DAVID HONNELL

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Aquatic Plant Control Research Program

Field Evaluation of Triclopyr (Garlon 3A) for Controlling Eurasian Watermilfoil in the Pend Oreille River, Washington

by Kurt D. Getsinger, John D. Madsen, Michael D. Netherland, WES
E. Glenn Turner, AScI Corporation

Prepared for Headquarters, U.S. Army Corps of Engineers
and U.S. Army Engineer District, Seattle

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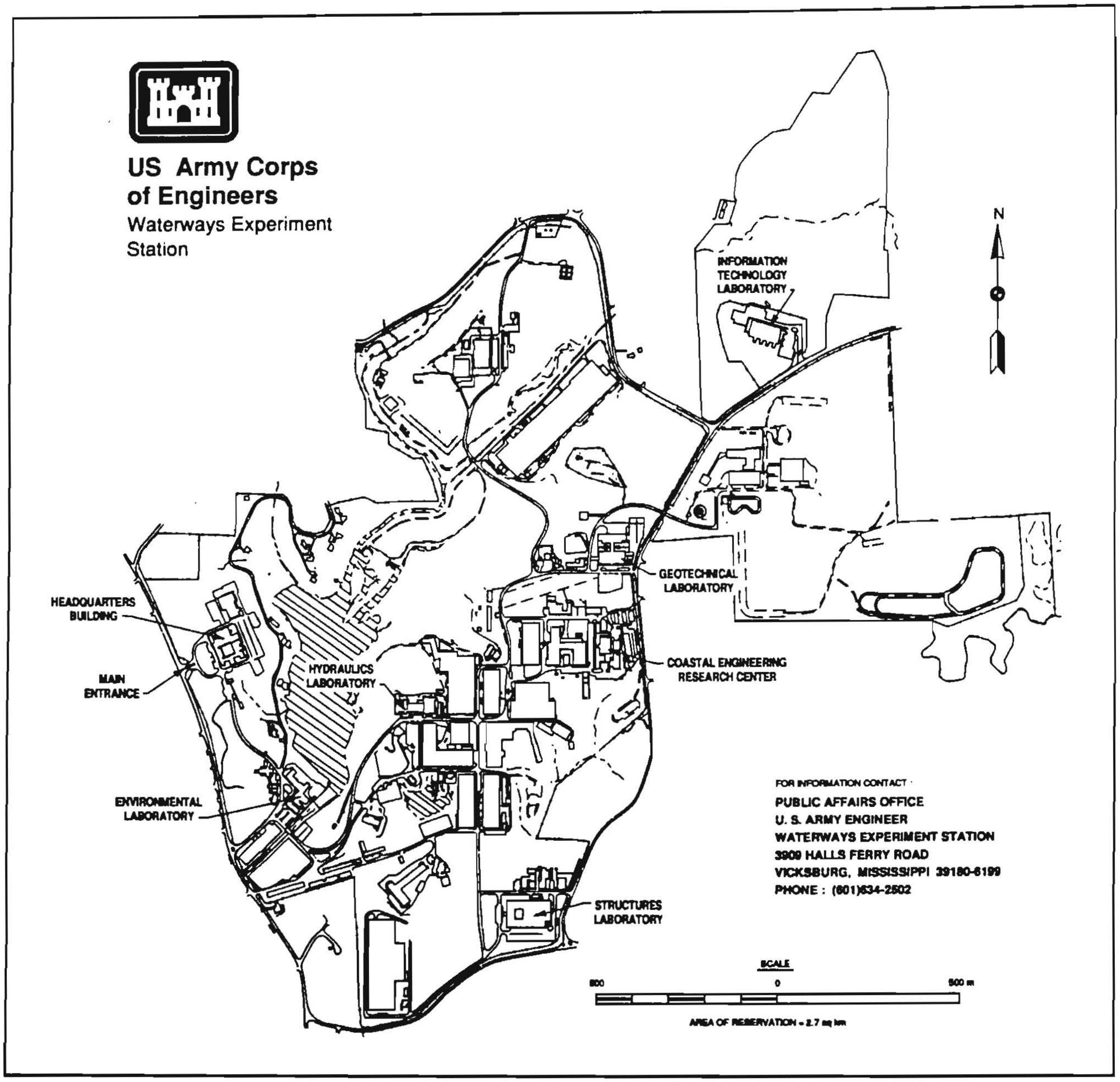

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Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 32404. The APCRP is sponsored by the Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation No. 96X3122, "Construction General." Additional funding and logistical support was provided by the U.S. Army Engineer District, Seattle. The APCRP is managed under the Environmental Resources Research and Assistance Programs (ERRAP), Mr. J. L. Decell, Manager. Mr. Robert C. Gunkel, Jr., was Assistant Manager, ERRAP, for the APCRP. Program Monitor during this study was Ms. Denise White, HQUSACE.

The Principal Investigator for this report was Dr. Kurt D. Getsinger, Ecosystem Processes and Effects Branch (EPEB), Environmental Processes and Effects Division (EPED), EL, WES. The study was conducted and the report prepared by Dr. Getsinger, Dr. John D. Madsen, and Mr. Michael D. Netherland, EPEB, and Mr. E. Glenn Turner, AScI Corporation.

Technical reviews of this report were provided by Dr. Susan Sprecher, EPEB, and Dr. Larry Lawrence, EPED. Technical assistance was provided by Mr. Robert Rawson, Seattle District; Mr. John B. Coyle and personnel, U.S. Army Engineer Libby-Albeni Falls Project; Ms. Kathy Hamel, Mr. Allen Moore, and Mr. Stephen Saunders, Washington State Department of Ecology; Ms. Sharon Sorby, Pend Oreille County Noxious Weed Control Board; Mr. Terry McNabb and personnel, Resource Management, Inc. (RMI); Ms. Vanelle Carrithers, Dr. John Troth, and Dr. Steve Rosser, DowElanco; and Dr. Lawrence, Dr. Michael Smart, Mr. Joel Everett, Ms. Linda Nelson, and Dr. Sprecher, WES. DowElanco provided the herbicide used in this study, and RMI conducted the dye/herbicide applications.

The investigation was performed under the general supervision of Dr. John W. Keeley, Director, EL; Mr. Donald L. Robey, Chief, EPED; and Dr. Richard E. Price, Acting Chief, EPEB.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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1 Introduction

Background

The submersed plant Eurasian watermilfoil (*Myriophyllum spicatum* L.), hereafter called milfoil, has spread throughout many rivers and reservoirs since its introduction into the United States prior to the 1940s (Reed 1977; Couch and Nelson 1985). Once established, growth and physiological characteristics of milfoil enable it to form a surface canopy and develop into immense stands of weedy vegetation, outcompeting and displacing native species of the submersed plant community (Grace and Wetzel 1978; Aiken, Newroth, and Wile 1979; Madsen, Eichler, and Boylen 1988; Madsen, Hartleb, and Boylen 1991; Smith and Barko 1990). These surface mats can severely impair many of the functional aspects of regulated rivers such as maintenance of water quality for wildlife habitat and public health, water storage capacity, navigation, and recreation (Hansen, Oliver, and Otto 1983; Ross and Lembi 1985; Newroth 1985; Nichols and Shaw 1986). Furthermore, a milfoil-dominated submersed plant community can greatly reduce the biodiversity of an aquatic system (Smith and Barko 1990; Madsen et al. 1991).

In an effort to develop methods for controlling the growth and spread of milfoil in public waters, scientists from the U.S. Army Engineer Waterways Experiment Station are evaluating the effectiveness of herbicides for restoring aquatic habitats dominated and degraded by this nonindigenous species. One such herbicide is triclopyr (3,5,6-trichloro-2-pyridinyl-oxyacetic acid), a pyridine-based systemic compound registered since the mid-1970s in the United States for control of broadleaf weeds and woody plants on rights-of-way, rangeland, industrial sites, and other noncrop areas. Furthermore, in 1995, triclopyr received U.S. registration for controlling weeds in rice grown for food production. Since the chemical has demonstrated potential for selectively controlling several aquatic weeds, including milfoil (Getsinger and Westerdahl 1984; Langeland 1986; Green et al. 1989; Wujec 1990), Dow-Elanco Chemical Company is pursuing an aquatic registration for the triethylamine salt formulation of triclopyr (presently labeled as Garlon 3A) under an Experimental Use Permit (EUP) issued by the U.S. Environmental Protection Agency (USEPA).

Previous aquatic testing has shown that triclopyr is susceptible to photolytic degradation and has a low order of toxicity to nontarget organisms (Gersich et al. 1984; Mayes et al. 1984; McCall and Gavit 1986; Dow Chemical Co. 1988; Woodburn et al. 1993; Woodburn, Green, and Westerdahl 1993). Field dissipation studies have indicated that triclopyr accumulation in sediment, shellfish, and fish is negligible (Getsinger and Westerdahl 1984; Woodburn, Green, and Westerdahl 1993). While laboratory studies have clearly shown that triclopyr efficacy is dependent upon the concentration and length of time milfoil remains exposed to the herbicide (Netherland and Getsinger 1992), this compound can be subject to rapid dilution and dispersion from treatment areas through gravity flow, tides, and thermal- and wind-induced water circulation patterns, etc. (Fox, Haller, and Getsinger 1991; Getsinger, Fox, and Haller 1992). Although rapid dissipation may be environmentally desirable, this process can reduce the degree of plant control because of insufficient herbicide exposure. Therefore, successful triclopyr treatment of milfoil in rivers and reservoirs requires knowledge of herbicide concentration and exposure-time requirements for this species, as well as site-specific water-exchange characteristics.

The 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. Water 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 discrete 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 (Fox, Haller, and Shilling 1991; Fox, Haller, and Getsinger 1992, 1993). Results from these studies indicated that aquatic herbicide dissipation can be predicted by monitoring dye movement and concentration and by collecting only enough samples to establish the relationship between dye and herbicide values. However, correlations in dispersal patterns must first be established for each herbicide.

The Pend Oreille River, a regulated system located in northeastern Washington, is a major tributary of the Columbia River and has been infested with milfoil for over a decade (Rawson 1985, 1987; WATER Environmental Sciences 1986, 1987). Various attempts at milfoil control in the past have included herbicides such as 2,4-D (2,4-dichlorophenoxy acetic acid) and fluridone {1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl-4(1H)-pyridinone} and have been only moderately successful (Durando-Boehm 1983; WATER Environmental Sciences, Inc. 1986, 1987). Recent water-exchange studies conducted in selected sites on this river suggested that triclopyr contact times sufficient to provide acceptable levels of milfoil control could be achieved in these areas (Getsinger, Sisneros, and Turner 1993). Moreover, the presence of a multispecies submersed plant community (albeit dominated by milfoil) provided the opportunity to assess the selective properties of this herbicide under field conditions.

Objectives

A large-scale study was designed with the following objectives: (a) to determine the efficacy of triclopyr on milfoil and associated native plants when applied to cove and shoreline areas in a regulated river; (b) to determine water dissipation of triclopyr from the treated areas; (c) to establish the relationship between triclopyr and rhodamine WT dye dissipation under field conditions; (d) to verify laboratory-derived triclopyr dosage rate relationships for controlling milfoil; and (e) to provide guidance for using triclopyr applications as a technique for restoring native submersed plant communities previously dominated by milfoil.

2 Materials and Methods

Study Site

The study was conducted along a stretch of the Pend Oreille River (48° N, 117° W) between Albeni Falls and Box Canyon dams (Figure 1). River levels in this region are controlled by water inflowing from Albeni Falls Dam on Lake Pend Oreille, Idaho, and outflowing at Box Canyon and Boundary Dams in Washington and at two dams in British Columbia, Canada. River discharge measured at the Albeni Falls Dam averages 565 cms per year, with a maximum of ~1,500 cms in May or June and a minimum of ~165 cms in January and February or in August and September.

In mid-August 1991, milfoil-dominated submersed plant stands, one in the main stem of the river approximately 0.5 km upstream from River Mile (RM) Marker 61 and one in a protected cove approximately 0.3 km downstream from RM Marker 48, were selected for the study. In shallow areas of these stands (< 1 m deep), entangled shoots of milfoil covered the surface of the water forming a dense mat. In deeper regions of the stands, milfoil shoots were 15 to 20 cm below the surface of the water, forming a submersed canopy. Although milfoil was the dominant species in the plots, an understory comprised of 13 other submersed plants (one exotic and 12 natives) was encountered during the pretreatment evaluation (Table 1). The other exotic plant was the monocotyledonous (monocot) species curlyleaf pondweed (*Potamogeton crispus* L.). Principal natives included the monocots elodea (*Elodea canadensis* L.), flatstem pondweed (*Potamogeton zosteriformis* Fernald), and water stargrass (*Heteranthera dubia* (Jacq.) MacM.), and the dicotyledonous (dicot) species coontail (*Ceratophyllum demersum* L.) and white watercrowfoot (*Ranunculus longirostris* Godron).

The submersed plant communities selected for the study represented problematic milfoil-dominated stands that might be targeted for operational herbicide treatments. However, water-exchange characteristics of the two sites were dissimilar ($t_{1/2} < 20$ hr in the river and > 50 hr in the cove), thus providing the opportunity to compare the efficacy, selectivity, and dissipation of triclopyr under different flow and concentration and exposure time conditions.

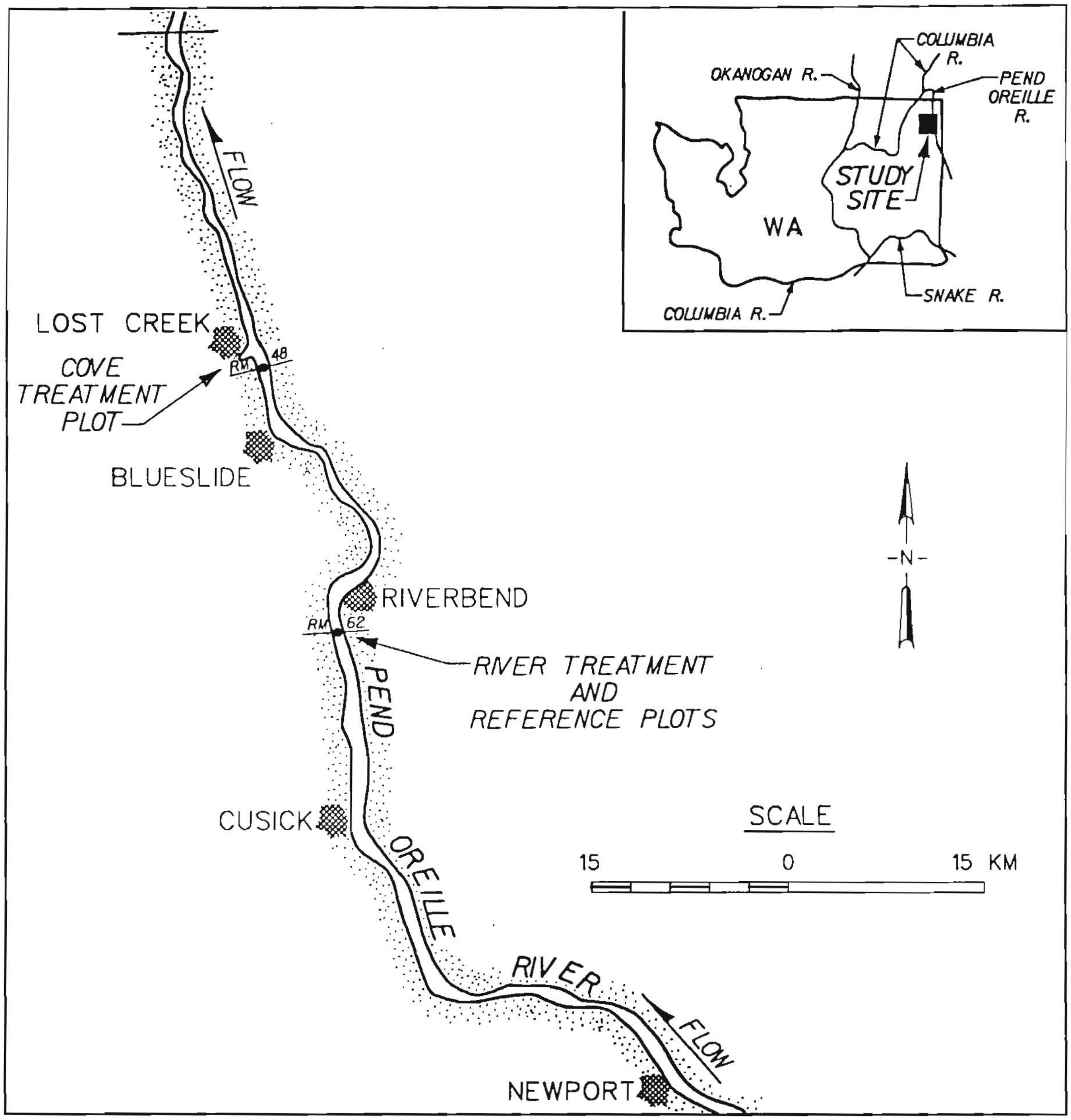

Figure 1. Location of study site for triclopyr herbicide treatment on Pend Oreille River, Washington

Study Plots

Two river plots were established in submersed plant stands in the River Bend area near RM 61. A 6-ha river treatment (RT) plot was located 250 m downstream from the 2-ha river reference (RR) plot (Figure 2). Both plots were situated in a parallel arm of the main river channel, bounded on the west by a narrow island, and bordered on the north, south, and east sides by submersed plant stands or open water. These plots ranged in depth from 0.3 m

Table 1
Frequency of Plant Species in Study Plots in Pend Oreille River, Washington (1991-93), for All Transects per Plot and Year

	RR[1] Plot			RT[2] Plot			CT[3] Plot		
	Year								
Species	91	92	93	91	92	93	91	92	93
Coontail (DN) *Ceratophyllum demersum* L.	2	5	10	9	28	28	20	59	61
Elodea (MN) *Elodea canadensis* L.	21	9	20	7	50	33	28	93	79
Water stargrass (MN) *Heteranthera dubia* (Jacq.) MacM.	3	1	8	8	8	18	0	1	3
Northern watermilfoil (DN) *Myriophyllum sibiricum* Komarov	0	0	0	7	<1	0	0	0	0
Eurasian watermilfoil (DE) *M. spicatum* L.	100	98	95	94	56	78	89	25	59
Whorled watermilfoil (DN) *M. verticillatum* L.	0	0	1	<1	<1	5	0	0	0
Curlyleaf pondweed (ME) *Potamogeton crispus* L.	17	27	87	4	27	12	7	15	30
American pondweed (MN) *P. nodosus* Poiret	8	5	5	<1	<1	0	0	0	0
Blunt-leaf pondweed (MN) *P. obtusifolius* Mert. & Koch	0	0	<1	0	39	0	6	7	<1
Sago pondweed (MN) *P. pectinatus* L.	12	0	8	5	9	7	11	1	2
Redhead grass (MN) *P. perfoliatus* L.	2	0	<1	2	6	3	<1	1	1
Whitestem pondweed (MN) *P. praelongus* Wulfen	0	0	0	0	0	<1	0	0	<1
Small pondweed (MN) *P. pusillus* L.	0	0	<1	0	0	32	0	0	1
Vasey's pondweed (MN) *P. vaseyii* Robbins	0	0	0	10	0	<1	8	1	0
Flatstem pondweed (MN) *P. zosteriformis* Fernald	15	11	16	28	64	77	40	36	53
White watercrowfoot (DN) *Ranunculus longirostris* Godron	5	8	21	12	50	16	3	19	1

Note: M = monocot; D = dicot; N = native; and E = exotic.
[1] River reference plot.
[2] River treatment plot.
[3] Cove treatment plot.

(west side) to 2.5 m (east side), with a mean depth ($\pm$ SE) of 1.62 $\pm$ 0.07 m (n = 60). Six water sampling stations (1 through 6) were established inside the RT plot representing three flow zones: Stations 1 and 2, upstream zone; Stations 3 and 4, midstream zone; and Stations 5 and 6, downstream zone. One water sampling station was established in the center of the RR plot.

