribuzin	150	1	100	2.84	6.8	1931.2	1969.567	14.309	14.59327
02/03/95	75	Metribuzin	150	2	100	9.25	2.2	2035		15.07809	
02/03/95	65	Metribuzin	150	3	100	9.25	2.1	1942.5		14.39273	

Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
02/10/95	39	Control	0	1	100	29.34	3.9	11442.6	11736	97.5	100
02/10/95	17	Control	0	2	100	29.34	3.7	10855.8		92.5	
02/10/95	27	Control	0	3	100	29.34	4.4	12909.6		110	
02/10/95	30	2–4D	6250	1	100	29.34	4.5	13203	12225	112.5	104.1667
02/10/95	58	2–4D	6250	2	100	29.34	4.2	12322.8		105	
02/10/95	4	2–4D	6250	3	100	29.34	3.8	11149.2		95	
02/10/95	52	2–4D	12500	1	100	29.34	4.3	12616.2	12225	107.5	104.1667
02/10/95	8	2–4D	12500	2	100	29.34	3.8	11149.2		95	
02/10/95	41	2–4D	12500	3	100	29.34	4.4	12909.6		110	
02/10/95	46	2–4D	25000	1	100	29.34	3.7	10855.8	10855.8	92.5	92.5
02/10/95	34	2–4D	25000	2	100	29.34	3.2	9388.8		80	
02/10/95	68	2–4D	25000	3	100	29.34	4.2	12322.8		105	
02/10/95	32	2–4D	50000	1	100	9.25	4.4	4070	3946.667	34.67962	33.62872
02/10/95	64	2–4D	50000	2	100	9.25	4.4	4070		34.67962	
02/10/95	20	2–4D	50000	3	100	9.25	4	3700		31.52693	
02/10/95	56	2–4D	100000	1	1	9.25	4.4	40.7	39.46667	0.346796	0.336287
02/10/95	12	2–4D	100000	2	1	9.25	4.2	38.85		0.331033	
02/10/95	36	2–4D	100000	3	1	9.25	4.2	38.85		0.331033	

Appendix I. Raw data from Selenastrum studies.

Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
02/10/95	39	Control	0	1	100	29.34	3.9	11442.6	11736	97.5	100
02/10/95	17	Control	0	2	100	29.34	3.7	10855.8		92.5	
02/10/95	27	Control	0	3	100	29.34	4.4	12909.6		110	
02/10/95	16	Bromoxynil	1562	1	100	29.34	4	11736	12518.4	100	106.6667
02/10/95	69	Bromoxynil	1562	2	100	29.34	4.8	14083.2		120	
02/10/95	37	Bromoxynil	1562	3	100	29.34	4	11736		100	
02/10/95	57	Bromoxynil	3125	1	100	29.34	3.8	11149.2	11638.2	95	99.16667
02/10/95	19	Bromoxynil	3125	2	100	29.34	4.3	12616.2		107.5	
02/10/95	65	Bromoxynil	3125	3	100	29.34	3.8	11149.2		95	
02/10/95	29	Bromoxynil	6250	1	100	29.34	2.7	7921.8	7613.933	67.5	64.87673
02/10/95	47	Bromoxynil	6250	2	100	9.25	8.2	7585		64.6302	
02/10/95	10	Bromoxynil	6250	3	100	29.34	2.5	7335		62.5	
02/10/95	71	Bromoxynil	12500	1	100	9.25	3.4	3145	3052.5	26.79789	26.00971
02/10/95	11	Bromoxynil	12500	2	100	9.25	3	2775		23.64519	
02/10/95	49	Bromoxynil	12500	3	100	9.25	3.5	3237.5		27.58606	
02/10/95	61	Bromoxynil	25000	1	1	9.25	4.2	38.85	37.61667	0.331033	0.320524
02/10/95	23	Bromoxynil	25000	2	1	9.25	4	37		0.315269	
02/10/95	43	Bromoxynil	25000	3	1	9.25	4	37		0.315269	

Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
02/10/95	39	Control	0	1	100	29.34	3.9	11442.6	11736	97.5	100
02/10/95	17	Control	0	2	100	29.34	3.7	10855.8		92.5	
02/10/95	27	Control	0	3	100	29.34	4.4	12909.6		110	
02/10/95	50	EPTC	6250	1	100	29.34	2.2	6454.8	6221.6	55	53.01295
02/10/95	54	EPTC	6250	2	100	9.25	6.4	5920		50.44308	
02/10/95	60	EPTC	6250	3	100	9.25	6.8	6290		53.59577	
02/10/95	21	EPTC	12500	1	100	2.84	4.4	1249.6	1401.067	10.64758	11.9382
02/10/95	74	EPTC	12500	2	100	2.84	5	1420		12.09952	
02/10/95	48	EPTC	12500	3	100	2.84	5.4	1533.6		13.06748	
02/10/95	5	EPTC	25000	1	100	2.84	3	852	861.4667	7.259714	7.340377
02/10/95	45	EPTC	25000	2	100	2.84	3.5	994		8.469666	
02/10/95	2	EPTC	25000	3	100	2.84	2.6	738.4		6.291752	
02/10/95	31	EPTC	50000	1	100	2.84	3.2	908.8	852	7.743695	7.259714
02/10/95	26	EPTC	50000	2	100	2.84	3.2	908.8		7.743695	
02/10/95	63	EPTC	50000	3	100	2.84	2.6	738.4		6.291752	
02/10/95	51	EPTC	100000	1	100	2.84	5.2	1476.8	1467.333	12.5835	12.50284
02/10/95	9	EPTC	100000	2	100	2.84	5.2	1476.8		12.5835	
02/10/95	25	EPTC	100000	3	100	2.84	5.1	1448.4		12.34151	

Appendix I. Raw data from Selenastrum studies.

Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
02/17/95	42	Control	0	1	100	29.34	4.3	12616.2	13594.2	92.80576	100
02/17/95	11	Control	0	2	100	29.34	5.1	14963.4		110.0719	
02/17/95	46	Control	0	3	100	29.34	4.5	13203		97.1223	
02/17/95	21	Dicamba	6250	1	100	29.34	5.1	14963.4	15648	110.0719	115.1079
02/17/95	37	Dicamba	6250	2	100	29.34	5.4	15843.6		116.5468	
02/17/95	15	Dicamba	6250	3	100	29.34	5.5	16137		118.705	
02/17/95	23	Dicamba	12500	1	100	29.34	4.8	14083.2	13594.2	103.5971	100
02/17/95	45	Dicamba	12500	2	100	29.34	5.1	14963.4		110.0719	
02/17/95	6	Dicamba	12500	3	100	29.34	4	11736		86.33094	
02/17/95	29	Dicamba	25000	1	100	29.34	3.4	9975.6	11149.2	73.38129	82.01439
02/17/95	20	Dicamba	25000	2	100	29.34	3.6	10562.4		77.69784	
02/17/95	33	Dicamba	25000	3	100	29.34	4.4	12909.6		94.96403	
02/17/95	39	Dicamba	50000	1	100	9.25	5	4625	4070	34.02186	29.93924
02/17/95	8	Dicamba	50000	2	100	9.25	4.2	3885		28.57836	
02/17/95	44	Dicamba	50000	3	100	9.25	4	3700		27.21749	
02/17/95	17	Dicamba	100000	1	1	9.25	5.4	49.95	46.55833	0.367436	0.342487
02/17/95	26	Dicamba	100000	2	1	9.25	4.9	45.325		0.333414	
02/17/95	49	Dicamba	100000	3	1	9.25	4.8	44.4		0.32661	

Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
03/03/95	46	Control	0	1	100	29.34	4.1	12029.4	12811.8	93.89313	100
03/03/95	23	Control	0	2	100	29.34	4.2	12322.8		96.18321	
03/03/95	55	Control	0	3	100	29.34	4.8	14083.2		109.9237	
03/03/95	15	Cyanazine	9	1	100	29.34	5.6	16430.4	15843.6	128.2443	123.6641
03/03/95	70	Cyanazine	9	2	100	29.34	5.4	15843.6		123.6641	
03/03/95	21	Cyanazine	9	3	100	29.34	5.2	15256.8		119.084	
03/03/95	51	Cyanazine	19	1	100	29.34	3.2	9388.8	9388.8	73.28244	73.28244
03/03/95	28	Cyanazine	19	2	100	29.34	3.1	9095.4		70.99237	
03/03/95	63	Cyanazine	19	3	100	29.34	3.3	9682.2		75.57252	
03/03/95	32	Cyanazine	38	1	100	9.25	4.8	4440	4378.333	34.65555	34.17422
03/03/95	3	Cyanazine	38	2	100	9.25	4.4	4070		31.76759	
03/03/95	71	Cyanazine	38	3	100	9.25	5	4625		36.09953	
03/03/95	67	Cyanazine	75	1	100	9.25	2.2	2035	2035	15.88379	15.88379
03/03/95	26	Cyanazine	75	2	100	9.25	2.2	2035		15.88379	
03/03/95	39	Cyanazine	75	3	100	9.25	2.2	2035		15.88379	
03/03/95	59	Cyanazine	150	1	100	2.84	3.9	1107.6	1098.133	8.645155	8.571265
03/03/95	11	Cyanazine	150	2	100	2.84	3.7	1050.8		8.201814	
03/03/95	41	Cyanazine	150	3	100	2.84	4	1136		8.866826	

Appendix I. Raw data from Selenastrum studies.

Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
03/03/95	46	Control.	0	1	100	29.34	4.1	12029.4	12811.8	93.89313	100
03/03/95	23	Control	0	2	100	29.34	4.2	12322.8		96.18321	
03/03/95	55	Control	0	3	100	29.34	4.8	14083.2		109.9237	
03/03/95	64	Chlorosulfur	9	1	100	29.34	4.2	12322.8	12029.4	96.18321	93.89313
03/03/95	36	Chlorosulfur	9	2	100	29.34	4	11736		91.60305	
03/03/95	52	Chlorosulfur	9	3	100	29.34	4.1	12029.4		93.89313	
03/03/95	9	Chlorosulfur	19	1	100	29.34	3.4	9975.6	10855.8	77.8626	84.73282
03/03/95	47	Chlorosulfur	19	2	100	29.34	4.1	12029.4		93.89313	
03/03/95	73	Chlorosulfur	19	3	100	29.34	3.6	10562.4		82.44275	
03/03/95	72	Chlorosulfur	38	1	100	29.34	3.4	9975.6	9877.8	77.8626	77.09924
03/03/95	35	Chlorosulfur	38	2	100	29.34	3.7	10855.8		84.73282	
03/03/95	44	Chlorosulfur	38	3	100	29.34	3	8802		68.70229	
03/03/95	56	Chlorosulfur	75	1	100	29.34	3	8802	8410.8	68.70229	65.64885
03/03/95	30	Chlorosulfur	75	2	100	29.34	2.6	7628.4		59.54198	
03/03/95	60	Chlorosulfur	75	3	100	29.34	3	8802		68.70229	
03/03/95	4	Chlorosulfur	150	1	100	9.25	6.5	6012.5	6226.9	46.92939	48.60285
03/03/95	18	Chlorosulfur	150	2	100	9.25	6.4	5920		46.2074	
03/03/95	53	Chlorosulfur	150	3	100	29.34	2.3	6748.2		52.67176	

Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
3/10/95	66	Control	0	1	100	29.34	4.7	13789.8	13300.8	103.6765	100
3/10/95	14	Control	0	2	100	29.34	4.4	12909.6		97.05882	
3/10/95	8	Control	0	3	100	29.34	4.5	13203		99.26471	
3/10/95	32	Metolachlor	9	1	100	29.34	5	14670	14474.4	110.2941	108.8235
3/10/95	63	Metolachlor	9	2	100	29.34	5.1	14963.4		112.5	
3/10/95	30	Metolachlor	9	3	100	29.34	4.7	13789.8		103.6765	
3/10/95	39	Metolachlor	19	1	100	29.34	4.5	13203	13594.2	99.26471	102.2059
3/10/95	1	Metolachlor	19	2	100	29.34	4.2	12322.8		92.64706	
3/10/95	36	Metolachlor	19	3	100	29.34	5.2	15256.8		114.7059	
3/10/95	51	Metolachlor	38	1	100	29.34	4.4	12909.6	12811.8	97.05882	96.32353
3/10/95	28	Metolachlor	38	2	100	29.34	4.2	12322.8		92.64706	
3/10/95	67	Metolachlor	38	3	100	29.34	4.5	13203		99.26471	
3/10/95	53	Metolachlor	75	1	100	9.25	7.4	6845	6875.833	51.46307	51.69489
3/10/95	62	Metolachlor	75	2	100	9.25	7.7	7122.5		53.54941	
3/10/95	4	Metolachlor	75	3	100	9.25	7.2	6660		50.07218	
3/10/95	22	Metolachlor	150	1	100	9.25	2.1	1942.5	2065.833	14.60438	15.53165
3/10/95	43	Metolachlor	150	2	100	9.25	2.1	1942.5		14.60438	
3/10/95	72	Metolachlor	150	3	100	9.25	2.5	2312.5		17.38617	

Appendix I. Raw data from Selenastrum studies.

Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
3/10/95	66	Control	0	1	100	29.34	4.7	13789.8	13300.8	103.6765	100
3/10/95	14	Control	0	2	100	29.34	4.4	12909.6		97.05882	
3/10/95	8	Control	0	3	100	29.34	4.5	13203		99.26471	
3/10/95	48	Simazine	150	1	100	29.34	7.1	20831.4	19560	156.6176	147.0588
3/10/95	17	Simazine	150	2	100	29.34	6.4	18777.6		141.1765	
3/10/95	70	Simazine	150	3	100	29.34	6.5	19071		143.3824	
3/10/95	11	Simazine	300	1	100	29.34	6.1	17897.4	18777.6	134.5588	141.1765
3/10/95	35	Simazine	300	2	100	29.34	6.7	19657.8		147.7941	
3/10/95	44	Simazine	300	3	100	29.34	6.4	18777.6		141.1765	
3/10/95	50	Simazine	600	1	100	29.34	4.4	12909.6	12127.2	97.05882	91.17647
3/10/95	25	Simazine	600	2	100	29.34	4.2	12322.8		92.64706	
3/10/95	73	Simazine	600	3	100	29.34	3.8	11149.2		83.82353	
3/10/95	27	Simazine	1200	1	100	29.34	2.4	7041.6	7188.033	52.94118	54.04211
3/10/95	57	Simazine	1200	2	100	9.25	8	7400		55.63575	
3/10/95	15	Simazine	1200	3	100	9.25	7.7	7122.5		53.54941	
3/10/95	23	Simazine	2400	1	100	9.25	3.7	3422.5	3422.5	25.73153	25.73153
3/10/95	13	Simazine	2400	2	100	9.25	4	3700		27.81788	
3/10/95	2	Simazine	2400	3	100	9.25	3.4	3145		23.64519	

Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
3/10/95	66	Control	0	1	100	29.34	4.7	13789.8	13300.8	103.6765	100
3/10/95	14	Control	0	2	100	29.34	4.4	12909.6		97.05882	
3/10/95	8	Control	0	3	100	29.34	4.5	13203		99.26471	
3/10/95	71	Triallate	6.25	1	100	29.34	4.3	12616.2	13887.6	94.85294	104.4118
3/10/95	34	Triallate	6.25	2	100	29.34	4.9	14376.6		108.0882	
3/10/95	20	Triallate	6.25	3	100	29.34	5	14670		110.2941	
3/10/95	7	Triallate	12.5	1	100	29.34	4.2	12322.8	12909.6	92.64706	97.05882
3/10/95	47	Triallate	12.5	2	100	29.34	4.4	12909.6		97.05882	
3/10/95	45	Triallate	12.5	3	100	29.34	4.6	13496.4		101.4706	
3/10/95	9	Triallate	25	1	100	29.34	3.8	11149.2	10758	83.82353	80.88235
3/10/95	16	Triallate	25	2	100	29.34	3.7	10855.8		81.61765	
3/10/95	37	Triallate	25	3	100	29.34	3.5	10269		77.20588	
3/10/95	56	Triallate	50	1	100	9.25	7.1	6567.5	6339.633	49.37673	47.66355
3/10/95	49	Triallate	50	2	100	29.34	2.1	6161.4		46.32353	
3/10/95	3	Triallate	50	3	100	9.25	6.8	6290		47.29039	
3/10/95	59	Triallate	100	1	100	2.84	3.7	1050.8	1079.2	7.900277	8.113798
3/10/95	41	Triallate	100	2	100	2.84	3.7	1050.8		7.900277	
3/10/95	55	Triallate	100	3	100	2.84	4	1136		8.54084	

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Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
3/10/95	66	Control	0	1	100	29.34	4.7	13789.8	13300.8	103.6765	100
3/10/95	14	Control	0	2	100	29.34	4.4	12909.6		97.05882	
3/10/95	8	Control	0	3	100	29.34	4.5	13203		99.26471	
3/10/95	68	Trifluralin	150	1	100	29.34	4.8	14083.2	13594.2	105.8824	102.2059
3/10/95	12	Trifluralin	150	2	100	29.34	4.1	12029.4		90.44118	
3/10/95	52	Trifluralin	150	3	100	29.34	5	14670		110.2941	
3/10/95	31	Trifluralin	300	1	100	29.34	4	11736	12029.4	88.23529	90.44118
3/10/95	65	Trifluralin	300	1	100	29.34	4.3	12616.2		94.85294	
3/10/95	19	Trifluralin	300	2	100	29.34	4	11736		88.23529	
3/10/95	5	Trifluralin	600	1	100	9.25	7.8	7215	7197.2	54.24486	54.11103
3/10/95	33	Trifluralin	600	2	100	29.34	2.5	7335		55.14706	
3/10/95	42	Trifluralin	600	3	100	29.34	2.4	7041.6		52.94118	
3/10/95	29	Trifluralin	1200	1	100	9.25	3.6	3330	3299.167	25.03609	24.80427
3/10/95	54	Trifluralin	1200	2	100	9.25	3.8	3515		26.42698	
3/10/95	64	Trifluralin	1200	3	100	9.25	3.3	3052.5		22.94975	
3/10/95	10	Trifluralin	2400	1	100	9.25	2.5	2312.5	2189.167	17.38617	16.45891
3/10/95	21	Trifluralin	2400	2	100	9.25	2.3	2127.5		15.99528	
3/10/95	38	Trifluralin	2400	3	100	9.25	2.3	2127.5		15.99528	

Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
03/17/95	2	Control	0	1	100	29.34	4.6	13496.4	15550.2	89.61039	103.2468
03/17/95	57	Control	0	2	100	29.34	5.9	17310.6		114.9351	
03/17/95	73	Control	0	3	100	29.34	5.4	15843.6		105.1948	
03/17/95	21	Atrazine	19	1	100	29.34	7.4	21711.6	22689.6	139.6226	145.9119
03/17/95	61	Atrazine	19	2	100	29.34	8.2	24058.8		154.717	
03/17/95	45	Atrazine	19	3	100	29.34	7.6	22298.4		143.3962	
03/17/95	4	Atrazine	38	1	100	29.34	7.7	22591.8	21809.4	145.283	140.2516
03/17/95	39	Atrazine	38	2	100	29.34	7.2	21124.8		135.8491	
03/17/95	12	Atrazine	38	3	100	29.34	7.4	21711.6		139.6226	
03/17/95	58	Atrazine	75	1	100	29.34	6.2	18190.8	17506.2	116.9811	112.5786
03/17/95	26	Atrazine	75	2	100	29.34	6	17604		113.2075	
03/17/95	76	Atrazine	75	3	100	29.34	5.7	16723.8		107.5472	
03/17/95	50	Atrazine	150	1	100	29.34	4.2	12322.8	11247	79.24528	72.32704
03/17/95	35	Atrazine	150	2	100	29.34	3.7	10855.8		69.81132	
03/17/95	3	Atrazine	150	3	100	29.34	3.6	10562.4		67.92453	
03/17/95	25	Atrazine	300	1	100	29.34	2.3	6748.2	6552.6	43.39623	42.13836
03/17/95	62	Atrazine	300	2	100	29.34	2.2	6454.8		41.50943	
03/17/95	22	Atrazine	300	3	100	29.34	2.2	6454.8		41.50943	

Appendix I. Raw data from Selenastrum studies.

Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
03/17/95	32	Control	0	1	100	29.34	4.6	13496.4	15061.2	89.61039	100
03/17/95	15	Control	0	2	100	29.34	5.1	14963.4		99.35065	
03/17/95	65	Control	0	3	100	29.34	5.7	16723.8		111.039	
03/17/95	28	Diquat	11	1	100	29.34	5.2	15256.8	15941.4	101.2987	105.8442
03/17/95	52	Diquat	11	2	100	29.34	5.5	16137		107.1429	
03/17/95	69	Diquat	11	3	100	29.34	5.6	16430.4		109.0909	
03/17/95	43	Diquat	22	1	100	29.34	5.1	14963.4	14376.6	99.35065	95.45455
03/17/95	40	Diquat	22	2	100	29.34	4.2	12322.8		81.81818	
03/17/95	16	Diquat	22	3	100	29.34	5.4	15843.6		105.1948	
03/17/95	66	Diquat	44	1	100	29.34	5.2	15256.8	14278.8	101.2987	94.80519
03/17/95	1	Diquat	44	2	100	29.34	4.4	12909.6		85.71429	
03/17/95	14	Diquat	44	3	100	29.34	5	14670		97.4026	
03/17/95	53	Diquat	88	1	100	29.34	2.2	6454.8	5295.167	42.85714	35.15767
03/17/95	20	Diquat	88	2	100	29.34	2.3	6748.2		44.80519	
03/17/95	48	Diquat	88	3	100	9.25	2.9	2682.5		17.81067	
03/17/95	11	Diquat	175	1	100	9.25	3.3	3052.5	3114.167	20.26731	20.67675
03/17/95	38	Diquat	175	2	100	9.25	3.4	3145		20.88147	
03/17/95	24	Diquat	175	3	100	9.25	3.4	3145		20.88147	

Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
03/17/95	74	Control	0	1	100	29.34	5.1	14963.4	16137	99.35065	107.1429
03/17/95	10	Control	0	2	100	29.34	5.6	16430.4		109.0909	
03/17/95	54	Control	0	3	100	29.34	5.8	17017.2		112.987	
03/17/95	49	Metsulfuron	19	1	100	29.34	5.4	15843.6	14963.4	98.18182	92.72727
03/17/95	13	Metsulfuron	19	2	100	29.34	4.9	14376.6		89.09091	
03/17/95	29	Metsulfuron	19	3	100	29.34	5	14670		90.90909	
03/17/95	71	Metsulfuron	38	1	100	29.34	5.4	15843.6	15256.8	98.18182	94.54545
03/17/95	33	Metsulfuron	38	2	100	29.34	4.6	13496.4		83.63636	
03/17/95	68	Metsulfuron	38	3	100	29.34	5.6	16430.4		101.8182	
03/17/95	51	Metsulfuron	75	1	100	29.34	3.8	11149.2	11344.8	69.09091	70.30303
03/17/95	5	Metsulfuron	75	2	100	29.34	4	11736		72.72727	
03/17/95	42	Metsulfuron	75	3	100	29.34	3.8	11149.2		69.09091	
03/17/95	46	Metsulfuron	150	1	100	29.34	3.2	9388.8	9975.6	58.18182	61.81818
03/17/95	60	Metsulfuron	150	2	100	29.34	3.6	10562.4		65.45455	
03/17/95	17	Metsulfuron	150	3	100	29.34	3.4	9975.6		61.81818	
03/17/95	55	Metsulfuron	300	1	100	29.34	2.4	7041.6	6650.4	43.63636	41.21212
03/17/95	31	Metsulfuron	300	2	100	29.34	2.2	6454.8		40	
03/17/95	67	Metsulfuron	300	3	100	29.34	2.2	6454.8		40	

Appendix I. Raw data from Selenastrum studies.

Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
03/24/95	32	Control	0	1	100	29.34	4.6	13496.4	13007.4	103.7594	100
03/24/95	5	Control	0	2	100	29.34	4.1	12029.4		92.4812	
03/24/95	18	Control	0	3	100	29.34	4.6	13496.4		103.7594	
03/24/95	44	Alaclor	0.94	1	100	29.34	5.3	15550.2	13496.4	155.1034	134.618
03/24/95	1	Alaclor	0.94	2	100	29.34	4	11736		117.0592	
03/24/95	29	Alaclor	0.94	3	100	29.34	4.5	13203		131.6916	
03/24/95	17	Alaclor	1.88	1	100	29.34	4.8	14083.2	13007.4	140.471	129.7406
03/24/95	35	Alaclor	1.88	2	100	29.34	4.4	12909.6		128.7651	
03/24/95	11	Alaclor	1.88	3	100	29.34	4.1	12029.4		119.9856	
03/24/95	15	Alaclor	3.75	1	100	29.34	4.1	12029.4	9222.1	119.9856	91.9846
03/24/95	3	Alaclor	3.75	2	100	29.34	4.1	12029.4		119.9856	
03/24/95	31	Alaclor	3.75	3	100	9.25	3.9	3607.5		35.98252	
03/24/95	19	Alaclor	7.5	1	100	29.34	2.2	6454.8	6559.333	64.38254	65.42519
03/24/95	38	Alaclor	7.5	2	100	29.34	2.3	6748.2		67.30902	
03/24/95	13	Alaclor	7.5	3	100	9.25	7	6475		64.58402	
03/24/95	21	Alaclor	15	1	100	9.25	3.5	3237.5	2682.5	32.29201	26.75624
03/24/95	26	Alaclor	15	2	100	9.25	2.6	2405		23.98835	
03/24/95	33	Alaclor	15	3	100	9.25	2.6	2405		23.98835	

Date	Random Number Code	Chemical Name	Dilution	Rep	MULT.	SENS.	SCALE	Fluor Unit	Avg Fluor Unit	% of control	Avg % of control
03/24/95	32	Control	0	1	100	29.34	4.6	13496.4	13007.4	103.7594	100
03/24/95	5	Control	0	2	100	29.34	4.1	12029.4		92.4812	
03/24/95	18	Control	0	3	100	29.34	4.6	13496.4		103.7594	
03/24/95	14	Paraquat	114	1	100	29.34	4.6	13496.4	13398.6	103.7594	103.0075
03/24/95	30	Paraquat	114	2	100	29.34	4.5	13203		101.5038	
03/24/95	6	Paraquat	114	3	100	29.34	4.6	13496.4		103.7594	
03/24/95	36	Paraquat	227	1	100	29.34	4.2	12322.8	10758	94.73684	82.70677
03/24/95	4	Paraquat	227	2	100	29.34	3.8	11149.2		85.71429	
03/24/95	39	Paraquat	227	3	100	29.34	3	8802		67.66917	
03/24/95	37	Paraquat	454	1	100	29.34	3.1	9095.4	8606.4	69.92481	66.16541
03/24/95	24	Paraquat	454	2	100	29.34	3.1	9095.4		69.92481	
03/24/95	22	Paraquat	454	3	100	29.34	2.6	7628.4		58.64662	
03/24/95	20	Paraquat	907	1	100	9.25	2.8	2590	2651.667	19.91174	20.38583
03/24/95	8	Paraquat	907	2	100	9.25	2.7	2497.5		19.20061	
03/24/95	34	Paraquat	907	3	100	9.25	3.1	2867.5		22.04514	
03/24/95	12	Paraquat	1814	1	100	0.9	6.2	558	577.2667	4.289866	4.437987
03/24/95	27	Paraquat	1814	2	100	2.84	2.2	624.8		4.80342	
03/24/95	42	Paraquat	1814	3	100	0.9	6.1	549		4.220674	

Appendix II. Raw data from Lemna studies

File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
01/30/95	Control	0	1	25	13	16.33333	79.59184	100
01/30/95	Control	0	2	29	17		104.0816	
01/30/95	Control	0	3	31	19		116.3265	
01/30/95	Atrazine	19	1	31	19	17.66667	116.3265	108.1633
01/30/95	Atrazine	19	2	27	15		91.83673	
01/30/95	Atrazine	19	3	31	19		116.3265	
01/30/95	Atrazine	38	1	23	11	14.33333	67.34694	87.7551
01/30/95	Atrazine	38	2	25	13		79.59184	
01/30/95	Atrazine	38	3	31	19		116.3265	
01/30/95	Atrazine	75	1	22	10	12.66667	61.22449	77.55102
01/30/95	Atrazine	75	2	28	16		97.95918	
01/30/95	Atrazine	75	3	24	12		73.46939	
01/30/95	Atrazine	150	1	19	7	9	42.85714	55.10204
01/30/95	Atrazine	150	2	23	11		67.34694	
01/30/95	Atrazine	150	3	21	9		55.10204	
01/30/95	Atrazine	300	1	18	6	4	36.73469	24.4898
01/30/95	Atrazine	300	2	14	2		12.2449	
01/30/95	Atrazine	300	3	16	4		24.4898	

File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
01/30/95	Control	0	1	25	13	16.33333	79.59184	100
01/30/95	Control	0	2	29	17		104.0816	
01/30/95	Control	0	3	31	19		116.3265	
01/30/95	Metribuzin	9	1	30	18	17.33333	110.2041	106.1224
01/30/95	Metribuzin	9	2	28	16		97.95918	
01/30/95	Metribuzin	9	3	30	18		110.2041	
01/30/95	Metribuzin	19	1	22	10	12	61.22449	73.46939
01/30/95	Metribuzin	19	2	26	14		85.71429	
01/30/95	Metribuzin	19	3	24	12		73.46939	
01/30/95	Metribuzin	38	1	19	7	8.666667	42.85714	53.06122
01/30/95	Metribuzin	38	2	19	7		42.85714	
01/30/95	Metribuzin	38	3	24	12		73.46939	
01/30/95	Metribuzin	75	1	15	3	3.666667	18.36735	22.44898
01/30/95	Metribuzin	75	2	20	8		48.97959	
01/30/95	Metribuzin	75	3	12	0		0	
01/30/95	Metribuzin	150	1	14	2	1	12.2449	6.122449
01/30/95	Metribuzin	150	2	13	1		6.122449	
01/30/95	Metribuzin	150	3	12	0		0	

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File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
02/13/95	Control	0	1	32	20	19	105.2632	100
02/13/95	Control	0	2	26	14		73.68421	
02/13/95	Control	0	3	35	23		121.0526	
02/13/95	Diquat	11	1	24	12	10.66667	63.15789	56.14035
02/13/95	Diquat	11	2	19	7		36.84211	
02/13/95	Diquat	11	3	25	13		68.42105	
02/13/95	Diquat	22	1	21	9	8.666667	47.36842	45.61404
02/13/95	Diquat	22	2	21	9		47.36842	
02/13/95	Diquat	22	3	20	8		42.10526	
02/13/95	Diquat	44	1	19	7	7	36.84211	36.84211
02/13/95	Diquat	44	2	16	4		21.05263	
02/13/95	Diquat	44	3	22	10		52.63158	
02/13/95	Diquat	88	1	15	3	3	15.78947	15.78947
02/13/95	Diquat	88	2	16	4		21.05263	
02/13/95	Diquat	88	3	14	2		10.52632	
02/13/95	Diquat	175	1	12	0	0	0	0
02/13/95	Diquat	175	2	12	0		0	
02/13/95	Diquat	175	3	12	0		0	

File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
02/13/95	Control	0	1	32	20	19	105.2632	100
02/13/95	Control	0	2	26	14		73.68421	
02/13/95	Control	0	3	35	23		121.0526	
02/13/95	Paraquat	14	1	36	24	19.33333	126.3158	101.7544
02/13/95	Paraquat	14	2	29	17		89.47368	
02/13/95	Paraquat	14	3	29	17		89.47368	
02/13/95	Paraquat	28	1	26	14	12.66667	73.68421	66.66667
02/13/95	Paraquat	28	2	23	11		57.89474	
02/13/95	Paraquat	28	3	25	13		68.42105	
02/13/95	Paraquat	57	1	21	9	7.666667	47.36842	40.35088
02/13/95	Paraquat	57	2	19	7		36.84211	
02/13/95	Paraquat	57	3	19	7		36.84211	
02/13/95	Paraquat	173	1	18	6	5.666667	31.57895	29.82456
02/13/95	Paraquat	173	2	18	6		31.57895	
02/13/95	Paraquat	173	3	17	5		26.31579	
02/13/95	Paraquat	227	1	16	4	2.333333	21.05263	12.2807
02/13/95	Paraquat	227	2	14	2		10.52632	
02/13/95	Paraquat	227	3	13	1		5.263158	

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File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
02/13/95	Control	0	1	32	20	19	105.2632	100
02/13/95	Control	0	2	26	14		73.68421	
02/13/95	Control	0	3	35	23		121.0526	
02/13/95	Dicamba	6250	1	29	17	17.33333	89.47368	91.22807
02/13/95	Dicamba	6250	2	32	20		105.2632	
02/13/95	Dicamba	6250	3	27	15		78.94737	
02/13/95	Dicamba	12500	1	25	13	16	68.42105	84.21053
02/13/95	Dicamba	12500	2	32	20		105.2632	
02/13/95	Dicamba	12500	3	27	15		78.94737	
02/13/95	Dicamba	25000	1	28	16	13.66667	84.21053	71.92982
02/13/95	Dicamba	25000	2	22	10		52.63158	
02/13/95	Dicamba	25000	3	27	15		78.94737	
02/13/95	Dicamba	50000	1	27	15	12.66667	78.94737	66.66667
02/13/95	Dicamba	50000	2	25	13		68.42105	
02/13/95	Dicamba	50000	3	22	10		52.63158	
02/13/95	Dicamba	100000	1	28	16	12.33333	84.21053	64.91228
02/13/95	Dicamba	100000	2	23	11		57.89474	
02/13/95	Dicamba	100000	3	22	10		52.63158	

File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
03/10/95	Control	0	1	30	18	17.33333	103.8462	100
03/10/95	Control	0	2	37	25		144.2308	
03/10/95	Control	0	3	21	9		51.92308	
03/10/95	Metolachlor	93	1	20	8	12	46.15385	69.23077
03/10/95	Metolachlor	93	2	30	18		103.8462	
03/10/95	Metolachlor	93	3	22	10		57.69231	
03/10/95	Metolachlor	187	1	29	17	11.66667	98.07692	67.30769
03/10/95	Metolachlor	187	2	22	10		57.69231	
03/10/95	Metolachlor	187	3	20	8		46.15385	
03/10/95	Metolachlor	375	1	16	4	5.333333	23.07692	30.76923
03/10/95	Metolachlor	375	2	18	6		34.61538	
03/10/95	Metolachlor	375	3	18	6		34.61538	
03/10/95	Metolachlor	750	1	21	9	8.333333	51.92308	48.07692
03/10/95	Metolachlor	750	2	22	10		57.69231	
03/10/95	Metolachlor	750	3	18	6		34.61538	
03/10/95	Metolachlor	1500	1	18	6	5.333333	34.61538	30.76923
03/10/95	Metolachlor	1500	2	16	4		23.07692	
03/10/95	Metolachlor	1500	3	18	6		34.61538	

Appendix II. Raw data from Lemna studies

File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
03/10/95	Control	0	1	30	18	17.33333	103.8462	100
03/10/95	Control	0	2	37	25		144.2308	
03/10/95	Control	0	3	21	9		51.92308	
03/10/95	Simazine	38	1	29	17	16.33333	98.07692	94.23077
03/10/95	Simazine	38	2	30	18		103.8462	
03/10/95	Simazine	38	3	26	14		80.76923	
03/10/95	Simazine	75	1	28	16	15	92.30769	86.53846
03/10/95	Simazine	75	2	27	15		86.53846	
03/10/95	Simazine	75	3	26	14		80.76923	
03/10/95	Simazine	150	1	21	9	9.333333	51.92308	53.84615
03/10/95	Simazine	150	2	23	11		63.46154	
03/10/95	Simazine	150	3	20	8		46.15385	
03/10/95	Simazine	300	1	15	3	4	17.30769	23.07692
03/10/95	Simazine	300	2	17	5		28.84615	
03/10/95	Simazine	300	3	16	4		23.07692	
03/10/95	Simazine	600	1	12	0	0.333333	0	1.923077
03/10/95	Simazine	600	2	12	0		0	
03/10/95	Simazine	600	3	13	1		5.769231	