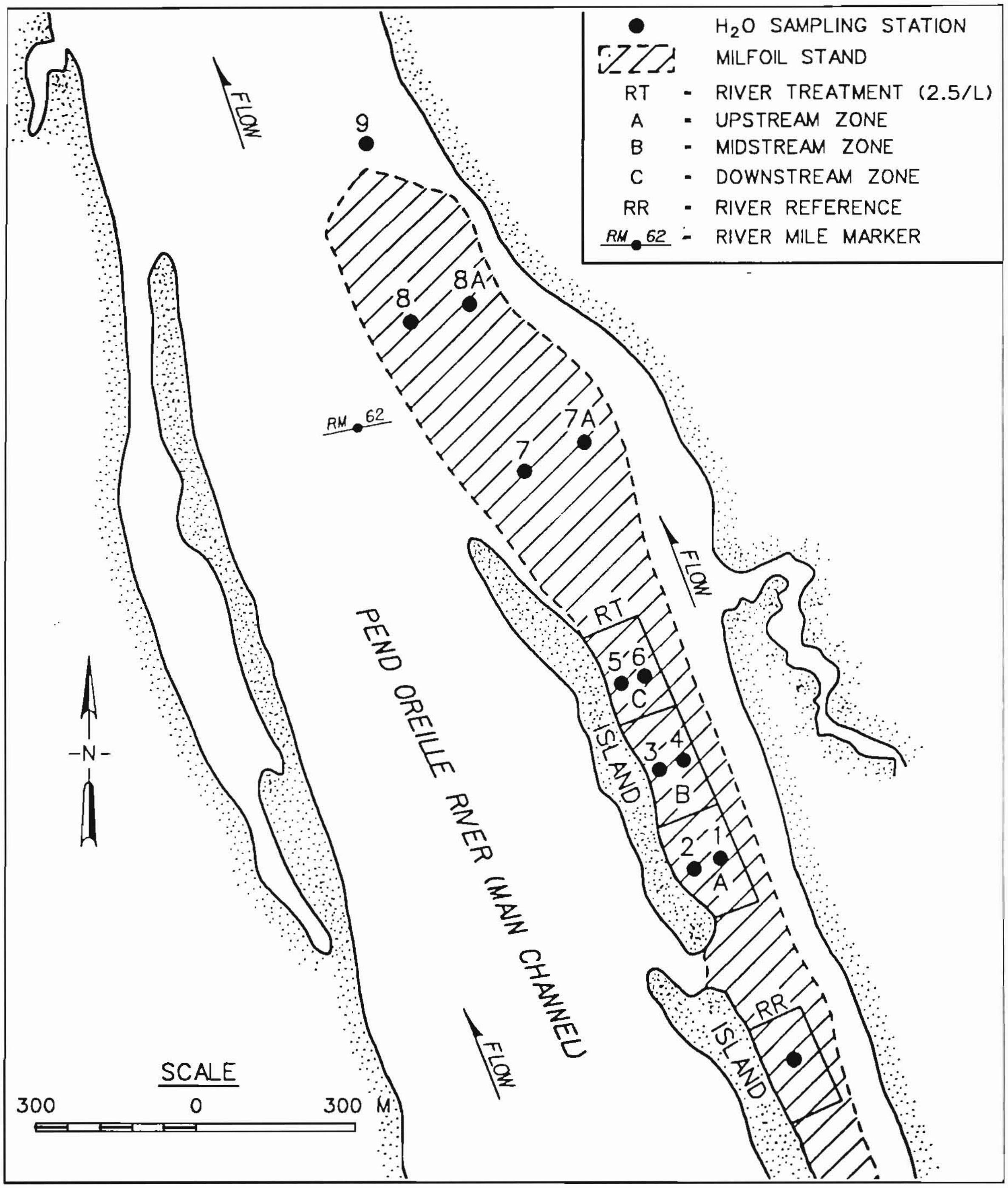

Figure 2. River treatment (RT) and river reference (RR) plots and water sampling stations on Pend Oreille River, Washington

A 4-ha cove treatment (CT) plot was established in the submersed plant stand in Lost Creek Cove, located on the west shore of the river (Figure 3), approximately 21 km downstream from the river plots. Water depth in this plot ranged from 0.75 to 2.8 m, with a mean depth of 1.72 ± 0.04 m (n = 80). Three water sampling stations were established inside the CT plot, with

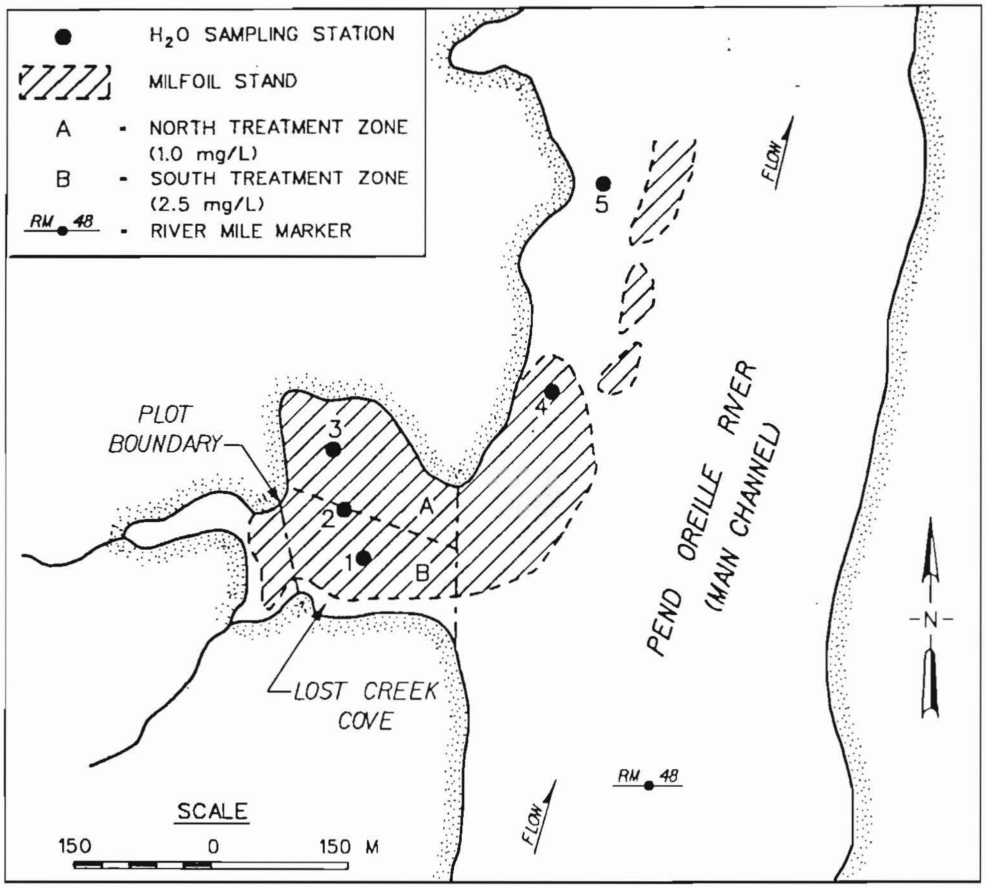

Figure 3. Cove treatment (CT) plot and water sampling stations on Pend Oreille River, Washington

Station 1 located in the southern half of the plot, Station 2 in the center of the plot, and Station 3 in the northern half of the plot.

In addition, several water sampling stations were established outside and downstream of the two treated plots. The locations of each of these stations was based on the presence and quantity of a fluorescent dye applied concurrently with the herbicide (described below). Downstream stations were used to monitor movement of triclopyr out of the treated plots. This dissipation information can be used to establish any label restrictions for potable water tolerance (PWT) set-back distances in relation to triclopyr treatment sites and water intake structures. PWT set-back distances ranging between 400 m (0.25 miles) and 800 m (0.50 miles) are currently being considered for the triclopyr aquatic label. In the RT application, five water sampling stations were established downstream of the northern edge of the plot (Figure 2): Stations 7 and 7a, 300 m downstream; Stations 8 and 8a, 675 m downstream; and Station 9, 975 m downstream. In the CT application, two water sampling stations (4 and 5) were established at 150 and 395 m, respectively, downstream of the plot (Figure 3).

Herbicide Application

On 21 and 22 August 1991, the RT and CT plots, respectively, were treated with a liquid formulation of the herbicide Garlon 3A (31.8-percent triclopyr acid equivalent (ae)), Formulation Lot No. MM910321-37 (March 1991), using a conventional submersed application technique. The herbicide was injected 30 to 60 cm below the surface of the water using a pressurized diaphragm pump, fitted with a 208-ℓ (55-gal) holding tank and a manifold with six hoses (60-cm length) attached at 30-cm intervals. Tee jet #6 nozzles affixed to the ends of the hoses provided an average nozzle output of 2.3 ℓ/min at a pressure of 206 kilopascals (30 psi). The manifold was stern-mounted on an airboat, allowing the nozzles to penetrate the water column to a depth of 20 to 30 cm and providing a 2.4-m application swath width.

The RT plot was treated as four subplots (1.5 ha each), with the application beginning in the downstream subplot (0800 hr) and, once completed, proceeding upstream until the entire 6-ha plot was treated (1130 hr). While treating each subplot, the airboat was cruising at approximately 5 km/hr in an alternating east-west pattern that provided an even areal distribution of the herbicide throughout the plot. This subsurface application technique was designed to achieve a nominal concentration of 2.5 mg/ℓ triclopyr in the plot, which is the maximum triclopyr application rate permitted under the EUP label for milfoil control. The maximum application rate was selected for this plot based on results of previous studies that showed that water-exchange half-lives in this plot were 6 to 17 hr (Getsinger, Sisneros, and Turner 1993) and on results of laboratory-derived concentration and exposure-time evaluations that demonstrated that triclopyr efficacy on milfoil decreased dramatically when contact time was < 10 hr (Figure 4). At time of treatment, skies were clear, water column temperature was essentially isothermal (~25 °C), and winds ranged from calm to 2 km/hr from the east.

The CT plot was treated as two subplots of 2 ha each, with the northern subplot treated first (0950 to 1020 hr), at a nominal triclopyr application rate of 1.0 mg/ℓ, and the southern subplot receiving a nominal triclopyr application rate of 2.5 mg/ℓ at 1035 to 1135 hr. The nominal triclopyr application rate for the entire plot was 1.75 mg/ℓ. During application, the airboat was cruising at approximately 5 km/hr in an alternating east-west pattern that provided an even areal distribution of the herbicide throughout both subplots. The split application rates selected for the CT plot were also based on results of previous water-exchange studies in this site (Getsinger, Sisneros, and Turner 1993) and laboratory-derived triclopyr concentration and exposure-time requirements (Figure 4). These field studies showed a water-exchange half-life of approximately 35 hr for the CT plot as a whole, but dye measurements at individual stations indicated that exchange rates in portions of the southern subplot were greater than in portions of the northern subplot; hence, the selection of a high triclopyr application rate for the southern subplot. At treatment time, skies were partly cloudy, water column temperature was essentially isothermal (~24 °C), and wind was southeast at approximately 10 km/hr.

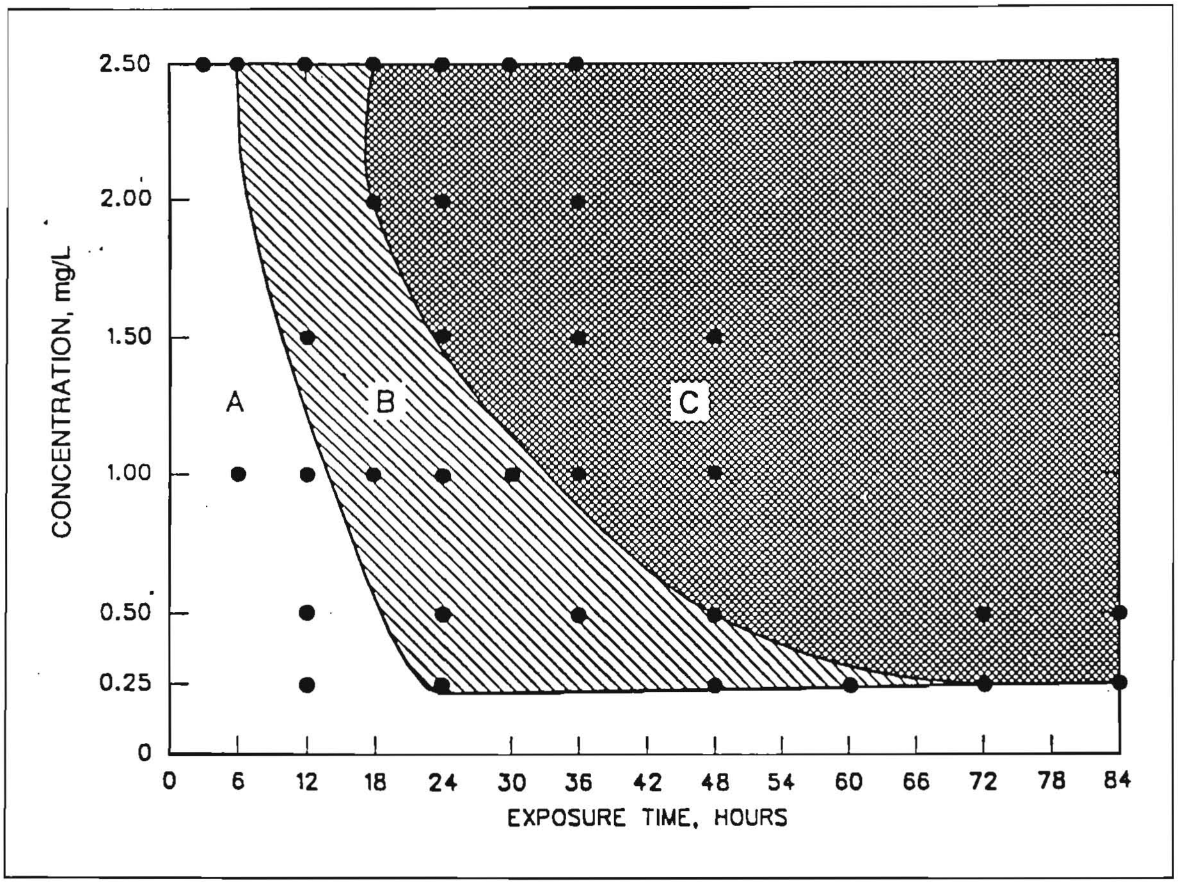

Figure 4. Summary figure of triclopyr concentration/exposure time (CET) relationships for control of Eurasian watermilfoil (Zone C represents CET combinations that provided >85-percent milfoil control; Zone B represents combinations that gave between 70- and 85-percent control; and Zone A represents combinations that gave <70-percent milfoil control)

Dye Application

The inert fluorescent dye rhodamine WT was applied immediately following the triclopyr treatment in the RT plot using the same herbicide application technique to provide a nominal aqueous concentration of 10 $\mu g/\ell$. The dye was tank-mixed with the herbicide formulation to provide a nominal aqueous concentration of 4 and 10 $\mu g/\ell$ in the north and south portions, respectively, of the CT plot. The different dye target rates in the CT plot reflected the two triclopyr target application rates and ensured that the empirical relationship between triclopyr and dye quantities would remain consistent throughout the plot.

Rhodamine WT was used to characterize water exchange and movement during the study and to aid in the selection of water sampling stations outside of the treated areas. This dye (USEPA-approved for use in potable water at concentrations up to 100 $\mu g/\ell$) can be quantified in situ and is routinely used for water tracing and exchange studies (Johnson 1984; Kilpatrick and Wilson 1989). The dye has also been used to successfully simulate aqueous dissipation of several herbicides used for aquatic plant control (Fox, Haller, and Shilling 1991; Fox, Haller, Getsinger 1992, 1993). Dye concentrations were measured at 25-cm-depth intervals at each sampling station using Turner Designs Model 10-005 field fluorometers equipped with high-volume continuous flow cuvette systems. Water was circulated through the fluorometers with submersible pumps attached to the end of weighted opaque hoses. All dye values were temperature-corrected according to Smart and Laidlaw (1977) using Cole-Parmer thermistors attached to the exhaust hoses of the fluorometers.

Water Sampling Regime and Analyses

Water samples were collected for triclopyr residues concurrently with dye measurements, using fluorometers and pump systems described above, from each station inside the plots at one-third total depth below the surface (upper sample) and one-third total depth above the bottom (lower sample). Water was collected at a depth of 1 m at the RT plot downstream stations and at 0.5 and 0.75 m at the CT plot downstream stations. Water was pumped into 500-ml amber polyethylene bottles, stored on ice in the field, and frozen when returned to the field station, within 6 hr. Dye levels were recorded and triclopyr water samples were collected from all RT plot stations at pretreatment, 1, 5, 8, and 12 hr after treatment (HAT) and at 1, 2, 3, and 7 days after treatment (DAT). Dye levels were recorded and triclopyr water samples were collected from all CT plot stations at pretreatment, 1.5, and 8 HAT and at 1, 2, 3, and 7 DAT. Additional triclopyr water samples were collected from all stations at 14 and 21 DAT. In the untreated upstream RR plot, triclopyr water samples were collected at middepth at pretreatment and 8 and 24 HAT. Dye measurements were recorded on the downstream edge and at selected locations in the RR plot from 1 HAT through 7 DAT.

Water samples were analyzed for triclopyr residues (detection limit < 0.01 mg/ℓ) using a high performance liquid chromatography method (DOW Chemical, Midland, MI) by the Tennessee Valley Authority Water Chemistry Laboratory, Chattanooga, TN. Mean percent recovery of all triclopyr-spiked samples ($n = 38$) was 98.12 $\pm$ 0.69 SE.

Dye and triclopyr data were subjected to statistical analysis to obtain dissipation curves using Statgraphics 3.0 (Statistical Graphics Corporation). Mean dye and triclopyr values were regressed against time using the exponential model:

$$y = \exp(a + bt)$$

where

y = chemical concentration at time t

a = intercept of regression line

b = slope of regression line (dilution factor)

Dissipation half-lives were then calculated according to:

$$t_{1/2} = \frac{\text{natural logarithm of } 0.5}{\text{slope of regression line}}$$

Photodegradation Assessment

Since photolysis is a major degradation pathway of triclopyr in aqueous systems (McCall and Gavit 1986; Woodburn et al. 1993), light intensity at 400 to 700 nm was measured in the treatment plots using a Li-Cor Model 1000 submersible photometer. Light intensity on the day of triclopyr application, 0900 to 1400 hr, was recorded through the water column in open-water areas adjacent to the plots, and in milfoil stands with surface and near-surface canopies, to a 30-cm depth. To provide an estimate of triclopyr photodegradation rates, an enclosure designed to preclude triclopyr dissipation via water exchange was anchored near the center of each treated plot. Enclosures consisted of translucent polyethylene bags (32 by 35 cm wide by 101 cm deep; $v = 113\ \ell$) with the opening of the bag attached at the surface to floating wooden/polyvinyl chloride (PVC) frames. Immediately following chemical applications to the plots, these enclosures were filled with treated water. Water samples were collected from middepth at 0, 5, 8, 12, 24, 48, 72, and 168 HAT from the RT plot enclosure and at 0, 8, 24, 48, 72, and 168 HAT from the CT plot enclosure. Samples were stored and analyzed for triclopyr residues as described earlier. Light intensity was measured at 1400 hr from the surface to a depth of 30 cm within each enclosure.

River Discharge and Flow Rates

River discharge, as measured from the Albeni Falls Dam, ranged from 360 to 405 cms on the triclopyr application dates. River discharge slowly declined to a level of 245 cms by 4 DAT and stabilized to a level of 170 cms by 7 DAT. Flow rates were measured using a Montedora-Whitney electronic flow meter in the open channel adjacent to the plant stands and ranged from 2 to 3 cm/sec. Flow rates were generally below the detection limits of the meter (<0.1 cm/sec) 1 to 2 m inside the plant stands.

Plant Biomass

At each plot, four 100-m-long transects were established at equally spaced intervals (40-m, RR plot; 75-m, CT plot; 120-m, RT plot) in an east to west direction to quantify the amount of submersed vegetation (Figures 5 and 6). At each transect, three biomass samples were collected by a SCUBA diver from stratified-random locations using a 0.1-m^2 quadrat (Madsen 1993), for a total of 12 biomass samples per plot. Samples were sorted to species, separated into roots and shoots, and dried at 50 °C. Biomass samples were collected pretreatment (August 18-20, 1991) and 4 weeks (September 18-20, 1991), 1 year (August 10-14, 1992), and 2 years (August 16-20, 1993) after treatment. Biomass levels between years at given plots were compared statistically using a one-way analysis of variance (ANOVA), with significant differences between means calculated using a Bonferroni test at the $p = 0.05$ level.