File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
03/10/95	Control	0	1	30	18	17.33333	103.8462	100
03/10/95	Control	0	2	37	25		144.2308	
03/10/95	Control	0	3	21	9		51.92308	
03/10/95	Trifluralin	38	1	29	17	13.66667	98.07692	78.84615
03/10/95	Trifluralin	38	2	23	11		63.46154	
03/10/95	Trifluralin	38	3	25	13		75	
03/10/95	Trifluralin	75	1	25	13	11	75	63.46154
03/10/95	Trifluralin	75	2	23	11		63.46154	
03/10/95	Trifluralin	75	3	21	9		51.92308	
03/10/95	Trifluralin	150	1	22	10	9.333333	57.69231	53.84615
03/10/95	Trifluralin	150	2	22	10		57.69231	
03/10/95	Trifluralin	150	3	20	8		46.15385	
03/10/95	Trifluralin	300	1	21	9	6.666667	51.92308	38.46154
03/10/95	Trifluralin	300	2	18	6		34.61538	
03/10/95	Trifluralin	300	3	17	5		28.84615	
03/10/95	Trifluralin	600	1	15	3	4.666667	17.30769	26.92308
03/10/95	Trifluralin	600	2	15	3		17.30769	
03/10/95	Trifluralin	600	3	20	8		46.15385	

Appendix II. Raw data from Lemna studies

File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
03/17/95	Control	0	1	24	12	12.33333	97.2973	100
03/17/95	Control	0	2	25	13		105.4054	
03/17/95	Control	0	3	24	12		97.2973	
03/17/95	2–4D	6750	1	29	17	13.33333	137.8378	108.1081
03/17/95	2–4D	6750	2	24	12		97.2973	
03/17/95	2–4D	6750	3	23	11		89.18919	
03/17/95	2–4D	12500	1	22	10	10	81.08108	81.08108
03/17/95	2–4D	12500	2	19	7		56.75676	
03/17/95	2–4D	12500	3	25	13		105.4054	
03/17/95	2–4D	25000	1	17	5	8.666667	40.54054	70.27027
03/17/95	2–4D	25000	2	26	14		113.5135	
03/17/95	2–4D	25000	3	19	7		56.75676	
03/17/95	2–4D	50000	1	23	11	10.66667	89.18919	86.48649
03/17/95	2–4D	50000	2	22	10		81.08108	
03/17/95	2–4D	50000	3	23	11		89.18919	
03/17/95	2–4D	100000	1	23	11	9	89.18919	72.97297
03/17/95	2–4D	100000	2	20	8		64.86486	
03/17/95	2–4D	100000	3	20	8		64.86486	

File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
03/17/95	Control	0	1	24	12	12.33333	97.2973	100
03/17/95	Control	0	2	25	13		105.4054	
03/17/95	Control	0	3	24	12		97.2973	
03/17/95	EPTC	625	1	29	17	15.66667	137.8378	127.027
03/17/95	EPTC	625	2	30	18		145.9459	
03/17/95	EPTC	625	3	24	12		97.2973	
03/17/95	EPTC	1250	1	35	23	19.66667	186.4865	159.4595
03/17/95	EPTC	1250	2	30	18		145.9459	
03/17/95	EPTC	1250	3	30	18		145.9459	
03/17/95	EPTC	2500	1	29	17	15	137.8378	121.6216
03/17/95	EPTC	2500	2	21	9		72.97297	
03/17/95	EPTC	2500	3	31	19		154.0541	
03/17/95	EPTC	5000	1	32	20	15.33333	162.1622	124.3243
03/17/95	EPTC	5000	2	26	14		113.5135	
03/17/95	EPTC	5000	3	24	12		97.2973	
03/17/95	EPTC	10000	1	15	3	1	24.32432	8.108108
03/17/95	EPTC	10000	2	12	0		0	
03/17/95	EPTC	10000	3	12	0		0	

Appendix II. Raw data from Lemna studies

File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
03/17/95	Control	0	1	24	12	12.33333	97.2973	100
03/17/95	Control	0	2	25	13		105.4054	
03/17/95	Control	0	3	24	12		97.2973	
03/17/95	Cyanazine	75	1	27	15	14	121.6216	113.5135
03/17/95	Cyanazine	75	2	24	12		97.2973	
03/17/95	Cyanazine	75	3	27	15		121.6216	
03/17/95	Cyanazine	150	1	24	12	13.33333	97.2973	108.1081
03/17/95	Cyanazine	150	2	26	14		113.5135	
03/17/95	Cyanazine	150	3	26	14		113.5135	
03/17/95	Cyanazine	300	1	23	11	12	89.18919	97.2973
03/17/95	Cyanazine	300	2	25	13		105.4054	
03/17/95	Cyanazine	300	3	24	12		97.2973	
03/17/95	Cyanazine	600	1	21	9	8.666667	72.97297	70.27027
03/17/95	Cyanazine	600	2	17	5		40.54054	
03/17/95	Cyanazine	600	3	24	12		97.2973	
03/17/95	Cyanazine	1200	1	14	2	1.333333	16.21622	10.81081
03/17/95	Cyanazine	1200	2	14	2		16.21622	
03/17/95	Cyanazine	1200	3	12	0		0	

File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
03/24/95	Control	0	1	31	19	17	111.7647	100
03/24/95	Control	0	2	27	15		88.23529	
03/24/95	Control	0	3	29	17		100	
03/24/95	Alachlor	31.8	1	23	11	14	64.70588	82.35294
03/24/95	Alachlor	31.8	2	27	15		88.23529	
03/24/95	Alachlor	31.8	3	28	16		94.11765	
03/24/95	Alachlor	62.5	1	25	13	11.66667	76.47059	68.62745
03/24/95	Alachlor	62.5	2	22	10		58.82353	
03/24/95	Alachlor	62.5	3	24	12		70.58824	
03/24/95	Alachlor	125	1	25	13	10.33333	76.47059	60.78431
03/24/95	Alachlor	125	2	22	10		58.82353	
03/24/95	Alachlor	125	3	20	8		47.05882	
03/24/95	Alachlor	250	1	20	8	7.666667	47.05882	45.09804
03/24/95	Alachlor	250	2	21	9		52.94118	
03/24/95	Alachlor	250	3	18	6		35.29412	
03/24/95	Alachlor	500	1	18	6	5.333333	35.29412	31.37255
03/24/95	Alachlor	500	2	16	4		23.52941	
03/24/95	Alachlor	500	3	18	6		35.29412	