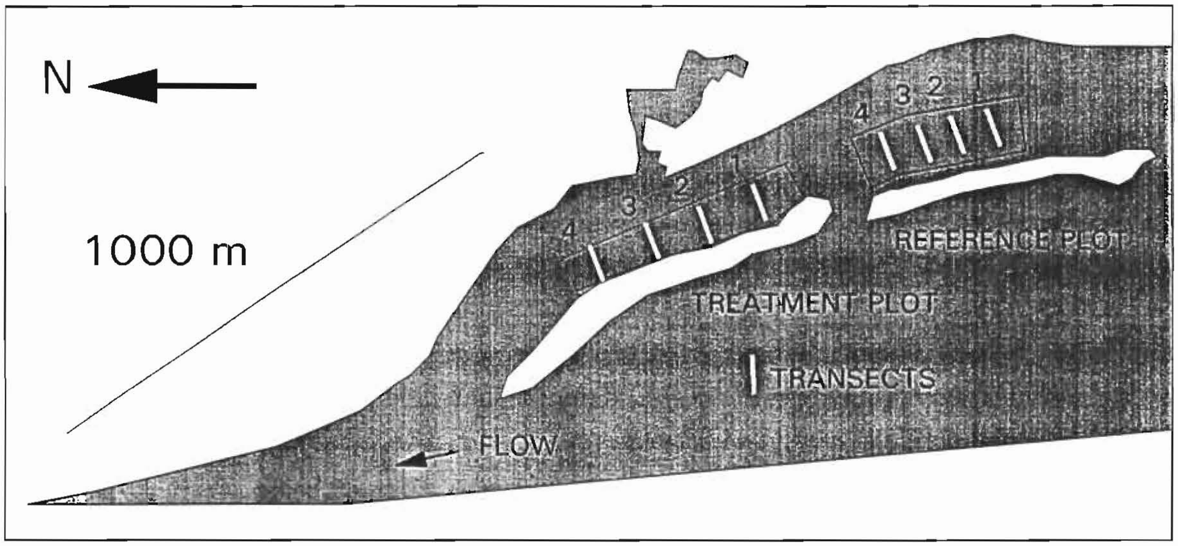

Figure 5. Location of plant biomass and species diversity transects in river treatment (RT) and river reference (RR) plots, Pend Oreille River, Washington

Plant Diversity

Transects were also used to quantify the distribution and diversity of aquatic plants. Each 100-m transect was divided into 1-m intervals, and species present under each interval were recorded by a diver (Madsen et al. 1994). Transects were examined concurrently with biomass collection at pretreatment and 1 and 2 years after treatment. Frequency of species or community classes (i.e., native or exotic monocots or dicots) were compared for all transects at a given plot between years using Chi-square analyses of two-by-two comparisons between means of actual number of transect intervals with and without that species or community class. Average number of species or species classes per interval were compared for all transects at a given plot

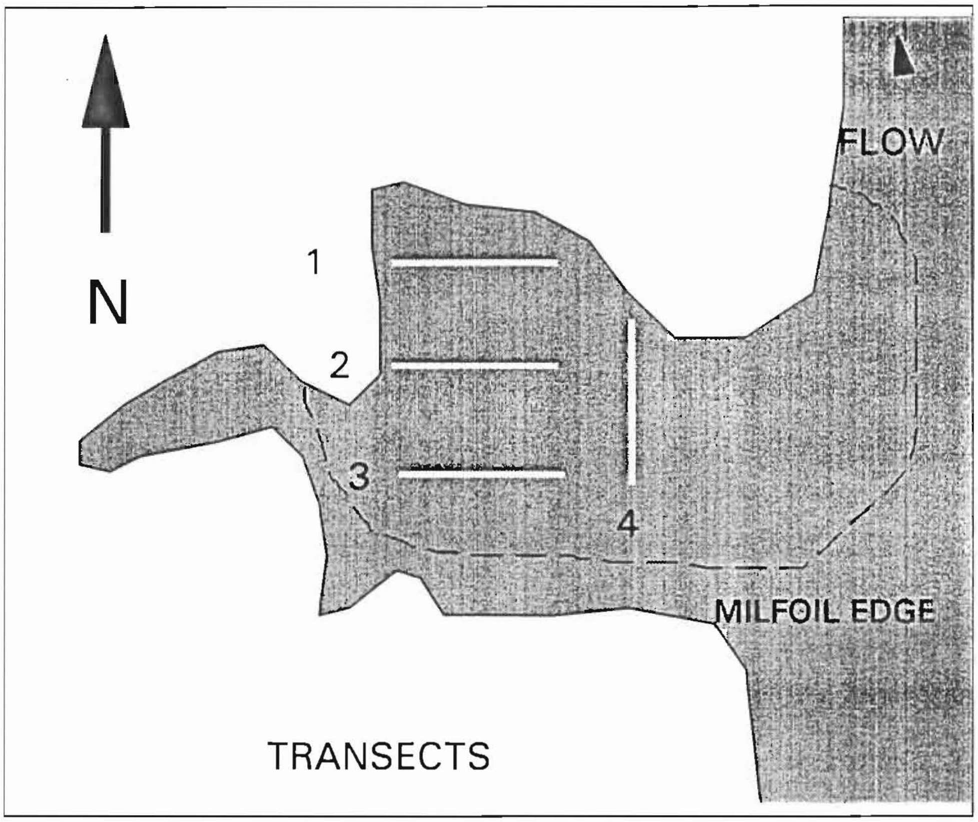

Figure 6. Location of plant biomass and species diversity transects in cove treatment (CT) plot, Pend Oreille River, Washington

between years using a one-way ANOVA, with significant differences between means calculated using a Bonferroni test at the $p = 0.05$ level.

3 Results and Discussion

Herbicide and Dye Dissipation

Inside river treatment plot

At 1 HAT, the whole-plot aqueous triclopyr residue (mean ± SE of all stations, all depths) was 4.59 ± 1.46 mg/ℓ (Table 2). This greater than predicted whole-plot triclopyr concentration was primarily caused by high residue levels of 14 mg/ℓ found at Station 2 (Table 3), which was located in a shallow area (z = 0.5 m) of the plot. Elevated herbicide residues are not uncommon in site-specific regions of a treatment area immediately following a submersed application, which typically occurs in the upper levels of the water column. In addition, water column mixing of herbicides can be inhibited by factors such as linear flow, thermal stratification, and wind-driven circulation patterns (Fox, Haller, and Getsinger 1991; Getsinger, Fox, and Haller 1992). Although measured triclopyr residues were initially greater than the nominal application rate, concentrations are well below acute and chronic toxicity levels established for nontarget aquatic organisms and are present for only short periods of time. Conversely, some locations within the treated area received below the intended dose of herbicide in the first few hours following application. If data from the shallow sampling station are excluded, the whole-plot triclopyr concentration was 2.71 ± 0.88 mg/ℓ, very near to the nominal application rate of 2.5 mg/ℓ.

Whole-plot triclopyr concentrations remained ≥2 mg/ℓ through 12 HAT and were >1 mg/ℓ at 1 DAT. Based on laboratory-derived concentration and exposure-time relationships, a triclopyr dose of ≥1 mg/ℓ for 24 hr should provide up to 85-percent milfoil control (Figure 4), with some regrowth potential likely by 5 weeks posttreatment (Netherland and Getsinger 1992). Although the whole-plot aqueous triclopyr value was still relatively high at 1 DAT (1.27 ± 0.43 mg/ℓ), residues were below the proposed PWT level of 0.5 mg/ℓ by 2 DAT, when herbicide concentrations were measured at 0.27 ± 0.13 mg/ℓ. By 3 DAT, triclopyr concentration in the plot was 0.17 ± 0.1 mg/ℓ and was near or below detection (<0.01 mg/ℓ) in the upstream (Stations 1-2) and midstream (Stations 3-4) zones. Triclopyr concentrations were below detection in all sampling zones by 7 DAT.

Table 2
Mean Triclopyr Residues (mg/ℓ ± SE) in Water Column Inside Treatment Plots Following Garlon 3A Applications, Pend Oreille River, Washington, August 1991

	Hours After Treatment					Days After Treatment					
Station	1	1.5	5	8	12	1	2	3	7	14	21
RT[1]											
1 - 6	4.59 ± 1.46	NS[2]	2.72 ± 0.92	2.00 ± 0.48	2.23 ± 0.52	1.27 ± 0.43	0.27 ± 0.13	0.17 ± 0.10	BD[3]	NS	NS
1 - 2	8.15 ± 3.44	NS	4.69 ± 2.43	2.53 ± 0.75	1.98 ± 1.19	0.02 ± 0.01	BD	BD	BD	NS	NS
3 - 4	1.86 ± 0.92	NS	1.18 ± 0.48	1.21 ± 0.32	2.08 ± 0.55	1.66 ± 0.57	0.06 ± 0.02	BD	BD	NS	NS
5 - 6	3.75 ± 1.97	NS	2.31 ± 0.98	2.27 ± 1.24	2.63 ± 1.09	2.14 ± 0.96	0.81 ± 0.22	0.41 ± 0.28	BD	NS	NS
CT[4]											
1 - 3	NS	2.32 ± 0.56	NS	2.03 ± 0.41	NS	0.78 ± 0.22	0.68 ± 0.23	0.47 ± 0.16	0.22 ± 0.03	BD	BD
1	NS	1.95 ± 0.05	NS	2.55 ± 0.05	NS	0.12 ± 0.09	0.07 ± 0.06	0.06 ± 0.05	0.12 ± 0.06	BD	BD
2	NS	3.55 ± 0.25	NS	2.75 ± 0.05	NS	1.03 ± 0.17	1.25 ± 0.25	0.45 ± 0.16	0.29 ± 0.02	BD	BD
3	NS	0.90 ± 0.30	NS	0.80 ± 0.50	NS	1.20 ± 0.00	0.72 ± 0.25	0.89 ± 0.08	0.25 ± 0.01	BD	BD

[1] River treatment; nominal triclopyr concentration = 2.5 mg/ℓ.
[2] No sample collected.
[3] Below detection (<0.01 mg/ℓ).
[4] Cove treatment; nominal triclopyr concentration = 1.75 mg/ℓ.

Table 3
Triclopyr (mg/ℓ) and Rhodamine WT (µg/ℓ) Data for River Treatment Plot (inside and downstream), Pend Oreille River, Washington

Station	Depth, cm	Time, hr							
		1	5	8	12	24	48	72	168
1	60	3.90 (18.3)	0.40 (2.9)	0.71 (1.7)	0.13 (0.2)	<0.01 (0.0)	<0.01 (0.0)	-- (0.0)	-- (0.0)
	140	0.72 (0.3)	0.55 (4.8)	1.90 (2.8)	0.11 (0.1)	<0.01 (0.0)	<0.01 (0.0)	-- (0.0)	-- (0.0)
2	15	14.00 (27.2)	8.70 (25.8)	3.50 (19)	5.10 (8.4)	0.04 (0.0)	<10 (0.04)	-- (0.0)	-- (0.1)
	35	14.00 (18.4)	9.10 (24.8)	4.00 (17.3)	2.60 (4.9)	0.02 (0.0)	<10 (0.07)	-- (0.0)	-- (0.1)
3	50	4.00 (9.4)	1.50 (14.7)	1.90 (13.9)	3.20 (20.3)	2.60 (10.1)	0.11 (0.6)	0.06 (0.2)	<0.01
	100	0.15 (0.2)	0.33 (2.3)	0.70 (2.2)	2.70 (14.2)	2.70 (8.0)	0.87 (0.6)	0.28 (0.7)	<0.01
4	50	2.80 (16.5)	2.40 (13.6)	1.60 (8.7)	0.74 (2.0)	0.71 (1.6)	0.02 (0.0)	<0.01	-- (0.0)
	100	0.51 (3.1)	0.51 (3.9)	0.63 (3.7)	1.70 (7.1)	0.65 (1.4)	0.02 (0.05)	<0.01	-- (0.0)
5	50	9.20 (4.2)	4.90 (6.5)	6.00 (16.2)	5.30 (22.3)	3.80 (15.5)	1.20 (4.6)	0.40 (1.4)	<0.01
	100	4.00 (1.4)	0.54 (1.1)	0.98 (3.7)	3.40 (9.0)	3.80 (15.9)	1.20 (4.5)	1.20 (3.8)	<0.01
6	50	1.50 (7.6)	2.70 (6.7)	1.00 (4.8)	1.40 (7.7)	0.55 (2.1)	0.46 (1.1)	0.01 (0.0)	<0.01
	100	0.32 (0.4)	1.10 (5.6)	1.10 (4.2)	0.41 (3.8)	0.41 (1.3)	0.39 (1.0)	0.01 (0.0)	<0.01
7	100	<0.01 (0.0)	0.23 (0.9)	0.55 (0.8)	0.97 (2.0)	1.20 (2.2)	0.57 (1.9)	0.57 (1.4)	0.06 (0.3)
		-- (0.1)							
7a	100	0.10 (0.1)	0.21 (0.3)	0.42 (2.1)	0.03 (0.1)	0.02 (0.0)	0.02 (0.0)	-- (0.0)	-- (0.0)
8	100		<0.01 (0.0)	0.07 (0.04)	0.13 (0.2)	0.47 (1.9)	0.02 (0.1)	0.15 (0.3)	<0.01
8a	100			0.12 (0.6)	0.09 (0.5)	<0.01 (0.0)	<0.01 (0.0)	-- (0.0)	-- (0.0)
9	100			0.02 (0.0)	<0.01 (0.0)		-- (0.0)	-- (0.0)	-- (0.0)

Note: Rhodamine WT values in parentheses.

Whole-plot aqueous half-life of triclopyr, all depths (Table 4, Figure 7), was calculated to be 19.4 hr (r^2 = 93.9), which was very similar to the calculated half-life of the dye (20.1 hr, r^2 = 96.5). Aqueous half-lives of triclopyr and dye for the upstream, midstream, and downstream zones of the plot (all depths) and upper and lower depths of the water column (whole plot and all treatment zones) are presented in Table 4. In addition, whole-plot aqueous half-lives of triclopyr and dye for the upper and lower depths are presented in Figures 8 and 9. In most cases, triclopyr and dye dissipations match up reasonably well. Correlation of dye and triclopyr concentrations was based on data presented in Table 3 and was significant ($p < 0.001$), with an r^2 value of 0.80 (Figure 10).

When analyzed by flow zones (all depths), actual mean triclopyr concentrations and calculated half-lives (Tables 2 and 4) showed that the minimum herbicide contact time occurred in the upstream zone ($t_{1/2}$ = 2.7 hr, near detection limit by 1 DAT). Triclopyr exposure times in the midstream ($t_{1/2}$ = 15.9 hr, near detection limit by 3 DAT) and downstream ($t_{1/2}$ = 24 hr, near detection limit by 7 DAT) zones were much longer. The relatively constant gravity flow in the river would be expected to produce this type of progressive herbicide dissipation pattern through the zones of the plot. Also, a water passage connecting the main river channel with the southwest corner of the plot may have contributed to the accelerated dilution of the herbicide in the upstream zone. The extended triclopyr contact times in the midstream and downstream zones would be expected to provide a greater degree of milfoil control in those regions of the plot. Aqueous triclopyr dissipation varied between the upper ($t_{1/2}$ = 14.9 hr) and lower ($t_{1/2}$ = 26.4 hr) water sampling locations in the plot (Table 4, Figures 8 and 9), suggesting that laminar flow patterns (and perhaps triclopyr degradation rates) were dissimilar in these different layers of the water column.

Downstream river treatment plot

Aqueous triclopyr residues peaked at Stations 7 and 7a, located 300 m downstream from the northern edge of the RT plot, at 1.20 mg/ℓ (1 DAT) and 0.42 mg/ℓ (8 HAT), respectively (Table 5). Based on these residues, some off-target injury and/or milfoil control was expected downstream of the RT plot. At Stations 8 and 8a, located 675 m downstream from the plot, triclopyr residues peaked at 0.47 mg/ℓ (1 DAT) and 0.12 mg/ℓ (8 HAT), respectively. Residues at the 975-m downstream station (Station 9) were near or below detection throughout the posttreatment sampling regime. These low downstream triclopyr concentrations indicate that the PWT level (0.5 mg/ℓ) set-back distances of 400 to 800 m (0.25 to 0.50 mile) being considered for the triclopyr aquatic label are appropriate for applications made along shorelines of slow-flowing rivers.

Table 4
Triclopyr and Dye Dissipation Data in Plots Treated with Garlon 3A and Rhodamine WT, Pend Oreille River, Washington, 1991

Plot	Station	Depth	n	r^2	LS	Half-life, hr
River	1 - 6	all	72 (70)	93.9 (96.5)	0.003 (<0.001)	19.4 (20.1)
	1 + 2	all	18 (18)	94.3 (88.6)	0.006 (0.017)	2.7 (1.6)
	3 + 4	all	26 (26)	68.6 (82.4)	0.021 (0.005)	15.9 (13.4)
	5 + 6	all	28 (28)	95.4 (52.3)	<0.001 (0.066)	24.0 (34.2)
	1 - 6	upper	37 (37)	98.4 (99.5)	<0.001 (<0.001)	14.9 (14.5)
	1 - 6	lower	37 (37)	84.7 (77.1)	0.003 (0.009)	26.4 (31.3)
	1 + 2	upper	9 (9)	92.7 (89.3)	0.008 (0.015)	2.9 (1.5)
	1 + 2	lower	9 (9)	95.1 (86.8)	0.004 (0.021)	2.5 (1.6)
	3 + 4	upper	13 (13)	89.5 (92.2)	0.001 (<0.001)	11.2 (10.3)
	3 + 4	lower	13 (13)	21.3 (22.9)	0.296 (0.101)	32.2 (22.9)
	5 + 6	upper	14 (14)	98.6 (76.2)	<0.001 (0.010)	16.0 (20.1)
	5 + 6	lower	14 (14)	38.9 (0.91)	0.134 (0.839)	55.4 (251.1)
Cove	1 - 3	all	33 (33)	87.6 (87.4)	0.006 (0.006)	52.7 (52.0)
	1 - 3	upper	15 (15)	83.7 (84.2)	0.010 (0.009)	47.9 (46.8)
	1 - 3	lower	18 (18)	89.1 (88.1)	0.004 (0.005)	57.3 (57.7)

Note: Values for dye dissipation are presented in parentheses.
n = sample number, LS = least significance.

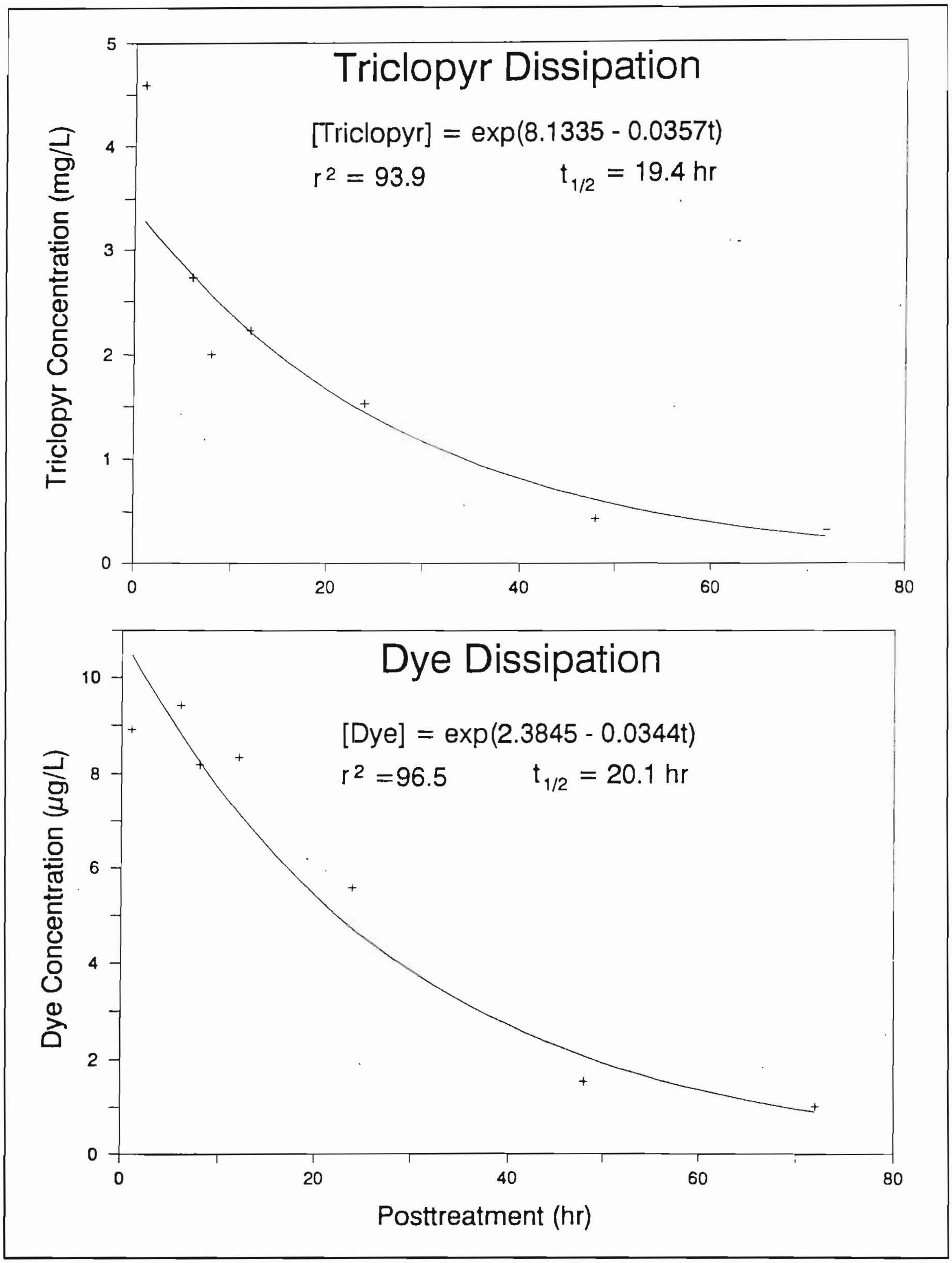

Figure 7. Dissipation of triclopyr and dye in river treatment (RT) plot following application of Garlon 3A and rhodamine WT, Pend Oreille River, Washington (Lines represent calculated dissipation curves using an exponential model, and symbols represent actual values)

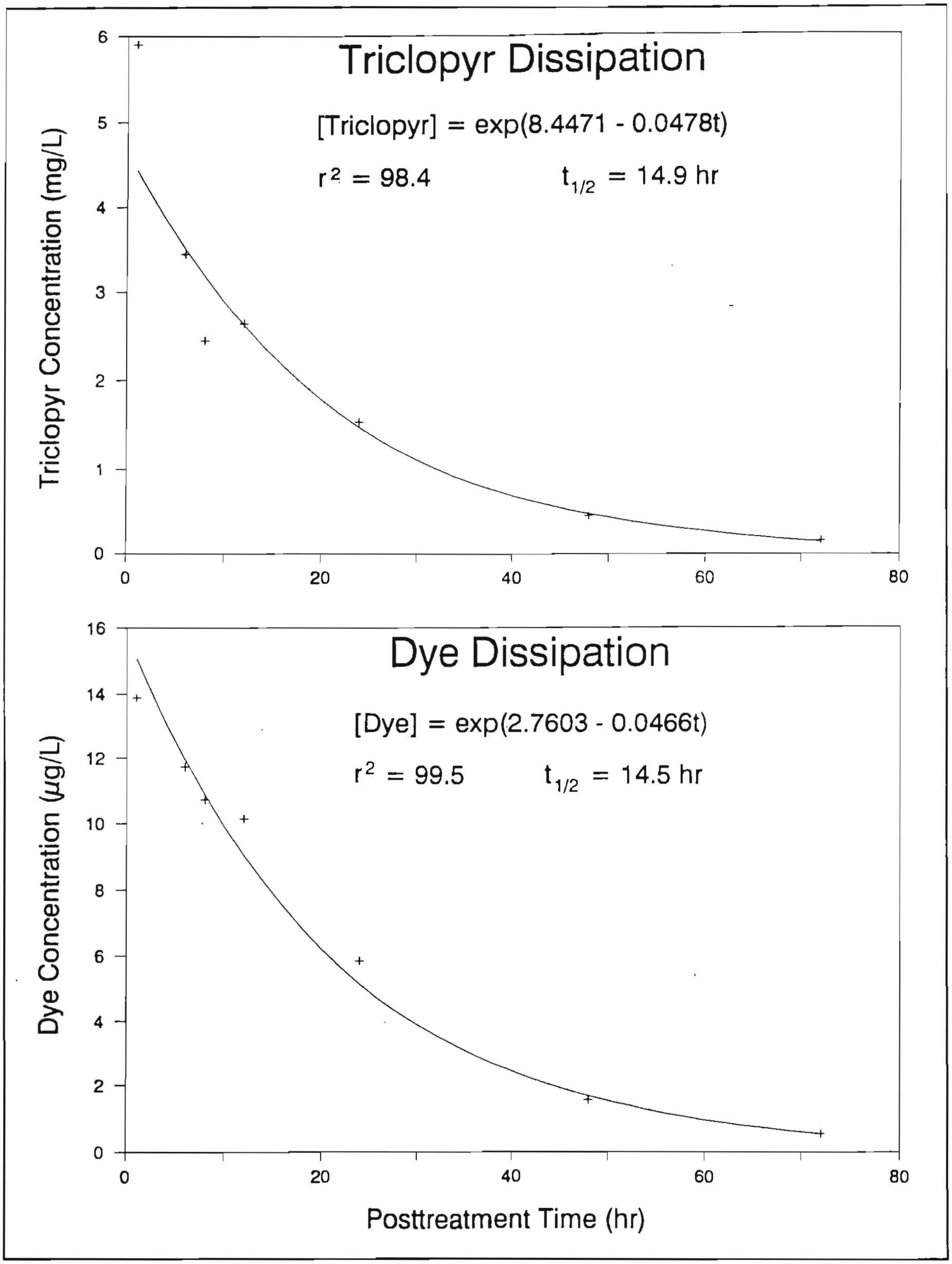

Figure 8. Dissipation of triclopyr and dye in upper portion of water column in river treatment (RT) plot following application of Garlon 3A and rhodamine WT, Pend Oreille River, Washington (Lines represent calculated dissipation curves using an exponential model, and symbols represent actual values)

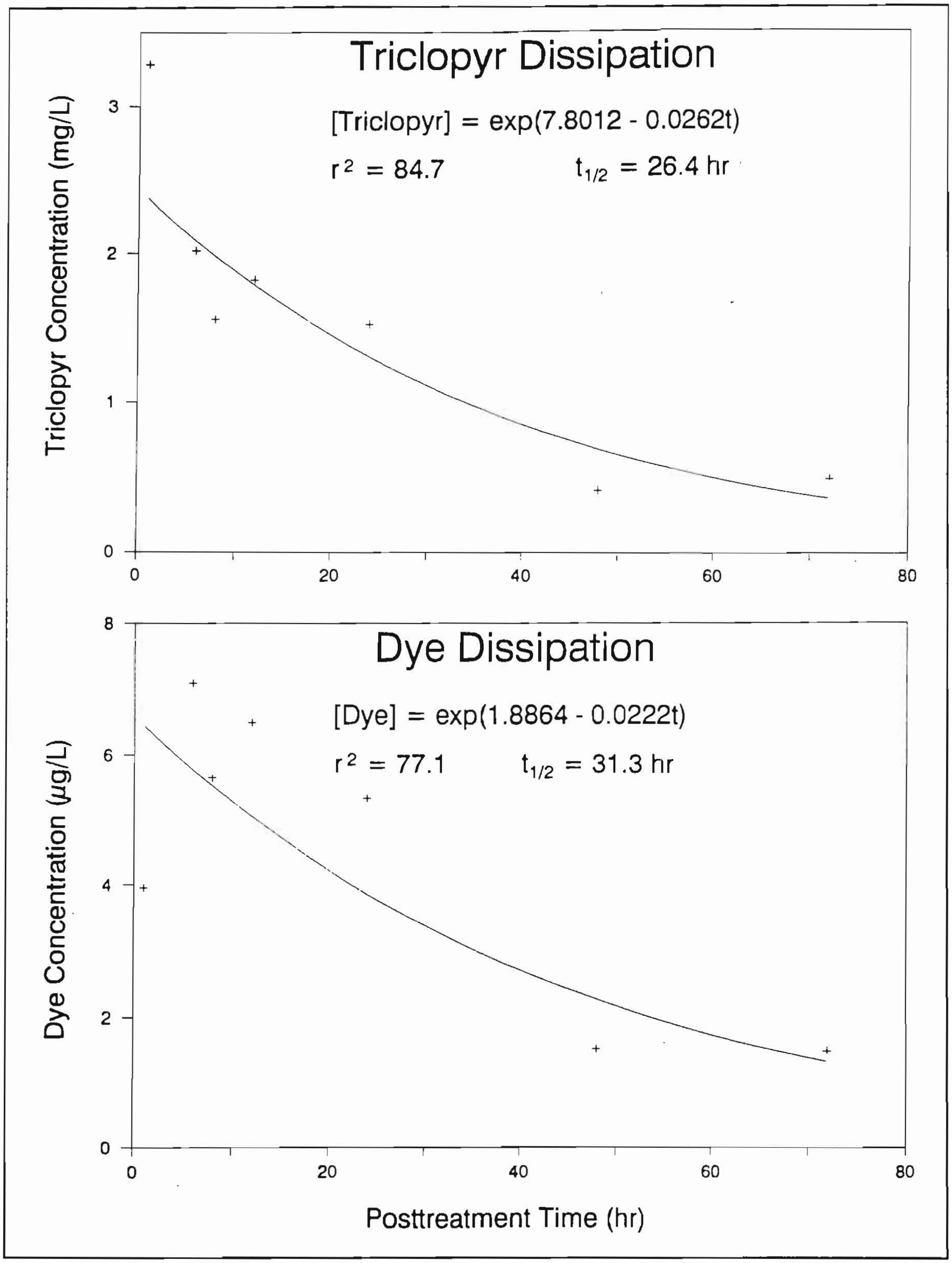

Figure 9. Dissipation of triclopyr and dye in lower portion of water column in river treatment (RT) plot following application of Garlon 3A and rhodamine WT, Pend Oreille River, Washington (Lines represent calculated dissipation curves using an exponential model, and symbols represent actual values)

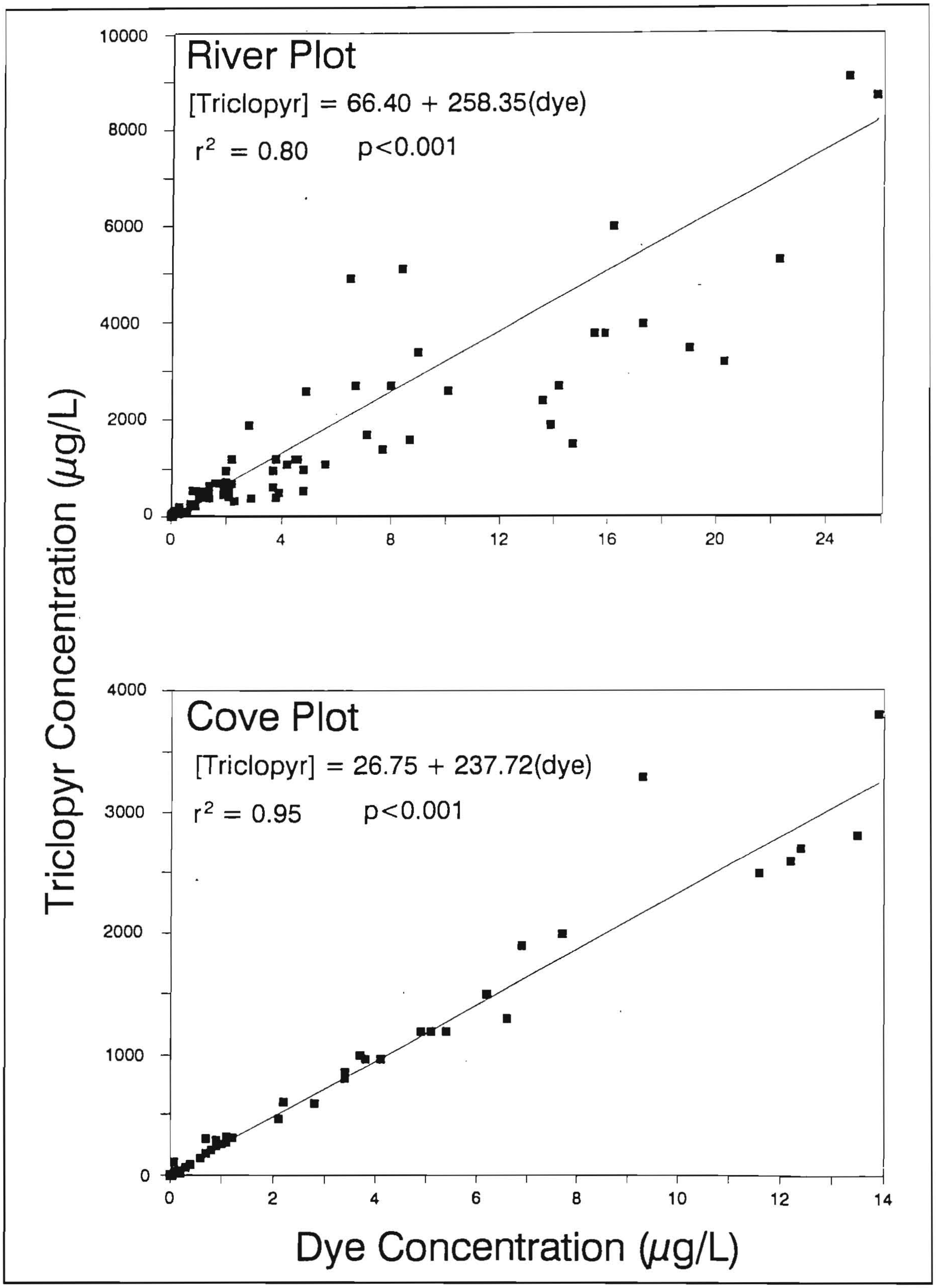

Figure 10. Correlations of dye and triclopyr following application of Garlon 3A and rhodamine WT to plots on Pend Oreille River, Washington

Table 5
Triclopyr Residues in Water Downstream From Treatment Plots Following Garlon 3A Application, Pend Oreille River, Washington, August 1991

Station	Hours After Treatment					Days After Treatment					
	1	1.5	5	8	12	1	2	3	7	14	21
RT[1]											
7 (300 m)[2]	BD[3]	NS[4]	0.23	0.55	0.97	1.20	0.57	0.57	0.06	NS	NS
7a (300 m)	0.10	NS	0.21	0.42	0.03	0.02	0.02	BD	BD	NS	NS
8 (675 m)	NS	NS	BD	0.07	0.13	0.47	0.02	0.15	BD	NS	NS
8a (675 m)	NS	NS	BD	0.12	0.09	BD	BD	BD	BD	NS	NS
9 (975 m)	NS	NS	BD	0.02	BD	BD	BD	BD	BD	NS	NS
CT[5]											
4 (150 m)	NS	0.30	NS	0.28	NS	0.02	BD	BD	BD	BD	BD
5 (395 m)	NS	0.09	NS	0.32	NS	0.04	BD	BD	BD	BD	BD

[1] River treatment, samples collected at 1-m depth.
[2] Distance downstream from plot.
[3] Below detection.
[4] No sample collected.
[5] Cove treatment; samples collected at 0.5-m (Station 4) and 0.75-m (Station 5) depths.

Inside cove treatment plot

At 1.5 HAT, the whole-plot aqueous triclopyr residue (mean ± SE, all stations, all depths) was 2.32 ± 0.56 mg/ℓ (Table 2), somewhat greater than the nominal application rate of 1.75 mg/ℓ. However, triclopyr concentration in the plot was 2.03 ± 0.41 mg/ℓ at 8 HAT; by 1 DAT, a level of 0.78 ± 0.22 mg/ℓ was measured. Triclopyr concentrations were below the proposed PWT level of 0.5 mg/ℓ by 3 DAT, when triclopyr was measured at 0.47 ± 0.16 mg/ℓ. By 7 DAT, the mean triclopyr concentration in the plot was 0.22 ± 0.03 mg/ℓ and was below detection at all stations and all depths by 14 DAT. Based on laboratory-derived concentration and exposure-time requirements (Figure 4), a triclopyr dose of >0.25 mg/ℓ for ≥72 hr should provide excellent milfoil control with little or no regrowth (Netherland and Getsinger 1992).

Whole-plot aqueous half-life of triclopyr (all depths) in the CT plot (Table 4, Figure 11) was calculated to be 52.7 hr (r^2 = 87.6), which was nearly identical to the calculated half-life of the dye (52 hr, r^2 = 87.4). Aqueous half-lives of triclopyr and dye (upper and lower depths) are shown in Table 4 and Figures 12 and 13. Dissipation of both products is very similar. Moreover, correlation of dye and triclopyr concentrations (based on data presented in Table 6) was significant ($p < 0.001$), with an r^2 value of 0.95 (Figure 10). This high correlation coefficient indicates that a tank-mix, rather than sequential (RT plot, $r^2 = 0.80$), application of triclopyr and rhodamine WT can improve the herbicide simulation characteristics of the dye.

When analyzed by individual sampling stations, mean triclopyr concentrations were near target levels for both north and south subplots through 8 HAT (Table 2). Residue levels declined most quickly at Station 1 in the higher water-exchange subplot, diminishing to levels of approximately 0.10 mg/ℓ or less by 1 DAT. The proximity of this southern portion of the plot to the main river channel and a tributary stream undoubtedly increased the degree of water exchange in that region of the plot. In contrast, triclopyr water residues at Stations 2 (midplot) and 3 (low water-exchange, northern subplot) remained at levels ≥0.25 mg/ℓ through 7 DAT. These data suggested that optimum milfoil control could be expected in the mid and northern sections of the plot. Triclopyr dissipation half-lives in the upper ($t_{1/2}$ = 47.9 hr) and lower ($t_{1/2}$ = 57.3 hr) portions of the water column were more comparable in the CT plot (Table 4) than in the RT plot. Consequently, laminar flow was probably not a key component in the dissipation of triclopyr in the cove treatment.

Downstream cove treatment plot

Aqueous triclopyr residues peaked at 1.5 HAT at Station 4 (150 m downstream) and at 8 HAT at Station 5 (395 m downstream) at 0.30 and 0.32 mg/ℓ, respectively (Table 5). Residues at both of these stations were near or below detection by 1 DAT. Based on these triclopyr levels, little off-target injury and/or milfoil control was expected. As shown in the river

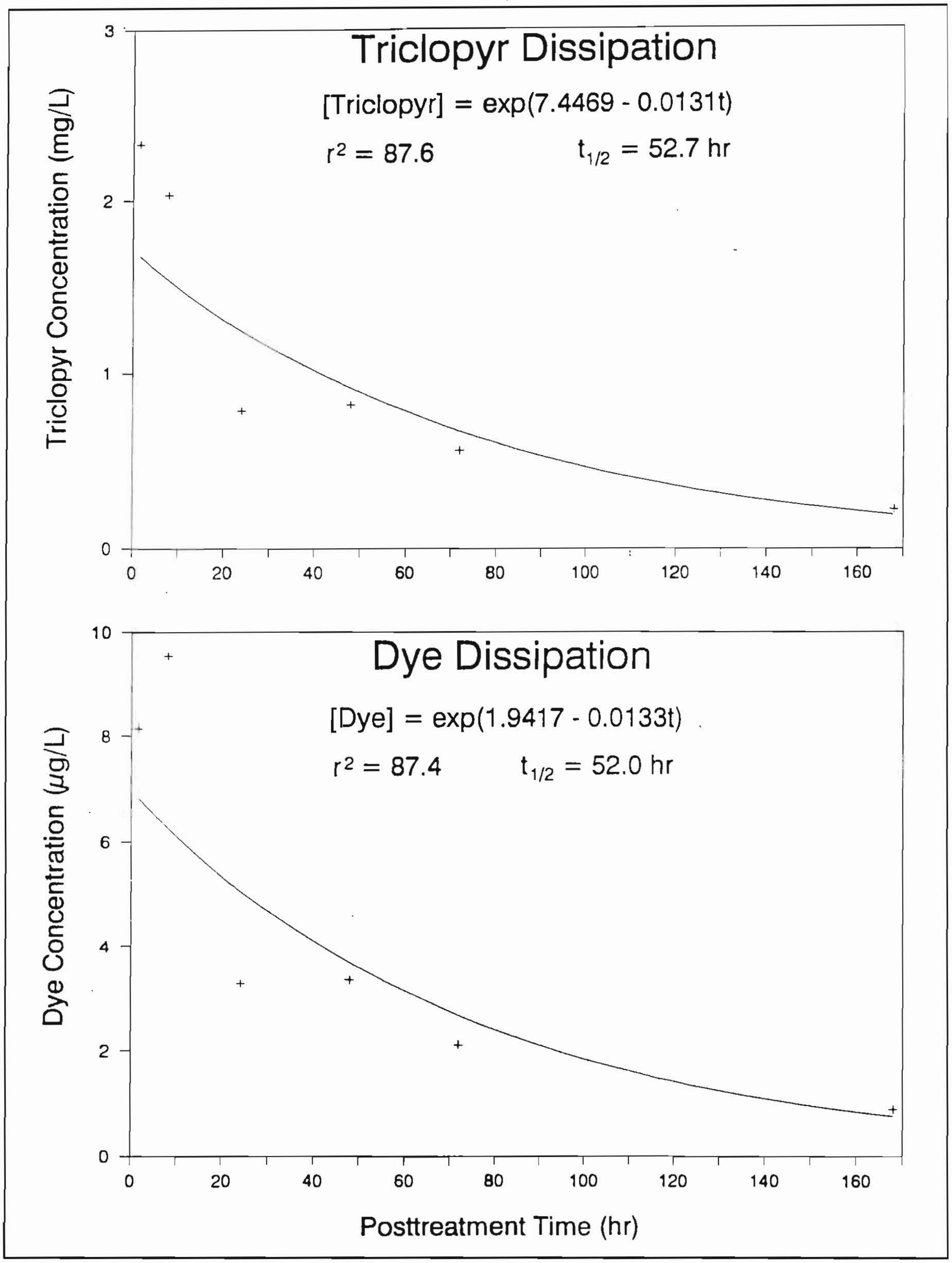

Figure 11. Dissipation of triclopyr and dye in cove treatment (CT) plot following application of Garlon 3A and rhodamine WT, Pend Oreille River, Washington (Lines represent calculated dissipation curves using an exponential model, and symbols represent actual values)