Appendix II. Raw data from Lemna studies

File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
03/17/95	Control	0	1	29	17	17.66667	137.8378	143.2432
03/17/95	Control	0	2	30	18		145.9459	
03/17/95	Control	0	3	30	18		145.9459	
03/17/95	Bromoxynil	3125	1	25	13	16.66667	73.58491	94.33962
03/17/95	Bromoxynil	3125	2	35	23		130.1887	
03/17/95	Bromoxynil	3125	3	26	14		79.24528	
03/17/95	Bromoxynil	6250	1	24	12	13	67.92453	73.58491
03/17/95	Bromoxynil	6250	2	25	13		73.58491	
03/17/95	Bromoxynil	6250	3	26	14		79.24528	
03/17/95	Bromoxynil	12500	1	27	15	12.66667	84.90566	71.69811
03/17/95	Bromoxynil	12500	2	23	11		62.26415	
03/17/95	Bromoxynil	12500	3	24	12		67.92453	
03/17/95	Bromoxynil	25000	1	22	10	7.666667	56.60377	43.39623
03/17/95	Bromoxynil	25000	2	19	7		39.62264	
03/17/95	Bromoxynil	25000	3	18	6		33.96226	
03/17/95	Bromoxynil	50000	1	12	0	0	0	0
03/17/95	Bromoxynil	50000	2	12	0		0	
03/17/95	Bromoxynil	50000	3	12	0		0	

File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
03/24/95	Control	0	1	31	19	17	111.7647	100
03/24/95	Control	0	2	27	15		88.23529	
03/24/95	Control	0	3	29	17		100	
03/24/95	Triallate	625	1	33	21	16.33333	123.5294	96.07843
03/24/95	Triallate	625	2	27	15		88.23529	
03/24/95	Triallate	625	3	25	13		76.47059	
03/24/95	Triallate	1250	1	30	18	19.66667	105.8824	115.6863
03/24/95	Triallate	1250	2	34	22		129.4118	
03/24/95	Triallate	1250	3	31	19		111.7647	
03/24/95	Triallate	2500	1	29	17	18.66667	100	109.8039
03/24/95	Triallate	2500	2	29	17		100	
03/24/95	Triallate	2500	3	34	22		129.4118	
03/24/95	Triallate	5000	1	29	17	16	100	94.11765
03/24/95	Triallate	5000	2	27	15		88.23529	
03/24/95	Triallate	5000	3	28	16		94.11765	
03/24/95	Triallate	10000	1	21	9	9.333333	52.94118	54.90196
03/24/95	Triallate	10000	2	19	7		41.17647	
03/24/95	Triallate	10000	3	24	12		70.58824	

Appendix II. Raw data from Lemna studies

File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
03/24/95	Control	0	1	31	19	17	111.7647	100
03/24/95	Control	0	2	27	15		88.23529	
03/24/95	Control	0	3	29	17		100	
03/24/95	Chlorosulfur	0.19	1	27	15	16	88.23529	94.11765
03/24/95	Chlorosulfur	0.19	2	27	15		88.23529	
03/24/95	Chlorosulfur	0.19	3	30	18		105.8824	
03/24/95	Chlorosulfur	0.38	1	25	13	14	76.47059	82.35294
03/24/95	Chlorosulfur	0.38	2	25	13		76.47059	
03/24/95	Chlorosulfur	0.38	3	28	16		94.11765	
03/24/95	Chlorosulfur	0.75	1	18	6	6.666667	35.29412	39.21569
03/24/95	Chlorosulfur	0.75	2	17	5		29.41176	
03/24/95	Chlorosulfur	0.75	3	21	9		52.94118	
03/24/95	Chlorosulfur	1.5	1	16	4	3.666667	23.52941	21.56863
03/24/95	Chlorosulfur	1.5	2	17	5		29.41176	
03/24/95	Chlorosulfur	1.5	3	14	2		11.76471	
03/24/95	Chlorosulfur	3	1	13	1	2.333333	5.882353	13.72549
03/24/95	Chlorosulfur	3	2	15	3		17.64706	
03/24/95	Chlorosulfur	3	3	15	3		17.64706	

File Date	Chemical Name	Dilution	Rep	Frond Count	Frond Growth	Avg Frond Growth	% of Control Frond Growth	Avg % of Control Frond Growth
03/24/95	Control	0	1	31	19	17	111.7647	100
03/24/95	Control	0	2	27	15		88.23529	
03/24/95	Control	0	3	29	17		100	
03/24/95	Metsulfuron	0.19	1	26	14	14.33333	82.35294	84.31373
03/24/95	Metsulfuron	0.19	2	27	15		88.23529	
03/24/95	Metsulfuron	0.19	3	26	14		82.35294	
03/24/95	Metsulfuron	0.38	1	21	9	8.333333	52.94118	49.01961
03/24/95	Metsulfuron	0.38	2	21	9		52.94118	
03/24/95	Metsulfuron	0.38	3	19	7		41.17647	
03/24/95	Metsulfuron	0.75	1	16	4	5	23.52941	29.41176
03/24/95	Metsulfuron	0.75	2	20	8		47.05882	
03/24/95	Metsulfuron	0.75	3	15	3		17.64706	
03/24/95	Metsulfuron	1.5	1	13	1	0.666667	5.882353	3.921569
03/24/95	Metsulfuron	1.5	2	13	1		5.882353	
03/24/95	Metsulfuron	1.5	3	12	0		0	
03/24/95	Metsulfuron	3	1	13	1	0.333333	5.882353	1.960784
03/24/95	Metsulfuron	3	2	12	0		0	
03/24/95	Metsulfuron	3	3	12	0		0	