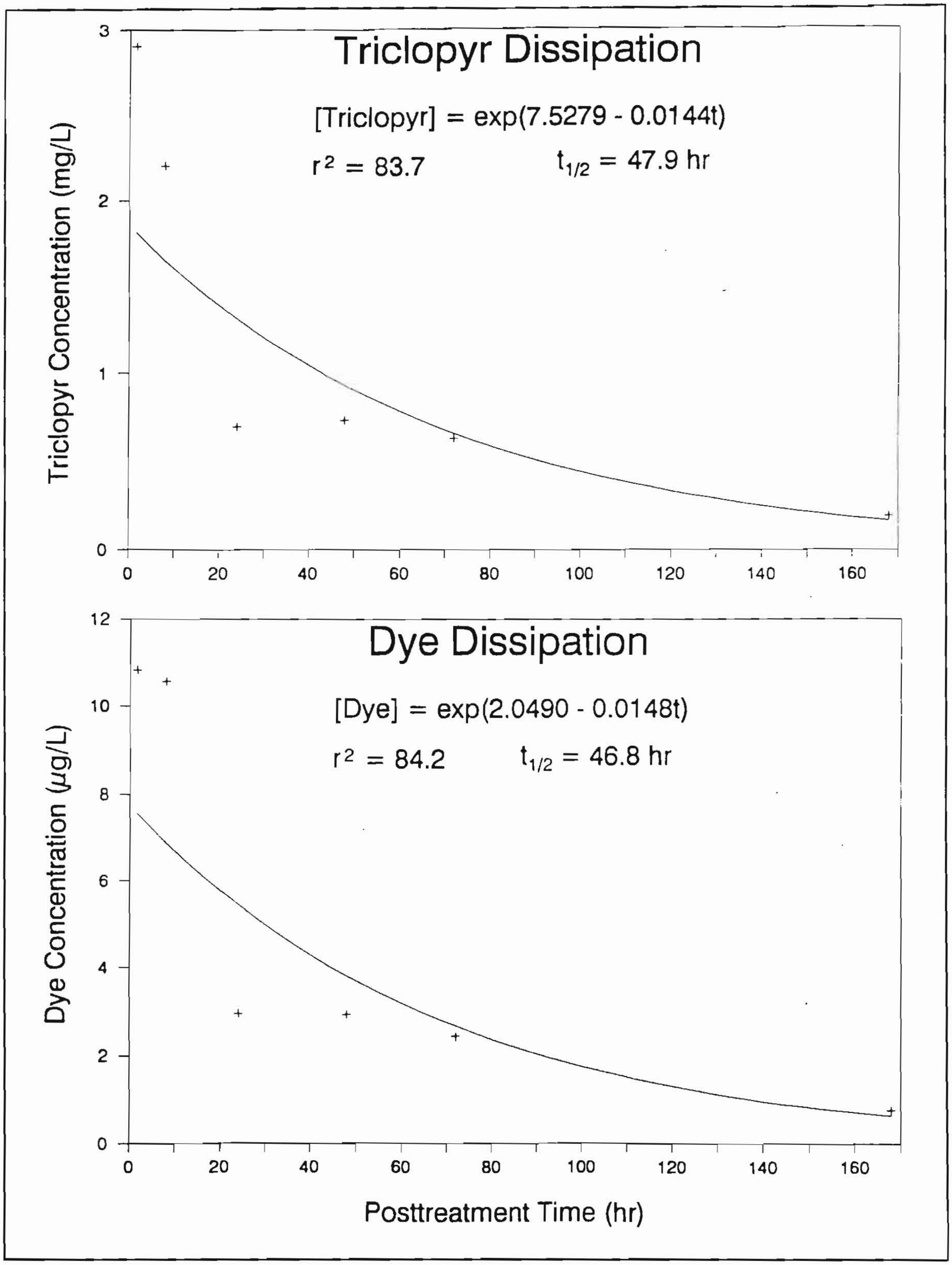

Figure 12. Dissipation of triclopyr and dye in upper portion of water column in cove treatment (CT) plot following application of Garlon 3A and rhodamine WT, Pend Oreille River, Washington (Lines represent calculated dissipation curves using an exponential model, and symbols represent actual values)

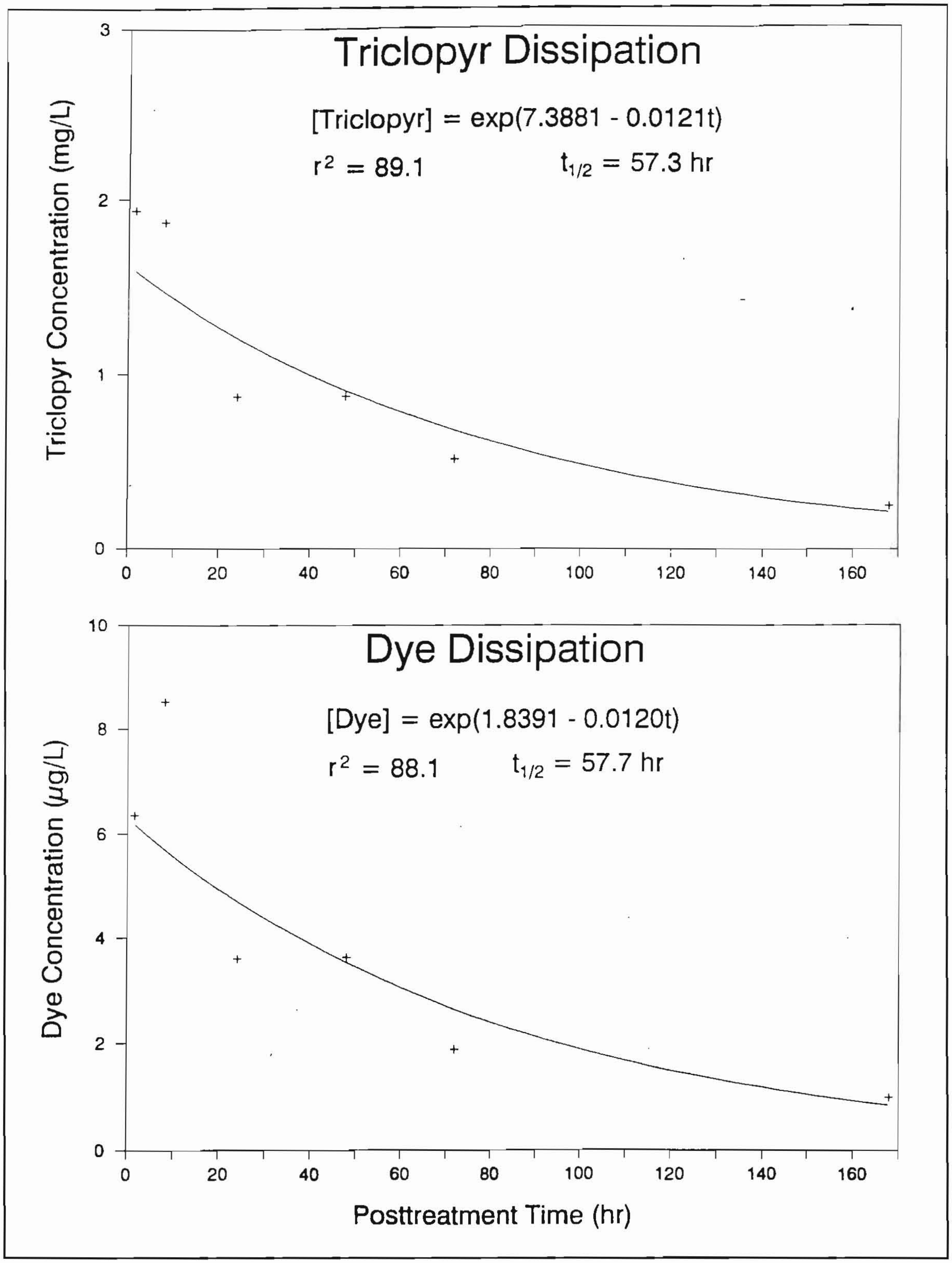

Figure 13. Dissipation of triclopyr and dye in lower portion of water column in cove treatment (CT) plot following application of Garlon 3A and rhodamine WT, Pend Oreille River, Washington (Lines represent calculated dissipation curves using an exponential model and symbols represent actual values)

Table 6
Triclopyr (mg/ℓ) and Rhodamine WT (μg/ℓ) Data for Cove Treatment Plot (inside and downstream), Pend Oreille River, Washington

Station	Depth, cm	Hours After Treatment							
		1.5	8	24	48	72	168	336	504
1	50	2.00 (7.7)	2.50 (11.6)	0.04 (0.1)	<0.01 (0.0)	<0.01 (0.0)	0.07 (0.3)		
	100	1.90 (6.9)	2.60 (12.2)	0.21 (0.8)	0.14 (0.6)	0.11 (0.08)	0.18 (0.7)	All residues <0.01	All residues <0.01
2	50	3.80 (13.9)	2.80 (13.5)	0.86 (3.4)	1.00 (3.7)	0.29 (1.1)	0.27 (1.1)		
	100	3.30 (9.3)	2.70 (12.4)	1.20 (4.9)	1.50 (6.2)	0.61 (2.2)	0.31 (1.2)	No dye readings	No dye readings
3	50	1.20 (5.9)	1.30 (6.6)	1.20 (5.4)	0.47 (2.1)	0.97 (3.8)	0.24 (0.9)		
	100	0.60 (2.8)	0.29 (0.9)	1.20 (5.1)	0.97 (4.1)	0.81 (3.4)	0.26 (1.0)		
4	50	0.30 (0.7)	0.28 (1.1)	0.02 (0.2)	<0.01 (0.0)	<0.01 (0.0)	-- (0.0)		
5	75	0.09 (0.04)	0.32 (1.1)	0.04 (0.2)	0.01 (0.0)	<0.01 (0.0)	-- (0.0)		

treatment, these low downstream triclopyr residues indicate that the proposed PWT level (0.5 mg/ℓ) set-back distances of 400 to 800 m are appropriate for triclopyr applications in relatively quiescent coves of slow-flowing rivers.

River reference plot

No triclopyr residues were detected in the untreated, upstream reference plot (RR) at pretreatment and 8 and 24 HAT. In addition, dye was never detected at the downstream edge of the RR plot nor anywhere inside of the plot during the 7-day posttreatment sampling period. These results showed that there was no upstream migration of the chemicals from the RT plot, and no milfoil injury and/or control was anticipated.

Herbicide and Dye Photodegradation

Triclopyr residues in the RT plot enclosure decreased 53 percent over the 7-day posttreatment sampling period (Table 7). The initial triclopyr water residue of 3.0 mg/ℓ declined to 2.4 mg/ℓ by 3 DAT, and reached 1.4 mg/ℓ by 7 DAT. Similarly, triclopyr water residues in the CT plot enclosure decreased by 46 percent during the 7-day sampling period, from an initial concentration of 2.5 to 1.6 mg/ℓ by 7 DAT. Since the enclosures prevented water exchange and plants were excluded, the decrease in triclopyr levels was primarily attributed to photodegradation. Based on these data, the calculated

Table 7
Degradation in Water of Triclopyr and Rhodamine WT in Enclosures of River and Cove Treatment Plots, Pend Oreille River, Washington

Plot	Time, hr	Triclopyr, mg/ℓ	Dye, μg/ℓ
River	0	3.0	11.2
	12	2.7	11.3
	24	2.6	10.8
	48	2.5	10.5
	72	2.4	9.6
	168	1.4	7.2
Cove	0	2.5	9.0
	24	2.2	9.1
	48	1.9	8.5
	72	1.9	8.9
	168	1.6	8.5

mean half-life for triclopyr within the enclosures was 8.7 days ($r^2 = 98.3$, $p < 0.001$). This is greater than the average half-life of 1.3 days reported for natural river water (Woodburn et al. 1993) and 3 to 4 days for natural lake water (Solomon et al. 1988). However, photodegradation rates are highly dependent on site-specific environmental conditions and would be expected to vary between geographic locations.

Dye concentration in the RT plot enclosure decreased by 36 percent, and in the CT plot enclosure by only 6 percent, over the 7-day posttreatment sampling period. The lower rates of decline exhibited by rhodamine WT, compared with triclopyr, indicate that this dye is not as susceptible to photolysis and/or microbial degradation as is the herbicide.

In hydrodynamic areas (e.g., plots RT and CT), actual contribution of photolysis to triclopyr dissipation can only be addressed in broad terms. Given the calculated water-exchange half-life of 20.1 hr in the RT plot (based on rhodamine WT dissipation, which is relatively resistant to photodegradation) and a triclopyr photolytic half-life of 8.7 days, it is likely that photolysis played only a minor role in initial (1 to 2 DAT) herbicide reductions within the water column in this plot. Dilution and dispersion would have been the primary forces operating to reduce triclopyr levels. In the quiescent CT plot (water-exchange half-life = 52 hr), photolysis probably played a more significant role in triclopyr loss from the water column because of the longer water retention time. Water movement out of the cove would still act as a major factor affecting triclopyr reduction, especially in the higher water-exchange regions of the southern subplot.

Since photolytic rates are dependent on ambient light intensity, light attenuation through the water column must also be considered. In open-water areas and within the two enclosures, surface irradiance was reduced by 48 to 70 percent at a depth of 30 cm. At a similar depth, irradiance was reduced by almost 99 percent beneath milfoil surface canopies. Thus, even within each treated plot, photodegradation rates of triclopyr may have varied considerably, both horizontally and vertically. In areas where milfoil surface mats were present, photolytic loss of triclopyr would be expected to be minimal, whereas greater loss would be expected in relatively open water. Similarly, the potential for photodegradation of triclopyr would be greater at or near the water surface than in deeper areas.

Treatment Efficacy: Biomass

Total plant biomass

An examination of total biomass alone (Figure 14) indicated that although the triclopyr treatment significantly reduced the amount of plants present in both plots 4 weeks after application, there was no effect on total community

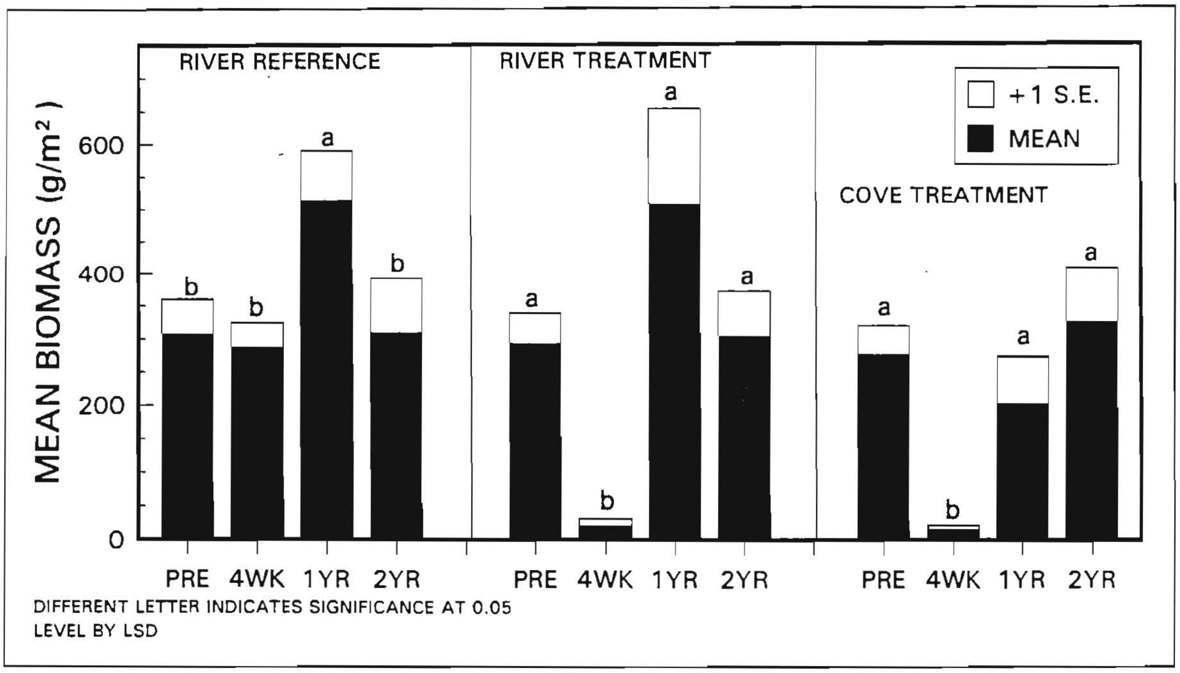

Figure 14. Total submersed plant community biomass at three study plots in Pend Oreille River, Washington (Letters indicate significant difference at p = 0.05 level using ANOVA Bonferroni LSD)

biomass 1 and 2 years posttreatment. In this respect, the triclopyr treatment had no long-term effect on plant productivity. However, closer inspection showed that the composition of biomass within the triclopyr-treated submersed plant community was significantly affected over the long term.

Milfoil biomass

Milfoil biomass in the untreated RR plot maintained constant levels with the exception of higher biomass during the first year after treatment (Figure 15). In contrast, milfoil biomass was considerably reduced in both the RT and CT plots through 2 years posttreatment. The amount of milfoil at 4 weeks posttreatment was 1 percent of pretreatment levels in both treatment plots, indicating excellent triclopyr efficacy on the target plant. One year posttreatment, milfoil biomass in the RT plot was 28 percent of pretreatment and 1 percent of pretreatment in the CT plot and was still significantly lower (47 to 66 percent) in both plots 2 years posttreatment. Close examination of milfoil rootcrowns, an important source of new plant growth, revealed that most of these perennating structures were severely damaged or completely destroyed in both treated plots by 4 weeks posttreatment. These observations indicate that current-borne transport of healthy milfoil stem fragments, which is the species' primary reproductive strategy (Madsen, Eichler, and Boylen 1988), from plants growing outside of the treatment areas were primarily responsible for regrowth that occurred in the plots. Despite this reinvasion,

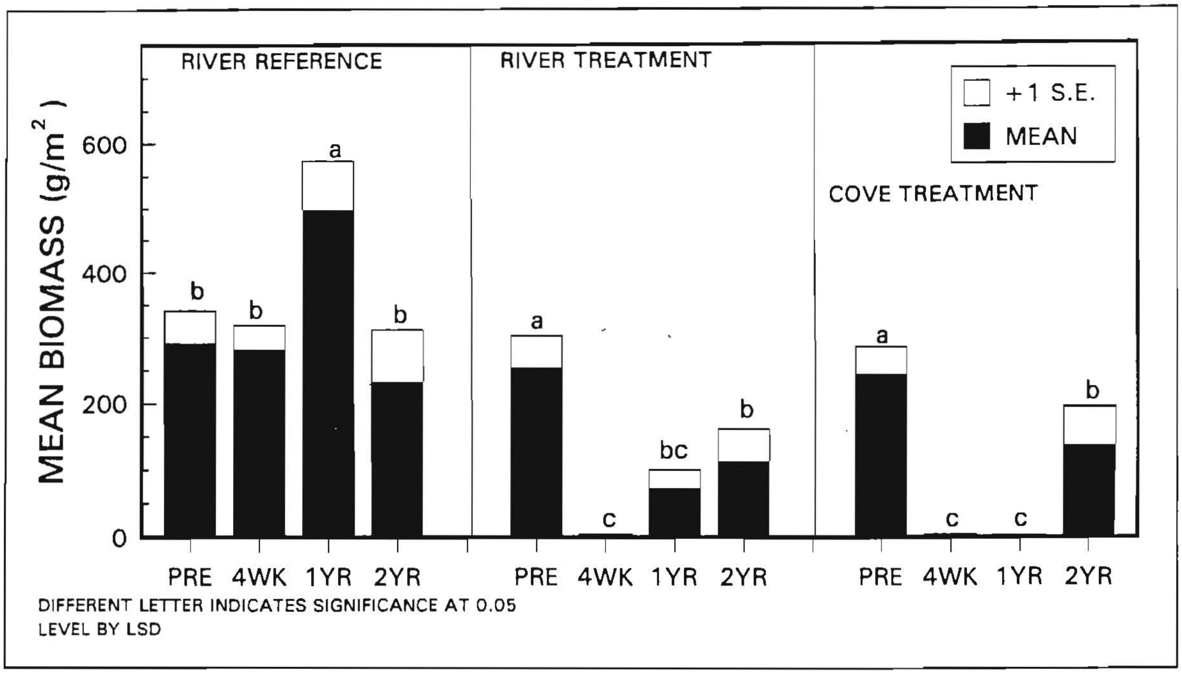

Figure 15. Eurasian watermilfoil biomass at three study plots in Pend Oreille River, Washington (Letters indicate significant difference at $p = 0.05$ level using ANOVA Bonferroni LSD)

duration of acceptable milfoil control at these sites using triclopyr was at least 1 year longer than reported from previous 2,4-D and fluridone applications in identical or similar locations in the river (Durando-Boehm 1983; WATER Environmental Sciences, Inc. 1986, 1987).

Based on laboratory-derived concentration and exposure time relationships (Netherland and Getsinger 1992), triclopyr levels in the RT plot should have at least 85-percent milfoil control, with some regrowth occurring by 5 weeks posttreatment; while milfoil control in the CT plot should have been >85 percent, with little to no regrowth occurring by 5 weeks posttreatment. In fact, field efficacy was better than the laboratory prediction, with triclopyr applications providing excellent control (99-percent milfoil biomass reduction) for the remainder of the growing season in both plots. Moreover, excellent (99-percent milfoil biomass reduction) and acceptable (72-percent milfoil biomass reduction) control were still being maintained in the CT and RT plots, respectively, at 1 year posttreatment. This enhanced field efficacy has been observed with other aquatic herbicides (Getsinger 1993; Langeland 1993; Netherland, Getsinger, and Turner 1993; Nelson et al. 1995) and may be related to levels of environmental stress (e.g., wave action, currents, water turbidity, microbes, and pathogens) that are lacking or minimized in evaluations conducted under laboratory conditions.

Although water-exchange and triclopyr half-lives in the RT plot suggested that milfoil control in the upstream zone might be less than that in the midstream and downstream zones, this was not the case. The 4-week posttreatment efficacy evaluation showed excellent milfoil control throughout the plot, even along the upstream (southern) treatment boundary. High triclopyr concentrations (4.69 to 8.15 mg/ℓ) measured in the upstream zone through 5 hr posttreatment and concentrations in that zone of 2 to 2.5 mg/ℓ through 12 hr posttreatment probably accounted for the good milfoil control in the upstream regions of the plot. Observations confirmed that milfoil was partially controlled at distances of up to 250 m directly downstream from the northern RT plot boundary, with more complete control occurring < 100 m downstream. This level of off-target control was not surprising, since triclopyr residues at Station 7 (300 m downstream) peaked at 1.2 mg/ℓ at 1 DAT. As expected, no milfoil control was observed > 10 m upstream of the southern boundary or more than 10 to 20 m beyond the eastern boundary of the plot. Triclopyr injury symptoms were not observed on milfoil growing > 400 m downstream of the RT plot; this was expected from the low herbicide residues measured at those distances.

In contrast to the presence of off-target triclopyr efficacy in the river application, no collateral damage was observed on milfoil growing a few meters past the eastern boundary of the cove application. Dye measurements taken during previous water-exchange studies (Getsinger, Sisneros, and Turner 1993) and during this treatment demonstrated that water exchange between the cove and river was relatively low; therefore, efficacious levels of triclopyr extending beyond the confines of the cove were unlikely. The quiescent nature of the cove waters would restrict rapid transport of triclopyr into the river and would enhance the photolytic and microbial degradation of the herbicide. Lack of off-target injury symptoms and/or milfoil control observed at the CT plot was supported by the low triclopyr residues measured at the downstream water sampling Stations 4 and 5.

In addition to verifying laboratory-derived dosage rates, the CT plot treatment demonstrated the value of matching herbicide application rates with site-specific water exchange information. Knowledge of the water-exchange characteristics of Lost Creek Cove, allowed for 30 percent less herbicide to be used (1.75 mg/ℓ, versus maximum rate of 2.5 mg/ℓ) with a high degree of confidence to achieve excellent milfoil control. Most importantly, this technique of coupling herbicide dosage rate and water-exchange data can aid in reducing the amount of herbicide used in operational treatments, lowering environmental loading of chemicals and costs associated with herbicide applications, without sacrificing efficacy. In regulated rivers, herbicide contact might be maximized by appropriately modifying discharge rates during and after chemical applications or by scheduling herbicide applications to take advantage of normal dam/spillway operations. While contact time is of primary importance, laboratory studies have shown that a relatively moderate increase in triclopyr exposure (i.e., from 12 to 24 hr) can provide acceptable control of milfoil at rates as low as 0.25 mg/ℓ, 10 times below the maximum EUP label rate (Netherland and Getsinger 1992).

Native plant biomass

Native plant biomass levels responded dramatically to the removal of milfoil (Figure 16). At the untreated RR plot, native plant biomass remained mostly unchanged, with a slight increase 2 years posttreatment. Although native plant biomass remained low 4 weeks after triclopyr application in the RT and CT plots, in part because of the lateness of the growing season, it had increased dramatically (500 to 1,000 percent) in both treatment plots 1 year posttreatment (Figure 4C). Native plant biomass remained significantly higher in both plots 2 years posttreatment. Thus, selective control of milfoil resulted in higher abundance of native plants up to 2 years after treatment and suggests that a timely restoration of a diverse native plant community can delay the reinvasion and dominance of an aggressive and opportunistic weed. In fact, this reinfestation was delayed for at least 2 years in the treated plots, even though milfoil was selectively removed from only small areas (4 to 6 ha) surrounded by hundreds of untreated hectares infested with milfoil.

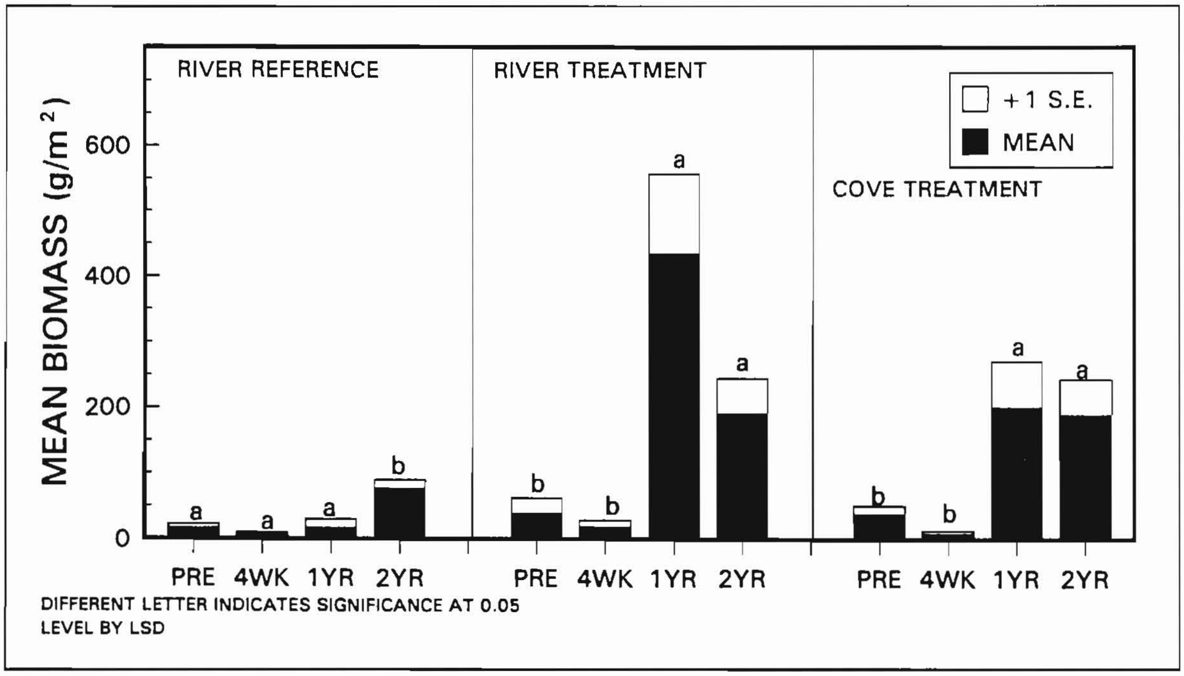

Figure 16. Native submersed plant community biomass at three study plots in Pend Oreille River, Washington (Letters indicate significant difference at p = 0.05 level using ANOVA Bonferroni LSD)

As expected from a product having an activity spectrum similar to 2,4-D and other auxin-type growth regulators that are nontoxic to most dicots, monocot species were not adversely affected by the triclopyr application. Rather, monocots significantly increased in abundance in posttreatment years 1 and 2 (Figure 17). The dense milfoil canopy had apparently inhibited native

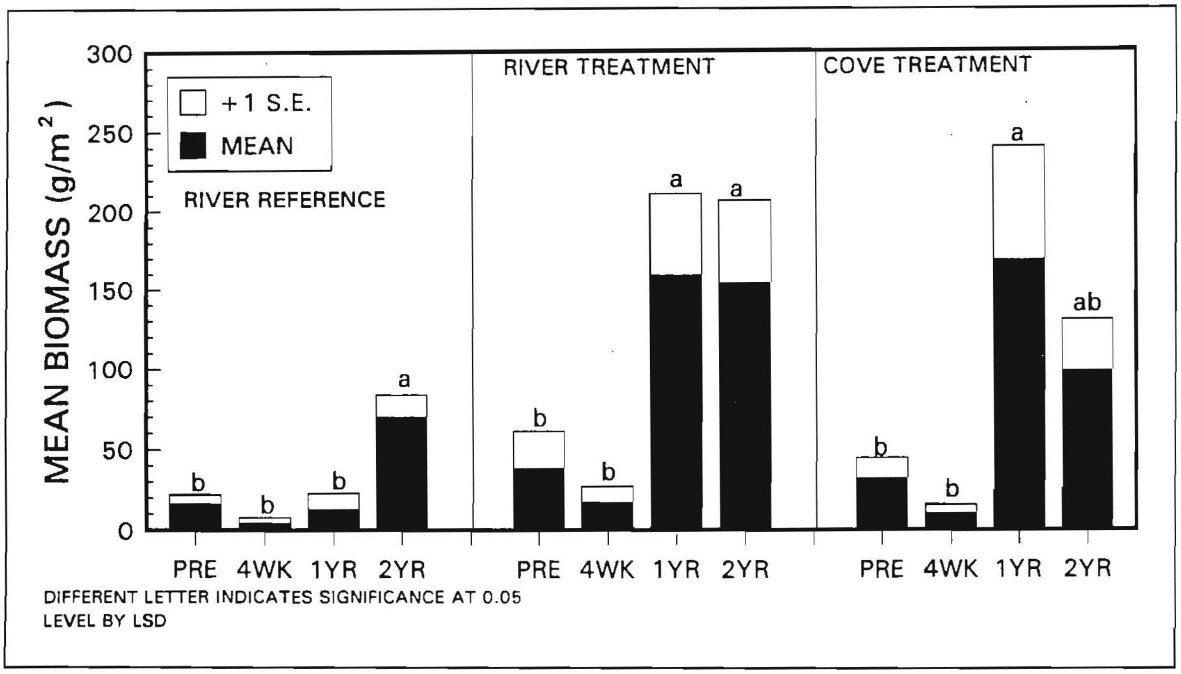

Figure 17. Submersed plant biomass (g m^{-2} dry weight) categorized by taxonomic class (monocots) at three study plots in Pend Oreille River, Washington (Letters indicate significant difference at $p = 0.05$ level using ANOVA Bonferroni LSD)

monocot growth; once this canopy was removed by triclopyr, monocots were able to flourish.

Response of dicots as a group to triclopyr includes the response of the target plant (Figure 18); although milfoil was significantly reduced, overall dicot biomass was not consistently different in the treated plots 1 and 2 years after treatment. Native dicots (Figure 19) increased significantly in the RT plot 1 year after treatment and in the CT plot 2 years after treatment, largely because of regrowth of white watercrowfoot.

Treatment Efficacy: Community Diversity

Species frequency

A total of 17 submersed plant species were encountered during the 1- and 2-year posttreatment evaluations; two were nonnative (exotic) species, 15 were native species, 12 were monocots, and 5 were dicots (Table 1). Transect data provided an assessment of the distribution of plants throughout each plot and, as such, is a measure of evenness. Milfoil was observed in virtually all transect intervals in the untreated RR plot in all 3 years (Figure 20). Before triclopyr treatment, more than 90 percent of transect intervals had milfoil in both the RT and CT plots. These high pretreatment frequency values,

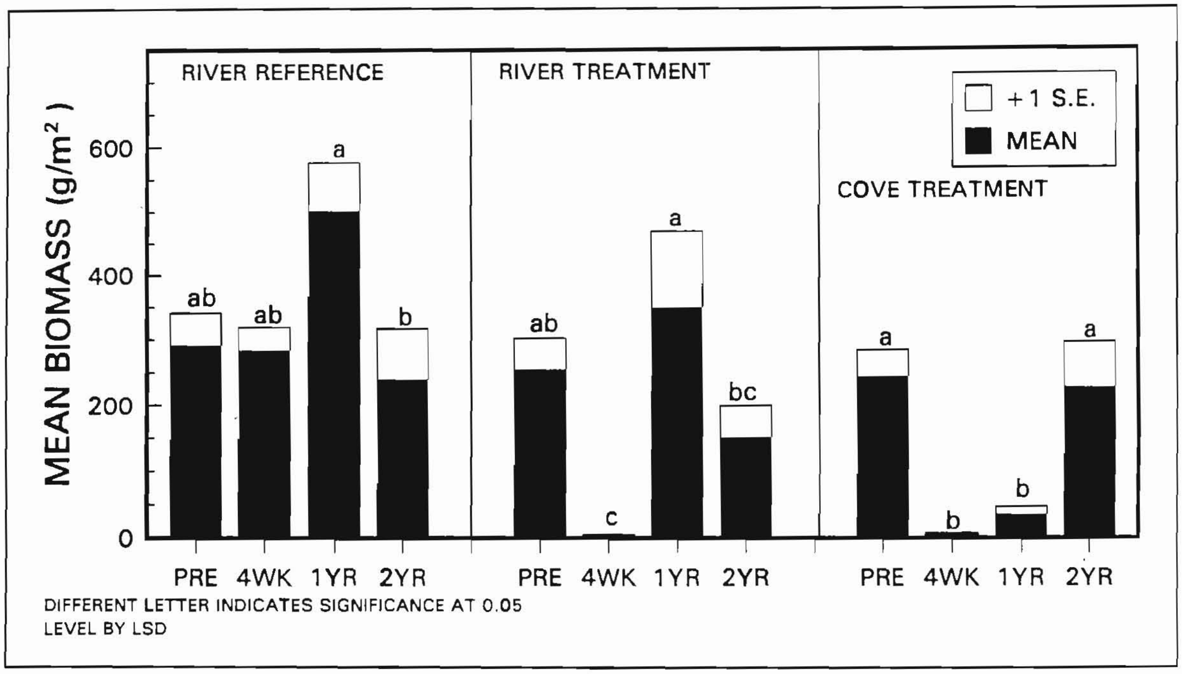

Figure 18. Submersed plant biomass (g m^{-2} dry weight) categorized by taxonomic class (dicots) at three study plots in Pend Oreille River, Washington (Letters indicate significant difference at p = 0.05 level using ANOVA Bonferroni LSD)

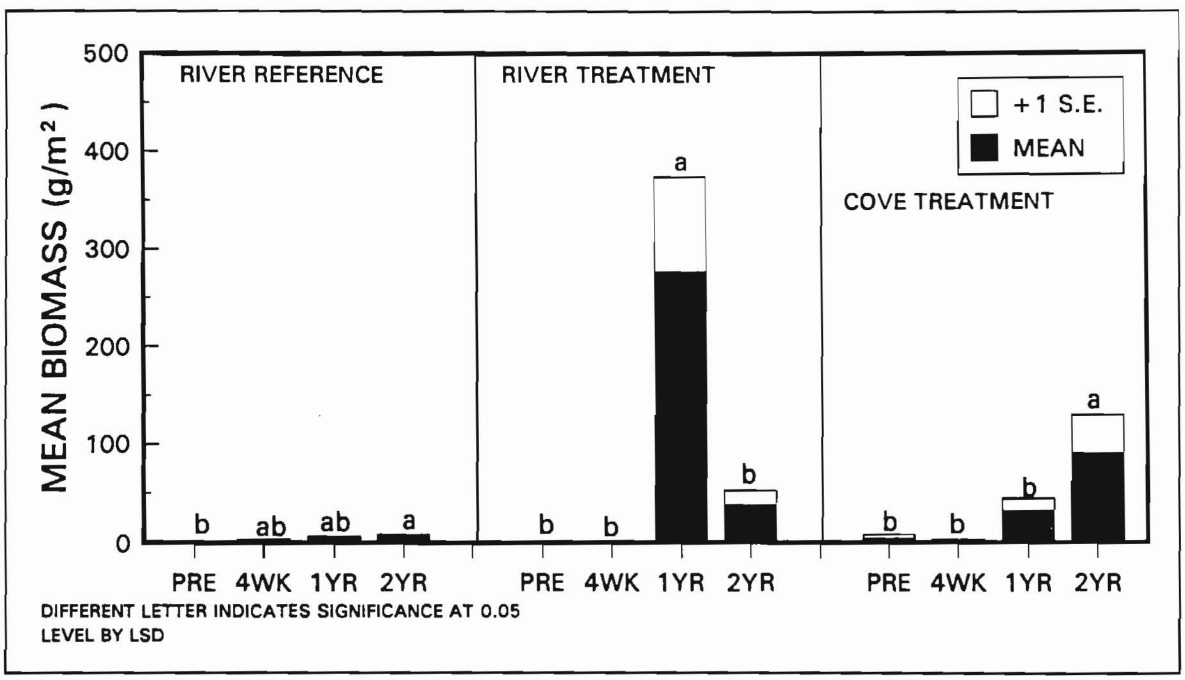

Figure 19. Submersed plant biomass (g m^{-2} dry weight) categorized by taxonomic class (native dicots) at three study plots in Pend Oreille River, Washington (Letters indicate significant difference at p = 0.05 level using ANOVA Bonferroni LSD)

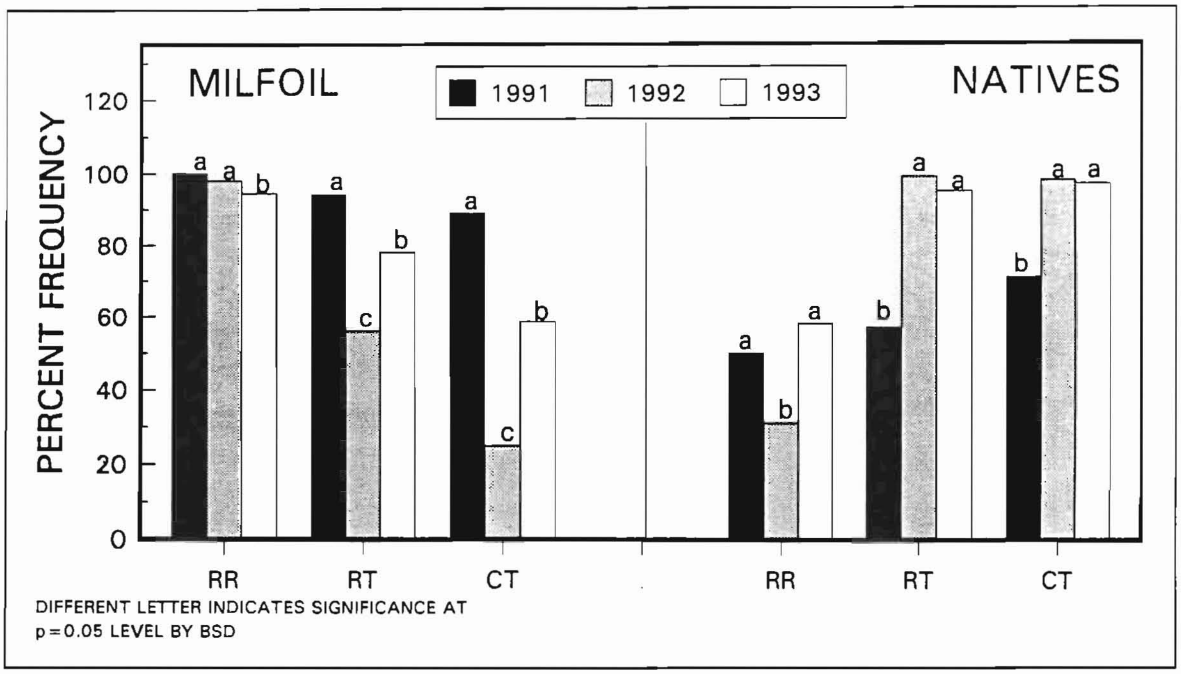

Figure 20. Frequency of plants along transects at three study plots in Pend Oreille River over three study years: Eurasian watermilfoil; all native plant species (RR, River Reference; RT, River Treatment; CT, Cove Treatment. Letters indicate significant difference at p = 0.05 level using Chi-square analysis)

coupled with biomass levels and observations by SCUBA divers, showed that mature milfoil plants were evenly distributed throughout the plots.

Following triclopyr application, milfoil frequency in the RT plot dropped to 60 percent 1 year after treatment and remained less than 80 percent at 2 years posttreatment. CT plot milfoil was more affected, with less than 30 percent frequency 1 year posttreatment and 60 percent 2 years posttreatment. When these frequency values are coupled with corresponding biomass levels and observations by SCUBA divers, a clear depiction of triclopyr efficacy emerges: young shoots of milfoil (initiating from imported stem fragments) unevenly distributed within the treated plots, particularly at 1 year posttreatment.

Frequency of native species (nonmilfoil, noncurlyleaf pondweed) was approximately 50 to 70 percent in the treatment plots before triclopyr treatment (Figure 20). The untreated RR plot had native plant frequency values from 40 to 60 percent (Figure 20). Once treated however, natives increased to nearly 100-percent frequency 2 years after treatment. Thus, the seed/propagule bank was sufficient in these submersed plant communities to provide sources for re-establishing native plants; removal of the dense milfoil canopy was all that was required to restore the native plant community.

Species diversity

The diversity measure used in this study was average number of species per transect interval or average species richness. When all species are included, the three plots were at approximately two species per interval prior to triclopyr treatment (Figure 21). Species richness remained low in the untreated RR plot 1 year posttreatment, but increased to over 2.5 at 2 years posttreatment because of the increased distribution of the exotic monocot, curlyleaf pondweed. Richness increased to over three species per interval in both treated plots 2 years posttreatment. When only native species are considered, all three plots were at approximately one per interval before treatment, and the untreated RR plot remained near this level throughout the study (Figure 21). Following herbicide treatment, richness of native species increased to over two species per interval, more than doubling the diversity of native species in both treatment plots. Higher plant diversity remained in both the RT and CT plots 2 years posttreatment.

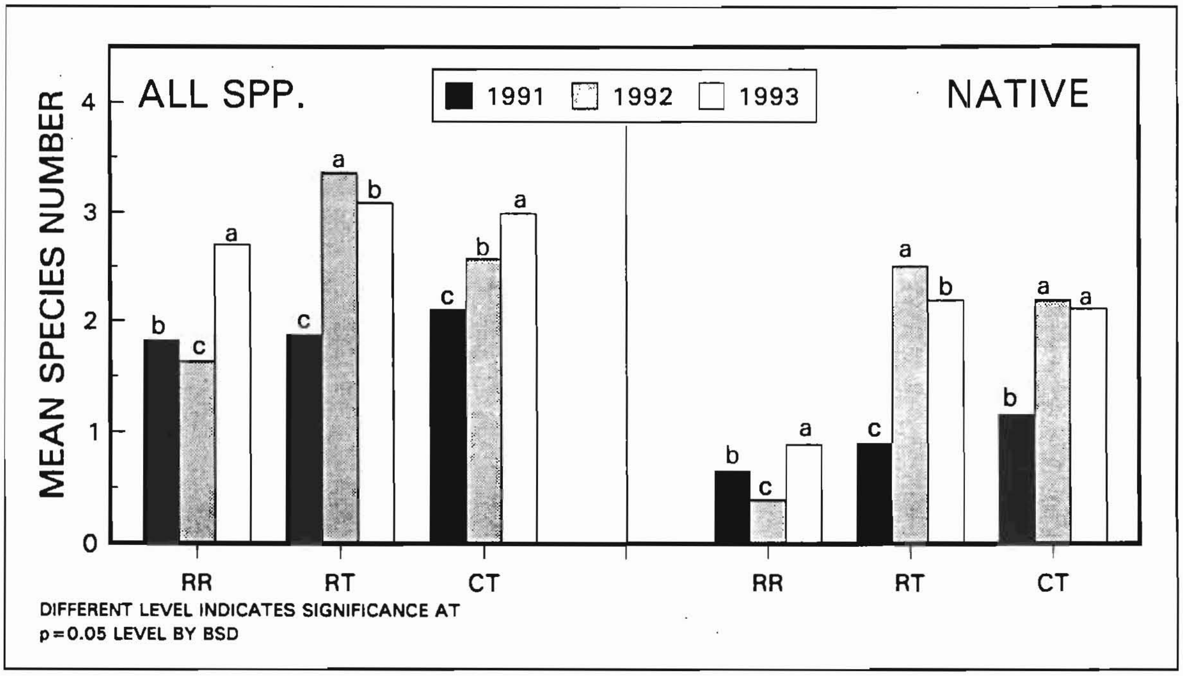

Figure 21. Average number of species per transect interval at three study plots in Pend Oreille River over three study years: all species; native species only (RR, River Reference; RT, River Treatment; CT, Cove Treatment. Letters indicate significant difference at $p = 0.05$ level using ANOVA Bonferroni LSD)

The main component in this restoration of plant diversity was the monocot species, which more than doubled in average diversity along transects in the treated plots, both 1 and 2 years after treatment (Figure 22). These were predominantly the native pondweeds (*Potamogeton* spp.). Dicot diversity as a whole was unchanged because of the substantial decrease in milfoil distribution (Figure 22). As with the monocot community, native dicot diversity increased substantially in the RT and CT plots, more than doubling after

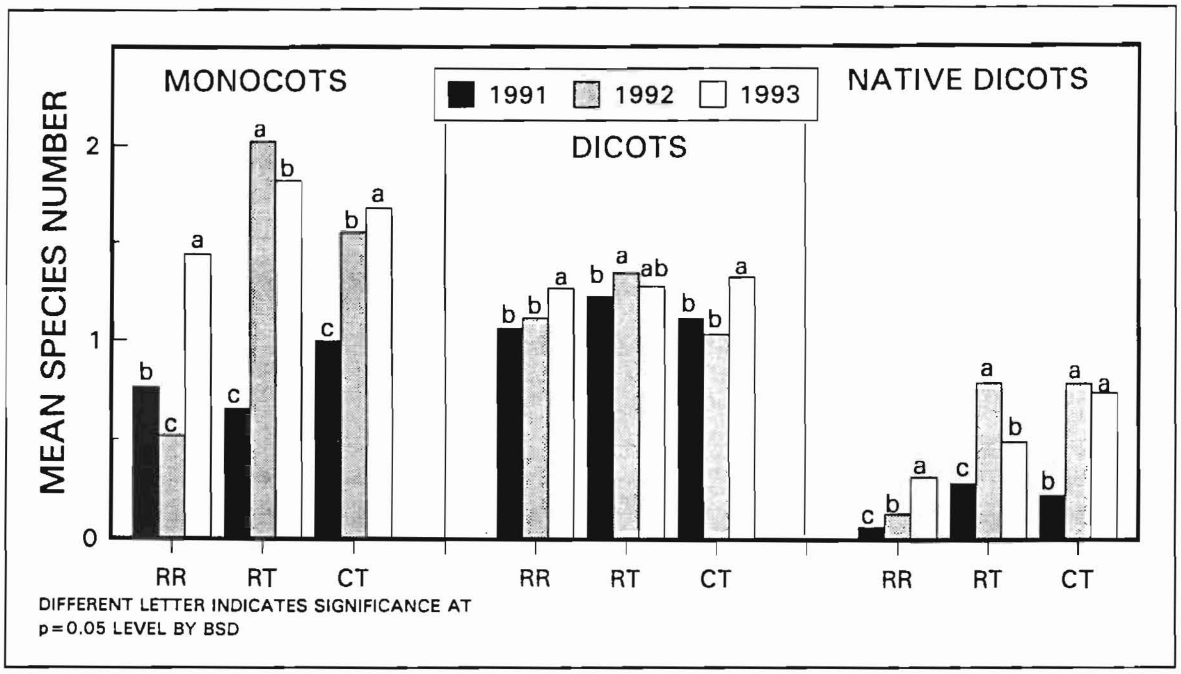

Figure 22. Average number of species per transect interval at three study plots in Pend Oreille River over three study years: monocots; all dicots; native dicots only (RR, River Reference; RT, River Treatment; CT, Cove Treatment. Letters indicate significant difference at p = 0.05 level using ANOVA Bonferroni LSD)

triclopyr treatment (Figure 22). It is apparent that the triclopyr treatment did not have a prolonged negative effect on the native dicot community and in fact allowed these dicots to flourish by removing the dense monoculture of milfoil that had been suppressing their growth.

4 Conclusions and Recommendations

Conclusions

This study has demonstrated that the herbicide triclopyr can be used to selectively control the exotic weed Eurasian watermilfoil in coves and along shorelines in regulated rivers, while restoring diverse native submersed plant communities in these sites. Such native communities can delay the reestablishment of problematic levels of milfoil for up to three growing seasons. Within a similar areal scale and under comparable hydrodynamic and environmental conditions, triclopyr residues in treated water can be expected to dissipate and/or degrade to very low levels in a short period of time. In addition, this study shows that judicious planning and application can maintain triclopyr concentrations outside of treated areas at levels that are extremely low or below detection, and that proposed potable water tolerance set-back distances of 400 to 800 m are adequate. Finally, a knowledge of site-specific water-exchange characteristics, coupled with well-established herbicide concentration and exposure time relationships, can be used to prescribe applications that will minimize herbicide dosage rates while maximizing effectiveness against a target plant.

Recommendations

Based on the results of this study, recommendations for the use of a liquid triethylamine salt formulation of triclopyr for selective control of Eurasian watermilfoil in the Pend Oreille and similar Pacific Northwest rivers are as follows:

Operational

a. Treatment areas should be at least 4 ha (10 acres) in size, and flow patterns in those areas should provide a water-exchange half-life of at least 8 hr. In locations with water-exchange half-lives of >35 hr (e.g., quiescent coves), triclopyr treatment rates of at least 20 percent less than the maximum label rate of 2.5 mg/ℓ (ppm) should be considered.

b. Water-exchange characteristics should be coupled with triclopyr concentration/exposure time relationships to provide prescription treatments for site-specific locations (e.g., coves, riverine backwater areas, and side channels). This technique will allow managers to select the appropriate dose of triclopyr, while ensuring desired efficacy and minimizing costs.

c. Applications should be coordinated to match low-flow conditions (based on project discharge data) with the active growth phase of the target plant, potentially minimizing the amount of herbicide required for desired efficacy.

d. While probably unnecessary for applications to quiescent protected coves, estimates of triclopyr dissipation should be calculated using available flow and/or water-exchange information to predict potential impacts to potable water intakes less than 800 m (0.5 miles) downstream from applications to more open, riverine areas.

Research

a. Additional studies are needed to firmly establish the relationship between areal extent of treatment, triclopyr application rate, and potable water tolerance set-back distances in flowing-water conditions.

b. Environmentally compatible carriers should be evaluated for the slow release of triclopyr, at rates below established potable water tolerance levels (0.5 mg/ℓ), in flowing-water conditions.

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Appendix A
Dye and Temperature Profiles for River Treatment Plot

Table A1
Dye (µg/ℓ) and Temperature (°C) Profiles for River Treatment Plot Following Treatment With Rhodamine WT and Triclopyr, Pend Oreille River, Washington, 1991

SS	z	Dye Concentration (Temperature)							
		Posttreatment, hr							
		1	5	8	12	24	48	72	168
1	0	17.8 (25.4)	17.3 (26.2)	0.9 (26.6)	0.5 (24.5)	0.0 (23.4)	0.0 (23.5)	0.0 (21.1)	0.0 (18.6)
	25	18.4 (25.0)	13.4 (26.0)	1.1 (26.4)	0.1 (24.6)	0.0 (23.5)	0.0 (23.3)	0.0 (21.3)	0.0 (18.6)
	50	19.3 (24.9)	6.1 (25.7)	1.4 (26.4)	0.1 (24.7)	0.0 (23.3)	0.0 (23.4)	0.0 (21.3)	0.0 (18.6)
	75	19.2 (24.7)	5.4 (25.2)	1.5 (26.2)	0.1 (24.8)	0.0 (23.2)	0.0 (23.3)	0.0 (21.4)	0.0 (18.6)
	100	14.2 (24.2)	8.6 (25.3)	6.5 (25.8)	0.1 (24.8)	0.0 (23.1)	0.0 (23.1)	0.0 (21.3)	0.0 (18.6)
	125	3.6 (23.2)	5.2 (24.8)	5.3 (25.1)	0.0 (24.6)	0.0 (23.1)	0.0 (23.1)	0.0 (21.2)	0.0 (18.6)
	150	0.0 (23.2)	0.2 (24.3)	2.5 (24.8)	0.0 (24.4)	0.0 (22.9)	0.0 (23.1)	0.0 (21.1)	0.0 (18.3)
	175	0.0 (23.1)	0.0 (24.0)	0.0 (24.1)	0.2 (23.6)	0.0 (22.8)	0.0 (23.1)	0.0 (21.1)	0.0 (18.2)
	200	0.0 (23.0)	0.1 (23.7)	0.0 (23.9)	0.1 (23.0)	0.0 (22.6)	0.0 (23.1)	0.0 (20.9)	0.0 (18.2)
2	0	35.0 (27.7)	24.7 (29.6)	25.9 (29.9)	10.9 (25.9)	0.0 (25.1)	0.0 (24.0)	0.0 (24.3)	0.1 (18.3)
	25	23.7 (25.8)	26.6 (27.0)	18.4 (27.3)	8.3 (25.6)	0.0 (23.5)	0.0 (23.5)	0.0 (21.7)	0.0 (18.2)
	50	12.4 (24.7)	25.6 (25.8)	17.4 (26.5)	2.5 (25.1)	0.0 (22.8)	0.0 (23.4)	0.0 (21.3)	0.0 (18.2)
3	0	60.9 (28.3)	31.3 (28.0)	39.1 (30.8)	30.6 (27.2)	13.8 (24.7)	0.5 (24.7)	0.0 (23.0)	0.0 (18.3)
	25	21.1 (26.2)	31.3 (26.9)	35.7 (29.5)	17.7 (27.0)	13.2 (24.2)	0.6 (24.8)	0.0 (21.7)	0.0 (18.3)
	50	4.6 (25.4)	26.5 (25.7)	16.1 (25.6)	7.9 (26.3)	12.6 (23.8)	0.5 (24.8)	0.0 (21.6)	0.0 (18.3)
	75	1.7 (25.0)	12.1 (25.0)	9.2 (24.8)	11.3 (25.6)	9.9 (23.5)	0.5 (24.6)	0.1 (21.1)	0.0 (18.3)
	100	0.3 (24.8)	1.7 (24.5)	3.2 (24.2)	19.6 (24.8)	8.7 (23.5)	0.5 (24.6)	0.6 (20.6)	0.0 (18.3)
	125	0.1 (24.4)	0.8 (24.2)	1.1 (23.8)	2.7 (23.9)	110.9 (23.1)	0.4 (24.6)	0.6 (20.6)	0.0 (18.3)
	150	0.0 (24.3)	0.1 (23.9)	0.7 (23.6)	NS	10.6 (23.1)	0.4 (24.6)	NS	NS

Note: NS = Not sampled, SS = Sampling station, and depth (z) is reported in centimeters.

(Sheet 1 of 4)

Table A1 (Continued)

SS	z	Dye Concentration (Temperature)							
		Posttreatment, hr							
		1	5	8	12	24	48	72	168
4	0	23.0 (25.4)	22.5 (27.2)	16.2 (28.2)	8.8 (26.2)	5.1 (24.0)	0.0 (24.3)	0.0 (22.1)	0.0 (18.3)
	25	25.9 (25.6)	21.9 (27.5)	11.9 (27.3)	7.4 (26.2)	3.3 (23.6)	0.0 (24.3)	0.0 (22.0)	0.0 (18.4)
	50	25.2 (25.2)	19.2 (26.0)	8.7 (26.4)	2.5 (26.2)	2.7 (23.3)	0.0 (24.2)	0.0 (21.9)	0.0 (18.3)
	75	6.9 (24.5)	10.4 (25.4)	6.8 (25.6)	4.4 (25.7)	1.4 (23.3)	0.0 (24.1)	0.0 (21.7)	0.0 (18.4)
	100	3.0 (24.2)	5.7 (24.8)	3.2 (24.9)	7.3 (25.0)	1.3 (23.1)	0.0 (23.8)	0.0 (21.6)	0.0 (18.5)
	125	0.7 (24.0)	0.5 (24.2)	0.1 (23.9)	6.8 (24.4)	2.0 (23.0)	0.1 (23.7)	0.0 (21.5)	0.0 (18.5)
	150	1.0 (23.8)	0.6 (23.6)	0.2 (23.7)	2.5 (23.7)	4.7 (22.5)	3.0 (23.1)	0.0 (21.3)	NS
5	0	6.6 (25.3)	30.4 (28.9)	33.8 (29.8)	32.2 (27.9)	16.4 (24.3)	4.6 (23.9)	1.5 (22.1)	0.0 (18.2)
	25	3.1 (24.8)	13.1 (27.0)	21.1 (27.8)	29.0 (27.7)	15.5 (24.2)	4.5 (24.0)	1.5 (22.1)	0.0 (18.2)
	50	2.8 (24.5)	8.5 (25.4)	16.1 (25.6)	16.0 (26.6)	15.4 (24.0)	4.6 (24.0)	1.3 (22.1)	0.0 (18.3)
	75	1.1 (24.3)	5.7 (24.9)	3.7 (24.7)	9.4 (25.6)	15.8 (23.5)	4.8 (24.1)	1.2 (22.0)	0.0 (18.3)
	100	0.1 (24.1)	1.7 (24.5)	1.3 (24.4)	9.8 (25.2)	17.9 (23.4)	5.4 (24.0)	4.0 (21.1)	0.0 (18.3)
	125	0.0 (24.0)	0.2 (24.2)	0.9 (24.0)	4.4 (24.3)	21.7 (23.1)	NS	5.3 (20.9)	0.0 (18.3)
6	0	11.6 (24.8)	17.8 (27.3)	10.0 (27.7)	13.6 (27.3)	2.4 (23.8)	1.1 (23.9)	0.0 (22.2)	0.0 (18.3)
	25	10.6 (24.8)	9.7 (26.4)	6.9 (27.0)	10.3 (27.1)	2.2 (23.7)	1.1 (23.9)	0.0 (21.8)	0.0 (18.4)
	50	6.9 (24.5)	4.7 (25.4)	2.4 (25.4)	7.6 (26.7)	2.1 (23.6)	1.1 (23.9)	0.0 (21.7)	0.0 (18.5)
	75	1.1 (24.2)	5.6 (24.9)	1.8 (24.8)	7.1 (26.5)	1.9 (23.5)	1.1 (23.9)	0.0 (21.6)	0.0 (18.4)
	100	0.2 (24.3)	5.5 (24.4)	1.8 (24.2)	6.1 (26.0)	2.4 (23.5)	1.1 (23.9)	0.0 (21.6)	0.0 (18.4)
	125	0.0 (24.2)	1.8 (24.3)	2.8 (23.7)	2.4 (25.2)	1.2 (23.4)	1.9 (23.8)	0.0 (21.5)	NS
	150	0.0 (24.1)	0.5 (24.1)	0.4 (23.3)	0.9 (24.6)	1.3 (23.3)	2.1 (23.7)	0.0 (21.4)	NS

(Sheet 2 of 4)

Table A1 (Continued)

SS	z	Dye Concentration (Temperature)							
		Posttreatment, hr							
		1	5	8	12	24	48	72	168
7	0	0.0 (25.0)	0.7 (27.0)	1.4 (27.0)	2.6 (25.1)	2.2 (23.5)	1.9 (23.7)	1.6 (22.2)	0.3 (18.5)
	25	NS	0.7 (27.0)	0.9 (26.7)	2.6 (25.2)	2.3 (23.5)	1.9 (23.7)	1.6 (22.2)	NS
	50	0.0 (24.8)	0.5 (26.7)	0.8 (26.6)	2.6 (25.2)	2.1 (23.4)	1.9 (23.7)	0.9 (22.0)	0.3 (18.4)
	75	NS	0.3 (26.4)	0.6 (26.4)	1.5 (24.9)	1.8 (22.8)	1.8 (23.6)	1.0 (21.9)	NS
	100	0.0 (24.4)	0.0 (25.3)	0.2 (26.0)	0.3 (24.5)	1.8 (22.9)	1.7 (23.7)	1.3 (21.7)	0.3 (18.3)
	125	NS	0.0 (24.9)	0.0 (25.4)	0.0 (24.2)	1.6 (22.7)	1.6 (23.7)	1.4 (21.7)	NS
	150	0.0 (24.0)	NS	0.0 (25.0)	0.0 (23.9)	1.2 (22.7)	0.9 (23.7)	1.4 (21.8)	0.2 (18.3)
	175	NS	NS	NS	NS	1.2 (22.7)	1.2 (23.6)	1.3 (21.5)	NS
7a	0	0.1 (24.1)	1.4 (26.4)	2.6 (26.8)	0.1 (24.7)	0.0 (22.1)	0.0 (23.8)	0.0 (22.0)	0.0 (19.0)
	25	0.1 (23.9)	1.1 (26.3)	2.2 (26.7)	0.1 (24.8)	0.0 (22.0)	0.0 (23.8)	NS	NS
	50	0.1 (23.9)	0.9 (26.1)	1.9 (26.6)	0.1 (24.9)	0.0 (21.9)	0.0 (23.8)	0.0 (22.1)	0.0 (19.0)
	75	0.0 (24.0)	0.6 (25.9)	1.8 (26.6)	0.1 (24.8)	0.0 (21.9)	0.0 (23.8)	NS	NS
	100	0.0 (24.0)	0.2 (25.6)	1.8 (26.6)	0.1 (24.9)	0.0 (21.9)	0.0 (23.8)	0.0 (22.0)	0.0 (19.0)
	125	0.0 (24.1)	0.0 (25.6)	1.4 (26.3)	0.1 (24.9)	0.0 (21.9)	0.0 (23.7)	NS	NS
	150	0.0 (24.0)	0.0 (24.8)	0.0 (25.6)	0.0 (24.2)	0.0 (21.9)	0.0 (23.7)	0.0 (21.9)	0.0 (19.2)
	175	0.0 (24.0)	0.0 (24.7)	0.0 (25.2)	0.0 (23.7)	0.0 (21.6)	0.0 (23.5)	NS	NS
8	0	NS	0.0 (27.0)	0.0 (26.0)	0.5 (24.5)	1.9 (24.9)	0.0 (23.5)	0.0 (22.3)	0.0 (20.2)
	25	NS	NS	0.0 (26.0)	0.5 (24.5)	1.7 (24.8)	NS	NS	NS
	50	NS	0.0 (26.0)	0.0 (25.5)	0.2 (24.3)	0.5 (24.7)	0.0 (23.7)	0.0 (22.3)	0.0 (20.1)
	75	NS	NS	NS	0.0 (24.2)	0.0 (24.6)	NS	NS	NS

(Sheet 3 of 4)

Table A1 (Concluded)

SS	z	Dye Concentration (Temperature)							
		Posttreatment, hr							
		1	5	8	12	24	48	72	168
	100	NS	0.0 (25.7)	0.0 (25.6)	0.0 (24.2)	0.0 (24.6)	0.0 (23.6)	0.0 (22.3)	0.0 (20.3)
	125	NS	NS	NS	NS	0.0 (24.6)	NS	0.2 (22.3)	NS
	150	NS	NS	NS	NS	0.0 (24.6)	0.1 (23.6)	0.3 (22.4)	0.3 (19.4)
	175	NS	NS	NS	NS	0.1 (24.2)	NS	0.6 (21.8)	NS
	200	NS	NS	NS	NS	0.1 (24.2)	0.1 (23.6)	0.7 (21.8)	0.3 (19.0)
8a	0	NS	NS	0.1 (26.1)	0.3 (24.7)	0.0 (24.2)	0.0 (23.1)	0.0 (22.1)	0.0 (19.1)
	25	NS	NS	0.7 (25.7)	0.3 (24.8)	0.0 (24.3)	NS	NS	NS
	50	NS	NS	1.0 (25.6)	0.3 (24.8)	NS	0.0 (23.9)	0.0 (22.0)	0.0 (19.3)
	75	NS	NS	0.4 (25.9)	0.3 (24.8)	NS	NS	NS	NS
	100	NS	NS	0.8 (25.7)	0.5 (24.6)	0.0 (23.8)	0.0 (23.9)	0.0 (22.2)	0.0 (19.0)
	125	NS	NS	1.0 (25.6)	0.6 (24.7)	NS	NS	NS	NS
	150	NS	NS	0.7 (25.5)	0.1 (24.2)	0.0 (23.9)	0.0 (23.8)	0.0 (22.0)	0.0 (19.0)
	175	NS	NS	0.0 (24.9)	0.0 (24.2)	NS	NS	NS	NS
	200	NS	NS	0.0 (24.9)	0.0 (23.9)	0.0 (23.3)	0.0 (23.8)	0.0 (21.9)	0.0 (19.1)
9	0	NS	NS	0.0 (25.7)	0.0 (24.2)	0.0 (24.7)	0.0 (22.9)	0.0 (22.5)	0.0 (20.0)
	50	NS	NS	0.0 (25.3)	0.0 (24.1)	0.0 (24.7)	0.0 (22.9)	0.0 (22.3)	0.0 (19.7)
	100	NS	NS	0.0 (25.0)	0.0 (24.1)	0.0 (24.5)	0.0 (23.0)	0.0 (22.3)	0.0 (20.1)
	150	NS	NS	0.0 (24.9)	0.0 (23.9)	0.0 (24.5)	0.0 (23.0)	0.0 (22.2)	0.0 (20.0)
	200	NS	NS	NS	NS	0.0 (24.4)	0.0 (23.1)	0.0 (22.2)	0.0 (20.3)

(Sheet 4 of 4)

Appendix B
Dye and Temperature Profiles for Cove Treatment Plot

Table B1
Dye ($\mu g/\ell$) and Temperature (°C) Profiles for Cove Treatment Plot Following Treatment With Rhodamine WT and Triclopyr, Pend Oreille River, Washington, 1991

		Dye Concentration (Temperature)					
		Posttreatment, hr					
SS	z	1.5	8	24	48	72	168
1	0	8.1 (24.1)	12.2 (25.4)	0.1 (25.6)	0.0 (24.2)	0.0 (22.8)	0.1 (20.3)
	25	8.4 (24.1)	11.7 (25.3)	0.1 (25.5)	0.0 (24.2)	0.0 (22.9)	0.1 (20.4)
	50	7.9 (24.0)	11.2 (25.2)	0.1 (25.4)	0.0 (24.0)	0.0 (22.6)	0.2 (20.3)
	75	9.8 (23.9)	11.1 (24.9)	0.3 (24.9)	0.0 (23.9)	0.0 (22.3)	0.6 (20.0)
	100	8.1 (23.5)	11.7 (24.7)	1.4 (24.4)	0.4 (23.0)	0.1 (21.8)	0.4 (20.1)
	125	2.4 (22.9)	8.2 (24.2)	2.4 (24.0)	1.1 (22.3)	0.1 (21.7)	0.5 (20.1)
	150	0.7 (22.8)	4.5 (23.8)	2.1 (23.9)	1.0 (22.4)	0.1 (21.6)	NS
2	0	13.1 (24.6)	14.3 (25.9)	1.1 (26.2)	0.7 (24.3)	0.1 (22.4)	0.3 (19.8)
	25	14.3 (24.3)	14.3 (26.0)	1.5 (26.1)	0.7 (24.3)	0.2 (22.4)	0.8 (19.5)
	50	14.6 (24.2)	14.3 (25.9)	3.2 (26.0)	3.7 (23.9)	0.9 (22.2)	1.2 (19.4)
	75	8.4 (23.5)	11.8 (25.0)	5.4 (25.3)	5.5 (23.1)	1.9 (21.6)	1.2 (19.3)
	100	10.7 (23.5)	11.6 (24.4)	5.3 (24.9)	7.0 (22.4)	2.1 (21.3)	1.2 (19.2)
	125	2.9 (22.8)	5.8 (23.6)	7.0 (24.3)	7.0 (21.9)	2.2 (20.9)	1.3 (19.5)
	150	0.7 (22.5)	0.4 (23.2)	7.3 (24.2)	5.0 (21.5)	1.7 (20.6)	1.2 (19.2)
3	0	5.8 (24.2)	9.7 (25.9)	5.0 (26.4)	1.6 (24.1)	3.7 (21.8)	0.9 (19.2)
	25	6.3 (24.2)	9.6 (26.0)	5.0 (26.3)	1.7 (24.1)	3.7 (21.8)	1.0 (19.2)
	50	6.6 (24.4)	8.6 (26.0)	5.5 (26.1)	1.8 (24.1)	3.7 (21.6)	1.0 (19.2)
	75	5.2 (23.9)	5.2 (25.3)	5.5 (25.9)	3.9 (22.3)	3.5 (21.6)	0.9 (19.2)
	100	1.9 (23.1)	2.7 (24.2)	5.2 (25.8)	4.3 (22.8)	3.5 (21.5)	1.0 (19.2)
	125	1.5 (22.7)	0.4 (23.5)	5.3 (24.6)	4.6 (22.4)	3.5 (21.5)	1.0 (19.3)
	150	0.4 (22.2)	0.2 (23.0)	2.4 (23.7)	4.5 (22.1)	3.4 (21.3)	1.1 (19.2)
4	0	0.9 (24.3)	1.4 (24.1)	0.1 (25.2)	0.0 (23.6)	0.0 (22.4)	0.0 (20.6)
	25	0.7 (24.0)	1.1 (24.2)	0.1 (25.2)	0.0 (23.6)	0.0 (22.5)	0.0 (20.6)
	50	0.6 (24.0)	1.1 (24.1)	0.1 (25.3)	0.0 (23.6)	0.0 (22.5)	0.0 (20.7)
	75	0.6 (24.0)	1.1 (24.2)	0.2 (25.1)	0.0 (23.6)	0.0 (22.3)	0.0 (20.7)
5	0	0.4 (24.2)	1.2 (24.0)	0.2 (25.1)	0.0 (24.2)	0.0 (22.6)	0.0 (20.4)
	25	0.4 (24.2)	1.1 (24.1)	0.1 (25.0)	0.0 (24.0)	0.0 (22.6)	0.0 (20.4)
	50	0.5 (24.3)	1.1 (24.1)	0.1 (24.9)	0.0 (23.9)	0.0 (22.5)	0.0 (20.4)
	75	0.5 (24.3)	1.1 (24.2)	0.1 (24.9)	0.0 (23.9)	0.0 (22.5)	0.0 (20.4)
	100	0.4 (24.4)	1.1 (24.1)	0.1 (24.9)	0.0 (23.8)	0.0 (22.5)	0.0 (20.4)
	125	0.4 (24.3)	1.1 (24.1)	0.1 (24.9)	0.0 (23.7)	NS	0.0 (20.4)

Note: NS = Not sampled, SS = Sampling station, and depth (z) is reported in centimeters.

Appendix C Physical-Chemical Properties of Triclopyr[1]

Empirical Formula	3,5,6-trichloro-2-pyridinyloxyacetic acid
Molecular Formula	$C_7H_4Cl_3NO_3$
Molecular Weight	256.5
Decomposition Temperature	290 °C
Melting Point	148 to 150 °C
Primary Metabolic By-Product	TCP (3,5,6-trichloro-2-pyridinol)
Aqueous Photolytic Half-life	2 hr to 6 days depending on environmental conditions
Microbial Decomposition	Subject to microbial breakdown with rates dependent upon environmental conditions. Half-lives ranging from 10 to 46 days with averages of 30 and 40 days having been reported.
Solubility in Water	430 to 440 mg/ℓ at 25 °C
Solubility in Ethanol	Very soluble
Solubility in Benzene	Slightly soluble

[1] Extracted from Weed Science Society of America (1989)[2] and Dow Chemical Company (1988).

[2] References cited in this appendix are located at the end of the main text.

Appendix D
Summary of Toxicological Properties of Triclopyr

Table D1
Summary of Toxicological Properties of Triclopyr[1]

Test[2]	Species	Triclopyr Concentration	
		Triclopyr Acid	Garlon 3A[3]
96-hr LC_{50}	Trout	117 ppm	552 ppm
	Bluegill	148 ppm	891 ppm
	Shrimp	-	895 ppm
	Crab	-	>1,000 ppm
48-hr LC_{50}	Oyster	-	>56 ppm
Acute Oral LD_{50}	Rat (female)	713 mg/kg	2,140 mg/kg
	Rat (male)	713 mg/kg	2,830 mg/kg
	Rabbit	550 mg/kg	-
	Guinea Pig	310 mg/kg	-
Acute LD_{50}	Mallard	1,698 mg/kg	3,176 mg/kg
8-day Dietary LC_{50}	Mallard	>5,000 ppm	>10,000 ppm
	Bobwhite Quail	2,935 ppm	11,622 ppm
90-day Subacute Toxicity	Rat	No effect	30 mg/kg/day
Teratology	Rabbit	Not Teratogenic	100 mg/kg/day

[1] From Weed Science Society of America (1989).[4]
[2] LC_{50} = Lethal concentration that kills 50 percent of the individuals, plant or animal.
LD_{50} = Lethal dose, given as milligram per kilogram of body weight, which kills 50 percent of a group of test organisms.
[3] Garlon 3A = Triethylamine salt formulation of triclopyr; used in aquatic environments.
[4] References cited in this appendix are located at the end of the main text.

Appendix E
Supplemental Labeling

U.S. Crop Production

Supplemental Labeling

DowElanco

DowElanco	Quad IV, 9002 Purdue Road	P.O. Box 681428	Indianapolis, Indiana 46268-1189 USA

Garlon* 3A
Herbicide

Supplemental Labeling to Evaluate Garlon 3A Herbicide for Selective Control of Woody Plants and Certain Annual or Perennial Weeds in Streams, Rivers, Drainage Canals and Ditches, Irrigation Canals and Ditches, Ponds, Lakes, Reservoirs, Marshes and Wetlands and the banks and shores of these sites.

For Experimental Use Only
E.P.A. Experimental Use Permit No. 62719-EUP-1

Directions for Use

- It is a violation of Federal Law to use this product in a manner inconsistent with its labeling.
- Read and follow general directions, precautionary statements, use precautions and limitations on the Garlon 3A Herbicide label. In addition, follow all use directions, precautions and limitations applicable to the above listed uses described in this supplemental labeling.
- This labeling is for use only by employees, cooperators and contractors of the U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, and DowElanco at the application site of a cooperator and in accordance with the terms and conditions of an EPA approved experimental use permit.
- This labeling must be in the possession of the user at the time of pesticide application.

Notice to Applicators (State and Local Coordination): Before application under any project program, notification and approval of local and state authorities may be required, either by letter of agreement or issuance of special permits for such use.

Selective Weed and Brush Control in Wetlands and on the Banks and Shores of Streams, Rivers, Drainage Canals and Ditches, Irrigation Canals and Ditches and Other Aquatic Sites.

Precautions
- Do not trap or dig for shellfish within treated areas for two weeks.
- Do not treat within 5 miles of a potable water intake.
- Delay irrigation use of water in contact with treated areas for two weeks after treatment.
- Do not contaminate water when disposing of equipment washwaters.
- Do not apply when weather conditions favor drift from the target area.

Annual and Perennial Herbaceous Weeds: Apply 1/3 to 2 gallons of Garlon 3A Herbicide per acre in approximately 20 to 100 gallons of water per acre. Treat when weeds are young and actively growing before the bud or early bloom stage.

Woody Brush and Patches of Perennial Herbaceous Weeds: Apply 2 to 3 gallons of Garlon 3A in enough water to make 20 to 100 gallons of total spray per acre. Wet foliage thoroughly. To improve coverage of spray volumes less than 50 gallons per acre, add a non-ionic agricultural surfactant such as Ortho X-77 or Triton AG-98 to the spray mixture. When using a surfactant, observe all precautions, directions and limitations on the surfactant label.

Application Directions
Apply with low pressure spray equipment mounted on a truck, tractor, boat or helicopter. Nozzles and spray pressures should be selected to minimize the opportunity for drift.

When treating weeds on banks or shores, do not attempt cross-stream spraying to treat target vegetation on the opposite bank. When spraying weeds on banks or shores,allow no more than a two-foot overspray onto water and maintain an average of less than one-foot overspray to minimize introduction of greater than negligible amounts of chemical into the water. Ground or boat applications to banks or shores of flowing streams, rivers, canals or ditches should be made while traveling upstream to minimize concentration of chemical in moving water.

Aquatic Weed Control

To be applied by Federal, state or local public agency personnel, trained in aquatic weed control, or by licensed commercial applicators in cooperation with DowElanco or agencies listed under "Directions for Use" above. For use in streams, rivers, drainage canals and ditches, irrigation canals and ditches, ponds, lakes, reservoirs, marshes and wetlands and the banks and shores of these sites.

Precautions
- **Avoid Oxygen Depletion in Water of Treated Areas:** Decaying vegetation following treatment with Garlon 3A Herbicide may deplete dissolved oxygen in water of treated areas. To avoid fish kills or damage to other aquatic organisms as a result of dissolved oxygen depletion, do not treat more than one-half of a pond or lake at one time. Delay treatment of untreated areas for 4-5 weeks or until dead vegetation has decomposed, or until a favorable dissolved oxygen concentration has been restored.
- **Irrigation:** - Delay irrigation use of water within treated areas for two weeks after treatment.
- **Potable Water:** When application rates exceed 0.5 ppm, delay the use of treated water for domestic purposes for a period of 2 weeks.
- **Fishing:** Do not fish treated areas within 24 hours after treatment. Do not trap or dig shellfish within treatment area for two weeks.

Water Hyacinth (*Eichhoria crassipes*) And Other Susceptible Emersed And Floating Herbaceous Weeds: Apply 2 to 8 quarts per acre of Garlon 3A Herbicide using surface or aerial equipment. Spray the weed mass only. Use higher rates in the rate range when plants are mature, when the weed mass is dense, or for difficult to control species.

Application Timing: Apply when plants are actively growing. Repeat as necessary to control regrowth and plants missed in the previous operation.

Application Directions
Surface Application: Use a spray boom, hand gun or other similar suitable equipment mounted on a boat, tractor or truck. Thorough wetting of foliage is essential for maximum effectiveness. Use 20 to 200 gallons per acre of spray mixture. Special precautions such as the use of low spray pressure, large droplet producing nozzles or addition of thickening agents may minimize spray drift in areas of sensitive crops.

Aerial Application: Use a Microfoil™ or Thru-Valve™ boom, or a drift control additive in the spray solution. Apply in a minimum of 10 gallons of total spray mix per acre. Do not apply when weather conditions favor drift from the target area.

Eurasian Watermilfoil (*Myriophyllum spicatum*) And Other Susceptible Submersed Weeds: To control susceptible submersed aquatic weeds in ponds, lakes, reservoirs, and slow moving or quiescent areas of canals, ditches, streams and rivers, apply Garlon 3A Herbicide as either a surface, subsurface or aerial application. Rates should be selected according to the rate chart below to provide a concentration of 1.0 to 2.5 ppm a.e. in treated water. Higher rates in the rate range are recommended in areas of greater water exchange. These areas may require a repeat application.

Application Rates:

Depth	Gallons Garlon 3A per Acre Required to Provide the Specified Water Concentration in ppm			
	1.0 ppm	1.5 ppm	2.0 ppm	2.5 ppm
1 ft	1.0	1.5	2.0	2.5
2 ft	2.0	3.0	4.0	5.0
4 ft	4.0	6.0	8.0	10.0
6 ft	6.0	9.0	12.0	15.0

Application Timing: For best results, apply in spring or early summer when watermilfoil or other submersed weeds are actively growing.

Application Directions
It is suggested that areas near susceptible crops or other desirable broadleaf plants be treated by subsurface injection applied by boat to avoid aerial drift. Do not contaminate water outside treated areas when disposing of equipment washwaters. **Note:** Do not treat water areas that are not infested with aquatic weeds.

Subsurface Application: Apply desired amount of Garlon 3A per acre as a concentrate directly into the water through boat-mounted distribution systems. Treat from the shore outward.

Surface Application: Apply desired amount of Garlon 3A in a minimum spray volume of 5 gallons per acre. Do not apply when weather conditions favor drift from target area.

Aerial Application: Use Microfoil or Thru-Valve boom, or thickening agents approved for use with aquatic herbicides. Apply through standard boom systems with a minimum of 10 gallons of spray mix per acre. Do not apply when weather conditions favor drift from target area.

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Revisions:
1. Higher rates for emerged or floating weeds.
2. Label revised to accommodate new DowElanco format.

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STRACT *(Maximum 200 words)*

In an effort to evaluate the selective control of the exotic weed Eurasian watermilfoil (*Myriophyllum spicatum* L.) and to sess the recovery of the native submersed plant community, a 6-ha river and 4-ha cove plot were treated with the herbicide clopyr at application rates of 2.5 and 1.75 mg/ℓ, respectively, in the Pend Oreille River, Washington, in August 1991. ater-exchange half-lives within the plots were measured using rhodamine WT dye (river, $t_{1/2}$ = 20 hr; cove, $t_{1/2}$ = 52 hr), d triclopyr dissipation rates were also calculated (river, $t_{1/2}$ = 19 hr; cover, $t_{1/2}$ = 53 hr). Triclopyr concentrations were low proposed potable water tolerance levels (0.5 mg/ℓ) within the river treatment plot by 3 days after treatment (DAT) 0.01 to 0.41 mg/ℓ), and 675 m downstream of that plot by 1 days after treatment (DAT) (<0.01 to 0.47 mg/ℓ). Following cove treatment, triclopyr residues ranged from 0.12 to 0.29 mg/ℓ by 7 DAT, and from <0.01 to 0.06 mg/ℓ as close as 0 m downstream from the plot.

Eurasian watermilfoil biomass was reduced by 99 percent in the treated plots at 4 weeks posttreatment, remained low 'ear later (river treatment, 28 percent of pretreat levels; cove treatment, 1 percent of pretreat levels), and was still at ceptable levels of control at 2 years posttreatment (river treatment, 47 percent of pretreat levels; cove treatment 24 percent

(Continued)

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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. Native species diversity doubled following herbicide treatment, and this robust community delayed the reestablishment and dominance of Eurasian watermilfoil for three growing seasons.